Experimental Tests of Multimetric Gravity

Gravitational Waves and the Cosmos

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DER FORSCHUNG | DER LEHRE | DER BILDUNG

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Idea

- ΛCDM model: only 5% visible matter. [Komatsu *et al.* '09]
  - Dark matter needed to explain "missing mass" in galaxies.
  - Dark energy needed to explain accelerating expansion.
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- Simple idea: two metrics $g^{\pm}_{ab}$, two standard model copies $\Psi^{\pm}$.
- 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:

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

- Symmetric volume form $g_0 = (g^1 g^2 \dots g^N)^{1/N}$.
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$$T^I_{ab} = \sqrt{\frac{g_0}{g^I}}\left[-\frac{1}{2N}g^I_{ab}\sum_{J,K=1}^{N}(x+y\delta^{JK})g^{Jij}R^K{}_{ij} + \sum_{J=1}^{N}(x+y\delta^{IJ})R^J{}_{ab}\right]$$
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$\Rightarrow$ Repulsive Newtonian limit for $N \geq 3$. [MH, M. Wohlfarth '10]

$\Rightarrow$ Post-Newtonian limit consistent with solar system. [MH, M. Wohlfarth '10]

Simple cosmological model

- Standard cosmology:
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  - Matter content: perfect fluid.
  - Early universe: radiation; late universe: dust.
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$$\rho = \frac{3}{2-N}\left(\frac{\dot{a}^2}{a^2} + \frac{k}{a^2}\right).$$

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- Acceleration equation:

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

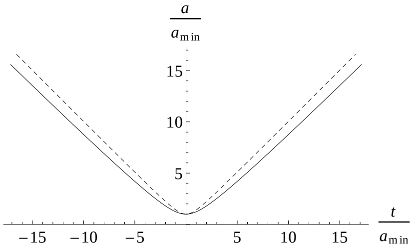
$\Rightarrow$ Acceleration must be positive.

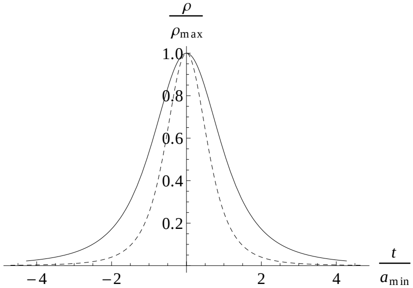
Explicit solution

- Equation of state: $p = \omega\rho$; dust: $\omega = 0$, radiation: $\omega = 1/3$.
- General solution using conformal time η defined by $dt = a\,d\eta$:

$$a = a_{\text{min}} \left(\cosh\left(\frac{3\omega+1}{2}\eta\right)\right)^{\frac{2}{3\omega+1}},$$

$$\rho = \frac{3}{(N-2)a_{\text{min}}^2}\left(\cosh\left(\frac{3\omega+1}{2}\eta\right)\right)^{-\frac{6\omega+6}{3\omega+1}}.$$

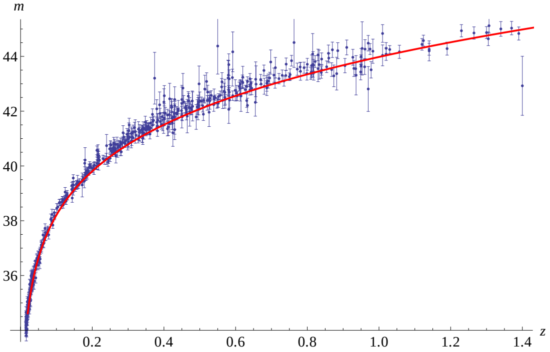




$\Rightarrow$ Big bounce at $t = 0$. [MH, M. Wohlfarth '10]

Cosmological parameters

- Friedmann equation: $(2 - N)\Omega_M + \Omega_K = 1$.
- Matter density:
$$\Omega_M = \frac{\rho_0}{3H_0^2} \sim \sinh^{-2}\left(\frac{3\omega + 1}{2}\eta_0\right).$$
- Curvature parameter:
$$\Omega_K = -\frac{k}{a_0^2 H_0^2} = \frac{1}{\dot{a}^2(t_0)} \to 1\,.$$
- Fitting of supernova data: [Amanullah *et al.* '10]



