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The energetic source in nearby and high redshift ULIRGs

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Abstract. Ultraluminous Infrared Galaxies (ULIRGs) are powered by AGNs and/or starbursts (SB). In order to disentangle the relative AGN/SB contribution in ULIRGs we analyzed two large samples of local ($z < 0.15$) ULIRGs through 3-5 μm spectroscopy (VLT-ISAAC data) and 5-8 μm low resolution spectroscopy (*Spitzer-IRS* data). We Analyzing pure SB ULIRGs and sources known to host an AGN, we derived well calibrated diagnostic tools that can be used to deconvolve the relative AGN/starburst contributions to both the 3-8 μm and the bolometric luminosities. Applying these diagrams to a complete sample of ULIRGs optically classified as LINERs we show that 40% of them host an AGN even if its contribution to the bolometric luminosity is relevant only on 20% of the sources. Finally a preliminary study on high redshift ($z \sim 2$) sources suggest the presence of heavily obscured AGNs in 24 μm-selected galaxies.

Key words. Galaxies: active – Galaxies: starburst – Infrared: galaxies

1. Introduction

Determining the physical properties of the engine in Ultraluminous Infrared Galaxies is fundamental for many reasons. With a 8-1000 μm luminosity of $L_{IR} = 10^{12} L_{\odot} \backsimeq L_{Bol}$ ULIRGs are the most luminous sources in the local Universe and dominate the bright end of the infrared background (Sanders & Mirabel 1996). Unveiling the origin of the huge IR emission of ULIRGs is therefore important in itself, given the relevance of this class of objects in the low-redshift Universe, and in order to understand the nature of the high-redshift FIR sources. Observational and theoretical studies on ULIRGs, point out two main aspects of their physics: a) the IR emission is due to dust reprocessing of UV and X-ray photons; b) ULIRGs are mostly found in interacting systems or highly irregular galaxies (Sanders et al. 1988). Two different physical processes are possible as the primary energy sources of ULIRGs: nuclear activity due to an active galactic nucleus (AGN) and/or strong starburst activity (SB); nevertheless it is still not clear which fraction of ULIRGs host an AGN, and which are the relative contributions of AGN and SB to the bolometric luminosity. To answer these questions several indicators, in a wide range of wavelengths (from mid-IR (Genzel et al. 1998) to X-ray (Franceschini et al. 2003)), have significantly enhanced our understanding of emission in ULIRGs, but still have important limitations which prevent us

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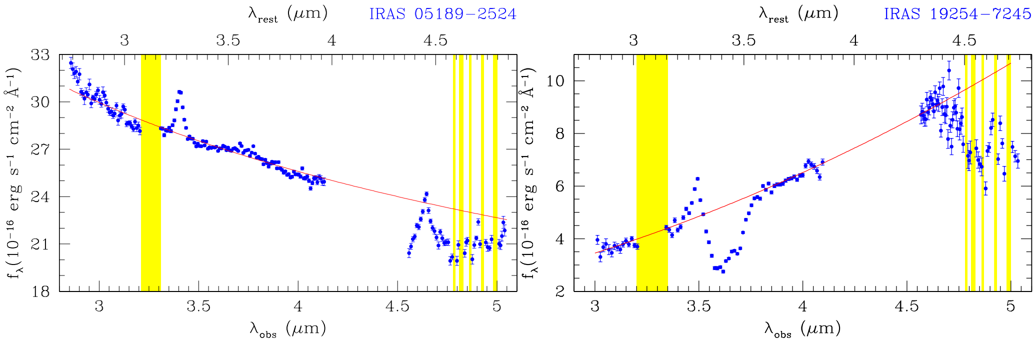

Fig. 1. 3-5 μm high quality spectra. Top panel: a flat spectrum ($\Gamma = -0.5$), diluted PAH emission ($EW_3.3 = 4$ nm) and the absence of strong absorption features point a SB process combined with unobscured AGN. Bottom panel: a reddened spectrum ($\Gamma = 2.21$), PAH emission ($EW_3.3 = 24$ nm) hydrocarbon and CO absorption features ($\tau_{3.4} = 0.59$, $\tau_{4.6} = 0.39$) are due to a starburst with a heavily obscured AGN.

to find an AGN when it is intrinsically faint or heavily obscured. A promising new approach to the study of ULIRGs is L-band (3-4 μm) spectroscopy: a comparison between the spectral energy distributions of AGN and SB shows that the L-band emission by an AGN is a factor of ~100 higher than that of a SB with the same bolometric luminosity (Risaliti et al. 2006). Therefore, when studying mixed sources, where both an AGN and a SB are present, the emission of the AGN component can be revealed even if the SB is bolometrically dominant and/or the AGN is heavily obscured. The limit of this method resides in the low quality of the available L-band spectra (Risaliti et al. 2006; Imanishi, Dudley, & Maloney 2006), which give uncertain results except for the brightest sources (Sani et al. 2007; Risaliti et al. 2006). However it is possible to perform a similar analysis based on *Spitzer* IRS 5-8 μm spectra: in this range an AGN is "only" ~ 30 times more luminous than a SB with the same bolometric luminosity, but the high quality of *Spitzer* data allows a much more accurate spectral deconvolution of the AGN/SB components than in the ground-based L-band spectra (Nardini et al. 2007).

