SIMULATING GALAXY SURVEYS WITH FIRST (PACS & SPIRE)

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Abstract

The next generation of submillimetre/millimetre instruments will provide us with a deeper insight into the mechanisms that rule galaxy formation. As the brightest starbursts are thought to be heavily obscured at optical wavelengths, the opening of this new window will complement the present observations, and enable a detailed investigation of the hierarchical merging of galaxies at remote epochs. In this context, we will present preliminary results of simulations currently developed for deep galaxy surveys with FIRST.
N−body simulations of galaxy mergers are being developed to produce realistic morphologies and star formation histories. A Schmidt law is used to account for the evolution of the stellar and gas content of each particle. These simulations will be gathered in a library, including the temporal information with a timestep of 10 Myr. We then build consistent spectra accounting for this star formation history at each resolution element of the simulations. These morphologies will be included in the framework of the GalICS hybrid model of hierarchical galaxy formation, which reproduces the main observational constraints. We intend to present synthetic maps with the characteristics of the FIRST PACS/SPIRE instruments and discuss the optimal strategy for deep surveys complemented with the ground-based ALMA project.

Key words: Galaxies: formation – Stars: formation – Missions: FIRST – macros: LaTeX

1. Introduction

The understanding of galaxy formation and evolution is a rapidly evolving field. The infrared/submillimetre sources detected with SCUBA/JCMT are compatible with the IR Background detected with COBE. The dusty galaxies, whose identification (redshift, morphology) is so difficult (e.g. Downes et al. 1999), probably escape current optical surveys. The new generation of instruments, which will become available in the coming years, will provide us with an unprecedented multi-wavelength view of these galaxies. From this perspective, we have undertaken a comprehensive simulation work that will be used to reproduce current observations and to predict forthcoming ones.

In this paper, we present the main framework of this study as well as preliminary applications to FIRST. In Section 2, we present a simple analytic model of starburst spectra and apply it to known starburst galaxies. In Section 3, the simulations of galaxy mergers being developed are described together with preliminary applications. In Section 4, we conclude with a short overview of the general framework of the GalICS hybrid model of hierarchical galaxy formation, within which the previous work will be incorporated.

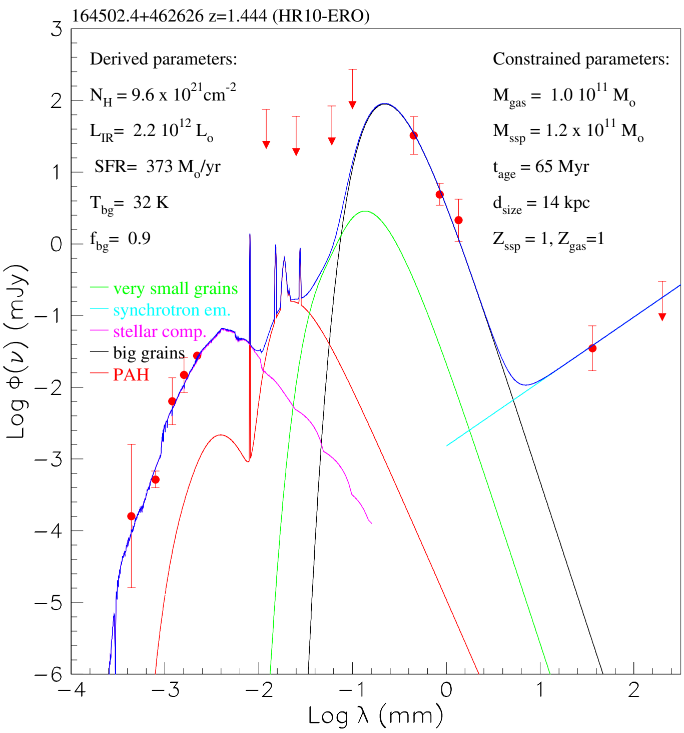

Figure 1. Best model for the spectra of the ERO J164502+4626.4 (HR10). The measurements have been published by Dey et al. (1999).

2. A simple model for galaxy spectra

We have built an analytic tool to produce spectra of starbursts, that will be used to produce images of galaxy mergers based on N-body/SPH simulations. Each of these

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spectra will be associated with each resolution element, and it is essential to have a restricted number of parameters. This minimal treatment is intended to model high-z galaxies and to get a deeper insight into the process of star formation.

