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# Simulating Rotating Newtonian Universes


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## Abstract

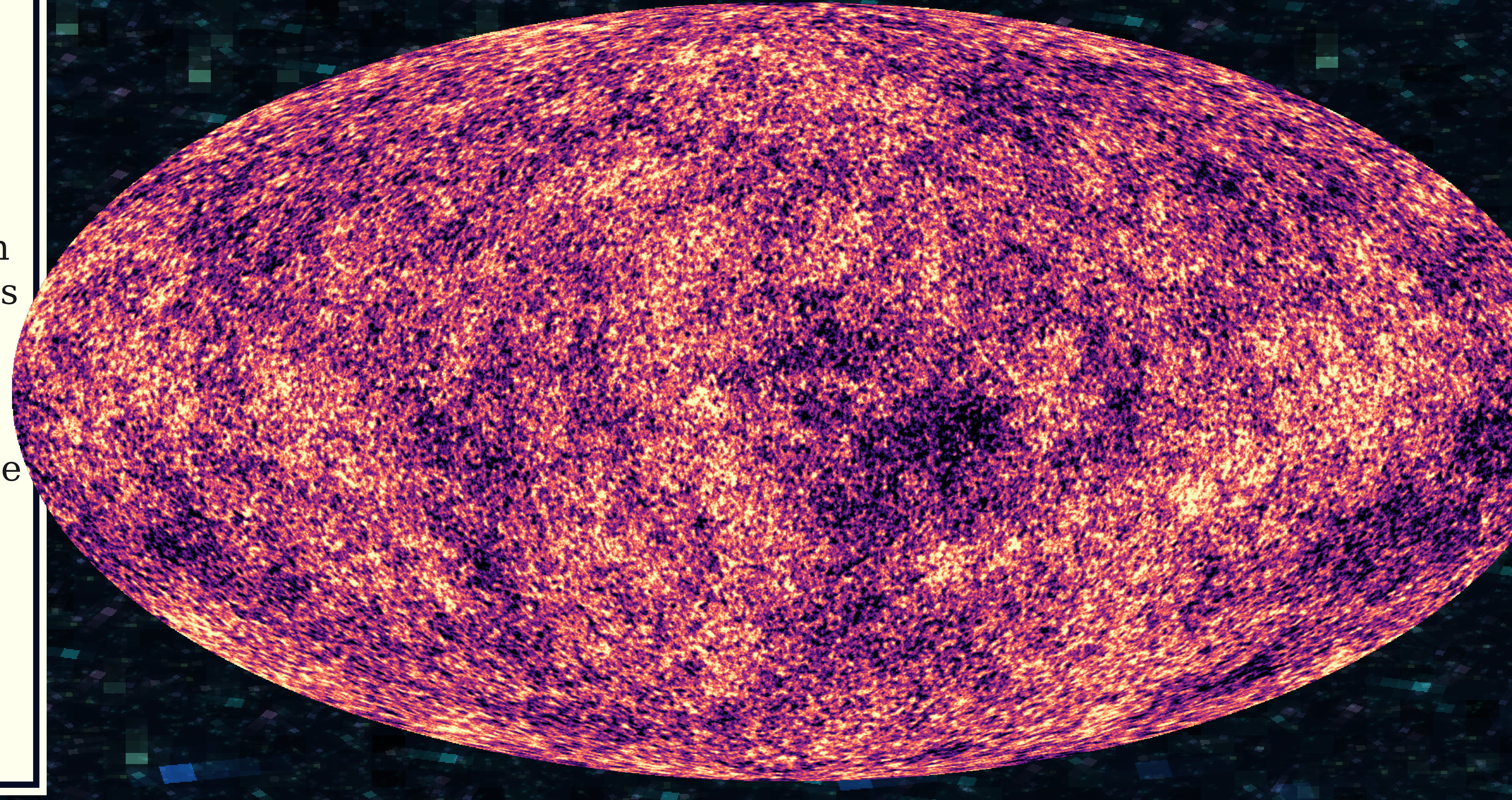
We present the results of a novel type of numerical simulation that realizes a rotating Universe with a shear-free, rigid body rotation inspired by a Gödel-like metric. We run cosmological simulations of unperturbed glasses with various degrees of rotation in the Einstein−de Sitter and the ΛCDM cosmologies. To achieve this, we use the StePS N-body code capable of simulating the infinite Universe, overcoming the technical obstacles of classical toroidal (periodic) topologies that would otherwise prevent us from running such simulations. Results show a clear anisotropy between the polar and equatorial expansion rates with more than 1% deviation from the isotropic case for maximal rotation without closed timeline curves within the horizon, $\omega_0 \approx 10^{-3}\,\mathrm{Gyr}^{-1}$; a considerable effect in the era of precision cosmology.

