Evolution of the far-infrared luminosity functions in the *Spitzer* Wide-area Infrared Extragalactic Legacy Survey

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ABSTRACT

We present new observational determination of the evolution of the rest-frame 70 and 160 μm and total infrared (TIR) galaxy luminosity functions (LFs) using 70 and 160 μm data from the *Spitzer* Wide-area Infrared Extragalactic (SWIRE) Legacy survey. The LFs were constructed for sources with spectroscopic redshifts only in the XMM-LSS and Lockman Hole fields from the SWIRE photometric redshift catalogue. The 70 μm and TIR LFs were constructed in the redshift range 0 < z < 1.2 and the 160 μm LF was constructed in the redshift range 0 < z < 0.5 using a parametric Bayesian and the 1/Vmax methods. We assume in our models that the faint-end power-law index of the LF does not evolve with redshift. We find that the double power-law model is a better representation of the infrared (IR) LF than the more commonly used power-law and Gaussian model. We model the evolution of the far-IR LFs as a function of redshift where the characteristic luminosity \( L^\star \) evolves as \( \propto (1 + z)^{\alpha_L} \). The rest-frame 70 μm LF shows a strong luminosity evolution out to \( z = 1.2 \) with \( \alpha_L = 3.41^{+0.18}_{-0.25} \). The rest-frame 160 μm LF also showed rapid luminosity evolution with \( \alpha_L = 5.53^{+0.28}_{-0.23} \) out to \( z = 0.5 \). The rate of evolution in luminosity is consistent with values estimated from previous studies using data from IRAS, ISO and *Spitzer*. The TIR LF evolves in luminosity with \( \alpha_L = 3.82^{+0.28}_{-0.18} \) which is in agreement with previous results from *Spitzer* 24 μm which find strong luminosity evolution. By integrating the LF we calculated the comoving IR luminosity density out to \( z = 1.2 \), which confirms the rapid evolution in number density of luminous IR galaxies which contribute \( \sim 68^{+10}_{-07} \) per cent to the comoving star formation rate density at \( z = 1.2 \). Our results based on 70 μm data confirm that the bulk of the star formation at \( z = 1 \) takes place in dust-obscured objects.

Key words: galaxies: evolution – galaxies: starburst – cosmology: observations – infrared: galaxies

1 INTRODUCTION

The galaxy luminosity function (LF) and its evolution is an important probe which describes the distribution of galaxies as a function of luminosity over the history of the Universe. LFs have been used to constrain galaxy formation and evolution models and to quantify the evolution of the star formation rate (SFR). The infrared (IR) LF is essential to understand the amount of energy released by processed dust emission from star formation and active galactic nuclei (AGN). The discovery of IR luminous galaxies from ground-based photometry (Rieke & Low 1972) and by the *Infrared Astronomical Satellite* (IRAS) has found them to be locally very rare and to contribute only \( \sim 5 \) per cent to the local IR luminosity density (IRLD; Soifer & Neugebauer 1991). The detection of the cosmic infrared background (CIB; Puget et al. 1996; Fixsen et al. 1998), however, has shown that roughly half of the energy released in the Universe has been absorbed by dust and re-radiated into the IR, which implies that dust-obscured star formation was much more important at higher redshifts.

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Studies using observations performed by IRAS and the Infrared Space Observatory (ISO) have shown that dusty star-forming galaxies have undergone strong evolution, as demonstrated by their LFs. Saunders et al. (1990) construct the 60 and 40–120 μm far-IR (FIR) LFs based on IRAS observations finding strong luminosity evolution (modelled as $L^*(z) \propto (1+z)^{a_L}$, where $L^*$ is the characteristic luminosity and $z$ is the redshift) with $a_L = 3 \pm 1$. Similar rates of positive evolution ($a_L = 3–5$) are seen in LFs constructed from ISO surveys at 12 μm (Clements, Desert & Franceschini 2001), 90 μm (Serjeant et al. 2004) and 170 μm (Takeuchi et al. 2006). Pozzi et al. (2004) determine the 15 μm LF of galaxies from the European Large Area ISO Survey (ELAIS) to find that the starburst population evolves both in luminosity, with $a_L = 3.5$, and density (modelled as $\phi^*(z) \propto (1+z)^{a_D}$, where $\phi^*$ is the characteristic number density) with $a_D = 3.8$ being consistent with model predictions of source counts and redshift distribution.

The sensitivity and spatial resolution of the Spitzer Space Telescope (Spitzer; Werner et al. 2004) have revolutionized our understanding of the evolution of IR galaxies particularly at high redshifts ($z > 1$). Several studies based on Multiband Imaging Photometer for Spitzer (MIPS) 24 μm observations have been used to construct the rest-frame 8 μm (Babbedge et al. 2006; Caputi et al. 2007; Rodighiero et al. 2010), 12 μm (Pérez-González et al. 2005), 15 μm (Le Floc’h et al. 2005), 24 μm (Babbedge et al. 2006; Rodighiero et al. 2010; Rujopakarn et al. 2010) and total IR (TIR) LFs (Le Floc’h et al. 2005; Caputi et al. 2007; Magnelli et al. 2009; Rodighiero et al. 2010). These studies have found strong luminosity evolution with $a_L \approx 3–5$ and moderate density evolution out to $z \sim 1$ implying that IR galaxies were more luminous and numerous at higher redshifts than at $z = 0$. Pérez-González et al. (2005) analysed the IR galaxy LF at higher redshifts ($z > 3$) and found that the evolution remains constant from $z \sim 1.2$ to 3.

All these studies have shown an evolution of IR LFs with look-back time, and the relative contribution from quiescent ($L_{IR} < 10^{11} L_{\odot}$), luminous IR galaxies (LIRGs; $L_{IR} = 10^{11}–10^{12} L_{\odot}$) and ultraluminous IR galaxies (ULIRGs; $L_{IR} = 10^{12}–10^{13} L_{\odot}$) to the cosmic SFR density (CSFRD). At $z < 0.5$, the SFR is dominated by quiescent galaxies whereas at $z > 1$, LIRGs are responsible for $\sim 50$ per cent of the TIR density and dominate the star-forming activity beyond $z \geq 0.7$. Pérez-González et al. (2005) show that this evolution continues up to $z \sim 2.5$, and that ULIRGs play a rapidly increasing role for $z \geq 1.3$. Caputi et al. (2007) have shown that at $z \sim 2$, around 90 per cent of the IRLD associated with star formation is produced by LIRGs and ULIRGs. Recent results from the analysis of IR LFs using data from the AKARI satellite have found good agreement with the previous studies from IRAS, ISO and Spitzer (see Béthermin et al. 2010a; Goto et al. 2010).

Most of the previous LF work has been carried out in the mid-IR (MIR; $\lambda = 8–40$ μm), while studies of LFs at FIR wavelengths ($\lambda = 40–200$ μm) have been restricted to $z < 0.3$ (see Saunders et al. 1990; Serjeant et al. 2004; Takeuchi et al. 2006). Studying the redshift evolution of LF at FIR wavelengths is vital because both the CIB and the SEDs of most IR luminous galaxies peak in this region of the IR spectrum. Furthermore, most of the progress in understanding the evolution of IR LFs has utilized Spitzer 24 μm observations, which are strongly dependent on the SED library as at high redshifts the 24 μm channel samples shorter wavelengths. Further uncertainties in obtaining reliable estimates of the bolometric IR luminosities are introduced by redshifting of the polycyclic aromatic hydrocarbon emission and silicate absorption features into the 24 μm band at $z \gtrsim 1$.

In this work, we investigate the evolution of the rest-frame 70 μm and TIR LFs out to $z \sim 1.2$ and 160 μm LF out to $z \sim 0.5$. We use optical and IR data from the XMM-LSS and Lockman Hole (LH) regions of the Spitzer Wide-area InfraRed Extragalactic (SIRIUS) survey (Lonsdale et al. 2003; Lonsdale, Polletta & Surace 2004). In Babbedge et al. (2006) SIRIUS optical and IR data were used to estimate photometric redshifts (values of photo-$z$) and construct LFs at 3.6, 4.5, 5.8, 8 and 24 μm over the redshift range $0 < z < 2$ for galaxies and $0 < z < 4$ for optical quasi-stellar objects. In this work, the LFs are constructed using spectroscopic redshifts taken from the literature and our spectroscopic follow-up of SIRIUS selected 70 μm sources. The analysis using values of photo-$z$ works best at high redshifts, where fractional errors of $\Delta z/(1+z) \sim 0.05$ would be acceptable. For example, for a source at $z = 1$, the uncertainty in $z$ would be a tolerable 10 per cent, whereas a source at $z = 0.3$ would have an uncertainty of $\sim 22$ per cent.

The paper is organized as follows. In Section 2, we present the optical and IR data and the spectroscopic redshifts from SIRIUS-XMM-LSS and SIREW-LH regions used in this study. In Section 3, we describe the methodology used in calculating the LFs, starting with derivations of luminosities, parametrization of the evolution of the LF with redshift and the estimation of SFR with the LF. The results of the LFs are presented in Section 4 including the estimation of the evolution of the integrated SFR and further discussed in Section 5. We adopt a flat Λ cold dark matter cosmology model with $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$ and $\Omega_{\Lambda} = 0.7$.

