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First ISOCAM images of the Milky Way *

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Abstract. ISOGAL is a 15 μm ISOCAM survey of $\sim$ 12 deg^2 in the Galactic Plane interior to $|\ell| = 45°$. In combination with IJK data from the near-infrared southern sky survey DENIS, the ISO images allow the first detailed study of stellar populations throughout the inner Galaxy. We present preliminary results from a test observation at $\ell = -45°$ with 6" pixels and completeness limit 8 mJy. Of the $\sim$ 3000 sources deg^{-2} detected, about half are KM giants, seen through extinction of up to A$_v$ $\sim$ 30, while most of the remainder are probably dusty young stars. Although away from bright IRAS regions, the field displays spectacular emission features, and, unexpectedly, a number of regions which are optically thick at 15 μm. The dark regions are presumably dense filaments with A$_v$ > 25.

Key words: The Galaxy: stellar content – Interstellar medium: general – Interstellar medium: dust, extinction – Infrared: galaxies – Infrared: stars

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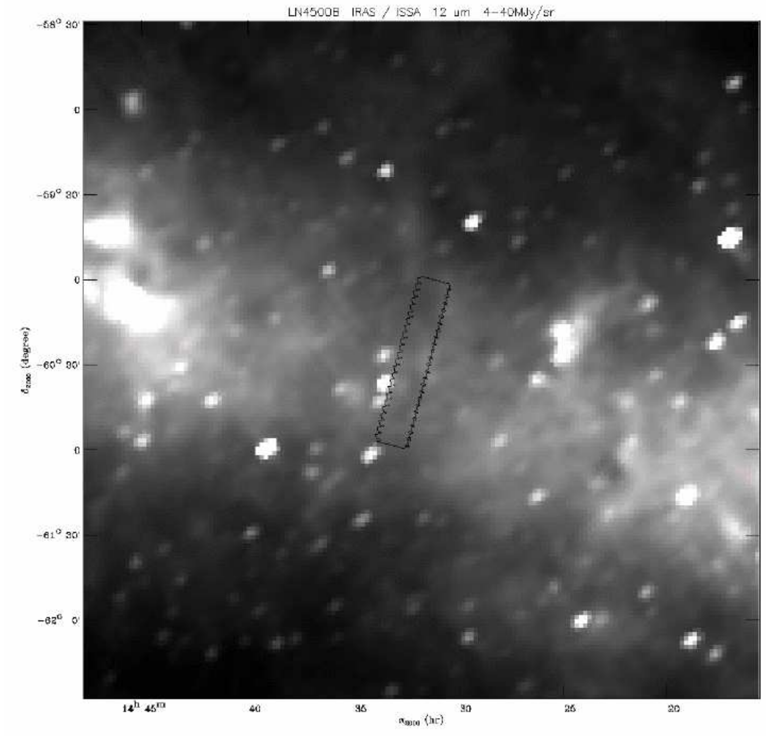
1. Introduction

In the wavelength range 3-20 μm ISOCAM, the camera of the *Infrared Space Observatory*, is able to detect point sources more than 100 times fainter than IRAS. Indeed the 1000 pixels covering about the area of a single IRAS detector, give access to major stellar populations at galactic scale. Interstellar extinction and intrinsic colors can be derived from the combination of mid-infrared data with ground-based near-infrared surveys. Dusty pre-main-sequence stars down to 1 M$_\odot$ will trace the formation of low mass stars several kpc from the Sun, while embedded OB stars and HII regions will be detected throughout the Galaxy, as well as supergiants, asymptotic giant branch (AGB) stars and Planetary Nebulae. Individual late-M giants, visible beyond the Galactic Center are expected to dominate the deep source counts, tracing the old disk population and thereby allowing determination of a reliable picture of the structure of the inner obscured Galaxy (central star cluster, bar, inner old disk, molecular ring, young disk and the spiral arms).

With these goals in mind, we have initiated a 15 μm ISOCAM survey (ISOGAL, Omont et al. 1994) of 12 deg^2 distributed along the inner Galactic disk. Our default camera parameters are a 6" pixel field-of-view and the LW3 ISOCAM filter (12-18 μm). The fields selected to optimise the range of studies outlined above are the following: $|b| < 0.5°$ and with $\delta\ell = 0.5°$, centered at $|\ell| = 2.75$, 4.25, 5.75, 7.25, 9.75, 12.25, 15.75, 19.25, 22.75, 26.25, 30.0 and 45.15°, and a central field with $|b| < 0.5°$ and $|\ell| < 1.5°$.



