The discovery by IRAS of luminous ($L_{\text{IR}}>10^{11} \, L_\odot$) and ultraluminous ($L_{\text{IR}}>10^{12} \, L_\odot$) IR galaxies (LIRGs / ULIRGs) opened a new window in extragalactic astronomy, since it revealed that they are for those luminosities the dominant population of extragalactic objects in the local Universe ($z<0.3$). It is now widely accepted that i) nearly all ULIRGs are advanced mergers harboring powerful nuclear starbursts and/or enshrouded AGN, and ii) the mid-IR is a powerful tracer of the star formation activity and bolometric luminosity of galaxies. The poor spatial resolution of IRAS though, due to the large ($\sim 1\text{arcmin}$) pixels used, made it impossible to resolve the physical extent of the region which produces the bulk of the mid-IR emission. Recently, ground based 10 and 18µm imaging for a number of the nearest and brightest objects, has revealed compact nuclear emission from regions of just few arcsecs in diameter, (i.e. Soifer et al. 2001), even though the ground measurements are hampered in sensitivity by the low mid-IR atmospheric transmission. Using ISOCAM, the most sensitive mid-IR camera to date and the good spatial resolution images it provides, we searched for extended emission from a sample of nearby luminous IR galaxies (Arp220, Arp299, NGC6240, VV114, IRAS14248-1447, IRAS19254-7245, IRAS23128-5919) for which the 5-16µm spectral energy distribution was available.

We find that with the exception of VV114 more than 90% of the integrated IRAS 12 micron flux originates from their nuclear regions ($\sim 5\text{arcsec}, <2\text{kpc}$). This result suggests that the 10-15µm properties of distant unresolved ULIRGs would likely to also be dominated not by their disks, but by their nuclear region instead.
Arp220

$L_{IR} = 1.2 \times 10^{12} \ L_\odot$, $D=72 \text{Mpc} \ (z=0.018)$, IRAS12=0.48Jy, $f(12-18\mu m)\sim 732 \text{mJy}$

The prototypical ULIRG. The two nuclei of the merger are separated by 0.94" ($\sim 330 \text{pc}$) and are unresolved by ISOCAM. No diffuse emission which can not be attributed to the central point source has been observed down to our sensitivity limit ($\sigma \sim 0.02 \text{mJy arcsec}^{-2}$).

![Image of Arp220 observed with ISOCAM at 6.75 µm (LW2 filter). The lowest contour is at 0.2mJy/pixel while the peak emission is 25mJy/pixel. b) The ISOCAM image at 15µm (LW3 filter). The lowest contour is at 0.4mJy/pixel while the peak emission is 64mJy/pixel. The pixel size has been convolved from 1.5arcsec to 3arcsec ($\sim 1 \text{kpc}$). In both cases the two nuclei remain unresolved.]

For comparison we show an HST/NICMOS 2.2µm image of Arp220 by Scoville et al. 2000 along with 7.9 and 18µm images taken with Keck (Soifer at al. 2001). We see that the thermal warm dust emission is localized to sub-arcsec regions.
**NGC6240**

$L_{\text{IR}} = 0.6 \times 10^{12} L_\odot$, $D=97\text{Mpc}$ ($z=0.025$),

IRAS12=0.56Jy, $f(12-18\mu\text{m})\sim785\text{mJy}$

A “nearly” ultraluminous merger of two counter-rotating gas rich galaxies. The two nuclei are separated by 1.6arcsec($\sim0.8\text{kpc}$). The southern galaxy is brighter, more dusty than the norther one (see Scoville et al. 2000) and it displays a LINER spectrum. Strong emission from warm H$_2$ gas has been observed in the near-IR (van der Werf 1993). We observed no diffuse emission. Furthermore the AGN does not contribute significantly in the mid-IR to be identified via our low spectral resolution mid-IR diagnostic (see Laurent et al. 2000) or via the high-ionization lines (see Genzel et al. 1998, ApJ, 498, 579)

The mid-IR SED of NGC6240. Taking into account the PAH emission features the spectrum can be fitted with a warm blackbody of $T\sim150\text{K}$, extinct by $A_V\sim30\text{mag}$ assuming a screen model and the extinction curve of Dudley & Wynn-Williams (1997). The red line indicates the IRAS12 flux and bandwidth. Note the strong H$_2$ lines (this is the only system in our sample displaying them as prominently) which are due to warm shocked molecular gas as the two progenitor counter-rotating disks interact in the regions between the nuclei.

