THE NATURE OF THE EXTENDED EMISSION FEATURES IN IRAS 04210+0400

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ABSTRACT

The IRAS source 04210+0400 coincides with a galaxy that exhibits strong double-lobed radio emission extending 15 kpc outside the optical galaxy. New high-resolution radio maps reveal a classical low-luminosity double radio structure and an extended nuclear source that is aligned toward a hot spot in one of the lobes. Visible spectroscopy shows that the light from the features that were originally thought to be spiral arms is neither starlight nor light scattered from the nucleus; the spectra show strong emission lines whose relative intensity, radial velocity, and velocity dispersion vary with position. The data suggest that the extended spiral features are photoionized remnants of earlier radio jet activity and that the unusual properties of this object might be characterized as those of a radio galaxy that has an unusually high dust content and a strong source of ultraviolet radiation at its core. The nuclear activity may be related to an interaction with a nearby companion galaxy.

Subject headings: galaxies: individual (04210+0400) — galaxies: interactions — galaxies: jets — galaxies: structure — radio sources: galaxies

I. INTRODUCTION

IRAS 04210+0400 is the only IRAS-selected galaxy studied to date that shows powerful extended ($\pm$ 15 kpc) double-lobed radio morphology. Beichman et al. (1985; hereafter B85) speculated that the galaxy was a spiral because of its optical morphology, its strong far-infrared emission, and its reddened nucleus ($A_v = 2.0$). Its visual spectrum is consistent with a Seyfert 2 or narrow emission-line radio galaxy (e.g., Osterbrock and Mathews 1986). The radio-emitting regions are much stronger and more extended than those of Seyfert galaxies (Ulvestad and Wilson 1984) and have the properties of radio sources that have hitherto always been found associated with elliptical rather than spiral galaxies. The source therefore appears to be of a uniquely hybrid nature.

To test if the "spiral" morphology of 04210+0400 is indeed due to stellar features in a disk galaxy, we have combined new high spatial resolution Very Large Array (VLA)$^1$ observations with new high spectral resolution visible spectroscopy of the spiral-like extended emission features. Throughout this paper we take $H_0 = 75$ km s$^{-1}$ Mpc$^{-1}$, which places the galaxy at a distance of 185 Mpc for the redshift of 0.0463. The paper is arranged as follows: we discuss the observations and results in § II and § III. In § IV we derive physical information from the spectra, and in § V we discuss the nature and origin of the extended emission features.

II. OBSERVATIONS

The new radio map (Fig. 1) was obtained at the VLA in 1985 February using the A array at 6 cm. The map is smoothed to a resolution of 1.45 FWHM. The central region is shown at full resolution (0'0.53) in Figures 2 and 3: only the regions of highest surface brightness show up on these maps.

$^1$ The National Radio Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation.

Narrow-band images in the light of the redshifted [O III] 5007 Å line and in a region of line-free continuum are shown in Figure 4. The data were obtained in 1984 October with an 800 x 800 Texas Instruments virtual-phase CCD and a focal reducer mounted at the Cassegrain focus of the University of Hawaii (UH) 2.2 m telescope on Mauna Kea. The plate scale was 0'0.42 per pixel. The filters used were an 80 Å wide interference filter centered on 5198 Å and a 500 Å wide filter centered on 5950 Å; the exposures were 300 s and 1200 s, respectively. Because of nonphotometric conditions, flux calibration of the images was not possible. The exposures were unguided and are therefore slightly trailed in the east-west direction.

Spectroscopic observations are summarized in Table 1. Two different systems were used on the UH 2.2 m telescope to obtain spectra at the locations illustrated in Figure 2. The observations with a north-south slit orientation were obtained using the UH grism spectrograph and the IFA/Galileo CCD camera. We estimate the positioning accuracy of the slit with respect to the nucleus to be about ±0.5. The spectra were sky subtracted and linearized with respect to a neon spectrum reflected from the dome. The instrument response was calibrated with reference to the spectrophotometric standard BD +17°4708 (Oke and Gunn 1983). The observations with an east-west slit were made with the UH Faint Object Spectrograph and a camera with a GEC CCD (Wright and Mackay 1981). They were linearized with reference to an internal iron-argon source and calibrated with reference to the spectrophotometric standard HD 19445 (Oke and Gunn 1983). Two arcsec slits were used for all observations.