## 2 THE DATA

### 2.1 Infrared data

The SIRIUS survey (Lonsdale et al. 2003, 2004) is one of the largest Spitzer legacy programmes covering 49 deg$^2$ in six different fields (ELAIS-N1, ELAIS-N2, ELAIS-S1, Chandra Deep Field South, LH and XMM-LSS) with both the InfraRed Array Camera (IRAC) (3.6–8 μm channels) and MIPS (24–160 μm channels) instruments. Typical 5σ sensitivities are 3.7, 5.3, 48 and 37.7 mJy in the IRAC 3.6, 4.5, 5.8 and 8 μm bands. For MIPS the 5σ limits are 230 μJy, 20 mJy and 120 mJy at 24, 70 and 160 μm (Surace et al. 2005). The IRAC data were processed by the Spitzer Science Centre (SSC) IRAC pipeline and sources were extracted using SExtractor (Bertin & Arnouts 1996). The MIPS 24 μm data were processed by the SSC’s MOPEX software and source extraction was performed using SExtractor. The MIPS 70 and 160 μm data were also processed at SSC using the MOPEX software and source extraction was carried out through the Point Response Function fitting capabilities of MOPEX. Full details of the SIREW data release can be found in Surace et al. (2005).

The final data products consist of a cross-matched IRAC and MIPS 24 μm catalogue and single-band catalogues at 24, 70 and 160 μm. The IRAC and MIPS 24 μm catalogue consists of sources detected with a signal-to-noise ratio (S/N) $> 5$ in one or more IRAC bands and their 24 μm associations with a S/N $> 3$. In more than 90 per cent of the cases, the sources in the merged catalogue are within 1.5 arcsec for IRAC channel pairs and within 3 arcsec for MIPS-24 to IRAC pairs and hence can be considered reliable. Surace et al. (2005) evaluated the completeness of the IRAC data by comparing to deeper data in the ELAIS-N1 region taken as part of the Extragalactic First Look Survey (FLS) programme. The 95 per cent completeness level was calculated to be at 14, 15, 42 and 56 mJy in the IRAC 3.6, 4.5, 5.8 and 8 μm bands. The 24 μm data are $\sim 97$ per cent complete at 500 mJy (Babbedge et al. 2006).
The MIPS 70 and 160 μm sources single-band catalogues were matched to the IRAC and MIPS 24 μm band-merged catalogues to produce a SWIRE IRAC and MIPS seven-band catalogue assuming a search radius of 9.3 and 19.5 arcsec for 70 and 160 μm sources, respectively, which corresponds to half the full width at half-maximum at the two wavelengths (see Frayer et al. 2006). Thus, almost all of the 70 and 160 μm sources are also detected at 24 μm. The 70 and 160 μm catalogues are 90 per cent complete down to 14 and 75 mJy for 70 and 160 μm sources with S/N > 3 (Vaccari et al., in preparation). Full details on the data processing, completeness and reliability for the SWIRE 70 and 160 μm observations will be provided in Vaccari et al. (in preparation).

In this paper, we have used data from the latest release of the SWIRE photometric redshift catalogue of Rowan-Robinson et al. (2008). The catalogue contains photometric redshifts for over 1 million IR sources, estimated by combining the optical and IRAC 3.6 and 4.5 μm photometry to fit the observed SEDs with a combination of galaxy and AGN templates (Babbedge et al. 2004; Rowan-Robinson et al. 2005). Our analysis uses multiwavelength data from the XMM-LSS and LH regions of the SWIRE survey.

2.2 Optical data

Optical photometry is available for >70 per cent of the SWIRE area in at least three of the U, g, r, i and Z photometric bands (Rowan-Robinson et al. 2008; Trichas et al. 2009). Spitzer-optical cross-identification (XID) was carried out between the optical and the IRAC-24 μm catalogues using a search radius of 1.5 arcsec (Rowan-Robinson et al. 2005; Surace et al. 2005). The XID process ensured that each SWIRE source had only one optical match. Completeness and reliability of the XID were investigated by Surace et al. (2005), which showed that essentially the Spitzer-optical XIDs are almost 100 per cent complete. The requirement that the sources be detected at both 3.6 and 4.5 μm at S/N ≥ 5 appears to eliminate spurious sources effectively and give a high-reliability catalogue (Rowan-Robinson et al. 2005; Surace et al. 2005).

The LH region centred on α = 10^{h}45^{m}, δ = +57^d59^m covers ~ 10.5 deg^2. Optical photometry is available covering 7.53 deg^2 in the g, r and i bands, obtained using the Mosaic camera on the 4m-Mayall Telescope at Kitt Peak National Observatory (KPNO). The 5σ limiting magnitudes (Vega) are 25.1, 24.4 and 23.7 in the three bands for point-like sources (Berta et al. 2007). U-band photometry is available in a smaller 1.24 deg^2 region to 5σ limiting magnitude (Vega) of 24.1. The data reduction was performed with the Cambridge Astronomical Survey Unit (CASU) pipeline (Irwin & Lewis 2001).

The XMM-LSS field was centred on α = 02^{h}21^{m} and δ = −04^{d}30^{m}, and covered 9.1 deg^2. Optical data are available for 6.97 deg^2 of XMM-LSS, which was observed as part of the Canada–France–Hawaii Telescope Legacy Survey (CFHTLS) in the u, g, r, i and z bands to magnitude (Vega, 5σ for a point-like object) limits of 24.9, 26.4, 25.5, 24.9 and 23.4, respectively. The photometry was taken from Pierre et al. (2007). In addition there is 10-band photometry (ugrizUBVRI) from the Visible MultiObject Spectrograph Very Large Telescope Deep Survey (VVDS) programme (Le Fèvre et al. 2004) covering 0.79 deg^2 and very deep five-band photometry (BVRIz) at 1.12 deg^2 of the Subaru XMM Deep Survey (SXDS; Furusawa et al. 2008).

2.3 Sample selection

To study the 70 and 160 μm LFs and their evolution, we select (1) 70 μm sources with r < 22 mag and S_{70} > 10 mJy and (2) 160 μm sources with r < 22 mag and S_{160} > 60 mJy. Furthermore, we require the sources to have measured spectroscopic redshifts. The adopted 70 and 160 μm flux limits correspond to 70 per cent completeness of the SWIRE survey. The TIR LF is derived using the 70 μm sample.

The SWIRE photometric redshift catalogue of Rowan-Robinson et al. (2008) is the parent catalogue from which we select the 70 and 160 μm sources. In LH there are 4046 and 1276 sources detected at 70 and 160 μm, respectively. Applying our selection criterion, 2159 70 μm and 584 160 μm sources were selected. Spectroscopic redshifts are available for 354 70 μm and 166 160 μm sources, which were collated from the literature.

In XMM-LSS, 2358 sources have 70 μm detections. We selected 1606 70 μm sources of which 299 have spectroscopic redshifts. At 160 μm we found 1604 sources with 739 brighter than the flux limits stated above. We have spectroscopic redshifts for 81 160 μm sources. The spectroscopic redshifts in XMM-LSS were obtained from our spectroscopic follow-up programme conducted over six nights between 2008 November and 2009 November at the William Herschel Telescope (WHT) using the AutoFib2/WYde Field Fiber Optic Spectrograph instrument. The details of the spectroscopic follow-up are presented in Patel et al. (2011).

We choose to construct the 70 μm and the TIR LFs in the redshift range 0 < z ≤ 1.2 because only ~3 per cent of the 70 μm sample is at z > 1.2. The 160 μm LF is determined in the redshift range 0 < z ≤ 0.5 because 90 per cent of the sources are at z < 0.5. Thus, the final total sample of galaxies considered for the 70 μm and TIR LFs consists of 634 (343 in LH and 291 in XMM-LSS) objects and for the 160 μm LF consists of 221 (157 in LH and 64 in XMM-LSS) objects. We show in Fig. 1 the r-band magnitude as a function of the 70 μm flux for all sources in the LH and XMM-LSS regions (filled blue circles) and the final spectroscopic sample (filled red circles).

A summary of the parent catalogue and the final sample is presented in Table 1. We display the spectroscopic redshift distribution of the final 70 and 160 μm sample in Fig. 2. The redshift distributions of the two fields are different because of large-scale structures in the XMM-LSS field where the cluster distribution peaks around z = 0.3 (Pacaud et al. 2007), which also corresponds to the peak in the redshift distribution of our sample.

3 INFRARED LUMINOSITIES

To determine the 70, 160 μm and TIR LFs from our sample, we need to derive the rest-frame 70 and 160 μm and the TIR luminosities. In order to do this, we model the SEDs for each source following the method described in Rowan-Robinson et al. (2005, 2008) used for the SWIRE photometric redshift catalogue, using optical (at least three of the five optical U, g, r, i and Z bands) and IR photometry (Spitzer IRAC 3.6–8 μm and MIPS 24–160 μm bands). The SED fitting follows a two-stage approach, by first fitting the optical to near-IR (U to 4.5 μm) SED using the six galaxy and three AGN templates used by Rowan-Robinson et al. (2008).

We calculate the IR excess by subtracting the galaxy model fit from the 4.5 to 24 μm data. We then fit the IR excess, 70 and 160 μm (for 83 70 μm sources) data points with the IR template of Rowan-Robinson et al. (2004, 2005, 2008). The IR templates are derived from radiative transfer models dependent on interstellar dust grains, the geometry and the density distribution of dust. The IR templates are: (1) IR ‘cirrus’: optically thin emission from interstellar dust
illuminated by the interstellar radiation field; (2) an M82 starburst; (3) a more extreme Arp220-like starburst and (4) an AGN dust torus. We also allow the sources to be fit by a mixture of (1) M82 starburst and cirrus; (2) M82 starburst and AGN dust torus; and (3) Arp220 and AGN dust torus to properly represent the IR excess (Rowan-Robinson & Crawford 1989; Rowan-Robinson et al. 2005).

