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ORIGIN AND EVOLUTION OF THE SAGITTARIUS DWARF GALAXY USING N-BODY SIMULATIONS

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RESUMEN

Se estudia la evolución de la galaxia enana esferoidal Sagitario mediante simulaciones numéricas de N-cuerpos. Se encontraron las condiciones iniciales de la órbita del satélite tal que, después de un tiempo menor a 10 años, este objeto astrofísico tenga la posición y la velocidad radial galactocéntrica actualmente observada (16 kpc y 171 km s^{-1}, respectivamente). Posteriormente, estos resultados son usados para simular la evolución del progenitor de Sagitario sólo con materia bariónica y con diferentes contenidos de materia oscura. Estas simulaciones fueron hechas utilizando una modificación del código Gadget-2. El satélite es representado por una esfera de plummer y el halo por una distribución del tipo NFW. El número de partículas para cada objeto fue de 10^6. La Vía Láctea se modeló como un potencial rígido de tres componentes. En este artículo se presentan algunos de los resultados más significativos obtenidos en las simulaciones.

ABSTRACT

We study the evolution of the Sagittarius dwarf galaxy by means of N-body numerical simulations. We find the initial conditions of the orbit of the satellite, such that after a time shorter than 10 Gyrs, this astrophysical object has the position and galactocentric radial velocity currently observed (16 kpc and 171 km s^{-1}, respectively). Subsequently, these results are used to simulate the evolution of the progenitor of Sagittarius both with only barionic matter and with different contents of dark matter. These simulations were made by using a modification of the code Gadget-2. The satellite is represented by a plummer sphere and the dark halo by a NFW distribution. The number of particles for each object is 10^6. The Milky Way is modeled as a rigid potential of three components. In this paper we present some of the most significant results obtained in our simulations.

Key Words: dark matter — galaxies: dwarf — galaxies: evolution — galaxies: individual (Sagittarius)

1. INTRODUCTION

Sagittarius main body is located at 16 ± 2 kpc from the galactic centre (Ibata et al. 1997). This galaxy, moves to the north with a transversal velocity of 250 ± 90 km s^{-1} (Ibata 1999); its radial velocity is 171 km s^{-1} (Gómez-Flechoso 1999). Some of the physical properties currenlty observed in this satellite are (Gómez-Flechoso 1999): the half light radius, $r_{1/2} = 0.55$ kpc; the central velocity dispersion, $\sigma_0 = 11.4$ km s^{-1}; the total luminosity $L_0 = 2 \times 10^7\ L_\odot$ and the mass-to-light ratio $M/L = 14 - 16\ M_\odot/L_\odot$.

On the other hand, many studies have found tidally stripped material associated to Sagittarius with an age between 3 and 6.5 Gyrs ago (Belokurov et al. 2006); this tidal tails can be correlated with filaments found at distances of 45, 46 and 62 ± 6 kpc from the galactic centre (Martínez-Delgado et al. 2004). Taking into account the physical properties observed and the tidal tails associated to Sagittarius, we simulated a broad range of dwarf spheroidal galaxies and compared their physical properties with the ones of Sagittarius. With this, we could investigate some possible features of the progenitor of this dwarf galaxy.

2. RESULTS OF SIMULATIONS

We modeled the Milky Way as a three-component rigid potential; where the disk is represented by a Miyamoto-Nagai potential, the bulge by a Hernquist potential and the dark matter halo as a logarithmic potential (Johnston et al. 1995):

$$\phi_d = -\frac{GM_d}{\sqrt{R^2 + \left(a + \sqrt{z^2 + b^2}\right)^2}}, \qquad (1)$$

$$\phi_s = -\frac{GM_s}{r + c}, \qquad (2)$$

$$\phi_h = \nu_h^2 \ln\left(r^2 + d^2\right), \qquad (3)$$

where the disk mass, $M_d = 1 \times 10^{11}\ M_\odot$; spheroid mass, $M_s = 3.4 \times 10^{10}\ M_\odot$; halo circular velocity

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$\nu_h = 140$ km s^{-1} and the parameters $a = 6.5$ kpc; $b = 0.26$ kpc; $c = 0.7$ kpc and $d = 12$ kpc (Johnston et al. 1995). The satellite was modeled by a plummer sphere whose potential is of the form:

$$\phi = -\frac{GM_{\rm sat}}{\sqrt{r^2 + r_0^2}}\,, \tag{4}$$

where the mass of the satellite $M_{\rm sat}$ was varied between 5×10^8 and 1×10^9 $M_\odot$. We took plummer radii r_0 of 0.3, 0.5, 0.6 and 1.2 kpc. The NFW dark halo was constructed with the method proposed by Mashchenko & Sills (2005).

