dSph–like Galaxies of a Milky Way like Galaxy and their Dark Matter Content

A Numerical Study

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Abstract

By using N–body simulations we study the possible formation of dSph-like galaxies as remnants after several perigalactic passages of an initial satellite without a dark matter content. The initial satellite corresponds to bound system of one million particles obeying a Plummer model, whereas the galaxy is modeled with a three component rigid potential: a Miyamoto-Nagai potential for the disk, a Hernquist potential for the bulge and a Logarithmic potential for the dark matter halo. The initial satellite is introduced into the galactic potential at different apogalactic distances and with several velocities and it is evolved for 12 Gyr. In particular we are interested in the initial mass, size and orbit of a satellite that can lead to an out-of-equilibrium object containing about 1% of the initial mass of the satellite, that survives for a long enough time, so that the remnant could be taken by an observer at earth as a dSph galaxy of the host galaxy.

Here we present some preliminary results from our study, for a single initial satellite with mass $10^7\,M_\odot$ on different orbits. We found that for some values of the initial conditions (orbit) it is possible to get a long–lived remnant from an initial satellite without dark matter, confirming previous studies that used a different galactic potential. We show the region of the initial conditions space (orbit) that allow the formation of such remnants.

Introduction

Observations suggest the existence of a large amount of dark matter in the universe, which is the dominant mass component at galactic and galaxy clusters scales. Nevertheless there are no observational evidence of dark matter at scales smaller than globular clusters.

There are several dSph galaxies orbiting the Milky Way at distances ranging from tens to hundreds of kiloparsecs, with non isotropic distribution and all of them near a plane perpendicular to the galactic plane (PMJ02). The velocity dispersions of stars in these galaxies ($\sigma \approx 10$ km/s) are similar to the ones observed in globular clusters, and have similar masses ($M_{st} \approx 10^5\,M_\odot$) and photometric luminosity in the V band ($L \approx 10^5\,L_\odot$), but the dSph's are approximately two times more extended than globular clusters ($R \approx 300$ pc). Some dSph satellites present a large M/L value, implying that these objects may be completely dominated by dark matter (Kro97). Generally it is assumed that those dSph galaxies are cold dark matter dominated.

One possible explanation for the large M/L ratio for dSph galaxies is that they are objects out of virial equilibrium and may not be spherical but with non isotropic velocity dispersions (i.e. the M/L ratios are not real) (KK98). In that case the dSph masses would be overestimated. Kroupa (Kro97) performed simulations of the evolution of an initially spherical satellite with 300.000 particles and mass of $10^7\,M_\odot$ on different orbits. He used an extended dark matter halo with circular velocity of 200 km/s for the host galaxy and found that unbound systems without dark matter, resembling dSph galaxies, may exist. In our study we are using an initially spherical satellite with more particles and a three component rigid potential.

In the following we present study the orbital conditions for an initially bound satellite, without dark matter, of a galaxy that resembles the Milky Way. The initial object has 10^6 particles and mass of $10^7\,M_\odot$. We show the parameters of the orbits that allow the formation of an out–of–equilibrium remnant that could be interpreted as a dSph galaxy without dark matter. The comparison of the remnants and actual dSph galaxies will be done soon.

The Galaxy

The main galaxy is modeled using a rigid potential with three components:

$$\Phi_{disk} = -\frac{GM_d}{\sqrt{R^2 + \left(a + \sqrt{z^2+b^2}\right)^2}} \tag{1}$$

$$\Phi_{sph} = -\frac{GM_s}{r+c} \tag{2}$$

$$\Phi_{dark-halo} = V_h^2\, ln\left(r^2 + d^2\right) \tag{3}$$

where $r^2 = R^2 + z^2$, $M_d = 10^{11}\,M_\odot$, $M_s = 3.4 \times 10^{10}\,M_\odot$, $V_h = 128$ km/s, $a = 6.5$ kpc, $b = 0.26$ kpc, $c = 0.7$ kpc, and $d = 12$ kpc (JSH95)