From the SED fitting we find all but 12 of the $z < 1.2$ sample are fitted with a galaxy template in the optical, which implies that the contamination by AGNs is low in our sample. Thus, we choose to include all sources in our analysis and do not separate the galaxies from AGNs. We illustrate in Fig. 3 the distribution of TIR luminosity (estimated by integrating the SED models between 8–1000 µm) as a function of redshift for the $z < 1.2$ sample, with symbols representing the best-fitting IR SED. The figure shows that in the IR the entire sample is dominated either by the starburst (Arp220 or M82-like) or the cirrus component, which is consistent with previous studies (Symeonidis et al. 2010; Trichas et al. 2009; Patel et al. 2011). Fig. 3 also shows that most of the 70 µm sample

**Figure 1.** Left: $r$-band magnitude against 70 µm flux. The blue dots are all 70 µm detected sources with an optical counterpart in the LH and XMM-LSS. The filled red circles are the sources in the final 70 µm sample. The vertical line marks the 70 µm selection limit of 10 mJy and the horizontal line is at $r = 22$. Right: $r$-band magnitude against 160 µm flux. The blue dots are all 160 µm detected sources with an optical counterpart in the LH and XMM-LSS. The filled red circles are the sources in the final 160 µm sample. The vertical line marks the 160 µm selection limit of 60 mJy and the horizontal line is at $r = 22$.

**Table 1.** Summary of the sample selection used to study the 70 and 160 µm LFs.

| Field       | $\alpha$ (J2000) | $\delta$ (J2000) | Survey area (deg$^2$) | $N_{\text{det}}$ | $N_{\text{sel}}$ | $N_{\text{sp}}$ | $N_{\text{sp}}$ | $N_{\text{sp}}$ | $N_{\text{sp}}$ |
|-------------|------------------|------------------|----------------------|-----------------|-----------------|----------------|----------------|----------------|----------------|
| LH          | 10$^h$45$^m$22$^s$ | +57$^d$59$^m$05$^s$ | 7.53 | 4046 | 2159 | 354 | 343 | 1276 | 584 | 166 | 157 |
| XMM-LSS     | 02$^h$21$^m$20$^s$ | −04$^d$30$^m$0$^s$ | 6.97 | 2358 | 1606 | 299 | 291 | 1604 | 739 | 81 | 64 |

*Number of sources detected.
*Number of sources selected using the selection criteria.
*Number of sources with spectroscopic redshift.
*Number of sources with spectroscopic redshift below 1.2.
*Number of sources with spectroscopic redshift below 0.5.

**Figure 2.** Left: spectroscopic redshift distribution for the final 70 µm sample. Right: spectroscopic redshift distribution for the final 160 µm sample.
are LIRGs and none of our sources have a pure AGN dust torus-dominated IR SED.

We show in Fig. 4 the rest-frame 70 µm luminosity (L_{70}) distribution as a function of redshift (left-hand panel) and the rest-frame 160 µm luminosity (L_{160}) distribution as a function of redshift (right-hand panel). The 70 and 160 µm luminosities were computed using k-corrections derived from the best-fitting model templates. The uncertainty in the 70 and 160 µm and L_{IR} are typically 0.1 dex as stated in Patel et al. (2011). The SED model templates are also used to determine I/V_{max}, which is the volume corresponding to the maximum redshift at which a source could be detected by the survey given the optical and IR limits set in Section 2.3.

4 METHODOLOGY

In this section, we describe the methods used to determine the redshift evolution of the rest-frame 70, 160 µm and TIR LFs, derived using the spectroscopic sample described in Section 2.3 and using the optical and IR SED model of each source described in the previous section. The LF, denoted as Φ(L) d log L, defines the number of objects per comoving volume within a luminosity range log L, log L + d log L. We construct the 70 µm and TIR LFs in the redshift bins [0–0.2], [0.2–0.4], [0.4–0.8] and [0.8–1.2] and the 160 µm LF in the redshift bins [0–0.2] and [0.2–0.5] using the I/V_{max} method (Schmidt 1968; Avni & Bahcall 1980). We also develop a Bayesian method to study the evolution of the 70 and 160 µm and the TIR LFs. In our LF estimation methods, we accurately model the different completeness and selection effects affecting our data. The selection and incompleteness functions are described in Section 4.1 and the binned and parametric LF methods are discussed in Sections 4.2 and 4.3, respectively.

4.1 Selection and incompleteness function

The data set we have used to estimate the FIR LFs was selected by imposing multivariate flux limits to determine whether a source is included in our sample. In addition, we require each of the sources to then have a spectroscopic redshift. Here we use the 70 µm LF selection functions as an example but the general procedure is the same for the TIR and 160 µm LFs.

The 70 µm LF is calculated by selecting sources in the SWIRE catalogue that have S_{70} > 10 mJy, r < 22 mag and measured spectroscopic redshift. Therefore, our first selection function considers the probability that a source of a given 70 µm flux (which is a function of luminosity L and redshift z) is detected by the survey. This is denoted as p(det | L, z) and has been determined by Vaccari et al. (in preparation) for each field in the SWIRE survey using Monte Carlo simulations. The second selection function considers the probability that a given 70 µm source with luminosity L at redshift z is associated with an optical counterpart at r < 22 mag and is defined as p(r < 22 | L, z). This was quantified by taking the SWIRE catalogue and constructing a source count distribution for all sources detected at 70 µm and then constructing a similar source count distribution for all 70 µm sources with r < 22 mag and the ratio is used to estimate p(r < 22 | L, z).

Finally, we take into account the probability of a given source to be characterized with a spectroscopic redshift. The spectroscopic incompleteness is primarily determined by the r-band magnitudes and therefore they are added as weights in the computation of the
LF (see Sections 4.2-4.3). We define the weights, \( w_i \), as the inverse of the spectroscopic completeness. The spectroscopic completeness is determined by constructing the source distribution for all sources with a measured spectroscopic redshift as a function of \( r \) magnitude and dividing this by the source count distribution for all 70 \( \mu \)m sources with \( S_{\text{70}} > 10 \) mJy and \( r < 22 \) as a function of \( r \) magnitude.

The selection functions were estimated for LH and XMM-LSS regions separately and used in constructing the 70, 160 \( \mu \)m and TIR LFs. The selection function, defined as \( p(\text{selected} \mid L, z) \), is a combination of the two selection functions:

\[
p(\text{selected} \mid L, z) = p(\det \mid L, z)p(r < 22 \mid L, z).
\]

The selection function and the spectroscopic incompleteness were used to modify the LF methods discussed in the following section.

4.2 Binned estimates

We use the 1/\( V_{\text{max}} \) method as the binned estimate which has the advantage that it allows direct computation of the LF from the data, without any parametric dependence or model assumption. We divided the sample into redshift bins selected to ensure adequate number of galaxies in each bin. For each redshift bin, the LF is given by

\[
\Phi(L) \ d \log L = \left( \sum_i w_i \times \frac{1}{V_{\text{max},i}} \right),
\]

where \( V_{\text{max},i} \) is the comoving volume out to which the \( i \)th galaxy could be observed and \( w_i \) is the inverse of the spectroscopic incompleteness of the \( i \)th galaxy. The comoving volume, \( V_{\text{max},i} \), is

\[
V_{\text{max},i} = \int_{z_{\text{min},i}}^{z_{\text{max},i}} p(\text{selected} \mid L, z) \frac{dV}{dz} \, dz,
\]

where \( dV/dz \) is the differential comoving element per unit solid angle (Hogg 1999). Here \( z_{\text{max},i} \) corresponds to the maximum redshift at which the source could be detected by the survey given the optical flux limit (\( r < 22 \)) or the IR flux limits (\( S_{\text{70}} > 10 \) mJy or \( S_{\text{160}} > 60 \) mJy) and \( z_{\text{min},i} \) is the lower limit of the redshift bin. \( z_{\text{max},i} \) was determined by using the optical/near-IR and IR SED model of each source. The volume element integral in the LF calculation was weighted by the selection function to correct for the selection biases that are inherent in the spectroscopic catalogue. The IR SED models described in Section 3 are used in computing the selection function.

The associated root mean square (rms) error is given by

\[
\sigma_{\Phi(L)} = \sqrt{\sum_i w_i^2 \times \frac{1}{V_{\text{max},i}}},
\]

In order to accurately determine the uncertainty in the LF error, we use Monte Carlo bootstrapping analysis to randomly re-sample the final spectroscopic catalogue to generate 1000 realizations; each of these is analysed as described above and the rms of the results is quoted as the error.

4.3 Parametric Bayesian method

We use a Bayesian approach to determine the parametric LF, which requires prior knowledge of the appropriate functional form of the LF. As is the case for maximum likelihood (ML) methods (Sandage, Tamman & Yahil 1979; Marshall et al. 1983) the parametric LF has the advantage over the 1/\( V_{\text{max}} \) method in that it is insensitive to any local clustering effect whereas the 1/\( V_{\text{max}} \) LF assumes a uniform number density throughout the observed volume and therefore is vulnerable to density inhomogeneities present in the survey (Wang & Rowan-Robinson 2010). The advantage of using a Bayesian method to estimate the LF parameters over ML methods is that ML methods do not provide an estimate of the LF normalisation, which is often chosen to make the expected number of sources detected in a survey equal to the actual number of sources detected. In addition, the confidence intervals on the LF parameters are derived assuming that they have a Gaussian distribution which is not necessarily a good approximation for small sample sizes (Kelly, Fan & Vestergaard 2008).

In order to carry out a Bayesian analysis we first need to define the likelihood function, \( p(\{d\} \mid \{\theta\}) \), which is the probability of observing the data, \( \{d\} \), for a given LF model, that is described by some parameters \( \theta \). To do this we first define the probability of finding a source of a specific luminosity \( L \), in the range \( \log L \), \( \log L + d \log L \) at a redshift \( z_i \) in the range \( z + dz \) as

\[
p(L, z \mid \{\theta\}) = \frac{\Phi(L, z \mid \{\theta\})p(\text{selected} \mid L, z) \frac{dV}{dz}}{\lambda},
\]

where \( \lambda \) is the expected number of sources and is determined by

\[
\lambda = \sum_{\text{fields}} \int \Phi(L, z \mid \{\theta\})p(\text{selected} \mid L, z) \frac{dV}{dz} \, dz.
\]

The sum is taken over the fields present in our survey and the integrals are taken over all possible values of redshifts and luminosities.

