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Effects of galaxy mergers on the faint IRAS source counts and the background

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Abstract. Binary merging constitutes a complementary mode of galaxy evolution to the canonical hierarchical clustering theory. This merger-driven evolution not only influences the galaxy mass distribution function, but may drive the main galactic activity cycles, such as starbursts and the activity in the nuclei (AGNs). In this paper, we use galaxy aggregation dynamics together with a possible merger-driven starburst and AGN phenomena, to study the effects of evolution of these consequential activities for the faint IRAS source counts and the infra-red background. We find that the strong evolution of IRAS 60 μm source count at flux range of $10\,mJy\,\sim\,1\,Jy$ is difficult to be explained only by the merger rate decrease with cosmic time. We need to assume a redshift dependent infrared burst phase of ultraluminous infrared galaxies (ULIGs) from the gas rich mergers at high redshift and the gas poor mergers at low redshift. The background intensity at 60 μm which we get from this aggregation evolution is a lower limit of only $1.9\,nW\,m^{-2}\,sr^{-1}$, about half of those estimated by some previous models, but close to the lower end of the range derived by Malkan & Stecker (1998).

Key words: galaxies: starburst – galaxies: Seyfert – galaxies: spiral – galaxies: evolution – galaxies: interactions – galaxies: luminosity function, mass function

1. Introduction

Over the last few years, observational progress in discovering the faint Universe at ultraviolet (UV)/optical and infrared wavelength via the groundbased redshift surveys, Hubble Space Telescope (HST) multi-color images and the infrared satellites such as IRAS (Infrared Astronomical Satellite), ISO (Infrared Space Observatory) and COBE (Cosmic Background Explorer), challenges and renews our present understanding of cosmological structure formation and the evolution of luminous galaxies, which are usually based on two competing scenarios "traditional monolithic collapsing" versus "hierarchical clustering theories". The main difference between these two kinds of models is the formation mechanism and the first epoch of the formation of massive galaxies.

More recently it has been shown that the emission history (e.g. Madau plot) derived from UV/optical detections agrees quite well with the star formation history indicated by hierarchical clustering theories (Madau 1997, Madau et al. 1996, 1998, Ellis et al. 1996). Since the FIR/submm unveiled a dust-shrouded early active phase and the recent detection of high redshift evolving galaxies by deep NICMOS/VLT images (Lilly et al. 1998, Benitez et al. 1998), the discussion of the structure formation and the scheme of galaxy evolution is going to require more subtlety and sophistication. For a clear picture of the star formation history and the galaxy evolution, we probably need more information at high redshift, especially from FIR/submm deep surveys.

A successful interpretation of the excess of faint blue galaxies within the merger-trigger starburst scenario in a hierarchical clustering universe has been presented by Cavaliere & Menci (1997) using binary aggregation dynamics.

The binary aggregation dynamical approach for the galaxy evolution presented by Cavaliere & Menci (1993, 1997), which includes more dynamics to describe a further step in galaxy-galaxy interactions within the scheme of direct hierarchical clustering (DHCs), probably can help to alleviate some intrinsic problems in the DHC scenario, such as the overproduction of small objects and the difficulty of a reconciliation between the excess faint counts and the flat local luminosity function. While, on the other hand, binary merging which plays a different and complementary role in structure formation, can actually continue to flatten the mass distribution function $N(m, z)$ and hence the luminosity function $N(L, z)$ till even moderate redshift $z < 1$.

Although there are many other possible evolutionary scenarios which could interpret the present observations in this or that way, the reason that we are encouraged to explore here a merger-driven galaxy evolution picture with the binary aggregation dynamics, is simply because the IRAS database does show that most of the luminous infrared sources are actually interacting/merging systems (Kleinmann & Keel 1987, Sanders & Mirabel 1996, Hutchings & Neff 1987, Vader & Simon

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1987a,b), and many merger events can even occur till moderate redshift ($z < 1$).

