Serendipitous detection of an overdensity of Herschel-SPIRE 250 μm sources south of MRC 1138-26

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ABSTRACT

We report the serendipitous detection of a significant overdensity of Herschel-SPIRE 250 μm sources in the vicinity of MRC 1138-26. We use an adaptive kernel density estimate (AKDE) to quantify the significance, including a comparison with other fields. The overdensity has a size of ~ 3.5′-4′ and stands out at ~ 5σ with respect to the background estimate. No features with similar significance were found in four Herschel-observed extragalactic control fields: GOODS-North, Lockman, COSMOS and UDS. The chance of having a similar overdensity in a field with the same number but randomly distributed sources is less than 2%. The clump is also visible as a low surface brightness feature in the Planck 857 GHz map. We detect 76 sources at 250 μm (with a signal-to-noise ratio greater than 3), in a region of 4′ radius (or 1.51 ± 0.17 arcmin⁻²); 43 of those (or 0.86 ± 0.13 arcmin⁻²) are above a flux density limit of 20 mJy. This is a factor of 3.6 in excess over the average 0.24 ± 0.02 arcmin⁻² in the four control fields, considering only the sources above 20 mJy. We also find an excess in the number counts of sources with 250 μm flux densities between 30 and 40 mJy, compared to deep extragalactic blank-field number counts. Assuming a fixed dust temperature (30 K) and emissivity (β = 1.5) a crude, blackbody-derived redshift distribution, zBB, of the detected sources is significantly different from the distributions in the control fields and exhibits a significant peak at zBB ≈ 1.5, although the actual peak redshift is highly degenerate with the temperature. We tentatively suggest, based on zBB and the similar S250/S350 colours of the sources within the peak, that a significant fraction of the sources in the clump may be at a similar redshift. Since the overdensity lies ~ 7′ south of the z = 2.16 Spiderweb protocluster MRC 1138-26, an intriguing possibility (that is presently unverifiable given the data in hand) is that it lies within the same large-scale structure.

Key words: galaxies: clusters: general — galaxies: high-redshift — galaxies: individual: MRC 1138–26 — infrared: galaxies

1 INTRODUCTION

Star-formation in the local universe occurs mainly in late-type galaxies and they are predominantly found in the field, in loose galaxy groups, or in the infall regions of rich clusters of galaxies (e.g. Haines et al. [2009]). At higher redshift the situation is more complicated and there are reports of the so-called “reversal” of the star-formation density relation (e.g. Popesso et al. [2011]). At epochs near the peak of the star-formation rate density history (at redshifts 2–3; e.g. Hopkins & Beacom [2006]), the massive clusters of today are not yet formed or virialised, and the so called protoclusters are still accreting material from the surroundings, which in most cases include dusty star-forming galaxies (DSFG). As predicted by Granato et al. [2004], following the standard hierarchi-
In this paper we report the detection of a significant and visually compelling overdensity of SPIRE 250 μm detected galaxies. This is a pilot study of overdensities found in extragalactic Herschel maps. Note that throughout this paper, when we refer to overdensities, we mean a visual overdensity of sources in maps. We intentionally do not refer to these clumps as “candidate protoclusters” of dusty galaxies as they could just be chance alignments.

The structure of the paper is the following: in the next section (§2) we introduce the Herschel-SPIRE observations and the data processing, giving estimates of the map depth and sensitivity, the source detection procedure, the source catalogue statistics and completeness and we introduce the four extragalactic control fields used in the analysis. Then in §3 we proceed by presenting the adaptive kernel density estimate method employed to characterise the overdensity and the different strategies used to estimate its significance. In §4 we present the surface density measurements in comparison with the control fields and in §5 we do the same for the distribution of the 250 μm source flux densities. Next, in §6 we estimate their black-body derived redshifts and their distribution in a colour-magnitude diagram. The corresponding detection of the overdensity by Planck-HFI at 857 GHz is briefly discussed in §7. The conclusions are presented in §8.

We use the following cosmological parameters: $\Omega_m = 0.3$, $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$.