We now write the likelihood function as the probability of observing \( N \) objects, each with \( L_i \) and \( z_i \), drawn from the model LF as

\[
p(\{d\} \mid \{\theta\}) = p(N, \{L_i, z_i\} \mid \{\theta\})
\]

\[
= p(N \mid \{\theta\})p(\{L_i, z_i\} \mid \{\theta\}),
\]

where \( p(N \mid \{\theta\}) \) is the probability of observing \( N \) objects given the model LF and \( p(\{L_i, z_i\} \mid \{\theta\}) \) is the likelihood of observing a set of \( L_i \) and \( z_i \) given the model LF. We assume that the number of sources detected follows a Poisson distribution, where the expected number of detectable sources, \( \lambda \), is given by equation (6). Thus, the likelihood function is written as

\[
p(N, \{L_i, z_i\} \mid \{\theta\}) = \frac{\lambda^N e^{-\lambda}}{N!} \prod_{i=1}^{N} p(L_i, z_i \mid \{\theta\})
\]

\[
= \frac{\lambda^N e^{-\lambda}}{N!} \prod_{i=1}^{N} \Phi(L, z \mid \{\theta\})p(\text{selected} \mid L, z) \frac{dV}{dz}.
\]

We further modify the likelihood function by including the spectroscopic incompleteness by introducing a weighting factor, \( w_i / \langle w \rangle \), for each object (see Zucca, Pozzetti & Zamorani 1994; Ilbert et al. 2005; Aird et al. 2008). The weights, added as exponents of the individual source likelihoods \( p(L_i, z_i \mid \{\theta\}) \) artificially reduce the size of error estimates. Therefore, they are balanced by the average weight \( \langle w \rangle \) which do not affect the best-fitting parameters (Aird et al. 2008). Furthermore, \( N \), the total number of objects is now \( \sum w_i \), which gives the effective number of sources corrected for the spectroscopic incompleteness. Therefore, the likelihood function in equation (9) is

\[
p(N, \{L_i, z_i\} \mid \{\theta\}) \propto \lambda^{\sum w_i} e^{-\lambda}
\]

\[
\times \prod_{i=1}^{N} \left( \frac{\Phi(L, z \mid \{\theta\})p(\text{selected} \mid L, z) \frac{dV}{dz}}{\lambda} \right)^{w_i}. 
\]
Note that in the absence of the spectroscopic incompleteness weights, \(w\), equation (10) reduces to the form presented in Marshall et al. (1983).

We perform Bayesian inference by combining the LF with a prior probability distribution, \(p(\theta)\), to compute the posterior probability distribution, \(p(\theta) | (d)\), given by Bayes’ theorem:

\[
p(\theta) | (d) = \frac{p((d) | (\theta))p(\theta)}{\int p((d) | (\theta))p(\theta)d\theta},
\]

where the denominator is the Bayesian evidence and is determined by integrating the likelihood over the prior parameter space.

For parameter inference, the Bayesian evidence serves to normalize the posterior distribution and is vital for Bayesian model comparison. Calculating the Bayesian evidence is computationally expensive since it involves integration over \(n\) dimensions for an \(n\) parameter LF model. Therefore, we use standard Markov chain Monte Carlo methods to perform a random walk through the parameter space to obtain random samples from the posterior distribution. We employed the Metropolis–Hastings algorithm (Metropolis et al. 1953; Hastings 1970), in which a proposal distribution is used to guide the variation of the parameters. The algorithm uses a proposal distribution which depends on the current state to generate a new proposal sample. We accept a step if the probability of the model given the new parameter values is higher and also at random intervals when the probability is lower in order to allow the fit to proceed downhill to avoid local minima (Ptak et al. 2007; Kelly et al. 2008).

We assume a flat prior distribution for each parameter and ignoring the normalizing factor, the Bayesian evidence, the posterior distribution for each parameter is then given by

\[
p(\theta) | (d) \propto p((d) | (\theta)).
\]

We produce three chains for each analysis of at least 2 \(\times 10^6\) iterations and adjust the parameter step sizes to achieve an acceptance ratio in the range 0.3–0.5. Finally, we calculated the convergence \(R\) statistic from Gelman et al. (2004), which should be \(\leq 1.2\) if the chain has converged. For all the parameters the \(R\) value was \(<1.1\).

### 4.3.1 Luminosity function models

The first IR LF constructed from IRAS observations showed an excess in the number of galaxies at the high luminosity end (Soifer et al. 1987) from the value expected from the Schechter function (Schechter 1976). Soifer et al. (1987) fitted a double power-law model to the IRAS 60 \(\mu m\) LF which is adopted in our work. We use a continuous double power-law model given by

\[
\Phi(L | \theta) = \phi^* \left[ \left( \frac{L}{L^*} \right)^\alpha + \left( \frac{L}{L^*} \right)^\beta \right]^{-1}.
\]

Alternatively, Saunders et al. (1990) fitted the IRAS 60 \(\mu m\) LF with a combination of a power-law and log-normal LF model:

\[
\Phi(L | \theta) = \phi^* \left( \frac{L}{L^*} \right)^{(1-\mu)} \exp \left[ -\frac{1}{2\sigma^2} \log^2 \left( 1 + \frac{L}{L^*} \right) \right].
\]

In both models, \(L^*\) is the characteristic luminosity, \(\phi^*\) is the LF normalization and \(\alpha\) is the power law of the faint end of the LF. \(\beta\) in equation (13) is the power-law index of the bright end of the LF and \(\sigma\) in equation (14) gives the range over which the LF drops off.

We estimate the parameters of the double power-law model, defined as model 1, and the power-law and log-normal model, defined as model 2. Uniform prior probability for all parameters was assumed with limits as follows: \(-1 \leq \alpha \leq 2, 0 \leq \sigma \leq 1, 1 \leq \beta \leq 6, 8 \leq \log L^* \leq 12\) and \(-1 \leq \log \phi^* \leq -4\).

#### 4.3.2 Luminosity function evolution model

Several studies (see Le Floc’h et al. 2005; Pérez-González et al. 2005; Caputi et al. 2007; Magnelli et al. 2009; Rujopakarn et al. 2010) of the IR LFs, mainly at 24 \(\mu m\), have shown that out to \(z \sim 1.2\), while the luminosity and the number density of the LF evolves, the shape remains the same, that is \(\alpha, \beta\) (in equation 13) or \(\sigma\) (in equation 14) do not change. We parametrize the evolution of the FIR LFs in luminosity only:

\[
\Phi(L, z | \theta) = \Phi \left[ \frac{L}{f(z)} | \theta \right],
\]

where \(f(z) = (1+z)^\delta\). Therefore, in addition to the parameters listed in the previous section, \(\alpha_1\), the luminosity evolution power-law index was also constrained. Uniform prior probability distributions were assumed for \(\alpha_1\) with limits: \(1 \leq \alpha_1 \leq 7\). Thus, for each LF model (double power-law, and power-law and log-normal) five parameters were estimated.

#### 5 RESULTS

In this section, we present our determinations of the FIR LF and compare them to previous studies. We construct the rest-frame 70 \(\mu m\) and the TIR LFs in redshift range 0 \(< z \leq 1.2\) and the rest-frame 160 \(\mu m\) LF in the redshift range 0 \(< z \leq 0.5\). Finally, using the TIR LF we derive the comoving IRLDF and the CSFRD as a function of redshift in the range 0 \(< z \leq 1.2\).

### 5.1 Evolution of the rest-frame 70 \(\mu m\) luminosity function

In Fig. 5, we show the rest-frame 70 \(\mu m\) LF constructed using the \(1/V_{\text{max}}\) (black filled circles) and the parametric Bayesian (solid red and blue lines) methods described in Section 4. The parametric LFs are displayed using the best-fitting (posterior mode) parameters given in Table 2. We also display the \(z = 0\) LF (dashed red and blue lines), which shows the rapid evolution of the 70 \(\mu m\) LF, when compared with the binned and evolved parametric LFs. The parametric 70 \(\mu m\) LF uses \(k\)-correction according to the M82 starburst SED.

The examination of the binned and parametric LFs in Fig. 5 shows excellent agreement across all redshift bins. The comparison of the two LF models indicates that they are almost identical except at the brightest luminosities (\(L_{70} > 10^{12} L_\odot\)), where the power-law and log-normal LF model has a rapid drop-off when compared with the double power-law model. However, since there are no data points at these brightest luminosities, both LF models are a good description of the evolution of the 70 \(\mu m\) LF. The shape of the faint-end of the LF is also consistent; \(\alpha = 0.37^{+0.10}_{-0.13}\) for model 1 and; \(\alpha = 1.40^{+0.10}_{-0.25}\) for model 2 as observed in the 0 \(< z \leq 0.2\) redshift bin. The luminosity evolution parameter, \(\alpha_1\), which shows that the characteristic luminosity evolves rapidly as a function of redshift is almost identical for the two LF models (\(\alpha_1 = 3.39^{+0.12}_{-0.22}\) and \(\alpha_1 = 3.41^{+0.18}_{-0.25}\) for models 1 and 2, respectively). The best-fitting evolutionary parameter is consistent with studies performed at several IR wavelengths, in particular at 24 \(\mu m\), which find strong luminosity evolution with \(\alpha_1 = 3–5\) (see Le Floc’h et al. 2005; Babbedge et al. 2006; Magnelli et al. 2009; Rujopakarn et al. 2010). We find that both parametric models can describe the evolution of the 70 \(\mu m\) LF.
IRAS $\phi < z < \sigma < 0$ is shown as filled black circles, the solid blue line is the double power-law LF, and the solid red line is the power-law and log-normal LF. The parametric LFs are displayed using the best-fitting parameters listed in Table 3 and evaluated at $z = 0, 0.1, 0.3, 0.6$ and $1$. The dashed red and blue lines are the $z = 0$ LFs.

