The *IRIS* Far-Infrared Galaxy Survey: Expected Number Count, Redshift, and Perspective

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Received 1998 July 15; accepted 1998 December 7

ABSTRACT. *Infrared Imaging Surveyor* (*IRIS*) is a satellite that will be launched in the beginning of 2003. One of the main purposes of the *IRIS* mission is an all-sky survey at far-infrared (FIR) wavelengths with a flux limit much deeper than that of *IRAS*. In order to examine the performance of the survey, we estimated the FIR galaxy counts in four (50, 70, 120, and 150 μm) bands based on some models. We adopted a multicomponent model that consists of cirrus and starburst components for galaxy spectra and the nearby FIR luminosity function derived from that of *IRAS* galaxies. We derived the number counts, redshift distributions, and infrared diffuse background radiation spectra for (1) no evolution, (2) pure luminosity evolution, and (3) pure density evolution with \( q_0 = 0.1 \) and 0.5. We found that a large number of galaxies (~ a few \( \times 10^6 \) in the whole sky) will be detected in this survey. With the aid of a vast number of detections, we will detect the effect of galaxy evolution and evaluate the amplitude of evolution at least in the nearby universe in the *IRIS* survey, though it will be still difficult to constrain which type of evolution takes place from the number count alone. We also studied the estimation of redshifts of detected galaxies by their infrared colors alone. Although significant contamination takes place among nearby faint galaxies and high-\( z \) ones, we found that rough estimation of galaxy redshift can be practicable by jointly using present and future optical surveys.

1. INTRODUCTION

One of the important problems in astrophysics is to trace back the galaxy evolution to the epoch at which galaxies formed. Recently Steidel and collaborators have pioneered and widely utilized a multicolor technique to select young galaxies by use of the Lyman-break dropout and have discovered a class of actively star-forming galaxies in the high-redshift (~ 3) universe (Steidel, Pettini, & Hamilton 1995; Steidel et al. 1996; Lowenthal et al. 1997). Some lens-magnified normal galaxies at high redshift also show rather high star formation rate (Ebbels et al. 1996; Yee et al. 1996; Franx et al. 1997; Trager et al. 1997). Furthermore, Ohta et al. (1996) and Omont et al. (1996) detected CO emission lines in the quasar BR 1202–0725 at redshift \( z = 4.69 \), which suggests the existence of a large amount of molecular gas and dust in the object. All of these results imply that strong star formation and synthesis of heavy elements have already occurred in such an early stage of the universe. The violent initial bursts of star formation must have produced a large amount of dust, so that the optical deep surveys of protogalaxies inevitably suffer from the bias induced by severe dust extinction. The dust particles reprocess the starlight, and the bulk of the bolometric luminosity of these young galaxies will be emitted at far-infrared (FIR)–submillimeter wavelengths.

The FIR emission from galaxies, especially from those are so faint that we are unable to resolve, produces the cosmic infrared background radiation (CIRB). Therefore the CIRB provides important information on the past star formation history of galaxies including the inaccessible sources (see, e.g., Bond, Carr, & Hogan 1986; Burigana et al. 1997). The recently reported detection of an isotropic diffuse light at \( \lambda \sim 100–200 \) μm has given this field new impetus (Puget et al. 1996; see also Fixsen et al. 1998; Hauser et al. 1998).

Meanwhile, galaxy evolution at low redshift (~ 1) also has crucial implications for cosmological studies. Lilly et al. (1996) found a rapid rise of the comoving luminosity density with redshift in ultraviolet (UV), optical, and near-IR wavelengths up to \( z \sim 1 \). Madau et al. (1996) interpreted this as an increase of comoving star formation rate (SFR) by a factor of 10 in the redshift interval \( z = 0–1 \). Subsequent observational evidences support this conclusion (see, e.g.,
Ellis et al. 1996; Tresse & Maddox 1998). Because FIR is the wavelength at which dust reradiates the optical–UV radiation from young stars, the steeply increasing SFR density is expected to propose a significant increment of FIR source counts, which may be related to the evolving population of star-forming galaxies discovered by Infrared Astronomical Satellite (IRAS) (Hacking & Houck 1987, hereafter HH87; Hacking, Condor, & Houck 1987; Saunders et al. 1990; Oliver, Rowan-Robinson, & Saunders 1992; Ashby et al. 1996).

For the understanding of FIR properties of actively star-forming galaxies, vast advances have been provided by the IRAS all-sky survey with a flux limit of ~1 Jy at 60 μm (for a review, see Soifer, Houck, & Neugebauer 1987a). Recently, quite important results have been reported from the Infrared Space Observatory (ISO; Kessler et al. 1996). Kawara et al. (1998, hereafter K98) have performed a deep survey at the Lockman Hole region with a flux limit of 45 mJy at 175 μm. They reported that the surface density of the sources brighter than 150 mJy at 175 μm approximately reproduced by the model of Guiderdoni et al. (1997). Although this survey is much deeper than the IRAS survey, it covers only a small solid angle of the sky (1600 arcmin^2), and much wider sky coverage is necessary in the next step to obtain a huge sample.

Infrared Imaging Surveyor (IRIS) is a next-generation infrared satellite, which will be launched in the beginning of 2003. A near-/mid-infrared camera (IRC) and a FIR scanner (FIS) are planned to be on board. One of the main purposes of the IRIS mission is a FIR all-sky survey deeper than IRAS surveys, and the FIR instrument represents a significant improvement over IRAS, so that much higher sensitivity is achieved (detection limit is ~20 mJy at 50 μm, ~30 mJy at 120 μm, and ~50 mJy at 150 μm).

In order to examine the performance of the survey, we estimated the FIR galaxy counts based on a simple model with various sets of cosmological parameters and evolution types. There have been a number of attempts to predict the source counts or the CIRB properties. The models of the source counts and CIRB generally fall into two categories (see, e.g., Eales & Edmunds 1997): one is tied closely to the nearby observational results but makes no attempts to incorporate detailed galaxy evolution models (see, e.g., Beichman & Helou 1991, hereafter BH91; Pearson & Rowan-Robinson 1996). These models are based on the local FIR luminosity function (LF) and the observational evidence of spectral energy distribution (SED) of galaxies in the FIR–submillimeter, with the assumptions of simple functional forms for the evolution. The other is based on the models constructed by detailed physical processes related to the evolution of galaxies (see, e.g., Franceschini et al. 1994; Guiderdoni et al. 1997). They tend to be very complex with large numbers of parameters, which give rise to a number of related problems that are poorly understood. Ellis (1997) names the former the “empirical approach” and the latter the “ab initio approach.” Even though each category of models has its own merits and demerits, we preferred the “empirical approach” because it is free of the parameters that are inherent in specific models and thus it is easy to understand the dependence on the cosmological and evolutionary parameters.

