PROCEEDINGS OF SCIENCE

# Chemical and Dynamical Galactic Evolution in Smoothed Particle Hydrodynamics simulations

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We explore the evolution of an individual galaxy using Smoothed Particle Hydrodynamics simulations (Gadget-2 code). In order to follow the evolution of the baryonic component of the galaxy, the code includes gas cooling, star formation, gas and metal restitution from dying stars plus supernovae energy and chemical feedback (SNII and SNIa). We follow the formation and evolution of a disk-like galaxy and predict its final structure and its metallicity evolution. In this work preliminary results of a low resolution simulation are presented.

*Supernovae: lights in the darkness (XXIII Trobades Científiques de la Mediterrània)*
*October 3-5 2007*
*Mao, Menorca, Spain*

The evolution of chemical abundances in the Universe is nowadays a subject of great importance. Relevant issues are when and where the first metals were synthesized, and how they spread to enrich the individual host galaxies, as well as the intergalactic medium. To assess these issues it is necessary to couple chemical evolution with hydrodynamical evolution. We developed an algorithm to implement detailed chemical evolution in SPH models. Delayed gas restitution and different production timescales for metals are taken into account. The algorithm is specially conceived for SPH simulations with large numbers of particles, and for parallel SPH codes. This statistical approach is similar to the one used by Lia et al.[1]. We use this code to study galaxy formation and evolution in order to unveil how metals distribute in the ISM as well as in the IGM due to the galaxy winds.

## 1. The code

The code we use for our simulations is GADGET-2 [8], a parallel TreeSPH code capable of following a collisionless fluid, stars and dark matter, with the N-body method and an ideal gas by means of smoothed particle hydrodynamics (SPH). The original code allows to follow the evoultion of an adiabatic fluid; in the present case a spherical halo of dark matter and gas. In order to see how gas collapses in the center of the dark halo we need to implement radiative loses that drive the gas into star formation and to the subsequent metal release. So, in order to study the evolution of a galaxy we need to include the following ingredients in the code:

**Gas cooling** Radiative cooling is the crucial mechanism responsible for the condensation and collapse of baryonic component into galaxies and, inside galaxies, for the occurrence of star formation. We have taken the prescriptions from Sutherland & Dopita [9] that include different radiative processes for temperatures greater than 10.000 K and different metallicities.

**Star formation** The formation of stars is a poorly understood process, and therefore difficult to model properly. The most widely used strategy, and the one that we implement, consists in two steps. First, an element of fluid must satisfy the following conditions to be elegible to star formation (SF):
(i) The gas particle must be in a convergent flow (ii) the gas particle must be Jeans unstable (iii) the gas particle must remain cool during the collapse.
Secondly, the fluid element turns into stars according to a suitable star formation rate, which is deduced from the Schmidt law [7]. In our code, this SF law is seen as the probability that a single gas particle is completely transformed into a star particle in the next time-step.

$$Prob(SF) = 1 - exp(-c_* \frac{\Delta t}{\tau_{ff}})$$

where $c_*$ is the star formation efficiency, $\Delta t$ is the particle time-step and $t_{ff}$ is the free-fall time-scale.

**Gas restitution** Stars return part of their mass to the ISM through all their evolution in form of chemically processed gas. Like in the implementation of SF, we introduce this fenomena in a probabilistic way, associating a probability to the star particle in order to convert it again into gas. A star particle that borns has an equivalent mass of a single stellar population (SSP), and this population is described by an initial mass function (IMF) [6]. Lifetime associated to each star particle is calculated following the evolution equation from Tinsley [11], applied to a SSP: At time $t$, a star with mass $m$ and liftime $\tau$ that has born at $(t\text{-}\tau)$ returns to the interstellar medium (ISM) a quantity of mass $(m\text{-}m_r)$, where $m_r$ is the remnant mass of the star. For the whole SSP, the fraction of material ejected to the ISM is:

$$E(t) = \int_{m(t)}^{m_{max}} \frac{m - m_r}{m} \Phi(m) dm$$

where $m_{max}$ is the superior limit of the IMF and m(t) is the star with lower mass that dies and returns gas to the ISM at time t.

This rythm of ejection, that reaches one third after a Hubble time, is seen as the probability that a star particle converts again into gas. Differently as other codes, we only use this probability once for each particle: When a star particle is born immediately a lifetime is adjudged to it.

**Supernovae feedback** We consider SN rates as they enter the calculation of chemical evolution and feedback. Each star particle is considered as a SSP and the stellar mass distribution is taken from the IMF. Each star, belonging to the SSP, with mass up to $m_{up} = 6M_{\odot}$ explodes as a SNII so the rate of energy released from the whole star particle by this kind of explosions is:

$$E_{SNII}(t) = \varepsilon_{SNII} \int_{max[m(t),m_{up}]}^{m_{max}} \Phi(m) dm$$

where $\varepsilon_{SNII}$ is the energy released by a single explosion. SNIa rate is calculated by means of the observed rate of SNII/SNIa [5]. Energy feedback from SN explosions is introduced in the code as internal energy that heats the ISM. This heating inhibits star formation as it cancels cooling acting on gas particles and necessary for star formation. If this heating is strong enough it will be able to accelerate gas particles to the surrounding of the galaxy and even expel material to the IGM.