**Figure 5.** 70 $\mu$m LF split into redshift bins $0 < z \leq 0.2$, $0.2 < z \leq 0.4$, $0.4 < z \leq 0.8$ and $0.8 < z \leq 1.2$. The $1/V_{\text{max}}$ LF is shown as filled black circles, the solid blue line is the double power-law LF, and the solid red line is the power-law and log-normal LF. The parametric LFs are displayed using the best-fitting parameters listed in Table 3 and evaluated at $z = 0.1, 0.3, 0.6$ and $1$. The dashed red and blue lines are the $z = 0$ LFs.

**Table 2.** $1/V_{\text{max}}$ 70 $\mu$m LF values.

| $\log L_{\text{70}}$ (L$_{\odot}$) | $0 < z \leq 0.2$ | $0.2 < z \leq 0.4$ | $0.4 < z \leq 0.8$ | $0.8 < z \leq 1.2$ |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| 8.4             | $-1.96^{+0.29}_{-0.20}$ | $-1.59^{+0.20}_{-0.40}$ | $-3.25^{+0.12}_{-0.16}$ | $-3.43^{+0.05}_{-0.30}$ |
| 8.8             | $-1.99^{+0.16}_{-0.27}$ | $-2.99^{+0.07}_{-0.08}$ | $-3.80^{+0.10}_{-0.14}$ | $-5.42^{+0.02}_{-0.37}$ |
| 9.2             | $-2.33^{+0.15}_{-0.22}$ | $-3.55^{+0.07}_{-0.08}$ | $-4.60^{+0.13}_{-0.18}$ | $-7.06^{+0.02}_{-0.63}$ |
| 9.6             | $-2.39^{+0.08}_{-0.10}$ | $-4.49^{+0.13}_{-0.19}$ | $-5.14^{+0.16}_{-0.23}$ | $-6.36^{+0.10}_{-0.30}$ |
| 10.0            | $-2.59^{+0.06}_{-0.07}$ | $-4.49^{+0.13}_{-0.19}$ | $-5.14^{+0.16}_{-0.23}$ | $-6.36^{+0.10}_{-0.30}$ |
| 10.4            | $-2.87^{+0.05}_{-0.06}$ | $-5.28^{+0.31}_{-0.28}$ | $-5.62^{+0.34}_{-0.62}$ | $-7.06^{+0.02}_{-0.63}$ |
| 10.8            | $-3.49^{+0.09}_{-0.11}$ | $-5.62^{+0.34}_{-0.62}$ | $-7.06^{+0.02}_{-0.63}$ | $-6.36^{+0.10}_{-0.30}$ |
| 11.2            | $-4.71^{+0.27}_{-0.26}$ | $-7.55^{+0.07}_{-0.08}$ | $-9.43^{+0.05}_{-0.04}$ | $-11.43^{+0.05}_{-0.04}$ |
| 11.6            | $-5.28^{+0.31}_{-0.28}$ | $-9.43^{+0.05}_{-0.04}$ | $-11.43^{+0.05}_{-0.04}$ | $-13.43^{+0.05}_{-0.04}$ |
| 12.0            | $-5.62^{+0.34}_{-0.62}$ | $-11.43^{+0.05}_{-0.04}$ | $-13.43^{+0.05}_{-0.04}$ | $-15.43^{+0.05}_{-0.04}$ |
| 12.4            | $-5.62^{+0.34}_{-0.62}$ | $-11.43^{+0.05}_{-0.04}$ | $-13.43^{+0.05}_{-0.04}$ | $-15.43^{+0.05}_{-0.04}$ |
| 12.8            | $-5.62^{+0.34}_{-0.62}$ | $-11.43^{+0.05}_{-0.04}$ | $-13.43^{+0.05}_{-0.04}$ | $-15.43^{+0.05}_{-0.04}$ |
| 13.2            | $-5.62^{+0.34}_{-0.62}$ | $-11.43^{+0.05}_{-0.04}$ | $-13.43^{+0.05}_{-0.04}$ | $-15.43^{+0.05}_{-0.04}$ |

We show in Fig. 6 that the SWIRE 70 $\mu$m local luminosity function (LLF) constructed in the redshift bin $0 < z \leq 0.2$ is compared to the bandpass corrected (assuming an M82 starburst SED) IRAS 60 $\mu$m LFs determined by Saunders et al. (1990) (filled blue square), Takeuchi, Yoshikawa & Ishii (2003) (solid red line) and Wang & Rowan-Robinson (2010) (solid green line). Comparison of the LFs shows that the overall shape of the parametric and binned 70 $\mu$m LF is well matched to the bandpass corrected 60 $\mu$m LFs. Takeuchi et al. (2003) IRAS 60 $\mu$m LF report, $\log L^*$ ($L_{\odot}$) = 9.07 ± 0.09, $\alpha = 1.23 ± 0.04$, $\sigma = 0.72 ± 0.01$ and $\log \phi^*$ (Mpc$^{-3}$) = $-2.05 ± 0.05$ while Wang & Rowan-Robinson (2010) determine, $\log L^*$ ($L_{\odot}$) = 9.10, $\alpha = 1.29$, $\sigma = 0.72$ and $\log \phi^*$ (Mpc$^{-3}$) = $-2.05$. At the faint end, the 70 $\mu$m LF is steeper with $\alpha = 1.46^{+0.10}_{-0.09}$ for model 2, while with $\sigma = 0.66^{+0.02}_{-0.00}$ in excellent agreement with the value determined from IRAS surveys.

We have used the $k$-correction given by the M82 starburst SED template in order to determine $\phi_{\text{selected}}(L, z)$ in the likelihood function because a large fraction of the 70 $\mu$m population are fitted with this template (see Section 3 and Fig. 3). Although using a $k$-correction of a pure Arp220 starburst or a pure cirrus SED template results in different values for $\alpha$, we still find that the 70 $\mu$m LF evolves rapidly in luminosity ($\alpha > 3$). Studying the LF evolution of each SED component will be further investigated in future studies (see Section 6.3).

**5.2 Evolution of the rest-frame 160 $\mu$m luminosity function**

The rest-frame 160 $\mu$m LF constructed using the $1/V_{\text{max}}$ (filled black circles) and the parametric Bayesian (solid red and blue lines)
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shows a much better agreement with the $1/V_{\text{max}}$ LF in both redshift bins at $L_{160} > 10^{11} \, L_\odot$ implying that the double power-law LF model may be a better description of FIR LFs. The $160 \, \mu m$ LF evolves in luminosity with $\alpha_L = 5.73^{+0.29}_{-0.42}$ for model 1 and $\alpha_L = 5.53^{+0.28}_{-0.23}$ for model 2, which is stronger than the value found for the evolution of the $70 \, \mu m$ LF or from Spitzer 24 $\mu m$ studies (see Le Floc’h et al. 2005; Babbedge et al. 2006; Magnelli et al. 2009; Rujopakarn et al. 2010). Takeuchi et al. (2006) however find that the $ISO$ $170 \, \mu m$ LF evolves with $\alpha_L = 5.0^{+2.3}_{-0.5}$, being entirely consistent with the evolution of $160 \, \mu m$ LF. Recently, Dye et al. (2010) used data from the Herschel Astrophysical Terahertz Large Area Survey to find that the rest-frame $250 \, \mu m$ luminosity density evolves at a rate proportional to $(1 + z)^{3.1^{+2.4}_{-1.1}}$ to $z \simeq 0.2$ in agreement with the evolution of $160$ and $170 \, \mu m$ LFs.

Our results show that the $160 \, \mu m$ LF evolves more rapidly than the $70 \, \mu m$ LF suggesting that ‘cooler’ galaxies evolve more rapidly than ‘warmer’ galaxies (the $160 \, \mu m$ LF was determined using the $k$-correction given by a mixture of M82 starburst and cirrus template whereas the $70 \, \mu m$ LF was determined using the $k$-correction given by an M82 starburst template). This is in keeping with the work of Symeonidis, Page & Seymour (2011) who find that ‘cold’ galaxies evolve more rapidly than ‘warmer’ galaxies over a period of $0.1 < z < 1$. Dunne et al. (2011) have shown that the evolution of the rest-frame $250 \, \mu m$ LF out to $z = 0.5$ is driven in part by evolution in the dust mass and an increase in the luminosity or space density of cooler galaxies. They conclude that the evolution of the dust mass points to an enhanced supply of gas for star formation at earlier cosmic epochs.

We compare in Fig. 8 our $160 \, \mu m$ LLF with the $ISO$ $170 \, \mu m$ LF from Takeuchi et al. (2006) constructed using 55 galaxies at $z < 0.3$. The $170 \, \mu m$ binned LF shows a reasonable agreement within the error bars with the $160 \, \mu m$ LF except at $L_{160} > 10^{11} \, L_\odot$, where both the parametric LFs show a faster drop-off. In fact, the double power-law LF model and conclude that the parametric form (solid red
line in Fig. 8) underestimates the bright end of the LF, similar to the findings reported here. The combination of these results indicates that the double power-law model is the favoured analytic form for FIR LFs.

5.3 Total infrared luminosity function

In this section, we compute the TIR LF of galaxies using the observed 70 μm data. The TIR luminosity of a star-forming galaxy provides a direct estimate of current star formation activity because the IR emission is the re-processed ultraviolet (UV)/optical radiation produced by young stars. \( L_{\text{IR}} \) can be converted to SFR using the relationship provided by Kennicutt (1998):

\[
\text{SFR} \left( \text{M}_\odot \text{ yr}^{-1} \right) = 1.72 \times 10^{-10} L_{\text{IR}} L_\odot,
\]

where \( L_{\text{IR}} \) is estimated by integrating for each source the best-fitting SED in the interval 8–1000 μm (see Section 3). We can then use equation (16) and the TIR LF to derive an estimate of the IR comoving energy density and the CSFRD up to \( z \sim 1.2 \) and compare these results with other CSFRD calibrators.

