A STUDY OF THE SPATIAL FLUCTUATIONS OF FIR BRIGHTNESS IN THE LOCKMAN HOLE

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ABSTRACT

Two 44×44 arcmin^2 fields in the Lockman Hole were surveyed at 95 and 175 μm using ISOPHOT as a part of Japan/UH cosmology program using the ISAS guaranteed time (Kawara et al. 1998). In this paper we investigate the spatial characteristics of FIR brightness distribution in the Lockman Hole. We first calculated the angular correlation function of each 44×44 arcmin^2 field and then its Fourier transform (the angular power spectral density: PSD) over the spatial frequency range of $0.05 \sim 1$ arcmin^{-1}. The power law index of the 95 μm PSD is $-1 \sim 0$, unlike that of the IR cirrus: -3 (Gautier et al. 1992). We conclude that the fluctuation due to the IR cirrus is not dominant in the Lockman Hole. On the other hand, the power law index of the 175 μm PSD is about -2, and the IR cirrus may contribute at low spatial frequencies. However, the faint galaxy fluctuation must contribute significantly as proposed by Guiderdoni et al. (1997).

Key words: IR cirrus; galaxy evolution; diffuse radiation.

1. INTRODUCTION

The diffuse sky emission in the far-infrared (FIR) is dominated by emission from the interstellar dust. At high Galactic latitude, it is known as "IR cirrus", which has a complex spatial distribution (Low et al. 1984). The spatial structure of IR cirrus at 100 μm measured by IRAS was extensively studied by Gautier et al. (1992). From a Fourier analysis of the brightness distribution, the authors found a power spectral density (PSD) of the brightness fluctuation $P(f)$, written as

$$P(f) = P_0\left(\frac{f}{f_0}\right)^{\alpha} \tag{1}$$

where f is spatial frequency (inverse of the angular scale length d) and $\alpha \simeq -3$ below the spatial frequency corresponding to the IRAS beam size $d_{\rm beam}$ ($f_{\rm max} = d_{\rm beam}^{-1} \sim 0.25$ arcmin^{-1}). They also found a relation $P_0 \propto B_0^3$, where B_0 is the mean brightness of the IR cirrus in the sky area concerned. Assuming these power spectral characteristics are valid for higher spatial frequency and for all FIR wavelengths, Helou & Beichman (1990) predicted that the detectivity of 1m-class space FIR telescopes would be limited by the noise due to the fluctuation of the IR cirrus ("cirrus confusion noise") even at high Galactic latitude.

ISOPHOT (Lemke et al. 1996) on-board the Infrared Space Observatory ISO (Kessler et al. 1996) is capable to observe the IR cirrus at wavelengths longer than 100 μm, with a better spatial resolution than that of IRAS. Recently Herbstmeier et al. (1998) analyzed the spatial characteristics of four fields measured by ISOPHOT, and obtained the characteristics of the power spectra roughly consistent with the above power spectrum (Equation 1) for bright cirrus regions.

In this paper we investigate the spatial characteristics of FIR brightness distribution in the Lockman Hole, a region with a uniquely low HI column density (Lockman et al. 1986), and thus the IR cirrus contribution to the fluctuation is expected to be minimal among many FIR deep surveys executed using ISOPHOT. We expect that the detectivity of the ISOPHOT observations in the Lockman Hole is not limited by the cirrus confusion noise, but by the confusion noise by the faint, distant galaxies, as discussed by Helou & Beichman (1990). The fluctuation analysis of FIR brightness in the Lockman Hole can thus give unique information on the FIR galaxy counts of distant galaxies below its confusion limit.

