Herschel reveals a $T_{\text{dust}}$-unbiased selection of $z \sim 2$ ultraluminous infrared galaxies


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ABSTRACT

Using Herschel Photodetector Array Camera (PACS) and Spectral and Photometric Imaging Receiver (SPIRE) observations of Lockman Hole-North and Great Observatories Origins Deep Survey-North (GOODS-N) as part of the Herschel Multi-tiered Extragalactic Survey (HerMES) project, we explore the far-infrared (IR) properties of a sample of mid-IR-selected starburst-dominated ultraluminous infrared galaxies (ULIRGs) at \( z \sim 2 \). The selection of the sample is based on the detection of the stellar bump that appears in the spectral energy distribution of star-forming galaxies at 1.6 \( \mu \)m. We derive robust estimates of infrared luminosities \( (L_{\text{IR}}) \) and dust temperatures \( (T_{\text{d}}) \) of the population and find that while the luminosities in our sample span less than an order of magnitude \( (12.24 \leq \log(L_{\text{IR}}/L_{\odot}) \leq 12.94) \), they cover a wide range of dust temperatures \( (25 \leq T_{\text{d}} \leq 62 \text{ K}) \). Galaxies in our sample range from those that are as cold as high-\( z \) submillimetre galaxies (SMGs) to those that are as warm as optically faint radio galaxies (OFRGs) and local ULIRGs. Nevertheless, our sample has median \( T_{\text{d}} = 42.3 \text{ K} \), filling the gap between SMGs and OFRGs, bridging the two populations. We demonstrate that a significant fraction of our sample would be missed from ground-based (sub)mm surveys, showing that the latter introduce a bias towards the detection of colder sources. We conclude that Herschel observations confirm the existence of high-\( z \) ULIRGs warmer than SMGs, show that the mid-IR selection of high-\( z \) ULIRGs is not \( T_{\text{d}} \) dependent, reveal a large dispersion in \( T_{\text{d}} \) of high-\( z \) ULIRGs and provide the means to characterize the bulk of the ULIRG population, free from selection biases introduced by ground-based (sub)mm surveys.

Key words: galaxies: evolution – galaxies: high-redshift – galaxies: starburst – cosmology: observations – infrared: galaxies – submillimetre: galaxies.

1 INTRODUCTION

One of the most successful methods for selecting high-\( z \) ultraluminous infrared galaxies (ULIRGs; \( \text{L}_{\text{IR}} - 1000 \mu \text{m} > 10^{12} \text{L}_{\odot} \)) is their direct far-infrared (IR) detection via ground-based (sub)millimetre surveys (e.g. Barger et al. 1998; Hughes et al. 1998; Mortier et al. 2005; Pope et al. 2006; Austermann et al. 2010). This technique has revealed the population of the so-called submillimetre galaxies (SMGs) that represent a significant class of high-\( z \) ULIRGs. Attempts to characterize their dust temperature \( (T_{\text{d}}) \) show that these galaxies are colder when compared to local ULIRGs (e.g. Chapman et al. 2005), suggesting that in general high-\( z \) ULIRGs tend to have lower dust temperatures. However, the submillimetre technique introduces a bias towards the selection of ULIRGs with lower dust temperatures while it misses warmer ULIRGs. First observational evidence of a missing population of high-redshift dusty star-forming galaxies with hotter dust has been given by Chapman et al. (2004) using a selection of radio-detected but submm-faint galaxies with ultraviolet (UV) spectra consistent with high-redshift starbursts. These optically faint radio galaxies (OFRGs) share similar properties with SMGs (e.g. stellar mass, star formation rate) but some have considerably higher dust temperatures (Casey et al. 2009; Magnelli et al. 2010).

Another technique that has been proven to pick high-\( z \) starburst-dominated ULIRGs efficiently is based on mid-IR colour selection. This technique relies on the detection of the rest-frame 1.6 \( \mu \)m bump in the spectral energy distribution (SED) of star-forming galaxies, produced by thermal emission from late-type stars and enhanced by an apparent emission feature due to H ions in the atmospheres of giant stars (Simpson & Eisenhardt 1999; Sawicki 2002). The advent of Spitzer allowed the detection of this feature in \( z \sim 2 \) galaxies and subsequent Infrared Spectrograph (IRS) spectroscopy has demonstrated the efficiency of the method to select starburst-dominated ULIRGs in a redshift range of \( 1.5 < z < 2.5 \) (e.g. Farrah et al. 2008; Weedman & Houck 2008; Huang et al. 2009). Further studies (Fiolet et al. 2009; Lonsdale et al. 2009; Kovács et al. 2010) indicate that only 40 per cent of their sample is made up of bright mm sources and thus belong to the class of SMGs, while most of the rest have lower \( S_{1.2\text{mm}} \) fluxes.