In this paper, starting from the basic picture that galaxy evolution is driven by the galaxy-galaxy interaction complementary to the standard hierarchical clustering scenario (DHCs), we investigate a simple model with the basic concepts: 1) galaxy-galaxy interaction can even occur till quite moderate redshifts ($z < 1$) within large scale structures that could offer the best combination of volume and density contrast, and it could erase the dwarf part of the mass distribution and produce the massive tail, thus flatten the luminosity functions; 2) starburst/AGN activities may be triggered by the merger events during the structure formation and evolution. This is actually the point different from other models where only the starburst is considered as the consequence of merger events (Cavaliere & Menci 1997, Somerville & Primack 1998, Somerville et al. 1998); 3) the gas rich merger events at high redshift may trigger drastic starburst and AGN activities in the central region of the merging galaxies and thus enhance dramatically the FIR luminosity because of the accumulating of dust grains from their progenitor galaxies as well as the dust newly formed in the star forming regions. This FIR luminosity burst phase is usually called ultraluminous infrared galaxies (ULIGs); 4) in our model, we assume a redshift dependent infrared burst phase for the gas rich merger events at high redshift and the gas poor mergers at low redshift, which means the enhancement of the infrared luminosities by the high redshift gas rich mergers is much higher than those of low redshift gas poor mergers. The motivation for this kind of thinking is: 1) direct observation of enhanced starburst-AGN activities in interacting galaxies, especially the ULIGs. This extremely infrared bright burst phase is believed due to the starburst merger events with far infrared luminosity L_{fir} enhanced both by the accumulation of the dust mass M_d and the increase of dust temperation T_d as the relation $L_{fir} \propto M_d \, T_d^5$. This burst phase could increase the infrared luminosity by a factor of about 20 over that of normal starburst galaxies. (Ashby et al. 1992, Terlevich & Melnick 1985, Heckman 1997, Perry & Williams 1993, Taniguchi & Ohyama 1998); 2) numerical simulation of the starburst/AGN evolutions by galaxy mergers, especially for their correlation and the burst phase (Wang & Biermann 1998, 1999, Wang 1999); 3) the successful interpretation of the excess faint blue counts by galaxy merging and the consequential starburst activities (Rocca-Volmerange & Guiderdoni 1990, Cavaliere & Menci 1997, Carlberg 1992, Calberg & Charlot 1992); 4) the pair production absorption of high energy γ rays by intergalactic low energy photons is expected to produce a high energy cutoff in extragalactic γ ray spectra. The new data of Mkn501 appear to show an extension of the TeV γ ray spectrum till about 24 TeV, which sets an upper limit for the intergalactic infrared emission history during the structure formation (Aharonian et al. 1999).

Since the dust-shrouded geometry could strongly affect the AGN spectrum and cause significant radiation at infrared wavelength in the framework of a Unification Scheme, we thus add the statistics of nuclear activity in galaxies as one additional constraint in the context of the various models already in the literature. We know that nuclear activity is detected to very high redshift and provides a strong constraint on the cosmological evolution models. Therefore we are less conservative than Malkan & Stecker (1998), but use more constraints than, e.g., Somerville & Primack (1998). Obviously, any such modelling depends on the basic concepts used, and thus our results provide a strong lower limit to the far-infrared background.

The outline of this paper is as follows: 1) in Sect. 2, we introduce the binary aggregation dynamics, and the models of the interaction kernel; 2) we discuss the prescriptions of mass-to-light ratio in our model for the luminous infrared galaxies which is enhanced by the starburst and AGN activities in Sect. 3, especially modelling of the redshift dependent infrared burst phase for ultraluminous infrared galaxies (ULIGs) from gas rich mergers at high redshift and a suppressed burst phase for gas poor mergers at low redshift; 3) in Sect. 4, we discuss the numerical simulations and compare the Monte Carlo results with the IRAS $60\,\mu m$ source counts from three major infrared sources (starburst galaxies, Seyferts and spirals). We check also the redshift distribution of these infrared sources which are brighter than $S_{60} \sim 10\,mJy$, calculate the integrated background level at wavelength of $60\,\mu m$, and make an extrapolation to $25\,\mu m$ and $100\,\mu m$ based on the model spectrum and souce counts. Finally, we give our conclusions.

2. Binary aggregation theory

The classical approach to aggregation phenomena is based on the Smoluchowski(1916) equation. We start with the continuous form:

$$\frac{\partial \mathrm{N(m,t)}}{\partial t} = \frac{1}{2}\int_{m_*}^{m-m_*} dm^{'} K(m^{'}, m-m^{'}, t) N(m^{'}, t) N(m-m^{'}, t) - N(m,t)\int_{m_*}^{m_{**}-m_*} dm^{'} K(m, m^{'}, t) N(m^{'}, t) \qquad (1)$$

where $N(m,t)$ is the mass distribution function in "comoving" form, which describes the number density of galaxies within the mass range $(m,\ m+dm)$ at cosmic time t. The mass $m \equiv M/M_*$ is normalized in terms of M_*, which is the mass corresponding locally to the standard characteristic luminosity L_* (see Peebles 1993). m_* and m_{**} represent the lower and upper limits on the masses of galaxies. Usually we can set $m_* = 0, m_{**} = \infty$ in case when m_* is actually much smaller than the total mass of considered system.