III. RESULTS

a) Radio

The A array VLA map of 04210+0400 reveals considerable new structure (Fig. 1). The two radio lobes are resolved and
Fig. 1.—The 6 cm continuum VLA A-array map smoothed to 1.45 resolution. The contour interval is 0.05 mJy beam$^{-1}$. Dashed box shows the boundary of Fig. 2.

Fig. 2.—The radio map overlaid on a gray scale representation of the R-band image presented by Beichman et al. (1985). Dashed lines show the positions of the spectrograph slits. The lowest contour is at 0.08 mJy beam$^{-1}$; the subsequent contour interval is 0.04 mJy beam$^{-1}$.
show some apparent rotational symmetry about the nucleus. Such diffuse and distorted lobes are characteristic of low-luminosity radio galaxies such as Centaurus A, classified as FRI in the scheme of Fanaroff and Riley (1974). However, while the radio luminosity \( \log P_{1.5\,\text{GHz}} = 23.4\,\text{W Hz}^{-1} \) is fairly typical of FR I sources, the overall size of the radio source (\( \sim 35\,\text{kpc} \)) is somewhat smaller than the 80 kpc typical of such sources (Gavazzi and Perola 1978). As pointed out by B85, there is a continuity between the visible extended emission features and the radio lobes; the new maps indicate that the southern visible extended emission feature terminates in the vicinity of a "hot spot" in the southern radio lobe (Fig. 2).

The new 6 cm maps reveal a 0.7 mJy radio source at the center of the visible galaxy. It comprises two peaks separated by \( \sim 1'' \) in a north-south direction but is unresolved in the east-west direction (Fig. 3). The possibility that this central source represents a nucleus and a jet is supported by the fact that the source lines up with the southern hot spot and with a similar but fainter feature in the northern radio lobe. However, the astrometric accuracy of the CCD image of B85 is insufficient to determine which, if either, of the two peaks coincides with the nucleus of the visible galaxy.

**Table 1**

<table>
<thead>
<tr>
<th>UT Date</th>
<th>Spectrograph*</th>
<th>Integration (minutes)</th>
<th>Wavelengths (( \text{Å} ))</th>
<th>Resolution (( \text{Å} ))</th>
<th>Slit Orientation</th>
<th>Slit Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>1984 Oct 1</td>
<td>grism</td>
<td>15</td>
<td>5000–5400</td>
<td>24</td>
<td>north-south</td>
<td>nucleus</td>
</tr>
<tr>
<td>1984 Oct 1</td>
<td>grism</td>
<td>15</td>
<td>6500–7100</td>
<td>6</td>
<td>north-south</td>
<td>companion galaxy</td>
</tr>
<tr>
<td>1985 Dec 14</td>
<td>FOS</td>
<td>30</td>
<td>6500–7100</td>
<td>6</td>
<td>east-west</td>
<td>4'' north</td>
</tr>
<tr>
<td>1985 Dec 14</td>
<td>FOS</td>
<td>30</td>
<td>6500–7100</td>
<td>6</td>
<td>east-west</td>
<td>nucleus</td>
</tr>
<tr>
<td>1985 Dec 13</td>
<td>FOS</td>
<td>30</td>
<td>6500–7100</td>
<td>6</td>
<td>east-west</td>
<td>4'' south</td>
</tr>
<tr>
<td>1985 Dec 13</td>
<td>FOS</td>
<td>30</td>
<td>6500–7100</td>
<td>6</td>
<td>east-west</td>
<td>65'' south</td>
</tr>
</tbody>
</table>

* Grism and FOS refer to the UH grism and Faint Object spectrographs, respectively.

**b) Imaging**

Figure 4 presents the [O III] and continuum images. The dramatic differences between the images indicate that the extended emission features are dominated by emission lines. The extended features seen in B85's R band image are therefore presumably produced mainly by H\(\alpha\) and other emission lines. The total extent of strong [O III] emission is \( \sim 20'' \). The galaxy to the northeast of 04210+0400 is extended \( \sim 5'' \) to the northeast in the continuum image, but is faint in the [O III] image.

