DYNAMICAL SPH + N–BODY CODE FOR CHEMO–PHOTOMETRIC EVOLUTION OF DISK GALAXIES

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The chemical and photometric evolution of star forming disk galaxies is investigated. Numerical simulations of the complex gasdynamical flows are based on our own coding of the Chemo – Dynamical Smoothed Particle Hydrodynamical (CD – SPH) approach, which incorporates the effects of star formation. As a first application, the model is used to describe the chemical and photometric evolution of a disk galaxy like the Milky Way.

INTRODUCTION

Galaxy formation is a highly complex subject requiring many different approaches of investigation. Recent advances in computer technology and numerical methods have allowed detailed modeling of baryonic matter dynamics in a universe dominated by collisionless dark matter and, therefore, the detailed gravitational and hydrodynamical description of galaxy formation and evolution. The most sophisticated models include radiative processes, star formation and supernova feedback, *e.g.*, [8, 13, 6].

The results of numerical simulations are fundamentally affected by the star formation algorithm incorporated into modeling techniques. Yet star formation and related processes are still not well understood on either small or large spatial scales. Therefore, the star formation algorithm by which gas is converted into stars can only be based on simple theoretical assumptions or on empirical observations of nearby galaxies.

Among the numerous methods developed for modeling complex three dimensional hydrodynamical phenomena, Smoothed Particle Hydrodynamics (SPH) is one of the most popular [10]. Its Lagrangian nature allows easy combination with fast N–body algorithms, making possible the simultaneous description of complex gas-stellar dynamical systems [6]. As an example of such a combination, an TREE – SPH code [7, 11] was successfully applied to the detailed modeling of disk galaxy mergers [9] and of galaxy formation and evolution [8]. A second good example is an GRAPE – SPH code [13, 14] which was successfully used to model the evolution of disk galaxy structure and kinematics.

MODEL

The hydrodynamical simulations are based on our own coding of the Chemo – Dynamical Smoothed Particle Hydrodynamics (CD – SPH) approach, including feedback through star formation (SF). The dynamics of the “star” component is treated in the frame of a standard N–body approach. Thus, the galaxy consists of “gas” and “star” particles. For a detailed description of the CD – SPH code (the star formation algorithm, the SNII, SNIa and PN production, the chemical enrichment and the initial conditions) the reader is referred to [1, 2]. Here we briefly describe the basic features of our algorithm.

We modify the standard SPH SF algorithm [8, 13, 14], taking into account the presence of chaotic motion in the gaseous environment and the time lag between the initial development of suitable conditions for SF, and SF itself.

Inside a “gas” particle, the SF can start if the absolute value of the “gas” particle gravitational energy exceeds the sum of its thermal energy and energy of chaotic motions:

$$\mid E_i^{gr} \mid > E_i^{th} + E_i^{ch}. \tag{1}$$

The chosen “gas” particle produces stars only if the above condition holds over the time interval exceeding its free-fall time:

$$t_{ff} = \sqrt{\frac{3 \cdot \pi}{32 \cdot G \cdot \rho}}. \tag{2}$$

We also check that the "gas" particles remain cool, *i.e.*, $t_{cool} < t_{ff}$. We rewrite these conditions following [11]:

$$\rho_i > \rho_{crit}. \tag{3}$$

We set the value of $\rho_{crit} = 0.03$ cm^{-3}.

When the collapsing particle i is defined, we create the new "star" particle with mass m^{star} and update the "gas" particle m_i using these simple equations:

$$\begin{cases} m^{star} = \epsilon \cdot m_i, \\ \\ m_i = (1 - \epsilon) \cdot m_i. \end{cases} \tag{4}$$

In the Galaxy, on the scale of giant molecular clouds, the typical values for SF efficiency are in the range $\epsilon \approx 0.01 \div 0.4$ [4, 16].

We did not fix this value but rather also derived ϵ from the "energetics" condition:

$$\epsilon = 1 - \frac{E_i^{th} + E_i^{ch}}{\mid E_i^{gr} \mid}. \tag{5}$$

At the moment of birth, the positions and velocities of new "star" particles are set equal to those of parent "gas" particles. Thereafter these "star" particles interact with other "gas" and "star" or "dark matter" particles only by gravity.