Structure formation

- Structure formation in ΛCDM not fully understood:
  - Missing dwarf problem. [Moore *et al.* '99]
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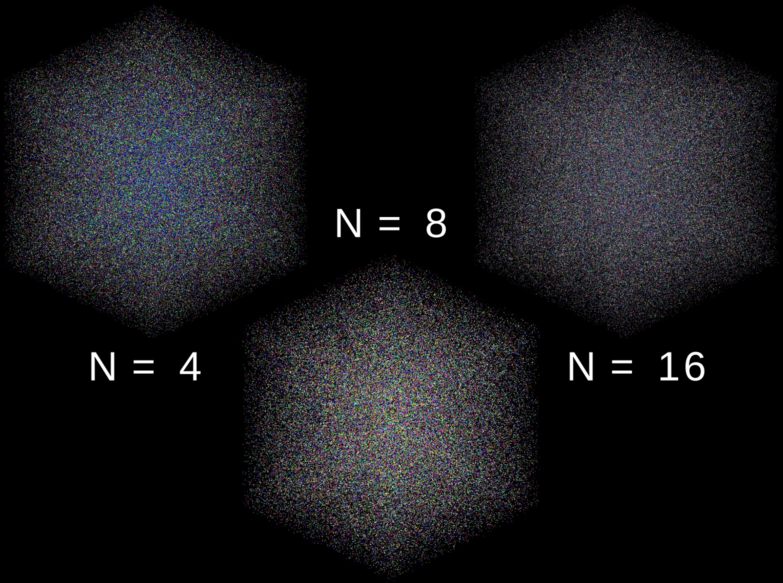
- Results:
  - Galactic clusters and filament-like structures.
  - Seemingly empty voids contain "invisible" matter.

  $\Rightarrow$ Repulsive gravity effects from galactic voids.

  $\Rightarrow$ Negative gravitational lenses in galactic voids?

Structure formation - all matter types



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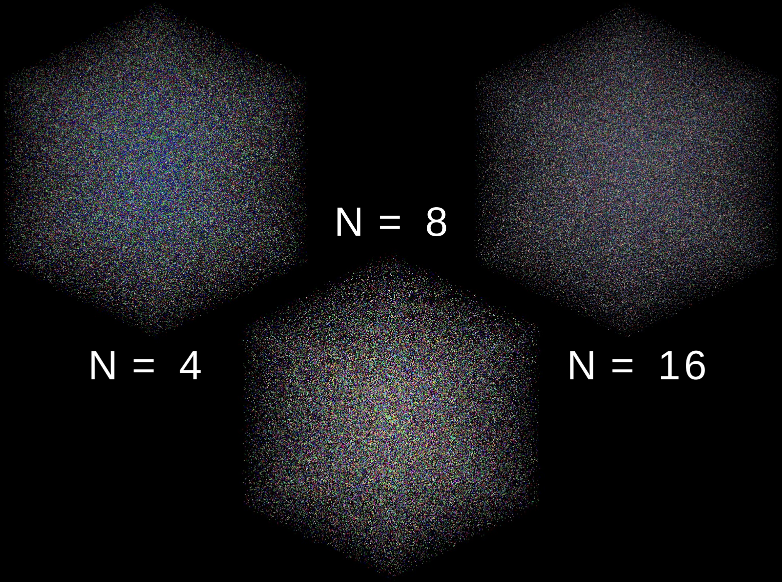

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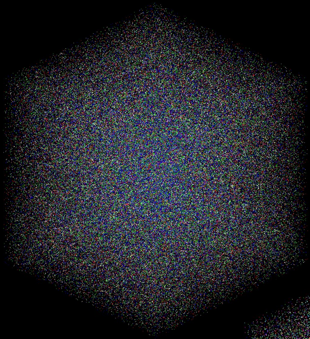

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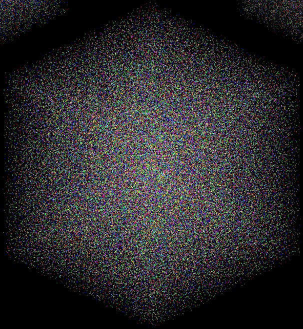

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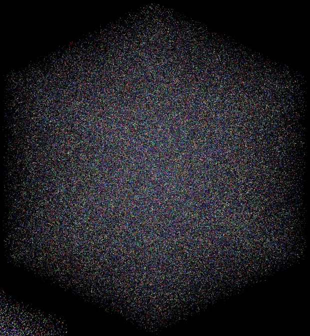

