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Final Analysis of ELAIS 15 μm Fields

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Abstract. The Final Analysis of ELAIS 15 μm observations carried out with the ISOCAM instrument onboard the ISO satellite is described. The production, properties and scientific potential of the resulting catalogue are discussed, including the latest enhancements to the employed data reduction technique and the substantial improvements of the results with respect to the Preliminary Analysis. The catalogue includes about 2000 sources in the 0.5 – 100 mJy flux range over an area of about 10 deg^2 and is thus the largest non-serendipitous extragalactic source catalogue obtained to date from ISO data.

Key words. infrared: galaxies – galaxies: formation, evolution, active, starburst – cosmology: observations – methods: data analysis – catalogues.

1. Introduction

The IRAS mission (Neugebauer et al. 1984; Soifer et al. 1987) was extremely successful in characterizing for the first time the global properties of the mid and far infrared sky, leading to sensational discoveries such as Luminous, Ultraluminous and Hyperluminous Infrared Galaxies (LIRGs, ULIRG and HLIRGs, respectively), a substantial population of evolving starburts and to the detection of large-scale structure in galaxy distribution (Saunders et al. 1991).

Unfortunately, the IRAS view was typically limited to the very local Universe ($z < 0.2$), thus hampering statistical studies of infrared-luminous galaxies at all redshifts. In particular only about 1 000 galaxies were detected detected all over the sky in IRAS 12 μm band.

Although conceived as an observatory-type mission, the Infrared Space Observatory (ISO, Kessler et al. 1996) was in many ways the natural successor to IRAS, bringing a gain of a factor ~ 1000 in sensitivity and ~ 10 in angular resolution. A substantail amount of ISO observing time was therefore devoted to field surveys aimed at detecting faint infrared galaxies down to cosmological distances. Such surveys were complementary in exploring the depth-area plane, allowing a systematic investigation of the sky down to so far unattainable flux densities at both mid and far infrared wavelengths.

In this context, the European Large Area ISO Survey (ELAIS, Oliver et al. 2000; Rowan-Robinson et al. 2003) was the most ambitious non-serendipitous survey and the largest Open Time project carried out with ISO, aimed at bridging the flux gap between IRAS all-sky survey and ISO deeper surveys mapping areas of about 10 deg^2 at 15 and 90 μm and smaller areas at 7 and 170 μm with the ISOCAM (Cesarsky et al. 1996) and ISOPHOT (Lemke et al. 1996) cameras. Thanks to an extensive multi-wavelength coverage, the ELAIS fields have now arguably become the best studied sky areas of their size, and natural targets of on-going or planned large-area surveys with the most powerful ground and space-based facilities. Further details on ELAIS multi-wavelength observations and catalogues are presented in Rowan-Robinson et al. (2003).

Besides, after the loss of the WIRE satellite and notwithstanding the deluge of data at several infrared wavelengths soon to come from SIRTF and later from SOFIA and Herschel, ISO observations will remain a most precious infrared database for many years to come. In particular, waiting for the advent of JWST and as far as large sky areas are concerned, ELAIS 15 μm data will provide an unrivalled sample. Thus the need of reducing such data with the uttermost care and provide the community with an agreed-upon legacy from the ISO mission.

This paper briefly describes the production and properties of the catalogue resulting from the Final Analysis of ELAIS 15 μm fields. Data reduction was carried out with the LARI Method (Lari et al. 2001, 2003a; Vaccari et al. 2003a), a technique specifically developed for the detection of faint sources in ISOCAM and ISOPHOT raster observations, which is here variously improved.

2. The ELAIS 15 μm Dataset

The ELAIS 15 μm main dataset is made up of 28 rasters (ISO basic imaging observations), each covering an area of about $40' \times 40'$, divided into 4 fields, one (S1) in the southern emisphere and three (N1, N2 and N3) in the northern one. Small superpositions at the boundaries and a limited degree of redundancy on portions of the fields give a total covered area of about 10 deg^2.

