RevMexAA (Serie de Conferencias), **6**, 48–51 (1997)

NIR IMAGING SPECTROSCOPY OF IRAS F10214+4724: EVIDENCE FOR A STARBURST REGION AROUND AN AGN AT $z = 2.3$

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RESUMEN

Presentamos espectroscopía en la banda K, con resolución de $1''$, de la galaxia IRAS F10214+4724, con $z = 2.284$. Encontramos que las líneas de emisión Hα y [N II] tienen diferentes distribuciones espaciales. Detectamos una componente ancha ($\Delta v_{\rm FWZP} \approx 3500\,{\rm km\,s^{-1}}$ en Hα. Concluimos que F10214+4724 es una galaxia muy luminosa, con un núcleo activo y un disco de formación estelar y además está amplificada por una lente gravitacional. Tanto el núcleo activo como el disco de formación estelar, contribuyen significativamente a la luminosidad total de $\sim 10^{13} L_\odot$.

ABSTRACT

We report $1''$ K-band imaging spectroscopy of the z=2.284 galaxy IRAS F10214+4724. We find that the rest-frame Hα and [N II] emission have different spatial extents. Furthermore, we detect broad ($\Delta v_{\rm FWZP} \approx 3500\,{\rm km\,s^{-1}}$) H$\alpha$ emission. We conclude that F10214+4724 is a very luminous gravitationally lensed galaxy, which intrinsically contains both a type 1 AGN and a more extended star-forming disk. The AGN and circumnuclear star formation both contribute significantly to the total luminosity of $\sim 10^{13} L_\odot$.

Key words: **GALAXIES: INDIVIDUAL: IRAS F10214+4724 — GALAXIES: STARBURSTS — INFRARED: GALAXIES**

1. INTRODUCTION

The z=2.284 IRAS source F10214+4724 has been interpreted to be the most luminous galaxy in the universe ($\geq 10^{14} L_\odot$ for $H_0 = 75\,{\rm km\,s^{-1} Mpc^{-1}}$ and $q_0 = 0.5$; $1\farcs0 = 5.3$ kpc; e.g., Rowan-Robinson et al. 1991, 1993) being in an early superstarburst. The rest frame UV/visible emission lines resemble those of Seyfert II nuclei (e.g., Elston et al. 1994). However, recent imaging (Eisenhardt et al. 1995; Broadhurst & Lehár 1995: Graham & Liu 1995) strongly suggest magnifications between 5 and 100 due to a gravitational lens.

We observed F10214+4724 in the K-band with the MPE imaging spectrometer, *3D*, at the 3.5-m telescope on Calar Alto, Spain (see Weitzel et al. 1996). The total on-source integration time was 9000 s, the spectral resolution was R=500 and the sampling $0\farcs5$ pixel. The seeing during the observations was $1''$ FWHM at 2 μm.

2. RESULTS AND DISCUSSION

Line and Continuum Maps: Differences in the Spatial Distribution. Figure 1 shows line and continuum maps obtained with *3D* overlayed on the K-band image of Graham & Liu (1995; *gray scale*). Our key findings are the different spatial morphologies in all of these maps: Hα and [N II] line emission is restricted to the immediate neighborhood of the brightest source of the F10214+4724 complex (source 1 in Matthews et al. 1994). No significant line emission is found in sources 2, 3, or 4, anywhere in the K-band. The [N II] emission is fairly compact and marginally extended (east-west), as concluded by Matthews et al. (1994). Hα is also compact, but is significantly more extended east-west, following approximately the $1\farcs5 - 2''$ arc structure of source 1 in the Keck K-band image. Line-free K-continuum is visible in source 1 as well, and has an extension north of it at the position of source 2 (Fig. 1, *right panel*). Source 2 is weaker than source 1 by a factor of 2. The integrated $1.95 - 2.4$ μm map (not shown) is in excellent agreement with the Keck K-band image. Thus, we conclude that a significant fraction of the east-west extent in the K-band maps is due to line emission.