For the thermal budget of the ISM, SNIIs play the main role. Following to [8, 6], we assume that the energy from the explosion is converted totally to thermal energy. The total energy released by SNII explosions (10^{44} J per SNII) within "star" particles is calculated at each time step and distributed uniformly between the surrounding "gas" particles [12].

In our SF scheme, every new "star" particle represents a separate, gravitationally bound, star formation macro region (like a globular clusters). The "star" particle has its own time of birth t_{begSF} which is set equal to the moment the particle is formed. After the formation, these particles return the chemically enriched gas into surrounding "gas" particles due to SNII, SNIa and PN events.

We concentrate our treatment only on the production of ^{16}O and ^{56}Fe, yet attempt to describe the full galactic time evolution of these elements, from the beginning up to present time (*i.e.*, $t_{evol} \approx 15.0$ Gyr).

In our calculations and as a first approximation, it is assumed that the model galaxy halo contains the CDMH component with Plummer – type density profiles [5]:

$$\rho_{halo}(r) = \frac{M_{halo}}{\frac{4}{3}\pi b_{halo}^3} \cdot \frac{b_{halo}^5}{(r^2 + b_{halo}^2)^{\frac{5}{2}}}. \tag{6}$$

Therefore, for the external force acting on the "gas" and "star" particles we can write:

$$-\nabla_i \Phi_i^{ext} = -G \cdot \frac{M_{halo}}{(\mathbf{r}_i^2 + b_{halo}^2)^{\frac{3}{2}}} \cdot \mathbf{r}_i. \tag{7}$$

The code also includes the photometric evolution of each "star" particle, based on the idea of the Single Stellar Population (SSP) [3, 15].

At each time – step, absolute magnitudes: M_U, M_B, M_V, M_R, M_I, M_K, M_M and M_{bol} are defined separately for each "star" particle. The SSP integrated colours (UBVRIKM) are taken from [15]. The spectro – photometric evolution of the overall ensemble of "star" particles forms the Spectral Energy Distribution (SED) of the galaxy.

We do not model the energy distribution in spectral lines nor the scattered light by dust. However, according to [15] our approximation is reasonable, especially in the UBV spectral brand.