**Chemical enrichment** Stellar winds and supernova explosions enrich the sorrounding gas with metals and we assume that this chemical enrichment proceeds in two steps:
(i) Calculation of metal production by star particles.
(ii) Metal diffusion among gas particles.
Following Tinsley [11] again, we know that at time $t$ a star with mass $m$ and liftime $\tau$ that has born at $(t\text{-}\tau)$ returns to the interstellar medium (ISM) a quantity of mass $(m\text{-}m_r)$. Metallic

material ejected from this star is $m_z = y_z + Z_0(m - m_r)$, where $Z_0$ is the metallicity of the gas from wich the star formed and $y_z$ is the quantity of metals synthesized by nuclear reactions in the star. We adopt stellar yields by [5] and [2]. So, for the whole SSP the fraction of metals ejected at time $t$ is:

$$E_z(t) = \int_{m(t)}^{m_{max}} \left[ \frac{m_z}{m - m_r} \right] \Phi(m) dm$$

When the star particle turns into gas again, it carries this metal fraction that will distribute among its neighbours. We consider that the mechanism used is diffussion due to supernovae explosions:

$$\frac{dZ}{dt} = -\kappa \nabla^2 Z$$

We get the diffusion coefficient $\kappa$ from supernovae models [10] and the value derived is $9.25 \times 10^{16} km^2 s^{-1}$.

## 2. The simulation

We examine the formation of a galaxy under idealized settings that allow us to cleanly study the properties of our model. To this end we consider that the initial configuration of the system is a spherical virialized halo in isolation with a NFW ([3], [4]) density profile with a total mass of $10^{12} M_{\odot}$ and a baryonic fraction equal to 0.1. We assign to the halo a spin parameter $\lambda = 0.1$. Gas component is forced to collapse by radiative cooling while angular momentum induces it to a final disk rotating structure. This thin galactic disk experiences a high star formation burst at the initial collapse generating a big amount of metals due to massive stars. After that, star formation reduces drastically and the main source of metals release changes to the low mass stars range reaching an almost constant metallicity gas fraction. In figure 1 it can be seen the disk-like distribution of dark matter, stars and gas at 13 Gyr (upper, central and lower panels respectively).

## 3. Discussion and conclusion

Star formation occurs mostly at the first collapse (figure 2), achieving quickly the configuration of a disk of stars. Total gas metallicity becomes almost constant. Remaining gas at the end of the simulation is in the form of a thin disk surrounded by a halo. We study the effect of supernovae explosions in galactic gas (figure 3) and we see that the kinetic energy ejected is always smaller than the scape velocity of the galaxy. Since gravitational galactic field is strong, ejected material from supernova is not able to produce outflows of material. We have tested each of the ingredients included in the code successfully so we demonstrate the capability of the algorithm in investigating chemo-dynamical evolution of galaxies. Next step is simulating a set of different initial configurations in order to realize more accurate studies about the role of supernovae explosions in gas release and chemical enrichment of the inter-galactic medium.

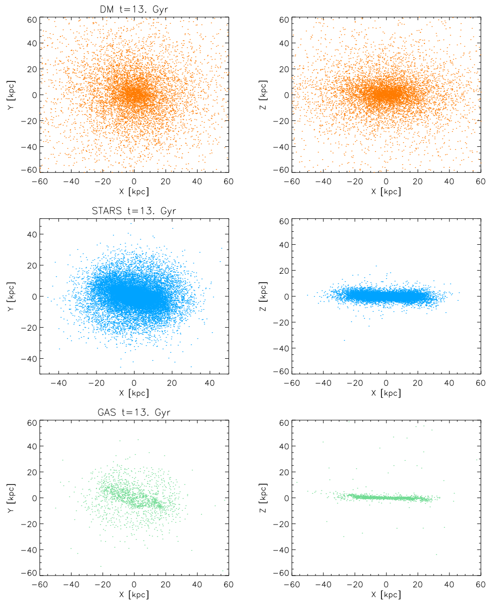

**Figure 1:** Final distribution of the galaxy at 13 Gyr: gas a the top panel, stars at the central one and dark matter at the bottom.

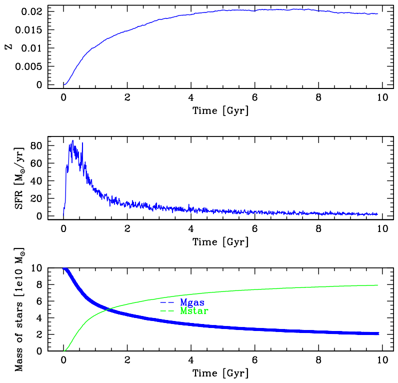

**Figure 2:** Chemical enrichment, star formation rate and mass evolution of the simulation

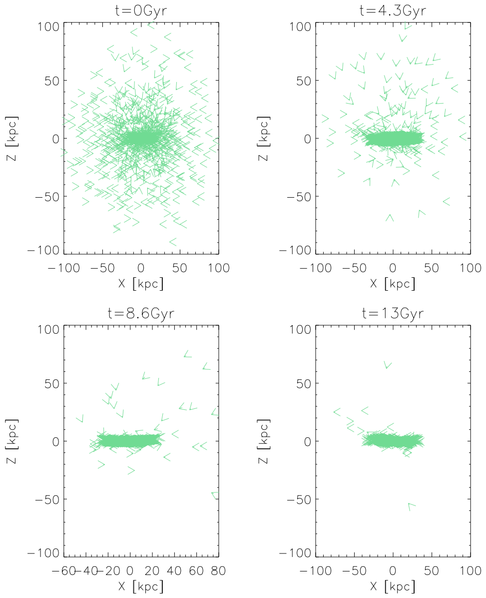

**Figure 3:** Time evolution of the gas flow. Labels in each panel give the elapsed time since the beginning of the simulation

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