Galaxy Formation and Chemical Evolution in Hierarchical Hydrodynamical Simulations

Cora, S. A.
Observatorio Astronómico de La Plata, Paseo del Bosque s/n, 1900 La Plata, Argentina.

Mosconi, M. B.
Observatorio Astronómico de Córdoba, Argentina.

Tissera, P. B.
Instituto de Astronomía y Física del Espacio, Buenos Aires, Argentina.

Lambas, D. G.
Observatorio Astronómico de Córdoba, Argentina.

Abstract. We report first results of an implementation of a chemical model in a cosmological code, based on the Smoothed Particle Hydrodynamics (SPH) technique. We show that chemical SPH simulations are a promising tool to provide clues for the understanding of the chemical properties of galaxies in relation to their formation and evolution in a cosmological framework.

1. Introduction

Recent observational data of the deep surveys (Canada-France Redshift Survey, Lyman-break galaxy surveys, the Hubble Deep Field) have provided information on the astrophysical properties of galactic objects at different stages of evolution of the Universe, making possible to carry out a suitable confrontation of different scenarios of structure formation and galaxy chemical evolution. Analytical models of chemical evolution are a very powerful tool to study galaxy formation (e.g., Chiappini et al. 1997 and references therein). However, they are restricted by several hypothesis (no inflows or outflows, instantaneous recycling, etc.), and cannot include dynamical and kinematical evolution of the matter according to its nature (dark matter, baryons) in consistency with a cosmological model. Steinmetz & Muller (1994) have implemented chemical enrichment in a code based on SPH for the first time (see also Raiteri, Villata & Navarro 1996). These works run prepared-cosmological initial conditions where the formation and evolution of one single object is studied.

Fully-consistent cosmological simulations have the advantage of providing a coherent well-described environment for all objects and a complete record of
their formation and evolution. We report here results of a chemical model implemented in a fully cosmological SPH code in hierarchical clustering scenarios.

2. Chemical Implementation and Results

We have developed a model to implement metal enrichment in a cosmological context based on the AP3MSPH code described by Tissera et al. (1997).

A star formation (SF) algorithm has been included based on the Smith law. Cold and dense gas particles that satisfy the Jean’s instability criterium are eligible to form stars. Each star cluster formed in a given baryonic particle at a SF episode is given by

\[ \Delta_{\text{star}} = C \left( \rho_{\text{gas}} / 2 \right)^{3/2} \Delta t, \]

where \( \Delta t \) is the integration time-step, \( \rho_{\text{gas}} \) the gas density of the particle and \( C \) the SF efficiency parameter. Baryonic particles carry out the information of the different stellar populations formed and the remanent gas mass (hybrid particles). When the gas reservoir of a particle is depleted, it is transformed in a star particle.

Particles are initially formed by Hydrogen and Helium in primordial abundances (\( H = 0.75, \) \( \text{He} = 0.25 \)). Metals are produced and ejected to the interstellar medium at the end of the life of stars. Most of the elements are produced by Type II supernovae (SNIe), except for the iron that is mainly produced by Type I supernovae (SNeI). Each \( \Delta_{\text{star}} \) formed can be followed up in time and the number of stars of a given mass estimated by assuming an Initial Mass Function (IMF). We adopted a Salpeter IMF with a lower and upper mass cut-off of \( 0.1 \) and \( 120 \, M_\odot \), respectively. We resort to Woosley & Weaver (1995) metal ejecta tables for SNeII. The adopted nucleosynthesis prescriptions for Type Ia SNe are taken from Thielemann, Nomoto & Hashimoto (1993). Type Ib SNe are assumed to be half the total number of SNeI and to produce only iron (\( \approx 0.3 M_\odot \) per explosion). We assume that the life time of binary stars that finish their lives as SNI (\( t_{\text{SNI}} \)) is \( \approx 0.5 - 1 \) Gyr. Ejected metals are distributed within the neighboring sphere of the particle where a \( \Delta_{\text{star}} \) is formed according to the SPH technique. Hydrogen and Helium are proportionally decreased according to the metal mass received by the particle (see for details Mosconi et al. 2000).

Given an IMF, the free parameters of our chemical model are \( C \), the relative rate of different types of supernovae (\( \Theta_{\text{SN}}=\text{SNRII}/\text{SNRI} \)) and \( t_{\text{SNI}} \). The effects of thermal or kinetic energy injection into the ISM due to SN explosions are not included in this work.

We performed SPH simulations consistent with a Cold Dark Matter (CDM) spectrum with \( \Omega = 1, \) \( \Lambda = 0, \) \( \Omega_b = 0.1, \) and \( \sigma_8 = 0.67 \). We used \( N = 262144 \) particles (\( M_{\text{part}} = 2.6 \times 10^8 M_\odot \)) in a comoving box of length \( L = 5 h^{-1} \) Mpc \( (H_0 = 100 h^{-1} \) km s\(^{-1}\) Mpc\(^{-1}\), \( h = 0.5 \)). The simulations performed (\( S1, S2, S3, S4 \)) share the same initial conditions but have different SF and SN parameters (see Figure 1 for values of these parameters).