## 2 OBSERVATIONS AND DATA PROCESSING

The Herschel-SPIRE and Photodetector Array Camera and Spectrometer (PACS, Poglitch et al. 2010) observations were performed as part of Herschel guaranteed time (PI: B. Altieri). The target of the Herschel observations is a well known protocluster: MRC 1138-26, also known as the Spiderweb protocluster. Its existence was confirmed by reports of significant overdensities of Ly α, H α emitters and near-IR galaxy colours consistent with the 4000 Å break at $z \approx 2.2$, close to the redshift $z = 2.16$ of the Spiderweb radio galaxy (e.g. Pentericci et al. 2000; Kurk et al. 2004a,b; Venemans et al. 2006). The SPIRE and PACS observations were used in a detailed analysis of the central massive star-forming radio galaxy (Seymour et al. 2012).

Comprehensive details of the Herschel data processing, map-making and source detection, and catalogues of the Herschel observations, will be presented in Sánchez-Portal et al. (in preparation).

### 2.1 SPIRE map making

The SPIRE observation (OBSID: 1342210877, on 07 Dec 2010) was executed in Large Map mode covering a field of $\sim 20' \times 20'$, centred on the radio galaxy (RA=11:40:48.360, Dec=−26:29:10.60, J2000.0). To increase the depth, the same area was observed four times in sequence (i.e. four map repetitions). Maps were produced with the Herschel Interactive Processing Environment (HIPE v10), following the standard data processing and map-making steps, using SPRE_CAL_10.1 calibration tree. The final maps have a resolution of (6, 10, 14)″ per pixel at (250, 350, 500) μm.

Figure 1 shows the SPIRE 250 μm map with the Herschel telescope turnaround data included. We include the turnaround data for...
Overdensity near MRC 1138-26

2.3 Source detection and completeness

We use the SUSSEXTRACTOR (SXT) source detection method developed for SPIRE maps (see Smith et al. 2012 for more details). The SXT is a maximum likelihood method that treats each potential source (e.g. the centre of each pixel) and considers two models at each location: an empty sky model and a source model. The two models are compared in order to determine whether a source is present at the particular location. The method assumes the source model is known, i.e. the beam profile for SPIRE. There are 817 sources detected at a signal-to-noise ratio (SNR) above 3 in the SPIRE 250 μm map of the Spiderweb field, 366 of those are within the region of relative coverage greater than 50% (indicated with a magenta contour in Figure 1). We use the SPIRE 250 μm detected sources as an input prior list for the maximum likelihood fits at 350 and 500 μm. The prior entries that result in a poor fit at 350 or 500 μm are replaced with 3σ upper limits based on the nominal confusion noise (i.e. 19 and 20 mJy respectively, see Sect. 2.2). Note that a single source at 250 μm may be multiple galaxies, but without shorter wavelength data we cannot flag this blending (see e.g. Elbaz et al. 2011). By using 250 μm detections as priors we may miss very high redshift sources (z > 3). As our maps are confusion noise dominated we can refer to the completeness estimates from other confusion dominated maps, for example GOODS-North from HerMES (Smith et al. 2012). Hence the flux density at 50% completeness levels are approximately (12,13,13) mJy at (250,350,500) μm.

2.4 Extragalactic control fields

We have chosen four well studied extragalactic fields to use as control fields: GOODS-North, COSMOS, Lockman, and UDS. These fields are part of HerMES (see Oliver et al. 2012 for more details on field locations and the Herschel observations). The SPIRE maps in these fields, shown in Figure 2, are larger (30′ × 30′) and much deeper than the Spiderweb observation, so we have reprocessed them by limiting to the same depth as the Spiderweb map, i.e. only using four map repetitions. Subsequently we apply the same map making and source detection procedure. In order to make sure that we match the depth of the Spiderweb observation we compare the derived 1σ noise in the 250 μm maps of the control fields: using the robust MAD estimator in a similar way as in Sect. 2.2 we obtain slightly lower but consistent value of 6 mJy in GOODS-North, COSMOS, UDS and 5.6 mJy in Lockman.