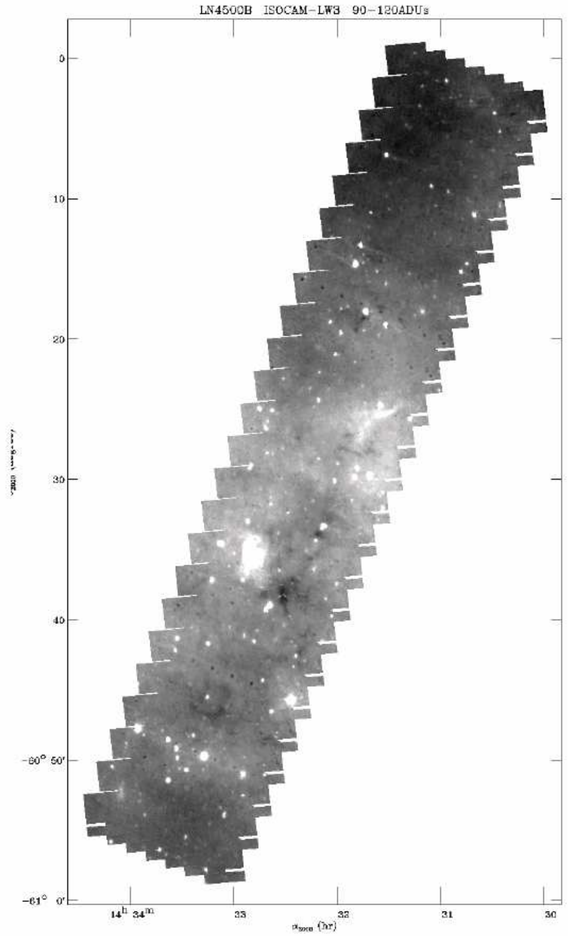


Fig. 1. Views of the field observed. a) 12μm finding chart (credit: IRAS project and IPAC). The limits of the ISO field are outlined. b) ISOCAM image at 15μm.

Because of the need to avoid strong sources potentially saturating the detectors, we devised rasters within these fields which avoid IRAS point sources stronger than 6 Jy at 12 μm. These sources were identified using the improved reduction of the Galactic plane IRAS data by Price (1994). Point sources and resolved compact sources detected in the ISOCAM data are being cross-identified with the IJK DENIS survey (Epchtein 1994, 1995, Copet 1996), which is currently also in progress.

In this paper we provide the results from the first ISOGAL field, observed with ISO in January 1996 as a part of commissioning of ISOCAM (Cesarsky et al. 1996). The complexity of the data reduction is such that we are presently limited to a preliminary analysis. Even so, the results already available illustrate the characteristics of the ISOGAL data and provide an indication of the scientific achievements that one can expect from this survey.

2. Observations

A 12 arcmin by 1° field, centered at l = -45.26°, b = 0.0° was imaged with a (l,b) raster of 7 by 24 pointings, allowing half an array overlap of the 6" pixel, so that each piece of sky is observed twice. 12 second exposures were obtained with the LW3 filter (12-18μm), with 0.28 second elementary integration time. End-of-integration minus reset, and 4 by 4 co-adding were performed on-board.

The data have undergone the following processing steps: data were extracted from the raw telemetry file, deglitched and linearly scaled with optimized offset and gain frames for the entire raster. Detector remanence ghosts of bright sources were then deleted from each pixel time series. The readout time series was sliced and mosaiced. The result is compared in Fig.1 to the IRAS Sky Survey Atlas at 12 μm. The rms fluctuation estimated from close to empty background positions is 2 mJy per pixel.

The main difficulties in point source extraction are: accurate deletion of glitches and ghosts; automatic detection of point source candidates against a much structured background; point source photometry from spatially undersampled data; allowance for the time- and signal-dependance of the pixel sensitivity when deriving photometry (Cesarsky et al. 1996). A catalogue has nevertheless been extracted through the following steps: low spatial frequency subtraction from the mosaiced image, allowing an easy detection of point-like spots; aperture photometry and theoretical PSF fitting in the mosaiced image at the previously determined candidate positions; aperture photometry at these positions in each of the (nominally 2) exposures; extrapolation of the time sequence of aperture photometry from individual readouts and elimination of candidates significantly more compact or more extended than the PSF, as well as of candidates in the close neighbourhood of bright extended sources. The consistency of the various flux derivations was then checked and the source list produced with flux, position, size, errors and quality flags. The flux error is presently estimated to be ±30%.

3. Stellar sources

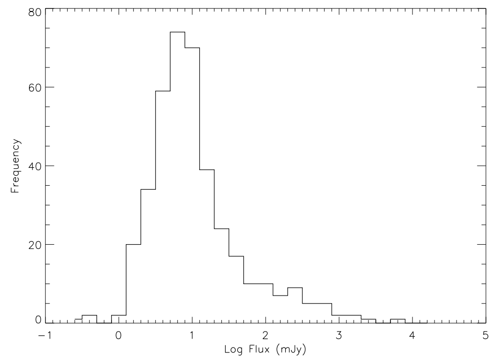


Fig. 2. Histogram of the 15 μm sources found in the $\ell \simeq$-45° field in 0.144 deg^2. The completeness limiting flux is approximately 8 mJy.