The above suggests that a considerable fraction of mid-IR-selected high-\( z \) ULIRGs are missed by ground-based (sub)mm surveys. While this could naturally be explained if their dust temperature (for a given luminosity) is higher than that of the SMGs, this is not yet clear, as up to now the study of their far-IR properties is restricted to objects with ground (sub)mm detection or to the most luminous examples of the population with the highly confused BLAST beam (e.g. Dunlop et al. 2009; Ivison et al. 2010). Hence, a far-IR study of the population, free of the selection bias introduced by the ground-based submm detection, is required. Furthermore, detailed study of high-\( z \) ULIRGs is essential as up to now theoretical models fail to account for the inferred luminosities, star formation rates and number counts (Baugh et al. 2005; Dave et al. 2010).

In this study, we use observations of Lockman Hole-North (LHN) and Great Observatories Origins Deep Survey-North (GOODS-N) fields obtained by the Herschel Space Observatory (Pilbratt et al. 2010) as part of the Herschel Multi-tiered Extragalactic Survey (HerMES; Oliver et al. 2010), to investigate the far-IR properties of a sample of mid-IR-selected ULIRGs at \( z \sim 2 \) [Infrared Array Camera (IRAC) peakers]. Taking advantage of both the Photodetector Array Camera (PACS; Poglitsch et al. 2010) and the Spectral and Photometric Imaging Receiver (SPIRE; Griffin et al. 2010) data that probe the peak of the SED of galaxies at this redshift, we derive robust dust temperature measurements for the bulk of the population.
and compare our sample to that of other high-$z$ ULIRGs. Throughout this paper we assume $\Omega_m = 0.3, H_0 = 71 \text{ km s}^{-1} \text{ Mpc}^{-1}$ and $\Omega_{\Lambda} = 0.7$.

2 SAMPLE SELECTION AND HERSCHEL OBSERVATIONS

To select our sample we adopt the IRAC colour criteria introduced by Huang et al. (2009). In particular we search for galaxies in LHN that satisfy the following IRAC colour criteria: $0.05 < [3.6]-[4.5] < 0.4$ and $-0.7 < [3.6]-[8.0] < 0.5$ have $f_{24} > 0.2 \text{ mJy}$ and $r_{\text{spec}} > 23.0$ to avoid low-redshift interlopers. These criteria probe the 1.6-µm stellar bump while the red colour cuts ensure the rejection of power-law active galactic nuclei (AGNs). Subsequent IRS spectroscopy of ULIRGs selected with the above method has shown that this selection picks ULIRGs at very narrow redshift range $1.7 < z < 2.3$ with strong polycyclic aromatic hydrocarbon (PAH) features, indicative of intensive star formation (Huang et al. 2009).

We use the Spitzer Wide-Area Infrared Extragalactic Survey (SWIRE) multiwavelength catalogue (U, G, R, I, z, J, H, K+IRAC+MIPS;Straizuzulio et al. 2010) over the 0.25 deg$^2$ of LHN covered by PACS and SPIRE, and we identify 32 objects that meet our criteria. We then match the sample with the joined Herschel PACS (100 and 160 µm) and SPIRE (250, 350 and 500 µm) XID catalogue (Roseboom et al. 2010). For the PACS data, where source confusion is less severe, we consider fluxes based on blind source extraction. For the SPIRE data we adopt the fluxes derived with source extraction based on 24-µm priors; we reject candidates with neighbouring ($d < 20$ arcsec) 24-µm sources whose $f_{24}$ is $> 50$ per cent that of our object. Finally, we require at least one PACS and SPIRE detection ($3\sigma$).