3 AN OVERDENSITY OF SPIRE SOURCES

3.1 Adaptive kernel density estimate (AKDE)

A visual overdensity of sources south-east of the Spiderweb galaxy stands out clearly with respect to the field in the 250 μm map (Figure 1). The feature has a low contrast at 350 and 500 μm. In order to quantitatively define the overdensity and assess its significance, we apply an iterative adaptive kernel density estimate on the detected 250 μm galaxies. We follow Pisani (1996) to compute the optimal Gaussian kernel width at any point within the map, based on the local density of detected sources. The method of Pisani (1996) is iterative and the optimal kernel width at each point is obtained after minimisation of a suitable function (the integrated square error of the true density and the estimated one, see Pisani 1996 for more details) using only the positions of the sources. Ferrusi et al. (2011)
provides more details and a comprehensive comparison of the different methods for density estimation.

The AKDE for the Spiderweb field is derived using all 366 detections at 250 μm within the area with coverage above 50%. The procedure provides the density estimate and the optimal Gaussian width at each input source. The maximum observed signal-to-noise density is 6.0σ, on a source indicated by a cross sign in Figure[1] where σ is taken as the standard deviation (std.dev.) of all 366 density estimates. The density and the optimal Gaussian width at each observed source are then used to make an AKDE map on a 301 by 301 pixels grid (similar to the observed 250 μm map of 328 × 356 including telescope turnaround data). As expected, the peak density on the map is smaller – at 5.1σ – as the gridding smooths out the signal. The AKDE result is shown as contours from 1 to 5σ in Figure[1]

3.2 AKDE peak significance relative to random fields

To properly quantify the significance of the overdensity we generate the same number of galaxies with random positions within the 50% map coverage area (the magenta contour in Figure[1] and we impose a minimum nearest neighbour distance of 2 pixels (or 12″) for the 250 μm map). This minimum distance is chosen to mimic the actual empirical observing selection by which distinct objects within 2/3 of the 18″ beam FWHM at 250 μm cannot be separated.

For each one of the 100 random realisations we derive the AKDE on a 301 × 301 pixels maps. In 2 out of 100 random realisations we observe a peak AKDE that exceeds the observed one of 5.1σ. The maximum random field peak is at 5.4σ with AKDE maximum values ranging from 3.5σ to 5.4σ. This means that the probability of finding a similar overdensity in a random field is less than 2%. Note that 2% is an upper limit, because in our estimate we only take into account the peak value of the AKDE map and we do not consider the actual size of the region – for example, a small number of closely packed sources would produce a greater AKDE value, but the AKDE contour above 3 or 4σ (as a measure of the size) would be much smaller in this case.

3.3 AKDE peak significance relative to control fields

Using the SXT catalogues in the four control fields (see Section 2.4) we calculated the AKDE following the same procedure and the results are shown in Figure[2] In GOODS-N, COSMOS and UDS the highest AKDE peaks are around 3.2–3.6σ. The most significant peak, at 4.9σ, is found in the Lockman field, with a number of large (≥ 10′) irregular regions at 4σ. These Lockman features are interesting, but we defer their analysis to a future work. As indicated in Figure[2] none of the 3σ or above regions can be linked to known protoclusters (Papovich et al. 2010, Chapman et al. 2009) or cluster candidates at z > 1 (Wen & Han 2011).

3.4 Definition of the overdensity

The AKDE peak at 5.1σ in the field of MRC 1138-26, is located at RA=11:41:04.44, Dec=−26:35:08.6 (J2000.0) and the major axis of the region within the 3σ contour is ≈ 3′. The AKDE peak is slightly off-centre with respect to the 3 and 4σ isocountours; consequently for the rest of the paper we consider the overdensity region as a circle with 4′ radius, centred at 1′1 west/south-west from the AKDE peak, on RA=11:40:59.5, Dec=−26:35:11. This region is shown as a red circle in Figure[1]. Note that the elliptical shape of the overdensity contours may be due to an edge effect; fewer sources are detected near the edge due to the drop in coverage.

4 SURFACE DENSITY EXCESS

There are 76 SPIRE 250 μm SXT sources at SNR above 3 and within the defined overdensity; 67 and 63 correspondingly at 350 and 500 μm or (1.51 ± 0.17, 1.33 ± 0.16, 1.25 ± 0.16) arcmin−2 in the three bands. In order to avoid incompleteness bias for the faintest sources we only consider detections above our nominal 3σ flux limit of 20 mJy at 250 μm, i.e. we have 43 detections or 0.86 ± 0.13 arcmin−2.

