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MID-INFRARED T-RECS SPECTROSCOPY OF LOCAL LIRGS

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RESUMEN

Se presenta espectroscopía de alta resolución espacial con T-ReCS en la banda N ($8-13\,\mu$m) de las regiones centrales (unos pocos kpc) de tres galaxias infrarrojas (IR) luminosas (LIRGs) locales. Los espectros nucleares presentan una profunda banda de absorción de los silicatos a $9.7\,\mu$m y la línea de emisión de [S IV]$10.5\,\mu$m en acuerdo con su clasificación como AGN. Las dos LIRGs con emisión en el IR medio no resuelta no muestran emisión PAH en $11.3\,\mu$m en sus espectros nucleares. Para NGC 5135 los datos de T-ReCS nos han permitido resolver los espectros del núcleo, una región H II y la zona difusa entre ambos, en escalas menores que $2.5'' \sim 600$ pc. La zona difusa presenta emisión PAH brillante con un continuo débil, mientras que la región H II presenta emisión PAH con menor anchura equivalente y la línea de [Ne II]$12.8\,\mu$m.

ABSTRACT

We present T-ReCS high spatial resolution N-band ($8-13\,\mu$m) spectroscopy of the central regions (a few kpc) of 3 local LIRGs. The nuclear spectra show deep $9.7\,\mu$m silicate absorption feature and the high ionization [S IV]$10.5\,\mu$m emission line, consistent with their optical classification as AGN. The two LIRGs with unresolved mid-IR emission do not show PAH emission at $11.3\,\mu$m in their nuclear spectra. The spatially resolved mid-IR spectroscopy of NGC 5135 allows us to separate out the spectra of the Seyfert nucleus, an H II region, and the diffuse region between them on scales of less than $2.5'' \sim 600$ pc. The diffuse region spectrum is characterized by strong PAH emission with almost no continuum, whereas the H II region shows PAH emission with a smaller equivalent width as well as [Ne II]$12.8\,\mu$m line.

Key Words: **GALAXIES: ISM — GALAXIES: SEYFERT — H II REGIONS — INFRARED: GALAXIES**

1. INTRODUCTION

Luminous Infrared (IR) Galaxies (LIRGs, $10^{11}L_\odot \leq L_{[8-1000\,\mu m]} \leq 10^{12}L_\odot$, Sanders & Mirabel 1996) dominate the star formation (SF) rate density (Pérez-González et al. 2005) at $z \sim 1$. The integrated properties of these high-z LIRGs are similar to their local universe analogs. Much of our knowledge of the mid-IR spectroscopic properties of local IR-bright galaxies comes from *ISO* (e.g., Genzel et al. 1998) and early results with IRS on *Spitzer* (Armus et al. 2004). However the majority of the *ISO* works focused on samples of local IR-bright starburst galaxies (Verma et al. 2003), or included mainly ULIRGs (e.g., Genzel et al. 1998). There have been few ground-based high spatial resolution studies of LIRGs (e.g., Soifer et al. 2002) but again they tend to study only the most luminous and famous examples in the LIRG class.

In this paper we present the first results of a T-ReCS (Telesco et al. 1998) spectroscopic study of three local LIRGs selected from the representative sample of local LIRGs of Alonso-Herrero et al. (2006a). For this sample we have already obtained Gemini-South/T-ReCS mid-IR imaging data (Alonso-Herrero et al. 2006b) which allowed us to initially select LIRGs with bright compact nuclear emission so high S/N spectra could be obtained. This tends to include those LIRGs in our sample hosting an AGN, although as we shall see, the superior spatial resolution achieved by T-ReCS allows us to separate the AGN emission from the circumnuclear emission (see §4).

2. OBSERVATIONS

We obtained T-ReCS N-band spectroscopy of the central (a few kpc) regions of NGC 5135, IC 4518W, and NGC 7130. We used the low-resolution mode ($R \sim 100$) with a slit width of $0.''72$. The pixel size of $0.089''$ provides a slit of $21.6''$ in length. The on-source integration times were 30 minutes per target. The observing conditions were excellent making the T-ReCS observations effectively diffraction limited (FWHM$\sim 0.''35$). The 1D-spectrum extraction (see Figures 1 and 2) for point sources was made λ-dependant, to account for the PSF variations, with an aperture of $0.''36$ at $\lambda = 10.37\,\mu$m.