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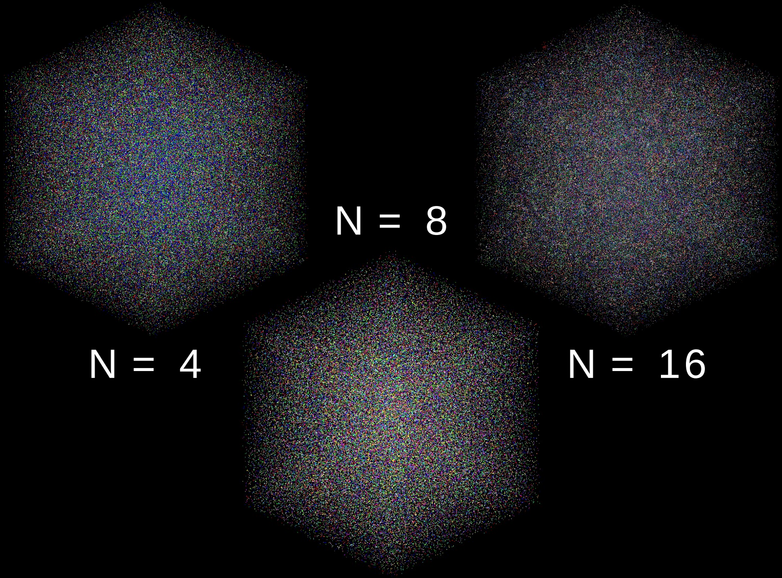

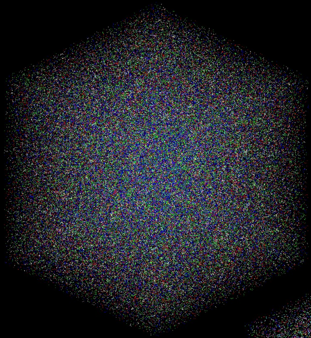

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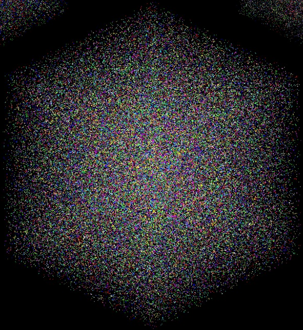

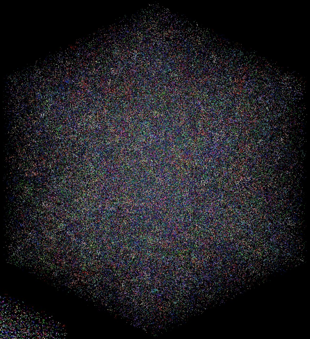

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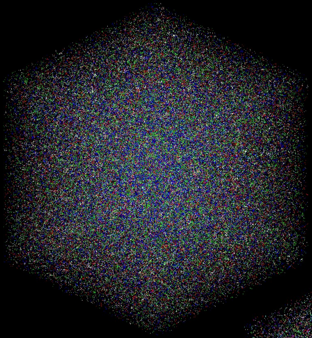

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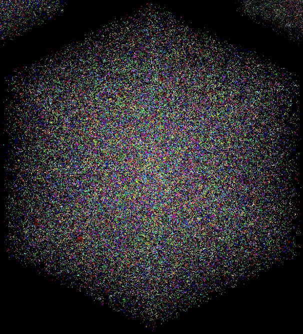

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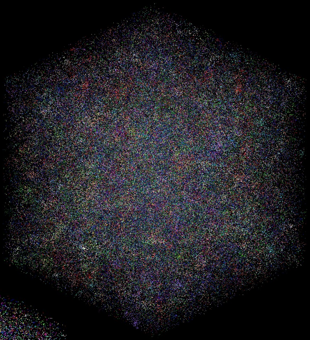