In the four control fields, the surface densities of the 250 μm detections above 20 mJy, derived using the area above 50% relative coverage, are 0.28 ± 0.02 arcmin−2 (or 14 ± 4 sources rescaled to a 4′ radius area) in COSMOS, 0.24 ± 0.01 arcmin−2 (or 12 ± 3) in GOODS-North, 0.24 ± 0.01 arcmin−2 (or 12 ± 3) in Lockman and 0.20 ± 0.02 arcmin−2 (or 10 ± 3) in UDS. These correspond to 0.24 ± 0.02 arcmin−2 on average, which means that there is a significant excess, a factor of 3.6, of the surface density in the overdensity with respect to the average levels in the control fields.

We also perform simulations of 4′ regions in each one of the control fields, making sure that the whole area is within the 50% relative coverage. From 1000 simulated areas the average numbers of 250 μm detections above 20 mJy in the four control fields are 21 ± 7 in COSMOS, 21 ± 6 in GOODS-North, 18 ± 5 in Lockman and UDS. The errors are the std.dev. of the counts from the 1000 simulated regions. The interpretation of these results must be taken with caution because the simulated regions are correlated and the results are expected to be biased. Nevertheless, these results also support the significant excess of the surface density in the overdensity.

The maximum number of detected sources from all 4′ simulated regions are 42 in COSMOS, 35 in GOODS-North, 33 in UDS and 31 in Lockman. So, there are regions of the same size and similar surface density in one (COSMOS) out of the three control fields. It is interesting to note that the maximum AKDE in COSMOS is at ~ 3σ (see Figure[2]) which is significantly smaller than the 5.1σ we see in the overdensity. We interpret this discrepancy as being due to the more centrally concentrated distribution of the overdensity galaxies within the 4′ region, as can be appreciated from Figure[1] where the overdensity region includes significant area with no sources outside the 3σ contour level. This effectively brings down the surface density. This result shows that regions with similar surface density excess are rare but they can be found. However, they do not necessarily correspond to a peak in the spatial density distribution.

Note that without imposing a flux limit of 20 mJy at 250 μm for the control fields we obtain on average 0.94 ± 0.04 arcmin−2 – this is close to the HerMES result of 1.02 arcmin−2 (Oliver et al. 2012) and makes the overdensity 1.51 arcmin−2 only marginally in excess with respect to the average surface density in the control fields.

5 SPIRE 250 μm FLUX DENSITY DISTRIBUTION

The 250 μm flux density (S250) distribution of the sources in the overdense region is shown in Figure[3] Using 1000 simulated 4′ regions in the control fields, we derive the average 250 μm flux distributions, which are also shown in Figure[3] renormalised to
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Figure 2. SPIRE 250 μm maps in: (a) Lockman; (b) UDS; (c) COSMOS; and (d) GOODS-North. The data have been cut to match the depth of the Spiderweb map (see Section 2.4 for more details) and the greyscale ranges are the same in all maps, matching those in Figure 1. The AKDE contours run from 1 to 5 σ; the region above 50% relative coverage is shown as a magenta contour. The highest peak in GOODS-North is at \( \sim 3 \sigma \) for UDS and COSMOS and the highest one is at \( \sim 4.5 \sigma \) in Lockman. The red circles of 4′ radius show the positions of the photometrically selected candidate clusters at 1 < z < 1.6 in Lockman, COSMOS and UDS from Wen & Han (2011), keeping only those within the 50% coverage. The only known confirmed protocluster in these fields, CLG 0218 at \( z = 1.62 \), is shown with a green circle in UDS (Papovich et al. 2010). In GOODS-North (d) we show the structure candidate at \( z = 1.99 \), reported by Chapman et al. (2009).

the same number of sources as in the overdensity region. We see a marginal excess in the bin from 30 to 40 mJy: the expected number of sources in this bin is on average 4.4 \( \pm \) 2.0 in a 4′ radius, derived from the control fields. The deep number counts at 250 μm derived from resolved sources in COSMOS from HerMES predict 4.3 \( \pm \) 0.3 (Béthermin et al. 2012). We detect 8, which is a factor of almost two in excess, but at 1-2σ only. The excess is quite likely to be partially due to the combined effect of source confusion and flux boosting, because of the closely packed sources in the clump. We also see a marginal excess in the 40-50 mJy bin. Nevertheless, the two-sided Kolmogorov-Smirnov (KS) test of the overdensity S250 distribution and each of the control fields indicate that they are significantly different in all cases: the probability, that the two distributions are drawn from the same parent one, is less than 3%.