We restrict the analysis to a central area of 0.144 deg^2 in which each sky point was observed twice. This contains some 395 point sources, with a completeness limit $\sim$ 8 mJy ($m_{15} \sim 8.5$), as shown in Fig.2. In the same 0.144 deg^2 field, observed in 1996 with DENIS at ESO La Silla, down to completeness limits K=12.5, J=14.5 and I=16.5 we found 2650, 3000 and 4300 sources respectively.

About 180 of the 15 μm sources have a clear identification with a bright K source (K<11). Among them 160 have a J counterpart. Our preliminary ISOGAL astrometry still requires a matching radius of $\sim$ 8" for the cross-identifications with DENIS. This is not a problem for the strong DENIS sources, but it severely plagues the association with weaker sources.

The two-colour diagram (Fig.3) allows identification of the main astrophysical classes of the ISO sources, in spite of the large scatter from our preliminary photometry. The sources distributed along the reddening vector (Rieke and Lebovsky 1985) are predominantely red giants and supergiants, with very few earlier-type foreground stars and luminous OB stars. Fig.3 provides clear identification of stars with an intrinsic 15 μm excess. These are a mix of bright, dust-enshrouded, young stars, and dusty AGB stars.

The nature and number of the other reddest stars is of considerable interest. Within a 6" coincidence radius,

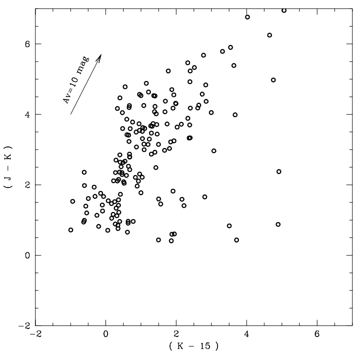


Fig. 3. Colour-colour diagram of the ISOGAL sources associated with bright DENIS sources (K≤11) for the l≃-45° field. For most of sources, the estimated error rms is ~0.2 mag for (J-K) and ~0.3 mag for (K-15).

52 ISOGAL sources are associated with DENIS sources with 11 < K < 12.5. This is twice the number of expected chance associations, assuming uniform distributions of sources. Of these 52, 27 are also matched at J. Most of these sources have colours typical of Ae, Be and T Tauri stars. In the remaining cases, and for a total of $\sim$ 160 ISOGAL sources, no K source is detected by DENIS. The actual number of 15 μm sources without real K association is thus almost half the total number (~1300/deg ^{2}). The expected numbers of detectable galaxies and asteroids in our field are less than 1 and 5 respectively. Thus, the only plausible candidates for such a large number of cold sources are dusty young stars.

The observed density of such sources is in the range of the expected number of young sources in a giant molecular cloud (GMC) a few kpc away, inferred from the IRAS results in nearby clouds. For instance in the L1641 cloud in Orion (d ~500 pc), there are $\sim$ 80 IRAS 12 μm sources identified as young stars with a dust disk or cocoon, in a projected area ~400 pc^2 (Strom et al. 1989). Among these sources 35 are stronger than 0.8 Jy ($\sim$ 7/deg^2). Roughly scaling this estimate to the CO surface brightness towards our field (Bronfman et al. 1989), dominated by molecular concentrations around the tangent point at 5 kpc, we would expect an object density of ~1400/deg^2 brighter than 8 mJy at 15 μm. This is the order of magnitude detected by ISOGAL.

4. Diffuse emission and absorption at 15 μm

The ISOGAL fields deliberately avoid the brightest IRAS sources and bright star forming regions, as traced by far-infrared and radio continuum peaks, or warm CO clouds, in order to avoid detector saturation and the extreme confusion that would result between highly contrasted star forming region and back and foreground populations. Lower luminosity regions however present a rich structure which can be studied with a relatively high level of detail.