The kernel $K(m, m^{'}, t) = n_g(t) < \Sigma V(t) >$ reflects the interaction rate for each pair of masses $(m, m^{'})$, and depends on the mechanism and environment of such aggregations. n_g is the density of galaxies, it scales on average with the expansion of Universe as $n_g \propto (1+z)^3$; $V(t)$ is the relative velocity of the interacting pairs, and Σ is the cross section. The average of them runs over the galaxy velocity distribution.

In aggregation dynamics, the interaction kernel $K = n_g < \Sigma V >$ is the key point for driving the whole evolutionary process, which depends strongly on the environment structures.

In this context, we discuss simply the case when the colliding galaxies are in certain structures, thus the cross section could be assumed to be the hyperbolic encounter prescription by Saslaw (1985), Cavaliere et al. (1991, 1992), which is in the form:

$$\Sigma = \epsilon\left(\frac{V}{v_m}\right)\pi\left(r_m^2 + r_{m'}^2\right)\left[1 + \frac{G(m+m')}{r_m V^2}\right] \quad (2)$$

with $r_m = r_* m^{1/3}, v_m = v_* m^{1/3}$, where v_* and r_* are the velocity dispersion and the dark halo radius of the present M_* galaxy. The function $\epsilon\left(\frac{V}{v_m}\right)$ describes the decreasing efficiency of the aggregations with an increasing relative velocities, which could be determined by the N-body simulations (see, Richstone & Malumuth 1983).

Because of the uncertainty and the complexity of the components in the interaction kernel, such as the average density of galaxies in the environment $n_g(t)$, the relative velocity distribution of the aggregation pairs $V(t)$ and the interaction cross section Σ, the exact prescription of the interaction kernel is still poorly known. We will thus adopt in our simulation a simplified formula for the aggregation kernel $K(m, m', t)$ with separated time evolution term and the cross section term. We give the interaction kernel $K(m, m', t)$ as:

$$K(m, m', t) \propto t^k (m^{2/3} + m'^{2/3})\left[1 + \alpha(m^{2/3} + m'^{2/3})\right] \quad (3)$$

where t^k is the cosmic time evolution term. The free parameter k depends on the specific structures like clusters, filaments or sheets; α is a free parameter in our model, which describes the relative importance of two kinds of encountering (geometric collisions and focused interactions) in the cross section. The aggregation time scale is τ, and thus the aggregation rate is τ^{-1}, which is proportional to the interaction kernel $K(m, m', t)$ as $\tau^{-1} \propto K(m, m', t)$.

3. Modelling the ultraluminous infrared phase at high redshift

The binary aggregation dynamics and Monte Carlo simulations give us information about the evolution of the galaxy mass distribution function $N(m, t)$. What we can actually observe and use to constrain the galaxy evolution model is: 1) the luminosity functions of galaxies in general or with certain morphologies; 2) the source counts, redshift distributions and the background intensity from various Hubble Deep Field surveys and the background measurements.

In this section, we will discuss the conversion of the mass distribution function $N(m, t)$ by Monte Carlo simulation of a merger-driven galaxy evolution scenario to the observable luminosity function $N(L, t)$.

In this case, we need to know i) a simple prescription of mass-to-light ratio for starburst galaxies and AGNs; and ii) the bolometric correction for certain spectral characteristics, especially at infrared wavelengths.

A simple discussion of the mass-to-light ratio for the starburst galaxies is given by Cavaliere & Menci (1997) for the faint blue galaxies who estimate the luminosity of starburst galaxies by the gaseous mass of the galaxies and the dynamical time scales. The mass to light relation of those blue starburst galaxies is given as:

$$\frac{L}{L_*} = \left(\frac{M}{M_*}\right)^\eta \quad and \quad L_*(z) \propto f(z, \lambda_0, \Omega_0) \quad (4)$$