The fields were selected on the basis of their high Ecliptic latitude ($|\beta| > 40°$, to reduce the impact of Zodiacal dust emission), low cirrus emission ($I_{100\mu m} <$ 1.5 MJy/sr) and absence of any bright ($S_{12\mu m} > 0.6$ Jy) IRAS 12 μm source. In Figure 1 the location on the sky of the survey fields is shown, overlaid on cirrus maps (COBE normalized IRAS maps of Schlegel et al. (1998)). Nearby IRAS sources with 12 μm fluxes brighter than 0.6 Jy are also plotted.

ELAIS 15 μm observations were carried out operating the ISOCAM instrument in raster mode using the LW3 filter. In this observing mode, the ISOCAM 32×32 pixel LW detector was stepped across the sky in a grid pattern, with about half detector width steps in one direction and the whole detector width steps in the other. Thus, reliability was improved as each sky position (apart from those at the boundaries of the raster region) were observed twice in successive pointings and overheads were reduced because each raster covered a relatively large area ($\sim 40' \times 40'$). At each raster pointing (i.e. grid position) the detector was read out several (typically 10) times, to increase the redundancy in order to be able to identify cosmic rays impacts and distinguish their severe effects on the electronics from real sources. Furtermore, on the raster first pointing, 80 readouts were actually carried out to allow the detector to approach stabilization. Table 1 describes the observation parameters for the LW3 observations.

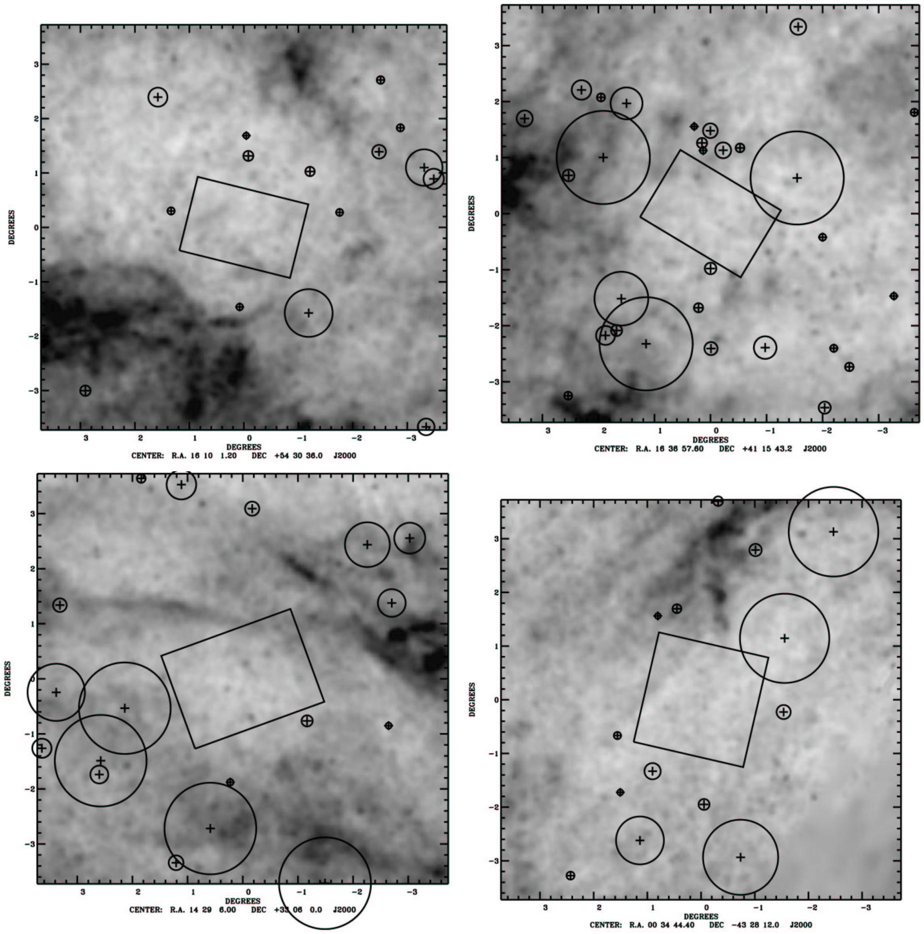

Fig. 1. Sky Locations of ELAIS 15 μm Fields. From top left to bottom right: N1, N2, N3 and S1 areas. Greyscales indicate COBE normalized IRAS 100 μm intensity maps from Schlegel et al. (1998). IRAS sources with 12 μm fluxes brighter than 0.6 Jy are also drawn as circles with radii proportional to their fluxes