This paper is organized as follows. In §2, we describe the general formulation of our model. The parameters to execute our calculations and their consistency with previous survey results are examined in §3. We present the IRIS-based results and related discussions in §4, and our conclusions are summarized in §5.

2. MODEL DESCRIPTION

2.1. Spectral Energy Distribution of Galaxies

First we construct a model of galaxy SED from FIR to submillimeter wavelengths. The FIR emission originates from several dust components of different grain sizes and temperatures, reprocessing the interstellar radiation (Desert, Boulanger, & Puget 1990). Rowan-Robinson & Crawford (1989, hereafter RC89) showed that the FIR spectrum of IRAS galaxies is well fitted by the combination of two components: cool disk emission from interstellar dust (cirrus component) and hot starburst-induced emission from optically thick dust clouds heated by numbers of OB stars. Therefore, we consider a simple model of two components, cool cirrus and hot starbursts, as the components of our model SEDs of galaxies. We must note that we ignore the power-law component seen in AGN or QSO spectra because contribution of these power-law objects is expected to be negligible in number compared with the total number of infrared (IR) sources and because their luminosity contribution is also small in the FIR wavelength range, though it might be slightly higher in a very high-\(z\) universe (Pearson 1996).

We define the total IR luminosity \( L_{\text{IR}} \) as follows:

\[
L_{\text{IR}} = \int_{\nu_{\text{min}}}^{\nu_{\text{max}}} L(\nu)\,d\nu ,
\]

where \( L(\nu) \) is the monochromatic luminosity of a galaxy, and we put \( \nu_{\text{min}} = 3 \times 10^{11} \text{ Hz} \) (\( \lambda_{\text{max}} = 1 \text{ mm} \)) and \( \nu_{\text{max}} = 10^{14} \text{ Hz} \) (\( \lambda_{\text{min}} = 3 \text{ μm} \)).

Here we assume that the IR luminosity of a galaxy less than \( 10^{10} \, L_{\odot} \) is composed of the cirrus component \( L_{\text{c}}(\nu) \) only. For galaxies with \( L_{\text{IR}} > 10^{10} \, L_{\odot} \), the IR luminosity in excess of \( 10^{10} \, L_{\odot} \) (i.e., \( L_{\text{IR}} - 10^{10} \, L_{\odot} \)) is assumed to come
from the starburst component, denoted as $L_s(v)$. Thus, the composite SED of a galaxy is expressed as follows:

$$L(v) = \begin{cases} L_s(v) & \text{for } L_{IR} < 10^{10} L_\odot \\ L_c(v) + L_s(v) & \text{for } L_{IR} > 10^{10} L_\odot \end{cases}$$

(2)

where $L_c(v)$ and $L_s(v)$ are normalized as

$$L_c \equiv \int_{v_{\text{min}}}^{v_{\text{max}}} L_c(v) dv = \begin{cases} L_{IR} & \text{for } L_{IR} < 10^{10} L_\odot \\ 10^{10} L_\odot & \text{for } L_{IR} > 10^{10} L_\odot \end{cases}$$

(3)

and

$$\int_{v_{\text{min}}}^{v_{\text{max}}} L_s(v) dv = \begin{cases} 0 & \text{for } L_{IR} < 10^{10} L_\odot \\ L_{IR} - 10^{10} L_\odot & \text{for } L_{IR} > 10^{10} L_\odot \end{cases}$$

(4)

This model formulation is in line of BH91. So as to make our model work well, $L_{IR}$ should be uniquely defined from the value $L(v)$ at any frequency $v$. The SEDs depend only on $L_{IR}$ and do not vary with redshift as long as $L_{IR}$ of a galaxy is constant.

2.1.1. The Cirrus Component

The cirrus spectrum we used is based on the model of Désert et al. (1990). Their model spectrum is the sum of three subcomponents that are polycyclic aromatic hydrocarbons (PAHs; peaked at $\sim 10$ $\mu$m), very small grains (peaked at $\sim 60$ $\mu$m), and big grains (peaked at $\sim 100$ $\mu$m). No IR emission lines are included in our model. As mentioned above, galaxies with $L_{IR} < 10^{10} L_\odot$ have only the cirrus component in the present model. At each IR luminosity, the galaxy SED is scaled properly to yield the given $L_{IR}$ according to equation (3).

2.1.2. The Starburst Component

As for galaxies with $L_{IR} \gtrsim 10^{10} - 11 L_\odot$, the bulk of the IR luminosity is due to dust emission from an intense starburst in giant molecular clouds (see, e.g., Sanders & Mirabel 1996). Therefore, we assume that, for galaxies whose IR luminosities are brighter than $10^{10} L_\odot$, their IR luminosities in excess of $10^{10} L_\odot$ consist of starbursts with two different temperatures according to BH91. We give the starburst flux $L_s(v)$ as a superposition of thermal blackbody radiation spectrum of temperature $T_{\text{hot}}$ (we call it the “hot component” of starbursts) and that of $T_{\text{cool}}$ (we call it the “cool component” of starbursts), multiplied with dust emissivity. We adopted the wavelength-dependent dust emissivity $\propto \lambda^{-1} \propto v$ (RC89). By using the above temperatures, $L_s(v)$ is expressed by

$$L_s(v) = \alpha v B_\alpha(T_{\text{cool}}) + \beta v B_\beta(T_{\text{hot}}) ,$$

(5)

where $B_\alpha(T)$ is the Planck function with temperature $T$ and both $\alpha$ and $\beta$ are normalizing constants (RC89). The temperatures of the starburst components are given by

$$T_{\text{cool}} = 60 \left( \frac{L_s}{10^{11} L_\odot} \right)^{0.1} K ,$$

(6)

and

$$T_{\text{hot}} = 178 \left( \frac{L_s}{10^{11} L_\odot} \right)^{0.1} K$$

(7)

(BH91; see also Rieke & Lebofsky 1986; Helou 1986; Soifer et al. 1987b). The cool component gives a good representation of the larger (0.01–0.1 $\mu$m) grains modeled by Rowan-Robinson (1986), and the hot component gives an approximate representation of the very small grains postulated by Boulanger, Baud, & van Albada (1985), Draine & Anderson (1985), and Rowan-Robinson (1992).