where $\eta = 4/3$; L is the bolometric luminosity and M is the mass of the galaxy; L_* is the local standard characteristic luminosity, with the corresponding mass M_* (Peebles 1993). $L_*(z) \propto f(z, \lambda_0, \Omega_0)$ represents a cosmological redshift dimming. Considering the large scale structure, Cavaliere & Menci (1997) gave a prescription of $f(z)$ being a function of dimensionality D of the large scale structure as $L_* \propto f(z) \propto (1+z)^{(3+D)/2}$. Studies of the origin of ultraluminous infrared galaxies such as Arp220, NGC1614, NGC3256 and IRAS18293-3413, show that the infrared luminosity of this kind of galaxies is about a factor of 20 higher than that of normal starburst galaxies, with a statistical relation of $L_{fir} \propto M_d T_d^5$ (Taniguchi & Ohyama 1998). The increase in both the dust mass M_d and the dust temperature T_d by starburst merger events could enhance the far infrared luminosities of starburst merging galaxies dramatically; we thus call them ultraluminous infrared galaxies (ULIGs). Because of the uncertainties of the gas/dust ratio and the complexity of the consequential heating of the dust grains, the mass-infrared luminosity correlation for the ultraluminous infrared galaxies is still unclear. In our calculation, we thus simply adopt the power law relation for the mass-to-infrared luminosity similar to that of starburst galaxies by Cavaliere & Menci (1997), with the exponent η increased by a factor of about two to simulate the situation of an enhancement of their infrared luminosity by about a factor of near 20 for a typical ULIGs of mass $\sim 10^{12}\,M_\odot$.

In our model, we basically assume that starburst and AGN activities which are triggered by the merger events at high redshift are more drastic than those of low redshift, simply because the mergers are usually between gas rich systems at high redshift and the progenitors of the low redshift mergers are already poor in cold gas. In this case, we assume in our model a redshift depenent infrared burst phase, which means the enhancement of infrared radiation from gas rich mergers at high redshift is much higher than that of low redshift. We simulate this effect with a power law suppression of the infrared burst luminosity simply as $L_{ir}(z - \triangle z) \propto L_{ir}(z)^{-\zeta}$ below a transition redshift $z \sim 1$, besides a normal redshift dimming defined in Eq. (4). This power law suppression means that the infrared luminous galaxies at the bright tail of the luminosity function become gas poor faster than the less luminous ones. On the other hand, choosing redshift $z \sim 1$ as a redshift transition for the gas rich mergers at high redshift and gas poor mergers at low redshift is based on the consideration that the cosmic time scale of $z \sim 1$ is about 3×10^9 years, which is approximately the time scale for the disk evolution (Lin & Pringle 1987), it probably indicates a stage when galaxies are becoming gas poor.

While the basic concept is clearly correct, the details of these assumptions are a bit crude and arbitrary, especially the assumptions for the transition redshift $z \sim 1$ and the consequential power law suppression of the infrared burst phase. But it seems that they are the important effects for the fitting of IRAS source counts in our simulation, especially the strong evolution at flux range $10\,mJy \sim 1\,Jy$. Varying any of the model parameters could influence more or less the evolution of the luminosity functions and the source counts finally. While all of the model parameters combine to influence the luminosity functions together, the impact from variation of one of the parameters such as $\alpha,\ D$ or η, probably still could be compensated by varying again other related parameters. As for the assumptions of transition redshift and the differential burst phase, there seems to be not much room left for the variation of these particular values. We checked the case when the transition redshift and the enhancement of the infrared burst phase η are both twice and half of the values in our model. Although we adjusted other parameters in order to approximately fit the observed local luminosity functions for the infrared luminous sources, it seems that they are far from giving an acceptable fit to the IRAS deep surveys (see Fig. 3). In this case, what we show here is only one of the most possible, realistic set of model parameters which could give the best fitting of available observations. Since our model is still too crude, we need probably further information about the evolution of infrared bright sources at high redshift, or the redshift distributions to high redshift, to give more robust model constraints. We will discuss this point again later.

4. Numerical simulation and discussion

We use a Monte Carlo inverse-cascading process to simulate the binary aggregation evolution of galaxies which is described by Eq. (1). In our simulation, we consider the initial galaxy mass distribution as a δ-function starting from redshift $z = 15$ and of mass $M = 2.5 \cdot 10^{10} M_\odot$ as an approximation. Since binary aggregation dynamics does not strongly depend on the initial condition, the memory of the initial condition will disappear after the transients and the mass distribution is independent of initial details with self-similar evolution. The specific discussion of this process was presented by Cavaliere et al. (1991, 1992) analytically and numerically.

In this case, evolution of the dwarf galaxies with mass less than $\sim 10^{10} M_\odot$ is not relevant to our results. Even for those dwarf galaxies of mass $\sim 10^{10}\,M_\odot$, we could see that their influence is not very important since our results only strongly depend on the evolution of infrared-luminous galaxies.