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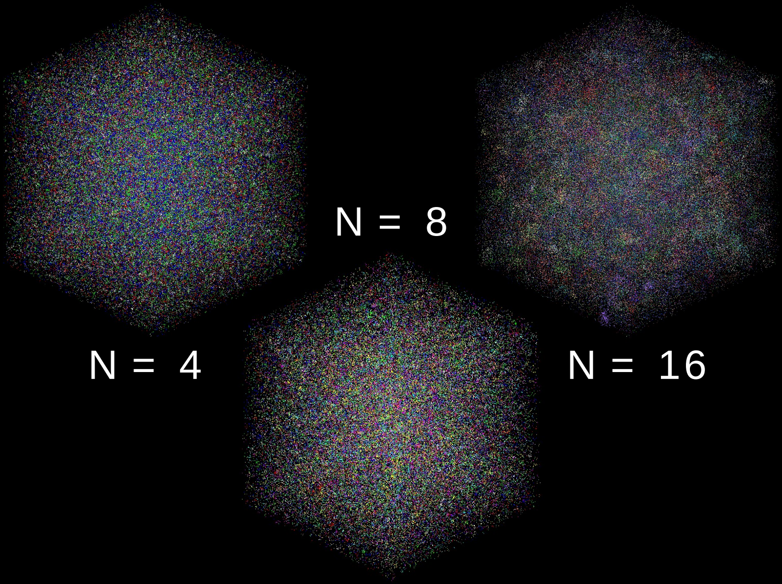

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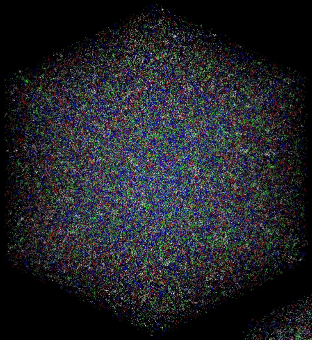

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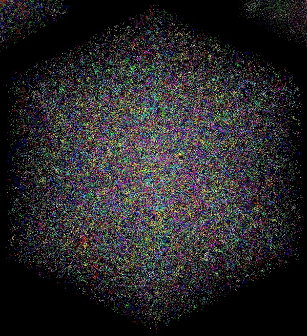

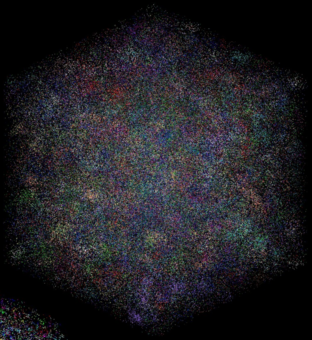

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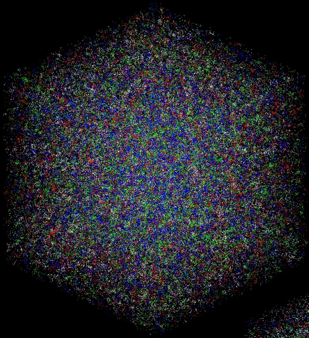

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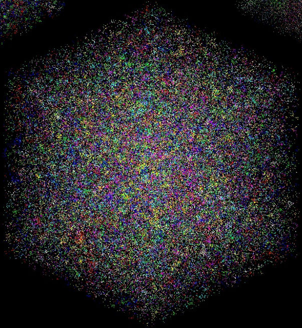

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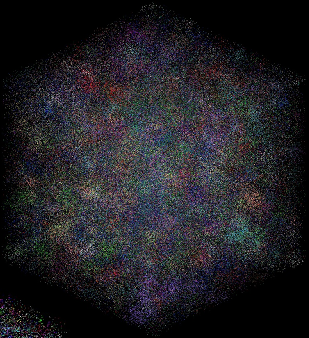

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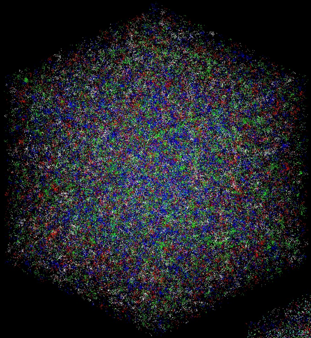

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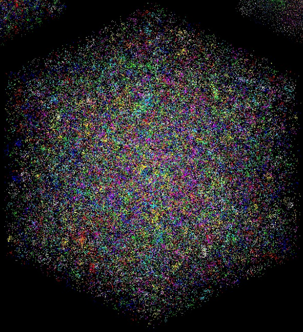

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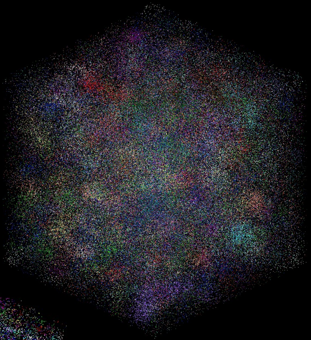

