Semi-analytic Model of Galaxy Formation in the Infrared: Predictions for *SPICA*

Ryu Makiya,[1] Tomonori Totani,[2] Masakazu A. R. Kobayashi,[3] Masahiro Nagashima,[4] and Tsutomu Takeuchi[5]

[1]*Institute of Astronomy, The University of Tokyo, Japan*
[2]*Department of Astronomy, The University of Tokyo, Japan*
[3]*Research Center for Space and Cosmic Evolution, Ehime University, Japan*
[4]*Faculty of Education, Nagasaki University, Japan*
[5]*Institute for Advanced Research, Nagoya University, Japan*

ABSTRACT

Understanding the galaxy dust emission is very important to obtain a full picture of galaxy formation, since it contains rich information about hidden star formation activity, physical properties of interstellar dust, and their role in galaxy formation. From the analysis of infrared spectral energy distribution (SED) of local galaxies which were observed by *AKARI*, we have found that a dust temperature averaged over the entire galaxy is strongly correlated with total infrared surface brightness, rather than total infrared luminosity. Combining this correlation with our cosmological galaxy formation model, we have computed dust SED of mock galaxies. By using this model, we present can theoretical predictions on the evolution of dusty universe.

1. INTRODUCTION

It is one of the most important issues in astronomy that understanding how the cosmological structures, such as galaxies, galaxy clusters and large-scale structures, have been formed and evolved. In order to fully understand the history of cosmological structure formation, we need to approach a variety of statistical natures of galaxies, such as luminosity functions in various wavelengths and correlations between several physical quantities, making full use of the multi-band observations and precise theoretical model. To explore the cosmological galaxy formation history hidden by dust, we use a so called "semi-analytical model (SAM)" of galaxy formation. If we would like to expand a SAM to IR to submm range, the key is how to theoretically calculate spectral energy distribution (SED) of dust emission. In this work we model the dust SED using the tight correlation between the surface density of total infrared luminosity and dust temperature, which is recently found by (Totani et al. 2011). In the following section we will show the our preliminary results.

2. MODEL

The detailed description of the basic model, the Mitaka model is given by Nagashima & Yoshii (2004). The model compute merging history of dark matter (DM) halos based on the standard structure formation theory driven by cold DM and include several important physical processes related to the evolution of baryons in DM halos such as radiative gas cooling, star formation, supernova feedback, galaxy merger, stellar population synthesis, chemical evolution, and extinction by interstellar dust.

The model can quantitatively reproduce a wide variety of observed characteristics of local galaxies, including luminosity functions and scaling relations among various observables such as magnitude, colors, surface brightness, size, gas mass-to-light ratio, and metallicity (Nagashima & Yoshii 2004); however, the dust radiation process does not included in our model and the model can not predict the FIR to submm properties of galaxies. Recently, we have found the tight correlation between the total infrared surface brightness and dust temperature from the analysis of infrared spectral energy distribution (SED) of local galaxies which were observed by *AKARI* (Totani et al. 2011). In this work, combining this correlation and mock galaxy catalog produced by the Mitaka model, we investigated the cosmological history of galaxy formation hidden by dust.

3. RESULTS

First, in Figure 1 we show the local luminosity function for the total IR, and the luminosity functions at 250 μm, 350 μm, and 500 μm, respectively. The data points are obtained by Vaccari et al. (2010). It can be seen that our model very well reproduces the observations at all wavelengths.

Figure 2 represents the differential number count of star forming galaxies at 100 μm. The data points are obtained by Magnelli et al. (2013). The model could reproduce the observed number count; therefore it can be say that our model is consistent with the observed trend of cosmic evolution of dusty star forming galaxies.