6 FAR-INFRARED COLOURS AND MODIFIED BLACK-BODY REDSHIFTS

6.1 Ancillary data

There are no ground-based optical or NIR observations nor Spitzer or Herschel-PACS observations that cover this region \( \sim 7′ \) south
of the Spiderweb radio galaxy (details on the available multi-wavelength data in this field are presented in Koyama et al. [2013]). Hence we utilise the available all-sky surveys, of which WISE (Wright et al. [2010] is the most useful. In general, the depth of the WISE band W1 allows us to detect an $L_*$ galaxy at 5 $\sigma$ out to $z \approx 1$ (Gettings et al. [2012]). This is rather shallow for SPIRE detected galaxies, which are predominantly at redshifts greater than 1. Nevertheless, these additional data are useful to identify low redshift sources. There are 158 WISE detected galaxies in the overdense region of $\sim 4'$ radius using the All Sky Data Release from March 2012. From those, 21 are within 5$''$ of a SPIRE detected galaxy and have a $> 3 \sigma$ detection in band W1 (3.4 $\mu$m). We do not use the WISE photometry for these 21 sources in any of the following analysis, but we simply flag the SPIRE sources that may be at low redshift ($z < 1$).

### 6.2 Modified black-body redshift

It is a challenge to derive good photometric redshifts when having only three bands (250, 350 and 500 $\mu$m) at best, each with a flux calibration uncertainty of $\sim 7\%$ (Swinyard et al. [2010] Bendo et al. [2013]). However, there are already a number of Herschel-based studies applying different techniques in order to overcome the complications of large beams, flux boosting and substantial flux uncertainties, especially for faint, distant, star-forming galaxies (e.g. Lapi et al. [2011] Roseboom et al. [2012] Casey [2012] Chakrabarti et al. [2012]). Hence, with no supporting ancillary data we decide to approach the problem using a simple fit with a redshifted, single-temperature, modified black-body:

$$S_\nu(z) \propto \nu^\beta \left( T, \nu_z \right), \tag{1}$$

where $\nu_z = \nu / (1 + z)$ is the redshifted frequency, $\beta$ is the dust emissivity spectral index, which we keep fixed at 1.5 (e.g. Magnelli et al. [2012]) and $B(T, \nu_z) = \frac{2\nu_z^2}{\pi^\frac{3}{2}} \frac{1}{e^{\nu_z/kT} - 1}$ is the Planck function. With at most 3 photometric detections, we proceed by fixing the temperature $T$ and leaving the redshift $z$ as a free parameter. For Herschel detected star-forming galaxies the representative dust temperatures are between $\sim 20$ K and $\sim 60$ K (e.g. Magdis et al. [2010] Magnelli et al. [2012]). Thus, we fix the temperature to 30 K, which is also close to the dust temperatures of 30-34 K of the four confirmed Spiderweb cluster members with spectroscopic redshifts (see later and Sánchez-Portal, in preparation). We further constrain the fit to sources that have at least 2 out of 3 photometry detections, which brings down the number of sources used in the $z_{BB}$ analysis to 58. Even with the simplification of fixing $T$ and $\beta$, the $\chi^2$ statistic is not very useful because we have at most 2 degrees of freedom and we fit two parameters: redshift and overall normalisation. This means that the error on the parameters is not representative.

We call the best-fit redshift the black-body redshift and denote it $z_{BB}$. Galaxies with similar far-infrared (FIR) SEDs and colours would have similar $z_{BB}$. We note that there is a strong degeneracy between $T$ and $z_{BB}$ and by definition, $z_{BB}$ would match the actual redshift only in some particular situations, i.e. dust temperature and dust emissivity $\beta$ close to our fixed values.