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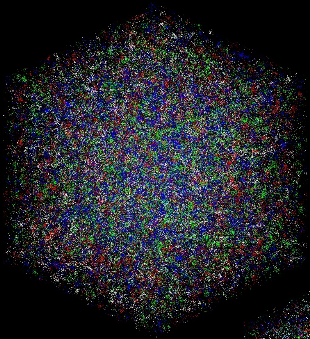

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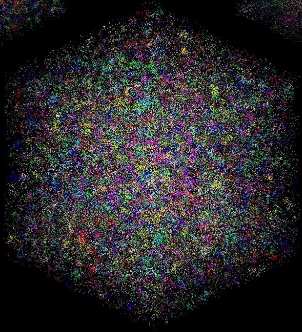

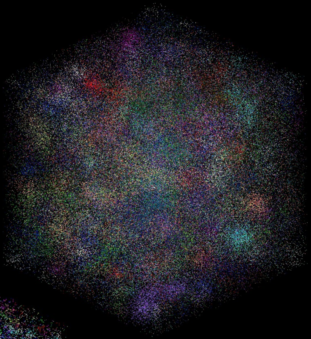

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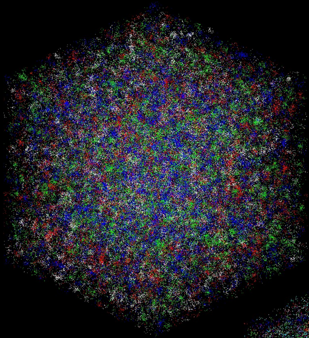

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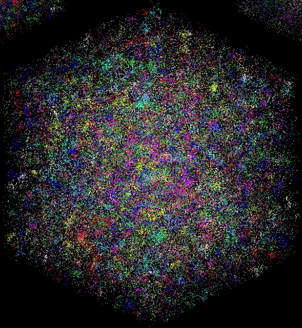

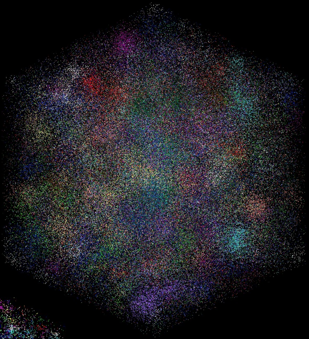

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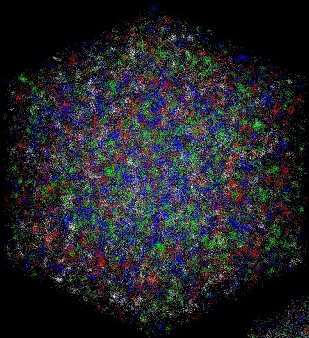

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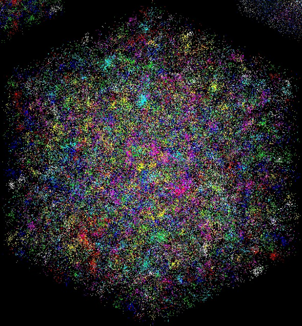

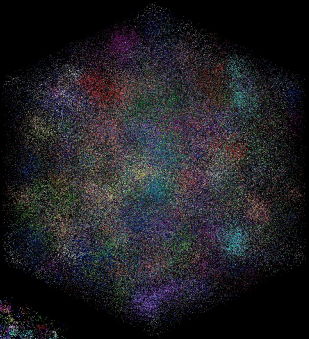

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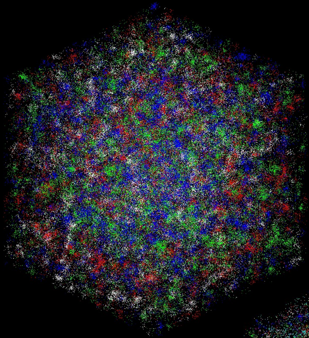

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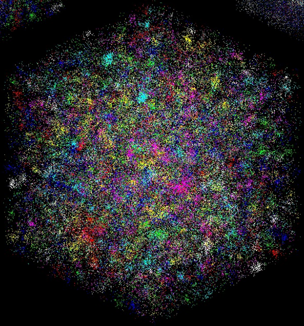