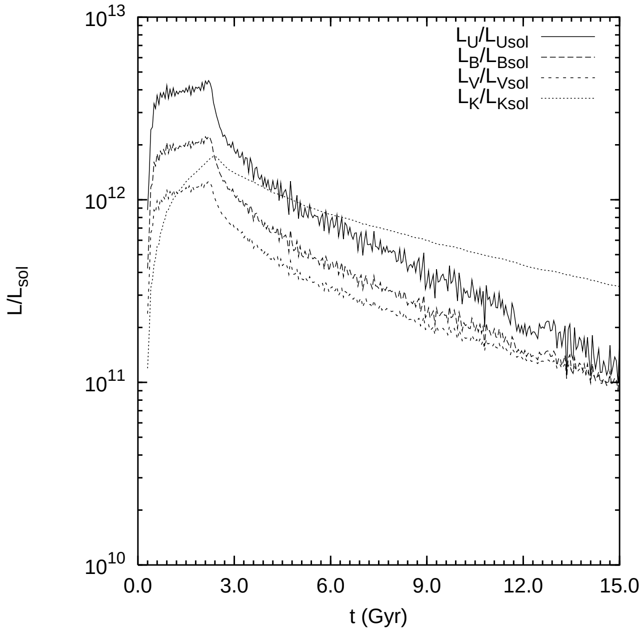

Figure 1: Luminosity evolution of the model

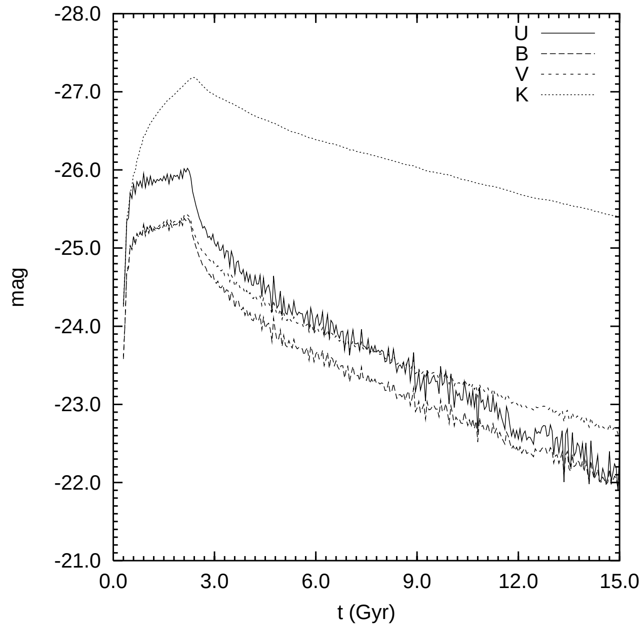

Figure 2: Photometric evolution of the model

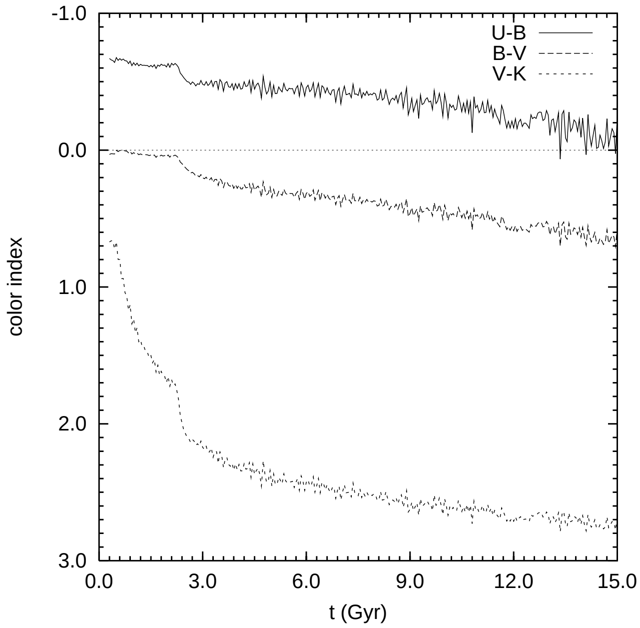

Figure 3: Color index evolution of the model

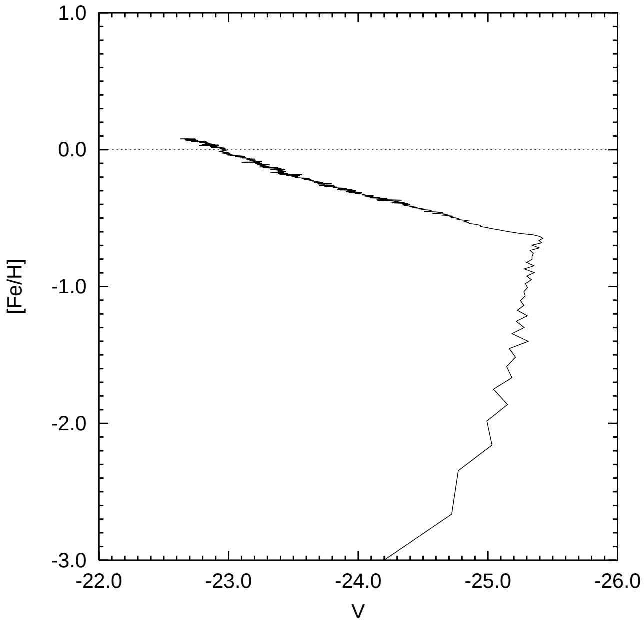

Figure 4: Evolution of model in the [Fe/H] *vs.* V plane

RESULTS

The model presented describes well the time evolution of the basic chemical and photometric parameters of a disk galaxy similar to the Milky Way. The metallicity, luminosity and colors obtained are typical of such disk galaxies.

- Figure 1. Luminosity evolution of the model galaxy.
- Figure 2. Photometric evolution of the model galaxy.
- Figure 3. Color index evolution of the model galaxy.
- Figure 4. Evolution of the model galaxy in the [Fe/H] *vs.* V plane.

This simple model provides a reasonable, self–consistent picture of the processes of galaxy formation and star formation in the galaxy. The dynamical, chemical and photometric evolution of the modeled disk-like galaxy is coincident with observations for our own Galaxy. The results of our modeling give a good base for a wide use of the proposed SF and chemical enrichment algorithm in other SPH simulations.

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