In the resulting LHN sample there are 25 candidate ULIRGs at $z \sim 2$, five of which have spectroscopic redshifts (Fiolet et al., in preparation). For the rest, we derive photometric redshifts, using the LEPHARE photo-z code (Ilbert et al. 2009). Namely, we fit the SED of the galaxies up to 8.0 µm with a wide range of template SEDs and consider dust attenuation that follows the prescription of Calzetti et al. (2000). For each object we adopt the redshift corresponding to the minimum $x^2$ value of the fit. Two examples of the best-fitting template for two galaxies in our sample are depicted in Fig. 1. The uncertainty of the photometric redshifts was derived based on the redshift probability distribution function (PDF(z)) and we choose to exclude from our analysis candidates with multiple solutions or uncertainties larger than $\Delta z = 0.5$. Furthermore, a comparison of the derived photometric redshifts with the spectroscopic redshifts that is available for five sources yields a very good agreement between the two values $\Delta z = (z_{\text{photo}} - z_{\text{spec}})/(1 + z_{\text{spec}}) < 0.1$. The final LHN sample consists of 18 ULIRGs with median $z = 1.98$ and range $1.5 < z < 3.0$. Finally, we match this sample to the radio Very Large Array (VLA) 1.4 GHz catalogue of LHN (Owen & Morrison 2008).

To increase the size of our sample, we perform the same procedure in the GOODS-N field. Using the mult wav e length catalogue and the SPIRE data (PACS data for GOODS-N are not available for this study), we identify candidate ULIRGs with at least two detections ($3\sigma$) at SPIRE bands. To exclude sources with strong AGN activity, candidates with X-ray detection ($L_X [0.5–8.0 \text{ keV}] > 3 \times 10^{42} \text{ erg s}^{-1}$) were removed. The final GOODS-N sample consists of seven sources. Out of these, one has a spectroscopic redshift ($z = 1.86$) while for the rest we adopt photometric redshifts by Le Borgne et al. (2009) (median $z = 1.83$ and $1.53 < z < 2.05$). The final combined sample (LHN and GOODS-N) consists of 25 ULIRGs with a median $z = 2.01$ and with 18 out of 25 objects lying in a narrow redshift range ($1.7 < z < 2.3$). PACS/SPIRE photometry of our sample is presented in Table 1, while IRAC, MIPS and mm and radio photometry is given in Table 2.

3 DERIVATION OF FAR-IR PROPERTIES

To derive estimates for the $L_{\text{IR}}(\lambda_{\text{int} - 1000 \text{ µm}})$ of the galaxies in our sample, we first convert their SED to rest frame applying $k$-corrections and then fit the PACS and SPIRE data with the libraries of Chary & Elbaz (2001, hereafter CE01) and Dale & Helou (2002). Results based on the two methods are in very close agreement indicating a median $L_{\text{IR}} = 3 \times 10^{12} L_{\odot}$. The CE01-derived $L_{\text{IR}}$ values for each object are summarized in Table 1, while examples of the rest-frame SEDs along with the best-fitting CE01 templates for two ULIRGs in our sample are shown in Fig. 1.

To derive the dust temperature of galaxies in our sample, we use a single temperature modified blackbody fitting form in which the thermal dust spectrum is approximated as $F_\nu \propto \nu^{\beta} / (\nu^{\beta} / k T_D - 1)$. This model was fitted to Herschel data with rest frame $\lambda > 40 \mu$m.
assuming a fixed emissivity index of $\beta = 1.5$. This wavelength cut was introduced to avoid fitting emission from very small grains (VSGs). The $T_d$ of each object was obtained from the best-fitting model, based on the minimization of the $\chi^2$ value. The uncertainty for each $T_d$ value was estimated by repeating the same procedure for random perturbations of the fitted photometric points within their errors (following a normal distribution). The best-fitting model for two ULIRGs in our sample is shown in Fig. 1 (solid blue line)
with the $T_d$ for each of the galaxies summarized in Table 1. Finally, to check whether the lack of PACS data for the GOODS-N sample introduces any systematic bias in the derived properties we repeated the fitting procedure for the LHN sample, excluding this time the PACS photometric points. The values derived with and without the PACS were in good agreement ($\langle \Delta T_d \rangle = 1.9$ K).

