Formation and Evolution of Galaxy Bulges
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SPH simulations of the chemical evolution of bulges

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Abstract. We have implemented a chemical evolution model on the parallel AP3M+SPH DEVA code which we use to perform high resolution simulations of spiral galaxy formation. It includes feedback by SNII and SNIa using the Q_{ij} matrix formalism. We also include a diffusion mechanism that spreads newly introduced metals. The gas cooling rate depends on its specific composition. We study the stellar populations of the resulting bulges finding a potential scenario where they seem to be composed of two populations: an old, metal poor, α-enriched population, formed in a multiclump scenario at the beginning of the simulation and a younger one, formed by slow accretion of satellites or gas, possibly from the disk due to instabilities.

Keywords. galaxies: abundances, galaxies: formation, galaxies: bulges, methods: n-body simulations

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1. Method

For the chemical enrichment, we adapt the Q_{ij} formalism (Talbot & Arnett 1971) to the SPH method, thus accounting for the nucleosynthetic sources of each element created in star particles. The Q_{ij} matrices explicitely depend on the total metallicity Z. The star particles create new elements at each timestep and release them to the closest gas neighbor. A SPH diffusion algorithm then accounts for the redistribution of elements in the gas due to interstellar turbulence.

For the cooling rate, we use the Mappings III code (Sutherland & Dopita 1993) to compute the cooling function of $\sim 10^5$ different compositions, all of them extracted from full cosmological simulations. We then apply a dimension reduction regression (Li 1991) algorithm to make the cooling functions dependent on a single parameter. We thus keep the dependence on 16 elemental abundances without high computational cost (see Martínez-Serrano *et al.*, in preparation for details on the chemical evolution and coling models).

2. Results: bulges from cosmological simulations

We have run three high resolution cosmological simulations to obtain three spiral galaxies using the multimass technique. All three objects have been extracted from a single low-resolution (2×64^3) full ΛCDM cosmological simulation with parameters $(\Omega_M, \Omega_\Lambda, \Omega_b, h, \sigma_8, L) = (0.3, 0.7, 0.04, 0.7, 1, 10$ Mpc) that included all the processes described above. The baryonic mass resolution for the resimulation of each of the objects is $(m_{b1}, m_{b2}, m_{b3}) = (29.24, 3.51, 3.51)\, 10^5$. These objects have good dynamical properties (see contributed talk by Domínguez-Tenreiro in this volume), as well as colors and sizes.

The SFRH in the bulge have two clearly differenciated stages. The first (namely old) stage is a multiclump-dominated phase with a high SFR and the second (namely young)

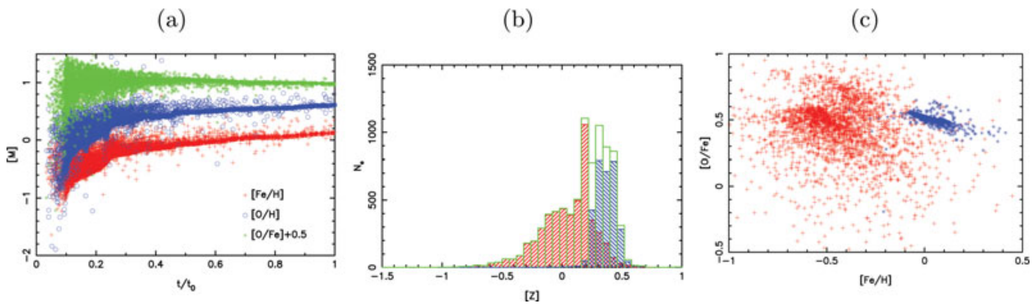

Figure 1.

stage to be more quiescent with star formation arising mainly due to gas infall. We find that the separation between both phases is at $t_c \simeq 0.32 t_0$ or $z_c \simeq 1.5$.

The age-metallicity relation for the present bulge stars (Fig. 1-a) shows this split between both phases as a change in the slope of the metallicity at t_c. [O/H] grows faster than [Fe/H], producing a higher [O/Fe] relation for stars formed at earlier times.

The metallicity distribution function (MDF) (Fig. 1-b) also shows a clear bimodality, with the old stars having a greater spread in total metallicity and typically lower values, such as those from elliptical galaxies. Meanwhile the young component, mostly formed from gas in the disk (see talk by Domínguez-Tenreiro), has less dispersion and a higher mean value. The composition of both distributions produces the typical shape observed in the bulge of M31, peaking around [Fe/H] = 0, with a steep decline at higher metallicities and a elongated tail to lower metallicities (Sarajedini & Jablonka 2005). The observed skew in the distribution is explained in our simulations as a consequence of the bimodality of the stellar populations: both MDFs are almost symmetrical when considered separately, but their ensemble has a significant skew.

The alpha-metallicity relation (Fig. 1-c) also shows two different shapes for both components, with the young population (stars) having an slope of ~ -0.25, consistent with observations of disk and bulge (Fulbright *et al.* 2007) and also with values predicted by standard chemical evolution models (Mollá *et al.* 2000).

3. Conclusions

We have performed three high resolution simulations of disk formation using our new P-DEVA code. The three bulges obtained have similar properties, consistent with a formation scenario in two phases: a fast, multiclump dominated one and a secular evolution phase with sporadic mergers. The shift between both phases appears at $z_c \sim 1.5$. Two stellar populations with different chemical properties appear accordingly. At z_c, the old component is already in place, while the young one is still a disk component and will not be completely in the bulge until much lower redshifts ($z \sim 0.2$).

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