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DO FAST ROTATING BARS PRESENT A PROBLEM TO THE HIERARCHICAL SCENARIO?

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RESUMEN

Se ha sugerido que la fricción dinámica entre las barras galácticas y los halos de materia obscura predichos por los modelos cosmológicos disminuiría la velocidad angular de éstas haciendolas incompatibles con la alta rotación medida en barras observadas . En este trabajo se estudia la formación y evolución de barras embebidas en halos de materia obscura consistentes con las predicciones cosmológicas. Nuestras simulaciones utilizan millones de partículas y alcanzan una resolución espacial de parsecs. Concluimos que es posible formar barras compatibles con las observaciones dentro de halos obscuros consistentes con los modelos cosmológicos.

ABSTRACT

It has been suggested that dynamical friction between bars and dark matter halos precludes the existence of fast rotating bars inside halos predicted by LCDM models. Using N-body simulations with millions of particles and parsecs we study the formation and evolution of bars inside cosmological motivated dark matter halos. We conclude that it is possible to produce fast rotating bars in hierarchical models.

Key Words: **GALAXIES: KINEMATICS AND DYNAMICS — GALAXIES: EVOLUTION — GALAXIES: HALOS**

1. INTRODUCTION

Predictions for the structure of individual galaxies in the framework of cosmological models is a difficult task. Until recently it was limited to modeling dark-matter-dominated systems such as dwarf galaxies and low surface brightness galaxies(e.g., Moore 1994, Flores & Primack 1994, van den Bosch & Swaters 2001). It is generally accepted that current models do not fare well on those tests because they predict a too fast rotation in the central region and an excessive amount of dark matter satellites (Klypin et al 1999, Moore etal 1999).

Another layer of problems lies on slightly larger scales: luminous parts of normal galaxies and masses in the range of $10^{10} - 10^{12} M_{\odot}$

One of the contentious issues is the pattern speed of bars. Using analytical arguments and a combination of N-body simulations with rotating solid bars, Weinberg (1985) and Hernquist & Weinberg (1992) argued that a non-rotating dark matter will exert so much dynamical friction that a bar should lose its angular momentum in a few rotation periods. If true, that would make it impossible for bars to exist in galaxies with dark matter halos. There is no doubt that dynamical friction works when a bar rotates inside a dark matter halo. Yet, the rate and the amount of the angular momentum lost by the disk is still a matter of debate. Fully self-consistent N-body simulations with live bars, disks, and dark matter halos (Combes & Sanders 1981, Sellwood & Athanassoula 1986, Debattista & Sellwood 1999, 2000, Athanassoula & Misiriotis 2002) show that bars slow down far less than what was predicted by Weinberg (1985), and Hernquist & Weinberg (1992). Bars in simulations rotate for billions of years, challenging the theoretical expectations. Yet, bars in numerical models are known to slow down. Debattista & Sellwood (1999, 2000) studied models where initially dark matter contributes with the same amount of mass as the stellar disk in the central regions of the galaxy. They found that the baryonic component (disk + bar) loses about 40 % of its angular momentum over ∼ 10 Gyrs. The bar pattern speed declines by a factor of five after the bar forms, producing a bar which rotates more than twice slower than observed ones. The speed of bar rotation is often characterized by the ratio R of corotation radius to the semi-major axis of the bar. This ratio has been estimated for a few galaxies; it takes the following values $R = 1.1 - 1.7$ (Elemgreen 1996). Bars in models of Debattista & Sellwood (2000) with considerable amount of dark matter have $R = 2.0 - 2.6$, which contradicts the observed values. Only the models which have an initial maximum disk were able to produce bars with $R < 2$. This result has been raised as a potential challenge to hierarchical models that