**c) Spectroscopy**

Figure 5 shows the spectra of the nucleus and extended emission features. The blue spectra are derived from the north-south long-slit observations by binning the data in 2'' sections, except for the spectra at 8'' north and south which include all the data between 7'' and 10''. The red spectra are based on the observations at different east-west slit positions (Fig. 2). Gaussian line profiles were fitted to each emission line with the redshift, line width, line intensity, and continuum intensity as free parameters, except that theoretical low-density limiting values were adopted for the [O III], [O I], and [N II] doublet...
ratios. The variations in line intensities are shown in Table 2 and plotted in Figures 6–8. Columns (2)-(6) of Table 2 describe the relative line strengths at a given position, while columns (7)-(9) provide comparison between the extended emission feature fluxes and those of the nucleus for Hβ, for Hα, and for the fitted continuum at 6850 Å. The radial velocities and dispersions are discussed in § 1Vα, and the decomposition of the 6.5 south data into broad and narrow components (Fig. 6) is discussed in § Ve.

Because of the narrowness of our slits we did not obtain a satisfactory flux calibration of our spectrophotometry using standard stars. Our flux calibration is therefore based on a comparison of our nuclear data with those of B85 and of Moorwood, Véron-Cetty, and Glass (1986) and a subsequent comparison of our spectra of the extended emission features with our spectrum of the nucleus. All the nuclear line ratios agree well if it is assumed that B85 underestimated the contribution of Hα in the Hα + [N II] blend by 10% when they analyzed their rather low-resolution spectrum.

d) Possible Variability

Despite the agreement in line ratios, the equivalent widths of the emission lines in our nuclear spectra as measured in 1984–1985 are significantly lower than those measured by B85 in

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1983 December, especially in the red spectrum. Such a change is much more likely to arise from variability of a compact nuclear source than from variation in the diffuse forbidden line gas, although the possibility that the difference between the spectra is due to differences in slit placement cannot be ruled out given the complexity and strength of the extended emission-line regions and the narrow slits used. If we use the nuclear [O III] and [S II] lines to calibrate the blue and red spectra relative to the values given by B85, we obtain the nuclear Hβ and Hα line fluxes given in the footnotes to Table 2. This normalization implies that the continuum from the nucleus of 04210 + 0400 has increased over its 1983 value (B85) by a factor of 1.5 in the 1984 blue spectrum and a factor of 3 in the 1985 red spectrum. We have insufficient data to tell whether the color of the continuum emission has varied. The final nuclear Hα flux that we adopt (Table 2) in a $2' \times 2'$ region agrees with that of B85 and is about twice that of Moorwood, Véron-Cetty, and Glass (1986) in a $1.5' \times 1.5'$ beam. Given the complexity of the emission region near the nucleus we consider this agreement satisfactory.

The absolute fluxes in Table 2 could be in error by as much as 50% given the normalization procedure; however, the relative line ratios have an error of between 5% for the bright lines and 10% for the weaker lines.

IV. DERIVED QUANTITIES

a) Radial Velocities and Velocity Widths

The nuclear redshift of $z = 0.0463 \pm 0.0001$ from the [O I], Hα, [N II], and [S II] lines is in good agreement with that given by B85. The redshift of the galaxy to the northeast is $z = 0.047 \pm 0.002$, indicating that it is presumably a companion of 04210 + 0400. It shows emission lines of hydrogen and [S II].

Intrinsic line widths and redshifts for the extended features were obtainable only from the higher resolution red spectra because the north-south blue slit was too wide to be uniformly illuminated by the narrow extended emission features. The velocity dispersions quoted in Table 2 and plotted in Figure 7 are the FWHM values after deconvolution in quadrature from the instrumental resolution of 5.6 Å (245 km s$^{-1}$) as determined from the night sky and Fe-Ar calibration lamp lines. At most positions the Hα and forbidden-line velocities and widths agreed with each other. At 6'5 S, however, the composite...
TABLE 2