Previous studies of the TIR LFs have largely been conducted at MIR wavelengths, with the greatest progress made at the Spitzer 24 μm band where MIPS is most sensitive (see Le Floc’h et al. 2005; Pérez-González et al. 2005; Babbedge et al. 2006; Caputi et al. 2007; Béthermin et al. 2010b; Rodighiero et al. 2010). The work presented here follows a similar approach to others in the literature, which relies on the conversion of \( L_\nu \) to \( L_{\text{IR}} \), usually calibrated using SED templates of local IR galaxies (Chary & Elbaz 2001) or semi-empirical SEDs (Dale & Helou 2002; Lagache, Dole & Puget 2003). Several authors (Elbaz et al. 2002; Appleton et al. 2004) and in particular Bajou et al. (2008) have shown that the extrapolation of the local \( L_\nu \sim L_{\text{IR}} \) remains reliable up to \( z = 1.1 \) for LIRGs and \( z \sim 2 \) for ULIRGs for FIR wavelengths. Furthermore, the wavelength closest to the peak of FIR emission provides the most accurate estimator of \( L_{\text{IR}} \) (Bouwens et al. 2008).

We use the SED templates of Rowan-Robinson et al. (2004, 2005, 2008) and therefore check the consistency of our \( L_{\text{70}} \sim L_{\text{IR}} \) correlation, we compare our results with those of Bouwens et al. (2008) and Symeonidis et al. (2008). In Fig. 9 we show the relationship between log \( L_{\text{70}} \) and log \( L_{\text{IR}} \) for all sources at \( z < 1.2 \) in our sample (black solid line) with the relations of Bouwens et al. (2008) (green solid line) and Symeonidis et al. (2008) (blue solid line). The three correlations show excellent agreement with a mean scatter of \( \sim 0.1 \) dex between our correlation and the other two in the luminosity range \( 9.5 \lesssim \log L_{\text{70}} \lesssim 12.5 \). Therefore, we choose to use our \( L_{\text{70}} \sim L_{\text{IR}} \) correlation in constructing the TIR LF.

To calculate the \( 1/V_{\text{max}} \) LF, we follow the same method as described in Section 4.2 and use the 70 μm selection function for each source. For the Bayesian analysis we use our linear relationship between \( L_{\text{70}} \) and \( L_{\text{IR}} \) to convert \( L_{\text{70}} \) into \( L_{\text{IR}} \) to determine the selection function \( p(\text{selected} \mid L, z) \) in the likelihood function. Thus, the Bayesian analysis is dependent on the values of the linear relationship shown in Fig. 9. We perform a test by estimating the

### Table 3.

Best-fitting parameters of the 70 and 160 μm and TIR LFs determined using the parametric Bayesian method. The errors include 68 per cent of the posterior probability. (a) Double power-law model and (b) power-law and log-Gaussian LF model.

| Parameter | 70 μm LF | 160 μm LF | TIR LF |
|-----------|----------|-----------|--------|
|           | (a)      | (a)       | (a)    |
| log \( L^* \) (L_\odot) | 10.38^{+0.12}_{-0.09} | 9.53^{+0.10}_{-0.11} | 10.21^{+0.10}_{-0.08} |
| \( \alpha \) | 0.37^{+0.10}_{-0.13} | 1.40^{+0.10}_{-0.09} | 0.46^{+0.17}_{-0.21} |
| \( \beta \) | 2.00^{+0.13}_{-0.12} | - | 3.79^{+0.36}_{-0.23} |
| \( \sigma \) | - | 0.66^{+0.07}_{-0.03} | - |
| log \( \phi^* \) (Mpc^{-3}) | -2.68^{+0.09}_{-0.14} | -2.32^{+0.14}_{-0.06} | -2.84^{+0.15}_{-0.11} |
| \( \alpha_L \) | 3.39^{+0.12}_{-0.22} | 3.41^{+0.18}_{-0.25} | 5.73^{+0.30}_{-0.62} |
|           | (b)      | (b)       | (b)    |
| log \( L^* \) (L_\odot) | 10.61^{+0.09}_{-0.13} | 9.71^{+0.19}_{-0.19} | 10.21^{+0.10}_{-0.08} |
| \( \alpha \) | 0.34^{+0.10}_{-0.12} | 1.38^{+0.09}_{-0.12} | 1.07^{+0.14}_{-0.58} |
| \( \beta \) | - | - | - |
| \( \sigma \) | - | 0.29^{+0.08}_{-0.05} | - |
| log \( \phi^* \) (Mpc^{-3}) | -2.68^{+0.12}_{-0.10} | -2.26^{+0.11}_{-0.12} | -2.43^{+0.11}_{-0.16} |
| \( \alpha_L \) | 3.82^{+0.24}_{-0.20} | 3.82^{+0.24}_{-0.20} | 5.53^{+0.28}_{-0.23} |

### Table 4.

The \( 1/V_{\text{max}} \) 160 μm LF values.

| log \( L_{160} \) (L_\odot) | log \( \Phi \) (Mpc^{-3}) |
|-----------------|-----------------|
| 0 < z ≤ 0.2    | 0.2 < z ≤ 0.5  |
| 8.8             | -1.70^{+0.26}_{-0.84} |
| 9.2             | -2.85^{+0.17}_{-0.29} |
| 9.6             | -2.55^{+0.19}_{-0.10} |
| 10.0            | -2.63^{+0.10}_{-0.08} |
| 10.4            | -3.08^{+0.09}_{-0.07} |
| 10.8            | -3.83^{+0.13}_{-0.12} |
| 11.2            | -5.05^{+0.23}_{-0.52} |
| 11.6            | -4.84^{+0.18}_{-0.31} |

Figure 8. The TIR LF (0 < z ≤ 0.2) 160 μm LF determined using \( 1/V_{\text{max}} \) (filled black circles) and the parametric Bayesian method (solid and dashed black lines) evaluated at \( z = 0.1 \). The solid black line represents the double power-law model, and the dashed black line is the power-law and Gaussian model. The parametric (red solid line) and non-parametric (red filled squares) ISO 170 μm LFs from Takeuchi et al. (2006) are shown for comparison.
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Figure 9. Correlation between rest-frame 70 µm luminosity (log $L_{70}$) and TIR luminosity (log $L_{\text{TIR}}$). The black solid line is our linear relationship determined using a Bayesian linear regression method. We also show for comparison the linear relation from Symeonidis et al. (2008) (blue solid line) and Bavouzet et al. (2008) (green solid line).

parameters of the local TIR LF using the correlations of Bavouzet et al. (2008) and Symeonidis et al. (2008) and found all parameters to be almost identical.

In Fig. 10, we display the TIR LF constructed using the $1/V_{\text{max}}$ (filled black circles) and the parametric Bayesian (solid black line) methods. The parametric LFs are displayed using the best-fitting parameters given in Table 3 and the $1/V_{\text{max}}$ values are listed in Table 5. The $z = 0$ LF is also displayed (dashed black line), which shows the rapid evolution of the TIR LF, when compared with the binned and the evolved parametric LFs. The parametric TIR LF was calculated using the $k$-correction given by the M82 starburst SED.

Comparison of the $1/V_{\text{max}}$ and parametric LFs in Fig. 10 shows good agreement across all redshift bins for both LF models. We find that the evolution of the TIR LF is independent of the two LF models used ($\alpha_L = 3.8^{+0.24}_{-0.20}$ for model 1 and $\alpha_L = 3.8^{+0.25}_{-0.16}$ for model 2), similar to the results of the 70 and 160 µm LFs. Thus, the choice of the LF model does not affect the conclusion that the TIR LF shows strong evolution in luminosity. The global evolution parameter of the TIR LF is consistent with values determined by previous studies, which typically find $\alpha_L \sim 3.5 \pm 0.5$ (Le Floc’h et al. 2005; Caputi et al. 2007; Magnelli et al. 2009) out to $z \sim 1$. In Fig. 10, the TIR LFs are compared with literature values in the higher redshift bins. As shown in this figure, our TIR LF shown is broadly consistent with the published results in the redshift bins $[0–0.2], [0.2–0.4]$ and $[0.4–0.8]$. We find excellent agreement when we compare our $1/V_{\text{max}}$ LF in the redshift bins $[0.3–0.45]$ and $[0.6–0.8]$ to the values of Le Floc’h et al. (2005) and Rodighiero et al. (2010) in the same redshift bins. In the highest redshift bin, $[0.8–1.2]$, our TIR LF shows good agreement with the LF determined by Le Floc’h et al. (2005). The SWIRE TIR LF however shows differences with the values of Caputi et al. (2007), Magnelli et al. (2009) and Rodighiero et al. (2010). Magnelli et al. (2009) investigated the difference between their and the Le Floc’h et al. (2005) LF values and found that the difference appears to be because of the choice of SED library and the correlation used to convert $L_\lambda$ into $L_{\text{TIR}}$. Thus, this may also be the reason for the difference seen in the comparison of this work with theirs. Therefore, although the $1/V_{\text{max}}$ LF values in the highest redshift bins are less robust, the parametric TIR LF and its evolution conforms to results that have been determined previously.