2. AGN/SB deconvolution model

To deconvolve AGN/SB components we reproduce the observed emission combining average spectral templates. The observed flux density is

$$f = \alpha\ f(AGN)\ e^{-\tau} + (1-\alpha) f(SB, PAH), \quad (1)$$

where α is the relative AGN luminosity contribution. The SB template in the L-band $f(SB, PAH)$ is a powerlaw with $\Gamma = -0.5$ plus a PAH emission line with $EW_{3.3} = 110$ nm in agreement with average L-band spectra of SB dominated ULIRGs (Imanishi & Dudley 2000). $f(AGN) \propto \lambda^{\Gamma}$ ($\Gamma = -0.5$) is the AGN template, in agreement with the L-band spectra of ULIRGs dominated by unabsorbed AGNs (Risaliti et al. 2006), and with L-band spectra of pure type 1 AGNs (Imanishi & Wada 2004). The AGN continuum is reddened by a cold dust component with a wavelenght dependent optycal depth $\tau_\lambda \propto \lambda^{-1.75}$ (Cardelli et al. 1989): an AGN is such a compact source that the direct IR radiation due to hot thin dust reprocessing can be reddened by a compact screen of cold dust wich can not cover the typical SB scales.

3. L and M band observations

3-5 μm data show several observational indicators of the starburst process and a possible AGN: - a large equivalent width of the 3.3 μm PAH emission feature ($EW_{3.3} \sim 110$ nm) is typical of SB-dominated sources, while the hard X-ray emission of an AGN partially or completely destroys PAH molecules.
- A strong absorption feature at 3.4 μm ($\tau_{3.4} > 0.2$) due to aliphatic hydrocarbon grains is an indicator of an obscured AGN and, indeed, such a deep absorption requires a point

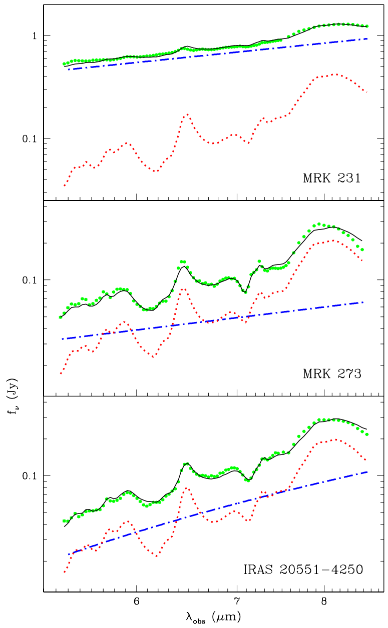

Fig. 2. Representative 5-8 μm spectral shapes of ULIRGs. Variations are due to the relative AGN/SB contribution to the observed emission. In Mrk 231 an AGN is the dominant power source, with a strong continuum diluting the PAH EW. Mrk 273 hosts a fainter AGN and the SB signature is clearly identified. IRAS 205514250 harbours an obscured AGN with less prominent features and a steeper continuum than the former ones. The dashed and the dotted lines show the AGN and SB contributions, respectively.

source behind a screen of dusty gas (Imanishi & Maloney 2003).
- A steep inverted continuum (described by a power law $f_\lambda \propto \lambda^\Gamma$, $\Gamma > 1$) suggests the presence of an obscured, reddened AGN: a high value of Γ implies strong dust reddening of a compact source.
- In a few sources M-band (4-5 μm) spectra shows strong ($\tau > 0.2$) gaseous CO at 4.67 μm connected with a reddened continuum and 3.4 μm absorptions, thus representing a new AGN indicator (Sani et al. 2007). Typical spectra of a SB combined with an unobscured AGN and an heavily absorbed one are shown in Fig.2

4. *Spitzer* observations

- The starburst mid-IR spectrum is homogeneus from one source to another in the 5-8 μm band (Brandl et al. 2006) and is dominated 6.2 μm and 7.7 μm PAH emission features. Then to describe the SB component in ULIRGs we use well known pure starburst spectra of ULIRGs such as Arp 220 and IRAS17208-0014 observed with *Spitzer* IRS
- As in the L-band case the mid-IR intrinsic emission of an AGN is described by a featureless power law with a fixed spectral index $f_\nu \propto \lambda^{1.5}$, reddened by the above extinction law. - In some spectra two additional absorption features are present, one attributed to water ice (at 6.0 μm) and the other attributed to aliphatic hydrocarbons (at 6.9 μm). An obscured AGN is associated with these features when it is impossible to reproduce them through the SB template, according to the continuum steepnes-features optical depth connection observed in 3-5 μm data.