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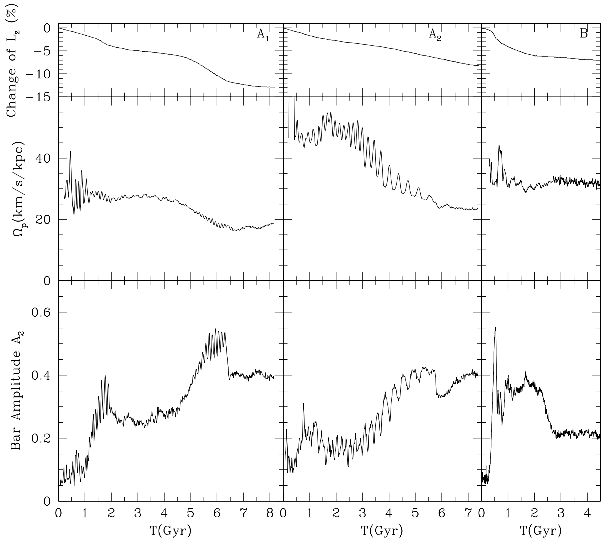

Fig. 1. Evolution of angular momentum, bar pattern speed and amplitude. The correlation between the growth of bar amplitude and the decrease of pattern speed is clear. This correlation suggests that the disk evolution is mostly responsible for the observed change in pattern speed.

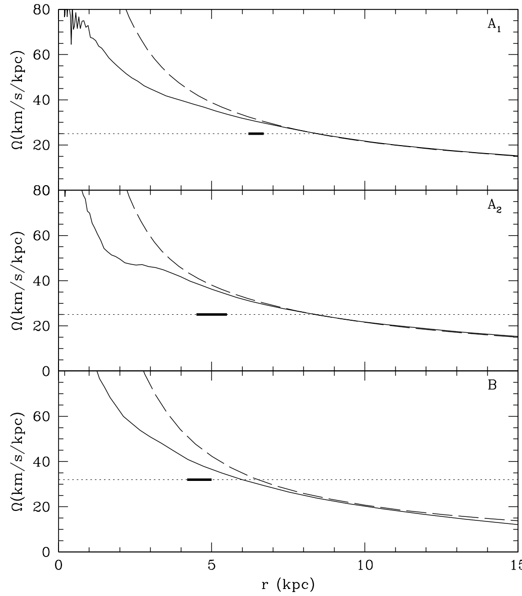

Fig. 2. Full curves show the frequency of rotation of the disk $\Omega_{\rm rot} \equiv V_\phi/R$. Dashed curves present the frequency of rotation for a cold disk $\Omega_{\rm circ} \equiv \sqrt{GM/R^3}$. The difference between the two frequencies is due to the asymmetric drift. The dotted horizontal lines show the frequency of bar rotation. The bar extension is indicated by thick lines. The distance of a bar from the rotation curves is a measure of how fast is the bar. Bar in model B is clearly a very fast one which ends almost up to corotation. Bars in models A1 nad A2 rotate slower, but they are still fast bars.

predict cuspy dark matter halos.

2. N-BODY SIMULATIONS

We have followed the evolution of three models that include an exponential disk inside a halo with a density profile consistent with cosmological models models (Navarro et. al. 1997) . Models A1 and A2 have the same contribution of dark and baryonic matter in the central region. The only difference is that the central value of velocity dispersion is greater for model A2. Model B is a maximum disk system. Simulations were performed using ART (Kravtsov et. al. 1997) reaching a maximum spatial resolution of 20-40 parsecs. A detailed discussion of the models and simulations including tests analyzing numerical effects is presented in Valenzuela & Klypin 2002.

3. DISCUSSION

A signature of the halo-disk interaction is the angular momentum exchange between both components. The maximum variation of disk angular momentum is 15 % and for the bar pattern speed is at most a factor of two as shown in Figure 1. This is far less than in previously reported simulations (Debattista & Sellwood 2000). Figure 2 shows the position of corotation and also indicates the bar size. For the three models R is between 1.0 and 1.7, in agreement with observational results. We conclude that evolution of bar rotation is mostly driven by interaction with the disk, not by dynamical friction with the dark matter halo. The internal properties of the disk have an influence on the bar evolution, as we can see from comparison between models A1 and A2. It is then possible to have fast rotating bars in hierarchical models.

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