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Dissipative phenomena in Local Group dwarf galaxies evolution

and their synthetic CMDs

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Abstract. Galaxies result from a complex interplay between dark-matter-driven hierarchical structure formation and feedback-controlled conversion of the baryonic matter into stars. The smaller (in mass) examples of these systems are the "dwarf"-galaxies. Dwarf galaxies are the most common type of galaxies in the universe and dominate by number the population of galaxies in clusters, groups, and so around our Galaxy, i.e. the Local Group (LG). In this work we present a method to investigate the interplay between environment and internal processes in the star formation history of dwarf galaxies neighbouring a hosting system, i.e. the dissipative phenomena ruling the star formation history of a dwarf galaxy.

Key words. instabilities - plasmas - methods: numerical - galaxies: structure - galaxies: dwarf - galaxies: stellar content

1. Introduction

To understand the processes that govern the formation of stars and galaxies is of paramount importance to improve our comprehension of the observed Universe. Stars commonly form in molecular cloud complexes, whose evolution is ruled by internal and external processes of heating, cooling and instability type.

The goal of this work is to study how these processes evolve and transform with time the molecular cloud complex in a galaxy whose properties we can observe. To achieve these results, we focused our attention on dwarf galaxies because they are the most common type of galaxies in the Universe (Marzke & da Costa 1997) and often offer a beautiful example of interaction between a major galaxy and its satellites (e.g., Peebles 1993). While orbiting, these satellites are affected by environmental effects that influence their evolution and affect their star formation history (e.g., Grebel et al. 2003; Pasetto et al. 2011).

In this study we develop a numerical investigation of dissipative phenomena occurring during the orbital evolution of a dwarf satellite galaxy orbiting around a host galaxy. The goal of this project is to reach a simple and qualitative description of the complicated connections existing between gas consumption processes (e.g., ram pressure, Kelvin-Helmholtz and Rayleigh-Taylor instabilities, tidal forces) and star formation processes in the context of the two extended-body interaction and with special attention to the dwarf galaxies dynamical regime involved in our local volume of galaxies, i.e., the Local Group (LG) (Mateo 1998; Grebel 1997). Moreover, these dynamical phenomena may leave signatures in the star formation activity and in the colour magnitude diagram of their galaxy stellar content. Thus, once established the theoretical framework that links orbital evolution of dwarf galaxies in the LG and star formation processes, we synthetically reproduced observable quantities as colour magnitude diagrams. Finally, this procedure allows us to compare the models predictions with the observational data.

2. Concepts

The methodology we want to apply is fully explained in a recently published paper by Pasetto et al. (2012). There we presented a new method suitable to account for star formation processes that take place (internal and due to the environment) in interactions between ”extended” objects (i.e. gravitational bounded system described not in point mass approximation but with a theoretical or observational scale parameter determining it size). The method combines synthetically tools to account for observational constraints like the synthetic CMDs generator and mathematical principles for orbital reconstruction from partial information stationary like the stationary action principle. Briefly, in order to link the theory of orbits for the orbiting systems to environmental effects and to star formation processes, we realized a fast algorithm that permits to sample a large number of initial conditions for an assigned orbit. The basis of this methodology are on the star formation models for stellar populations that I can relate with the orbit investigation and the synthetic CMD generation in order to reproduce observed star formation history (once they are convolved with observed errors or completeness factor).

The method imposes internal and external phenomena to evolve a spectrum of molecular clouds. The clouds mass function (whether atomic or molecular) is quite uncertain but is believed to span at least a factor of $\sim 10^6$ in mass. By dividing the molecular clouds according to their initial mass $M_i | M_i \in [M_{\min}, M_{\max}]$ we can assume $M_{\min} = 10^2 M_{\odot}$and . Due to this range we can logarithmically resolve the mass intervals with a ration α between subsequent intervals, i.e., from $\log_{10} \frac{M_{i+1}}{M_i} = \alpha$ with , say$M_i = 10^{\alpha} M_{\min}$. As a consequence we define a ”mass class” within the generic interval i as $\hat{M}_i \equiv M_{i+1} - M_i$ or, its fraction over a total massM_{tot}, is$\hat{f}_i \equiv \hat{M}_i / M_{tot}$. In Pasetto et al 2012 we assume that the evolution of each interval of mass clouds $\hat{M}_i$ will be ruled by the fraction of gas that is ejected from the stars, i.e. their gas ejection rate R_{stars} and by the amount of molecular gas recycled, i.e. the molecular gas recycle rate R_{mol} (post a brief atomic phase depending on metallicity). Then the decrease of $\hat{M}_i$ will simply depend on the life time scale for the molecular cloud, or e.g. the destruction time of a molecular cloud class $\hat{M}_i$ and pressure P trough a simple system of integro-differential equations on$\hat{f}_i$. The newly determined pressure formulation allows to account for extension and direction of the dwarf galaxy in a not inertial reference system thus extending preexisting point mass formalisms (e.g.,)1972ApJ...176....1G for ram pressure, Kelvin-Helmholtz and Rayleigh-Taylor instabilities. We used this novel technique to span a set of orbits eccentricity for bounded orbits a mass-time independent external potential tuned on the MW galaxy and its hot gas corona. We adopted an external force field, representative of the gravitational potential of the Milky Way (MW) and a hot plasma coronal gas (T=10^6-10^8K) model where to integrate the orbits of the dwarf galaxies (see Figure 1 for an example of the path that a standard-model of a