<table>
<thead>
<tr>
<th>Slit Position</th>
<th>[O III]/Hβ</th>
<th>[O I]/Hα</th>
<th>[N II]/Hα</th>
<th>[S II]/Hα Ratio</th>
<th>Hβ Strength*</th>
<th>Hα Strengthb</th>
<th>Continuum Strengthc</th>
<th>Velocity (km s$^{-1}$)d</th>
<th>Dispersion (km s$^{-1}$)</th>
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<tr>
<td>6° North</td>
<td>8.2</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>0.07</td>
<td>...</td>
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<td>6° North</td>
<td>9.8</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>0.18</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>4° North</td>
<td>9.1</td>
<td>0.16</td>
<td>0.53</td>
<td>0.72</td>
<td>1.42</td>
<td>0.39</td>
<td>0.21</td>
<td>0.32</td>
<td>46</td>
</tr>
<tr>
<td>Nucleus</td>
<td>14.2</td>
<td>0.13</td>
<td>0.35</td>
<td>0.48</td>
<td>1.09</td>
<td>1.0</td>
<td>1.0</td>
<td>0</td>
<td>380</td>
</tr>
<tr>
<td>4° South</td>
<td>10.3</td>
<td>0.15</td>
<td>0.43</td>
<td>0.66</td>
<td>1.37</td>
<td>0.54</td>
<td>0.38</td>
<td>0.20</td>
<td>−60</td>
</tr>
<tr>
<td>6.5° South</td>
<td>Total</td>
<td>5.7</td>
<td>0.19</td>
<td>0.53</td>
<td>0.81</td>
<td>1.06</td>
<td>0.36</td>
<td>0.30</td>
<td>0.03</td>
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<td>Broad</td>
<td>...</td>
<td>...</td>
<td>0.80</td>
<td>...</td>
<td>...</td>
<td>0.20</td>
<td>...</td>
<td>−90</td>
<td>730</td>
</tr>
<tr>
<td>Narrow</td>
<td>...</td>
<td>...</td>
<td>&lt;0.04</td>
<td>...</td>
<td>...</td>
<td>0.10</td>
<td>...</td>
<td>−150</td>
<td>160</td>
</tr>
<tr>
<td>8° South</td>
<td>8.5</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>0.05</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>


* Relative to nuclear Hβ line flux of 2.0 × 10$^{-17}$ W m$^{-2}$.

b Relative to nuclear Hα line flux of $1.1 \times 10^{-16}$ W m$^{-2}$.

c Relative to the 6850 Å nuclear continuum flux density of 1.2 mJy.

d Radial velocity relative to that of the nucleus.

Hα + [N II] profile (Fig. 6) is best fitted by a two-component model with a broad −90 km s$^{-1}$ Hα + [N II] feature combined with a narrower −150 km s$^{-1}$ pure Hα feature. The profiles of the [S II] and [O I] lines resemble that of the [N II] emission, but given the signal-to-noise ratio, a narrow component cannot be ruled out. This region, which coincides with a radio hot-spot, will be discussed in § Ve.

As can be seen in Figure 7 there are clear differences of radial velocity between the extended features and the nucleus in the sense that the northern feature is receding from us and the southern feature is moving toward us. Except at the 6.5° south position, the line widths do not vary significantly with position and have typical widths of several hundred km s$^{-1}$.

**b) Line Ratios**

Figures 8 and 9 show the variations in selected line ratios at nuclear and off-nuclear positions. Except for the Hα/Hβ ratio, each quantity is derived from a single spectrum and is hence

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**Fig. 6.—Deconvolution of Hα and [N II] lines at 6.5° south. Narrow Hα and broad Hα + [N II] are fitted with Gaussian line profiles, and the residual is plotted in the lower panel.**
Fig. 7.—Variation of radial velocity and velocity dispersion along the extended emission features.

Fig. 8.—The variation of line ratios with position. The line ratios of (a) [O I] 6300 Å, (b) [N II] 6583 Å, and (c) [S II] 6717 + 6731 Å to Hα as a function of position.
not affected by calibration errors. The data indicate that the strength of the low-excitation forbidden lines ([O i], [N ii], [S ii]) is greater in the extended features than in the nucleus, while the strength of the higher excitation [O iii] 5007 Å line is strongest at the nucleus.