3. Data Reduction

Reduction of data obtained with ISO instrumentation has always proved very difficult for a number of reasons. As far as ISOCAM observations carried out using its Long Wavelength (LW) detector are concerned, the two most important instrumental phenomena one has to deal with are the qualitatively very different effects produced on the detector's electronics by the frequent and severe cosmic ray impacts, which have long been known and referred to as *glitches*, and its sizable transient behaviours after changes in the incident photon flux, which we will hereafter simply refer to as *transients*. In both cases, the cryogenic operational temperatures of the detector caused it to very slowly respond after these events. Lack of an accurate modeling of these effects can thus lead to spurious detections or errors in flux determination.

Roughly speaking, glitches can be divided into three categories according to the way they shape the detector's output

Table 1. ELAIS CAM LW3 Observation Parameters

Parameter	Value
Band λ_{eff}	14.3 μm
Band FWHM Range	12.0–18.0 μm
Detector gain	$2\star$
Integration time	2 s
# of exp.s per pointing	10
# of stabilization exp.s	80
Pixel field of view	$6''$
# of pixels	32×32
# of hor. and ver. steps	28 , 14
# of rasters	28
Hor. and vert. step sizes	$90''$, $180''$
Total area covered	10.18 deg^2

$\star$ Except in raster N2_R_A where gain was 1

signal, their decay time and influence on the pixel responsivity: glitches belonging to these different classes are respectively dubbed *common glitches*, *faders* and *dippers*. Slow decreases of the signal following cosmic ray impacts are called faders, while prominent reductions of the pixel responsivity very slowly recovering afterwards are called dippers. These two effects are believed to be associated with proton or α particle impacts on the detector, and have a fairly long lasting impact on pixel responsivities. Conversely, the much more frequent impacts of cosmic ray electrons produce common glitches characterized by a relatively fast decay time, lasting only a few readouts. Therefore, the number of frames affected by a single fader or dipper is much higher than in the case of a common glitch, the pixel responsivity taking from tens to hundreds of seconds to recover completely. However, common glitches are much more frequent than faders and dippers and, may all the same hamper the quality of data reduction. Thus, all kinds of glitches, if not correctly removed, can lead to spurious detections (unreliability) or loss of genuine sources (incompleteness). On the other hand, transients all follow the same pattern, due to the fact that they arise from the non negligible time it takes for the output signal to reach the stabilization value after a change in the incident photon flux has taken place. The measured signal is thus always lower than the true one. Failing to model this time effect in data reduction can lead to a systematic underestimation of source fluxes. For these reasons, the data cleaning and modeling is an extremely delicate process requiring great care in order to produce highly reliable sky maps and source lists.

While it was variously demonstrated that it is possible, at least to a certain extent, to satisfactorily describe the detector's behaviour adopting some physical model, the large number of readouts involved in raster observations and the peculiar nature and strength of noise patterns also require efficient and robust algorithms to be developed so as to make the actual data reduction undertaking feasible in a nearly-automatic way.

A number of data reduction methods has thus been developed and tested, mostly on deep fields (e.g. the PRETI method by Starck et al. (1999) and the Triple Beam Switch method by Désert et al. (1999)). Unfortunately, such methods proved useless on shallower fields, leading to a high number of false detections and severe incompleteness. Besides, these methods suffered from the lack of an efficient way to interactively check the quality of the data reduction when needed.

The data reduction described in this paper was carried out using the LARI method (Lari et al. 2001, 2003a; Vaccari et al. 2003a), a very powerful technique developed by C. Lari to overcome these difficulties and provide a robust fully-interactive technique for the reduction and analysis of ISOCAM and ISOPHOT data, particularly suited for the detection of faint sources and thus for the full exploitation of their scientific potential. The method was variously refined, and substantially better results are now obtained, with respect to the technique used by Lari et al. (2001) for the reduction of the S1 field only, so that a thorough rereduction of all ELAIS fields seemed appropriate and was thus carried out.

