Repulsive gravity model for dark energy

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DER FORSCHUNG | DER LEHRE | DER BILDUNG

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Motivation

- ΛCDM model: only 5% visible matter.
  - Dark matter explains “missing mass” in galaxies.
  - Dark energy explains accelerating expansion.
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- Only interaction between both copies: repulsive gravity.
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- Only interaction between both copies: repulsive gravity.
- Universe contains equal amounts of both types of mass.
- Dark galaxies "push" visible matter & light towards visible galaxies.
  $\Rightarrow$ Explanation of dark matter!
- Mutual repulsion between galaxies drives accelerating expansion.
  $\Rightarrow$ Explanation of dark energy!

Repulsive Einstein gravity

- Positive and negative test masses follow different trajectories.
- Two types of test mass trajectories $\Rightarrow$ two types of observers.
- Observer trajectories are autoparallels of two connections $\nabla^{\pm}$.
- Observers attach parallely transported frames to their curves.
- Frames are orthonormalized using two metric tensors $g^{\pm}_{ab}$.

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- Frames are orthonormalized using two metric tensors $g^{\pm}_{ab}$.
- No-go theorem forbids bimetric repulsive gravity. [MH, M. Wohlfarth '09]
- Solution: $N \geq 3$ metrics g^{I}_{ab} and standard model copies Ψ^{I}.

Action and equations of motion

- Matter action: sum of standard model actions.
- Gravitational action:

$$S_G[g^1,\ldots,g^N] = \frac{1}{2}\int d^4x\sqrt{g_0}\left[\sum_{I,J=1}^{N}(x + y\delta^{IJ})g^{Iij}R^J_{ij} + F(S^{IJ})\right].$$

- Symmetric volume form $g_0 = (g^1 g^2 \ldots g^N)^{1/N}$.
- $F(S^{IJ})$ quadratic in connection difference tensors $S^{IJ} = \Gamma^I - \Gamma^J$.

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$\Rightarrow$ Equations of motion:

$$T^I_{ab} = \sqrt{\frac{g_0}{g^I}} \left[-\frac{1}{2N} g^I_{ab} \sum_{J,K=1}^{N} (x + y\delta^{JK}) g^{Jij} R^K{}_{ij} + \sum_{J=1}^{N} (x + y\delta^{IJ}) R^J{}_{ab} \right]$$
$$+ \text{ terms linear in } \nabla^I S^{JK}$$
$$+ \text{ terms quadratic in } S^{IJ} .$$

$\Rightarrow$ Repulsive Newtonian limit for $N \geq 3$.

Simple cosmological model

- Homogeneous and isotropic universe (FLRW metric).
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$\Rightarrow$ Single effective energy-momentum tensor $T^I_{ab} = T_{ab}$.

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$\Rightarrow$ Equations of motion simplify for repulsive Newtonian limit:

$$(2 - N)T_{ab} = R_{ab} - \frac{1}{2}Rg_{ab}\,.$$

$\Rightarrow$ Negative effective gravitational constant for early / late universe.

Multimetric cosmology

- Derive cosmological equations of motion:

$$\frac{\ddot{a}}{a} = \frac{N-2}{6}(\rho + 3p)\,.$$

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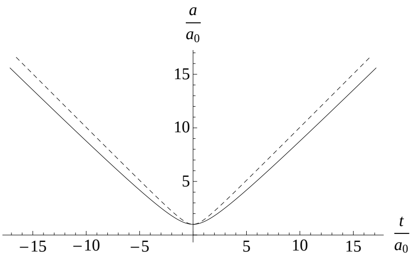
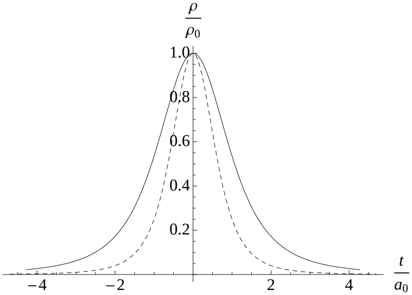
- Explicit solution for radiation (dashed) / dust (solid):

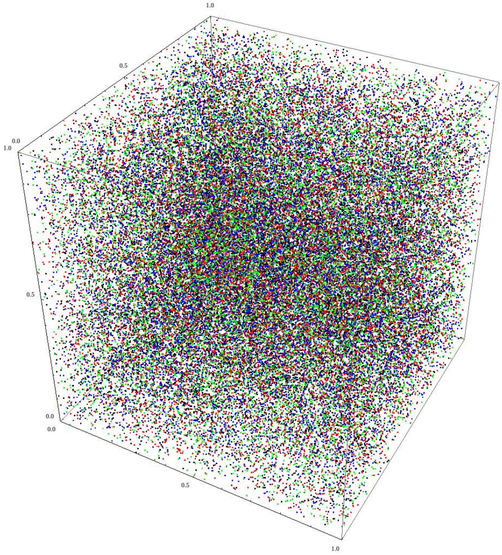




⇒ Big bounce. [MH, M. Wohlfarth '10]

Structure formation - all matter types

- $N = 4$.
- Different matter types separate.



