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Simulating the Formation and Evolution of Early-Type Galaxies: Multi-phase treatment of the ISM, Star Formation and Feed-back

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Abstract. We present the preliminary results of a "two-phases" description of the ISM suited to NB-TSPH models of galaxy formation and evolution.

Introduction. The interstellar medium (ISM) of a galaxy is made by at least four, nearly independent, gaseous phases: (i) the very cold, dense and clumpy molecular clouds; (ii) the warm, neutral gas surrounding the molecular clouds; (iii) the hot fully ionized tenuous material; (iv) and finally the very hot and rarefied coronal gas expelled by supernova (SN) explosions. Furthermore, stars are observed to preferentially form inside the molecular component. The four phases cannot be properly described by the standard Smooth Particle Hydrodynamics (SPH), which is designed to deal with a one-phase medium (Marri & White 2003), and even more important the whole gas content cannot be used to evaluate the star formation (SF) rate. To model this complicated situation with the Padua NB-TSPH code of galaxy formation and evolution (Carraro et al. 1998; Merlin & Chiosi, 2006 and references) we consider (and suitably modify) the *sticky particles* algorithm of Levinson & Roberts (1981) in which the "cold particles" are meant to represent self-gravitating clouds of molecular and neutral hydrogen, i.e. two of the above phases lumped together. In brief, a hot gas particle is turned into a cold gas particle if it is cooler than a threshold temperature, denser than a threshold density, belonging to a convergent flow, and losing thermal energy. When a gas particle becomes cold, it immediately loses its SPH properties. Therefore it can freely move across the tenuous ISM without feeling drag forces. A cold particle is supposed to be made of two components of different temperature: the "very cold" part corresponding to the molecular core and the surrounding warm one. The evolution of the two components by thermal instability is conceived in such a way that as the warm part cools down the mass of the "very cold" one increases so that their relative densities change (at given total volume of the particle). A "very cold" particle is thus formed. This is similar to what has been suggested by Springel & Hernquist (2003) in cosmological context. The evolution of the "very cold" particles is then governed only by gravity, radiative cooling, cloud-cloud collisions (which dissipate kinetic energy), and SN feed-back. A "very cold" gas particle is eventually turned into a star particle according to the Schmidt (1959) law, however interpreted in the probabilistic manner proposed by Lia et al. (2002). Star particles can later be turned back into gas, as a result of SN explosions. SNs release energy and metals to the ISM, leading to the evaporation of the nearby clouds and thus self-regulating the SF process.

Results. The above model has been used to simulate the formation and evolution of a galaxy whose initial conditions are derived from cosmological density perturbations according to GRAFIC2 of Bertshinger (2001) (see Merlin & Chiosi 2006 for details). The proto-galaxy has total mass (DM+BM) of $\sim 2 \times 10^{11} M_{\odot}$ and radius of 20 kpc. Each component is described by $\sim$ 7000 particles. The BM is initially in form of gas. The cosmological scenario is the W-Map3 ΛCDM. The proto-galaxy is framed into the conformal Hubble flow, and it is followed from the initial redshift z $\sim$ 60 down to z $\sim$ 1. Baryons follow the DM perturbations until they heat up by mechanical friction, radiative cooling becomes really efficient, the first cold clouds begin to form, and eventually stars are born. Owing to the mass resolution, each star particle has the mass size of a star cluster, in which real stars distribute according to a given initial mass function. In a star particle SN explosions may eventually occur. They release energy thus causing the evaporation of nearby clouds and eventually quenching SF. Two important features of the model are shown in Fig.1. The left panel displays the SF rate ($M_{\odot}$ per year) vs age, the right panel the spherically averaged star surface density profile at z $\sim$ 1 (dots). The SF consists of a single, prominent episode at high redshifts followed by a long tail. The formation of the galaxy is completed at z $\sim$ 1.5. The mean metallicity is about $\sim$ 75% solar. Likely, the stellar component has already relaxed to the Sersic (1968) profile with $m \sim 4.3$ (solid line). Finally, the hot gas, heated by SN explosions, causes strong galactic winds.

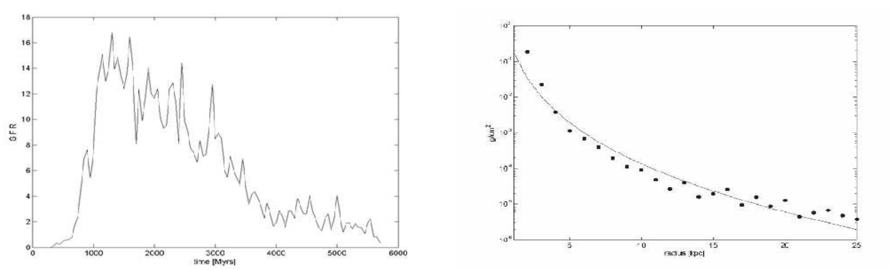

Figure 1. Left: SF rate vs time. Right: Surface density profile of star particles

Discussion. Owing to the early, intense burst of SF, the present model may reproduce many features of the so-called EROs (see e.g. Bundy et al. 2005). Fine tuning of the model parameters may yield results that closely fit many observational properties of early-type galaxies.

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