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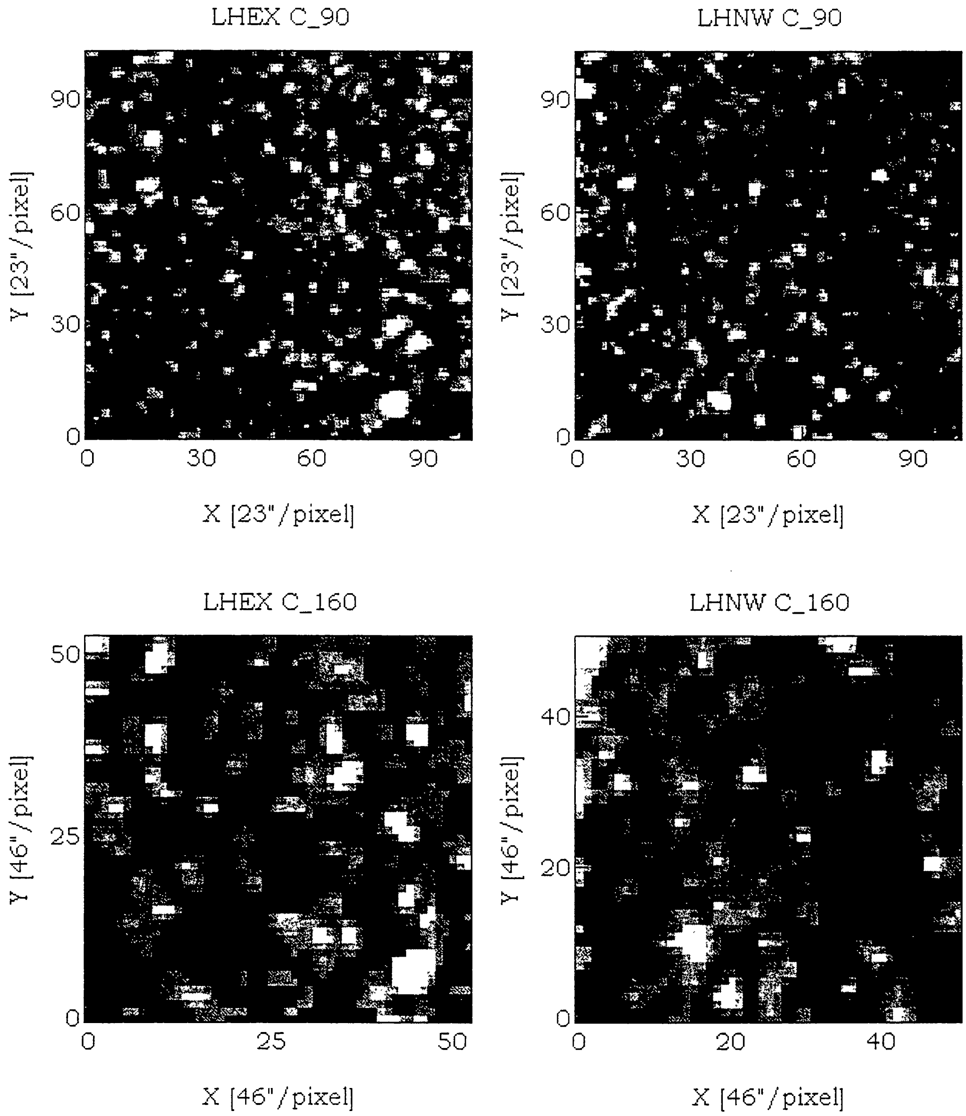

Figure 1. (top)95 μm images of LHEX (left) and LHNW (right), made of four 22×22 *arcmin*^{2} *sub-fields, and rebinned into* 103×103 *pixels (23 arcsec/pixel). Roughly the north is left and the west is top. (bottom) 175 μm images rebinned into* 53×53 *(LHEX) or* 51×51 *(LHNW) pixels (46 arcsec/pixel).*

2. OBSERVATIONS AND DATA PROCESSING

The FIR survey of the Lockman Hole, which was executed as a part of Japan/UH cosmology program using the ISAS guaranteed time, is described in Kawara et al. (1998) (see also Kawara et al. in these proceedings). Two 44×44 arcmin^2 fields named LHEX and LHNW were mapped with two filters: `C_90` (centered at 95 μm) and `C_160` (175 μm). Each of the two fields is made up of 4 sub-fields.

Each sub-field map was produced from the edited raw data by the PHT Interactive Analysis (PIA) version 7.1 or 7.2, and is hereafter called as an AAP (Astronomical Analysis Processing of PIA) map. Each AAP map is either 58×58 pixels (23 arcsec/pixel) for a 95 μm sub-field, or 31×31 pixels (46 arcsec/pixel) for a 175 μm sub-field. To correct the drift in the responsivity of the detectors, we applied the median filter smoothing (see Kawara et al. 1998 for details) onto the AAP data.

For flux calibration we used one of two FCS1 measurements, which was obtained just after the raster mapping of each sub-field. Based on this calibration, we found the mean brightness of both 95 μm and 175 μm images is consistent with the DIRBE/COBE brightness within 25 per cent. However, the IRAS point source (F10507+5723) flux obtained from the LHEX 95 μm image (see Figure 1) is about a factor of two smaller than the IRAS 100 μm flux.

On the other hand, the 175 μm flux of the IRAS source is consistent with the estimated flux assuming $f(175\mu m)/f(100\mu m) = 0.93$ (Kawara et al. 1998) within 20 per cent. Hence the adopted flux calibration is probably reliable within 25 per cent for 175 μm images while for 95 μm images the flux could be a factor of two larger if the ISO fluxes are scaled based on the IRAS flux.

Figure 1 shows the images of LHEX and LHNW used for the fluctuation analysis, each of which is the largest square area extracted from the mosaiced map made up from four sub-field AAP maps. Each image is rebinned into 103 × 103 pixels^2 (C_90), 53 × 53 pixels^2 (C_160 LHEX), or 51 × 51 pixels^2 (C_160 LHNW). The plate scale is 23 arcsec/pixel for 95 μm maps, and 46 arcsec/pixel for 175 μm maps.

