ISO DEEP FAR-INFRARED SURVEY IN THE LOCKMAN HOLE A SEARCH FOR OBSCURED OBJECTS AT HIGH REDSHIFT

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ABSTRACT

Two $44' \times 44'$ fields in the Lockman Hole were mapped at 95 and 175 μm using ISOPHOT. A simple program code combined with PIA works well to correct for the drift in the detector responsivity. The number density of 175 μm sources is 3 - 10 times higher than expected from the no-evolution model. The source counts at 95 and 175 μm are consistent with the cosmic infrared background.

Key words: Galaxies; evolution, Galaxies; formation, quasars; general, Galaxies; starburst, Cosmology; observations, Infrared; galaxies.

1. INTRODUCTION

As part of the Japan/UH cosmology program using the ISAS guaranteed time, 95 and 175 μm surveys were conducted in the Lockman Hole to search for obscured infrared galaxies at high redshift. The first results and preliminary discussion were presented by Kawara et al. (1998). This paper presents observations, image processing, and discussion on the nature of far-infrared sources. Point source extraction from the maps and source counts will be presented in a forthcoming paper (Kawara et al. 1999).

2. OBSERVATIONS

We have carried out a deep far-infrared survey at 95 and 175 μm by using ISOPHOT (Lemke et al. 1996) which is an imaging photopolarimeter on board the Infrared Space Observatory (ISO; Kessler et al. 1996). Two fields named LHEX and LHNW, each extending approximately $44' \times 44'$, were selected in the "Lockman Hole", a region with the smallest HI column density in the sky (Lockman et al. 1986), to minimize confusion noise due to infrared cirrus. The combinations of the filters and the detector arrays which were used for the observations are given in Kawara et al. (1998).

Raster mapping was performed with the AOT PHT22 staring raster map mode using 35.4 hours, which were executed between revolutions 194 and 215 (May 28 and June 19, 1996). Each of the two fields is made up of four sub-fields having an approximately $22' \times 22'$ area each. The parameters used for raster mapping of a single sub-field and details of the read-out settings are given in Kawara et al. (1998).

3. DATA REDUCTION

The PHT Interactive Analysis (PIA) - Gabriel et al. (1997) - version 6.4 was used with the default settings to reduce the edited raw data created in November, 1996 via the off-line processing version 5.1 or 5.2. Maps of 95 μm created from the PIA's Astronomical Analysis Processing (AAP) are dominated by noise due to drift in the detector responsivity. The AAP created maps are thus cleaned by a median smooth routine developed by Kawara et al. (1998).[1] The photometric error introduced from this correction is 4% or better and no extended brightness structures recognized within a $22' \times 22'$ area are affected.

The flux calibration can be made using either the COBE background measurements or the IRAS point source fluxes. Note that the intensity of interplanetary dust emission varies little at such high ecliptic latitude ($\beta \sim 45°$) as the solar elongation changes. The fields contain only one IRAS source (F10507+5723). This is the brightest source detected in our survey and identified with a Sb galaxy UGC 06009 (Thuan & Sauvage 1992). The IRAS fluxes are 533 mJy at 60 μm and 1218 mJy at 100 μm (IRAS FSC). Its flux ratio f(100 μm)/f(60 μm) =

[1]This routine is now included in PIA and called "Median Filtering."

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2.29 is fitted to a combination of the infrared cirrus and starburst spectra given by Pearson & Rowan-Robinson (1996), if 76% of the 100 μm flux comes from the cirrus component. This predicts f(175 μm) = 1133 mJy from f(175 μm)/f(100 μm) = 0.93 which is comparable to that in the inner arm of a Sc galaxy M101 (Hippelein et al. 1996). The COBE based scaling yields 347 mJy at 95 μm and 451 mJy at 175 μm, implying that the COBE based scaling may underestimate point source fluxes by 3.5 at 95 μm and 2.5 at 175 μm. The origin of these differences is unclear. In the following discussion, the ISO fluxes are scaled based on the IRAS measurements.

4. DISCUSSION

There are numerous spots in the 95 and 175 μm maps presented by Kawara et al. (1998). Bright spots cannot be attributed to peaks of the infrared cirrus. The total HI column density N_H in our fields is approximately 6×10^{19} cm^{-2} (Jahoda et al. 1990). The correlation between N_H and the infrared cirrus brightness indicates $B_{cirrus}(95\mu m) = 0.41$ MJy sr^{-1}and $B_{cirrus}(175\mu m) = 0.81$ MJy sr^{-1}(Table 2 in Boulanger et al. 1996). Using the models by Gautier et al. (1992) with $\alpha = -2.9$ for the index of the spatial power spectrum of the infrared cirrus, $\sigma_{cirrus}(95\mu m) \sim 0.14$ mJy and $\sigma_{cirrus}(175\mu m) \sim 1.7$ mJy are obtained for one sigma cirrus confusion noise. The 3 σ flux levels reached in our survey are tentatively estimated to be $\sim 45 \pm 20$ mJy at 95 μm and $\sim 45 \pm 25$ mJy at 175 μm. Hence, a probability of having a cirrus peak brighter than the detection limits is so low that most of spots are likely to be galaxies.

In the two fields LHEX and LHNW, covering 1.1 square degrees in total, there are 36 and 45 sources brighter than 150 mJy at 95 and 175 μm, respectively. Out of 45 175 μm sources, 36 sources are within the area which was observed at both wavelengths. 31 of the 36 sources have the 95 μm counterparts within 40″ that were detected above the 3 σ flux level. The completeness down to 150 mJy is estimated to be almost 100%, because of the low probability of cirrus confusion and the high SNR (signal to noise ratios) detection (typical SNR $\sim$ 10). The cumulative counts down to 150 mJy are thus 1.1×10^5 sources sr^{-1} at 95 μm and 1.3×10^5 sources sr^{-1} at 175 μm. Fig. 1 compares the 95 and 175 μm counts with the models developed by Guiderdoni et al. (1997, 1998). The number density of 175 μm sources brighter than 150 mJy are ten times higher than that expected from the no-evolution model. The counts both at 95 and 175 μm counts are consistent with the models containing a strongly evolving component which is required to account for the cosmic infrared background found by Puget et al. (1996).

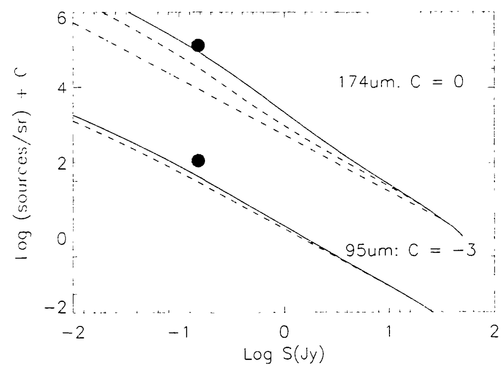

Figure 1. The cumulative number counts at 95 and 175 μm down to 150 mJy which are compared with the models by Guiderdoni et al. The no-evolution model is plotted with the dash-dot line, and scenarios E and A with the solid and dash lines, respectively.

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