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How hard is it to destroy a dwarf spheroidal galaxy?

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Abstract. The study of satellite galaxies and their interactions with the Milky Way (MW) have directly impacted our knowledge of its history of formation and evolution. In this context, it is of vital importance to seek to better understand the dynamical details within such satellites as they orbit around our Galaxy. Therefore, the goal of this work is to analyze which scenarios favor (or not) the resilience of dwarf spheroidal (dSph) galaxies around a MW-like potential. To achieve this, we made use of semi-analytical simulations: we created *N*-body systems using the Plummer model to represent dSph galaxies and used a static realistic analytical potential to account for the MW. We chose circular-polar orbits in which the Plummer spheres were put in motion. Afterwards, the flow of mass into and out of the core of each sphere was analyzed as they evolved in their orbits. Our results show that larger circular-polar orbits tend to make the Plummer spheres more resilient to the tidal forces, however this also depends on the central density of each system. For the scenarios explored in this work, there seems to exist a direct relation between the central densities of the dSph galaxies and the time it takes for their cores to lose a certain percentage of their initial masses.

Resumo. O estudo de galáxias satélites e suas interações com a Via Láctea (MW) tem impactado diretamente nosso conhecimento sobre sua história de formação e evolução. Nesse contexto, é de vital importância buscar melhor compreender os detalhes dinâmicos desses satélites enquanto orbitam nossa Galáxia. Portanto, o objetivo deste trabalho é analisar quais cenários favorecem (ou não) a resiliência de galáxias anãs esferoidais (dSph) em torno de potencial similar ao da MW. Para isso, fizemos uso de simulações semi-analíticas: criamos sistemas de *N*-corpos usando o modelo de Plummer para representar as galáxias dSph e usamos um potencial analítico realista e estático para descrever a MW. Escolhemos órbitas circulares polares nas quais as esferas de Plummer foram colocadas em movimento. Posteriormente, o fluxo de massa para dentro e para fora do núcleo de cada esfera foi analisado conforme elas evoluíram em suas órbitas. Nossos resultados mostram que órbitas circulares-polares maiores tendem a tornar as esferas de Plummer mais resistentes às forças de maré, porém isso também depende da densidade central de cada sistema. Para os cenários explorados neste trabalho, parece existir uma relação direta entre as densidades centrais das galáxias dSph e o tempo necessário para que seus núcleos percam uma certa porcentagem de suas massas iniciais.

Keywords. Galaxies: dwarfs – Galaxies: structure – Galaxies: evolution

1. Introduction

In the field of galactic dynamics, studies seeking to understand how satellite galaxies behave in relation to the Milky Way (MW) is of utmost importance for the construction of the history of formation and evolution of the Galaxy. In particular, many of these satellites are dwarf spheroidal (dSph) galaxies, which appear in a variety of degrees of dynamic destruction. In other words, some present a more robust and well-determined stellar structure, while others appear to be more disrupted and dispersed in ways that indicate intricate gravitational interactions. Therefore, the objective of this work is to investigate which orbital and structural characteristics make a dSph galaxy more or less resilient to the forces imposed by the gravitational potential of the MW.

2. Method

To investigate this issue, simulations of semi-analytical models were carried out (*N*-body system immersed in an analytical potential). Dwarf spheroidal galaxies were represented by *N*-body systems created using the Plummer model (Plummer 1911), whose density profile is of the form

$$\rho(r) = \frac{3M}{4\pi a^3}\left(1 + \frac{r^2}{a^2}\right)^{-\frac{5}{2}}, \tag{1}$$

where M corresponds to the total mass of the system and a is its scale length. Meanwhile the influence of the MW was accounted via a realistic, static and axisymmetric analytical potential (Bovy 2015) present in the gala python package (Price-Whelan 2017). Each Plummer sphere is characterized by its total mass and scale length, and its orbit is determined by the initial position and velocity vectors used to shift the center of mass. Therefore, the above-mentioned quantities constitute the space of parameters we wish to systematically explore: how do those parameters influence the destruction of the Plummer spheres? As a first approach, we only considered circular-polar orbits, i.e, those in the xy plane (the axis of symmetry of the MW potential is along the z axis) with radii 5 kpc, 12.5 kpc, and 20 kpc. Two values of total mass were chosen, 10^8 and 10^9 solar masses, and three values of scale length, 0.3 kpc, 0.6 kpc and 0.9 kpc. That is, we have 6 different spheres and 3 orbits in which each one can be placed in, a total of 18 simulations. Every sphere is composed of 10^5 particles and was evolved in time 5 Gyr using a softening length of 40 pc. We used an implementation of the falcON algorithm (Dehnen 2002) within UNSIO (Lambert 2014) to compute gravitational forces.

3. Results and analysis

Aiming to keep track of the degree of destruction of each sphere, for each time interval, we measure the relative mass (current mass divided by the initial one) inside the sphere defined by the respective half mass radius, which in the Plummer model is approximately equal to $1.3a$; this is how we define the core of each sphere. The results for the first billion years are shown in Fig. 1.