3. POWER SPECTRA OF THE FIR IMAGES

For each image shown in Figure 1, the 2-dimensional angular correlation function $C(x, y)$ was calculated from the brightness distribution $B(x_0, y_0)$:

$$C(x,y) = \ < (B(x_0,y_0) - \bar{B})(B(x_0+x, y_0+y) - \bar{B}) > \quad (2)$$

where bracket $<>$ represents the average over the whole area in each image shown in Figure 1, and $\bar{B} = < B >$. Then, the coordinates were expressed in polar coordinates as $C(r, \theta)$, and the Fourier transforms in various radial directions were calculated (*i.e.* θ is fixed for each transform), giving one-dimensional power spectral densities (PSDs) of the map. Finally, the PSDs were averaged with respect to θ and are shown in Figure 2. The small error bars of PSDs represent the deviations with respect to θ, showing that the PSDs are almost independent of θ. The PSDs at high frequencies ($f \geq 0.8$ arcmin^{-1} for 95 μm, and $f \geq 0.4$ arcmin^{-1} for 175 μm) suffers from smoothing by the instrumental beam, hence they are not real spatial characteristics of the sky.

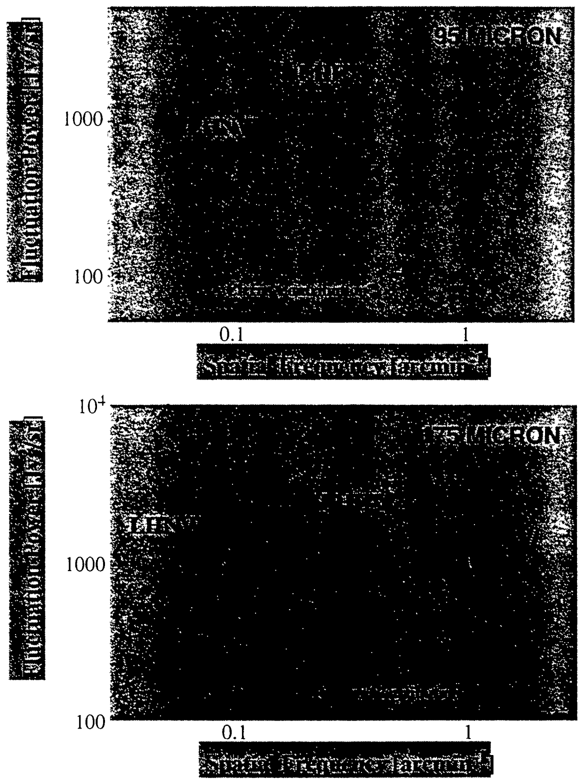

Figure 2. Fluctuation power spectrum densities (PSDs) of 95 μm (top) and 175 μm (bottom) images. Solid lines represent power spectra of LHEX, and dash-dotted lines represent power spectra of LHNW. The PSDs of LHEX are larger than those of LHNW due to the existence of an IRAS point source F10507+5723. Dotted line shows the estimated IR cirrus contributions based on the formula of Gautier et al. (1992).

4. DISCUSSION

In Figure 2 contributions by the IR cirrus fluctuation are also shown (dotted lines). This estimate is based on Equation 1 using the mean brightness B_0 of the IR cirrus, which is estimated from the atomic hydrogen column density towards the Lockman Hole of 6×10^{19} atoms cm^{-2}. Using the FIR emissivity of the cirrus dust given by Kawada et al. (1994), we obtain $B_0 = 0.32$ MJy/sr at 95 μm and $B_0 = 1.0$ MJy/sr at 175 μm.

At low spatial frequency, the 95 μm PSDs are nearly flat ($\alpha = -1 \sim 0$), and the value of the PSDs is comparable with those of the M04 and the Draco Nebula: $4 \sim 7 \times 10^3$ Jy^2/sr (Herbstmeier et al. 1998), even though the IR cirrus contribution to the PSD of the Lockman Hole should be much smaller than those to the PSDs of the above regions. Thus, as for the 95 μm images, we conclude that the IR cirrus fluctuation is not dominant at all spatial frequencies.

On the other hand, the 175 μm PSDs represent power-law with $\alpha \simeq -2$ at low frequency ($f \sim 0.1$ arcmin^{-1}), which may indicate the presence of IR cirrus contribution. However, as proposed by Guiderdoni et al. (1997), the contribution of faint galaxies located at $z = 0.5 \sim 2.5$ is probably important. As shown in Kawara et al. (1998), the cumulative counts of detected point sources at 175 μm down to 150 mJy are much higher than those expected from the no-evolution model, indicating the existence of an additional population, such as the ultraluminous infrared galaxies (scenario E of Guiderdoni et al. 1998). Such an evolutional scenario predicts the 175 μm PSD of $\simeq 10^3$ Jy^2/sr (Guiderdoni et al. 1997), which is comparable with the observed PSD at low frequencies. Further detailed study based on such a model of the FIR galaxy counts, however, requires the knowledge of point spread functions of the ISOPHOT detectors up to angular length $d \sim 10$ arcmin, and is still ongoing.

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