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# DYNAMICS OF MERGING SPIRALS AND Λ CDM MERGER TREES

X. Hernandez[1] and W. H. Lee[1]


RESUMEN

Calculamos una serie de simulaciones SPH para estimar los tiempos de relajación de la fusión de dos discos de galaxias espirales. Este tiempo se puede comparar con lo que la teoría estándar de formación de estructura predice para la ocurrencia de una fusión mayor, a cada corrimiento al rojo $z$. El resultado es la existencia de una masa máxima, a cada $z$, arriba de la cual no es posible pensar en una fusión mayor como la causa de la formación de una galaxia elíptica.

ABSTRACT

We run a series of SPH simulations to estimate the time it takes for the disks of two spiral galaxies of similar masses to fuse into a single relaxed spheroid. This timescale can then be compared to the time interval preceding an observed elliptical galaxy, observed at a certain redshift, within which a major merger is limited to have occurred, within the standard Press-Schechter theory. This comparison yields a limit mass, at every observation redshift, above which an elliptical galaxy could not have been the result of a major merger.


*Key Words:* **GALAXIES: FORMATION — GALAXIES: INTERACTIONS — GALAXIES: EVOLUTION**

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## 1. INTRODUCTION

We explore the idea that elliptical galaxies formed as the result of a major merger between two spiral disks, having occurred in the recent past of a system observed at $z = z_0$, a generic observation redshift. We quantify "recent" through calculating detailed SPH simulations of such a merger, under a wide variety of initial conditions in the relevant parameter space. Our simulations represent a cosmologically motivated exploration of the merger and relaxation of two spiral galaxies of similar masses.

Each galaxy is composed of 3 components: dark matter, forming a large halo having initially a King density distribution; stars, forming a disk in centrifugal equilibrium with the total gravity field; and gas, also initially in a centrifugally supported disk. The baryonic components have structural parameters chosen so as to fit the Tully-Fisher law, and disk scale lengths determined by the $\lambda$ spin parameter of each, chosen always in the range 0.03-0.06. All three components interact with each other gravitationally, with the gas being also subject to hydrodynamical interactions and perturbations. In some cases a bulge stellar component was added to the stars, which were given a velocity dispersion that would ensure a constant disk scale height. Most simulations were performed using 20,680 halo particles, 15,706 stellar particles, and an equal number of gas particles, with one test having been run at twice those numbers. All simulations used the GADGET parallel code.

At the beginning of the simulations both galaxies are placed at a distance of $2R_{vir1} + 2R_{vir2}$, where $R_{vir1}, R_{vir2}$ are the virial radii of the two systems, at the redshift at which the merger begins. No initial radial relative velocity is given to the galaxies, but an initial transverse velocity is used, such that the total $\lambda$ parameter of the combined system is close to the cosmological mean of 0.04.

## 2. RESULTS AND CONCLUSIONS

The simulation proceeds with the galaxies falling into each other, with strong tidal features developing as the distance becomes comparable to the sizes of the disks. A slightly off-center collision takes place, followed by a period of strong distortions and dissipative effects within the gas component, which eventually lead to a new equilibrium configuration, highly reminiscent of an elliptical galaxy. This process can be seen in Figure 1, which shows three of the simulations, where the orientation of the disks relative to the orbit spin was: both parallel, perpendicular and parallel, and both anti-parallel, columns from left to right, respectively. It is evident that even though the intermediary morphologies vary significantly with the initial conditions, with strong arms developing in any of the components which co-rotates with the orbit, the final relaxation times are highly insensitive to these details.

[1]Instituto de Astronomia, UNAM, México.