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2 From the Wien’s displacement law, $\lambda_0 T = \lambda_{BB} T/(1 + z) = \text{const.}$, where $z$ is the redshift, $\lambda_0$ is the wavelength of the black-body peak in rest-frame and $\lambda_{BB}$ is the peak location in observed wavelength. Consequently, for the same black-body SED, $T/(1 + z)$ is constant, see also Blain et al. (2003).

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**Figure 3.** SPIRE 250 $\mu$m flux density distribution for the overdensity (histogram and box symbol with error bar) and the four control fields (box symbols with error bars). The y-axis is the number of sources in a 4$''$ area. Note that the control fields points were displaced from the centre of the bin for clarity. The black filled circles are the deep number counts from Bethermin et al. [2012], rescaled to the area of the overdensity.

**Figure 4.** Distribution of the FIR redshifts $z_{BB}$ for the overdensity region (histogram) and the four control fields (box symbols with error bars, symbols displaced within the bins for clarity). The bin size is 0.1 and all error bars are Poissonian. The distributions in the fields were renormalised to the same number of sources as in the overdensity.

We compare the derived $z_{BB}$ for the Herschel-SPIRE detected galaxies with spectroscopic redshifts in Casey et al. (2012) hereafter C12). As expected, the Pearson correlation coefficient between the two is only 0.2, which means that there is practically no correlation between the spectroscopic redshift and the derived $z_{BB}$ at $z < 2$ (the limit of the spectroscopic data in C12). Nevertheless, if there is an excess of galaxies with similar colours (i.e. at a similar redshift) then the distribution of $z_{BB}$ would be informative and would show this excess.

Figure 4 shows the derived $z_{BB}$ distribution in the overdensity and we note that indeed there is a significant peak at $z_{BB} \sim 1.5$. Following the same approach, calculating $z_{BB}$ for the four con-
trol fields, we see that the distributions are similar to each other, while they are significantly different from the overdense field (see Figure 4), especially for the two $z_{BB}$ bins centred on 1.5 and 1.6, although there are some hints of excess at $z_{BB} \approx 0.9$ and $\approx 2.6$ too. The two-sided KS test gives the maximum probability of <5% that the overdensity and the fields $z_{BB}$ distributions are drawn from the same parent distribution. Using the average level and Poissonian error of $2.4 \pm 0.5$ at $z_{BB} = 1.5$ in the fields, we estimate the peak signal-to-noise ratio of more than 7. We must emphasise that the location of the $z_{BB}$ peak depends strongly on the assumed dust temperature and could range from $2.33 \, (T = 40 \, K)$ to 0.7 ($T = 20 \, K$). The effect of $\beta$ on $z_{BB}$ is not significant, i.e. changing $\beta$ from 1.5 to 2.0, for $T = 30 \, K$, will only change $z_{BB}$ by less than 5%.

We also check if the significant $z_{BB}$ peak is not narrower than expected for a natural spread of the galaxies SEDs and flux measurements. We use the empirical SED templates from Kirkpatrick et al. (2013, hereafter K13), derived from 24 $\mu$m detected galaxies that were observed with Herschel. We select the SED template for a $z = 2$ star-forming galaxy and redshifted it to $z = 1.5$, normalising the 250 $\mu$m flux density to 30 mJy (where we see excess sources, see Sect. 5). We generate flux densities at 250, 350 and 500 $\mu$m randomly from within the SED template flux confidence range, incorporating the 7% flux calibration uncertainty and the confusion noise of 6 mJy in quadrature for the measurement error. Then we fit a modified black-body for the $z_{BB}$, following exactly the same procedure as for the overdensity sources. From 1000 simulated galaxies we obtain $z_{BB} = 1.50 \pm 0.31$, where the spread $\Delta z_{BB}$ of 0.31 is obtained as the st.dev. of all $z_{BB}$ measurements. Similar results are obtained using the other SED template in K13 – for star-forming galaxies at $z = 1$. This result confirms the correct approach on estimating $z_{BB}$, as we recover exactly the simulated redshift and also provide us with the expected spread of the measurements $\Delta z_{BB}$. This $\Delta z_{BB}$ of 0.31 is somewhat larger than the observed one with width of 0.2 for the two significant bins, which may be an indication that the spread in the SED shapes in the galaxies within the peak is smaller than the spread in the empirical template in K12.