3.1 AGN contribution to our sample

It has been shown by previous studies that the selection criterion of our sample have been very successful in selecting starburst over AGN-dominated ULIRGs (e.g. Farrah et al. 2008; Huang et al. 2009). Indeed, for five ULIRGs in LHN, IRS spectroscopy indicates that their mid-IR emission is dominated by vigorous star formation rather than an AGN (Fiolet et al., in preparation). None of our objects in this field is detected by Chandra to a 0.3–2.5 keV flux limit of $5 \times 10^{-16}$ erg cm$^{-2}$ s$^{-1}$ ($L_X > 8.5 \times 10^{42}$ erg s$^{-1}$ for $z = 2.0$; Polletta et al. 2006), while on construction of the GOODS-N sample all candidate objects with X-ray detection at a flux limit of $1.95 \times 10^{-17}$ erg cm$^{-2}$ s$^{-1}$ were rejected from our analysis. As the moderate depth of the LHN X-ray data do not provide strong constraints on the AGN contribution we further explore this issue by the $q$ parameter ($q = \log(\frac{L_{40-120 \mu m}}{3.75 \times 10^{12} \text{W}}) - \log(L_{1.4 \text{GHz}}/\text{W Hz}^{-1})$; Helou, Soifer & Rowan-Robinson 1985). Given that almost all of our galaxies have radio detections, we estimate the $q$ parameter and find a mean $\langle q \rangle = 2.21$ with intrinsic dispersion $\sigma_q = 0.17$. This is in agreement with that found by Younger et al. (2009) and the $q$ of star-forming galaxies, quoted by Ivison et al. (2010) ($q = 2.40$, $2\sigma_q = 0.27$). These considerations support the conclusion of Huang et al. (2009) that an AGN contributes little (<10–20 per cent) to the bolometric luminosity of these objects.

4 RESULTS

4.1 Far-IR properties and comparison with other ULIRG samples

Galaxies in our sample have dust temperatures that span a wide range $25 \leq T_d \leq 62$ (K), while their luminosities vary by less than an order of magnitude $12.24 \leq \log(L_{\text{IR}}/L_\odot) \leq 12.94$. The median values are $T_d = 42.3$ K and $L_{\text{IR}} = 3 \times 10^{12} L_\odot$, indicating a star formation rate of $\sim 520 M_\odot $ yr$^{-1}$ (assuming a Salpeter initial mass function (IMF)). It is interesting to compare these values to those of ULIRG samples selected by different techniques.

We consider a large set of $z \sim 2$ SMGs (Chapman et al. 2005; Kovacs et al. 2006), a sample of $z \sim 2$ OFRGs (Casey et al. 2009) and a compilation of local/intermediate-$z$ (0 $< z < 0.98$) ULIRGs (Farrah et al. 2003; Yang et al. 2007; Clements, Dunne & Eales 2010). In all these studies, the method to derive $T_d$ estimates is similar to ours, fitting modified blackbody models to the far-IR photometric points. For studies that quote $L_{\text{IR}}$ instead of $L_d$, we adopt the following conversion factor between the two values: $L_{\text{IR}} = 1.4 \times L_d$ (Dale et al. 2001). We note that preliminary results by Hwang et al. (in preparation), Chapman et al. (in preparation) and Chanial et al. (in preparation) indicate that the far-IR properties of SMGs and OFRGs, when Herschel data are taken into account, are, in general, consistent with the results obtained in the pre-Herschel era.

In Fig. 2, we show the $L_{\text{IR}}$–$T_d$ relation for our sample as compared to that of local/intermediate-$z$ ULIRGs, SMGs and OFRGs. For the luminosity bin of our sample, SMGs have a median $T_d = 36 \pm 8$ K while OFRGs are considerably warmer with median $T_d = 47 \pm 3$ K (Magnelli et al. 2010) and dust temperatures similar to that of local ULIRGs. Therefore, it appears that the two methods select ULIRGs with significantly different dust temperatures, and with no significant overlap between them. Taking advantage of the wealth of multiwavelength data in GOODS-N, we find that a large fraction of SMGs (15/24) and OFRGs (4/5) in GOODS-N (Pope et al. 2006; Casey et al. 2009) that fall in the redshift bin ($1.5 < z < 3.0$) of our sample satisfy the IRAC-peakers colour criteria, if we relax the $f_{24}$ cut.