When we simulated the satellites only with baryonic matter, we found that in the case of the densest ones, i.e., satellites whose plummer radius is $\leq$0.5 kpc, more than 30% of its initial masses survives for 10 Gyrs. This means that this galaxies are more stables than the observed Sagittarius. Furthermore, we found galaxies whose 10% or 20% of their initial masses survives for 10 Gyrs; this type of galaxies neither reproduce the properties observed in Sagittarius. Finally, extended satellites, i.e., the ones whose plummer radius is 1.2 kpc, reproduce some properties of the dwarf; but in a very early time (at 3 Gyrs). These results point out two important things: Sagittarius, at the beginning of its evolution, might have been immersed in a dark matter halo and its plummer radius could not have been $\leq$0.5 kpc.

We simulated galaxies with plummer radius of 0.6 kpc immersed in different contents of dark matter. In the whole simulations, the half light radius of the satellites always was lesser than the one measured in Sagittarius; this fact indicates that the progenitor of this dwarf galaxy might have been an extended galaxy, i.e., its plummer radius should have been equal or higher than 1.2 kpc. This result was confirmed when we simulated a galaxy with initial radius of 1.2 kpc immersed in a dark halo. It was the only galaxy that reproduced the half light radius of Sagittarius. Figure 1 shows the evolution of a galaxy without dark matter and immersed in a dark halo. As we can see, the halo acts as a shield, because more percentage of initial mass can survive for 10 Gyrs.

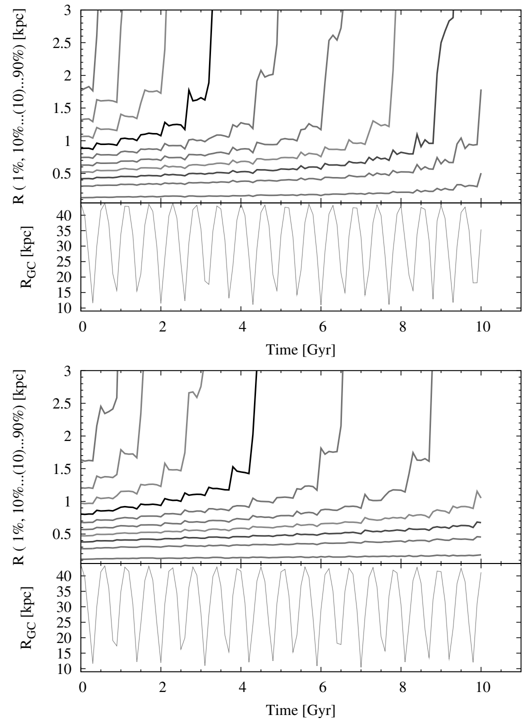

Fig. 1. Evolution of a satellite with 7×10^8 $M_\odot$ and plummer radius of 0.6 kpc, top: without dark matter and bottom: with a dark halo of 8×10^8 $M_\odot$. Note that for this case, the galaxy is more stable; 30% of its initial mass survives for 10 Gyrs. $R_{\rm GC}$ is the movement of the maximum density.

3. CONCLUDING REMARKS

Despite of the failed effort of some people to find out direct evidence of dark matter in Sagittarius, our simulations suggest that this galaxy at the beginning of its evolution might have been immersed in dark matter. This result has an important impact in the theories of formation of structure in the universe, which suggest that only big galaxies have dark matter halos. Nevertheless, our simulations are not enough to find the exact initial content of dark matter in Sagittarius; it would be necessary to have a larger range of mass and to simulate the Milky Way as a live component since dynamical friction effects become important. With respect to the features of the progenitor of Sagittarius, we found that it should have been an extended galaxy with plummer radius higher or equal to 1.2 kpc.

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