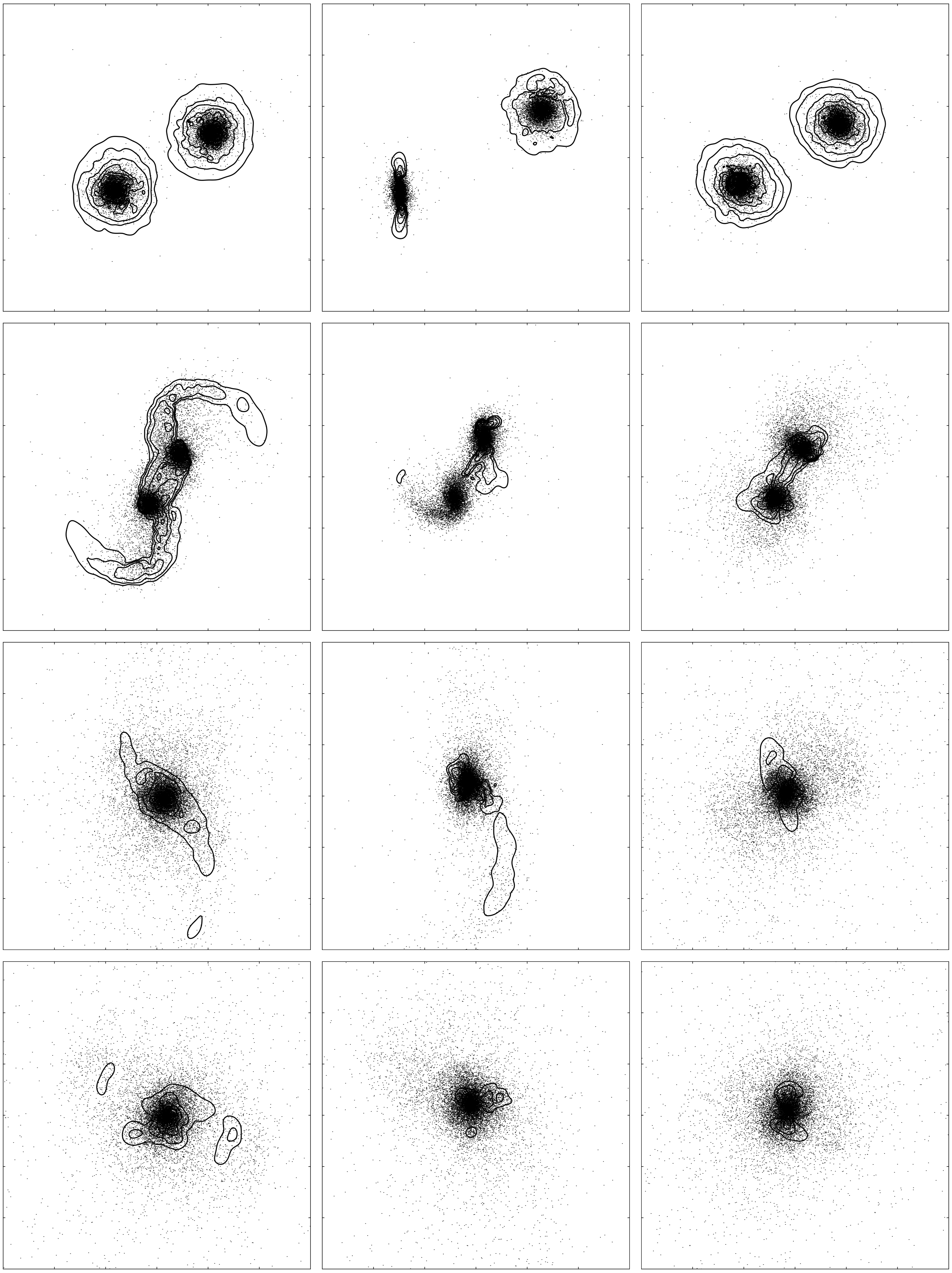

Fig. 1. Three of the simulations, showing the evolution of collisions having different initial orientations. In the first column individual spins were both parallel to the orbital spin, perpendicular and parallel in the middle column, and both anti-parallel in the third. Times shown are 3.53, 4.12, 4.70 and 5.3 Gyrs. Boxes are 300kpc on a side.