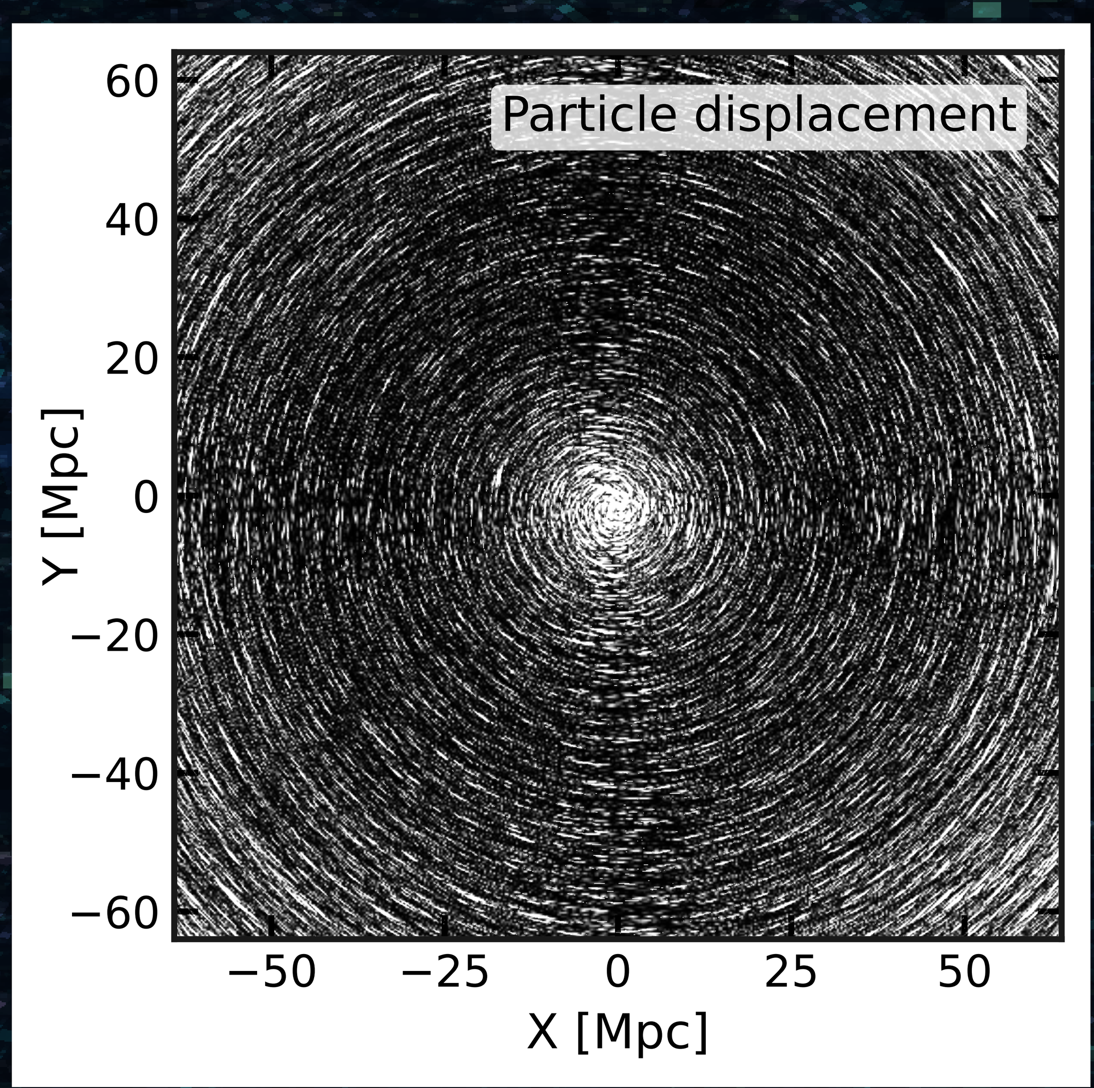

## Introduction

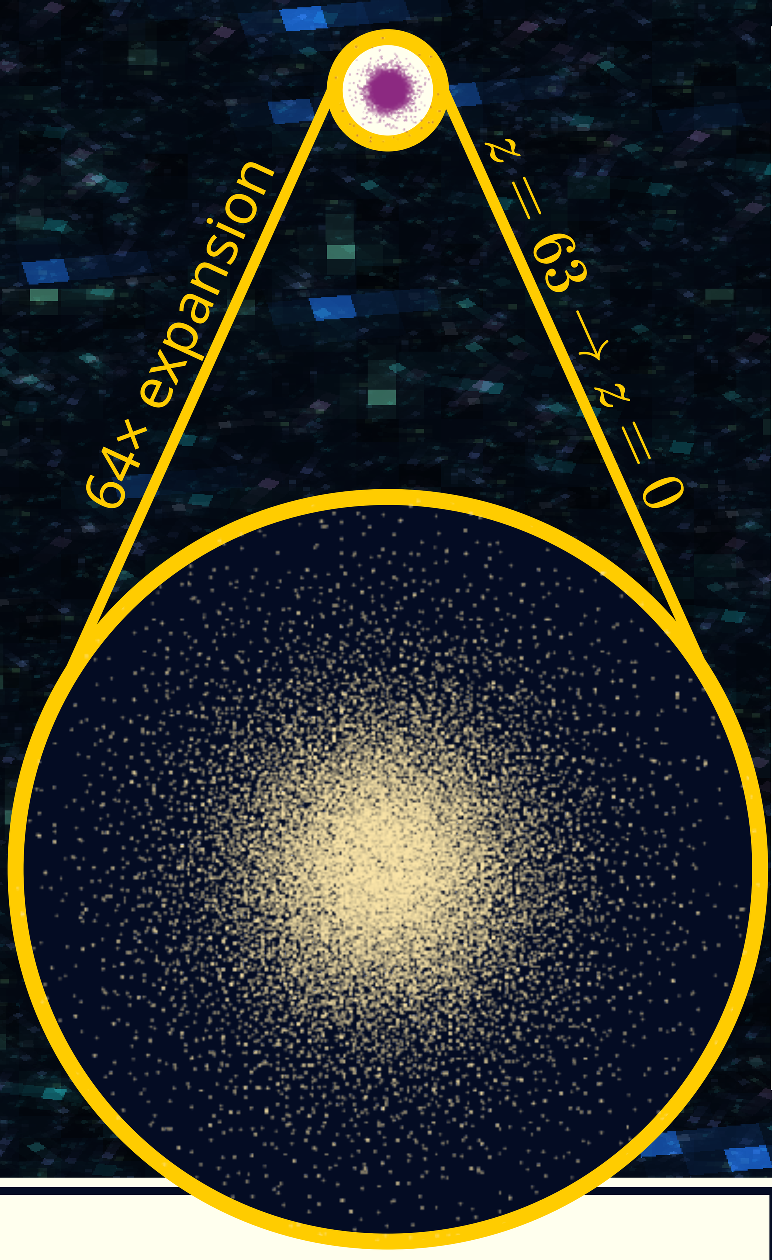
Recent analyses of cosmological surveys indicate a statistically significant anisotropy in the expansion rate of the Universe (e.g., [1-3]), suggesting phenomena beyond the standard ΛCDM model. One possible explanation could be a cosmological rotation of the Universe itself. The idea of cosmic rotation has a rich historical precedence, with the most notable contribution coming from Gödel [4], who proposed the metric of a rotating dust sphere as

$$\mathrm{d}s^2 = a^2\left[dt^2 - dx^2 + \frac{e^{2x}}{2}dy^2 - dz^2 + 2e^x dt dy\right].$$

While measurements by the Planck satellite ruled out most rotating Universe models [5], placing an upper limit of their vorticity at $(\omega/H)_0 < 7.6 \times 10^{-10}$, they still permit shear-free and parallax-free rotation, as in Gödel-like metrics. Despite rotation being pervasive across all physical scales, the phenomenon of cosmological rotation has never been studied using cosmological simulations in a full 3D setting, although numerical approaches have been considered previously [6].






