Generation of composite galaxies in dynamic equilibrium

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Introduction

We present a program to calculate initial positions and velocities for a self-gravitating, nearly self-consistent composite galaxy (which can consist of disk, halo, bulge, and point mass black hole components). We use the standard moment-based approach [3], involving numerical solution of the Jeans equations, to determine initial conditions. The unique design of this code features a grid which must be determined only once for a given galactic shape, and which can be scaled to a given mass. We plan on constructing a library of grids for common galactic shapes; following this, the low overhead and short computing time of this code allows rapid initialization of model galaxies. As well as being capable of research-grade results, this code is intended to occupy a valuable niche in instructional use, allowing galaxies to be built rapidly in the classroom to a student's specification. The code is written for compatibility with Volker Springel's popular N-body code GADGET-2 [5], but could easily be adapted to other formats.

User Options

User inputs include the following:

- A density profile for each desired component
- A potential caused by the component (not necessarily analytic)
- Mass, scale lengths, and number of particles of each component
- Grid resolution and limits

Future work will be directed towards creation of a library of density profiles and associated potentials, so the user will need only to select a density profile and desired masses, scale lengths, and number of particles for each component.

Currently only axisymmetric systems with distribution functions dependent on E and L_z are supported.

Methods

The final code will contain support for multiple axisymmetric density profiles. In the current implementation, we consider a galaxy consisting of an exponential disk and an NFW halo [4], described by the density profiles:

$$\rho_{disk}(R,z) = \rho_0 \exp(-R/R_0)\exp(-|z|/z_0)$$

$$\rho_{halo}(r) = \frac{\rho_h c^3 g(c)}{(r/r_s)(1+r/r_s)^2}$$

The potential of the disk is computed numerically [2] and added to the analytical potential of the halo.

Solution of the Jeans equation for an axisymmetric system yields the velocity moments:

$$\langle v_R^2\rangle = \langle v_z^2\rangle = \frac{1}{\rho}\int_z^\infty \rho\frac{\partial\Phi}{\partial z'}dz'$$

$$\langle v_\phi^2\rangle = \langle v_R^2\rangle + \frac{R}{\rho}\frac{\partial}{\partial R}(\rho\langle v_R^2\rangle) + R\frac{\partial\Phi}{\partial R}$$

The final implementation will consist of two parts:

Grid calculations

The R-z plane is discretized into a grid which is linear inside the virial radius of the halo and logarithmic outside. For a given galactic shape (based on input scale lengths), the potential, first derivatives of potential, and velocity dispersions are calculated at each grid point. Data is output to a binary file. If a grid for the desired shape already exists in the grid library, this step is skipped.

Model construction

The grid is read into the second program and scaled to match the desired mass. Positions are determined via rejection sampling of the density profile of each component. Velocities are sampled from a triaxial Gaussian with dispersions interpolated from the grid. Data is written to file in the GADGET-2 file format.

Postprocessing

If desired, multiple galaxies can be combined to set up initial conditions for a galactic merger.

Results

We model a Milky Way-like galaxy with a disk with a radius of 17.5 kpc (radial/vertical scale lengths of 3.5 kpc and 0.35 kpc respectively) and a mass of 6×10^{10} solar masses. The dark matter halo has a virial radius of 245 kpc, a concentration $c = 10$, and a mass of 10^{12} solar masses [1]. The disk is assumed to be an isotropic rotator.

Figure 1: Galactic disk projected density (top view)