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We explored intensively the available parameter space, including changes of orientation, mass ratios (always between 1.0 and 0.5), gas fractions, presence of a bulge, total masses, initial redshift, numbers of particles, sound speed of the gas and structural parameters of the disks. Overall, close to 20 cases were examined. The end result concerning relaxation times, $\tau_R$, was that the total time which elapses from the initial conditions at $z = z_1$ to the final relaxation (defined through the fluctuations of the total potential and kinetic energies of the system) was always well represented by:

$$\tau_R = \frac{21.1}{(1+z_1)^{3/2}} Gyr$$

At this point we computed the maximum time interval, previous to a given observation redshift, $z_0$, within which a major merger might have taken place. Using the extended Press-Schechter theory, we can calculate the mass function of progenitors of a system of mass M, occurring at an observation redshift of $z = z_0$, at a previous redshift, $z = z_1$, from:

$$P(M_1) = \frac{M_0}{(2\pi)^{1/2}} \frac{\delta_c(z_1 - z_0)}{(S_1 - S_0)^{3/2}} exp\left[\frac{\delta_c^2(z_1 - z_0)^2}{2(S_1 - S_0)}\right] \left|\frac{dS_1}{dM_1}\right|.$$

In the above equation $P(M_1)$ is the probability of finding a progenitor of mass $M_1$, at $z = z_1$, where clearly $z_1 > z_0$ e.g. Lacey & Cole (1993), Nusser & Sheth (1999) and Hernandez & Ferrara (2001). $\sqrt{S_i}$ is the rms density fluctuation in a top hat window function of radius $(3M_i/4\pi\rho_0)^{1/3}$ and $\delta_c$ the critical overdensity for collapse, with $\rho_0 = 3\Omega_M H_0^2/8\pi G$ being the present mean mass density of the universe. All quantities were evaluated in an $\Omega_\Lambda = 0.7, \Omega_M = 0.3, h = 0.65$ universe.

We can now define $\Delta t_M$, the time interval previous to $z_0$ beyond which no major merger could have taken place, as that corresponding to the redshift at which the mass function of progenitors has less than 5% of its progenitors upwards of $0.3M$. i.e., only less than 0.25% of objects at $(M, z_0)$ could have suffered a major merger beyond that redshift.

$\Delta t_M$ is, of course, a complex function of both mass and redshift, which we evaluate numerically from eq.(2). Setting $\Delta t_M = \tau_R$ fixes the limit mass upwards of which an elliptical galaxy observed at $z_0$ could not possibly have originated through a major merger. If that were the case, it would look like an interacting system, $\tau_R$ being larger than $\Delta t_M$. This curve is plotted in Figure 2.

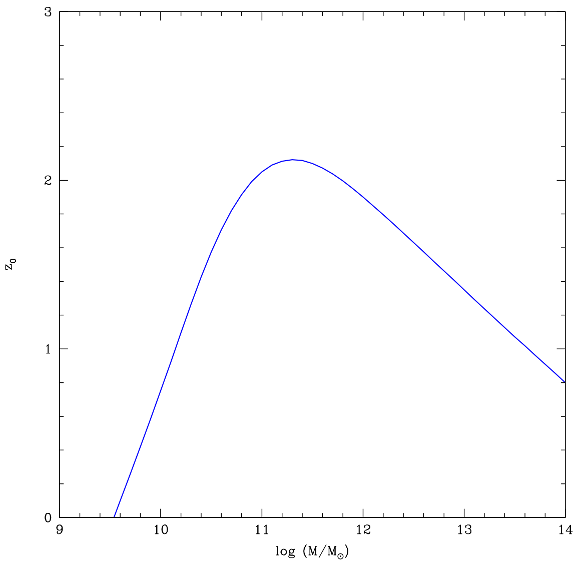


Fig. 2. Limit total mass for an observed elliptical galaxy above which the system could not possibly be the result of a major merger, as a function of the observation redshift, $z_0$.

Several important features can be noted about this curve, the first being the presence of a maximum redshift of $z = 2.1$ above which, for no mass will the condition $\Delta t_M > \tau_R$ be satisfied. This means that elliptical galaxies observed at redshifts greater than 2.1, cannot have formed as the result of a major merger. The second is the existence of regions above the curve, even at very low redshifts. For example, an elliptical galaxy with a total mass of $10^{10} M_\odot$ (around $5 \times 10^8 M_\odot$ in baryons) can only be thought of as having been formed in a major merger if observed at a redshift below $z = 0.6$. It is clear that many real galaxies can be observed below the curve; however, the equally clear presence of elliptical galaxies above the curve shows that not all such systems are the result of major mergers, other mechanisms for their formation must be invoked.

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X. Hernandez. and W. H. L.: IA-UNAM, AP 70-264, 04510 México, D.F., México; (xavier,wlee@astroscu.unam.mx)