A NEW DEEP SCUBA SURVEY OF GRAVITATIONALLY LENSING CLUSTERS

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Abstract
We have conducted a new deep SCUBA survey, which has targeted 12 lensing galaxy clusters and one blank field. In this survey we have detected several sub-mJy sources after correcting for the gravitational lensing by the intervening clusters. We here present the preliminary results and point out two highlights.

Keywords: Survey — Infrared: Galaxies — Submillimetre

1. Introduction

The extragalactic background light determined for the whole spectrum shows that from the structures in the universe most of the energy is emitted in the IR and in the optical/UV (e.g., Fixsen et al., 1998; Madau & Pozzetti 2000). The latter is the stellar light, while the former is the processed light, optical/UV photons absorbed by dust and re-emitted in the IR. The total energy output at the wavelengths ranges are comparable. Studies resolving the IR background have found that it is powered by a relatively small number of dusty star forming galaxies. These galaxies have large star formation rates, $100 - 3000 M_{\odot} yr^{-1}$, and are very luminous in the IR, typically $10^{11-12} L_{\odot}$, thus they are a.k.a. (ultra-)luminous IR galaxies.

As half of the cosmic star formation appears to be hidden behind dust, studies of the high-z universe in the IR are imperative. The redshifted far-IR emission is observable at the submillimetre (submm) wavelengths with ground based telescopes and instrumentation. An important aspect of submm cosmology is the negative $k$-correction, which allows observations of objects out to a redshift of 10. The observed flux density is approximately constant with redshift, which is of great benefit for detection experiments, but as a result it does not give an indication of redshift. Even if the source counts are known, different models with largely different redshift distributions can be used to reproduce
the source counts (Blain et al. 1999). As a consequence, to study the star formation history of these objects the redshift distribution must be determined by measuring the redshift of the individual objects. The negative $k$-correction is unique to only a few wavelengths. At most other wavelengths the positive $k$-correction makes it difficult to observe objects at high redshift. This of course affects the follow-up and identification studies the submm sources.

2. **A new deep SCUBA survey**

We have conducted a survey with SCUBA (Submillimeter Common User Bolometer Array; Holland et al. 1999), mounted at the J.C. Maxwell Telescope, Hawaii, aimed at studying the faint submm population. We have targeted 12 galaxy cluster fields and one blank field. The clusters are strongly gravitationally lensing and have redshifts between 0.03 and 0.88. The cluster fields have been observed to a depth of $1\sigma_{\text{rms}} \sim 1 - 2 \, \text{mJy/beam}$ (one field shallower). 55 sources have been detected in those fields. The blank field is the NTT Deep Field, which was observed to $1\sigma_{\text{rms}} \sim 1 \, \text{mJy/beam}$. Here 5 sources were detected. The total area surveyed is $70 \, \text{arcmin}^2$. The analysis and source extraction involved Mexican Hat Wavelets (Cayon et al. 2000) and Monte Carlo simulations (Knudsen et al. *in prep.*, Barnard et al. *in prep*).

3. **Lensing and counts**

The gravitational lensing by the foreground clusters amplifies the background sources. Furthermore, it magnifies the regions behind the clusters. As a result the area surveyed in the source plane is 2-3 times smaller than the area seen in the image plane. The effect of lensing is only of benefit when the counts are steep, which they are in the case of submm sources. The lensing moves the confusion limit to fainter flux density levels, hence allowing us to reliably pick out the faint sources. Most of the previous surveys made in the submm have targeted blank fields, and thereby studied the bright and intermediate population (e.g., Scott et al., 2002; Webb et al., 2003). Only a limited number of surveys have been able to study the faint population (e.g., Smail et al., 1998). In our survey, after correcting for the gravitational lensing, we have been able to observe objects with sub-mJy fluxes and survey an area large enough for us to study the counts of the faint population. The preliminary number counts based on half of our survey are shown in Fig. 1. Tentatively we find a slope $\alpha = 1.5$, when assuming a power law $N(> S) \propto S^{-\alpha}$. This is comparable to other surveys.

4. **Follow-up and Identifications**

We have done follow-up observations with ISAAC at the VLT, obtaining deep $Ks$ images (limiting magnitude $\sim 21.5$ mag (Vega)). This has been com-
A new deep SCUBA survey of gravitationally lensing clusters

Figure 1. The cumulative 850 µm source counts based on half of our survey. The asterisks represents this work. For comparison the counts from Smail et al. (2002) (diamonds) and from Scott et al. (2002) (triangles) have been included. The dotted line shows the best fit to our data points.

combined with archival, deep optical data from HST and VLT, and when possible also with observations at other wavelengths (radio, mid-IR). A substantial fraction of the plausibly identified submm sources turn out to be very or extremely red objects (the EROs are often defined to have $I - K > 4$). Remarkably, in many cases, counterparts identified as red objects have close neighbours which are also red objects. Examples are shown in Fig. 2.

We finally point out two highlights of the project: a multiple imaged galaxy and a type-1 quasar.

The multiple imaged galaxy is found in the field of A2218 (van der Werf et al. in prep). Three submm sources were identified with three images of the same very red galaxy, SMM J16359+6612, detected both in optical and near-IR. The submm source is detected both at 850 µm and 450 µm with the same colour for all three images. The magnification factor in total for all three images is 40. The lensing corrected flux density is $f_{850} = 0.9$ mJy. Based on detailed lensing models the galaxy has an estimated redshift of 2.5. Its spectral energy distribution is similar to that of Arp220 and HR10, though about a factor 5 fainter.

A quasar was identified in the field of A478. The submillimetre source, SMM J04135+10277, has $f_{850} = 25$ µm and $f_{450} = 55$ µm – these fluxes should be corrected with a magnification factor of 1.3. This is the brightest source in the entire survey and also bright for other similar surveys. The quasar has a redshift of 2.837. CO has been detected at $z = 2.84$ (Hainline et al., in prep). An analysis of the SED suggests that the quasar has a larger submm/far-
IR emission than other quasars. The IR luminosity is $L_{IR} = 3 \cdot 10^{13} L_{\odot}$.

An analysis of the optical spectrum suggests that the viewing angle from the relativistic beam is large, which can have consequences for the identification of other submm sources (Knudsen et al., 2003).

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