Normalizing constants, $\alpha$ and $\beta$, are determined by the following equations (BH91):

$$0.7L_s = \alpha \int_{v_{\text{min}}}^{v_{\text{max}}} v B_\alpha(T_{\text{cool}}) dv ,$$

(8)

$$0.3L_s = \beta \int_{v_{\text{min}}}^{v_{\text{max}}} v B_\beta(T_{\text{hot}}) dv .$$

(9)

The model SEDs of galaxies with $L_{IR} = 10^8 - 10^{14} L_\odot$ constructed in this manner are shown in Figure 1. The solid curves represent our model SEDs with various $L_{IR}$ (the lowest one: $L_{IR} = 10^8 L_\odot$; level interval: $\Delta$ log $L_{IR} = 1.0$). We also presented the observed SEDs of three representative IR galaxies, M82 (Klein, Wielebinski, & Morsi 1988), IRAS F10214 + 4724 ($z = 2.286$; Rowan-Robinson et al. 1993), and SMM 02399 – 0136 ($z = 2.803$; Ivison et al. 1998). Open triangles stand for the observed SED of M82, open squares depict the SED of IRAS F10214 + 4724, and open diamonds represent the SED of SMM 02399 – 0136. Small downward-pointing arrows show upper limit values. The IR luminosity of M82 is $\sim 4 \times 10^{10} L_\odot$ and that of IRAS F10214 + 4724 is $\sim 3 \times 10^{14} L_\odot$, but the latter has been revealed to be magnified by gravitational lensing by a factor of $\sim 20$ (Broadhurst & Lehár 1995). Its $L_{IR}$ turns out to be $\sim 10^{13} L_\odot$, and its SED is corrected in Figure 1. SMM 02399 – 0136 is also a lensed object, and its unlensed $L_{IR}$ is $\sim 4 \times 10^{13}$ (Ivison et al. 1998). The SED of this galaxy is also corrected for the lensing (by factors of 3.5). Their SEDs are approximately fitted by our models with corresponding $L_{IR}$. 

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F. IG. 1. Model spectral energy distributions (SEDs) of galaxies with various $L_{IR}$ values (the lowest one: $L_{IR} = 10^9 L_\odot$; level interval: $\Delta \log L_{IR} = 1.0$). We also present the observed SEDs of two representative IR galaxies, M82 (Klein, Wielebinski, & Morsi 1988), IRAS F10214+4724 (Rowan-Robinson et al. 1993), and SMM 02399–0136 (Ivison et al. 1998). Open triangles stand for the observed SED of M82, open squares depict the SED of IRAS F10214+4724, and open diamonds represent the SED of SMM 02399–0136. Small downward-pointing arrows show upper limit values. The IR luminosity of M82 is $D_{410}=10^{10}$ and that of IRAS F10214+4724 is $D_{314}=10^{14}$, but the latter has been revealed to be magnified by gravitational lensing by a factor of $D_20$ (Broadhurst & Lehár 1995). Its turns out to be $D_{13}$ and its SED is corrected in this manner. SMM 02399–0136 is also a lensed object, and its unlensed is $D_{410}=10^{13}$ (Ivison et al. 1998). The SED of this galaxy is also corrected for the lensing. Their SEDs are approximately fitted by our models with corresponding $L_{IR}$.

2.2. Local Luminosity Function

We adopted the LF based on the IRAS by Soifer et al. (1987b) as the local IR LF of galaxies. Their LF is defined by $L_{60\mu m}$, so we converted it into $L_{IR}$, using our model SEDs. Then we performed an analytical fitting to the resultant data points, and obtained the following double power-law form for our LF:

$$\log \left[ h_7 \phi_0 (h_7^2 L_{IR}) \right] = \begin{cases} 7.9 - 1.0 \log (h_7^2 L_{IR}/L_\odot) & \text{for } 10^9 L_\odot < h_7^2 L_{IR} < 10^{10.3} L_\odot \\ 17.1 - 1.9 \log (h_7^2 L_{IR}/L_\odot) & \text{for } 10^{10.3} L_\odot < h_7^2 L_{IR} < 10^{14} L_\odot \\ \text{no galaxies otherwise} & \end{cases}$$

where $\phi_0$ is the number density of galaxies in Mpc$^{-3}$ dex$^{-1}$ in the case of $h_7 = 1$, where $h_7$ is the Hubble parameter normalized by 75 km s$^{-1}$ Mpc$^{-1}$ (i.e. $h_7 = H_0/75$ km s$^{-1}$ Mpc$^{-1}$). This LF is presented in Figure 2. We note that, because the volume element (defined in eq. [26]) depends on $H_0^{-3}$, the luminosity function multiplied by the volume element has no dependence on the Hubble parameter. This means that neither the galaxy number count nor the expected redshift distribution depend on the Hubble parameter in the empirical approach. Thus, we do not have to consider the effect of the Hubble parameter in the following analyses.

The faint-end slope of the LF of Soifer et al. (1987b) is much steeper than that derived by Saunders et al. (1990). Little is known about the population that occupies the faint end of the LF. We discuss the effect of it in §§ 2.5 and 4.3.
2.3. Treatment of Galaxy Evolution

For galaxy evolution, we deal with the following three cases: (1) no evolution, (2) pure luminosity evolution, and (3) pure density evolution. We define the LF at \( z, \phi(z, L_{\text{IR}}) \) in comoving volume. Then various types of galaxy evolution are characterized by the form of the functions that represent the relation between \( \phi(z, L_{\text{IR}}) \) and \( \phi(z, L_{\text{IR}}) \). We also define cumulative LF at redshift \( z, \Phi(z, L_{\text{IR}}) \),

\[
\Phi(z, L_{\text{IR}}) = \int_{L_{\text{IR}}}^{\infty} \phi(z, L'_{\text{IR}}) d \log L'_{\text{IR}}
\]

\[
= \int_{L_{\text{IR}}}^{L_{\text{IR, max}}} \phi(z, L'_{\text{IR}}) d \log L'_{\text{IR}} ,
\]

where \( L_{\text{IR, max}} \) is the maximum IR luminosity at the epoch.

2.3.1. No Evolution

The term “no evolution” means that the luminosity function is independent of \( z \):

\[
\phi(z, L_{\text{IR}}) = \phi_0 (L_{\text{IR}}) .
\]

Thus the cumulative LF reduces to

\[
\Phi(z, L_{\text{IR}}) = \int_{L_{\text{IR}}}^{\infty} \phi_0 (L'_{\text{IR}}) d \log L'_{\text{IR}} .
\]

Although the no-evolution model seems to describe an unphysical situation, its prediction acts as a valuable standard baseline from which the various evolutionary differences can be compared.

2.3.2. Pure Luminosity Evolution

The effect of the luminosity evolution of galaxies is modeled by

\[
L_{\text{IR}}(z) = L_{\text{IR}}(0) f(z) ,
\]

\[
f(z) \equiv \exp \left[ Q \frac{\tau(z)}{t_H} \right] ,
\]

where \( Q, \tau(z) \), and \( t_H \) are, respectively, a parameter defining the magnitude of evolution, look-back time as a function of \( z \), and the Hubble time \( 1/H_0 \). This functional form of evolution is proposed by Broadhurst, Ellis, & Glazebrook (1992). Peacock (1987) derived a useful approximation for the look-back time:

\[
\frac{\tau(z)}{t_H} \sim \frac{1}{\beta} \left[ 1 - (1 + z)^{-\beta} \right] ,
\]

where

\[
\beta = 1 + \frac{(2q_0)^{0.6}}{2} .
\]

This expression for the look-back time is exact for \( q_0 = 0 \) and \( q_0 = 1/2 \) and is accurate within the error of \( \leq 1\% \) for \( q_0 \leq 3/2 \) (Peacock 1987). The function reduces to the simpler form \( f(z) \approx (1 + z)^{\beta} \) at the low-\( z \) epoch.

