Estimation of the Confusion Limit for *SPICA*

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ABSTRACT

Since the most fundamental limit to detect very distant objects is the source confusion, the estimation of the source confusion limit of *SPICA* is very important to decide the observational strategy. We estimated the confusion limit of *SPICA* from 5 to 200 μm. For the mid- and far-IR (MIR and FIR) galaxy counts, we used an updated version of the empirical galaxy number count model of Takeuchi et al. (2001). At 5 μm, we used a semi-analytic galaxy evolution model "νGC" to construct the galaxy number counts. Based on his, confusion limits for *SPICA* were estimated by the analytic formulation that can deal with angular clustering of the galaxies (Takeuchi & Ishii 2004).

1. INTRODUCTION

Despite of the fundamental importance of the IR, it is the wavelength at which astronomers are still suffering a poor spatial resolution determined by diffraction. This is because IR telescopes should be operated at a very high altitude or in space, since the IR photons cannot penetrate the Earth atmosphere. The diameter of the telescopes is, then, inevitably limited by the size of balloons or rockets. This makes the IR to be one of the final frontiers in astronomical observations. The Space Infrared Telescope for Cosmology and Astrophysics (*SPICA*) is a part of the JAXA future science program, in collaboration with ESA. The wavelength coverage of *SPICA* will be $\lambda = 5$–210 μm. The advent of *SPICA* will provide a unique opportunity to explore the ultra high-z Universe at the IR with a high photometric sensitivity and unprecedentedly high angular resolution. It is, then, important to estimate the source confusion limit which determines the fundamental detection limit of a telescope. The confusion limit is determined by the sky surface density and clustering property of the sources (Takeuchi & Ishii 2004, hereafter T04, and references therein). In this work, we estimate the confusion limit of *SPICA* by the formulae developed by T04, which can include the effect of inhomogeneous distribution of the sources and angular clustering. All the details will be shown in our main paper (Takeuchi et al. 2013, in preparation).

2. INFRARED NUMBER COUNTS AND CONFUSION LIMITS

We use the theoretical formulae developed by T04 to estimate the confusion limit of *SPICA*. The advantage of their formulae is that we can include the effect of the angular source clustering. Details are found in T04 and we do not show the equations here. However, we stress that the redshift information of IR galaxies is not necessary to calculate the confusion limits. Actually, only the fit to the differential counts determines the confusion limit estimation. Since we do not know the counts deeper than the detection limits of current surveys, we need a model counts going down to very faint flux densities at all the wavelengths considered. We explain the adopted count models in this work.

2.1. MIR–FIR–Millimeter Counts

Takeuchi et al. (2001) have constructed an empirical IR galaxy count model to reproduce the observed counts and the CIB spectrum. Hence, we just tuned this model to successfully reproduce the MIR–FIR galaxy number counts and the CIB, especially at the latest FIR measurement presented by Matsuura et al. (2011). The counts are shown in Figure 1.

2.2. NIR Counts

Since the IR galaxy model of Takeuchi et al. (2001) does not include the stellar emission component, we need to deal with the counts at the NIR with a different model, since even at the rest 4.5 μm, we observe the redshifted stellar radiation of distant galaxies rather than dust emission. Nagashima et al. (2005) constructed "the Numerical Galaxy Catalog (νGC)", based on a semianalytic model of galaxy formation. Their strong feedback (SFB) model is in much better agreement with near-infrared (K'-band) faint galaxy number counts and redshift distribution than the WFB one (see their Figure 19). Since this is suitable for our purpose, we mainly used the SFB model.