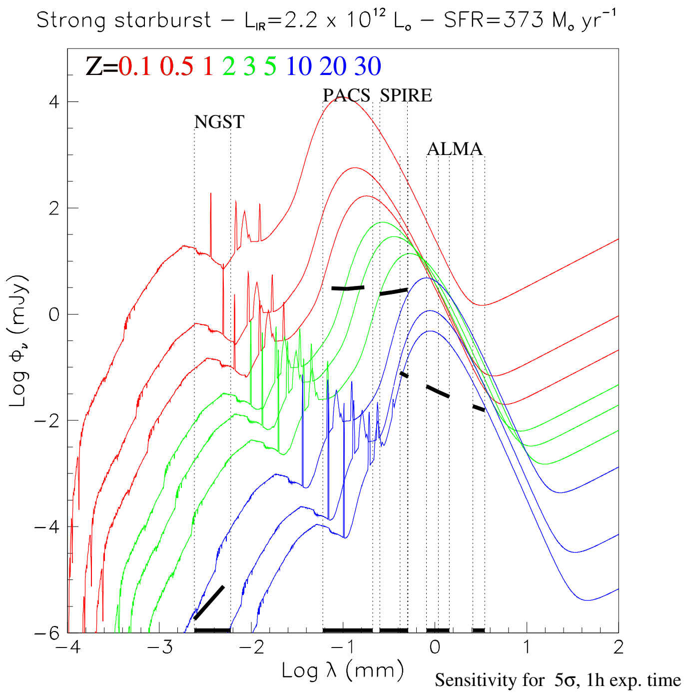

Figure 2. A typical strong starburst galaxy (HR10) spectra is extrapolated for different redshifts. The thresholds of PACS, SPIRE as well as NGST and ALMA are presented. Such galaxies could potentially be observed up to a redshift of 5.

2.1. Assumptions

First of all, we gathered a library of Simple Stellar Population (SSP) starting from PEGASE.2 (Fioc & Rocca-Volmerange (1997)) for different ages (1 Myr-20 Gyr) and different metallicities ($Z/Z_{\odot}$= 0.005, 0.02, 0.2, 0.4, 1., 2.5, 5). This library contains the sole stellar component. We then add the extinction based on local star-forming galaxies computed by Calzetti et al. (2000) depending on N_H and the gas metallicity. The energetic balance allows us to compute the luminosity L_{IR}, re-emitted in the infrared by the dust. In a similar fashion as Guiderdoni et al. (1998) and Devriendt et al. (1999) , we re-distribute this energy between 3 components (namely big grains, very small grains and PAH), following Désert et al. (1990). Last, the synchrotron emission is also included with a ν^{β} law ($\beta = -0.7$) following Condon et al. (1991).

2.2. Free parameters

This minimal modelling already has 6 free parameters:

- M_{ssp} : the mass of stars
- Z_{ssp} : the metallicity of the stars
- M_{gas} : the mass of gas
- Z_{gas} : the metallicity of the gas
- t_{ssp} : the age of the starburst
- d_{size} : the size of the galaxy or starburst encompassing the previous gas and stars

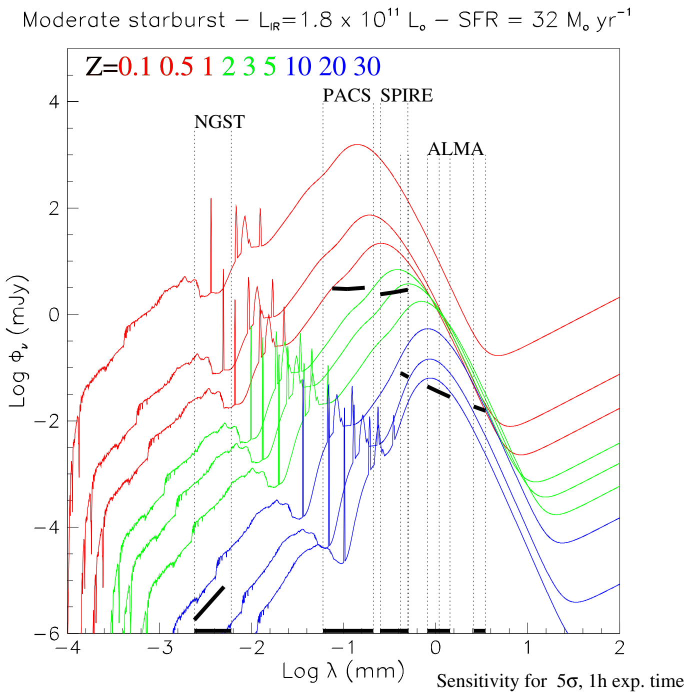

Figure 3. Same as Fig. 2 but for a moderate starburst. The characteristics are taken from NGC 6090 (at $z = 0.03$) as published by Calzetti et al. (2000). Galaxies up to a redshift of 2 can then be studied.

2.3. Modelling known galaxy spectra

In order to test the validity of this simple model, we fit known spectra of starburst galaxies. Given the small number of available measurements, we deliberately keep the metallicities to solar values. Firstly, we fit the optical part ($< 2\mu$m) in order to adjust M_{ssp}, M_{gas} and t_{ssp}. Secondly, the infrared/millimetre/radio measurements are used to define d_{size}.