For comparison we present the HST/NICMOS 2.2µm image of NGC6240 by Scoville et al. 2000

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a) Image of NGC6240 observed with ISOCAM at 6.75µm (LW2 filter). The lowest contour is at 0.2mJy/pixel while the peak emission is 18mJy/pixel. b) The ISOCAM image at 15µm (LW3 filter). The lowest contour is at 0.4mJy/pixel while the peak emission is 32mJy/pixel. The pixel size is 1.5arcsec ($\sim750\text{pc}$). We can marginally observe an extension along the north/south direction of the two nuclei.
Arp299 (IC694/NGC3690)

$\text{L}_{IR} = 0.52 \times 10^{12} \text{ L}_\odot$, $D=41 \text{ Mpc}$ ($z=0.01$)

A system with two galaxies (IC694, NGC3690) violently interacting. Its morphology changes dramatically between the optical and mid-IR where the enshrouded nuclear source in IC694 dominates the emission of the system. Even though some diffuse emission is detected in the various star forming regions of the tidal debris and disks it does not contribute substantially to the IRAS12 warm dust emission and it only accounts for less than 30% of the bolometric luminosity of Arp299. The latter was quantified via KAO imaging of the 37 µm emission, which unlike the 15 µm flux directly traces the IR luminosity.

We present as a background the HST/NICMOS J-band image of Arp299 obtained by Alonso-Herrero (2000) overlaid with contours of a) the 7 µm emission, b) the 15 µm emission, and c) the 38 µm emission. Note how IC694 dominates as we move to longer wavelengths. For more details see Charmandaris et al., ApJ, 2002, 571, 282.

a) A 12.5 µm image of Arp299 taken with Keck (Soifer et al. 2001) which displays the compact mid-IR morphology. b) Curves of growth (x-axis radius in kpc / y-axis normalized to IRAS12 flux) indicating that most mid-IR emission is compact (solid line 12.5 µm, dashed line 2 µm (from Soifer et al. 2001).

The SED of the various components of Arp299. IC694 (shown in red) even though inconspicuous in the optical is responsible for the bulk of the bolometric luminosity (Charmandaris et al. 2002).
IRAS 19254-7245 (The Superantennae)

$L_{\text{IR}} = 1.03 \times 10^{12} \text{ L}_{\odot}, \, D=250\text{Mpc (z=0.06)}, \, \text{IRAS12=0.22Jy, f(12-18}\mu\text{m}) \sim 290\text{mJy}$

Well known system of two gas rich interacting galaxies the nuclei of which are separated by 10kpc, displaying long tidal tails extending to 350kpc. The northern galaxy is a starburst of LINER while southern galaxy has been classified as a Seyfert 2. The presence of the Seyfert is visible in our spectrum as we can detect the elevated emission of hot dust originating from the AGN torus at the of the 5-6µm region. We find that more than 95% of the mid-IR flux (12-18µm) originates from the unresolved nuclear region of the southern galaxy. The 12-18µm luminosity of the system is ~4% of the total emitted in the IR (8-1000µm). For more info see Charmandaris et al. 2002 (astro-ph/0206150).

The integrated mid-IR SED of the galaxy summing all flux above 5σ. The 5-11µm spectrum of Rigopoulou et al. (1999) is included.

K-band image of the galaxy from Duc et al. 1997. The bar is 5kpc is size.

The mid-IR SED of the two galaxy components. The red line indicates the IRAS12 flux and bandwidth. Note that the southern galaxy emits more than 95% the mid-IR flux of the system.
**IRAS 23128-5919**

$L_{IR} = 0.92 \times 10^{12} \, L_\odot$, $D=180\,\text{Mpc}$ ($z=0.04$), $\text{IRAS12}=0.24\,\text{Jy}$, $\text{f}(12-18\mu\text{m}) \sim 316\,\text{mJy}$

Interacting system with two galaxies separated by 4kpc and displaying two tidal tails stretching 40kpc in opposite directions. The northern galaxy is a starburst, while the southern shows evidence of Seyfert/LINER activity.

We find that 75% of the mid-IR flux (12-18µm) originates from the unresolved nuclear region of the southern component. The 12-18µm luminosity of the system is ~3% of the total emitted in the IR (8-1000µm). For more info see Charmandaris et al. 2002 (astro-ph/0206150).

The integrated mid-IR SED of the galaxy summing all flux above 5σ. Note that we can account for the whole IRAS12 flux indicated in red.

The mid-IR SED of the two galaxy components. The red line indicates the IRAS12 flux and bandwidth. Note that the southern galaxy dominates the mid-IR emission of the system.

The K-band image of the galaxy from Duc et al. 1997. The bar is 5kpc size.
**IRAS 14348-1447**

$L_{IR} = 1.85 \times 10^{12} \, L_\odot$, $D=335\,\text{Mpc}$ ($z=0.08$), $\text{IRAS}12 < 0.14\,\text{Jy}$, $f(12-18\,\mu\text{m}) \sim 97\text{mJy}$

This interacting system is the most distant in the BGS. Its two galaxies are separated by 6kpc with a tail extending to more than 10kpc to the north. It is one of the most H$_2$ rich ULIRGs containing $\sim 6 \times 10^{10} \, M_\odot$ of molecular gas. The nucleus of the southern galaxy is a Seyfert 1.5 while the northern one is a Seyfert 2. We estimate that $\sim 75\%$ of the mid-IR flux originates from the unresolved nucleus of the southern galaxy. Due to limited mid-IR color information we are unable to comment on the evidence of AGN activity. The 12-18$\mu$m luminosity of the system is $\sim 2\%$ of the total emitted in the IR (8-1000$\mu$m). For more info see Charmandaris et al. 2002 (astro-ph/0206150).