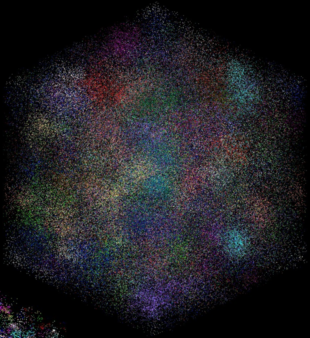

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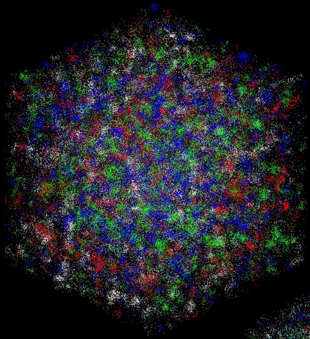

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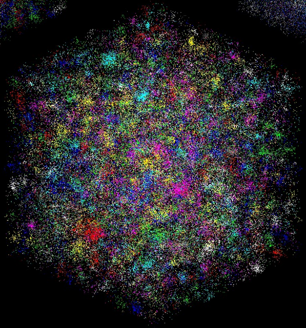

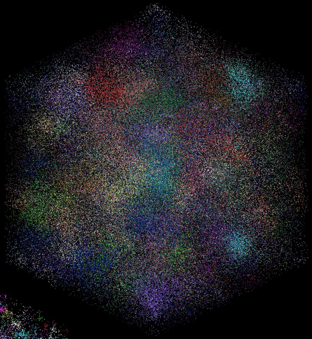

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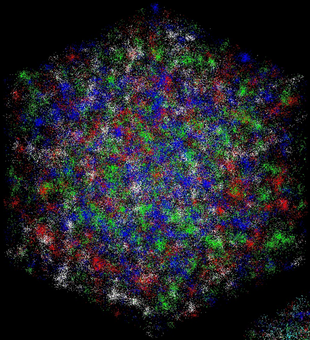

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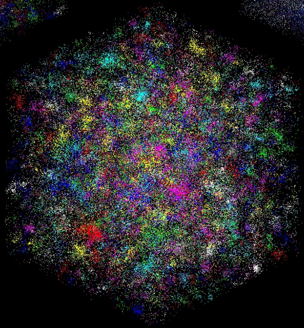

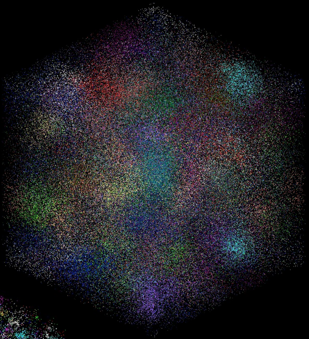

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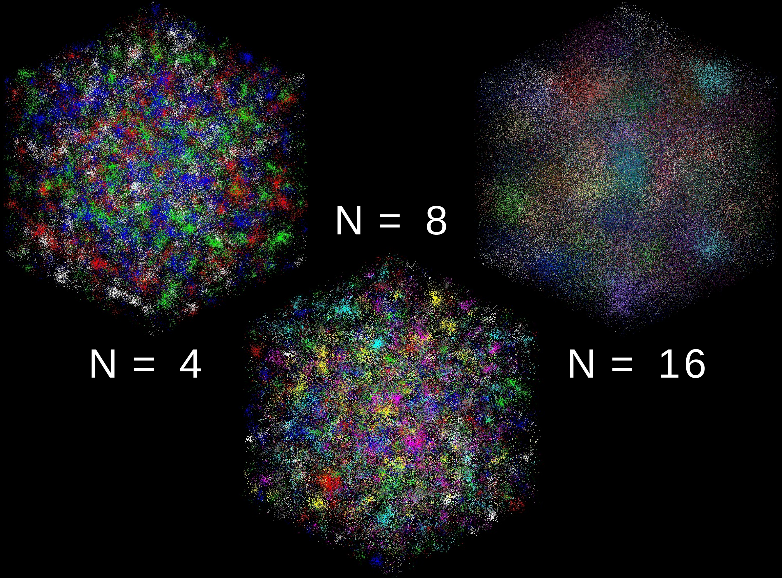

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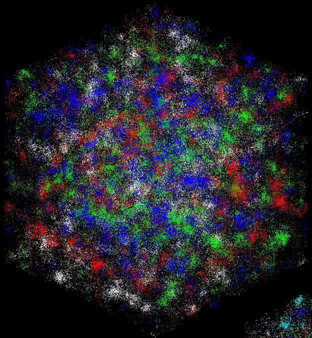

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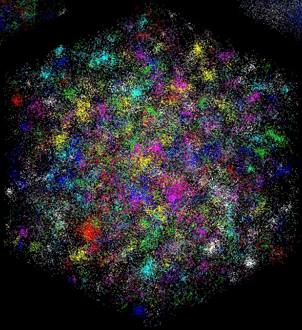