Veilleux and Osterbrock (1987) have published a series of diagnostic diagrams and a classification scheme based on the relative strengths of various emission lines in astrophysical systems. Figure 10 represents a summary of their results for the [O iii]/Hβ and [S ii]/Hα ratios, with the data for 04210 + 0400 added. It may be seen that both the nucleus and the three samples of extended emission feature emission all have line ratios similar to those found in Seyfert galaxy nuclei. Such ratios are characteristic of plasmas ionized by a power-law continuum. The sulfur lines are too strong for an H ii region and the [O iii] line is too strong for a “Liner” (low-ionization nuclear emission-line region; Heckman, Balick, and Crane 1980). Similar conclusions are implied by the [O i] and [N ii] line strengths.

The existence of extended photoionized gas associated with the host galaxy of a double-lobed source is not unique to 04210 + 0400. Robinson et al. (1987) describe several examples of the phenomenon in a sample of southern Parkes radio galaxies. These radio galaxies are similar to 04210 + 0400 in their radio powers and optically active nuclei although the morphology of their emission line regions is less organized. From the line ratios, Robinson et al. deduce that as in 04210 + 0400 the extended emission regions are excited by a power-law UV continuum.

c) Electron Densities

Estimates for the electron density in the extended features may be derived from the Hα surface brightnesses and from the sulfur line ratios (e.g., Osterbrock 1974, p. 69). The Hα-based electron densities assume a geometric model in which the emission measured at each slit position emanates from a uniform density cube of projected size 2" (5 × 10^{-5} cm) with an electron temperature of 10^4 K. The values derived by this method (Table 3, col. [2]) are in the range 1–10 cm^{-3} and are much lower than the values derived from the [S ii] 6716/6731 line ratio (col. [3]). The probable explanation for this discrepancy is that the ionized gas is strongly clumped both in the extended features and in the nucleus.

d) Reddening

B85 report a visual extinction of A_v = 1.7 ± 0.2 mag, of which 0.3 mag is attributed to material within the Galaxy. This value was obtained from the Balmer decrement assuming case B recombination and is increased to A_v = 2.0 ± 0.2 mag by the correction we have applied to their Hα line flux. From Figure 9b it can be seen that the Hα/Hβ ratio is smaller in the extended emission features than in the nucleus,
except at the position 6°5 S, coincident with the southern radio hot spot. Although the errors are large, the data indicate that the reddening of the extended emission features is probably smaller than that of the nucleus. The northern extended emission feature at 4° N has $A_v = 0.0 \pm 0.8$, consistent with the $A_v = 0.3$ attributed to our Galaxy. There is probably some reddening of the southern extended emission feature at 4° S; the H$\alpha$/H$\beta$ ratio gives $A_v = 1.0 \pm 0.5$ mag.

### (c) Photoionization Rates

In this section we examine quantitatively the possibility that the extended emission features are photoionized from the nucleus of 04210+0400. If we make the assumption that the H$\alpha$ emission from the extended emission features is due to case B recombination following ionization by a UV photon, then the recombination rate may be derived from the H$\alpha$ luminosity using a relation such as that given by Osterbrock (1974). The recombination rate $N_\phi$ has been calculated for the section of the extended emission feature at each of the slit positions and is presented in column (4) of Table 3. In column (5) we estimate the solid angle subtended by each section of extended emission feature at the nucleus. The quantity $N_\phi \times 4\pi/\Omega$ (col. [6]) is then a lower limit to the total production rate of ionizing photons from the nucleus, assuming that the nucleus radiates isotropically. Given the limited angular resolution of the observations and the lack of information about line-of-sight geometry, these estimates of the required nuclear ionizing flux are uncertain by a factor of at least 2.

The UV photon flux from the nucleus can be estimated in two ways. One way is to assume that in most directions the UV photons are absorbed by dust, so that the observed infrared luminosity is a good guide to the ultraviolet flux. On this basis the $2.8 \times 10^{44}$ ergs s$^{-1}$ infrared luminosity (B85) could have been produced by $130 \times 10^{43}$ 13.6 eV ionizing photons per second. This number is an upper limit to the ionizing flux, since photons of either lower or higher energy will be less effective sources of ionization than 13.6 eV photons. An alternative way of estimating the ionizing photon flux is to deredden and extrapolate the observed visible continuum into the ultraviolet. Adopting B85's suggested dereddened power law of index $-1$ and 1983 flux density of 1.4 mJy at 0.55 $\mu$m gives an ionizing flux of $140 \times 10^{33}$ s$^{-1}$.