Based on this plot there are a number of significant results to be drawn. First of all, our observations confirm the existence of ULIRGs in the high-$z$ Universe with dust temperature higher than that of SMGs. Furthermore, it seems that the selection of high-$z$ ULIRGs based on the detection of the 1.6-$\mu$m bump does not favour a particular $T_d$, selecting ULIRGs that overlap with the SMGs and OFRGs but also ULIRGs of intermediate $T_d$. Indeed, we see that objects in our sample range from those that are as cold as SMGs to objects as warm as OFRGs, while a significant fraction lies in the intermediate region between the two samples, bridging the two populations. We also note that a large fraction of the sample falls in the $T_d$–$L_{\text{IR}}$ relation of the local ULIRGs. Finally, our data indicate that the $T_d$ dispersion of high-$z$ ULIRGs is larger than that of the local ULIRGs as derived based on IRAS observations. This discrepancy mainly arises due to the absence of cold sources in the local Universe, although the IRAS selection might miss existing cold sources, introducing a bias towards warmer ULIRGs.

4.2 SMGs: evidence of selection bias towards colder ULIRGs

There is growing evidence that ground-based (sub)mm observations introduce a systematic bias towards the detection of cold ULIRGs. As mentioned above this was first discussed by Chapman et al. (2004), introducing the populations of OFRGs, while a similar conclusion was reached recently by Chapin et al. (2010) using BLAST.
Herschel observations of $z \sim 2$ ULIRGs

Figure 3. Dust temperature versus the estimated $S_{850}$ flux densities of galaxies in our sample (red circles). We also include $T_d$ measurements and observed $S_{850}$ flux densities of high-$z$ SMGs by Chapman et al. (2005) (blue squares). Solid lines represent tracks in constant $L_{IR}$ while the vertical dotted line indicates the confusion limit of current ground-based submm surveys. It is evident that a significant fraction of our sample lies below the detection limit and would be missed by the SCUBA 850 µm surveys, if we consider that the detection limit should be above the confusion limit.

Figure 4. The far-IR part of the SED of two MAMBO-detected (blue circles) and two MAMBO-undetected sources (black squares) from our sample (divided by 1+z). All four sources are chosen to have comparable $L_{IR}$ and $f_{250}$. The far-IR part of the SED of Arp 220 (coral shaded area) and that of NGC 2369 (grey shaded area) are also shown. For the MAMBO-undetected sources the open boxes correspond to the 1.2-mm flux density based on the SED extrapolation. The red arrow indicates the confusion limit of 850-µm surveys. The SED of MAMBO-undetected sources peaks at shorter wavelengths, indicating warmer $T_d$ and lower 850–1200 µm emission when compared to that of IRAM-detected sources. This plot illustrates that among sources with comparable $L_{IR}$ those with higher $T_d$ are missed by current ground-based surveys.

Table 3. SHARC 350-µm and MAMBO 1.2-mm flux densities of our LHN sample.

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<thead>
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<th>ID</th>
<th>$S_{350}$ (mJy)</th>
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<tbody>
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<td>39.7 ± 5.9</td>
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</tr>
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<td>LHN8</td>
<td>31.9 ± 4.9</td>
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<tr>
<td>LHN16</td>
<td>49.7 ± 6.5</td>
<td>2.66 ± 0.78</td>
</tr>
<tr>
<td>LHN29</td>
<td>31.8 ± 5.9</td>
<td>2.48 ± 0.74</td>
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Flux densities by Kovács et al. (2010).

Flux densities by Fiolet et al. (2009).

Data in Fig. 2, we showed that a fraction of IRAC peakers also tends to be warmer than high-$z$ SMGs. We now ask whether these IRAC peakers would be missed by the submm selection.

To investigate this, we estimate the $S_{850}$ flux densities of our sample based on the best-fitting CE01 model that was obtained through the fitting of the Herschel photometric points. The predicted $S_{850}$ flux densities of our sample along with the measured submm flux of high-$z$ SMGs are plotted over the derived $T_d$ of the two populations in Fig. 3. We also overplot tracks in constant $L_{IR}$. This plot illustrates that a significant fraction (~60 per cent) of the mid-IR-selected ULIRGs in our sample have $S_{850}$ flux densities lower than that of the SMGs, lie below the confusion limit at 850 µm (2–3 mJy; Knudsen, van der Werf & Kneib 2008) and hence would be missed by ground-based (sub)mm surveys. Nevertheless, we also find IRAC peakers with predicted $S_{850}$ above the detection limit and which therefore should be detected in the submm. Indeed, four of our objects in LNH (LHN1, LHN8, LHN16 and LHN29) have been detected [signal-to-noise ratio ($S/N > 3$) by the Max Planck Millimetre Bolometer array (MAMBO) 1.2 mm (Fiolet et al. 2009; Kovács et al. 2010). For these objects we use the formula described by Ivison et al. (2005) to convert the observed 1.2 mm to 850 µm flux densities and then compare these values with the predicted $S_{850}$ flux densities that we derived from our analysis. The two values are in close agreement for all objects, with a median difference of 0.15 mJy. Furthermore, we find that all galaxies in our sample with MAMBO observations but no detection (LHN0, LHN19, LHN25; Fiolet et al. 2009) have predicted fluxes below the detection limit. The same test for the GOODS-N sample reveals that our analysis successfully predicts the submm fluxes of two objects with Submillimeter Common User Bolometer Array (SCUBA) 850-µm detection (GN17, GN06; Borys et al. 2005; Pope et al. 2006).