There are 11 sources within the peak ($1.45 \leq z_{BB} \leq 1.65$). Figure 5 shows their IDs from the SXT catalogue and their distribution within the overdensity: they are mostly between the 3 and the 4$\sigma$ AKDE contours. It is interesting to note that they are not preferentially found near the AKDE peak. Nevertheless, this is a significant excess of sources with similar $z_{BB}$ and thus similar colours and SED shapes.

Figure 5 shows the modified black-body fit (as a red curve) for these 11 sources as well as the SED template from K13, fixed to the $z_{BB}$ redshift. Of the 11 sources, 3 have WISE W1 (3.4$\mu$m) counterparts above the photometric limits: IDs 117, 371 and 442; one of them (ID 371) is detected in W2 (4.6$\mu$m) and one (ID 442) in W3 (12$\mu$m). The photometry of ID 371 is likely affected by the neighbouring very bright 250$\mu$m source and its detection by WISE at 3.4 and 4.6$\mu$m is probably indicative of low redshift or a blended source.

6.3 Colour-magnitude diagram

Figure 6 shows S250 vs S250/S350 colour-magnitude diagram of the overdensity sources, compared to the colour-magnitude results from the spectroscopic sample in C12 for $z < 1$ and $z > 1$ galaxies. The two regions occupied by the C12 galaxies were constructed by keeping only sources with S250/S350 $< 3$ and S250 $< 100$ mJy (thus removing some outliers with peculiar colours or higher fluxes). We already demonstrated that there is no correlation be-

6.4 Connection with the Spiderweb protocluster?

It is interesting to note that the overdensity can in principle be part of a large complex at the redshift of the Spiderweb protocluster. As reported in Koyama et al. (2013), there is a large-scale filament in the Spiderweb field traced by H$\alpha$ emitters of a comoving size of $\gtrsim 10$ Mpc, going from NW to SE. Unfortunately, the narrow band filter observations do not reach as far as the overdensity region. A preliminary analysis of the Herschel data identify only four SPIRE-detected counterparts of spectroscopically confirmed Spiderweb protocluster galaxies (Sánchez-Portal, in preparation), including the radio galaxy Seymour et al. (2012). Their S250/S350 colours, as shown in Figure 7, are similar to the overdensity galaxies in the $z_{BB}$ peak. In addition, due to the temperature-redshift degeneracy, the peak of $z_{BB}$ would match the protocluster redshift at $z = 2.2$ if we fix the temperature to 38 K instead of 30 K. We do not want to enter into further speculation regarding this scientifically interesting hypothesis, because there are large uncertainties in the colour-magnitude diagram and there are too few SPIRE-detected confirmed Spiderweb galaxies. We presently lack auxiliary data that may help to establish the veracity of this claim.
7 PLANCK VIEW OF THE OVERDENSITY

We also identified the overdensity in the Planck-HFI 857 GHz map, shown in Figure 8 as a low surface brightness feature (2.56 MJy/sr peak value measured from the map), hence its absence from the Planck Early Release Compact Source Catalog (ERCSC, Planck Collaboration 2011). The detection with Planck is in support of the efficiency of the beam matching detection (Planck-HFI 857 GHz beam FWHM is 5') although the overdensity is not well pronounced at 350 µm (corresponding to the HFI 857 GHz band). This hints that the majority of the sources in the clump are brighter at 250 µm and thus at redshift below 3, where Planck is not that efficient for sources dominated by dust emission.

8 CONCLUSIONS

In this study we presented a serendipitous detection of a significant (5.1σ) overdensity of 250 µm detected star-forming galaxies. To quantify the significance we made use of an adaptive kernel density estimate of the galaxy distribution. In fields with the same geometry and the same number but randomly distributed sources we found that only 2% show similar peaks. We do not see an overdensity of similar size or similar significance in four extragalactic control fields: GOODS-North, COSMOS, Lockman and UDS.

The surface number density of the detected SPIRE 250 µm galaxies in the overdensity region are significantly in excess with respect to the average galaxy surface density from the four control fields. A similar surface density in a 4' region was found in the COSMOS field, hence regions with similar excess over the background do exist, but they do not necessarily correspond to a significant density peak, e.g. in COSMOS. Our interpretation is that the sources in the COSMOS region are more homogeneously distributed within the 4' region, while they are more centrally concentrated in the overdensity that is discussed here.