The result of the comparison of the available and necessary ionizing fluxes is that with some reasonable geometric and energetic assumptions it does appear possible for the extended emission features to be ionized by photons from the nucleus of

### Table 3

<table>
<thead>
<tr>
<th>Slit Position</th>
<th>$n_\phi$(H$\alpha$) (cm$^{-3}$)</th>
<th>$n_\phi$(S ii) (cm$^{-3}$)</th>
<th>$N_\phi$ (10$^{43}$ s$^{-1}$)</th>
<th>Solid Angle (sr)</th>
<th>Required Nuclear Ionizing Flux (10$^{33}$ s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4° North</td>
<td>4.5</td>
<td>&lt;100</td>
<td>0.76</td>
<td>0.25</td>
<td>38</td>
</tr>
<tr>
<td>Nucleus</td>
<td>9.7</td>
<td>800</td>
<td>3.6</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>4° South</td>
<td>6.0</td>
<td>130</td>
<td>1.4</td>
<td>0.25</td>
<td>70</td>
</tr>
<tr>
<td>6°5 South</td>
<td>5.3</td>
<td>900</td>
<td>1.1</td>
<td>0.10</td>
<td>140</td>
</tr>
</tbody>
</table>
04210 + 0400. Two caveats must be noted, however. One is that the light travel time from the nucleus to the extended emission features is of order 10,000 yr so that a detailed comparison of the nuclear and extended emission feature fluxes will be compromised by any nuclear variability. Second, the presence of a significant quantity of dust between the nucleus and the extended emission features would greatly increase the photon production requirements of the nucleus. Specifically, if the same column density of dust ($A_v = 2$) lay between the nucleus and the extended emission features as along our line of sight to the nucleus, then the ionizing photon flux from the nucleus would be attenuated by such a large factor at 912 Å that photoionization of the extended emission features would be impossible. We therefore conclude that for the photoionization model to work the dust around the nucleus of 04210 + 0400 must be unevenly, or at least anisotropically, distributed.

V. DISCUSSION

Our spectroscopy and the quantities derived from it allow us to analyze some possible explanations for the extended emission features.

a) Spiral Arms

B85 suggested that the extended emission features were the arms of a spiral galaxy, implying that they contained a typical mixture of stars and H II regions. As shown by the narrowband imagery, as well as by the spectroscopy, the light from the extended emission features comes mainly from ionized gas rather than from stellar photospheres. Furthermore, the line ratios in the extended emission features differ from those expected from H II regions excited by stars (Fig. 10). This discounts the suggestion of Moorwood, Véron-Cetty, and Glass (1986) that the extended emission features are H II regions. The kinematic data also show that the features have a larger velocity dispersion and smaller rotational velocity than in typical spiral arms (e.g., Faber and Gallagher 1979). We therefore conclude that, despite their appearance, the extended emission features are not spiral arms.

b) Scattered Light from the Nucleus

The possibility that the extended emission features represent light scattered by the nucleus can be ruled out by the result that the line ratios and the line-to-continuum strengths in the extended emission features in almost all cases differ from those of the nucleus. Except at 4° north, the continuum (Table 2) is weaker relative to the line emission, which must therefore be due to ionized gas present in the extended emission features themselves.

c) Tidal Tails Photoionized by the Nucleus

The proximity of a nearby companion to 04210 + 0400 raises the possibility that the extended emission features could be tidal tails formed as a result of a close gravitational encounter of the kind discussed by Toomre and Toomre (1972). Encounters between a galaxy and a smaller satellite can result in spiral bridges extending toward and away from the companion. There is considerable evidence that tidal encounters can trigger nuclear activity and star formation (e.g., Balick and Heckman 1982), and it is interesting to note that the companion galaxy also shows emission lines of Hz and [S II]. Hansen et al. (1987) point out that a “Z” shaped morphology is seen in some other radio galaxies showing strong extended emission lines, and in at least one case (0349−27) they attribute this morphology to tidal interaction. In none of the Hansen et al. cases, however, is there a smooth position angle variation between the ionized gas and the radio emission as is seen in 04210 + 0400. The main weakness of the tidal hypothesis is that it offers no natural explanation for the close morphological association between the extended emission features and the extended radio lobes (Fig. 2).