The integrated mid-IR SED of the galaxy summing all flux above 5$\sigma$. The horizontal lines indicate our ISOCAM broad band measurements while the 5-11$\mu$m spectrum is the ISO/PHOT-S data of Rigopoulou et al. 1999. Note that we can account for the whole IRAS12 flux indicated in red.

- **a)** Image of IRAS14348-1447 observed with ISOCAM at 6.75$\mu$m (LW2 filter). The contours are 5, 10, 20, 40 and 80$\sigma$ ($\sigma=0.048\,\text{mJy/pixel}$).
- **b)** Image of IRAS14348-1447 observed with ISOCAM at 15$\mu$m (LW3 filter). The contours are 5, 10, 20 and 30$\sigma$ ($\sigma=0.073\,\text{mJy/pixel}$).

R-band image of the galaxy from Duc et al. 1997. The northern tail extending to more than 10kpc is visible. The vertical bar corresponds to 10kpc.
VV114 (Arp236)

\[ L_{\text{IR}} = 0.4 \times 10^{12} \, L_\odot, \quad D = 80 \, \text{Mpc} \, (z=0.02), \quad \text{IRAS12}=0.64\text{Jy} \]

Interacting system with two galaxies separated by 6kpc. Even though VV114W dominates the optical, near- and mid-IR emission, it is VV114E (which is resolved in two components) that is \( \sim 4 \)x more mid-IR luminous. Based on our diagnostic (Laurent et al. 2000, A&A, 359, 887) VV114E appears to harbor an embedded AGN which can be responsible for \( \sim 40\% \) of mid-IR flux.

**Image 1**

- A 12.5µm image of VV114E taken with Keck (Soifer et al. 2001), resolving the NE and SW components.
- Curves of growth (x-axis radius in kpc / y-axis flux normalized to IRAS12) revealing the presence of extended mid-IR emission (solid line) following the near-IR light profile (Soifer et al. 2001).

**Image 2**

- A 15µm image of VV114 with an overlay of the integrated PAH emission.
- An HST/NICMOS J-band image of VV114 (Scoville et al. 2000) with an overlay of the 15µm contours. The contour levels are 0.45, 0.65, 0.90, 1.35, 2.10, 4.45 and 8.45 mJy/arcsec². Note how even though the peak of the mid-IR emission originates from VV114E, diffuse emission is seen from the whole “overlap” region of the system (Le Floc’h et al. 2002 A&A, astro-ph/0205401).

**Image 3**

- The mid-IR SED of the two nuclei of the two interacting components, with VV114W normalized to the 14µm flux of VV114E. Note the hot continuum excess at 5µm indicative of an AGN at VV114E.
- The integrated spectrum of VV114 separated in various regions. The red line indicates the IRAS12 flux and bandwidth. Contrary to the other galaxies presented here, we observe the extended mid-IR emission of the system is more than 1/3 of the total.
Using deep ISOCAM mid-IR imaging we searched for the presence of extended emission in the 8-16\(\mu\)m range in a number of nearby luminous and ultraluminous infrared galaxies which were detected by IRAS at 12\(\mu\)m. Our goal was to examine whether cases of extended extranuclear activity which can account for a considerable fraction of the mid-IR thermal emission similar to those observed by ISO in interacting systems such as NGC4038/39 (Mirabel et al. 1998) or Stephan’s Quintet (Xu et al. 1999) are also present in LIRGs or ULIRGs. All systems examined are rather close-by and consist of two well defined galaxies which are either currently violently interacting, or are mergers containing double nuclei. For most galaxies high resolution near-IR data were available. Ground based mid-IR imaging for the brightest galaxies (Arp220, Arp299, VV114) only identified emission compact regions associated with the nuclei of the galaxies. Our results indicate that:

- Despite are superior sensitivity and improved spatial resolution (~4" at 15\(\mu\)m) of ISOCAM compared to IRAS no significant extended emission was observed and we can account for nearly all of the IRAS12 flux from areas confined in the nuclei of the galaxies. This would suggest that the excess of thermal emission at 15\(\mu\)m which is observed in distant unresolved IR luminous galaxies does not originate from an ensemble of discrete sources in their interacting members but more likely is due to the enshrouded energy source of their nuclei.

- VV114 is the only exception to the abovementioned result (Le Floc’h et al. 2002). This could be due to the fact the VV114 (a LIRG) is in the process of becoming a ULIRG. The strong radiation from the AGN and circumnuclear starbursts of its eastern component can heat the gas/dust which was stripped during an earlier phase of the interaction out to distances of ~3kpc.

- Since all galaxies presented here are targets of the SIRTF GTO programs, and several of them have revealed numerous young star clusters, it would be interesting to take advantage of the ~100x increase of sensitivity provided by SIRTF to re-examine this issue at the 3-8\(\mu\)m region by tracing the PAH emission from weak extra-nuclear enshrouded star forming regions.

For more information see our recent work at: