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# The dependency of merger time-scales on the orbital parameters and internal spins of galaxies. Implications on the observability of AGN pairs.

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## Abstract

A massive set of hundreds of collisionless binary major-merger simulations is being built for the purpose of having a wealth of experimental data which allow to investigate the dependence of the most important properties of merger remnants on both the initial orbital configuration of the progenitor galaxies and the spin of their dark halos. These simulations follow the evolution of galaxy mergers in bound orbits using high-resolution $N$-body models of late- and early-type galaxies, composed of a rotating dark matter halo and a central stellar core, with mass ratios from 1:1 to 3:1, and for values of the orbital parameters consistent with the predictions of the currently favored cosmological model. Here we present preliminary results based on the subset of equal-mass mergers of an ongoing investigation on the importance of the halo spin of the interacting galaxies in the merger time. The simulations analyzed so far indicate that the higher the orbital circularity, the more sensitive is the duration of the mergers to the relative orientations of the orbital and halo spin vectors, with prograde encounters merging substantially faster than retrograde encounters for the highest circularities explored. As an example of other potential applications of this type of experiments, we have inferred predictions for the expected fraction of dual AGNs in major mergers. By converting both the conditions for nuclear activity and the limitations in the detection of AGN pairs through imaging and spectroscopy into constraints on the relative positions and velocities of the merging pairs, we find that the fraction of the merger time in which strong dual AGN activity can be detected is independent of the orbital configuration and typical of the order of a few percent in agreement with observations.

# 1 Introduction

We use an extensive suite of high-resolution $N$-body simulations of isolated major mergers of equal-mass galaxies embedded in extended rotating dark matter halos to explore merger timescales over a range of orbital parameters, galaxy relative orientations and morphologies, and dark halo spins. A great deal of past numerical simulations of binary mergers are based on initial equilibrium galaxy models that do not conform to the paradigm currently accepted for these systems —especially regarding the structure and spin of the dark matter halos— and adopt ad-hoc initial conditions intended to lead to fast merger that saves computational time. In this presentation, we introduce a study of dynamical friction based on well-resolved galaxy progenitors modeled after local galaxies in the framework of the standard concordant ΛCDM cosmology. Our simulations set-up relies on physically consistent initial conditions inferred from the most recent cosmological simulations that take into account the role of baryons on structure formation [7, 2]. While it is true that this sort of idealized experiments are less astrophysically realistic than simulations in a cosmological volume, they are necessary to complement the results of the latter. Dealing with closed systems enables one to both isolate the effects of specific parameters and make clean and accurate measurements. Conversely, studies developed in a fully cosmological context must look at mergers amidst hierarchical structure formation, which both promotes uneven sampling and distorts the measurements, leading to a substantial increase in the uncertainty of the results.

As an example of the many additional applications that this type of modelling may have, we utilize our simulations to test the merging active galactic nucleus (AGN) pair scenario. If one assumes that AGNs are essentially triggered by major galaxy interactions and that the two components in a merging pair shone at uncorrelated times, the expected fraction of dual AGN events can be inferred from the ratio between the typical lifetime of nuclear activity in galaxies and the dynamical timescale of galaxy mergers convolved with the observational limitations for pair detection. We have constructed a phenomenological model in which the duration of the mergers is calculated directly from our suite of simulations, while both the physical conditions leading to AGN activity, as well as the typical definitions and detection thresholds adopted in observational studies of galaxy pairs, are translated into contraints in the relative separations in phase space of our merging galaxies. In order to get results that can be compared with a good number of existing datasets, we have applied to our simulations the imaging and spectroscopic biases characteristic of Sloan Digital Sky Survey (SDSS) observations [6]. Thus, for instance, to derive predictions based on imaging data we have excluded from detection those pairs with nuclear projected separations smaller than 1.5 arcsec —about $r_{\rm proj} \sim 5\,h_{70}^{-1}$ kpc for a typical redshift of $z \sim 0.16$— that are too small to be resolved by the deblending algorithm of SDSS photometry. In the same vein, to estimate the fraction of spectroscopically selected AGNs we have excluded pairs with line-of-sight velocities smaller than 150 km s$^{-1}$, due to the limited spectral resolution of SDSS spectra, as well as pairs with a projected separation larger than $3''$ (i.e. $8\,h_{70}^{-1}$ kpc) that would not fall within a single SDSS fiber.