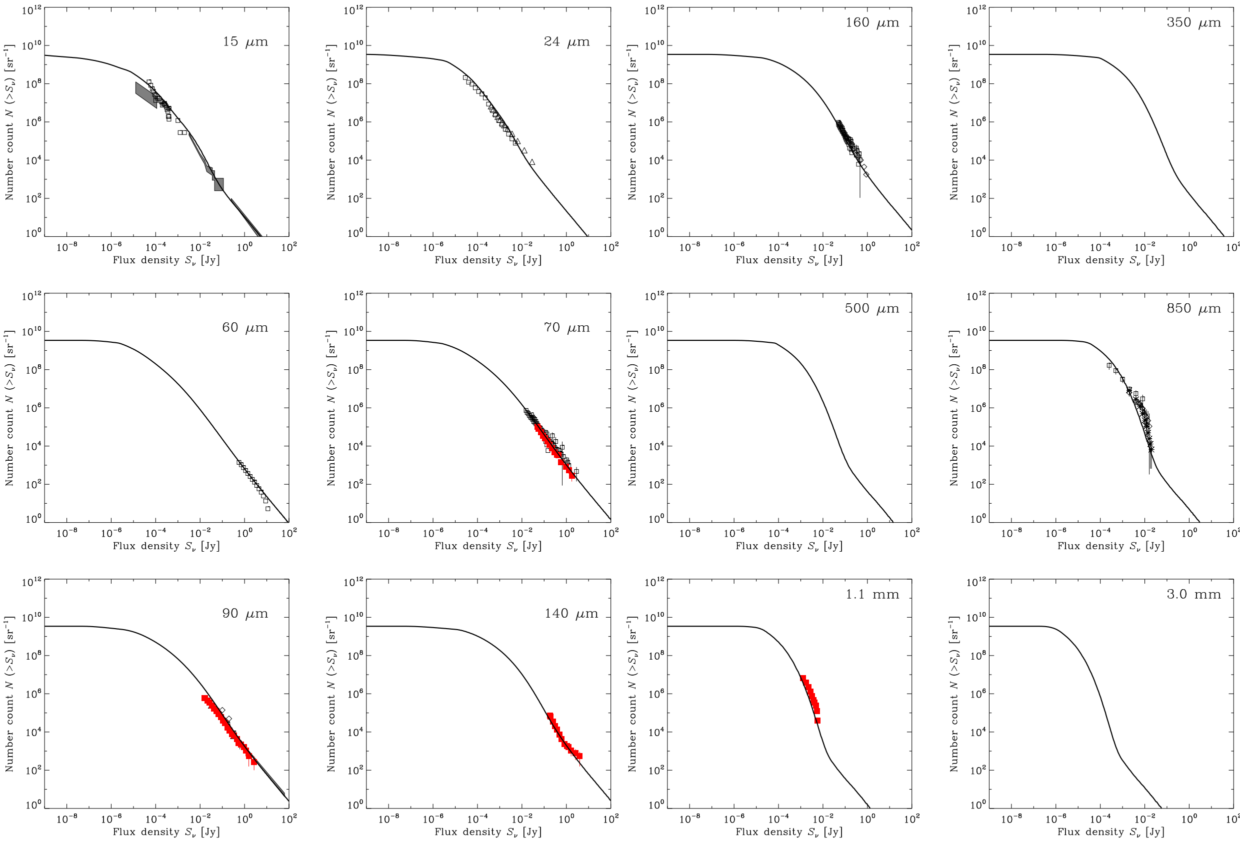

Figure 1. The model number counts at the IR–submm wavelengths, with various observations. The ADF-S data are indicated by filled squares (IR: Shirahata et al. 2009; submm: Hatsukade et al. 2011).

2.3. Clustering Model of IR Galaxies

Since the redshifts of galaxies we consider here will be very high, the clustering is diluted by superposition along the line of sight (e.g. Peebles 1980). We examined the clustering effect on the result, and found that it is really negligible for ultra high-z galaxies expected to be observed by *SPICA*. Then we do not discuss it here (see Takeuchi et al. 2013, in preparation).

2.4. Settings for *SPICA*

We adopt a simple assumption for the optics of *SPICA* in this work. We calculated the cases with the diameter $\phi_{\rm mirror} = 2.9, 3.1, 3.3$, and 3.5 m. The optics is assumed to be axisymmetric and free from abberation. The main mirror is occulted by the second mirror. This effect, as well as the occultation by spiders of the second mirror, is handled simply by assuming the occultation fraction $f_{\rm occ}$. A pure Airy beam corresponding to the effective area of the main mirror, i.e., reduced by the occultation by the second mirror, is assumed. The fraction of $f_{\rm occ} = 0.1$ (goal) and 0.125 are calculated. In this case, the effective area of the telescope $A_{\rm eff}$ becomes

$$A_{\rm eff} = A_{\rm mirror}\,(1 - f_{\rm occ}) \ . \qquad (1)$$

3. RESULT AND DISCUSSION

We first show the case of $\phi = 3.5$ m in Figure 2. We show the results for the occultation fraction $f_{\rm occ} = 0.125$ and 0.1 in Figure 2. The confusion limit of *SPICA* at longer wavelengths ($\lambda = 150$–$200\,\mu$m) does not change so significantly, since the increase of the diffraction limit and decrease of the IR galaxy number counts roughly balance at these wavelengths. At wavelengths shorter than $\lambda = 150\,\mu$m, the confusion limit starts to decrease more steeply toward 50 μm. This is because the number counts become lower toward shorter wavelengths, because both diffraction and number counts decrease. Around 30 μm, there is a "shoulder" of the confusion. This is a complicated effect caused by the combination of the PAH features and upturn of the continuum of hot dust emission (see, e.g., T01). Then, the confusion limit decreases very rapidly toward 10 μm. For the SFB model of Nagashima et al. (2005), the confusion limit still decreases toward NIR.