The Satellite

The initial object corresponds to a Plummer sphere with 10^6 particles, mass of $10^7\,M_\odot$, plummer radius $r_0 = 0.3$ kpc and a cutoff radius of 1.5 kpc, constructed using the algorithm proposed by Aarseth (Aar63).

$$\Phi_{sat} = -\frac{GM_{sat}}{r^2 + r_0^2}\,;\ \rho_{sat} = \frac{3M}{4\pi r_0^3}\left(1 + \frac{r^2}{r_0^2}\right)^{-\frac{5}{2}} \tag{4}$$

After construction, the object is evolved under its own gravitation, so that it undergoes a relaxation phase.

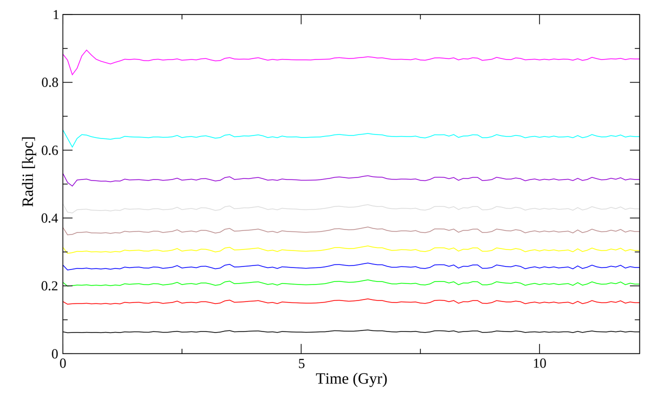

FIGURE 1: Relaxation of the initial object. From bottom to top, lines show radii containing 10%, 20%, ..., 90% of the initial mass of the object

N–Body Simulations

The simulations are performed using the simulation code GADGET–2 (SYW01; Spr05) on a Pentium IV PC.

After relaxation, the initial object is introduced into the galactic potential at a given position on the galactic disk, with a given velocity parallel to the z–axis and its evolution is followed for 12 Gyr. This procedure is repeated for many initial conditions in order to find the ones leading to disrupted objects with only 1% of the initial mass that survive for more than 1 Gyr.