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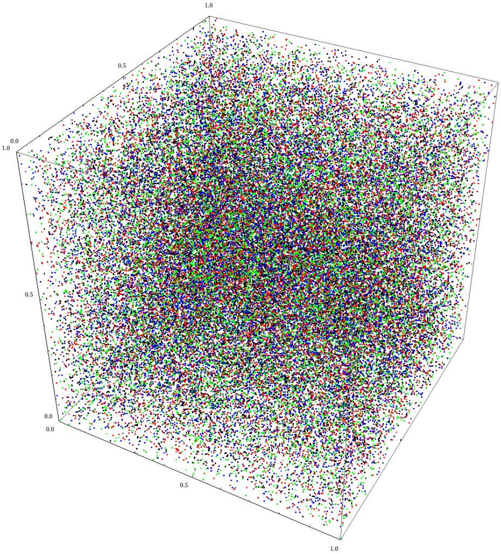

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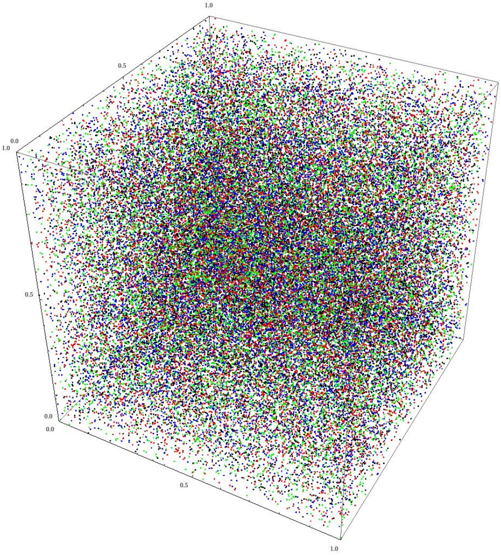

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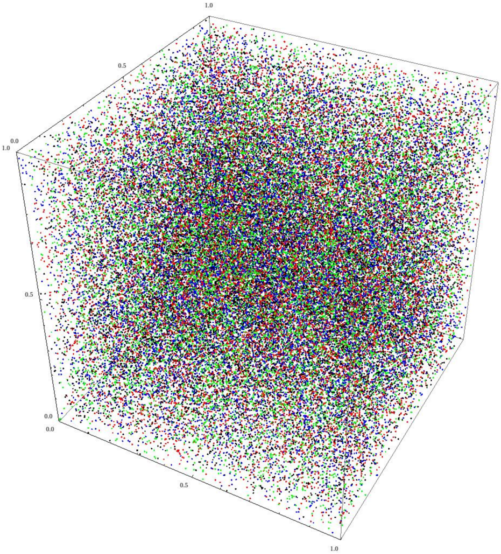

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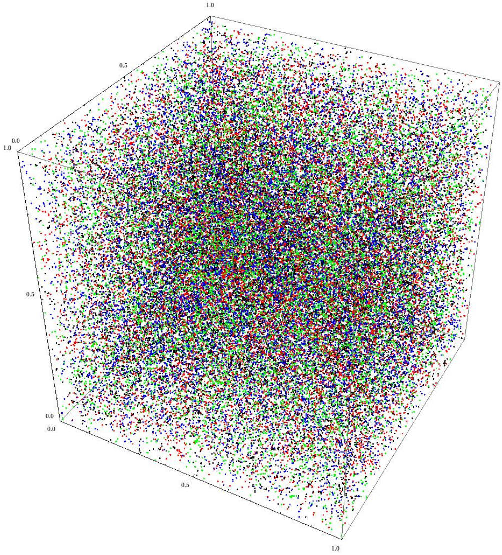

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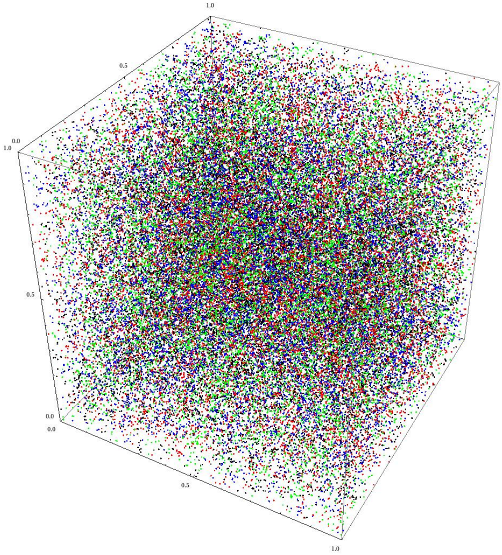

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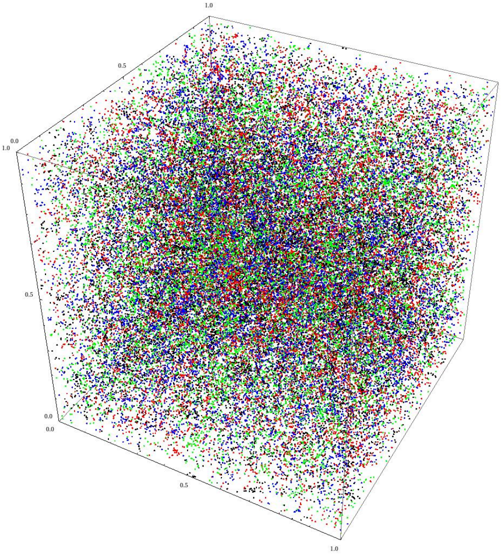

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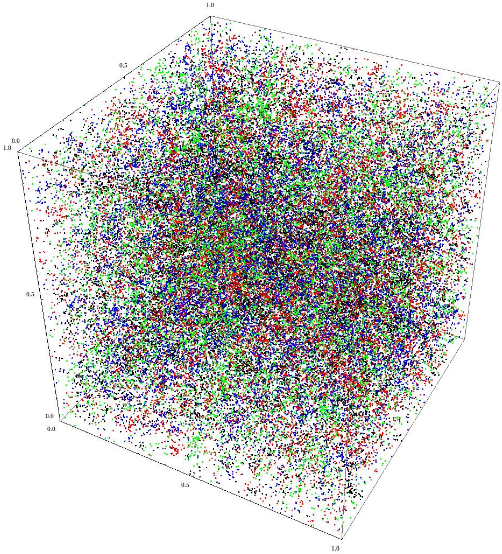

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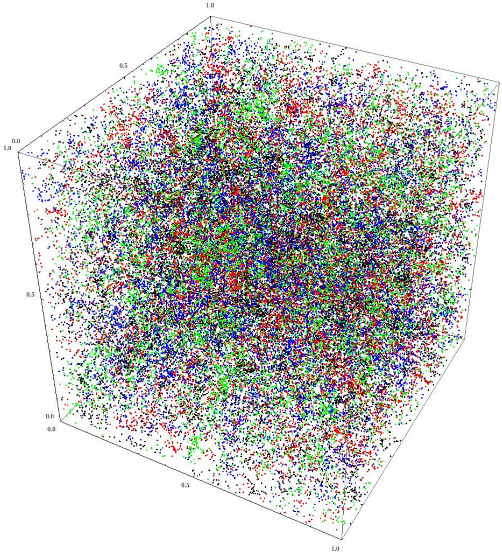

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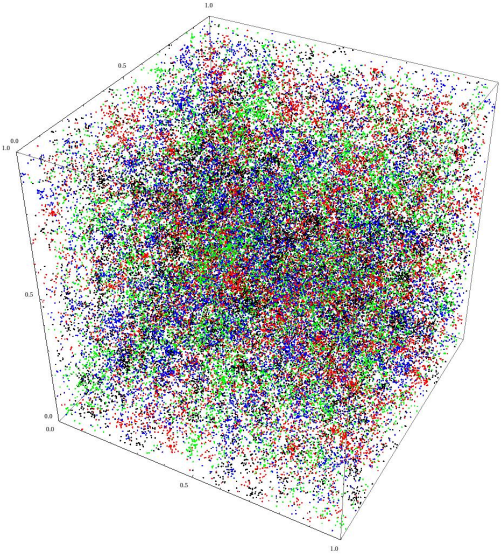

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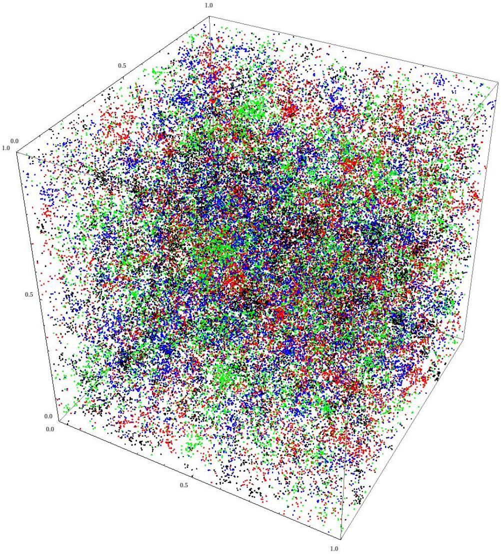

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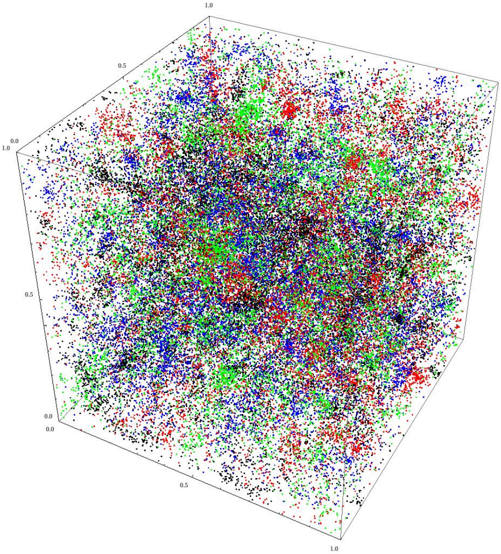

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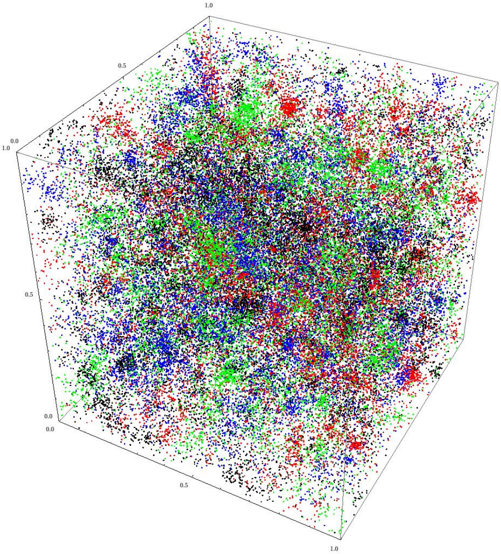

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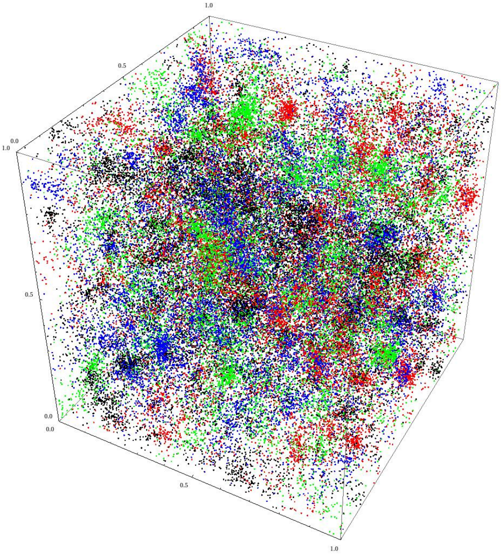

