## Title

The bar-halo interaction - I. From fundamental dynamics to revised N-body requirements

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## Abstract

A galaxy remains near equilibrium for most of its history. Only through resonances can non-axisymmetric features, such as spiral arms and bars, exert torques over large scales and change the overall structure of the galaxy. In this paper, we describe the resonant interaction mechanism in detail, derive explicit criteria for the particle number required to simulate these dynamical processes accurately using N-body simulations, and illustrate them with numerical experiments. To do this, we perform a direct numerical solution of perturbation theory, in short, by solving for each orbit in an ensemble and make detailed comparisons with N-body simulations. The criteria include: sufficient particle coverage in phase space near the resonance and enough particles to minimize gravitational potential fluctuations that will change the dynamics of the resonant encounter. These criteria are general in concept and can be applied to any dynamical interaction. We use the bar–halo interaction as our primary example owing to its technical simplicity and astronomical ubiquity. Some of our more surprising findings are as follows. First, the inner Lindblad like resonance, responsible for coupling the bar to the central halo cusp, requires more than inline image equal-mass particles within the virial radius or inline image inside the bar radius for a Milky Way like bar in a Navarro, Frenk & White profile. Secondly, orbits that linger near the resonance receive more angular momentum than orbits that move through the resonance quickly. Small-scale fluctuations present in state-of-the-art particle–particle simulations can knock orbits out of resonance, preventing them from lingering and, thereby, decrease the torque per orbit. This can be offset by the larger number of orbits affected by the resonance due to the diffusion.

However, noise from orbiting substructure remains at least an order of magnitude too small to be of consequence. Applied to N-body simulations, the required particle numbers are sufficiently high for scenarios of interest that apparent convergence in particle number is misleading: the convergence with N may still be in the noise-dominated regime. State-of-the-art simulations are not adequate to follow all aspects of secular evolution driven by the bar–halo interaction. It is not possible to derive particle number requirements that apply to all situations, for example, more subtle interactions may be even more difficult to simulate. Therefore, we present a procedure to test the requirements for individual N-body codes to the actual problem of interest.

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## Comments

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