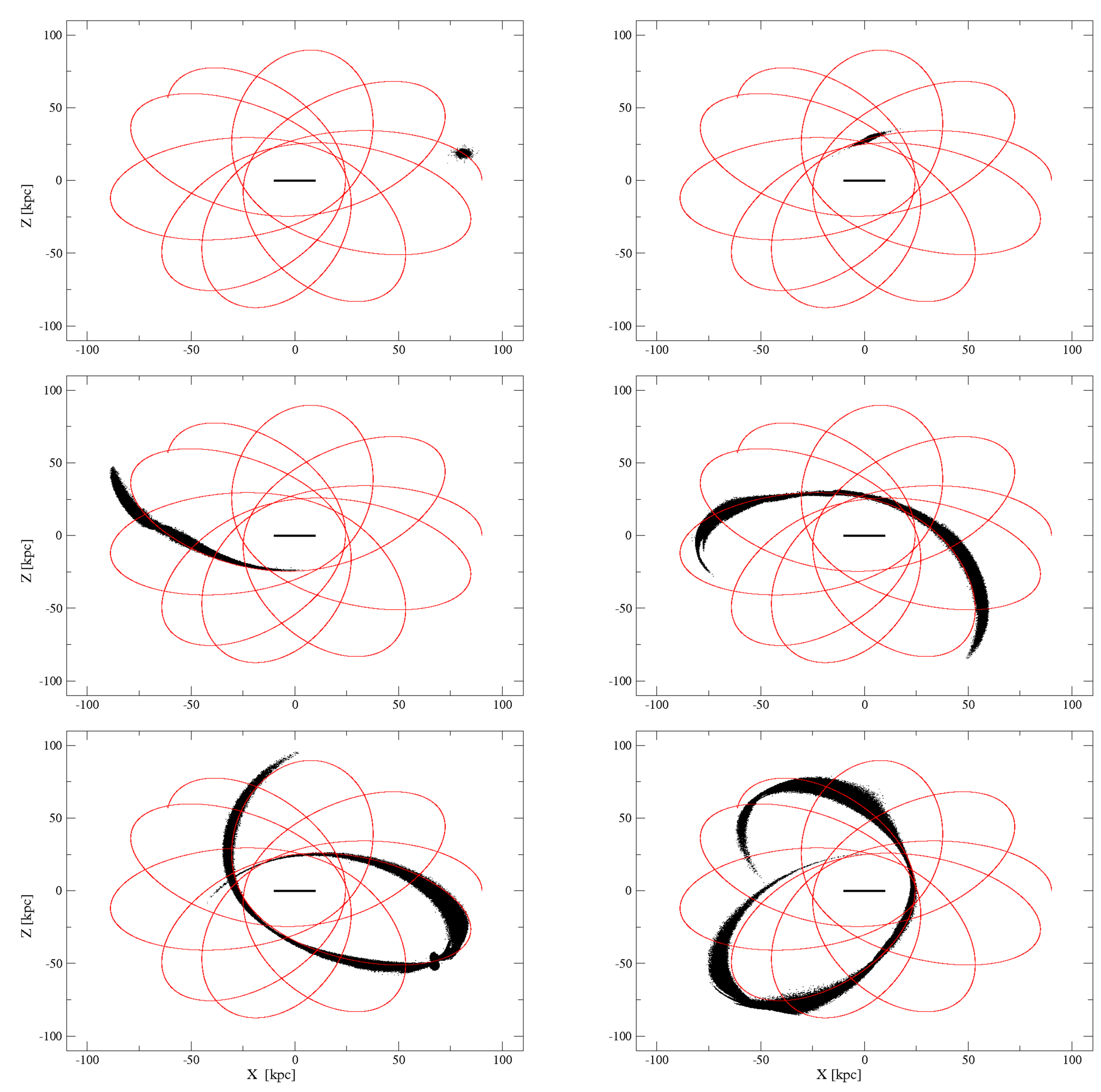

FIGURE 2: Evolution of a satellite with apogalactic distance of 90 kpc and eccentricity of 0.56. Snapshot times are: 0.2, 0.6, 3.0, 6.0, 9.0 and 11.0 Gyr

Results

We performed more than 60 different simulations with eccentricities: $0.1 \leq e \leq 0.85$ and apogalactic distances: $30 \leq d_{ag} \leq 240$ kpc. Below we show some typical behavior of the satellites on their orbits around the galaxy.