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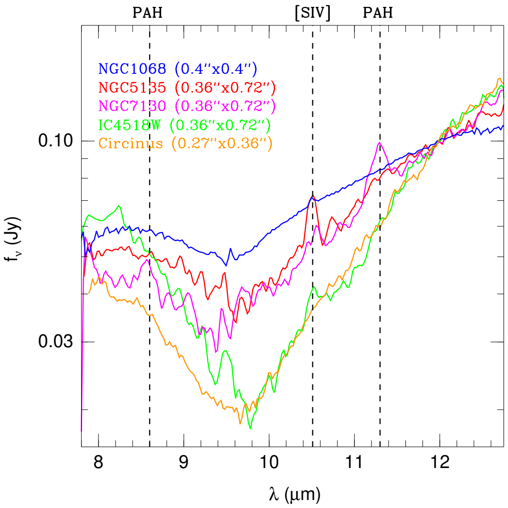

Fig. 1. T-ReCS rest-frame nuclear spectra of our three LIRGs: NGC 5135, IC 4518W, and NGC 7130, as well as two comparison Sy 2 galaxies: Circinus and NGC 1068, shown in the order (top to bottom) given by the labels. The spectra have been normalized to 0.1 Jy at 12 μm for a better comparison of the depth of the 9.7 μm silicate feature. The scaling factors of the spectra are: 1.23, 0.92, and 0.90 for NGC 5135, IC 4518W, and NGC 7130, and 0.008 and 0.07 for NGC 1068 and Circinus.

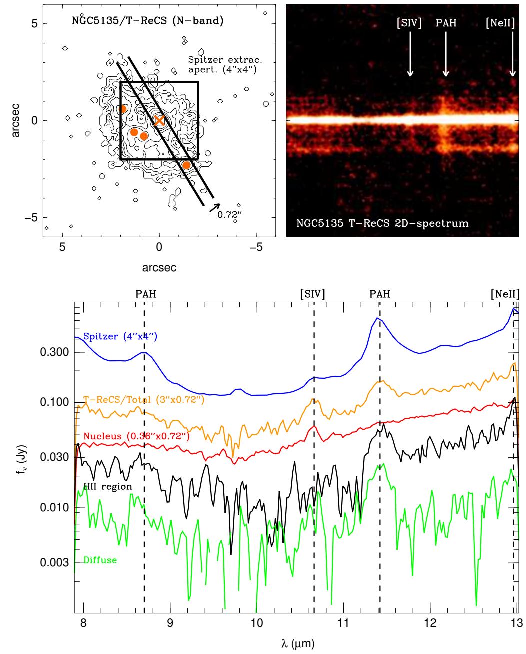

Fig. 2. *Upper left panel*: Contour plot at 10.4 μm of the central region of NGC 5135. The solid lines indicate the position and orientation of the T-ReCS slit. The square indicates the approximate size of the extraction aperture of the *Spitzer*/IRS spectrum (see bottom panel). The cross marks the Sy 2 nucleus, whereas the filled circles indicate the locations of luminous H II regions detected both in the mid-IR and Paα (see Alonso-Herrero et al. 2006b for more details). *Upper right panel*: 2D T-ReCS spectrum of NGC5135. *Lower panel*: Low-res IRS spectrum extracted with the smallest possible aperture, and T-ReCS spectra for the three regions discussed in the text: nucleus, H II region, and diffuse region.

3. NUCLEAR EMISSION

The 3 LIRGs host an optically identified AGN (NGC 5135 and IC 4518W are Seyfert (Sy) 2s, whereas the NGC 7130 has been classified as Sy 2 or LINER). From our T-ReCS and NICMOS imaging data we have detected unresolved nuclear emission in NGC 5135 and IC 4518W, implying sizes of $< 40 - 51$ pc, respectively, whereas the mid-IR nuclear emission of NGC 7130 appears resolved with a size of ~ 190 pc (see Alonso-Herrero et al. 2006b). In addition we have detected in NGC 5135 and NGC 7130 bright H II regions within the central $1 - 2$ kpc. The nuclear T-ReCS spectra of these LIRGs are presented in Figure 1. The T-ReCS slit width covers approximately the central 200 pc. For comparison we include T-ReCS nuclear spectra of 2 bright nearby Sy 2 galaxies for which the T-ReCS slit probes smaller physical regions (~ 30 pc for NGC 1068, Mason et al. 2006; ~ 6 pc for Circinus, Roche et al. 2006).

The presence of the 9.7 μm silicate absorption feature in all of the nuclear spectra is clear, but its depth varies significantly from galaxy to galaxy (see Figure 1). This feature is commonly seen in absorption in Sy 2s and in emission in some type 1 AGNs (Roche et al. 1991; Clavel et al. 2000; Shi et al. 2006). Shi et al. (2006) have found for Sys a relation between the depth of the silicate feature measured from *Spitzer*/IRS spectra and the hard X-ray column density. All the galaxies shown in Figure 1, except IC 4518W for which there are no X-ray data, are Compton-thick so they should show similar depths. We note that although the limited T-ReCS spectral range makes it difficult to reliably estimate the continuum to measure the depth of this feature, the observed range of depths seems to be real.