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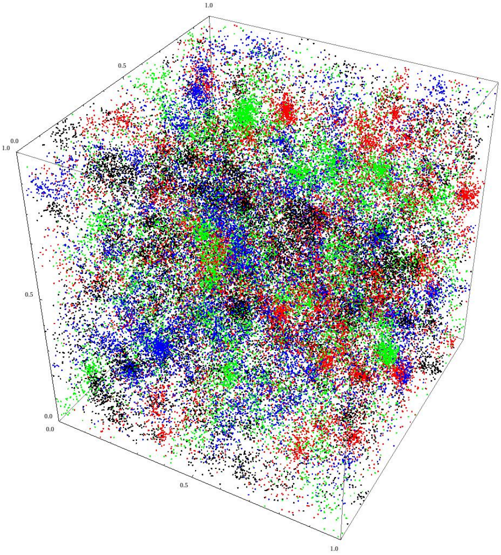

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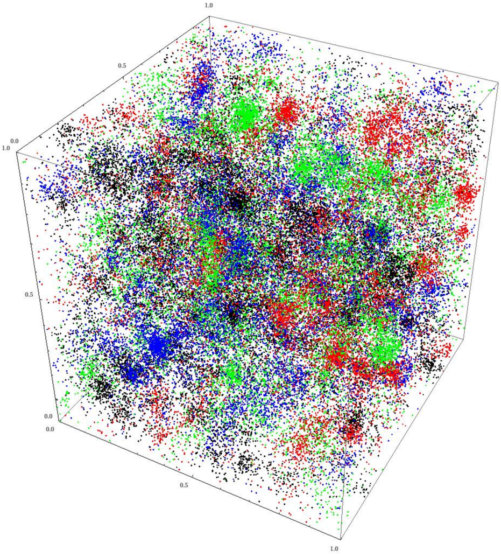

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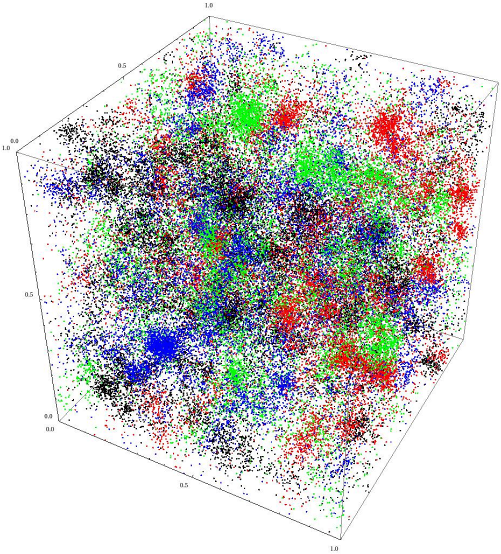

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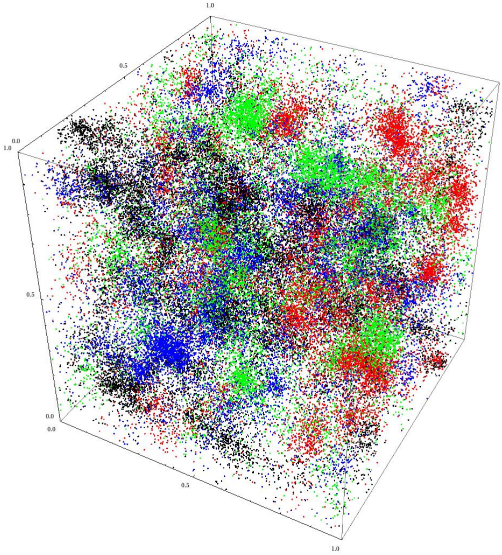

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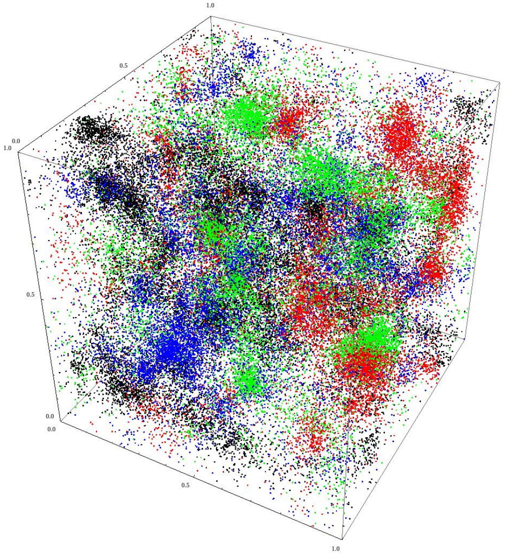

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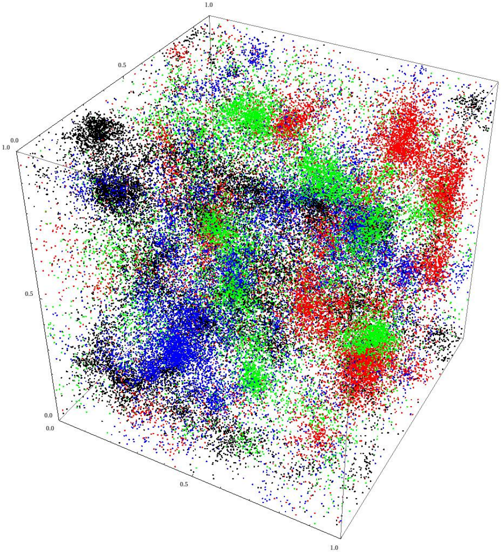