We identify galaxy-like objects (GLOs) at \( z = 0 \) at their virial radius (\( \delta \rho / \rho \approx 200 \)) and consider only those with more than 250 baryonic particles within their virial radius.

In hierarchical clustering scenarios, the SF process in GLOs is affected by mergers and interactions (Tissera 2000, see also observational evidence in Barton et al. 1999). In our simulations, we found that SF rate histories can be described as series of starbursts superposed to a continuous component.
For each GLO we can also follow the evolution of the metallicity of the stellar component and calculate the age-metallicity relation (AMR; e.g. Rocha-Pinto et al. 2000). The mean AMRs estimated for our GLOs show the expected trend with high metallicity stars forming at more recent times in agreement with observations. The dispersion found in the simulations indicates the existence of coeval SF sites of different metallicities at a given time. The values and trend of these relations depend on the particular evolutionary history of each GLO, and the SF and SN model parameters (see Tissera et al. 2000 for details).

The [O/Fe] versus [Fe/H] is an important observational constrain for chemical models and may give information on the chemical history of our Galaxy. We estimated this relation for our GLOs. Figure 1 shows a typical example where we can see how the SN and SF parameters affect the distributions. These abundance relations also depend on the the evolutionary history of each GLO.

The chemical abundances in the ISM in gas-rich galaxies allows to trace the evolution of individual galaxies, being HII regions and early B-type main sequence objects the most accesible probes of interstellar abundances. Fairly steep negative gradients are found: $-0.07 \pm 0.01$ dex Kpc$^{-1}$ within $6 < R_G < 18$ Kpc for oxygen (Smartt & Rolleston 1997). Figure 2 shows abundance gradients of the oxygen for GLOs 596 and 325 as examples. The curves represent the mass-weighted averages of the metal abundances at each particle position: they clearly show negative abundance gradients. The slopes of the calculated gradients range from $-0.01$ to $-0.4$ dex kpc$^{-1}$, in agreement with observations. The differences in the abundance gradient slopes for a given GLO are due to the SF mechanism and SN parameters, and the fact that we are only including gas in hybrid particles.

The slopes of GLO 325 are less pronounced than those of GLO 596. The different behaviour may be due to the fact that the gas in GLO 596 forms a well-defined disk, while GLO 325 is a clear spheroid, indicating that their histories of formation and evolution have been very different.

To sum up, in our simulations, GLOs have different evolutionary history in consistency with a hierarchical clustering scenario that affect their SF rates and chemical evolution. This chemical model can take all these physical processes into account, resulting in a powerful tool to study galaxy formation.

References

Barton, E. J., Geller, M. J., & Kenyon, S. J. 1999, A&AS, 195, 2104
Chiappini, C., Matteucci F., & Gratton, R. 1997, ApJ, 477, 765
Gratton, R., Cannetta, E., Matteucci, F., & Sneden, C. 1996, in Formation of the Galactic Halo, Inside Out, ed. H. Morrison & A. Sanajedinii, 92, 307
Mosconi, M. B., Tissera, P. B., Lambas, D. G., & Cora, S. A. 2000, MNRAS, submitted
Figure 2. Oxygen abundance gradient for gas in hybrid particles of GLOs 596 and 325 in experiments S1 (thick full line), S2 (thick dashed line), S3 (thin dashed line) and S4 (thin full line).

Raiteri, C. M., Villata, M., & Navarro, J. F. 1996, A&AS, 315, 105
Rocha-Pinto, H. J., Maciel, W. J., & Flynn, C. 2000, A&A, submitted (astro-ph/0001383)
Smartt, S. J., & Rolleston, W. R. 1997, ApJ, 481, L47
Steinmetz, M., & Müller, E. 1994, A&A, 281, L97
Thielemann, F. K., Nomoto, K., & Hashimoto, M. 1993, in Origin and Evolution of the Elements, ed. N. Prantzos, E. Vangoni-Flam, & M. Cassé (Cambridge University Press), 299
Tissera, P. B., Lambas, D. G., & Abadi, M. G. 1997, MNRAS, 286, 384
Tissera, P. B. 2000, ApJ, 534, 636
Tissera, P. B., Mosconi, M. B., Cora, S. A., & Lambas, D. G. 2000, in preparation
Woosley, S. E., & Weaver, T. A., 1995, ApJS, 101, 181
This figure "coras1.jpg" is available in "jpg" format from:

http://arxiv.org/ps/astro-ph/0007072v1