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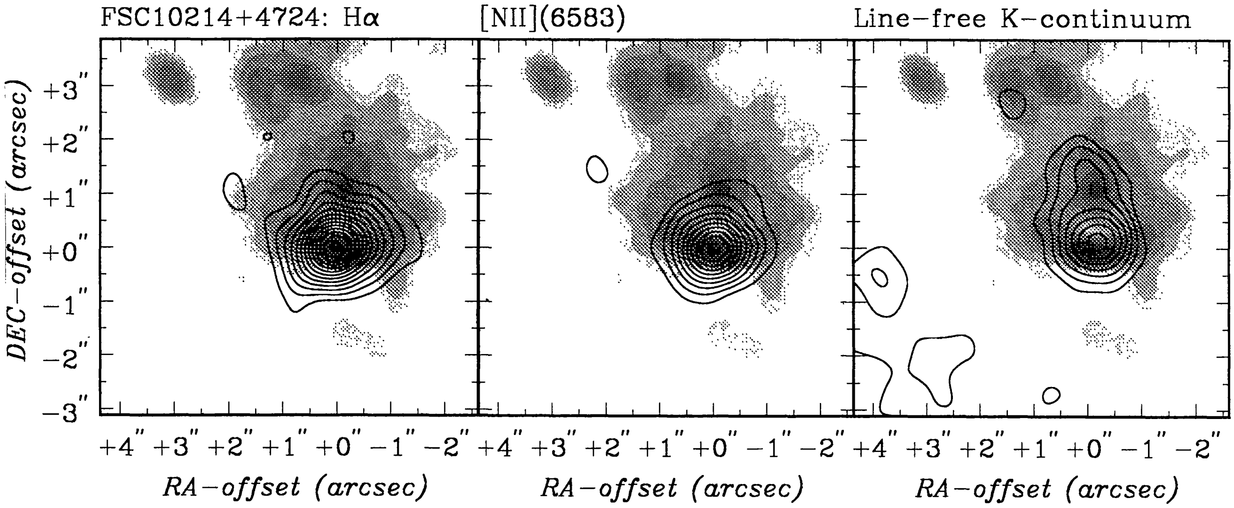

Fig. 1. ***3D*-channel maps (contours; linear scale) of three spectral regions ontop of the Keck *K*-band map of** Graham & Liu (1995) (logarithmic grey scale). *left*: Hα. *middle*: [N II]λ6583. Contours for both maps in $2\,\sigma$ steps, starting with $3\,\sigma$. *right*: line-free K-continuum (98 continuum channels between 2.02 and 2.32 μm). Contours are in $1\,\sigma$ steps, starting with $1\,\sigma$.

Broad Hα Emission. We have fitted multiple Gaussians to the Hα/[N II]$\lambda\lambda$ 6548, 6583 spectra for different spatial regions: aperture sizes of 0.″75, 1.″25, 1.″75 and 2.″25, centered on the Hα peak; two ringlike regions containing the flux from the 2.″25 aperture, but not the central 0.″75 and 1.″25 aperture, respectively; and, finally, a region covering just the wings (more than 0.″7 east-west distance from the center) of the 2″ arc (source 1). Fixing the [N II]λ6583/[N II] λ6548 ratio to its theoretical value, results in a fit with unacceptably large residuals (Fig. 2a) for a fit with three Gaussians. It is necessary to add emission contributing blueward of the Hα peak to account for the line wing to the blue of [N II]λ6548. The most plausible such component is a broad Hα emission line. As demonstrated in Figure 2 b-d, the fits using a fourth, broad Gaussian centered on the narrow Hα line are very satisfactory. The contribution of broad Hα to the total line flux of the Hα+[N II] line system is 50% for the 2.″25 aperture, the line width is 2400 km s^{-1} FWHM (FWZP=3500 km s^{-1}) for all fitted regions, while the three narrow lines are unresolved (FWHM 600 ± 100 km s^{-1}). Thus, we conclude that the nucleus of F10214+4724 contains a buried BLR and, therefore, is likely to have a type 1 (Seyfert I or QSO) nucleus.

Extended Hα Emission: Circumnuclear Star Formation. The [N II]λ6583/H$\alpha_{\rm broad}$ line ratio does not vary with aperture size, which is consistent with a dominating compact AGN origin of both lines. Therefore, we finally constrained the fit by fixing the [N II]λ6583/H$\alpha_{\rm broad}$ line ratio and fitted six parameters to our data set: a narrow and a broad linewidth, two amplitudes, a wavelength position and a continuum level. In contrast, the [N II]λ6583/H$\alpha_{\rm narrow}$ line ratio shows spatial variation in our data; it drops from $1.66 \pm 0.06(1\,\sigma)$ in the peak-centered 0.″75 aperture to 1.2 ± 0.16 within the 2.″25 aperture. In the extreme wings of the 2″ arc the ratio is 0.6 ± 0.2. Thus, we find that 30% of the total narrow Hα flux is in an east-west extended component, corresponding to the 2″ arc in the Keck K-band image. For small apertures, the [N II]λ6583/H$\alpha_{\rm narrow}$ line ratio is consistent with a classical photoionized NLR. In the east-west wings that undiluted ratio is ≤ 0.5 and resembles that of an HII region galaxy ([N II]λ6583/Hα=0.2–0.5, Osterbrock 1989, p. 346). We propose that this extended component is a starforming disk and may be associated with the zone of FIR continuum and submm CO emission. Although the S/N substantially decreases in the outer region, the main signature of the changing physical conditions, which is the change in [N II]/Hα ratio, is a robust result. Even the fourth component (H$\alpha_{\rm broad}$) is not critical at all for this conclusion; in fact just fitting three components without fixing the [N II]λ6583/[N II]λ6548 flux ratio would make the result even clearer because the [N II]λ6583/H$\alpha_{\rm narrow}$ line ratio would drop even more dramatically in the outer regions.