Pure luminosity evolution leads to the following expressions as cumulative LF:

\[
\Phi(z, L_{\text{IR}}) = \int_{L_{\text{IR}}}^{\infty} \phi_0 (L'_{\text{IR}}) d \log L'_{\text{IR}}
\]

\[
= \int_{L_{\text{IR}}/f(z)}^{\infty} \phi_0 (L'_{\text{IR}}) d \log L'_{\text{IR}}
\]

\[
\bar{L}_{\text{IR}} = \frac{L_{\text{IR}}}{f(z)} .
\]

2.3.3. Pure Density Evolution

We, here, consider the model that only the comoving number density of galaxies changes as a function of redshift, which is called “pure density evolution.” Pure density evolution is expressed as

\[
\phi(z, L_{\text{IR}}) = \phi_0 (L_{\text{IR}}) g(z) .
\]

The function \( g(z) \) is defined by

\[
g(z) \equiv \exp \left[ P \frac{\tau(z)}{t_H} \right] ,
\]

where \( P \) is a parameter defining the amplitude of evolution. This is the same type of function considered in the previous subsection. We note that this type of galaxy evolution is not aimed at describing the “merging” process. The number count model including merging process is widely discussed by Gardner (1998). The cumulative LF becomes

\[
\Phi(z, L_{\text{IR}}) = \int_{L_{\text{IR}}}^{\infty} \phi_0 (L'_{\text{IR}}) g(z) d \log L'_{\text{IR}} .
\]

2.4. Galaxy Number Count

Using the above formulae, now we calculate the flux-number relation, or the so-called galaxy number count. We assume that galaxies are regarded as point sources (i.e., cosmological dimming of surface brightness is not taken into account). Then the relation between observed flux \( S(v) \)
and emitted monochromatic luminosity \( L(v) \) is given by

\[
S(v) = \frac{(1 + z) L[(1 + z)v]}{4\pi d_L^2},
\]

where \( d_L \) is luminosity distance. In the universe without the cosmological constant \( \Lambda \), \( d_L \) is expressed by an analytical form, in terms of redshift \( z \), deceleration parameter \( q_0 \), and Hubble parameter \( H_0 \) (Mattig 1958):

\[
d_L = \frac{c}{H_0 q_0} [z q_0 + (q_0 - 1)(\sqrt{2q_0 z + 1} - 1)],
\]

where \( c \) is the velocity of light. When we fix a certain \( S(v) \), we obtain \( L[(1 + z)v] \) by using equation (23). Then the corresponding \( L_{IR}(S(v), z) \) at the redshift \( z \) is uniquely determined (see § 2.1).

We define \( N[> S(v)] \) as the number of galaxies with a detected flux density larger than \( S(v) \); then it is formulated as

\[
N[> S(v)] = \int d\Omega \int_0^{z_{\text{max}}} dz \frac{d^2V}{dz d\Omega} \int_0^{\infty} \phi(z, L_{IR}) d\log L_{IR}.
\]

The expression for pure density evolution is obtained in the same manner:

\[
N[> S(v)] = \int d\Omega \int_0^{z_{\text{max}}} dz \frac{d^2V}{dz d\Omega} \int_0^{\infty} \phi_0(L_{IR}) d\log L_{IR}.
\]

2.5. Redshift Distribution

When the flux detection limit \( S_{\text{lim}}(v) \) is given, the limiting luminosity at redshift \( z \) can be obtained by the following process. From equation (23), the limiting monochromatic luminosity \( L_{\text{lim}}(v_{\text{em}}) \), where \( v_{\text{em}} \) is the emitted frequency at the rest frame of a galaxy at redshift \( z \), can be calculated as

\[
L_{\text{lim}}(v_{\text{em}}) = \frac{4\pi d_L^2}{1 + z} S_{\text{lim}}\left(\frac{v_{\text{em}}}{1 + z}\right).
\]

We then obtain the total IR luminosity \( L_{\text{IR,lim}} \), which uniquely corresponds to the given \( L_{\text{lim}}(v_{\text{em}}) \), and galaxies with \( L_{\text{IR}} \) larger than \( L_{\text{IR,lim}} \) are detected. In terms of the derived \( L_{\text{IR,lim}} \), the redshift distribution is formulated as

\[
\frac{dN}{d\Omega dz} = \frac{dV}{d\Omega dz} \int_0^{\infty} \phi(z, L_{\text{IR}}) d\log L_{\text{IR}}.
\]

The evolutionary effect can be easily introduced in the redshift distribution by using equations (14) or (20), as \( \phi(z, L_{\text{IR}}) \) in equation (31) and substituting \( L_{\text{IR,lim}} \) instead of \( L_{\text{IR}} \).

3. PARAMETERS FOR THE EVOLUTIONARY MODELS

In this section, we estimate the evolutionary parameters \( P \) and \( Q \) defined in § 2.3 in order to perform our calculation. Then we check the validity and consistency of our predictions by comparison with the IRAS- and ISO-based number counts and the CIRB spectrum obtained by COBE.

3.1. Evolutionary Parameters

We used IRAS extragalactic source count data to obtain the values of parameters \( P \) and \( Q \). Among IRAS bandpasses (12, 25, 60, and 100 \( \mu \)m), the 60 \( \mu \)m band is known to be the most suitable for extragalactic studies and is intensively used in the context of the investigation of galaxies (see, e.g., Soifer et al. 1987a). Therefore we employed the 60 \( \mu \)m data of IRAS galaxies.

