An ISOCAM Mid-IR Survey through Gravitationally Lensing Galaxy Clusters

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**Abstract.** We present imaging results and source counts from a deep ISOCAM cosmological survey at 15μm, through gravitationally lensing galaxy clusters. We take advantage of the cluster gravitational amplification to increase the sensitivity of our survey. We detect a large number of luminous mid-IR sources behind the cluster lenses, down to very faint fluxes, which would have been unreachable without the gravitational lensing effect. These source counts, corrected for lensing distortion effects and incompleteness, are in excess of the predictions of no-evolution models that fit local IRAS counts. By integrating the 15 μm source counts from our counts limit, 30 μJy, to 50 mJy we estimate the resolved mid-IR background radiation intensity.
1. Introduction

The high sensitivity of the CAMera on board the ISO\(^1\) satellite (Cesarsky et al. 1996) has allowed detection of distant \(z \sim 1\) galaxies at mid-infrared (MIR hereafter) wavelengths. These detections are crucial for understanding galaxy evolution, since theoretical models predict that dust obscuration can be quite an important effect in high redshift galaxies (e.g. Guiderdoni et al. 1997) and the dust-processed stellar radiation is re-emitted in the IR.

The evidence emerging from various IR number count surveys (e.g. Aussel et al. 1999, Elbaz et al. 1999, Flores et al. 1999) indicates that strong IR emitters at \(z \sim 1\) are an order of magnitude more numerous than the extrapolation from local IRAS counts indicate, when assuming no evolution.

In this paper we report key results of a very deep ISOCAM survey we have conducted in three cluster fields. We took advantage of the gravitational lensing amplification by the cluster potential wells to detect the intrinsically faintest sources ever detected at 15 \(\mu\)m. A description of our survey and results can be found in Altieri et al. (1999) and Metcalfe et al. (1999), and even more refined analysis is ongoing.

2. Observations

We observed the fields of three well-studied gravitationally lensing clusters (Abell 370, Abell 2218, and Abell 2390) during \(\sim 40\) hours of ISO guaranteed time. The three fields were imaged in two (wide) ISOCAM filters, LW2 and LW3, centered at about 7 and 15 \(\mu\)m, respectively. We used a pixel-field-of-view of 3\(''\) and micro-rastering with 7\(''\) steps. This ensured good astrometric/positional results (essential for cross-correlating these mid-IR images with optical images, and for future observational follow-ups). The total area covered by our survey is \(\sim 56\) arcmin\(^2\).

For what concerns data reduction, source detection and photometry, error and completeness estimates, we refer the reader to Altieri et al. (1998, 1999). For reasons of space we here present only results obtained with the LW3 filter, the longest wavelength ISOCAM filter.

3. Results

Gravitational lensing has two (equally important) effects: it suppresses confusion because of surface area dilation, and it amplifies the flux from background sources (see, e.g., McBreen & Metcalfe 1987, Paczynski 1987). Clearly, detailed modelling of the lens is needed in order to recover the intrinsic fluxes of the lensed galaxies, and their space density. For this reason, we accurately chose our targets among the best studied clusters where gravitational lensing has been detected.

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We achieve apparent 5 $\sigma$ sensitivities (i.e. ignoring the effect of lensing) of 67 $\mu$Jy at 15 $\mu$m in the deepest field (A2390), and 80 % completeness levels (before accounting for lensing) of 100, 250 and 500 $\mu$Jy in the fields of A2390, A2218 and A370, respectively. In order to correct for lensing, we use detailed models of the three cluster lenses (see Kneib et al. 1996, Bézecourt et al. 1999). The highest lensing gains are found to be $\sim 10$. The intrinsically faintest detected source (i.e. after correcting for lensing amplification) is an 18 $\mu$Jy source, lensed to an apparent 80 $\mu$Jy source (a 6 $\sigma$ detection).

In total, 71 MIR sources are detected at 5 $\sigma$ over the three cluster fields. Most of them can be identified with (often rather faint) visual counterparts. While they rarely correspond to the optical arc(let)s, there are cases of impressive correlations between optical and MIR morphologies (see Figures 1, 2, and 3). On the basis of spectroscopic and photometric redshifts, and of redshift estimates from lensing inversion techniques, we find that almost all 15 $\mu$m sources are behind the cluster lens.

We estimate the number counts at 15 $\mu$m, after correcting for incompleteness (a non-uniform correction over the field, due to the variable lensing amplification and distortion; see Altieri et al. 1999 and Metcalfe et al. 1999). Our number counts are in good agreement with those derived in empty fields (the Lockman hole, Elbaz et al. 1999, and the Hubble Deep Field, Aussel et al. 1999). Moreover, the number counts in our deepest field – reaching deeper than any other survey – show no sign of flattening, being close to $-1.5 \pm 0.3$ down to 35 $\mu$Jy. Fitting such a steep slope requires strong evolution models.

Integrating the 15 $\mu$m number counts over the whole flux range (0.03–50 mJy) covered by ISOCAM surveys (including ours), we estimate the resolved background MIR light at 15 $\mu$m: $3.3 \pm 1.3 \times 10^{-9}$ W m$^{-2}$ sr$^{-1}$. This value is very close to the upper limit set by the gamma-CMBR photon-photon pair
production (Stanev & Franceschini 1998), and consistent with the predictions from the model of Tan et al. (1999).

4. Conclusions

We have detected a population of strong MIR emitters at high redshifts which cannot be fitted to the local IRAS counts with no evolution models. The nature of these faint MIR sources is still unclear. They could be dust-enshrouded AGN’s or dust-enshrouded starbursts, or both. Recently, Roche & Eales (1999) and Tan et al. (1999) have tried fitting the IR counts by invoking a population of starburst galaxies at high $z$ created by the numerous galaxy mergings predicted in a hierarchical clustering scenario. In order to elucidate this issue, we have recently performed high spatial resolution observations with ISAAC at the VLT for two of these sources, and submitted an XMM proposal for distinguishing the AGN’s by their strong X-ray emission. Observations have also been performed at the CFHT to help determine K-band morphology for several sources.

Counts of MIR sources allow us to estimate a MIR background which is slightly less than 50% of the I-band background. Extrapolating the MIR background to the far-IR, assuming typical galaxy spectral energy distributions, leads to the conclusion that the total cosmic IR background is actually larger than the optical background. Dust processing of stellar radiation is therefore much more important in distant galaxies than locally.

MIR surveys are therefore essential for tracing the evolution of galaxies at high redshifts. Great caution must be taken when trying to infer the global
star formation history of the Universe from UV luminosities, as these must be seriously affected by extinction.

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