5. Diagnostic diagrams

To identify a possible AGN and to disentangle its contribution from that of a starburst we have realized bidimensional diagnostic diagram using observational parameters. To carfully calibrate these diagrams we used all available L-band and *Spitzer* data of well known sources as pure SB or ULIRGs hosting an AGN. The diagnostic diagrams are in Fig.3. The L-band diagram contains data (from observations performed at VLT, SUBARU, and IRTF) of a complete sample of 55 local ($z < 0.15$) ULIRGs with 25% of identified AGNs, 22% of pure SB and 56% of LINERS for wich the energetic source is unknown. The *Spitzer* diagram contains data of 5-8 μm IRS spectra of a complete 68 local ULIRGs with 35 LINERs. Optycal LINERs are spread all across the two diagrams, thus these kind of sourches are rather heterogeneus in the nature of their energy source, and we can solve the ambiguity applying our diagrams. Moreover several ULIRGs optically classified as SB actually host an AGN, probing the limits of optical classification. Overall an

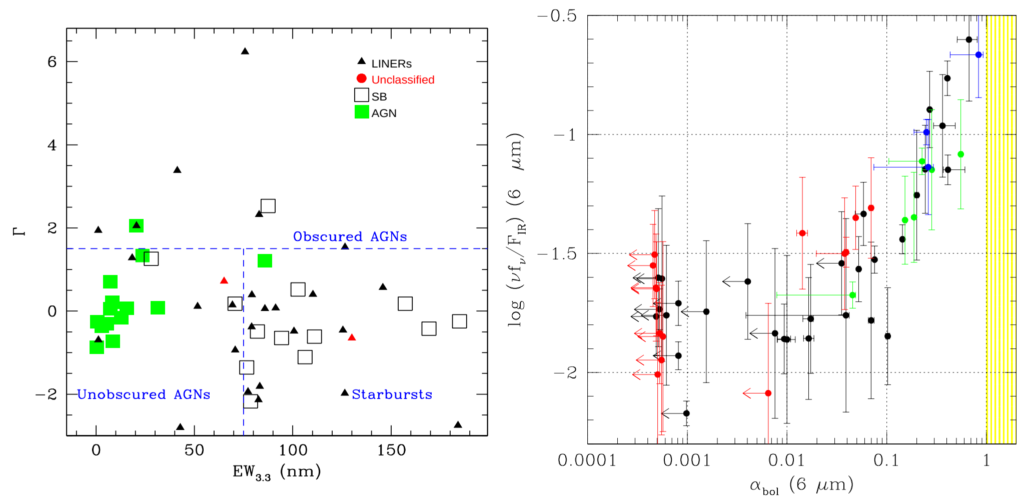

Fig. 3. Left panel: 3-4 μm continuum slope versus PAH equivalent width. Pure SB sources and ULIRGs hosting an AGN are completely separeted according to the optycal classification, moreover absorbed AGNs are separated from unobscured ones. Two exception are found among opticaly classified SB showing the presence of an AGN wich is obscured in one of it. Right panel: ratio between 6 μm total flux and IR flux versus the AGN bolometric contribution. AGN dominated ULIRGs are separeted from starbust one according to our model and optical classification (red SB, black LINER, blue type1 AGN, green type2 AGN)

AGN with contributing to 1% of the bolometric luminosity is detected in ∼ 60% of ULIRGs, but is significant ($\alpha_{Bol} > 0.2$) only in 30% of the cases. The SB process consist of the 90% of the ULIRGs infrared luminosity. Similar fractions are valid for the LINERs subsamples. Our analysis have also an immediate consequence on the nature of high-z infrared-bright galaxies found in 24 μm MIPS surveys. IRS spectroscopy of the brightest of these sources show that they are mostly z∼ 13 galaxies (Houck et al. 2005). Since the MIPS 24 μm filter samples the rest-frame wavelength range centered at 612 μm, our results imply that a strong bias toward AGN-dominated sources is expected, because of their ∼ 35 times higher relative emission. The topic is also shown in Fig.3 right panel were $log(\nu f_\nu/F_{IR}) > -1.5$ correspond to ULIRGs with a significative or dominant AGN.

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