The large scale structures (LSSs), which have the advantage of a larger density and lower velocity dispersions compared with the field and the virialized clusters, present an ideal environment for galaxy-galaxy interactions to take place in. However, they are still quantitatively less understood both from the observational and theoretical point of view. In the paper about the evolution of faint blue galaxies, Cavaliere & Menci (1997) simply discussed the relation of the evolution of merger rate which is represented by the term t^k in Eq. (3) with different environments, such as the homogeneous "field", the virialized clusters or groups and the large scale structures (sheets and filaments).

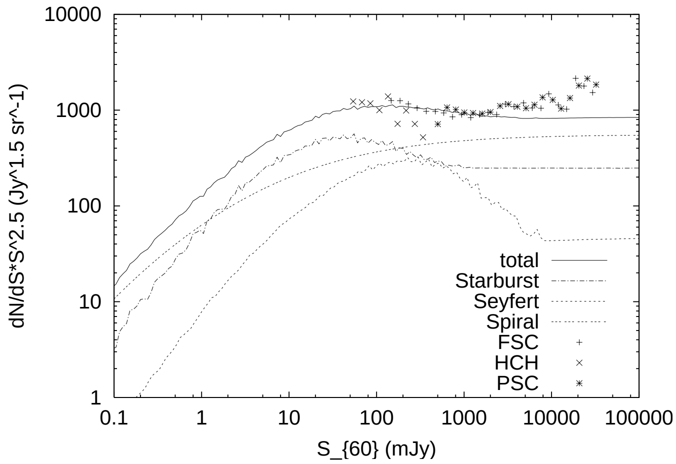

Fig. 1. This is our fit to the IRAS $60\,\mu m$ source counts using three major populations (starburst galaxies, Seyferts and spirals). The data are from IRAS Point Source Catalog (1985) with galactic latitudes $|b| \geq 50^\circ$ (PSC), Hacking et al. IRAS deep survey (HCH) (1987), FSC from deep surveys by Moshir et al. (1992) and Saunders (1990). We include here also the data by Gregorich et al. (1995) (GNS). It seems that the GNS data could overpredict the IR background and probably their sample has a biased detection (Bertin et al. 1997). The source counts of starburst galaxies and Seyferts are from the Monte Carlo simulation where the evolution of both activities are triggered by the galaxy-galaxy interactions/mergers during the structure formation and evolution. The spirals are assumed to have an almost constant star formation history since their formation. The wiggles in the curve are from the numerical inaccuracy of the binning during the Monte Carlo simulation. We consider the excess of the data of $\sim 10\,Jy$ to be a cosmologically local phenomenon, since we are inside a local sheet.

They include a free parameter D in the expansion of Universe for the Large Scale Structures.

$$f(z) = \left[\frac{1+z}{1+z_{in}}\right]^{(3+D)/2} \tag{5}$$

where z_{in} is the redshift when galaxy aggregation becomes effective; D is the dimensionality of the large scale structure, with $D = 2$ for sheetlike structures and $D = 1$ for filaments.

We can transform $f(z)$ to be a function of cosmic time t with the conversion of z to t for a flat universe (see Peebles 1993) as:

$$1 + z = \left(\frac{2}{3}\ \frac{t^{-1}}{H_0\,\Omega^{1/2}}\right)^{2/3} \tag{6}$$

so, we get $f(t) \propto t^k$, with k at range of (-4/3, -5/3) corresponding to $D = 1$ (filaments) and $D = 2$ (sheets).

In our simulation, the best fit structure for the luminous infrared galaxies are more like in the filaments with $D \sim 1$ and $k \sim -4/3$. The free parameter α in Eq. (3), which describes the relative weight of two kinds of interactions (geometric collisions or gravitationally focused interactions), is close to 0.9. But we know from our simulation, although varying these parameters could influence the final results, we probably still could compensate such effects with the adjustment of other relevant