Figure 10. TIR LF split into redshift bins $0 < z \leq 0.2$, $0.2 < z \leq 0.4$, $0.4 < z \leq 0.8$ and $0.8 < z \leq 1.2$. The filled black circles are the $1/V_{\text{max}}$ estimates and the black solid line is the parametric Bayesian LF displayed using the best-fitting parameters given in Table 3 at $z = 0.1, 0.3, 0.6$ and 1. The filled red circles are from Le Floc’h et al. (2005), the filled purple upside down triangles are from Caputi et al. (2007), the filled orange upside down triangles are from Magnelli et al. (2009) and the filled blue stars are from Rodighiero et al. (2010). The $z = 0$ LF is shown in each panel (black dashed line).
In Fig. 11, we compare our local TIR LF with the IRAS revised bright galaxy sample derived from the local LF of Sanders et al. (2003) (green filled squares) at $z < 0.1$, Spitzer 24 $\mu$m derived from the LLF of Rodighiero et al. (2010) (filled blue stars) at $z < 0.3$, Herschel Multi-tiered Extragalactic Survey Spectral and Photometric Imaging Receiver derived from the LLF of Vaccari et al. (2010) (filled red triangles) at $z < 0.25$ and the LF of AKARI galaxies from Goto et al. (2011) (solid orange line) at $< 0.3$. The shape of the SWIRE local TIR LF and literature values [except for the Goto et al. (2011) LF] are almost identical while the small difference between the local TIR LFs is most likely due to cosmic variance or the choice of the SED library used to calculate $L_{\text{IR}}$. Several authors (Le Floc’h et al. 2005; Rodighiero et al. 2010; Vaccari et al. 2010) have reported best-fitting parameters of the local TIR LF by fitting to the binned LF for the power-law and log-normal LF model of equation (14) using a $\chi^2$ minimization procedure. The slope of the faint end is not well constrained and is usually fixed to the local value of $-1.2$, while $\sigma$ values in the range 0.39–0.72 have been reported. The log $L^*_{\text{IR}}$ range is $\sim 9.24–10.6$ and log $\phi^* (\text{Mpc}^{-3})$ range is $\sim -2.00$ to $-2.06$ (Le Floc’h et al. 2005; Rodighiero et al. 2010; Vaccari et al. 2010). The best-fitting parameters of our LLF for model 2 are $\{\log L^*_{\text{IR}}, \alpha, \sigma, \log \phi^* (\text{Mpc}^{-3})\} = \{9.87, 1.38, 0.68, -2.26\}$, which are consistent with the published values. For the double power-law model, Sanders et al. (2003) find best-fitting power-law indices, $\alpha = -0.6 \pm 0.1$ and $\beta = -2.2 \pm 0.1$ and log $L^* \sim 10.5$, which are at least within the 99.7 per cent errors of the parameters estimated in our study. Goto et al. (2011) fit the AKARI local TIR LF with a double power-law model from Babbedge et al. (2006) to find best-fitting power-law indices, $\alpha = 1.8$ and $\beta = 3.6$; their faint end is much steeper and the bright end is much shallower when compared to our value and that of Sanders et al. (2003).

### 6 DISCUSSION

#### 6.1 Evolution of the infrared luminosity density

Having determined the global evolution of the TIR LF in the redshift range $0 < z < 1.2$, we can now estimate how the comoving IRLD and the space density of LIRGs and ULIRGs evolves with redshift. This is important because it allows us to evaluate the relative importance of IR luminous galaxies and their contribution to the CSFRD (associated with obscured star formation) out to $z \sim 1.2$.

We show in Fig. 12, the space density of normal galaxies (blue regions), LIRGs (green region) and ULIRGs (red region), which shows rapid evolution in the number density of LIRGs and ULIRGs while the number density of normal galaxies remains constant. The number density of LIRGs increases by a factor of $\sim 43^{+11}_{-12}$ for the double power-law LF model and $\sim 37^{+18}_{-10}$ for the power-law and log-normal LF model between $z = 0$ and 1, which is in agreement with the estimate of Magnelli et al. (2009), who find a factor of 40.

Magnelli et al. (2009) estimate an increase in the number density of ULIRGs by a factor of $\sim 100$ at $z \sim 1$ than in the local Universe, while in Fig. 12 ULIRGs increase by a factor of $\sim 316^{+246}_{-138}$ for model 1 and for model 2 the factor is $\sim 870^{+370}_{-299}$. The difference between the values of models 1 and 2 is because of the steeper drop-off at the bright end of the LF for the power-law and log-normal LF model.

| $\log L_{\text{IR}}$ (L$_{\odot}$) | $0 < z \leq 0.2$ | $0.2 < z \leq 0.4$ | $0.4 < z \leq 0.8$ | $0.8 < z \leq 1.2$ |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|
| 8.8                             | $-1.80^{+0.22}_{-0.49}$ | $-2.96^{+0.24}_{-0.64}$ | $-3.96^{+0.24}_{-0.69}$ | $-4.53^{+0.24}_{-0.56}$ |
| 9.2                             | $-2.08^{+0.18}_{-0.32}$ | $-3.60^{+0.13}_{-0.19}$ | $-3.60^{+0.13}_{-0.19}$ | $-4.53^{+0.24}_{-0.56}$ |
| 9.6                             | $-2.51^{+0.19}_{-0.36}$ | $-3.86^{+0.10}_{-0.31}$ | $-3.86^{+0.10}_{-0.31}$ | $-4.53^{+0.24}_{-0.56}$ |
| 10.0                            | $-2.43^{+0.08}_{-0.10}$ | $-3.74^{+0.13}_{-0.19}$ | $-3.74^{+0.13}_{-0.19}$ | $-4.53^{+0.24}_{-0.56}$ |
| 10.4                            | $-2.69^{+0.07}_{-0.09}$ | $-3.09^{+0.06}_{-0.09}$ | $-3.09^{+0.06}_{-0.09}$ | $-4.53^{+0.24}_{-0.56}$ |
| 10.8                            | $-3.02^{+0.07}_{-0.09}$ | $-2.73^{+0.15}_{-0.11}$ | $-2.73^{+0.15}_{-0.11}$ | $-4.53^{+0.24}_{-0.56}$ |
| 11.2                            | $-4.74^{+0.17}_{-0.30}$ | $-3.96^{+0.08}_{-0.09}$ | $-3.96^{+0.08}_{-0.09}$ | $-4.53^{+0.24}_{-0.56}$ |
| 11.6                            | $-5.28^{+0.31}_{-0.28}$ | $-4.95^{+0.13}_{-0.18}$ | $-4.95^{+0.13}_{-0.18}$ | $-4.53^{+0.24}_{-0.56}$ |
| 12.0                            | $-5.28^{+0.31}_{-0.28}$ | $-5.56^{+0.20}_{-0.38}$ | $-5.56^{+0.20}_{-0.38}$ | $-4.53^{+0.24}_{-0.56}$ |
| 12.4                            | $-5.28^{+0.31}_{-0.28}$ | $-5.56^{+0.20}_{-0.38}$ | $-5.56^{+0.20}_{-0.38}$ | $-4.53^{+0.24}_{-0.56}$ |
| 12.8                            | $-5.28^{+0.31}_{-0.28}$ | $-5.56^{+0.20}_{-0.38}$ | $-5.56^{+0.20}_{-0.38}$ | $-4.53^{+0.24}_{-0.56}$ |
| 13.2                            | $-5.28^{+0.31}_{-0.28}$ | $-5.56^{+0.20}_{-0.38}$ | $-5.56^{+0.20}_{-0.38}$ | $-4.53^{+0.24}_{-0.56}$ |

Figure 11. The local ($0 < z < 0.2$) TIR LF determined using $1/V_{\text{max}}$ (filled black circles) and the parametric Bayesian method (solid and dashed black line) evaluated at $z = 0.1$. The filled green squares are obtained from Sanders et al. (2003, S03), the filled blue stars are from Rodighiero et al. (2010, R10), the filled red triangles are from Vaccari et al. (2010, V10) and the solid orange line is from Goto et al. (2011, G11).
Evolution of FIR LFs in SWIRE

Figure 12. Evolution of the space density of normal galaxies (solid and dashed blue region), LIRGs (solid and dashed green region) and ULIRGs (solid and dashed red region) up to $z = 1.2$. The solid and dashed line region includes 68 per cent of the posterior probability for the double power-law, and power-law and log-normal LF models, respectively.

Nonetheless, the 68 per cent credible intervals shown in Fig. 12 for the two LF models are almost identical except for the ULIRG population, where the error for the power-law and log-normal LF model is larger.

We model the evolution of the space density of ULIRGs as $n = 8.30^{+0.83}_{-0.83}$, which is similar to the value determined in our study. In contrast, Jacobs et al. (2011) have estimated $n \approx 6 \pm 1$ using a sample of 160 $\mu$m selected sources from Spitzer observations of the 1 deg$^2$ ISO Deep Field region in the LH. Their analysis is based on only 40 galaxies while the current study includes 634 sources and therefore the value determined here should be more accurate and reliable.

In Fig. 13 we show the IRLD which is calculated by $\Omega IR = \int L \Phi(L, z | \theta) dL$. We only display IRLD determined using the double power-law LF model because the 68 per cent credible interval is almost identical when IRLD is calculated using the power-law and log-normal LF model. We follow the method presented in Le Floc’h et al. (2005) by determining IRLD for IR luminous galaxies (LIRGs and ULIRGs) and ‘normal’ galaxies as a function of redshift. The evolution of $\Omega IR$ is also represented in terms of an IR equivalent SFR using the calibration given by equation (16).

The model also suggests that LIRGs and ULIRGs are responsible for $\sim 68^{+10}_{-07}$ per cent of the total IRLD at $z = 1.2$. At $z = 0$, LIRGs and ULIRGs are responsible for less than $10^{+08}_{-02}$ per cent of the IRLD, while at $z = 1$, they produce $\sim 66^{+10}_{-05}$ per cent of it. These values are consistent with estimates of Le Floc’h et al. (2005) while Magnelli et al. (2009) suggest that LIRGs and ULIRGs produce less than 2 per cent of the IRLD. This difference is most likely due to the fact that Magnelli et al. (2009) use the faint-end power-law index, $\alpha = -0.6$, from the IRAS TIR LF of Sanders et al. (2003), which is steeper than the value used in this study ($\alpha = 0.34^{+0.10}_{-0.12}$ for the double power-law LF model) and this would lead to a higher contribution of normal galaxies to the IRLD at $z = 0$.