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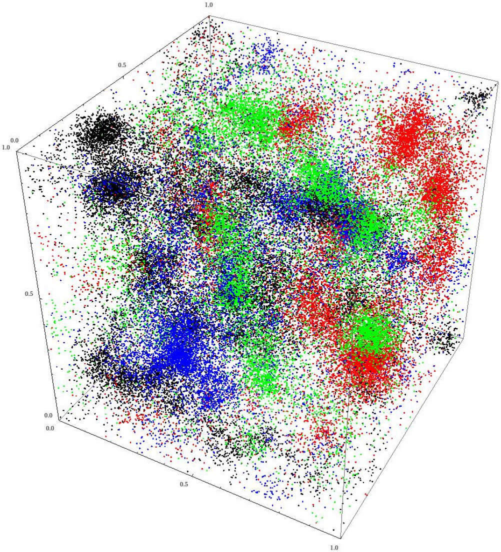

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Structure formation - only visible matter

- Galactic clusters.
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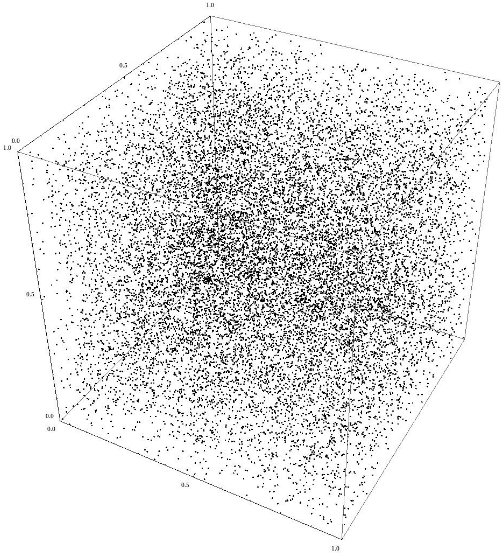

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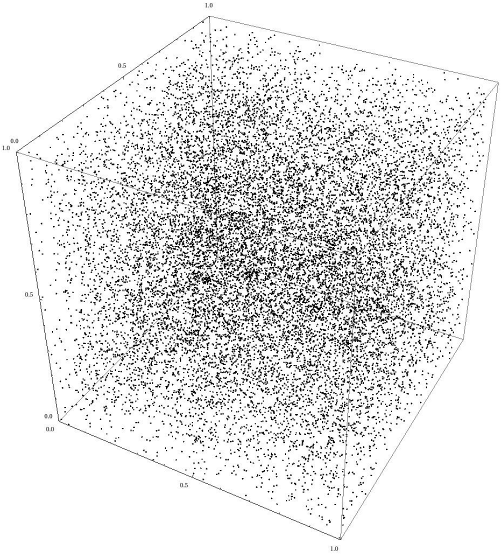

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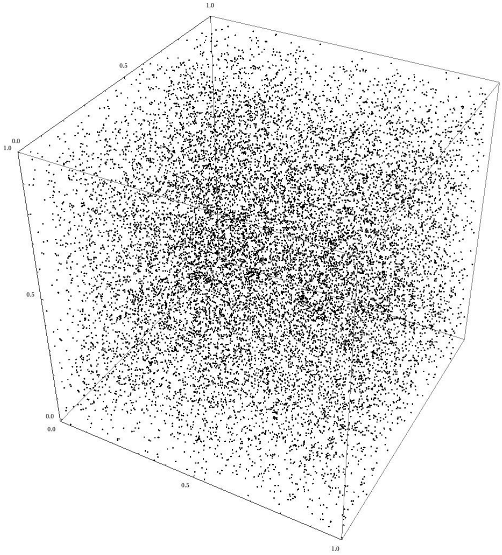

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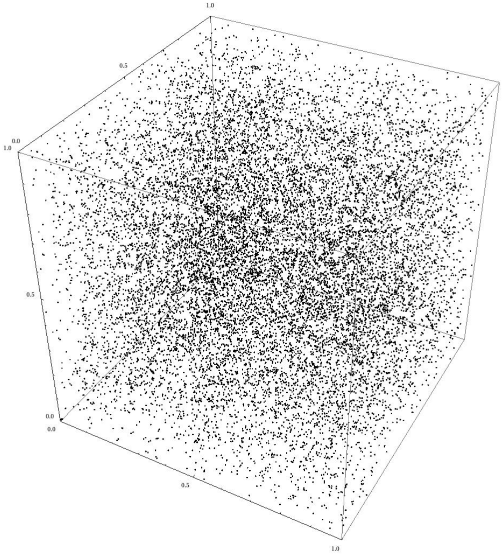

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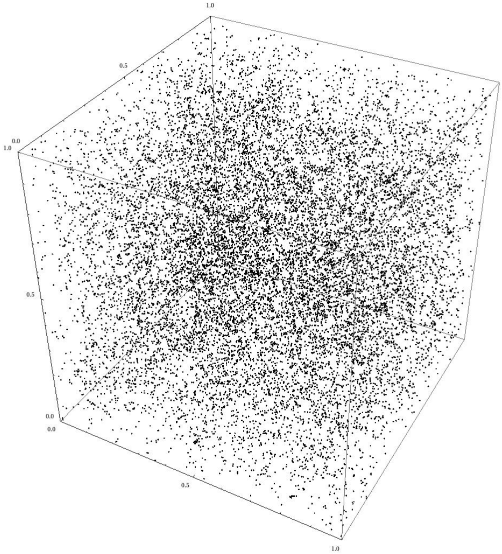