Then, we show the *SPICA* confusion limits with $\phi = 2.9, 3.1, 3.3$, and 3.5 m in the right panel of Figure 3. The effect of the telescope aperture is the largest at $\lambda \simeq 12\,\mu$m, and rather large at 5 μm. At these wavelengths, the difference between the limit for $\phi = 2.9$ m and 3.5 m is a factor of five. In contrast, the difference is a factor of 1.5 or smaller at $\lambda \gtrsim 50\,\mu$m.

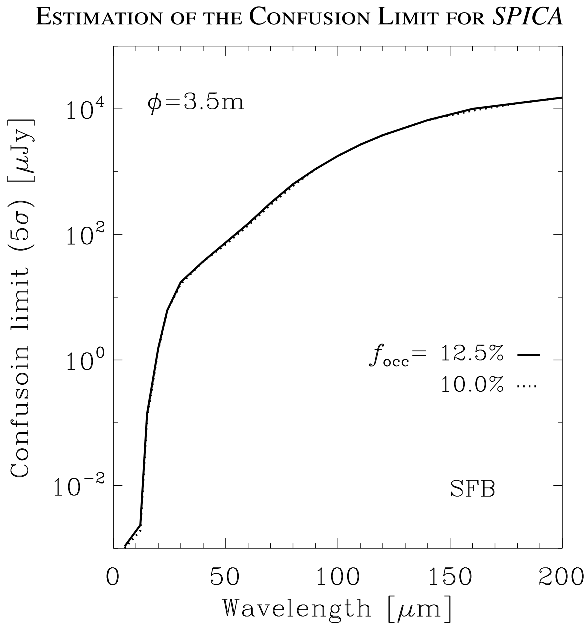

Figure 2. The confusion limit expected for *SPICA*. Results for the occultation fraction f_{occ} = 0.1 (goal: dotted line) and 0.125 (worst: solid line) are presented.

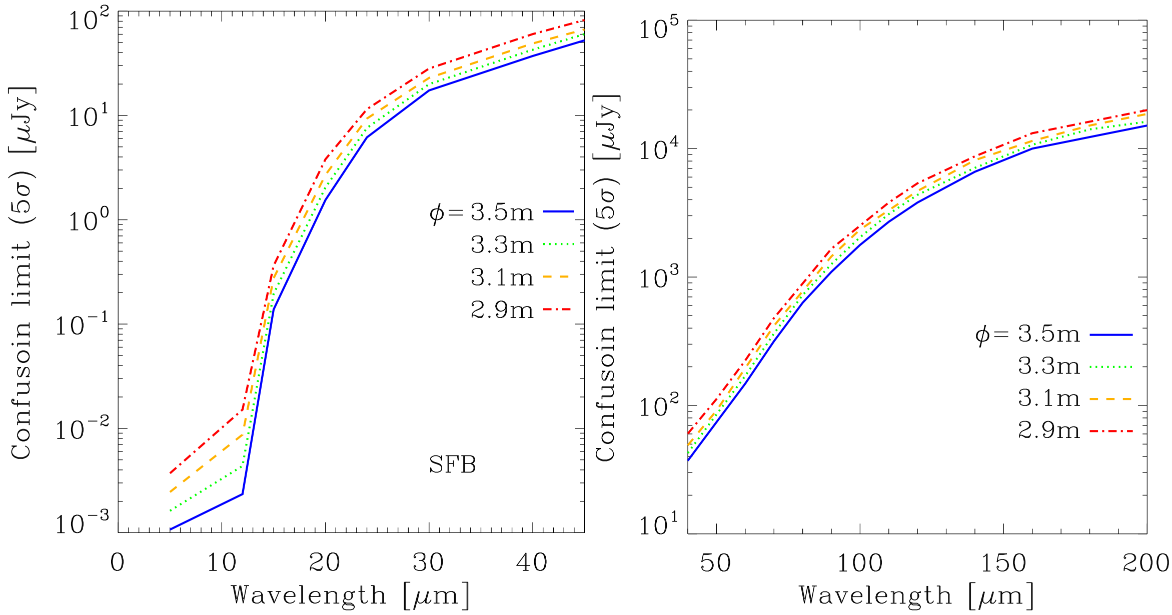

Figure 3. The *SPICA* confusion limits as a function of the mirror diameter. Left-hand panel shows the confusion limits at the MIR wavelengths, and right-hand panel shows the limits at the FIR wavelengths.

This means that the survey depth is more strongly affected by the final decision of the mirror diameter at the MIR than FIR. Since the detection limit of *SPICA* and confusion limit will be comparable, this is an important factor to design the telescope.

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