We first present the differential flux-number relation of IRAS 60 \( \mu \)m databases, IRAS Point Source Catalog (1985)
Fig. 3.—Differential flux-number relation for IRAS 60 μm databases and our model predictions. Open squares represent the data points for IRAS PSC, and filled squares, HH87. The no-evolution model tracks are also shown by solid curves. The upper panel shows the case of $q_0 = 0.1$, and the lower panel, of $q_0 = 0.5$. We performed least-squares fitting of our evolutionary models (see § 2.3) on these data points. When we adopt all data points with equal weight, the most likely value for the parameters are $(P, Q) = (1.3, 0.7)$ ($q_0 = 0.1$) and $(1.4, 0.8)$ ($q_0 = 0.5$). We obtain higher values $(P, Q) = (2.7, 1.4)$ ($q_0 = 0.1$) and $(2.8, 1.5)$ ($q_0 = 0.5$) when the four statistically poorest points around log $S$ [Jy] ~ −0.5 are removed. We adopt the latter in our studies.
squares represent the data points of IRAS. The most likely values for the parameters are \((P, Q) = (1.3, 0.7)\) \((q_0 = 0.1)\) and \((1.4, 0.8)\) \((q_0 = 0.5)\). We obtain higher values \((P, Q) = (2.7, 1.4)\) \((q_0 = 0.1)\) and \((2.8, 1.5)\) \((q_0 = 0.5)\) when the four statistically poorest points around \(\log S_{[\text{Jy}]} \sim -0.5\) are omitted. We adopt the latter for our studies on evolution. We note that the estimation of \(P\) and \(Q\) depends on the fiducial point which is used to determine the normalization of galaxy counts. Some authors define the parameters \(P\) and \(Q\) so that the model predictions have the same value of \((dN/dS)S^{2.5}\) at 1 Jy (see, e.g., Fig. 1 of Oliver et al. 1992). The others estimated \(P\) and \(Q\) by overall fitting, as we did, and did not make such a normalization (see, e.g., Fig. 5 of Ashby et al. 1996). Therefore, our values for \(P\) and \(Q\) seem smaller than those who adopted the former method, but the effect of the evolution is almost the same. These parameters are summarized in Table 1. They are almost independent of \(q_0\), at least within the available flux limit of IRAS data.

### 3.2. Galaxy Count: Comparison with IRAS and ISO Results

We compared our number count predictions with the previous survey results obtained by IRAS and ISO. In the upper two panels of Figure 4, the 60 \(\mu\)m number count predictions with two evolutionary models \((q_0 = 0.1\) and \(0.5)\) are presented with the result of the QMW IRAS galaxy survey (Rowan-Robinson et al. 1991). Within the depth of the QMW catalog, there is only a small difference between the no-evolution and evolutionary predictions, and the model predictions agree with the observed counts. The evolutionary effect is significant in the fainter flux regime (see, e.g., Bertin, Denebred, & Moshir 1997).

Comparison between our 175 \(\mu\)m galaxy number count and the results of the ISO Lockman Hole survey (K98) is illustrated in the lower panels of Figure 4. The source identification and flux calibration contain considerable difficulties, which turned out to be an uncertainty of the number count by a few factors. Both IRAS and ISO number counts are successfully reproduced by our model calculations.

### 3.3. Cosmic Infrared Background

The CIRB is generated from the integrated light of galaxies. Therefore, combining the SEDs of galaxies and number count predictions, we obtain the CIRB spectrum. The observed flux density of a galaxy whose IR luminosity is \(L_{\text{IR}}\), \(S(v, L_{\text{IR}})\) is given by equation (23) as follows:

\[
S(v, L_{\text{IR}}) = \frac{(1 + z)L[v(1+z), L_{\text{IR}}]}{4\pi d_L^2},
\]

where \(L(v, L_{\text{IR}})\) is the monochromatic luminosity of a galaxy with \(L_{\text{IR}}\). Then the CIRB spectrum \(I(v)\), i.e., the background flux density from the unit solid angle, is expressed as

\[
I(v) = \int_{0}^{z_{\text{max}}} dz \frac{dV}{dzd\Omega} \int_{0}^{\infty} \phi(z, L'_{\text{IR}})S(v, L'_{\text{IR}})dL_{\text{IR}}.
\]

We can deal with the evolutionary effect on \(I(v)\) through \(\phi(z, L_{\text{IR}})\), just as in the case of number count calculation. The expected CIRB spectra are presented in Figure 5. The upper panel shows the case of \(q_0 = 0.1\), and the lower panel, \(q_0 = 0.5\). We also put the observational constraints on \(I(v)\) obtained by COBE measurement in Figure 5. Red open triangles represent the “dark sky” upper limit to the CIRB measured by COBE Diffuse Infrared Background Experiment (DIRBE). The DIRBE sky brightness varies roughly sinusoidally over the year, owing to the complex features of the interplanetary dust cloud. The “dark sky” brightness is that of the darkest area on the sky at each wavelength. The filled squares are the result of a similar analysis of the COBE Far Infrared Absolute Spectrophotometer (FIRAS) high-frequency data, after removal of the CMB (cosmic microwave background) signal. The dark sky values of DIRBE and FIRAS show excellent agreement with each other. Blue open triangles represent the residual signal of DIRBE after removing the contributions from the model foreground sources such as Galactic diffuse emission and interplanetary dust emission. As described by Mather et al. (1994), the CMB spectrum in the wavelength range 0.5–5 mm deviates from a 2.726 K blackbody shape by less than 0.03% of the peak intensity. This deviation is shown by green horizontal lines. Details of these background signals are summarized in Hauser (1995). In addition, Puget et al. (1996) have reported the isotropic diffuse residual light of FIRAS data, after subtracting the foreground contributions. Fixsen et al. (1998) and Hauser et al. (1998) have also reported similar results. The orange broken solid lines are

| \(P\) | 2.7 | 2.8 |
| --- | --- | --- |
| \(Q\) | 1.4 | 1.5 |
the approximate shape of the spectrum of the residual light reported by Puget et al., Fixsen et al., and Hauser et al. with errors.

Within the wavelengths shorter than 300 μm, our model prediction is consistent with the CIRB intensity, but in the longer wavelengths, it seems to violate the limits from the CIRB (larger $q_0$ mitigates this discrepancy). In such a long-wavelength regime, the background radiation is dominated by the contributions from hyperluminous IR galaxies at very high redshifts. As we see from Figure 1, the SEDs of such luminous galaxies are well represented by our SED models. Thus, the functional form of the galaxy evolution might be too simple and possibly not valid in extremely high-z objects, or, alternatively, the high-luminosity end of...
Fig. 5.—Expected cosmic infrared background (CIRB) spectra with $q_0 = 0.1$ and $q_0 = 0.5$. The background intensity depends on $q_0$, so that larger $q_0$ leads to smaller $I(\nu)$. We also put the observational constraints on CIRB obtained by COBE measurement. Open red triangles represent the “dark sky” (see § 3.3) upper limit to the CIRB measured by COBE Diffuse Infrared Background Experiment (DIRBE). Filled squares are the result of a similar analysis of the COBE Far Infrared Absolute Spectrophotometer (FIRAS) high-frequency data, after removal of the cosmic microwave background signal. Open blue triangles represent the residual signal of DIRBE after removing the contributions from the model foreground sources such as Galactic diffuse emission and interplanetary dust emission. The green horizontal lines represent the upper limit derived from Mather et al. (1994), and the solid orange broken lines represent the approximate value of the residual light reported by Puget et al. (1996), Fixsen et al. (1998), and Hauser et al. (1998) with errors. The CIRB constraint on the magnitude of galaxy evolution is tighter than that obtained from the number count.
the LF might not be valid at high \( z \). In spite of the difficulty in the submillimeter range, our model works for our present purpose, which is IR source number count prediction in the wavelength region shorter than 300 \( \mu m \).