The first example corresponds to a strong starburst with SFR$\sim$370$M_{\odot}$yr^{-1} (see Fig. 1 and 2) and the second one is a more moderate one with SFR$\sim$30$M_{\odot}$yr^{-1} (see Fig. 3). Although real galaxies are probably composed of old stellar populations and young starbursts, this simple model based on starburst assumptions is already a good fit.

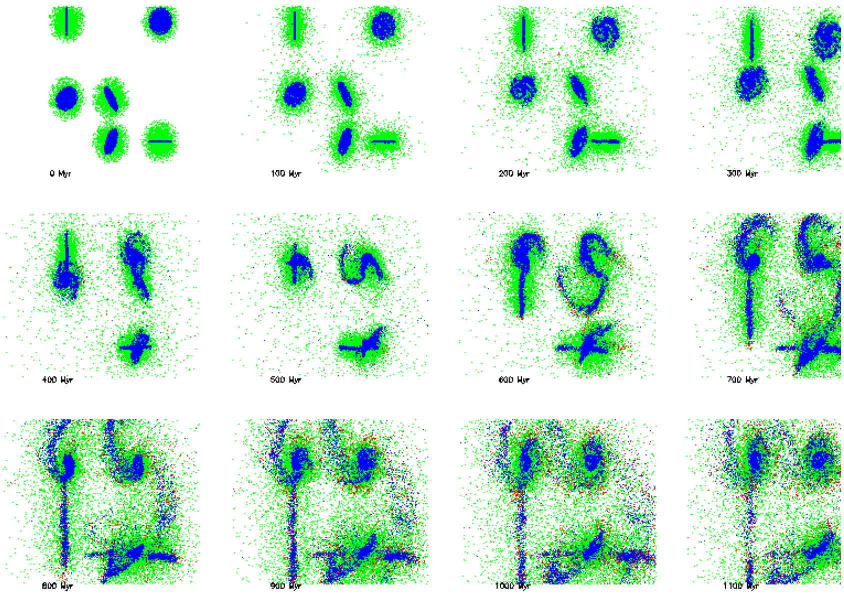

Figure 4. Sequence of a simulated merger, showing the evolution with a timestep of 100 Myr. Each panel presents a pair of galaxies in interaction with 3 different orientations, as follows: upper right=plane (XY), upper left=plane (ZY), bottom right=plane (XZ). The green points correspond to the dark matter, the blue ones to the gas and the red ones to the stars.

2.4. Application to FIRST

We use the spectra of Fig. 2 and 3 to study the sensitivity of PACS and SPIRE to high-z galaxies. These figures show starburst spectra at different redshifts as presented by Combes et al. (1999) together with the sensitivity of FIRST, ALMA and NGST. The wavelength coverage of PACS and SPIRE will be ideal to sample the maximum of the spectral luminosity distribution of starburst galaxies. These instruments will be unique to understand the luminosity budget and properties of the galaxies representative of the peak of the Madau curve (Madau et al., 1998), as well as the excitation conditions, which determine the infrared/millimeter flux. Indeed, as shown in Figures 2 and 3, a galaxy at redshift 5, detected in the optical by the NGST, might escape detection with FIRST if the starburst is not strong enough. In parallel, ALMA will be able to detect starburst galaxies up to $z = 30$ if they exist, though it will not be able to sample the peak below $z = 5$.

3. N-body simulations of galaxy mergers

3.1. Principle

We use these analytic starburst spectra to produce realistic maps of galaxy mergers, based on N-body simulations. We start from one N-body + hydrodynamics simulation (tree-code + SPH) of a galaxy encounter stored for different epochs. It is composed of 8 000 dissipative particles (hybrid: star or gas), 8 000 stellar particles and 8 000 particles for dark matter. We account for star formation with a Schmidt law ($\rho_{star} \propto \rho_{gas}^{1.5}$) for the hybrid particles, which thus encompass a variable fraction of gas and stars. In order to account for supernovae, the instant recycling approximation for the gas rejection into the interstellar medium is used with standard values for the yield.

Figure 4 displays preliminary simulations without the star formation and metallicity enrichment prescription for different epochs as well as different orientations. Although a single simulation can already be used to simulate a large variety of morphologies, we plan to generate several such simulations in order to span a reasonable range of possible morphologies.

3.2. Application

Figure 5 presents a very preliminary application of such a simulation for different epochs. Maps of such a merger at $z = 1$ are displayed as it could be observed by FIRST (PACS & SPIRE), NGST or ALMA. Whereas the NGST will be able to study the detailed morphology and possibly tidal arms, ALMA, after 1h of integration time, will only be able to detect the multiplicity of the source. The instruments of FIRST will sample the luminosity peak of the spectral energy distribution but will not be able to distinguish any signature of merging.

