Chemodynamical evolution of interacting galaxies

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Abstract. We have undertaken numerical simulations of galaxy interactions and
mergers, coupling the dynamics with the star formation history and the chemical
evolution. The self-gravity of stars and gas is taken into account through a tree-
code algorithm, the gas hydrodynamics through SPH, and an empirical law such
as a local Schmidt law is used to compute star formation. The gas and stellar
metallicity is computed at each position, according to assumed yields, and the dust
amount is monitored. At each step the spectra of galaxies are computed, according
to simple radiative transfer and dust models. Initial conditions for these simulations
will be taken from a large-scale cosmological framework. The aim is to build a
statistically significant library of merger histories. The first results of the project
will be discussed, in particular on predictions about galaxy surveys at high redshift.

1. Introduction

Although the quiescent or “steady-state” mode of star formation is
dominant today at $z = 0$, it appears that most of the star formation in
the Universe might have occurred in starbursts. In this violent second
mode of star formation, the rate can be one or two orders of magnitude
larger than in the quiescent mode, during short periods of time of $\sim 10^8$
yr. The fraction of starbursts increases with redshift, as revealed for
instance by the submillimetric surveys (e.g. Carilli et al 2000) and the
star formation rate increases as $(1 + z)^m$, where $m$ is a power between
3 and 4, as shown by the Madau curve (see the review by Genzel &
Cesarsky 2000). This is due first to the frequency of mergers triggering
starbursts, that increases with a high power (Le Fèvre et al. 2000); and
second to the much larger efficiency of mergers to form stars, which
can be explained by:
– 1- a larger gas fraction in young galaxies – 2- smaller dynamical time-
scales, since the first haloes to form are the densest – 3- more unstable
galaxies, since the bulge-to-disc ratio increases with time.

To determine which are the most important parameters in the z-
evolution of mergers, we have undertaken numerical simulations. Our
aim is to couple dynamics with star formation, chemical enrichment,
multiphase physics of the interstellar medium, and to deduce the ob-
servational properties of these mergers, computing their total spectral
energy distribution (SED) from stellar, gas and dust emission.

2. The numerical model

The gravitational dynamics of the interactions is simulated with a
TREE-SPH code; since the aim is to gain a statistical view with a large
number of parameters explored, the number of particles is modest, 24,000, divided into stars: 8000, gas: 8000, and dark matter: 8000. The preliminary results presented here do not include the collisional molecular clouds (simulated by a sticky particles code). The smallest timescale is of the order of 1 Myr, the resolved sizes between 150 pc and 0.5 kpc, and the mass scale of $10^6 M_{\odot}$ for the gas (column gas density ranges from $2 \times 10^{20}$ to $10^{23} \text{ cm}^{-2}$).

The adopted star formation recipe is a “local” Schmidt law (i.e. at the resolution scale): the fraction of any gas particle transformed to stars is $\propto \rho^{n-1}$, where $\rho$ is the volumic gas density, and $n$ the power of the Schmidt law. To avoid a variable number of particles, the algorithm of hybrid particles is used (cf Mihos & Hernquist 1994): some particles are transiently partly gaseous, and partly stellar, until their gas fraction drops below 5%; they are then turned into pure stars, the gas being spread among the neighbours.

Two possibilities have been explored for the stellar mass loss:

– First, as often done, instantaneous recycling is assumed; most of the gas is re-injected by the massive stars with a short life-time, in the first few Myrs. With a Scalo IMF, with a mass spectrum from 0.1 to 100 $M_{\odot}$, 9% of the gas turned into stars is re-injected in the ISM quasi-instantaneously. The adopted yield (the ratio of the mass of ejected metals to the stellar mass) is $y = 0.02$. The energy of supernovae and stellar winds is partly re-injected in the ISM under the form of kinetic energy, through expanding velocity of the surrounding gas.

– Second, the mass loss is now spread over much larger time-scale (Gyrs), and up to 40% of the stellar mass can be lost, with a loss-rate approximated by an $\propto 1/t$ law (Jungwiert, Combes & Palous 2001). This brings significant changes, since large amounts of gas become available where it was consumed out in a burst.

3. First results

A simulation of two spiral discs merging at late redshift is plotted in fig 1. We first test the star formation recipe: does it reproduce the
Figure 2. **Left:** Derived “global” Schmidt law from a merger simulation run, where the various points correspond to the various epochs of a simulation (where $n = 1.2$), for the two galaxies separately (red and blue). The slope of $n = 1$ is indicated by the dash line. **Right:** Star formation rate as a function of time for the same run. The second peak follows the closest approach leading to merging, at $t=700$ Myr

"global" (i.e. over the whole galaxy) Schmidt law observed when the total surface density of stars formed over the disc is compared to the average gas surface density (Kennicutt 1998). To check that, the radii of the galaxies were computed as those containing 90% of the baryonic mass, and only the recent stars (formed over the last 100 Myr) were considered. A linear law is observed in most cases (fig 2, left), whatever the power of the “local” Schmidt law, provided that $n \leq 1.5$. For $n = 2$, this was not verified.

The star formation rate as a function of time reveals one or two peaks of starburst activity, depending on the relative orbits between the merging galaxies (fig 2, right). Starbursts are concentrated in the nuclei. Gradients of metallicity are washed out in the discs by the merger, although there still is a high metallicity peak in the nuclei.

4. **Observations of the mergers**

The results of the simulation are "observed" at different wavelengths, from the millimeter to optical, with a "pixel" size adapted to present or future instruments (NGST, ALMA, etc.). To obtain the SED of the galaxy systems, at each epoch and for each pixel, we compute a synthesis of stellar population according to their formation age and metallicity (from PEGASE, Fioc and Rocca 1997). This distribution of populations gives the unobscured optical SED. Then, from the gas in front of stars, its column density and metallicity, the extinction is computed for each pixel, and all the luminosity absorbed is re-radiated.
by dust in the far-infrared domain (cf fig 3). The dust model is derived from that of the Milky Way, and local starbursts (Melchior et al. 2001).

5. Preliminary conclusions
Although the limited spatial resolution prevents to take into account the details of star formation, the large-scale dynamical triggering mechanisms appear to be taken into account rather realistically. Up to now, only isolated mergers have been considered, which suffer from gas fueling problems. In the future, the systems will accrete external gas, depending on environment. In the next step, each simulation will be coupled to larger-scale cosmological simulations, providing boundary conditions.

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Figure 3. Application of our SED modelling to HR10 (Dey et al. 1999). We developed a Simple Stellar Population library derived from the PEGASE package (Fioc & Rocca-Volmerange 1997) for different ages and metallicities. For each element of resolution (e.g. pixel), we compute a spectrum as follows. With the stellar age and metallicity, we choose the stellar emission from this library. We add an empirical extinction – constrained by nearby starbursts by Calzetti et al. (2000) – on this stellar flux. The absorbed flux is reemitted in the IR. Relying on Désert et al. (1990), we distribute this flux into 3 dust components: big grains, small grains and PAH.