3.1. The LARI Method

The LARI method describes the sequence of readouts, or time history, of each pixel of ISOCAM LW detector in terms of a mathematical model for the charge release towards the contacts. Such a model is based on the assumption of the existence, in each pixel, of two charge reservoirs, a short-lived one Q_b (*breve*) and a long-lived one Q_l (*lunga*), evolving independently with a different time constant and fed by both the photon flux and the cosmic rays. The signal as a function of time is processed independently for each pixel, a fitting procedure modeling transients attributable to changes in incident flux and the features on both short and long time scales produced by cosmic ray impacts on the time history. Iteration of the fitting procedure is interrupted when either a satisfactory (typically 0.2 ADU/gain/s) data-model rms deviation is achieved or the maximum number of allowed iterations is reached. After running the automatic fitting procedure, extensive interactive analysis of critical portions of the time history is carried out to visually check the goodness of the obtained results. After completion of these checks, sky maps are produced and source extraction and related flux estimation are carried out on these, adopting a sophisticated technique to correct flux estimates for ISO-CAM severe mapping effects. The method cannot be described in any more detail here, but the interested reader is referred to Vaccari et al. (2003b).

4. Simulations

Due to the peculiar nature of the data reduction method we make use of, one would like to carefully test its performance on "ideal" data and sources. Besides, systematic effects on flux estimates related to the data reduction method can only be probed by these means. However, due to the corresponding strong peculiarities of our dataset, characterized by several noise features on different time scales, only real data can be taken as representative of instrumental behaviour. Therefore, the effects of additional sources must be somehow simulated on the top of real pixel time histories and data reduction must then be carried out exactly as done for real sources. Quite suitably, as already mentioned, based as it is on a mathematical model, the LARI method offers a straightforward way to model the additional signal produced on real time histories by such additional sources. On this basis, an extensive set of simulations was carried out (and reduced exactly as done with real data) to assess the effects on flux estimates and the overall performance of data reduction in a statistically meaningful way. Such simulations allowed to assess the completeness and astrometric/photometric accuracy of our catalogue.

5. Optical/NIR Identifications

Optical and NIR identifications of our sources were carried out on a wide variety of observational data (both taken from data archives and taken by collaborators) to distinguish between stellar and galaxy-like sources, independently assess the astrometric and photometric accuracy and accurately calibrate our photometry in an absolute way on the basis of predicted vs. measured MIR stellar fluexs. This allowed to obtain an absolute photometric calibration which is estimated to be correct within an amazing 1 %. More in general, together with available spectroscopy, this will allow studies of MIR-selected populations to be carried out on large samples (Gonzalez-Solares et al. 2003; La Franca et al. 2003).

6. The Catalogue

The ELAIS 15 μm Final Analysis catalogue contains about 2000 sources detected with a S/N greater than 5 in the four fields N1, N2, N3 and S1, totalling an area of about 10 deg^2. For each entry, the catalogue (which will shortly become available at `http://web.pd.astro.it/poe/elais`) reports astrometric and photometric information as well as a number of ancillary quantities and flags related to source "peculiarity". Such catalogue will make up the backbone of the "ELAIS Final Catalogue", summarizing the results from the several ELAIS multi-wavelength obserrvational campaigns carried out in the past few years (Rowan-Robinson et al. 2003).

7. Conclusions

A very powerful technique for ISOCAM/PHOT data reduction, the LARI method, was variously refined and applied to ELAIS 15 μm main fields. The method now allows a substantially more robust and quicker data reduction than originally presented in Lari et al. (2001). Its application, in its new form, to the four fields composing the dataset (including a re-reduction of S1 observations already presented in Lari et al. (2001)) has produced a catalogue of about 2000 sources, detected with a S/N ratio greater than 5 over a total area of 10.18 deg^2. Source fluxes span the 0.5 - 100 mJy range, filling the existing gap between the Deep ISOCAM Surveys and the faint end of IRAS All Sky Survey. The astrometric and photometric accuracy of our catalogue have been tested through accurate simulations performed at fluxes covering levels.

Forthcoming papers (Vaccari et al. 2003b; Lari et al. 2003b) will present further details of data reduction and catalogue production, along with extragalactic source counts obtained from the whole catalogue in the crucial uncovered flux range 0.5 – 100 mJy, dividing ISOCAM deep surveys and IRAS All Sky Survey.

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