Figure 13. Evolution of the IRLD up to $z = 1.2$ (solid black line region) and the contribution by normal galaxies (solid blue line region), LIRGs (solid green line region) and ULIRGs (solid red line region) determined using the double power-law LF model. The black solid region includes 68 per cent of the posterior probability. The red line region is taken from Le Floc’h et al. (2005), orange line region is taken from Magnelli et al. (2009) and blue filled stars are taken from Rodighiero et al. (2010).
6.2 Evolution of the cosmic star formation rate density

In Fig. 14, we show the CSFRD as a function of redshift up to \( z = 1.2 \) and compare our results with the CSFRD estimates compiled by Hopkins (2004) and Hopkins & Beacom (2006) at wavelengths ranging from the X-ray to radio. We highlight for comparison in filled blue squares the SFR derived from 24 \( \mu \)m observations taken from Rujopakarn et al. (2010) (blue filled squares in Fig. 14). Overall, our prediction of \( \dot{\rho}_{\text{SFR}} \) show a good agreement with the results determined from previous experiments. At \( z = 0 \), the CSFRD is \( 1.04^{+0.31}_{-0.13} \times 10^{-2} \, \text{M}_\odot \, \text{yr}^{-1} \, \text{Mpc}^{-3} \) which agrees with previous values of the local \( \rho_{\text{SFR}} \) that have properly accounted for the internal extinction of the galaxy but slightly lower than the estimate of Rujopakarn et al. (2010) who find a local \( \rho_{\text{SFR}} \) of \( 1.65 \times 10^{-2} \, \text{M}_\odot \, \text{yr}^{-1} \, \text{Mpc}^{-3} \) [assuming a Salpeter (1955) initial mass function]. The dust-unobscured CSFRD estimated by Schiminovich et al. (2005) (dot–dashed orange line) is also displayed in Fig. 14. At \( z = 0 \), the dust-unobscured CSFRD is estimated to be \( \sim 5.01 \times 10^{-3} \, \text{M}_\odot \, \text{yr}^{-1} \, \text{Mpc}^{-3} \) and therefore without dust extinction corrections, the local CSFRD would be underestimated by \( \sim 65^{+8}_{-30} \) per cent. Modelling \( \rho_{\text{SFR}} \) as \( \propto (1 + z)^0 \), implies \( Q = 3.82^{+0.25}_{-0.16} \), which is higher than the value reported by Hopkins (2004) \( (Q = 3.29 \pm 0.26) \) but consistent with Rujopakarn et al. (2010) \( (Q = 3.50 \pm 0.20) \). The results presented here show that in general, most of the star formation over the last 8 billion years has taken place in dust-obscured galaxies.

6.3 Future prospects

In Section 5, we have presented the results of the evolution of the FIR LFs in the SWIRE XMM-LSS and LH fields, based on a spectroscopic redshift sample. The 70 \( \mu \)m and TIR LFs were constructed using the sample selected with \( S_{70} > 10 \, \text{mJy} \) and \( r < 22 \) and the 160 \( \mu \)m LF was constructed using sources with \( S_{160} > 60 \, \text{mJy} \) and \( r < 22 \). In this section, we discuss the limitations of the sample selection and the methodology in constructing the FIR LFs and suggest improvements that could be carried out in order to obtain better estimates of LFs.

We chose to study the evolution of the FIR LFs using only spectroscopic redshifts in order to reduce the uncertainties related to photometric redshifts as stated in Section 1. Some previous studies of the evolution of the IR LFs that have utilized photometric redshift (Babbedge et al. 2004; Pérez-González et al. 2005; Wang & Rowan-Robinson 2010) account for the uncertainty in the redshift by performing Monte Carlo analysis, where each source’s photometric redshift is replaced by a redshift drawn randomly from a Gaussian distribution centred on the original photometric redshift and then iterating the LF procedure. Few authors (Chen et al. 2003; Aird et al. 2010) have attempted to account for this uncertainty by modifying the likelihood function in equation (10) and including the actual redshift probability distribution function for each source likelihood \( p(L_{\lambda}, z_{\lambda} | \theta) \) rather than a Gaussian approximation. Therefore, including sources with photometric redshifts will not only increase the sample size but we will be able to apply a fainter magnitude cut in the optical and reach higher redshifts.

At IR wavelengths, the sample includes sources up to the flux limit of the SWIRE survey but with a strict magnitude cut of \( r < 22 \) our sample will not include those IR sources that are also optically faint. For the present sample, \( > 50 \) per cent of the 70 \( \mu \)m sources at 10 mJy have an optical counterpart that is brighter than 22 mag in the r-band and therefore inclusion of the photometric redshifts will also reduce the dependence on the spectroscopic incompleteness.
weights \( w_i \). Since future large surveys will discover many millions of galaxies, photometric redshifts will play a vital role in any statistical analysis and therefore the inclusion of this in our studies will be one of the next key steps.

The other limitation of the work is that in the parametric method, we have assumed a single evolving population. For the 70 \( \mu \)m and the TIR LF the selection functions are calculated assuming an M82 SED template and for the 160 \( \mu \)m LF we have used a mixture of M82 and Cirrus SED. As shown in Fig. 3, we observe a gradual change in the best-fitting SED type as we move out to higher redshift, with low redshift sources fitted with a cirrus-dominated SED and the higher redshift sources fitted with a starburst-dominated SED. This implies that the starburst component of the IR SED must evolve much faster than the cirrus component and therefore this evolution must be taken into account when studying the evolution of LFs using parametric methods. Therefore, studying the evolution of each SED component will be the second step in studying the evolution of the FIR LFs.

7 SUMMARY AND CONCLUSION

We have presented a new observational determination of the FIR LFs using 70 \( \mu \)m selected sources from the SWIRE survey with spectroscopic redshifts. The primary sample was selected from the photometric redshift catalogue of Rowan-Robinson et al. (2008), which contains over 1 million IR sources estimated by combining optical and IRAC 3.6 and 4.5 \( \mu \)m photometry. We computed the rest-frame 70 \( \mu \)m and TIR LF using sources with \( S_{70} > 10\) mJy and \( r < 22 \) and studied their evolution out to \( z = 1.2 \). The evolution of the 160 \( \mu \)m LF was determined using \( S_{160} > 60\) mJy and \( r < 22 \) out to \( z = 0.5 \).

We use the multiwavelength optical to IR data to model the SED for each source in our sample to estimate the rest-frame monochromatic luminosities to determine the 70 and 160 \( \mu \)m LFs using Bayesian parametric and the 1/\( V_{\text{max}} \) methods. The work presented here is an improvement on earlier works because we use 70 \( \mu \)m data rather than relying on extrapolations from 24 \( \mu \)m. In addition, the Bayesian method is a new approach to FIR astronomy, which can be used to further the study of IR LFs. For example, we can include photometric redshift data and properly account for the individual photometric redshift uncertainty of each source to investigate the evolution of the FIR LFs. The study of the evolution of FIR LFs using photometric redshifts will be presented in a future paper. In our analysis, we have corrected for the optical and IR selection biases and incompleteness of the spectroscopic sample, which have allowed us to accurately construct the LFs.

The parametric Bayesian FIR LFs were determined using two LF models: a double power-law, and a power-law and log-normal models. Comparison of the two models with the binned 1/\( V_{\text{max}} \) estimates showed that both LF models provide a good fit to the 70 \( \mu \)m and TIR LFs. For the 160 \( \mu \)m LF, however, the power-law and log-normal LF was found to underestimate the number density of sources at \( L_{160} > 10^{11} \) L\(_\odot\) when compared to the binned LF estimates, implying that the double power-law LF model provides a better description of FIR LFs.

The evolution of FIR LFs was modelled using a pure luminosity evolution model. The rest-frame 70 \( \mu \)m LF was found to evolve rapidly in luminosity with \( \alpha_1 = 3.39\pm0.12 \) for model 1 and \( \alpha_1 = 3.41\pm0.12 \) for model 2. Thus, the choice of LF model does not have a large effect on the evolution of the 70 \( \mu \)m LF. The 160 \( \mu \)m LF was found to evolve with \( \alpha_1 = 5.73\pm0.29 \) for model 1 and \( \alpha_1 = 5.62\pm0.24 \) for model 2. The faster rate of evolution of the 160 \( \mu \)m LF is consistent with the study of Takeuchi et al. (2006) which finds that the ISO 170 \( \mu \)m LF evolves with \( \alpha_1 = 5.0\pm2.2 \). Since cooler galaxies are detected more effectively at 160 \( \mu \)m than at shorter wavelengths, the strong evolution implies the presence of large amounts of cool dust at higher redshifts.

Finally, we used the best-fitting SEDs to estimate TIR luminosities of each source to derive the TIR LF to \( z = 1.2 \). The SWIRE TIR LF showed good agreement when compared with the literature values estimated from Spitzer and Herschel data across all redshifts bins. The TIR LF evolves with \( \alpha_1 = 3.82\pm0.20 \) for model 1 and \( \alpha_1 = 3.82\pm0.16 \) for model 2 corroborating the conclusions of previous results from Spitzer 24 \( \mu \)m studies which find strong luminosity evolution. The TIR LF was then integrated to calculate the IRLD out to \( z = 1.2 \), which confirms the rapid evolution in number density of LIRGs which contribute \( \sim66\% \) per cent to the IRLD, and hence the CSFRD at \( z = 1 \). The results presented in this paper, based on 70 \( \mu \)m data, confirm that the bulk of the star formation at \( z = 1 \) takes place in dust-obscured objects.

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