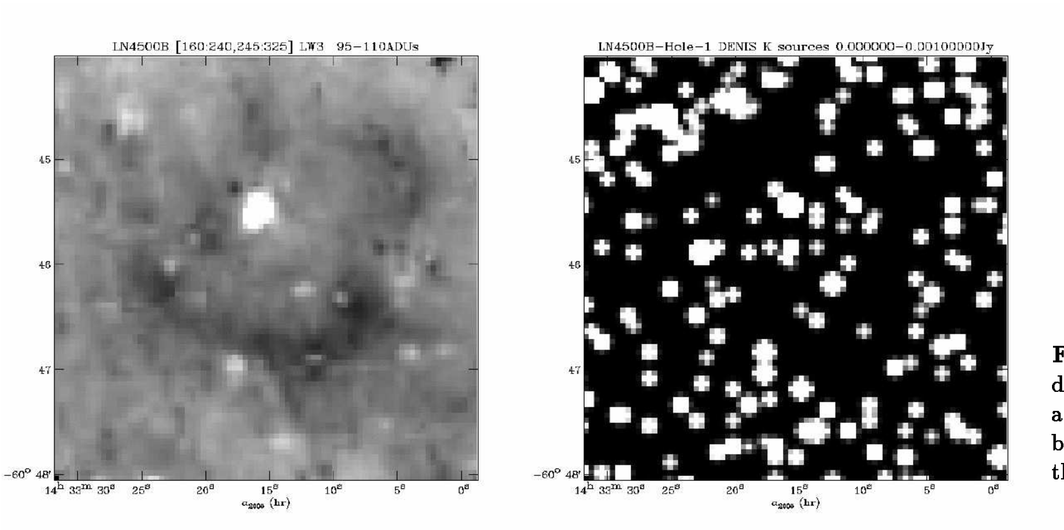


Fig. 5. Images of one of the dark areas detected by ISO. a) ISOCAM image at 15 μm. b) Image synthetized from the DENIS K catalog

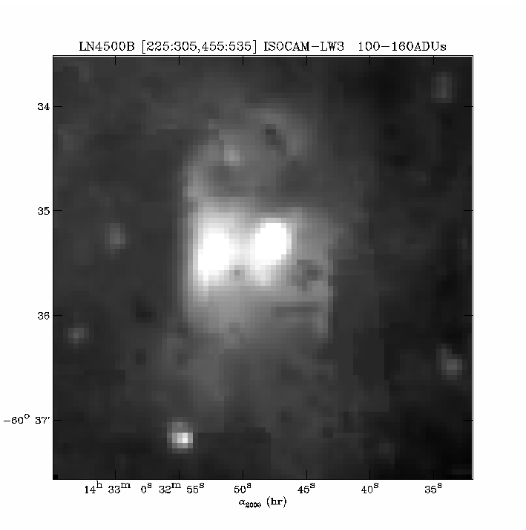


Fig. 4. ISOCAM 15 μm image of the brightest star forming region in the field.

For instance the brightest extended source in the field, that barely shows up in the IRAS plate, and is not detectable in optical plates, most likely corresponds to a moderately active star forming region associated to the concentration of molecular clouds at the tangent point, 5 to 6 kpc away from the Sun. The extent (roughly one arcmin) and infrared luminosity inferred from the image shown in Fig.4 ($\sim 3\,10^5$ $L_\odot$) make it comparable to the Orion Nebula, 10 times further away.

ISOGAL images present numerous dark features, which are likely due to absorption. The example shown in Fig.5 from the same field presents a convincing correlation with a depletion in 2 μm source counts. If 5 kpc away, such features would correspond to very dense filaments of width $\sim$0.2 pc, that absorb more than half of the background diffuse emission at 15$\,\mu$m, implying $A_v > 25$. These would be good candidates for precursors of star formation sites.

5. Conclusions

The first $\sim 1\%$ of the ISOGAL survey illustrates the considerable potential of ISOCAM for analyses of Galactic structure. ISOGAL, complemented by near-IR, radio and mm data, can provide detailed analyses of star formation rates, the distribution of both the ionised and the cold interstellar medium, the Galactic distribution of normal stars, and quantification of the number and distribution of both young stellar objects and AGB stars.

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References

Bronfman L., Alvarez H., Cohen R.S., Thaddeus P. 1989, ApJS 71, 481

Cesarsky, C. et al. 1996, A&A, this issue

Copet, E. 1996, Thèse de doctorat, Université de Paris 6

Epchtein, N., Omont, A., Burton, B. and Persi, P., 1994, eds, *Science with Near-Infrared Sky Surveys*, Kluwer Academic Publishers, Dordrecht.

Epchtein N. et al. 1995, Astrophys. Sp. Sci. 217, 3

Omont, A., Gilmore, G., Habing, H.L., Blommaert, J., Cesarsky, C., Epchtein, N., Guglielmo, F., Perault, M., Price, S., Robin, A. and Simon, G., 1994, ISO proposal.

Price, S. 1994, in *Science with Near-Infrared Sky Surveys*, op.cit., Kluwer Academic Publishers, Dordrecht.

Rieke G.H., Lebofsky M.J. 1985, ApJ 288, 618

Strom K.M., Newton G., Strom S.E., Seaman R.L., Carrasco L., Cruz-Gonzalez I., Serrano A. 1989, ApJS 71, 183

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