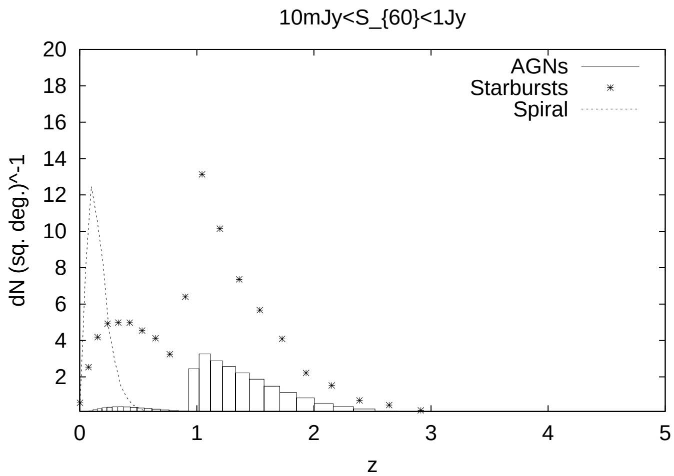

Fig. 2. This is the redshift distribution of starburst galaxies, Seyferts and spirals at flux density range of $10\,mJy \sim 1\,Jy$. The high redshift contribution ($z \sim 1.5$) is the ultraluminous infrared burst phase from the gas rich mergers of high redshift. The newest result from the ISO far-infrared survey at $175\,\mu m$ suggests that half of the FIRBACK sources are probably at redshifts greater than 1 (Dole et al. 1998), which gives further "motivation" for considering the model.

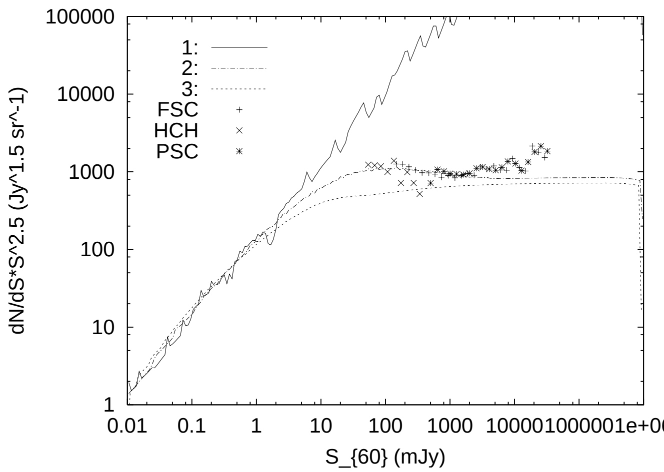

Fig. 3. This is the fitting of IRAS $60\,\mu m$ source counts for different transition redshift and the infrared burst phase η. case 1: $z = 2,\ \eta = 4.6$; case 2: $z = 1,\ \eta = 2.3$; case 3: $z = 0.5,\ \eta = 1.4$. We could see that case 2 is the best fit model parameters, meanwhile this set of parameters has the best fit also to the local luminosity functions of infrared luminous sources.

model parameters. So, what we show here is only one set of the most possible values which could give the best fit to the present observations.

In our model, we assumed a redshift dependent infrared burst phase for the merger triggered luminous infrared sources since a transition redshift $z \sim 1$, which means the enhancement of the far infrared luminosity of ULIGs from merging galaxies at high redshift is much higher than that of low redshift, simply because the high redshift mergers are usually between gas rich systems but between gas poor systems at low redshift. We found in our simulation although the assumption of the "differential burst" phase and the consequential power law supression is very arbitrary and crude, it is actually very important for the fitting of the strong evolution of IRAS $60\,\mu m$ source counts at flux range of $10\,mJy \sim 1\,Jy$. We show the results in Fig. 1, where the starburst galaxies and Seyferts are both assumed to be of the evolution which is driven by galaxy-galaxy mergers/interactions, while spirals basically keep a constant star formation history since their formation. We normalized our Monte Carlo simulation with the observed local luminosity function at $60\,\mu m$ of starburst galaxies from Saunders (1990) and Seyferts from Rush et al. (1993). Varying this transition redshift by a factor of two already has significant effects for the fitting of the source counts (see Fig. 3). But, since our model is still too crude, we probably only can say what we present here is a most probable scenario which gives best fit to the IRAS deep surveys and other available observations.

We consider in our simulation both types of AGNs with the assumption that the abundances of Seyfert I and Seyfert II at low redshift are approximately equal, which is suggested by the extended $12\,\mu m$ galaxy sample (Rush et al. 1993), and the recent Hubble Space Telescope imaging survey of nearby AGNs (Malkan et al. 1998). At high redshift ($z > 1$), we basically assume that the dust shrouded phase dominates and has a fraction of about 80% which is also suggested by the recent cosmic X-ray background (Gilli et al. 1999).