## Simulation

We examine a shear-free, rigid-body rotation of the Universe using ordinary, cosmological N-body simulations, where gravitational interaction between particles are reduced to Newtonian physics. Traditional cosmological codes that utilize periodic boundary conditions cannot properly model global rotation, as it would appear as a constant velocity field without acceleration.

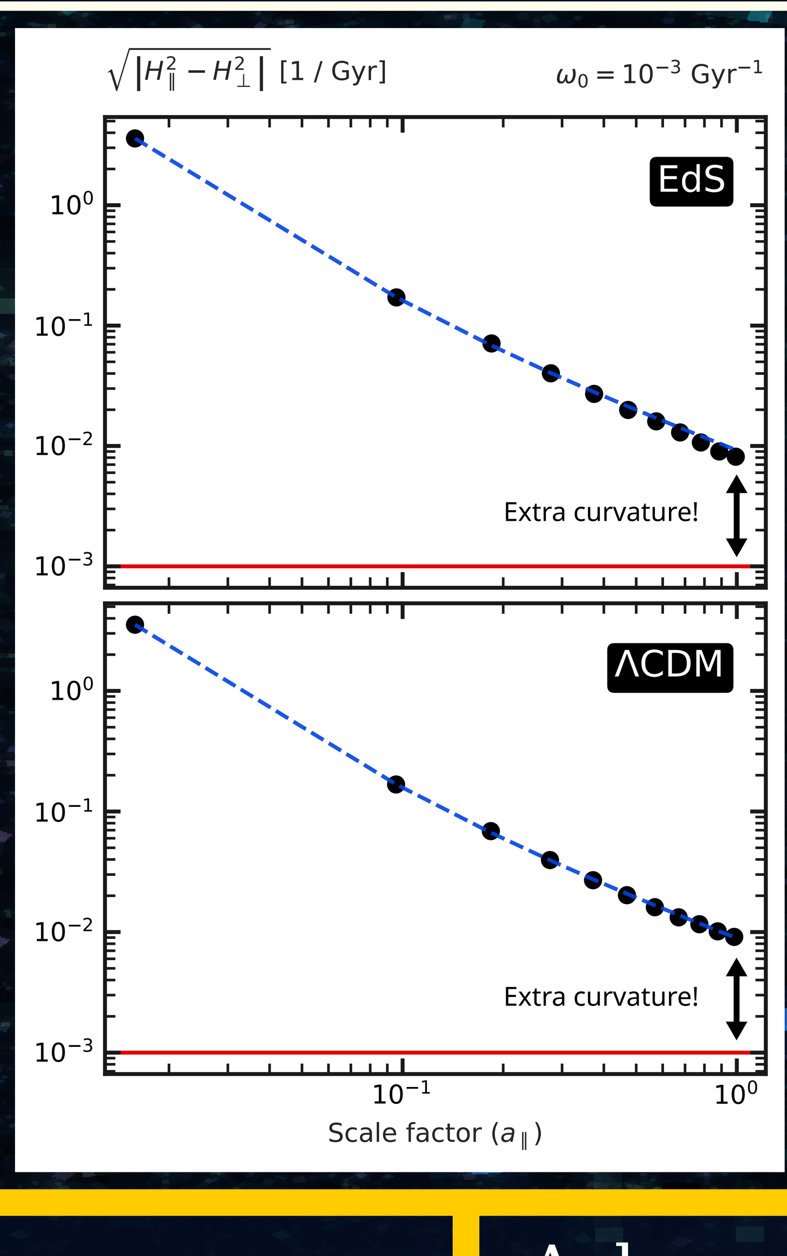
We overcome this using the StePS simulation code [7], which simulates the entire infinite Universe by compactifying it onto a 4D hypersphere [8]. We study an unperturbed particle distribution to isolate rotational effects from the LLS formation, applying various degrees of angular velocity. The magnitude of the rotation is constrained by requiring sub-lightspeed motion within the Hubble horizon, yielding a maximum present-day angular velocity of $10^{-3}\mathrm{Gyr}^{-1}$. One of the key challenges is addressing the apparent curvature that emerges due to the anisotropic expansion of a rotating Universe, which we attempt to resolve by carefully scaling velocity components to match the total kinetic energy of the non-rotating case.