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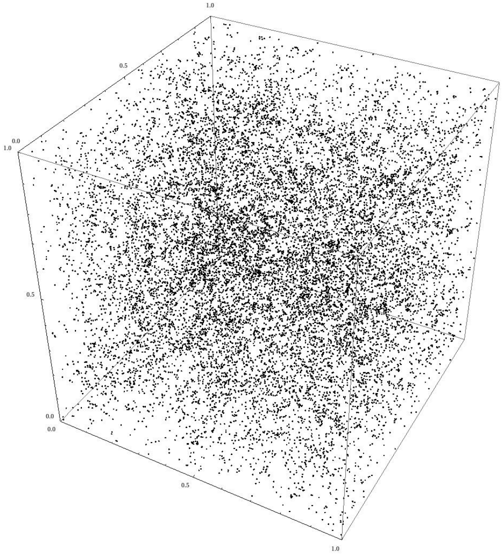

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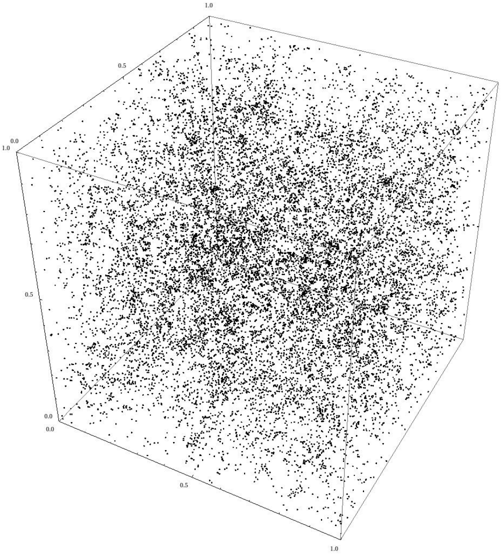

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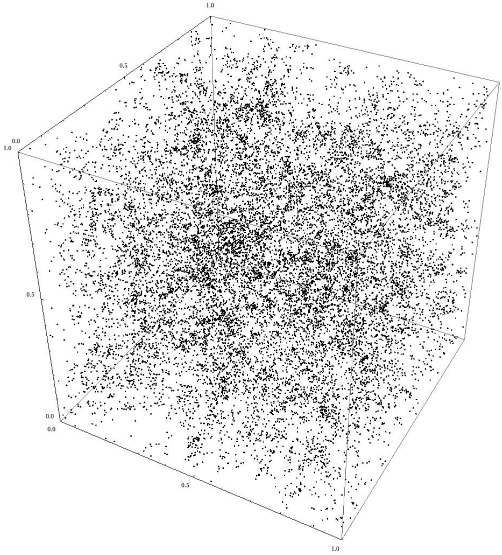

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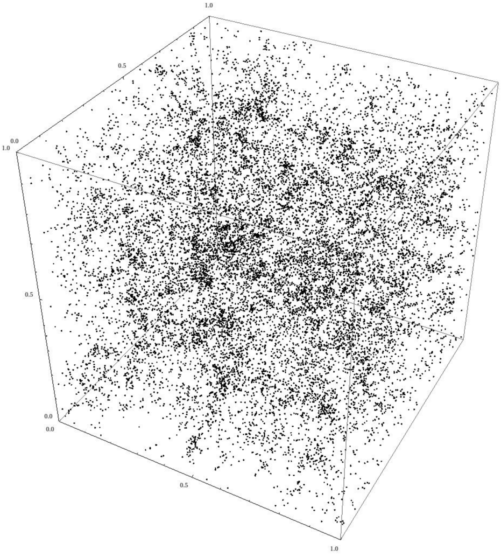

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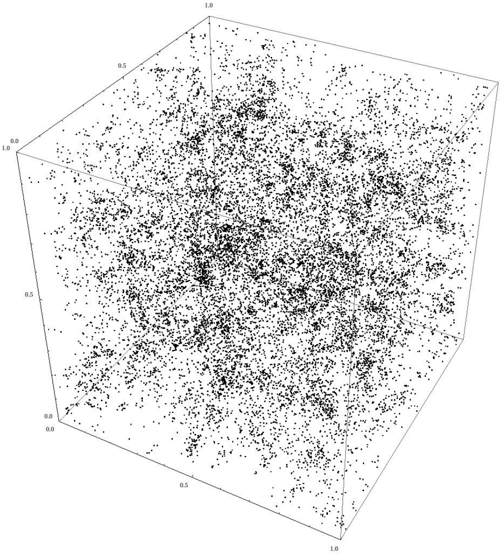

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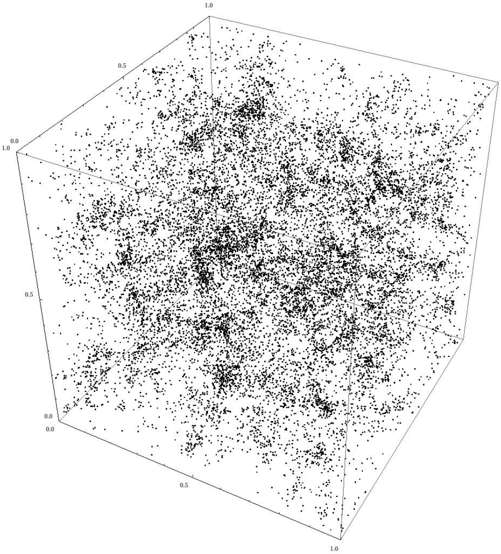