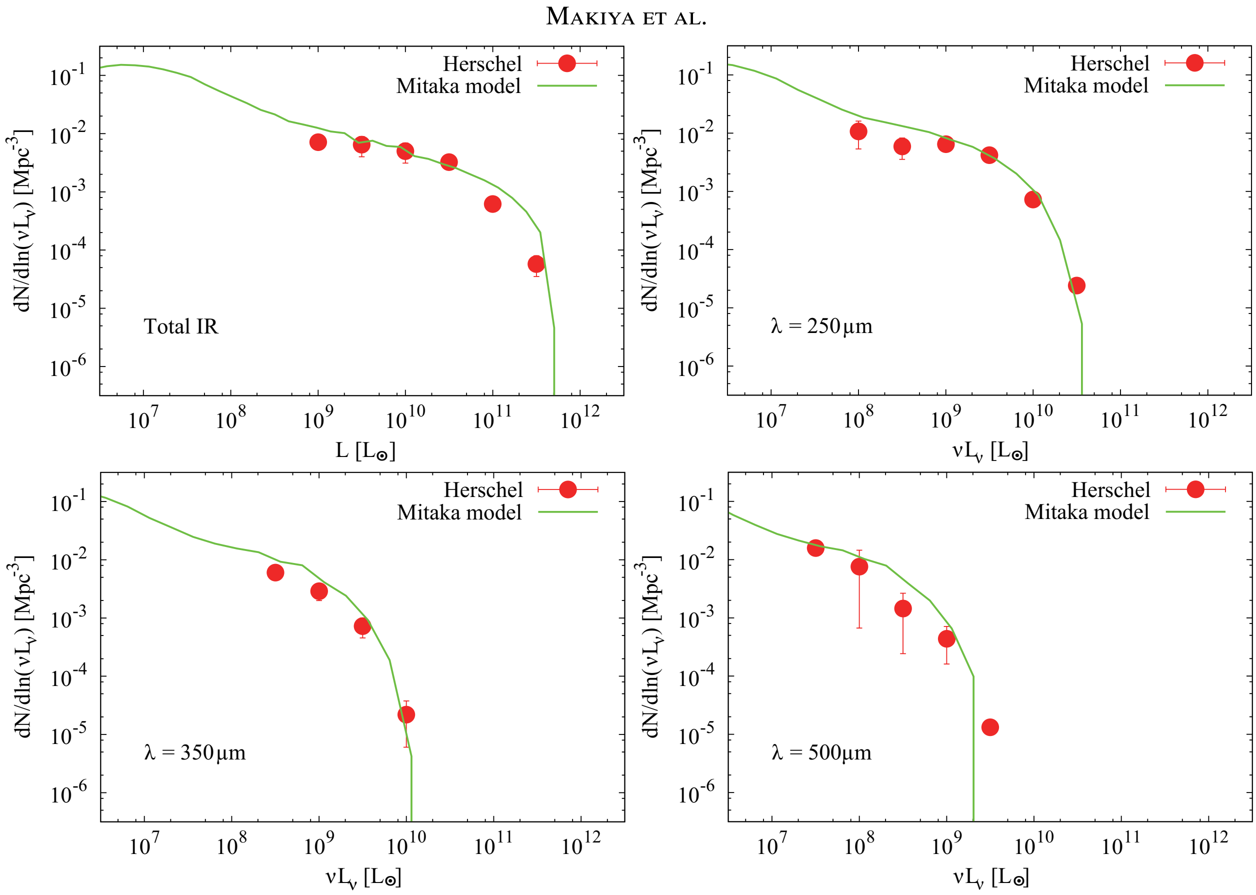

Figure 1. The local total IR luminosity functions (upper-left), and the luminosity functions at 250 μm (upper-right), 350 μm (bottom-left), and 500 μm (bottom-right), respectively. Data points are obtained by Vaccari et al. (2010). Our model well reproduces the observations in each band.