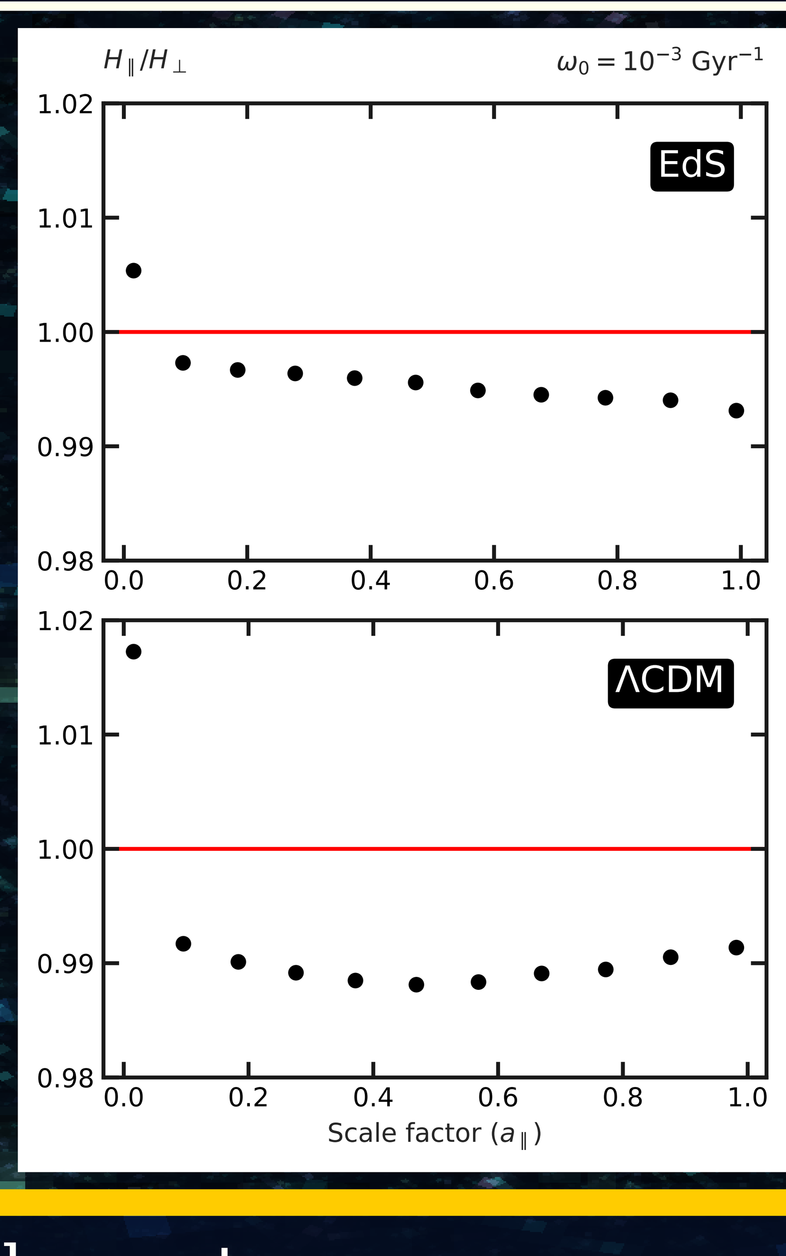
## Results

We measured the scale factor and the Hubble parameter both parallel and perpendicular to the rotation axis. Results show an approximately 1% anisotropy between the directions, with perpendicular expansion being consistently larger. The rotating Newtonian Friedmann equations predicts that the squared difference between the parallel and perpendicular Hubble parameters $(H_\perp^2 - H_\parallel^2)$ should equal $\omega_0^2$ at the present time.

However, simulations reveal an additional curvature-like term affecting both directions, suggesting our method for handling the emerging curvature was incomplete. This implies that rotation has a more complex 'back-reaction' effect than it can be assumed, affecting expansion in all directions.
A follow-up study will characterize this missing curvature term and validate the rotating Newtonian Friedmann equations.

Nevertheless, we demonstrated that creating rotating cosmological N-body simulations are feasible and they can capture the effects of global rotation.





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