We currently extend this kind of simulation in a systematic way (different morphologies) and from a cosmological perspective (within GalICS framework) in order investigate the current open questions. Firstly, the galaxies that will be observed in the optical (e.g. with the NGST) will not be necessarily accessible to the IR/mm instruments, especially if the star formation activity is moderate. Secondly, the difficulties encountered to find optical counterparts for SCUBA sources are hoped to be overcome with the next generation of instruments. This simulation work will help to understand the multi-wavelength dependence of these high-z galaxies and the process of galaxy formation.

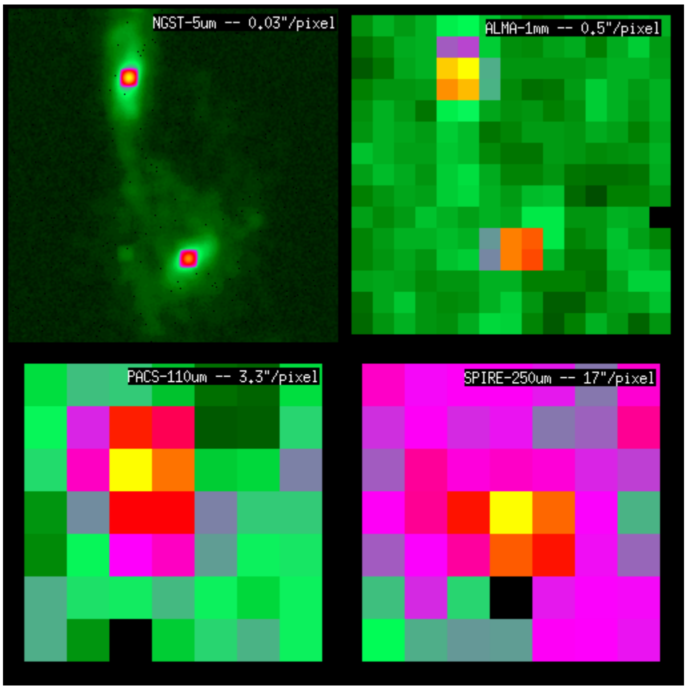

Figure 5. Preliminary projection of a merger at $z = 1$ ($L_{IR} = 2 \times 10^{12} L_{\odot}$) on a pixel grid with the characteristics of FIRST/PACS & SPIRE, NGST and ALMA. These images correspond to 1h integration time and account for the expected rms intrumental noise for each intrument.

4. GalICS model

The "hybrid" approach is a powerful tool to describe hierarchical galaxy formation. The GalICS model (for *Galaxies in Cosmological Simulations*, Hatton *et al.* 2001, Devriendt *et al.* 2001) uses a large cosmological N–body simulation (256^3 particles in a 150 Mpc box within a ΛCDM cosmology) achieved on the CRAY–T3E of the IDRIS computation centre. Halos with more that 20 particles are identified by the usual friend–of–friend algorithm, and a catalogue of haloes with a minimum halo mass of $1.7 \times 10^{11} M_{\odot}$ is built for each of the ~ 100 time outputs. Merging history trees are built from these 100 catalogues. Finally, the evolution and merging history trees are built for the galaxies. The processes of dissipative gas cooling and collapse, star formation, chemical evolution, stellar feedback are modelled along lines which are detailed in the papers. The UV to mm spectral energy distributions are computed from the STARDUST spectra (Devriendt *et al.* 1999). After halo merging, the satellite galaxies spiral down to the central galaxy with the dynamical friction time scale. Satellite–satellite merging is also taken into account. During the major mergers, a starburst light up and radiates mostly in the IR/submm range, and a bulge eventually forms. A new disk can form around this galaxy if it is at the cooling centre of its halo. The morphologies of the galaxies are fixed according to the B–band bulge to disk ratios. The final output at $z = 0$ includes about 70 000 galaxies, and the mass resolution progagates as an absolute magnitude resolution of $M_B = -18$. Fake images of deep fields can be achieved at any wavelength from the UV to the mm range from the output catalogues.

So far, the code includes only very crude recipes on how galaxies merge and how merging triggers a starburst event. As a first step, it is planned to generate fake images of deep galaxy fields at optical and IR/submm wavelengths from the catalogue of morphologies of interacting and merging galaxies described in section 3, by choosing the closest case to the initial conditions for the encounter fixed by GalICS. As a second step, the tree–code + SPH hydrodynamical simulations can be directly run from the galaxy merging trees with the initial conditions of GalICS. Such a program will allow us to assess the properties of mergers in a cosmological framework, and to study how this properties evolve with redshift. These fake fields will be used to study the observational strategy for deep galaxy surveys with *PACS* and *SPIRE*.

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