We choose NGC1068 IR spectra as the standard template for all the obscured AGNs at low redshift, while all "Type I" have a SED well represented by the mean SED(spectral energy distribution) of Seyfert I. We also assume that the early phase of these AGNs show the typical spectra such as the dust shrouded F10214+4724, and a phase poor in cold gas like the Cloverleaf quasar. The template of all these spectra were well modelled by Rowan-Robinson (1992), Rowan-Robinson et al. (1993) and Granto & Danese (1994), Granto et al. (1996, 1997).

In order to understand the contributing sources for the faint slope of the IRAS $60\,\mu m$ source counts, we plot out also the redshift distributions at flux range of $10\,mJy \sim 1\,Jy$ for the three important populations (starburst galaxies, Seyferts and spirals). We see from Fig. 2 that this faint slope comes from the low redshift starburst galaxies which peak at $z \sim 0.5$, the local spirals with mean redshift about 0.1 and the infrared burst phase of high redshift gas rich mergers which peaks at $z \sim 1.5$. Fig. 2 can be used to make powerful predictions about the redshifts of faint infrared sources. It seems to imply that about two-thirds of the faint $60\,\mu m$ sources should have redshifts from a little less than 1 to 2 (and that a fair fraction of those will be Seyferts). Recent ISO and NICMOS results of the high redshift ultraluminous infrared galaxies further increases our motivaton to consider the model (Dole et al. 1998, Benitez et al. 1998).

We calculate the background level νI_ν at $60\,\mu m$, it is approximately $1.9\,nW\,m^{-2}\,sr^{-1}$. We then extrapolate our simulation to wavelengths of $25\,\mu m$ and $100\,\mu m$. The background intensity are all shown in Fig. 4. Clearly, our extrapolation to $25\,\mu m$ is too low, compared to other models, which suggests that we have too low a mixture of intermediate dust temperatures in our templates for the emission spectra. However, our

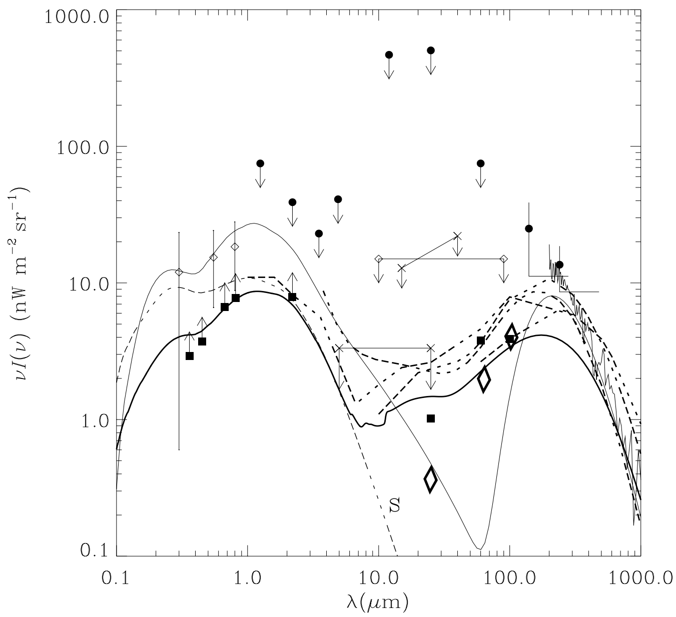

Fig. 4. The extragalactic IR background spectrum predicted by various evolution models and from the COBE results (Dwek et al. 1998). The DIRBE 2σ upper limits at 1.25 - 60 μm, and detections at 140 and 240 μm with $\pm 2\sigma$ error bars are represented by solid circles (Hauser et al. 1998). The FIRAS 125 - 5000 μm detection (Fixsen et al. 1997) is shown by a light dashed line; the UV-optical lower limits of Pozzetti et al. (1997) and the 2.2 μm lower limit (Gardner et al. 1997) are represented by solid squares. The "X" represent the upper limits on the EBL derived from TeV observations of Mrk 501 (Stanev & Franceschini 1998), and Mrk 421 (Dwek & Slavin 1994), and the open small diamonds represent the upper limits derived from the analysis of the fluctuations the DIRBE maps (Kashlinsky et al. 1996). The heavy solid curve represents the EBL spectrum calculated from the model with the UV/optical indicated SFR and the dust extinction effects (Dwek et al. 1998). Other models presented in the figure are the Backwards Evolution models of Malkan & Stecker (1998; dotted line), and of Beichman & Helou (1991; dashed dotted line); the Forward Evolution models of Franceschini et al. (1997, dashed line), and Guiderdoni et al. (1997, dashed triple dotted line); and the Cosmic Chemical Evolution model of Fall et al. (1996, thin solid line). The dashed line marked S represents the EBL spectrum calculated for a dust−free universe with the UVO cosmic star formation rate. The lower limits from IRAS counts at 25, 60 and 100 μm by Hacking & Soifer (1991) are also represented here by the solid squares. We plot out the revised lower limits at these wavelengths from our model with three bigger and thicker open diamonds "$\diamondsuit$".