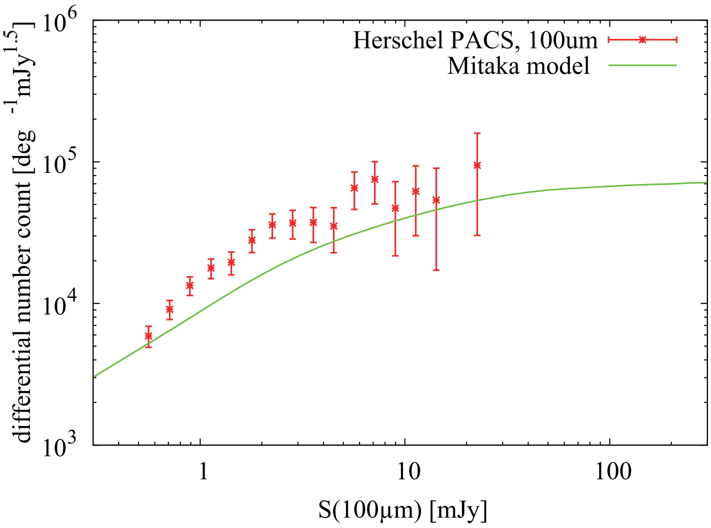

Figure 2. The differential number count at 100 μm. It can be seen that our model roughly well reproduces the observations at all flux ranges. Data points are obtained by Magnelli et al. (2013).

Figure 3 represents the redshift evolution of cosmic star formation rate density. In this Figure, we show the two theoretical predictions: one is estimated from UV luminosity density, and the other is estimated from the sum of UV and IR luminosity densities. It can be seen that there are large amount of star formation activity hidden by dust, especially at high redshift. According to the our preliminary estimation, *SPICA* SAFARI can easily detect numerous number of high-z

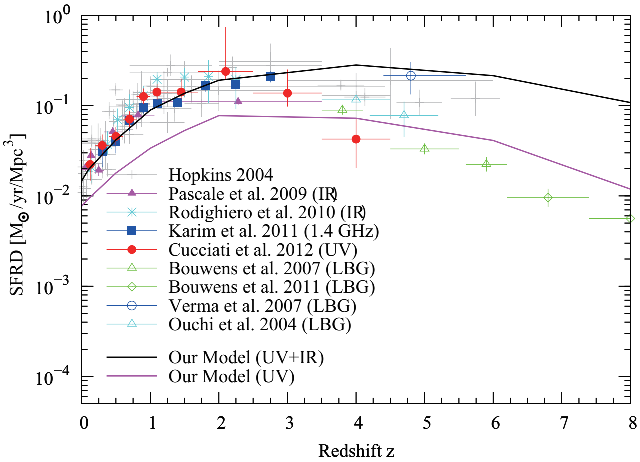

Figure 3. The redshift evolution of cosmic star formation rate density. The magenta solid line represents the our model prediction estimated from UV luminosity density, while the black solid line represents the results estimated from the sum of UV and total IR luminosity densities. Therefore the difference of these two lines denote the amount of star formation activity hidden by dust. The data points are obtained by Hopkins et al. (2004), Pascale et al. (2009), Rodighiero et al. (2010), Karim et al. (2011), Cucciati et al. (2012), Bouwens et al. (2007), Bouwens et al. (2011), Verma et al. (2007), and Ouchi et al. (2004).

($z \sim 4$) galaxies in FIR to submm range. Future facilities such as ALMA, TMT, and *SPICA*, will give us many useful insights on the early stage of galaxy formation hidden by dust.

REFERENCES

Bouwens, R. J., et al. 2007, ApJ, 670, 928
— 2011, ApJ, 737, 90
Cucciati, O., et al. 2012, A&A, 539, A31
Hopkins, A. M., et al. 2004, ApJ, 615, 209
Karim, A., et al. 2011, ApJ, 730, 61
Magnelli, B., et al. 2013, A&A, 553, A132
Nagashima, M., & Yoshii, Y. 2004, ApJ, 610, 23
Ouchi, M., et al. 2004, ApJ, 611, 685
Pascale, E., et al. 2009, ApJ, 707, 1740
Rodighiero, G., et al. 2010, A&A, 515, A8
Totani, T., et al. 2011, PASJ, 63, 1181
Vaccari, M., et al. 2010, A&A, 518, L20
Verma, A., et al. 2007, MNRAS, 377, 1024