4. RESULTS AND DISCUSSIONS

4.1. IRIS Survey Performance

4.1.1. Flux Detection Limit of IRIS FIS

The flux detection limit \( S_{\text{lim}}(\nu) \) is decided by several factors; the sensitivity of the device, the intervening emission, e.g., zodiacal light, interstellar emission of our Galaxy, and source confusion, etc. The dominant factor is different in different wave bands, and the resultant \( S_{\text{lim}}(\nu) \) is dependent on wavelength. Thus the calculation requires the careful consideration of \( S_{\text{lim}}(\nu) \) individually for each \( \lambda \) or \( \nu \). We assume 50, 70, 120, and 150 \( \mu m \) bandpasses for IRIS FIS. Unstressed gallium-doped germanium (Ge:Ga) is used for the shorter wavelength in FIR (50–110 \( \mu m \)) and stressed Ge:Ga for the longer wavelength (\(< 170 \ \mu m \)) (Kawada et al. 1998). In the shorter wavelength, sensitivity is limited by internal and background noises, while in the longer wavelength, it is constrained by the source and Galactic cirrus confusion (Gautier et al. 1992; Thronson et al. 1995). The resultant 5 \( \sigma \) detection limits of the assumed four wave bands are summarized in Table 2.

4.1.2. IRIS Galaxy Number Count Predictions

Our predictions for the galaxy number count at the assumed IRIS four bandpasses are shown in Figure 6. The upper four panels depict the number counts with \( q_0 = 0.1 \) and the lower four, \( q_0 = 0.5 \); from left to right, \( \lambda = 50, 70, 120, \) and 150 \( \mu m \). The black solid lines show the no-evolution prediction. The red and cyan lines represent the case of pure luminosity evolution and pure density evolution, respectively. The green dot-dashed lines in Figure 6 denote the IRIS FIS flux detection limit at each band. The integrated detection number to the flux limit of each bandpass is \( D \lesssim 10^5 \ \text{sr}^{-1} \) at 50 \( \mu m \), \( D \lesssim 2 \times 10^5 \ \text{sr}^{-1} \) at 70 \( \mu m \), \( D \lesssim 3 \times 10^5 \ \text{sr}^{-1} \) at 120 \( \mu m \), and \( D \lesssim 2 \times 10^5 \ \text{sr}^{-1} \) at 150 \( \mu m \) in

Fig. 6.—Galaxy number count predictions at assumed IRIS four bandpasses. The upper four panels depict the number counts with \( q_0 = 0.1 \) and the lower four, \( q_0 = 0.5 \); from left to right, \( \lambda = 50, 70, 120, \) and 150 \( \mu m \). The black solid lines show the no-evolution prediction. The red lines and cyan lines represent the case of pure luminosity evolution and pure density evolution, respectively. The green dot-dashed lines denote the IRIS FIS flux detection limit at each wave band.
TABLE 2
ADOPTED FLUX LIMITS OF IRIS FIS

| Wavelength (µm) | 5σ Detection Limit (mJy) |
|----------------|--------------------------|
| 50........... | 20                       |
| 70........... | 15                       |
| 120 ......... | 30                       |
| 150 ......... | 50                       |

the case of no evolution; thus, the expected detection number is largest at 120 µm, and the total number of galaxies is expected to be \(~ \text{several} \times 10^6\) in the whole sky. This is about 100 times larger than the number of IRAS galaxies, which is \(~ 25,000\) in the whole sky. It is clearly seen that \(q_0\) does not affect the number count within the detectable flux range of IRIS as shown in Figure 6.

The effect of evolution appears most significantly at 70 µm among the assumed bands, and the total detection number becomes twice larger. Thus, the determination of the amplitude of galaxy evolution is best estimated at around 70 µm in the wavelength and flux coverage of IRIS. With the aid of such a vast number of galaxy detections, we will be able to evaluate the evolution strength (\(P\) or \(Q\)) precisely. In the case of the 70 µm band, statistical fluctuation becomes much smaller than that of previous area-limited deep surveys. Consequently, the errors in the estimation of \(P\) or \(Q\) will be small enough, at least, to determine them in the relatively low-redshift (\(z \lesssim 1\)) universe. Unfortunately, there exists no drastic difference between luminosity and density evolution in the behaviors of number count, and judging which evolution takes place from number count alone still remains a difficult task.

4.2. Redshift Distribution

Using the IRIS FIS flux detection limits we gave in § 4.1.1, we calculate the redshift distribution of galaxies detected by the IRIS all-sky survey. Figure 7 shows the expected redshift distribution of galaxies detected in the assumed four bands. Figure 7a illustrates the prediction at 50 µm band. Figures 7b, 7c, and 7d are the same as Figure 7a, except that they show the predictions at 70, 120, and 150 µm bands, respectively. Solid curves denote the predictions for \(q_0 = 0.1\), and dashed curves, \(q_0 = 0.5\). Larger values of \(q_0\) lead to deeper \(z\) distribution. In any bandpasses, the numbers of galaxies at \(z \gtrsim 1\) are \(~ \text{a few} \times 10^3\) and are several times larger with evolution. Namely, low-\(z\) galaxies are the overwhelming majority among the detected objects. The steep increases of galaxy number at \(z \lesssim 0.5\) seen in Figures 7c and 7d are attributed to the peak at \(~ 100\) µm, which originates from big grains, in the SED of low-\(L_{\text{IR}}\) galaxies.

Fig. 7.—Expected redshift distribution of galaxies detected in the assumed four bands. (a) Prediction at 50 µm band. (b), (c), and (d): Same as (a), except that they show the predictions at 70, 120, and 150 µm bands, respectively. Solid curves denote the predictions for \(q_0 = 0.1\), and dashed curves, \(q_0 = 0.5\). Larger \(q_0\) leads to deeper \(z\) distribution. The steep increases of galaxy number at \(z < 0.5\) seen in (c) and (d) are attributed to the peak at \(~ 100\) µm, which originates from big grains, in the SED of low-\(L_{\text{IR}}\) galaxies.
The overall shape of the redshift distribution depends on the observing bandpass wavelength. The nearest galaxies ($z \sim 0$–0.5) are more likely to be detected at longer wavelengths ($\lambda = 120$–150 $\mu m$), and their detection number steeply decreases with increasing $z$ in the longest wavelengths. Galaxies which lie within the redshift range of $z \sim 0.5$–2.5 are expected to be detected more at 70 $\mu m$ than at the other bands. When the galaxy redshift exceeds $\sim 3$, they become harder to detect in the shorter bands, while they remain detectable in the longer bands. The detection numbers at $\lambda = 120$ $\mu m$ and 150 $\mu m$, therefore, surpass those at $\lambda = 50$ $\mu m$ and 70 $\mu m$ for the most distant galaxies. This is understood as follows. At significant redshift ($z \gtrsim 3$), the detected objects are the most luminous starbursts, whose SEDs peak at around 30 $\mu m$ in the rest frame. Since the peaks of luminous starbursts shift away from their rest wavelength, they are not detected at high-$z$ in shorter wavelengths. Instead, in the longer wave bands, the effect of redshift makes their observed flux density nearly constant (known as the negative $K$-correction), and they can be still seen at high-$z$.