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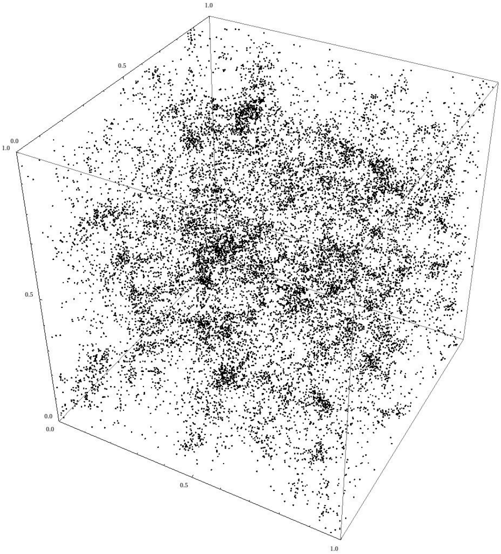

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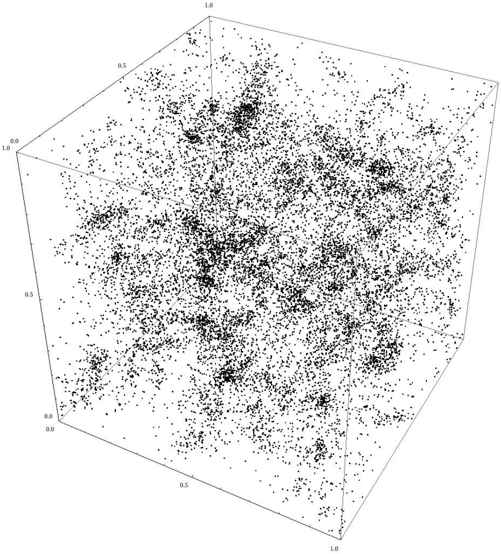

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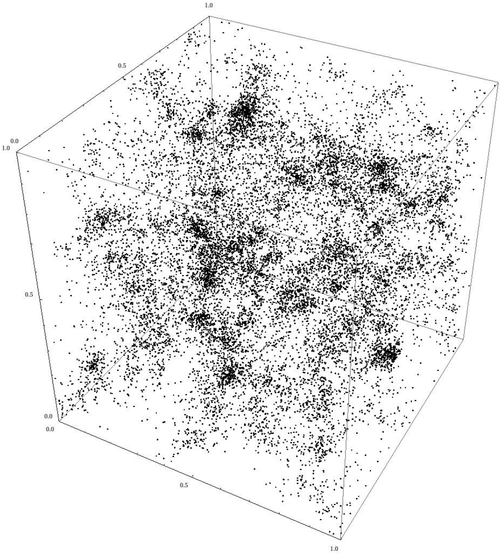

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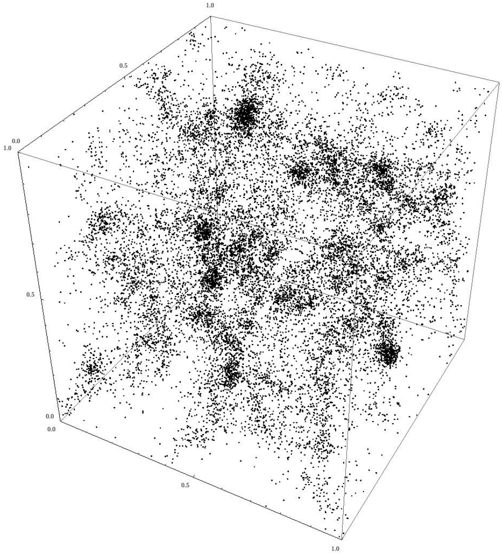

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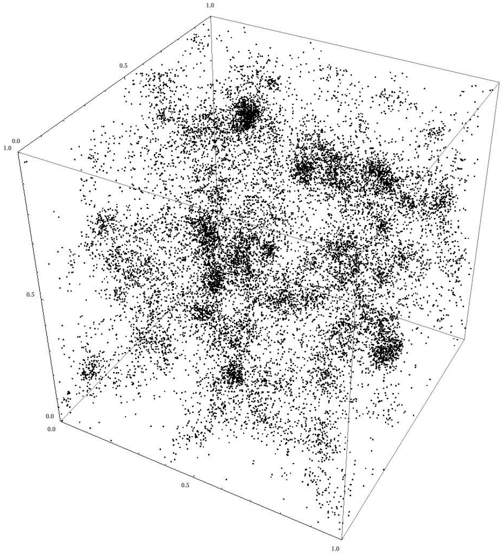

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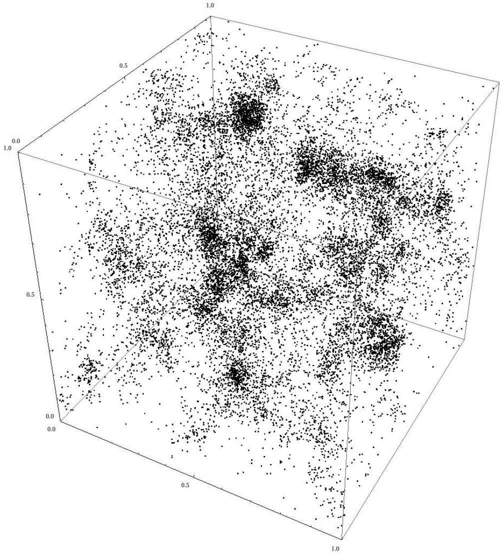

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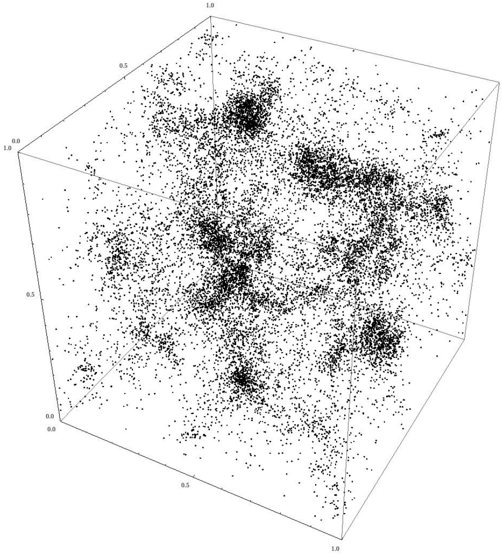