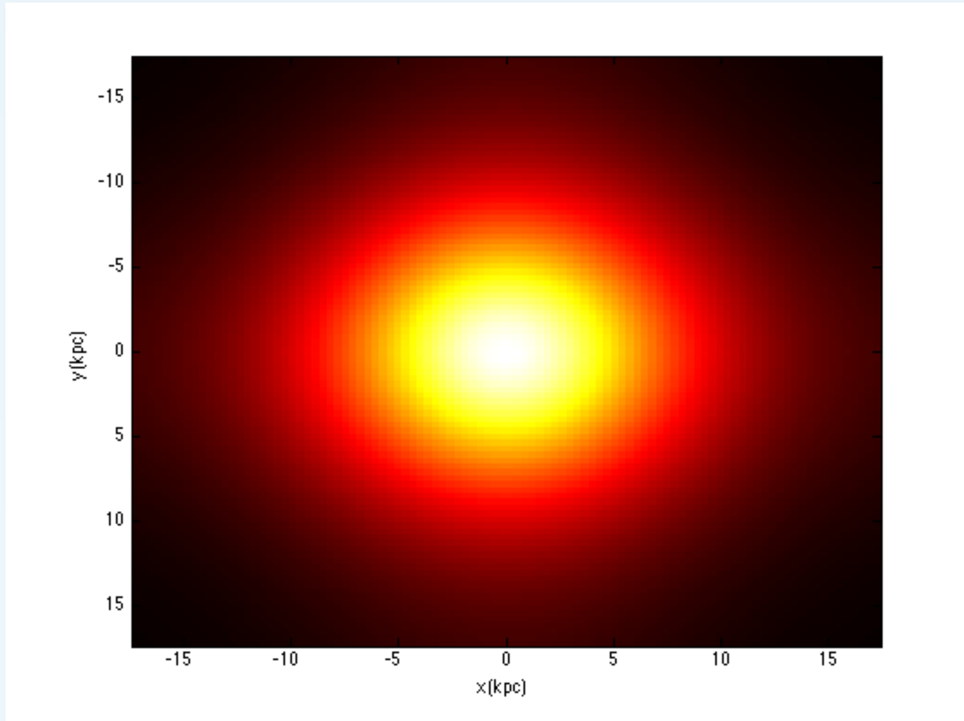
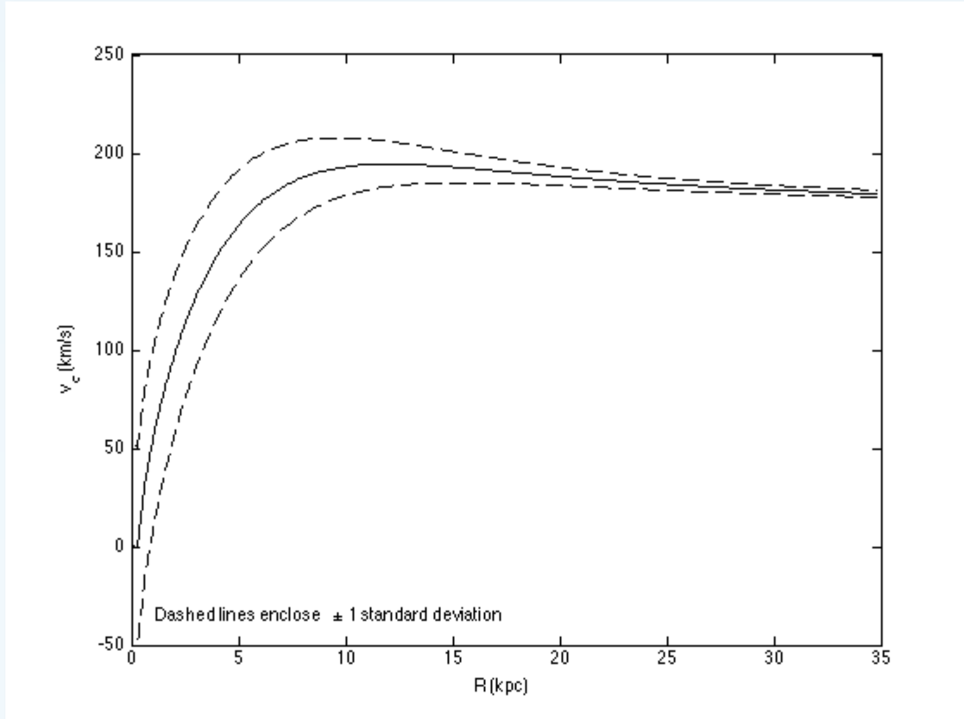


Figure 2: Rotation curve with Gaussian dispersions. 68% of stars have velocities inside the dashed envelope.



A Test Model

Initial conditions were generated for a coaxial merger of two disks with opposite rotational directions.

