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Dark matter and computational geometry

Traditional N-body simulations discretize the dark matter distribution into an ensemble of point particles. However, estimating the local density for a set of point particles is difficult due to Poisson noise. Abel et al. (2012) instead describe the phase-space distribution of dark matter as a 3D manifold tessellated into tetrahedra. This has the advantage of giving an unambiguous value for the density everywhere in configuration-space. Analyzing such a collection of tetrahedra requires a method for projecting a tetrahedron onto a uniform grid (voxelization). Various schemes have been tried (e.g. Angulo et al. 2013, Hahn et al. 2013), though each has its advantages and drawbacks.

I present here a new method for voxelizing polytopes. This method computes the exact intersection volume between the polytope and each voxel, so it is noiseless and exactly mass-conserving. In addition, polynomial functions defined over the polytope can be exactly voxelized, giving the ability to apply mass interpolation schemes over the phase-space sheet.

My implementation of this method yields an unprecedentedly smooth and continuous dark matter density field, with exciting prospects for studying the phase-space structure of dark matter haloes, WIMP annihilations, gravitational lensing, and more.

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