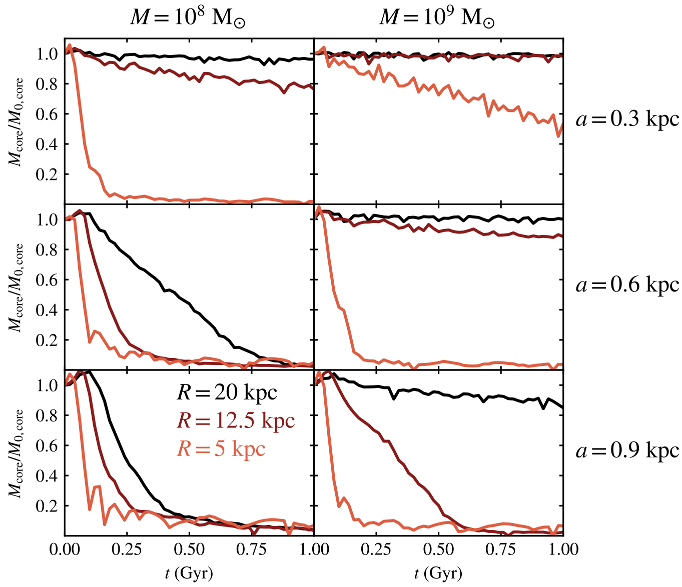

Figure 1. Relative mass inside the half mass radius as a function of time for all simulations. Each panel represents one sphere, characterized by the respective (M, a) pair, while the color indicates the orbit.

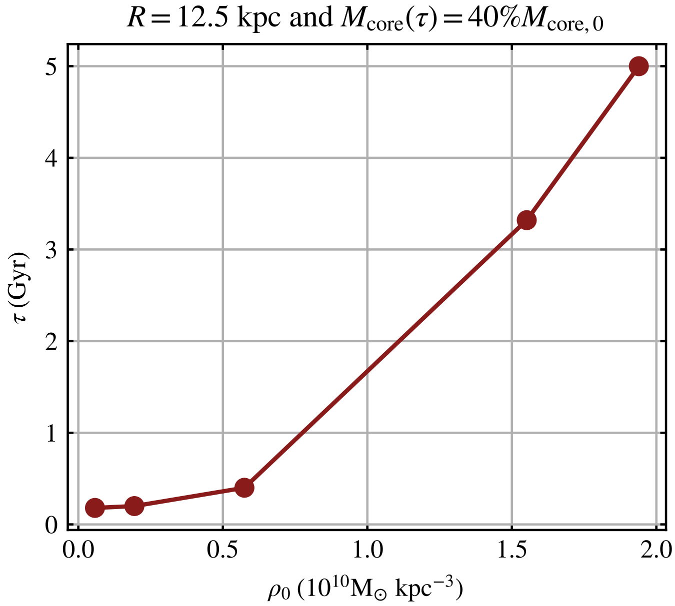

Figure 2. Destruction time as a function of central density. Each point indicates a sphere on the circular-polar orbit of radius 12.5 kpc whose core eventually lost 60% of its initial mass.

Despite of the total duration of 5 Gyr (which comprises eventual non-physical outputs), the most relevant destruction, for this space of parameters, occurs during the first 1 Gyr. We can see there is a certain hierarchy between the curves: for all spheres, the larger the radius of the circular-polar orbit, the more resilient the system. Beyond that, the interplay between the total mass and the scale length seems to be important, this is what determines how much concentrated or rarefied the distribution is: the more mass and the shorter the scale length, the more concentrated the sphere, inverting this relation we have the more rarefied case. This way, it is possible to note Fig. 1 also seems to indicate that more concentrated spheres tend to retain the mass of their cores for longer, however this also depends on the orbit. The larger orbits (12.5 kpc and 20 kpc) appear to make this relation clearer, while the small one (5 kpc) seems to not follow the relation or to make it harder to evidence (only the most concentrated sphere shows some resilience).

This analysis motivates the definition of a certain "time of destruction", the time at which the relative mass inside the core of the sphere reaches a determined value. Moreover, we represent how concentrated each sphere is via their central density which, in the Plummer model, corresponds to the total mass M divided by the volume of a sphere with radius a:

$$\rho_0 = \frac{3M}{4\pi a^3} \, . \tag{2}$$

Now, Fig. 2 shows a direct relation between the central density of each sphere and the time they take to lose 60% of the mass of their cores, as we had anticipated. This type of correlation is also present in the case of $R = 20$ kpc, but with even fewer points (only three spheres lose at least 60% of their cores' mass along the 5 Gyr). Finally, the relation is even weaker for the orbits with $R = 5$ kpc, in this case all spheres lose practically all the mass inside their cores at the same time, with the exception of the most concentrated sphere ($M = 10^9$ M$_\odot$, $a = 0.3$ kpc), the one with the greatest central density.

4. Conclusions and perspectives

We have investigated the internal structure of simulated dSph galaxies (represented by N-body systems built upon the Plummer model) immersed in the Milky Way's analytical potential. By systematically exploring the space of parameters in questions, we were able to show that, for the family of circular-polar orbits, there seems to exist a direct relation between the central density of a Plummer sphere and the time it takes for it to lose a certain percentage of the mass inside its core. As for our perspectives, we wish to continue this analysis for a more detailed space of parameters that shall include eccentric and inclined orbits. Eventually implementing the time dependent potential of the bar should also enrich and diversify the study of internal structures of distributions of particles.

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