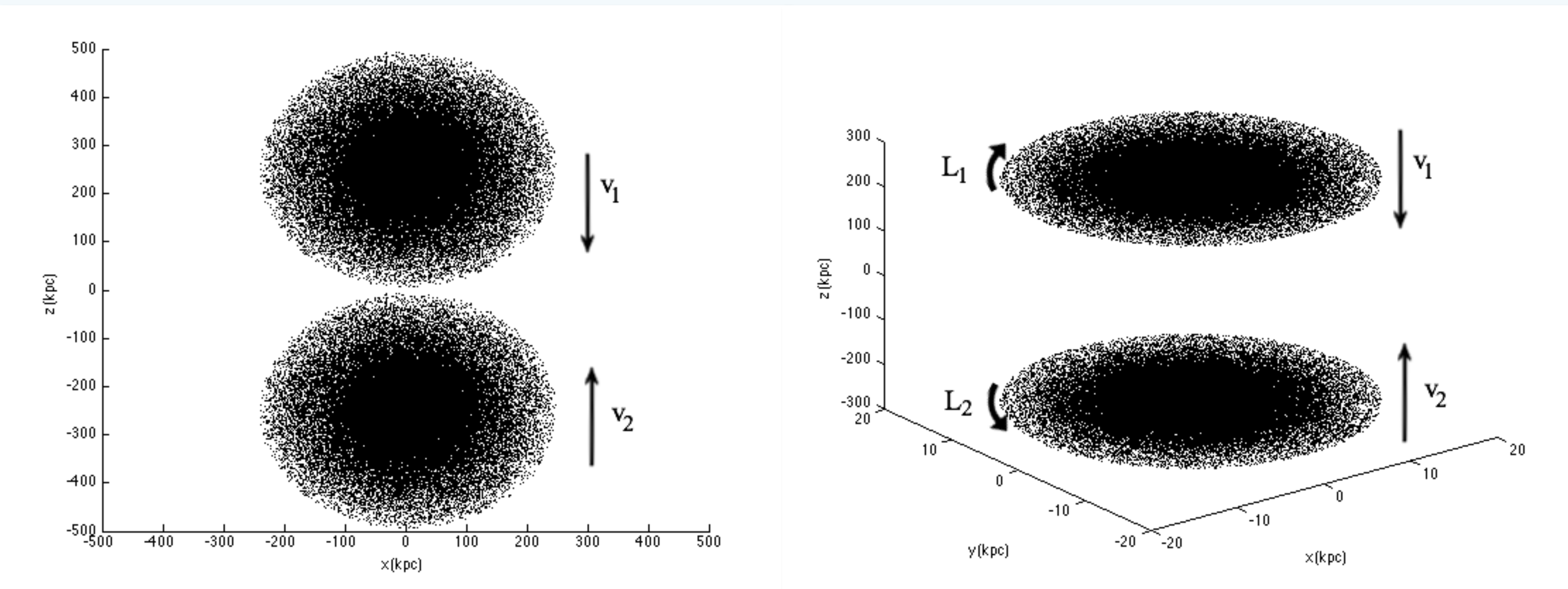


Figure 3: Initial conditions of the dark matter halos and the embedded disks. Each galaxy is generated to be in dynamical equilibrium if it were an isolated system.

We will investigate the effects of the merger with a number of varying initial parameters:

- Mass ratio of the two galaxies
- Initial relative velocity
- Impact parameter
- Initial angular momentum of each disk

Ongoing Work

- Testing the accuracy of this code against similar codes via N-body simulation
- Optimization to minimize computational effort for high-quality results
- Creation of a library of density profiles and associated potentials (see User Options)
- Creation of a library of grids for common galactic density profiles
- Extension to more general distribution functions, including triaxial elliptical galaxies
- Support for parallelization for grid calculations

References

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[3] Lars Hernquist. N-body realizations of compound galaxies. ApJS, 1993.

[4] Ewa L. Łokas and Gary A. Mamon. Properties of spherical galaxies and clusters with an NFW density profile. MNRAS, 321, 2001.

[5] Volker Springel. The cosmological simulation code GADGET-2. MNRAS, 364, 2005.

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