d) Line Emission Associated with the Radio Jet

There exist several examples of radio sources with extended emission-line regions coincident with the radio emission (see van Breugel et al. 1985 and references therein). For two reasons, however, we consider it doubtful that the extended emission features represent the paths of currently active jets. First, we note that the central radio source is elongated along a north-south line connecting the brightest points of the main radio lobes. We conjecture, based on the morphology of other radio galaxies, that one or both of the peaks in the elongated central radio source mark the start of jets connecting the nucleus to the extended radio lobes. If this is the case, then the jets probably follow a direct north-south path between the nucleus and the extended lobes rather than a curved path along the extended emission features. The radio jet and the extended emission features appear to be physically distinct. Second, in the cases of optical line emission associated with more powerful radio galaxies such as 3C 277.3 (van Breugel et al. 1985), there is a close spatial coincidence between the optical and the radio emission. IRAS 04210 + 0400 does not appear to fall into that class, for only at the position of the southern radio hot-spot is there any direct coincidence, and possible physical association, between the radio and optical emission.

e) Photoionized Remnant of the Radio Jet

We consider that the most likely explanation for the extended emission features is that they are the photoionized remnants of matter associated with, and entrained by, the plasma jets responsible for energizing the extended radio lobes. In our model, therefore, the extended emission features are made up of material that was once associated with the jets but that has become separated from them by some kind of rotational or precessional motion. The extended emission features are bright because they are photoionized by ultraviolet light from the nucleus. If the extended emission features have a uniform density of $5 \times 10^{-21} \text{ cm}^{-3}$ and a cross section of $5 \times 10^{-21} \text{ cm}^2$, then their total mass is of order $10^9 M_\odot$, a value that can be reduced by several orders of magnitude, depending on the unknown filling factor. Without a specific physical model it is difficult to know whether entrainment of this amount of matter is likely. De Young (1981), however, has discussed the case of Centaurus A, for which he predicted that up to $6 \times 10^7 M_\odot$ of ambient material could be entrained by a plasma jet over $10^8$ yr.

Some support for a current physical association between the extended emission features and the radio galaxy phenomenon is provided by the change in physical conditions 6°5 south of the nucleus at the location of the southern radio hot spot. The simple photoionization picture would have problems explaining the emission from this region if there is a significant amount of dust between the hot spot and the nucleus (§ IVe). However, the physical changes in this region raise the possibility that energy is deposited there by an interaction of a nuclear jet with slower material. This interaction could also
explain the strange Hα + [N ii] line profile at this point (Fig. 6); the narrow $-150$ km s$^{-1}$ pure-Hα component could be caused by fast-moving jet material that is dense enough ($N_e \gtrsim 7.8 \times 10^4$ cm$^{-3}$; Osterbrock 1974, p. 53) for the [N ii] lines to be de-excited, while the much broader $-90$ km s$^{-1}$ Hα + [N ii] component comes from the material onto which the jet is impinging. Another possibility is that the relativistic electrons may directly heat the gas in the hot spot (Ferland and Mushotzky 1984).

VI. CONCLUSIONS AND SPECULATIONS

The new VLA observations show that 04210+0400 has the radio morphology and luminosity of a classical FR I radio galaxy. There is now no evidence that the galaxy is a spiral. Its main unusual characteristics remain the bright extended emission features between its nucleus and radio lobes, and its high infrared luminosity. The extended emission features are probably remnants of material associated with the generation of the radio lobes and are currently visible because they are being photoionized by ultraviolet radiation from the nucleus. Given a clearer understanding of the relationship between the properties of the extended features and the radio jet, it may be possible to infer the age of the radio source.

A simple explanation for the properties of 04210+0400 is that it is a low-luminosity radio galaxy that contains an unusually large amount of dust and an unusually strong ultraviolet continuum. Much of the UV energy is converted by dust absorption and thermal reradiation into infrared radiation. In some directions enough UV radiation escapes the nucleus to illuminate and ionize gas that has been deposited outside the galaxy by the action of the plasma jets that power the radio lobes. We offer no explanation of why 04210+0400 has a powerful UV source at its center except to conjecture that an interaction with the neighboring galaxy might be in some way responsible.

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