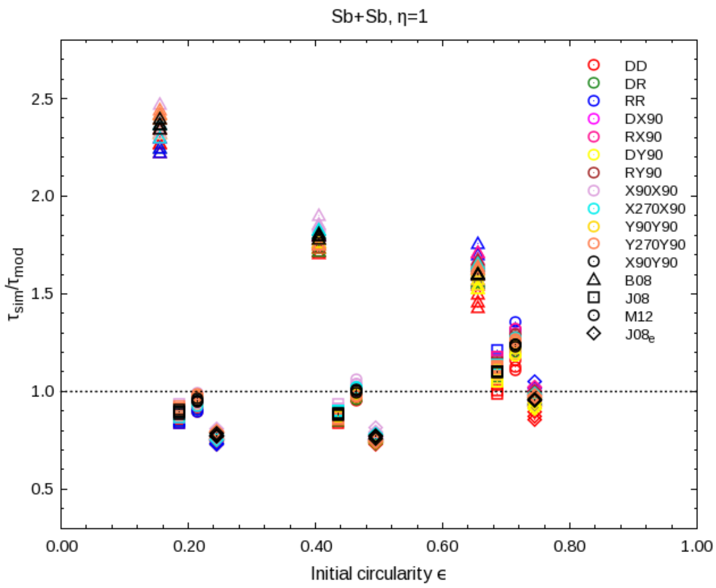


Figure 1: Comparison of merger times for equal-mass Sb mergers with the most likely orbital energy ($r_{\rm cir}(E)/r_{\rm vir} = 4/3$; [7]) as a function of the initial orbital circularity of the progenitors. In this plot we compare the times measured in our simulations, $\tau_{\rm sim}$, with the values derived from various empirical formulas inferred in cosmological simulations, $\tau_{\rm mod}$. In this and the next figures we use a color coding to represent the different relative orientations of the orbital and galactic spin vectors (see Section 2 and the inset legends).

## 2 Simulations set-up, definition of the merging timescale, and merger tracking scheme

Our late-type galaxy models consist of a virialized spherical NFW dark matter (DM) halo, and a central exponential disk of stars with a nonrotating spherical Hernquist stellar bulge of mass $0.25M_{\rm disk}$. Early-type objects also have a spherical NFW DM halo surrounding a nonrotating Hernquist stellar spheroid with an intrinsic flatening $c/a = 0.7$. In both cases, the total stellar mass is set to $0.05M_{\rm vir}$. The structural parameters of the luminous distributions have been determined from the total mass of the galaxies, $M_{\rm vir}$, following the analytic prescriptions given in [3]. Each galaxy in a 1:1 ($\eta = 1$) merger is represented by a total of $210,000$ particles with a fifty-fifty split in number between luminous and dark bodies.

A neat rotation à la [8] is imparted to the dark halos of the galaxies. For late-type objects we use up to four different spin values: $\lambda = 0.00$, $0.02$, $0.04$, and $0.06$. Since it is reasonable to expect that the dark halos associated with early-type galaxies have less angular momentum than those associated with disks, we have simply taken for the former $\lambda = 0.0$ and $0.02$.

The values adopted for the orbital parameters (i.e., the initial total orbital energy, $E$ —parametrized by the ratio $r_{\rm cir}(E)/r_{\rm vir}$—, and the initial orbital circularity, $\epsilon$) are represen-

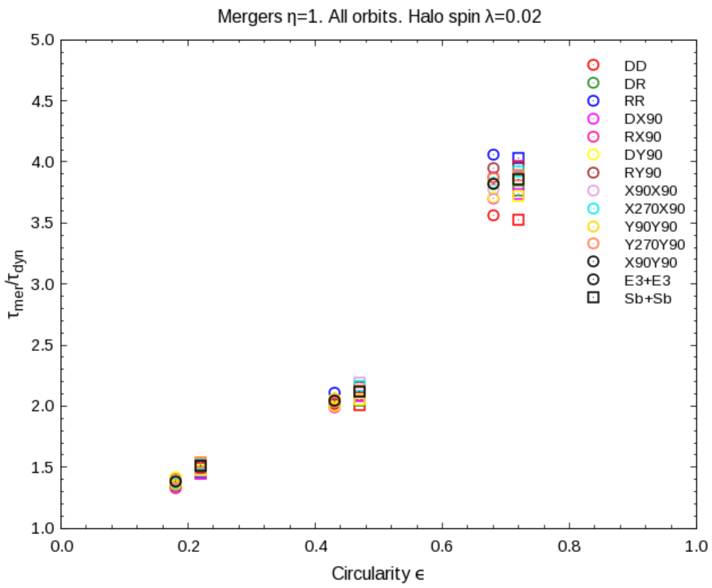


Figure 2: $\tau_{\rm mer}$ vs. $\epsilon$ for equal mass mergers of Sb- (open squares) and E3-like (open circles) galaxies, all embedded in halos with a spin parameter $\lambda = 0.02$ and having an orbital energy $r_{\rm cir}/r_{\rm vir} = 2$. As in Fig. 1, predictions are shown with a small offset in $\epsilon$ for clarity.

tative of their probability distribution functions obtained in recent cosmological simulations (e.g. [7]). Specifically, we deal with two orbital configurations defined by $r_{\rm cir}(E)/r_{\rm vir} = 4/3$ (representing the mode) and 2.0, and three different ellipticities: $\epsilon = 0.20$, 0.45 (mode), and 0.70.