We have also marked in Figure 1 the 8.6 and 11.3 μm PAH features. The Sy nuclei of NGC 5135 and IC 4518W do not show PAH emission as found for other Sy nuclei with high spatial resolution mid-IR spectroscopy (e.g., Circinus, Roche et al. 2006; NGC 1068, Mason et al. 2006). This supports the scenario that the PAH carriers are evaporated in the presence of a hard ionization field such as an AGN.

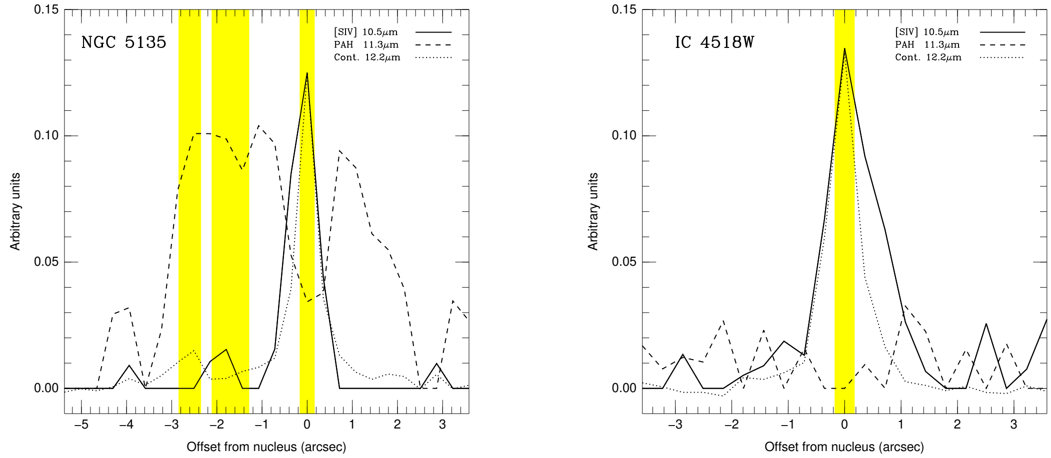

Fig. 3. T-ReCS spatial profiles of the [S IV] line, the 11.3 μm PAH emission, and the 12.2 μm continuum. The shaded areas indicate the extraction apertures for 1D spectra (Figures 1 and 2). The nuclei are located at the continuum peak.

The only exception, NGC 7130, shows extended near and mid-IR emission (Alonso-Herrero et al. 2006b), consistent with the presence of nuclear PAH due to SF.

The relatively high ionization potential (34.8 eV) of the [S IV]10.5 μm emission line may be interpreted as an AGN signature, but it has also been detected in very young starbursts (Roche et al. 1991; Verma et al. 2003) where the ionization is dominated by young hot stars. The line is detected in the three LIRGs (Figure 1). The spatial distributions show that [S IV] is clearly present in off-nuclear regions associated with the AGN with an asymmetric distribution, especially in the case of IC 4518W (Figure 3), as also found for Circinus (Roche et al. 2006).

4. SPATIALLY RESOLVED MID-IR SPECTROSCOPY OF NGC 5135

In NGC 5135 the T-ReCS slit was placed (Figure 2) such that we could observe the Sy2 and a bright H II region (with mid-IR and Paα emission) located $\sim 2.5'' \sim 600$ pc away, as well as the region with diffuse emission between them. The *Spitzer*/IRS spectrum of the central $4'' \times 4''$ ($\sim$ 1 kpc $\times$ 1 kpc) includes emission from the Sy nucleus and a number of H II regions, as well as diffuse emission. The [S IV] emission line arises only from the nuclear regions (Figures 2 and 3), and it is not detected in the H II region, whereas the lower ionization [Ne II]12.8 μm line is detected in both (Figure 2). There is 11.3 μm PAH feature in the H II region, and it is clearly extended in the diffuse region between the nucleus and the H II region. The spectrum of the H II region shows PAH feature emission, and [Ne II] emission. In contrast, the diffuse region shows faint continuum emission and no [Ne II] line, and strong PAH emission with a large equivalent width (Figure 2).

Summarizing, spatially resolved mid-IR T-ReCS spectroscopy has allowed us to separate out different emission mechanisms such as nuclear emission (SF and/or AGN), H II regions, and regions of diffuse emission not associated with strong ionizing sources. This kind of study will be ideally suited for the GTC/CanariCam system.

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