Energetics of F10214+4724: Contributions of AGN and Star Formation. From the observed broad- and narrow-line Hα fluxes, estimates of their extinctions, and model gravitational lens magnifications, it is now possible to derive a first rough estimate of the luminosities of these two components. Lens models (Broadhurst & Lehár 1995; Eisenhardt et al. 1995) predict a magnification of 50–100 for the central (0.″7, intrinsic size

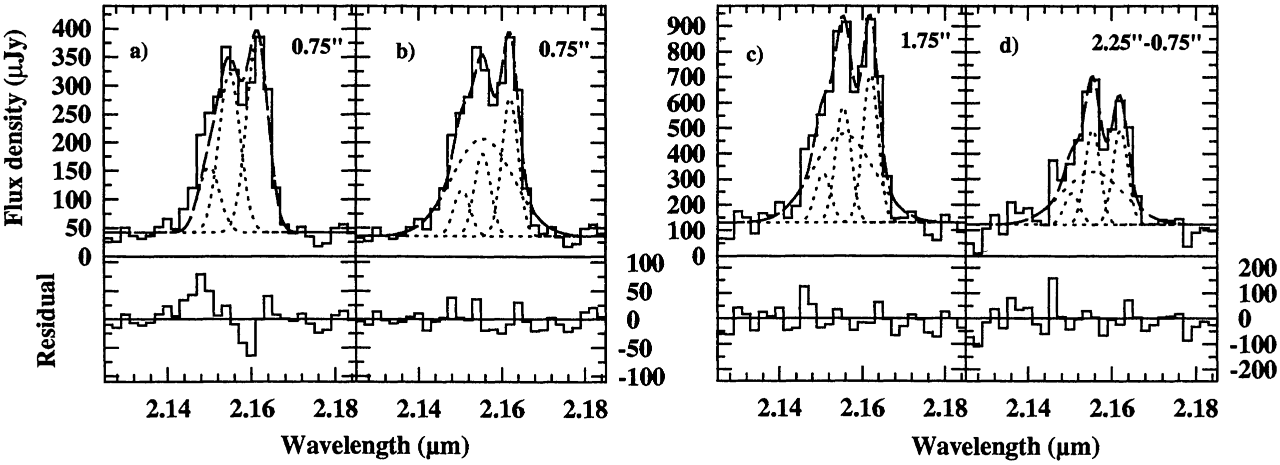

Fig. 2. Line fits to the Hα+[N II]$\lambda\lambda$ 6548, 6583 profile for different apertures: *(a)* : 0.″75, three Gaussians; *(b–d)* : 0.″75, 1.″75, and Annulus (2.″25 – 0.″75), fitted by four Gaussians. Histogram represents the data, short-dashed lines the single Gaussian fits, and long-dashed line the sum. Lower plots are the residuals of the fits.

TABLE 1
DERIVED LUMINOSITIES OF VARIOUS COMPONENTS

Component	Observed Luminosity[a]	Extinction Correction	Magnification Factor	$L_{bol}/L_{H\alpha}$	L_{bol}
$H\alpha_{broad}$	16 ± 4	8	50–100	400–600[b]	500–1500
$H\alpha_{narrow}$	5 ± 1	8	50–100	180[b]	70–140
$H\alpha_{starformation}$	1.5 ± 0.5	10–100	5–10	200[c]	300–6000

[a]All luminosities are in 10^9 $L_\odot$.
[b]Netzer 1990.
[c]case B recombination (e.g., Osterbrock 1989) and $L_{bol}/L_{Lyc} = 8$.

$\sim$ 0.01″ or 50 pc), bright component. For the more extended (2″, 0.4″ or 2 kpc intrinsic), fainter arc visible on the Keck-image, the magnification is 5–10. This is probably also the size scale of the FIR continuum and CO emission region (Downes et al. 1995). In Table 1 we give an estimate of the BLR, NLR and starburst contributions to the Hα flux. The visual extinction can be derived from the observed Hα/Hβ ratio of 8.6 (Iwamuro et al. 1995). For an intrinsic ratio of 3.1 this results in $A_V = 2.9$ and an extinction correction of a factor of 8. For the circumnuclear region a mixed dust-gas model is more likely, leading to much larger values for A_V. The CO fluxes of Downes et al. (1995) convert to $A_V \geq 10^2$ in the circumnuclear star forming region and an extinction correction of at least 10 or even 10^2. Finally, we estimated the $L_{H\alpha}$ to L_{bol} (case B recombination) for the star forming region, and for typical AGN NLR/BLR models (Netzer 1990) (see Table 1). While the details are still quite uncertain, the basic result is clear. Both a powerful AGN and a very luminous circumnuclear star formation region contribute to the total luminosity of F10214+4724. Thus, F10214+4724 has intrinsically similar characteristics as other luminous IRAS galaxies, although it is still one of the most luminous galaxies.

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