The outcome of a galactic collision is also expected to depend on the degree of alignment of the spin of the progenitor halos with the orbital spin for a given ratio of their moduli. To assess the full scope of this contribution, we have defined 12 extremal configurations in which the initial coupling of both vectors is either maximal or minimal. By putting the mergers orbit in the $XY$ plane, so the orbital spin always points towards the positive direction of the $Z$ axis, we use the capital letters 'D' and 'R', respectively, to identify galactic spins that are set parallel and anti-parallel to this axis, 'X90' to identify galaxies that have been rotated 90 degrees counterclockwise along the $X$ axis, and so on.

In agreement with recent high-resolution simulations that study dynamical friction timescales in a cosmological context [1, 4, 7], the merger timescale, $\tau_{\rm mer}$, is defined as the time elapsed between the moment when the secondary galaxy first crosses the virial radius of the primary, $r_{\rm vir}$, and the final coalescence of both. We use the center of mass of the most bound parts of the baryonic cores of our galaxies to track exactly the inter-center separation in phase space. Since in our simulations we deal only with major mergers, we do not have to worry about the possibility that the galaxies are tidally disrupted before coalescence.

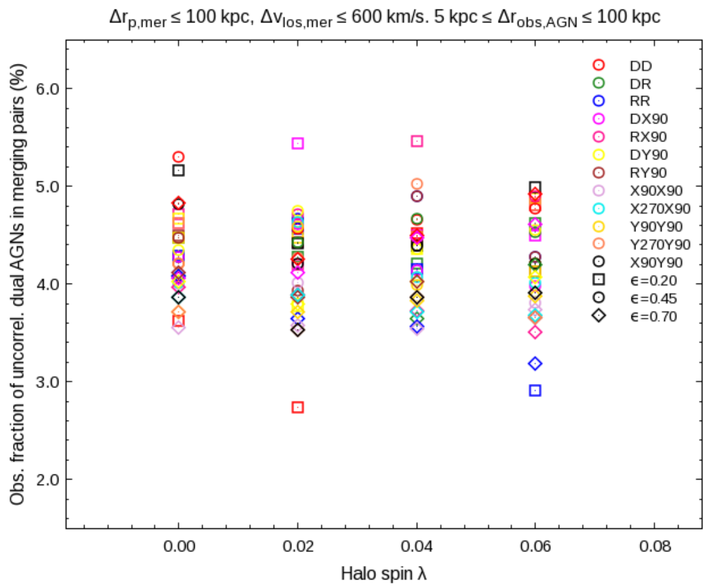


Figure 3: Percentage of uncorrelated double-peaked narrow-line AGNs in mergers of identical Sb galaxies vs the spin of their DM halos. The position and velocity offsets used to define both the galaxy pairs and the spectroscopic detectability of dual AGN match the observational limits commonly adopted in studies based on Sloan Digital Sky Survey data [6]. These estimates assume a typical AGN lifetime of $10^8$ yr.

## 3 Summary of preliminary results

- Our merger timescales show a reasonable agreement with the most recent predictions inferred from cosmological simulations [7], especially for radial ($\epsilon = 0.20$) and tangential ($\epsilon = 0.45$) encounters. The moderate over-prediction of $\tau_{\rm mer}$ shown by our elliptical mergers ($\epsilon = 0.70$) with respect to the cosmological prescriptions can be attributed to the fact that we have computed merger times for halos with $z \sim 0$ characteristics, while the dynamical friction drag at a given mass scale is expected to be stronger in the past due to the higher mean densities of halos and lower relative velocities of collisions. Another possible source of discrepancy is the undersampling of $\eta = 1$ major mergers in cosmological simulations.

- The influence of $\lambda$ on $\tau_{\rm mer}$ becomes stronger with increasing $\epsilon$. It translates into a progressive increase in the scatter of merger times, the breadth of which is highly correlated with the degree of alignment between orbital and halo spins. For encounters with an orbital energy $r_{\rm cir}/r_{\rm vir} = 2$, a circularity $\epsilon = 0.70$, and in which both galactic halos have a spin $\lambda = 0.06$, we measure variations in $\tau_{\rm mer}$ up to 40% (or about 2.8 Gyr in physical units) between the most prograde (faster) and most retrograde (slower) encounters.

- Merger timescales are shorter for early-type galaxies, reflecting the well known fact that the central regions of bulges are significantly denser than those of disks. The difference, however, is quite modest, becoming negligible for those configurations in which the two merger partners spend most of their time at large separations.

- The predicted frequencies of uncorrelated dual AGNs are independent of the configuration of the mergers. The low values inferred are fully consistent with observational estimates of the population of interacting galaxies (e.g. [5]). This suggests that the paucity of observed AGN pairs is compatible with the hypothesis that central supermassive black hole activity is mostly triggered by major galaxy collisions.

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