Additional support for the presence of the overdensity comes from the 250 µm number counts. There is a significant excess of sources with flux densities between 30 and 40 mJy in the overdensity compared to the control fields and the published SPIRE number counts. We note, however, that the excess in the 30-40 mJy bin may be due to the combined effects of source confusion and flux boosting, because of the closely packed sources in the clump.

Our photometric analysis, based on only the 3 SPIRE bands, makes use of a black-body redshift \( z_{BB} \). This is the best fit redshift of a modified black-body, with a fixed dust temperature and emissivity, to the three (at best) photometry measurements. The colour information and the SED shape are encapsulated in \( z_{BB} \). We have shown that the \( z_{BB} \) distribution exhibits a significant peak for the overdensity region. No similar peak in \( z_{BB} \) exists in the control fields. We showed that the galaxies within the peak have similar 250µm/350µm colours, as expected by the definition of \( z_{BB} \).

The reported overdensity can also be seen as a low surface brightness feature in the Planck 857 GHz map, although too faint to be included in the official public point source catalogue. This emphasises the need for a parallel search of visual overdensities of...
Overdensity near MRC 1138-26

Figure 7. The S250 vs S250/S350 colour-magnitude diagram for the overdensity galaxies. The filled polygons highlight the regions occupied by the Herschel detected galaxies with spectroscopic redshifts in C12: blue for \( z \leq 1 \) and red for \( z > 1 \). Note that the two regions overlap. The S250/S350 track for the SF2 SED (from K13) is shown as a vertical magenta line with the redshifts indicated. We only show the error bars for the 11 overdensity sources with \( 1.45 \leq z_{BB} \leq 1.65 \). Two dashed lines mark the upper and lower limits in S250/S350 colour for the galaxies with S250 above 20 mJy (3 \( \times \) rms) in the \( z_{BB} \) peak. The four SPIRE-detected counterparts to spectroscopically confirmed Spiderweb galaxies (Sánchez-Portal, in preparation) are shown as filled blue stars.

Figure 8. AKDE contours as in Figure 1 overlaid on the Planck 857 GHz map (Planck Collaboration 2013). The green box is 30' \( \times \) 30'. The peak Planck 857 GHz flux in the overdensity is 2.56 MJy/sr. Note: darker is brighter, as in previous figures. North is up, East is to the left.

dusty star-forming galaxies in fields observed with Herschel. Such clumps of dusty star-forming galaxies are expected to exist (e.g. Negrello et al. 2005) but there are no reports up to now, mainly because these clumps are rare, and because there was a lack of large extragalactic fields observed in the far-infrared, prior to Planck and Herschel.

All these results provide viable arguments that we may be seeing a real clump of dusty star-forming galaxies that may reside within the same large-scale structure. Moreover, the overdensity was identified in the field of a known protocluster: the Spiderweb. It lies close in projection (7 arcmin corresponding to a comoving distance of 10 Mpc at \( z = 2.0 \)) to the central protocluster massive and intensively star-forming radio galaxy MRC 1138-26. A large-scale filament traced by H\( \alpha \) emitters of a comoving size of \( \geq 10 \) Mpc and going from NW to SE was already reported in the Spiderweb field (see Koyama et al. 2013), although the narrow band filter observations did not cover as far as the overdensity region.

Nevertheless, the proximity to the protocluster raises the valid and scientifically attractive question: is the clump part of the same large-scale complex? Due to the scarce multi-wavelength data, poor statistics of SPIRE-detected spectroscopically confirmed Spiderweb members, and the large uncertainties in the colour-colour, colour-magnitude and the crude FIR redshift estimate, we cannot provide any conclusive evidence to support or discard this hypothesis. Moreover, there are known protoclusters in the control fields and none of them correspond to any visually compelling overdensities of 250 \( \mu \)m sources. Consequently this hypothesis remains highly speculative and extensive ground-based photometric and spectroscopic follow-up observations, which we are currently pursuing, will be needed in order to confirm or discard it.

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