### 4.3. Color-Color Diagram in FIR

As we saw in § 4.2, most of the objects detected in the IRIS galaxy survey are nearby ones. Hence, when we focus on very young or primeval galaxies, an efficient method for picking up such candidates without knowing their spectroscopic redshifts will be very useful. Here, we make attempts to utilize the peaks of the SEDs to estimate the redshifts roughly from their FIR colors alone. We suppose that all the Galactic objects are removed by certain methods. This may well be possible at high Galactic latitudes.

Figure 9 shows the loci of galaxies with various $L_{IR}$ on the FIR color-color $(\log S_{100}/S_{100}$–$\log S_{50}/S_{10}$) plane, where $S_\lambda$ is the detected flux density of galaxies at wavelength $\lambda$ [$\mu m$] in units of ergs$^{-1}$ cm$^{-2}$ Hz$^{-1}$. Filled symbols are placed on every $\Delta z = 0.05$ interval from $z = 0$. When the sources fade away from the IRIS detection limits, we do not show their loci and symbols. Red filled squares represent the colors of the low-$z$ ($z < 1$) galaxies; green filled squares, the intermediate-$z$ ($1 < z < 2.5$) galaxies; and blue filled circles, the high-$z$ ($2.5 < z$) ones. Because of the way our model SEDs are constructed, galaxies with $L_{IR} = 10^8$–$10^{10}$ $L_\odot$ have the same colors (the red filled square at the top right). To see how the existence of a starburst component changes the color of cool cirrus galaxies, we put the galaxies of $L_{IR} = 10^{10.1}$–$10^{10.9}$ $L_\odot$ with an interval of $\Delta \log L_{IR} = 0.1$ (denoted by open squares from the top right to lower left). They correspond to the galaxies whose IR luminosity fractions of the superposed starburst are 20.6%, 36.7%, 50.0%, 60.2%, 68.4%, 74.9%, 80.0%, 84.2%, and 87.4%, respectively.

When we consider the color selection criteria, the intrinsic scatter of galaxy color has to be taken into account. Schmitt et al. (1997) proposed the template SEDs of various classes of galaxies. Their SEDs show that the dispersion at $z = 0$ is also known to be an order of magnitude (RC89). Considering these scatters, we can estimate the domains in which galaxies locate on the FIR color-color plane. We show the domains of low-$z$ ($z < 1$), intermediate-$z$ ($1 < z < 2.5$) and high-$z$ ($z > 2.5$) galaxies with a red dashed rhomboid, a green solid rectangle, and a blue solid rectangle, respectively. The high-$z$ and mid-$z$ regions are well separated on this diagram.

We must consider the overlap between low-$z$ and mid/high-$z$ domains. The low-$z$ population creeping into the mid/high-$z$ domain consists of only low-$L_{IR}$ galaxies ($L_{IR} \lesssim 10^{11} L_\odot$). As we have seen in § 4.2, such galaxies quickly become undetectable with increasing redshift and reside in $z \lesssim 0.2$. The expected optical magnitude based on SEDs extended to the optical region ranges from 17 to 19 mag (Hirashita et al. 1998). Since the positional accuracy of the IRIS survey is quite good ($5''$–10'') and the surface density of such bright galaxies is low enough, these galaxies would be identified easily with optical counterparts. On the contrary, the high-$z$ galaxies are expected to have fainter magnitudes ($\sim 20$ mag) (Hirashita et al. 1998). Thus, the cross correlation with optical survey data such as POSS or the forthcoming SDSS would identify most of the low-$z$ IR...
IRIS FAR-INFRARED GALAXY SURVEY

Fig. 9.—Loci of galaxies with various $L_{\text{IR}}$ on the FIR color-color ($\log S_{50}/S_{70} - \log S_{50}/S_{150}$) plane. Filled squares are put on every $\Delta z = 0.5$ interval. Red filled squares represent the colors of the low-$z$ ($z < 1$) galaxies; green filled squares, the intermediate-$z$ galaxies ($1 < z < 2.5$); and blue filled squares, the high-$z$ ($2.5 < z$) ones. Since the sources fade away from the IRIS detection limits, we do not show their loci and symbols. To see how the starburst changes the color of cool cirrus galaxies, we put the galaxies of with an interval of $\log L_{\text{IR}}$ from the top right to the lower left). The domain that is occupied mainly by low-$z$, low-$L_{\text{IR}}$ galaxies is shown roughly by a red dotted rhomboid. The green rectangle shows the low-$L_{\text{IR}}$ domain of intermediate-$z$ ones, and the blue rectangle shows the region where high-$z$ galaxies to be located.

Galaxies. An evolutionary effect makes the mid/high-$z$ galaxy more abundant, and the fraction of such objects in the overlapped region will be higher. Thus, color classification of galaxy redshift can be practicable using sets of bandpasses 50, 70, and 150 $\mu$m with the aid of present and future optical surveys.

5. SUMMARY AND CONCLUSIONS

In this paper we examined the performance of the IRIS FIR all-sky survey, one of whose main purposes is to study galaxy evolution and formation. We used a simple empirical model for galaxy number count estimation by adopting a multicomponent SED model that consists of cirrus and starburst components, and the nearby FIR luminosity function derived from that of IRAS galaxies.

Our conclusions are as follows:

1. A few $\times 10^6$ galaxies will be detected by the IRIS all-sky survey, which consists of 100 times larger number of detections than that of IRAS.

2. A shorter wavelength bandpass (50–70 $\mu$m) is suitable for intermediate-$z$ ($1 < z < 2.5$) galaxy detection, while a longer wavelength (120–150 $\mu$m) one is for high-$z$ ($2.5 < z$) and nearby ($z < 1$) galaxies.