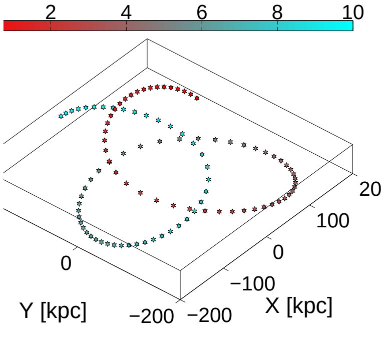

Fig. 1. Orbital evolution of a dwarf galaxy with pericentre r_p = 200 kpc on the MW plane and with eccentricity e = 0.50. Colorbar units are in Gyrs.

spherical dwarf galaxy that we followed on its orbit for 9 Gyrs)

3. Development

We succeeded in writing a code which is fast in handling these complex star formation processes. In the developing phase we realized a parallel integral-differential equations solver based on a parallelized version of the Runge-Kutta techniques with adaptive step-size control. The typical code runs are tuned to best perform on 650 processors. Higher resolution convergence and control tests have been performed scaling the code to higher number of processorsrecording peak performances of 23Tflops/sec at the Leibniz Supercomputing Centre in Munich (Germany) in 2011.

In this work we limit our study to the local sample of dwarf galaxies (LG) and with especial attention to the MW dwarf satellites. Because of its proximity, this set of dwarf galaxies represents an excellent laboratory where to investigate these difficult problems thanks to the richness of available observational data and exquisitely precise constraints.

4. Results

Once the orbital path of a standard dwarf galaxy in its last 9 Gyr of evolution is computed, a corresponding profile of the pressure acting on the molecular cloud complex of the primordial dwarf galaxy is determined as the one shown in Figure 2.

Once the pressure is determined as a function of the dwarf galaxies' orbital location, the corresponding star formation processes affecting the molecular clouds can be evaluated and the star formation history of the galaxy under exam estimated. For an initially assigned mass spectrum of the molecular clouds, star formation efficiency and destruction time can be evaluated as a function of the molecular cloud mass and pressure (e.g., Elmegreen 1989) and from them the star formation rate can be estimated as a function of the instantaneous location and mass of the dwarf galaxy in its orbit around the MW (Fujita 1998). We see in Figure 3 an example of star formation history of the dwarf galaxy corresponding to the path of the Figure 1.

Finally, from the star formation history, and assuming an initial stellar mass function, we are able to produce the corresponding synthetic theoretical colour magnitude diagram (Bertelli et al. 2009; Ng et al. 2002). The latter can be convolved with observational errors and shifted in magnitude and colours in order to be directly compared with the observed CMDs. An example of a theoretical colour

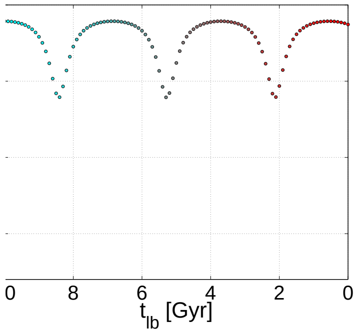

Fig. 2. Pressure distribution for the orbit of Fig.1. Note that the sign of pressure is a matter of convention and depend on the orientation of a surface: the same distribution of forces may be described as a positive pressure along one surface normal or as a negative pressure along the opposite surface normal. For different notation see Pasetto et al. 2012.

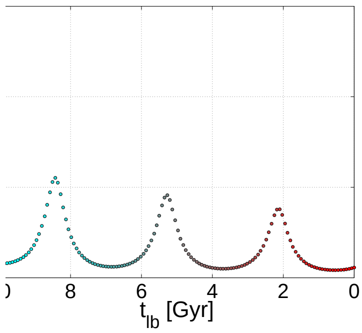

Fig. 3. Star formation history of the dwarf galaxy evolved in Fig.1. The decrease of the SFH peaks is due to the gas consumption.

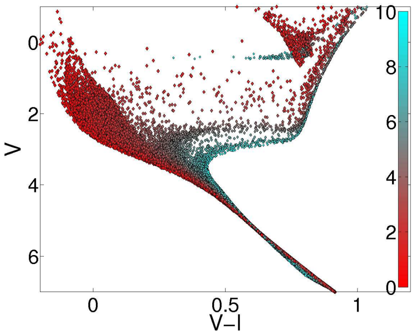

Fig. 4. Synthetically generated Hertzsprung-Russell diagram. The colour code represents the age of the stars and is kept coherent with the time evolution of the previous four figures. No convolution with any instrumental errors have been attempted.

magnitude diagram (the Hertzsprung-Russell diagram) can be seen in Figure 4 for a dwarf galaxy orbiting in the orbits of Figure 1.

5. On-going research / outlook

The results obtained so far are planned in two papers. The first explains the method developed here Pasetto et al. (2012).

In the second paper (representing our on-going project) we plan to extend and complete the family of orbits previously investigated and to study the relative importance of the instability processes implemented.

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