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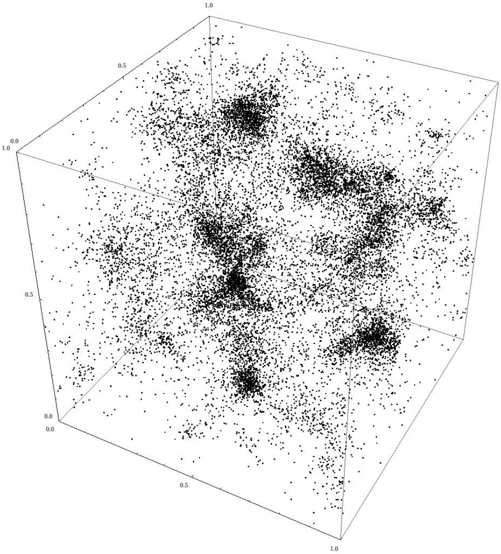

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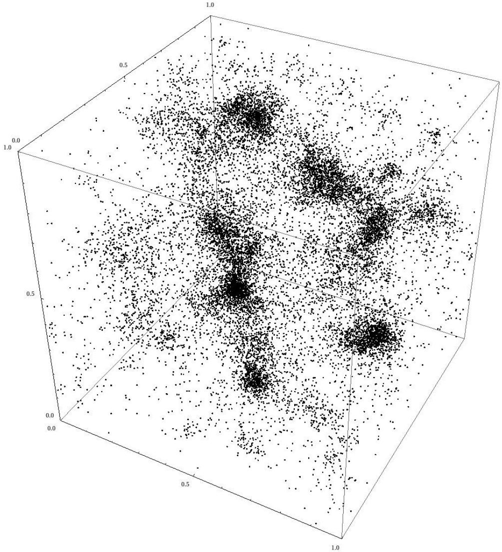

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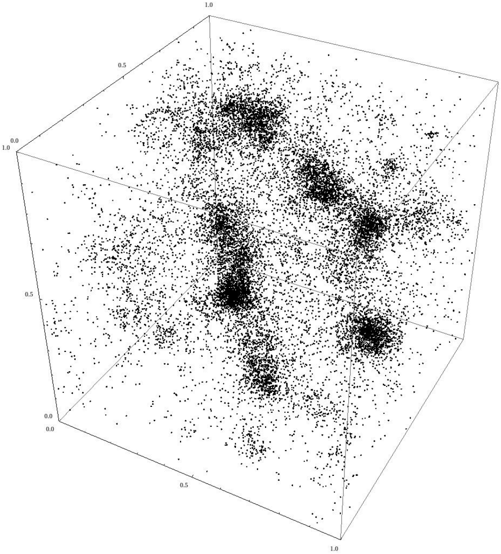

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- Example: action can be chosen such that
  - $\alpha^+ = 1$, $\theta^+ = 0$: standard PPN gauge choice.
  - $\gamma^+ = 1$, $\sigma_+^+ = -2$: experimental consistency.
  - $\alpha^- = -1$: repulsive Newtonian limit.
  - $\gamma^- = -1$, $\theta^- = 0$, $\sigma_+^- = 2$: additional "dark" PPN parameters.

$\Rightarrow$ Consistent with solar system experiments up to linear PPN order.

Gravitational waves

- Propagation velocity equals speed of light.
- Up to 6 polarizations in general metric theories.
- Theories classified by representations of E(2).
- E(2) class of multimetric gravity depends on 3 parameters:

$$\begin{tikzcd}
 & & & P \arrow[dll, "\neq 0"'] \arrow[drr, "=0"] & & & \\
 & P+2R \arrow[dl, "=0"'] \arrow[dr, "\neq 0"] & & & & M \arrow[dl, "\neq 0"'] \arrow[dr, "=0"] & \\
 \mathrm{N}_2 & & \mathrm{N}_3 & & \mathrm{III}_5 & & \mathrm{II}_6
\end{tikzcd}$$

2 tensors | +1 scalar | +2 vectors | +1 scalar

- PPN consistent theory shown before of class N_2.

$\Rightarrow$ Same class as general relativity.

Summary

- Idea: Repulsive gravity might explain dark matter & dark energy.

$\Rightarrow$ General relativity must be extended to allow repulsive gravity.

$\Rightarrow$ No-go theorem: bimetric repulsive gravity is not possible.

$\Rightarrow$ Multimetric repulsive gravity with $N \geq 3$ by explicit construction.

$\Rightarrow$ Cosmology features late-time acceleration and big bounce.

$\Rightarrow$ Structure formation features clusters and voids.

$\Rightarrow$ Repulsive gravity is consistent with solar system experiments.

$\Rightarrow$ Gravitational waves are null.

$\Rightarrow$ E(2) class can be one of N_2, N_3, III_5, II_6.

Outlook

- Remaining PPN parameters should be determined from full multimetric PPN formalism.
- Restrict multimetric gravity theories by additional PPN bounds.
- Establish further construction principles, e.g., continuous symmetry between sectors.
- Examine initial-value problem.
- Determine further exact solutions (single point mass. . .).
- Advanced simulation of structure formation including thermodynamics using GADGET-2 (Millenium Simulation).
- Search for repulsive gravity sources in the galactic voids through gravitational lensing.
- Application to binaries: gravitational radiation should be emitted in all sectors, but only one type is visible.

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