3. We will detect the effect of galaxy evolution and can evaluate the amplitude of evolution at least in the nearby universe in the IRIS survey, but it is still difficult to constrain which type of evolution takes place, from the number

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Fig. 10.—Integrated number counts of galaxies expected for SOFIA, SIRTF, FIRST, and LMSA. SOFIA (upper left): Blue and red solid lines represent our 120 and 450 \( \mu \text{m} \) predictions, respectively. The vertical blue and red dot-dashed lines show the 5 \( \sigma \) detection limit of SOFIA with 1 hr exposure. We adopted \( \text{Q} = 0.1 \) with pure luminosity evolution (\( \text{Q} = 1.4 \)) in this and the following figures. SIRTF (upper right): Integrated number counts of galaxies expected for SIRTF. Blue, green, and red solid lines represent our 25, 70, and 160 \( \mu \text{m} \) predictions, respectively. The vertical blue, green, and red dot-dashed lines show the 5 \( \sigma \) detection limit of SIRTF MIPS with 500 s exposure. FIRST (lower left): Integrated number counts of galaxies expected for FIRST. Blue, green, yellow, and red solid lines represent our 90, 250, 350, and 500 \( \mu \text{m} \) predictions, respectively. The vertical blue, green, yellow, and red dot-dashed lines show the 5 \( \sigma \) detection limit of FIRST PACS (90 \( \mu \text{m} \)) and SPIRE (250, 350, and 500 \( \mu \text{m} \)) with 1 hr exposure. LMSA (lower right): Integrated number counts of galaxies expected for LMSA. Blue, green, yellow, and red solid lines represent our 350, 450, 650, and 800 \( \mu \text{m} \) predictions, respectively. The vertical blue, green, yellow, and red dot-dashed lines show the 5 \( \sigma \) detection limit of LMSA with 8 hr exposure. The filled red circle represents the galaxy number count reported by Smail et al. (1998), the filled square shows the result in Hubble Deep Field (Hughes et al. 1998), and the filled triangle is the count in Lockman Hole (Barger et al. 1998), all obtained with SCUBA in JCMT at 850 \( \mu \text{m} \).
count alone. On the contrary, the intensity of the CIRB complementarily provides us with a much tighter constraint on the form of galaxy evolution at very high $z$.

4. Redshift estimation using galaxy FIR colors can be practicable using sets of bandpasses 50, 70, and 150 $\mu$m with the aid of present and future optical surveys.

We first thank the anonymous referee for valuable suggestions and corrections that greatly improved the paper. We owe a great debt to Hideo Matsuhara, Takao Nakagawa, Mitsunobu Kawada, and other members of the IRIS mission for useful discussions and comments. We also acknowledge Chris P. Pearson, Gavin Dalton, Toru Yamada, and Kimiaki Kawara for fruitful discussions. We offer our gratitude to Professors Mamoru Saitô, Hiroki Kurokawa, and Shin Mineshige for continuous encouragement. Two of us (T. T. T. and H. H.) acknowledge the Research Fellowships of the Japan Society for the Promotion of Science for Young Scientists. This research has also made use of the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. We also made extensive use of the NASA's Astrophysics Data System Abstract Service (ADS).

APPENDIX A

OTHER FUTURE MISSIONS

We show the expected number counts and redshift distributions of galaxies in other future missions now planned: SOFIA, SIRTF, FIRST, and LMSA. The present model is valid only within the mid-IR to submillimeter wavelengths; because of the SED used, we restrict the count predictions within this range. We calculated the number counts and redshift distributions in the same way as we did in the main text. In this Appendix, we consider only the case of $q_0 = 0.1$ cosmology with pure luminosity evolution ($Q = 1.4$). Though some of the facilities are not planned to be used for a large-area survey, we uniformly calculated the number counts per unit solid angle and the redshift distributions in the whole sky. We applied the detection limits from published papers or from the web pages of the missions if available.

A1. SOFIA

Stratospheric Observatory for Infrared Astronomy (SOFIA) is an airborne observatory with a 2.5 m telescope installed in a Boeing 747 aircraft, which will be flying in 2001. The detection limits (1 $\sigma$ noise level) for 1 hr exposure are 7 mJy at 100 $\mu$m
and 3.5 mJy at 450 μm (Becklin 1997). Based on these values we calculated the number count and redshifts with 5 σ detection limits (obtained by simply multiplying factor 5 to the above limits). The galaxy number counts are presented in the upper left-hand panel of Figure 10, and the redshift distributions are shown in the upper left-hand panel of Figure 11.

A2. SIRTF

The Space Infrared Telescope Facility (SIRTF) is the fourth and final element in NASA’s family of “Great Observatories.” SIRTF consists of a 0.85 m telescope and three cooled instruments, IRAC, MIPS, and IRS, capable of performing imaging and spectroscopy in the 3–180 μm wavelength range. It is planned to be launched in 2001 December. We present the predictions for MIPS (Multiband Imaging Photometer for SIRTF) at wavelengths 23.5, 70, and 160 μm. The 5 σ detection limits are 370 μJy, 1.4 mJy, and 7.5 mJy, respectively, by 500 s exposure (Heim et al. 1998). SIRTF will survey 60% of the whole sky. The upper left-hand panel of Figure 10 depicts the number counts, and the upper left-hand panel of Figure 11 shows the redshift distribution.

A3. FIRST

The Far Infrared and Submillimetre Telescope (FIRST) is the fourth cornerstone mission in the European Space Agency’s Horizons 2000 program, implemented in collaboration with NASA. FIRST will perform photometry and spectroscopy in the 80–670 μm range. Three instruments have been provisionally selected: HIFI, PACS, and SPIRE. Imaging photometry is performed by PACS (80–210 μm) and SPIRE (200–670 μm). The 5 σ detection limits (by 1 hr exposure) for PACS and SPIRE are 5 mJy and 3 mJy, respectively (G. Pilbratt 19987). We show 90 μm number count for PACS and 250, 350, and 500 μm for SPIRE in the lower left-hand panel of Figure 10. Redshift distributions of the objects detected at these bandpasses are presented in the lower left-hand panel of Figure 11.

A4. LMSA

The Large Millimeter and Submillimeter Array (LMSA) is the ground-based radio facility proposed in Japan. In the current design concept the array will consist of 50 10 m antennas and will be covering observing frequencies from 80 to 800 GHz. The array will be located at a very high site to realize subarcsecond resolution imaging at very high frequencies. We present the number counts expected by LMSA at 350, 450, 650, and 850 μm. The 5 σ sensitivities at these wavelengths (yearly mean values) are 3550, 1800, 750, and 115 μJy per beam, respectively, by 8 hr integration (R. Kawabe & K. Kohno 1998, private communication). Under the best weather conditions in winter, much higher sensitivities can be achieved. The galaxy number counts are shown in the lower right-hand panel of Figure 10. The lower right-hand panel of Figure 11 illustrates the expected redshifts. In the lower right-hand panel of Figure 10, we compared our prediction with the 850 μm number counts recently obtained by SCUBA in JCMT. The filled red circle represents the value obtained by Smail, Ivison, & Blain (1998), the filled square shows the result in the Hubble Deep Field (Hughes et al. 1998), and the filled triangle is the number count in Lockman Hole (Barger et al. 1998). Even though we include evolution in this calculation, our prediction is an order of magnitude smaller than those results. Thus, a very strong evolution is suggested by submillimeter observations. It requires further detailed analyses of the present observational data to study the history of galaxy evolution in a wide range of wavelengths.

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