60 μm background is very close to the lower end of the range empirically derived by Malkan & Stecker (1998), and so can be considered as a firm lower limit.

5. Conclusion

We described in this paper a Monte Carlo simulation of the inverse-cascading process of a merging-driven galaxy evolution scenario, where the evolution of infrared luminous starburst galaxies and AGNs may be triggered by the galaxy-galaxy interactions till even moderate redshift (say, $z < 1$) in the Large Scale Structures. We assume in our model a redshift dependent infrared burst phase which is based on the concepts that starburst and AGN activities triggered by gas rich mergers at high redshift are more drastic than those of low redshift, thus the enhancement of the far infrared luminosities in these ULIGs from the high redshift merger events are higher than that of low redshift. We simulate this effect in our calculation by a power law suppression of the infrared burst phase since a transition redshift $z \sim 1$. We adopt the transition redshift here at $z \sim 1$ simply because the cosmic time scale of $z \sim 1$ (3×10^9 years) is approximately the disk evolution time scale (Lin & Pringle 1987). Varying any of the model parameters could influence the evolution of luminosity functions of infrared luminous sources and thus influence the souce counts more or less. But, no matter how we adjust the relevant parameters, such as α, D and η, in order to get a strong decrease of merger rate with cosmic time around redshift $1 \sim 2$ for the source count fitting, it seems that the quick fading and suppression of the infrared burst phase at redshift $z \sim 1$ is a critical effect in our simulation to interpret the strong evolution of the IRAS 60 μm source counts at flux range $10\,mJy \sim 1\,Jy$. The impact from the variation of model parameters such as α, D and η, probably could be compensated by varying again other related parameters, thus their particular values in our model are not the critical points for such an evolutionary scenario; However, varying the transition redshift and the infrared enhancement η by a factor of two could strongly influence the final results. So, it appears that there is not much room for varying any of these parameters. Since our model is still too simple and crude, we probably need further information about the evolution of luminosity functions at high redshift for those infrared bright sources in order to give strong model constraints.

We checked also the redshift distribution of the three major infrared sources (starburst galaxies, Seyferts and spirals). We see from Fig. 2 that the mean redshift of starburst galaxies and AGNs which are brighter than $S_{60} \sim 10\,mJy$ is around $z \sim 0.5$ and quickly diminish till $z \sim 1$; a new population of high redshift ultraluminous infrared burst phase at mean redshift $z \sim 1.5$ then takes over. This seems to be consistent with the present groundbased NIR and optical/UV HDF surveys, where they failed to have enough detection of starburst galaxies near $z \sim 1$ (Ashby et al. 1992, Koo & Kron 1992). On the other hand, recent NICMOS/VLT and FIR/submm survey surely found a certain amount of infrared bright galaxies at high redshift, and the newest result of FIRBACK (Far Infrared Survey) with ISO shows that more than half of the ultraluminous infrared galaxies are at redshift $z > 1$ (Lilly et al. 1998, Benitez et al. 1998, Dole et al. 1998). This provides further motivation to consider their contribution to the strong evolution of the IRAS faint source counts at flux range of $10\,mJy \sim 1\,Jy$ in Fig. 1.

Meanwhile the new data of nearby blazars like Mkn501 by HEGRA team, appears to show an extension of the TeV γ ray spectrum till about 24 TeV, which sets an upper limit for the intergalactic infrared emission history during the structure formation (Aharonian et al. 1999). We calculated the background level at 60 μm from a possible merger driven starbursts and

AGNs scheme and a simple constant star formation history for the spiral galaxies. The infrared background level at $60\,\mu m$ is only $1.9\,nW\,m^{-2}\,sr^{-1}$, which is about half of those estimated by some previous papers and consistent with the upper limit from the new data of TeV γ ray spectrum of Mkn501 (Stecker 1999, Funk et al. 1998). Clearly, this is a strong lower limit, because any variation on our model could produce a higher background. The forth-coming data on direct source counts at infrared wavelengths will allow to further constrain the evolution of both AGN and starbursts, as well as the absorption at gamma rays near 10 TeV photon energy.

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