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Gravitational lensing in the infrared: the faintest ISOCAM sources

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Abstract. We present some results from one of the deepest ISOCAM surveys at 7 and 15μm. The survey areas are centered on the positions of well-studied clusters of galaxies at intermediate redshifts. Galaxy clusters serve as natural telescopes, allowing us to detect background galaxies whose flux is amplified by the gravitational lensing effect. While most of the detected galaxies at 7 μm are cluster members, the clusters are almost transparent at 15 μm, where most of the detected sources are in the background. Our deep source counts at 15 μm constrain the population of IR galaxies at high redshifts. Model fitting of the Spectral Energy Distributions of the detected sources allow us to characterize their nature. Comparison of the source counts with available models indicates a strong evolution of the IR galaxy population from $z = 0$ to $z \sim 1$.

Key words. galaxies: clusters: general – galaxies: evolution – cosmology: gravitational lensing – infrared: galaxies

1. Introduction

Because of its high sensitivity, CAM (Cesarsky et al. 1996) was the most suited of the four ISO[1] instruments for cosmological studies. As a matter of fact, several high-redshift ($z \sim 1$) galaxies were detected at mid-infrared (MIR hereafter) wavelengths by ISOCAM (e.g. Elbaz et al. 1999). These IR detections are crucial for constraining models of galaxy evolution, which generally predict an increase of the star formation activity of galaxies with z, accompanied by substantial dust-re-processing of the stellar radiation in the IR (e.g. Franceschini et al. 2001).

Here we report results of one cosmological ISOCAM survey we conducted in three cluster fields. Taking advantage of the gravitational lensing amplification by the clus-

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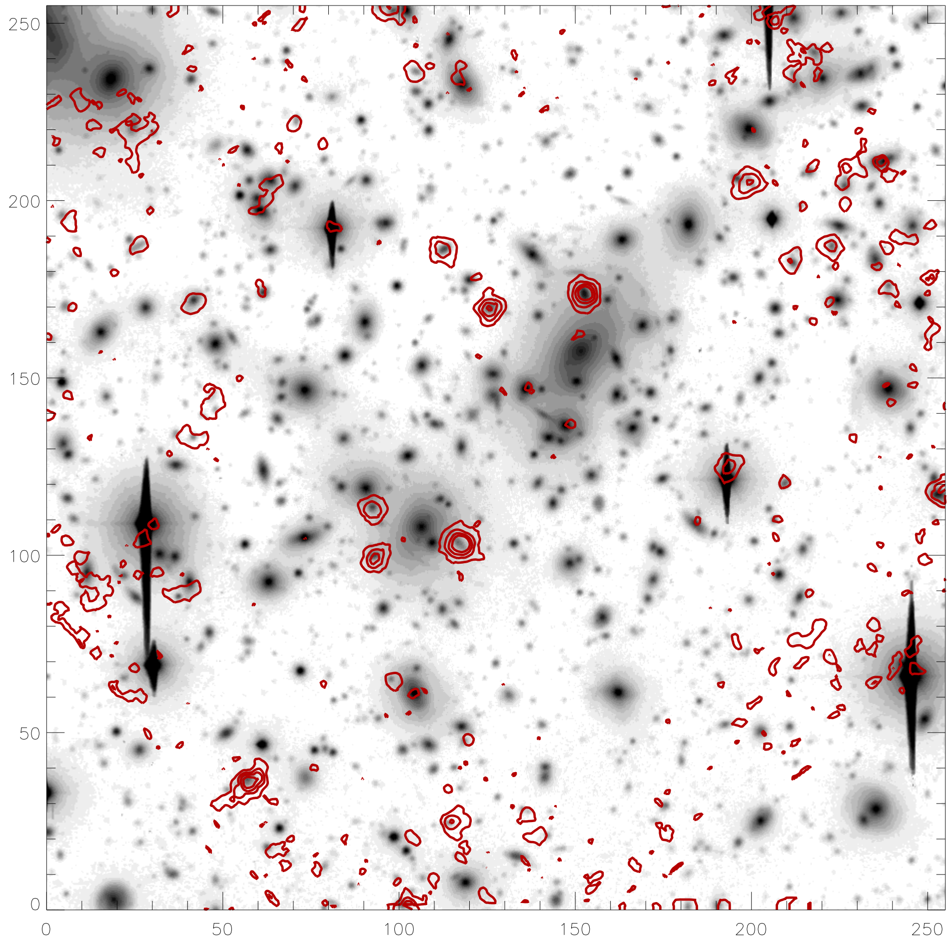

Fig. 1. ISOCAM 15 μm contours over a deep Palomar 5m I-band image of A2218. Note the ISOCAM detection of the giant arc at position (117,105). Units on both axes are in arcsec.

ter potential, the flux limit of our survey is the deepest ever at 15 μm. Part of the results given here have already been published in Altieri et al. (1999) and Metcalfe et al. (2000). A full description of our programme and its results will be given in Metcalfe et al. (2002).

2. Observations

In order to take advantage of the effects of gravitational lensing, it is mandatory to have a very accurate model of the lens itself. We therefore chose our targets among the best studied clusters where gravitational lensing has been detected. These clusters are ABCG370, ABCG2218, and ABCG2390, at $0.2 \leq z \leq 0.4$. We imaged these three clusters in two (wide) ISOCAM filters, LW2 and LW3, centered at about 7 and 15 μm, respectively, during ~ 40 hours of ISO guaranteed time. The observations were done with a pixel-field-of-view of $3''$, in the micro-rastering technique, allowing a good background subtraction, and good astrometric/positional results. We covered a total area of ~ 56 arcmin^2.