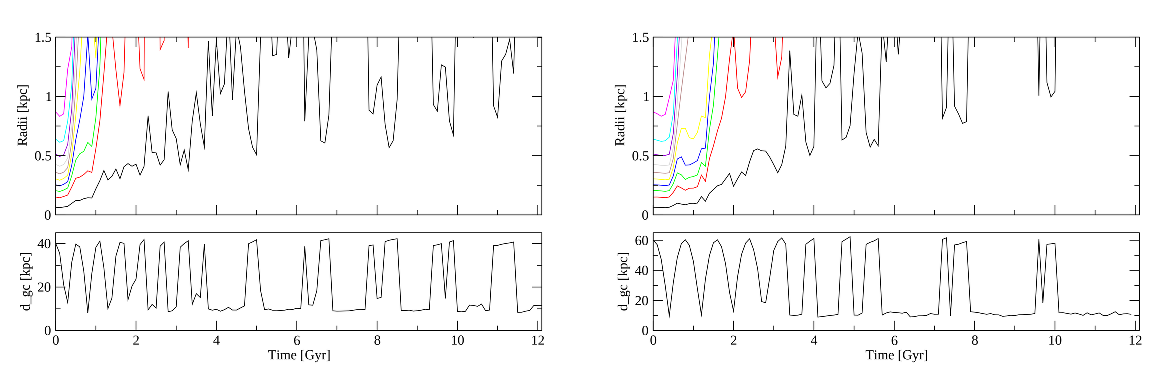

FIGURE 3: Initial satellite is rapidly destroyed. $d_{ag} = 50$ kpc, $e = 0.6$ (left) and $d_{ag} = 60$, $e = 0.7$ (right). From bottom to top, lines show radii containing 1%, 10%, 20%, ..., 90% of the initial mass of the object

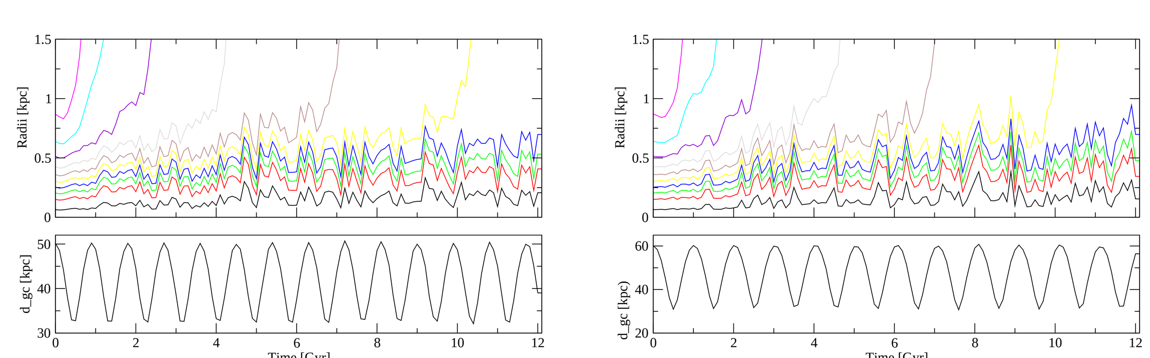

FIGURE 4: Initial satellite is not destroyed. $d_{ag} = 50$, $e = 0.2$ (left) and $d_{ag} = 60$, $e = 0.3$ (right). Lines as in figure 3.

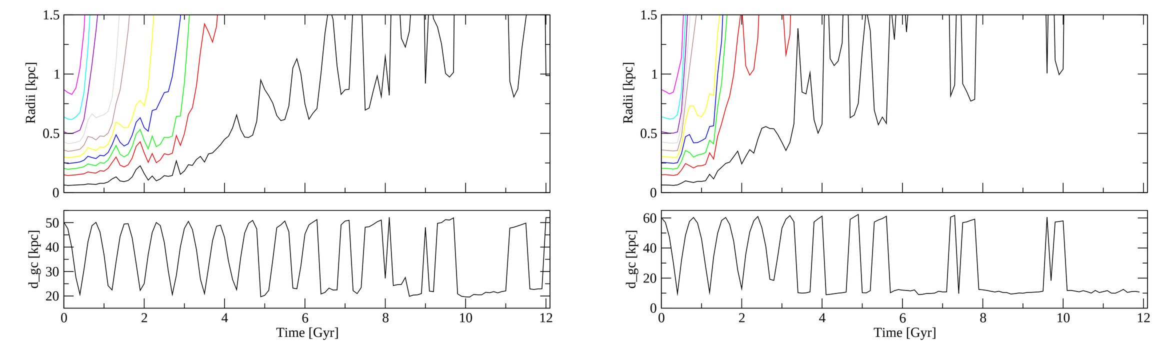

FIGURE 5: Disrupted remnant: $d_{ag} = 50$, $e = 0.4$ (left) and $d_{ag} = 60$, $e = 0.7$ (right). Lines as in figure 3.