Another way to explore this issue is a direct visualization of the SEDs of the sources. Such an approach is free of systematics and uncertainties of SED fitting that could possibly affect/bias our results. In Fig. 4, we show the far-IR SED of four sources in LHN that have been followed up by MAMBO 1.2-mm observations. Two sources are not detected at 1.2 mm while the other two have a $> 3\sigma$ detection. These sources are also chosen to have similar $L_{IR}(12.5 < \log(L_{IR}/L_\odot) < 12.7)$ and similar fluxes at 250 µm. It is evident that for the same luminosity, the far-IR SED of the MAMBO-undetected sources peaks at shorter wavelengths compared to that of the MAMBO-detected sources. This indicates a clear difference of the dust temperature and subsequently of the 850–1200 µm emission of the two samples, with MAMBO-undetected sources having warmer $T_d$ and considerably lower 850–1200 µm flux densities.

Recently, Kovács et al. (2010) presented a far-IR study of 20 luminous $z \sim 2$ mid-IR-selected starbursts based on SHARC-2 350 µm and concluded that their properties are indistinguishable from the purely SMG population. Although this seems to contradict our findings, this is not the case. Since their study focuses on IRAC peakers with $S_{1.2} > 2$ mJy, their sample is biased towards the most luminous galaxies among the mid-IR-selected ULIRGs and hence those that are likely to share similar properties with the SMGs. As illustrated in Fig. 3 such galaxies exist in our sample too. In fact, our sample shares four objects in common with that of Kovács et al. (2010) for which the estimates of the far-IR properties between the two studies are in very good agreement (Table 3). On the other hand, as we have shown above, due to the requirement of

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MAMBO detection, they miss a large fraction of mid-IR-selected ULIRGs that have faint 850–1200 µm flux densities and their properties are different from those of SMGs. Furthermore, although there are no 850–1200 µm observations for some galaxies in our sample, the fraction of galaxies with predicted $S_{\text{IR}}$ above the detection limit is consistent with the fraction of MAMBO-detected mid-IR ULIRGs (∼40 per cent) in the study of Lonsdale et al. (2009) and Fiolet et al. (2009). To summarize, Herschel data allow us for the first time to characterize the far-IR properties of ∼50 per cent of the mid-IR-selected ULIRGs that would be missed by ground-based (sub)mm surveys and reveal that their properties are different from those of SCUBA/IRAM-selected galaxies.

5 CONCLUSIONS

We have presented the far-IR properties of mid-IR-selected ULIRGs at $z \sim 2$ in LHN and GOODS-N fields, based on Herschel PACS and SPIRE observations. We showed that for a narrow range of luminosities, our sample spans a wide range of $T_{\text{d}}$, indicating that the mid-IR selection of high-$z$ ULIRGs does not introduce a systematic bias in $T_{\text{d}}$. Sources in our sample range from those that are as cold as high-$z$ SMGs to objects as warm as OFRGs, while a significant fraction has intermediate $T_{\text{d}}$, bridging the two populations. We also demonstrated that a significant fraction of our sample would be missed from (sub)mm surveys, showing that the submm technique introduces a bias towards the detection of colder ULIRG sources. We confirmed the existence of star-forming ULIRGs at high-$z$ that are warmer than SMGs and showed that the $T_{\text{d}}$ dispersion at high-$z$ is larger than that found in the local Universe. While this large dispersion in $T_{\text{d}}$ suggests a diversity of the physical mechanisms that drive the star formation activity in the early galaxies, its origin remains unclear. Herschel observations of larger samples in the rest of the HerMES survey will address this question as well as the contribution of ULIRGs to the star formation density and their clustering properties.

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