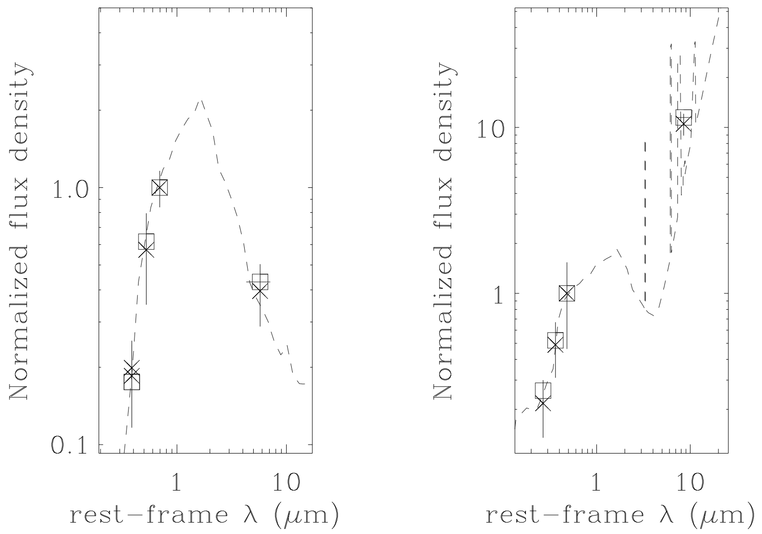

Fig. 2. The SEDs of two galaxies detected by ISOCAM. The wavelength scale is in the rest-frame of the galaxy. The flux density scale is normalized to the flux density in the I band. Crosses with error bars represent the observed data, the dotted line is the best-fit model from Silva et al. (1998), and the squares are the flux densities of the model computed at the central wavelengths and within the bandwidths of the observational filters. Left panel: A cluster member, at $z = 0.1641$ with a 3 Gyr old elliptical as best-fit model. Right panel: A background galaxy, $z = 0.68$ with a 3 Gyr late spiral as best-fit model.

A detailed description of our data reduction, source detection and photometry, error and completeness estimates, is given in Altieri et al. (1998).

3. Results

We achieve apparent 5 σ sensitivities of 80 μJy at 15 μm in the deepest field (ABCG2390), and 80 % completeness levels of 92, 167 and 293 μJy in the fields of ABCG2390, ABCG2218 and ABCG370, respectively. These are *apparent* fluxes and must be corrected for the amplification induced by gravitational lensing. The correction can be applied for the three cluster fields by adopting the very detailed lens models developed by Kneib et al. (1996) and Bezecourt et al. (1999). After applying the lensing correction, the faintest detected source has an *intrinsic* flux of 18 μJy. In total, over the three cluster fields, we detect 144 MIR sources; 70 of these are above the 80% completeness limit.

In order to better understand the nature of the detected sources, cross identification of the ISOCAM sources with optical and near-IR sources is needed. We have so far completed cross-identification of the ISOCAM sources in the field of ABCG2218 with the optical and near-IR catalogues of Le Borgne et al. (1992), and Smail et al. (2001). Most sources have visual counterparts; the 7 μm sources are generally associated with bright galaxies (and stars), while the 15 μm sources generally correspond to fainter I-band counterparts (see Figure 1). The 7 μm sources have magnitudes $B \leq 21$, while the 15 μm sources are generally fainter than this limit. The different magnitude distribution of 7 and 15 μm sources reflects their different redshift distributions. Based on the subset of counterparts for which we have (either photometric or spectroscopic) redshift estimates, we find that $\sim 90\%$ of the sources detected at 7 μm only, are cluster members, while $\sim 70\%$ of the sources detected also (or exclusively) at 15 μm, are in the cluster background, with redshifts $0.4 \leq z \leq 1.1$.

We fit the optical-to-MIR spectral energy distributions (SEDs, hereafter) of the ISOCAM sources with the models of Silva et al. (1998). These models include the effects of very small grains as well as polyciclic aromatic hydrocarbons, which are responsible for most of the MIR emission. Cluster galaxies detected by ISOCAM have SEDs typical of early-type galaxies. On the contrary, ISOCAM sources in the cluster background have SEDs typical of late-type galaxies, from young spirals with moderate star formation activity to moderate starburst galaxies like M82 (see Figure 2).

Using the background sources, and correcting for incompleteness and lensing effects, we estimate the number counts at 15 μm. Our number counts are in good agreement with those derived in empty fields (see e.g. Elbaz et al. 1999), and can be fitted by strong evolution models (Franceschini et al. 2001). According to the model of (Franceschini et al. 2001) the 15 μm galaxies detected out to $z \sim 1$ are normal galaxies observed during a dust-extinguished phase of intense star formation, probably triggered by galaxy-galaxy interactions. This is consistent with our finding that the ISOCAM background sources have SEDs typical of star-forming galaxies.

By integrating the 15 μm number counts over the whole flux range covered by ISOCAM surveys (including ours), we estimate that the resolved background MIR light at 15 μm is very close to the upper limit set by the gamma-CMBR photon-photon pair production (Stanev & Franceschini 1998). Extrapolating the MIR value to the far-IR, by assuming a moderate star-burst SED, we find that the ISOCAM galaxies could explain most (if not all) of the Cosmic IR Background (Puget et al. 1996). The planned Herschel mission could confirm the validity of the extrapolation by detecting and identifying the ISOCAM sources in the far-IR.

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