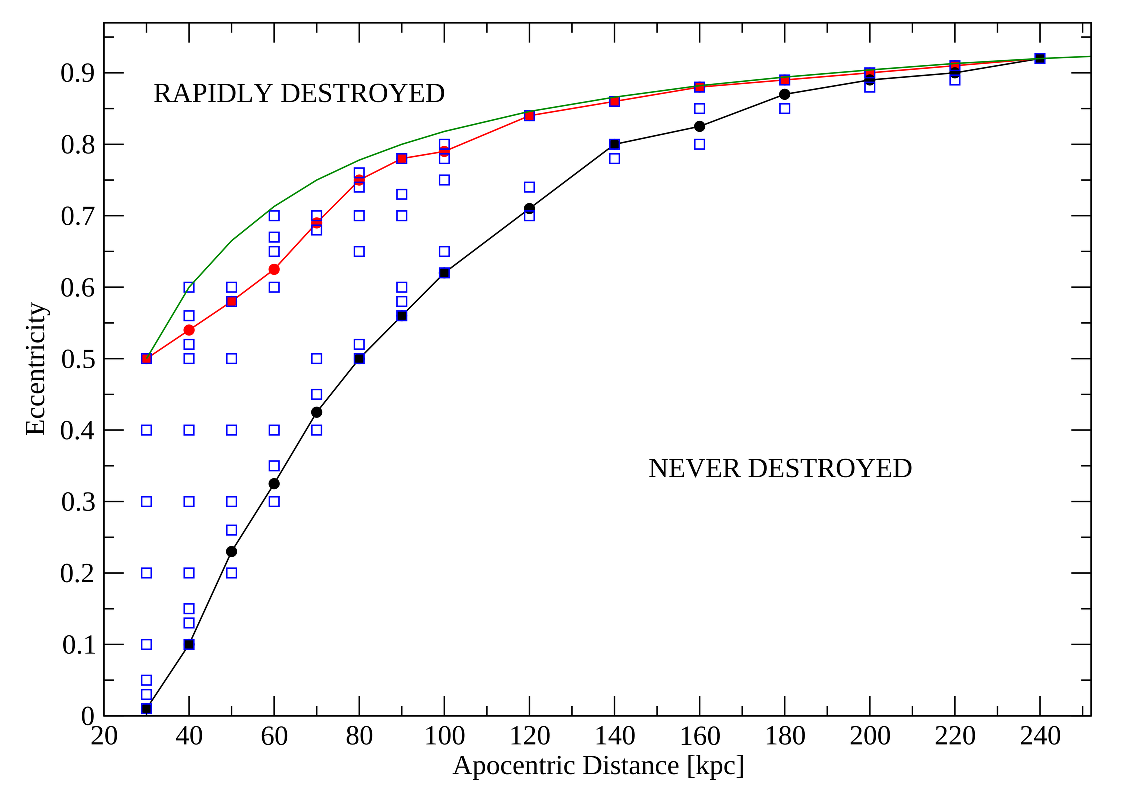

FIGURE 6: Higher and lower eccentricity of orbits as a function of apocentric distance, that could lead to out–of–equilibrium remnants. The symbols represent the simulation performed.

Conclusions

The simulations performed show that it is possible to obtain disrupted remnants of initially spherical bound objects, that survive as out–of–equilibrium systems for times larger than 1 Gyr, confirming so far the results from Kroupa (Kro97), but for a satellite with more particles and for a three component galaxy model, that resembles the Milky Way. Those remnants are candidates to be interpreted by an observer on earth as dSph–like satellites of the host galaxy (Milky Way).

The region in the orbital parameters of the satellite that lead to out–of–equilibrium remnants is large enough to keep alive the hypothesis of dSph galaxies without dark matter and of tidal origin. What is shown here are preliminary results and there is still a lot of work to do before we finish our study and draw strong conclusions. We are already running similar simulations for more massive initial satellites. We will start soon to analyze in detail the remnants, in order to see whether they are actually identifiable as dSph like galaxies by an observer on earth.

Acknowledgments

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