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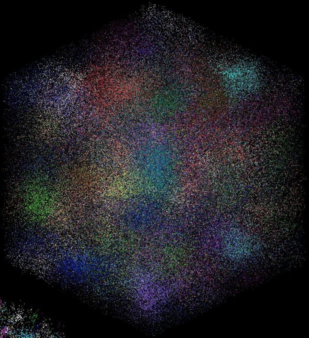

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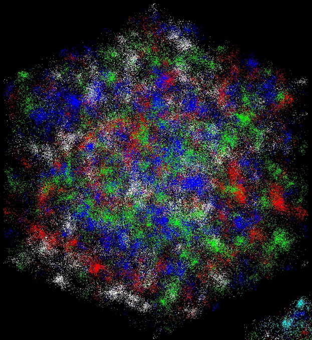

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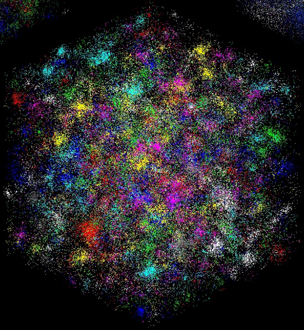

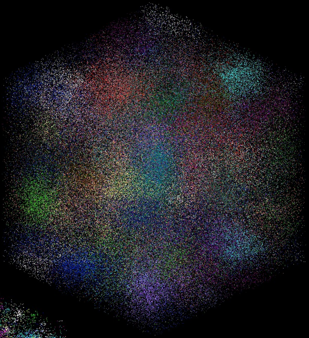

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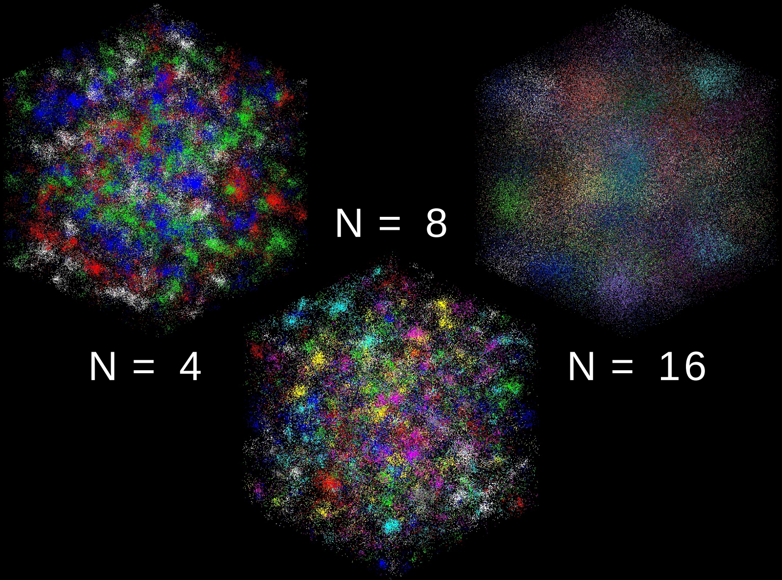
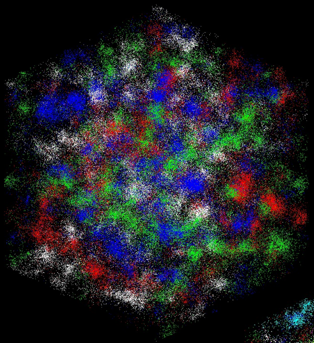
Structure formation - all matter types



Structure formation - all matter types



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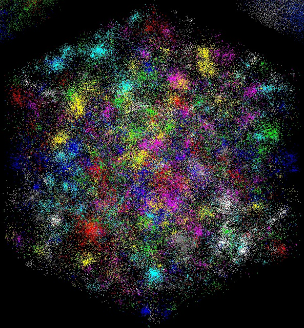

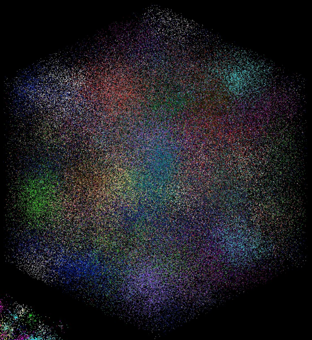

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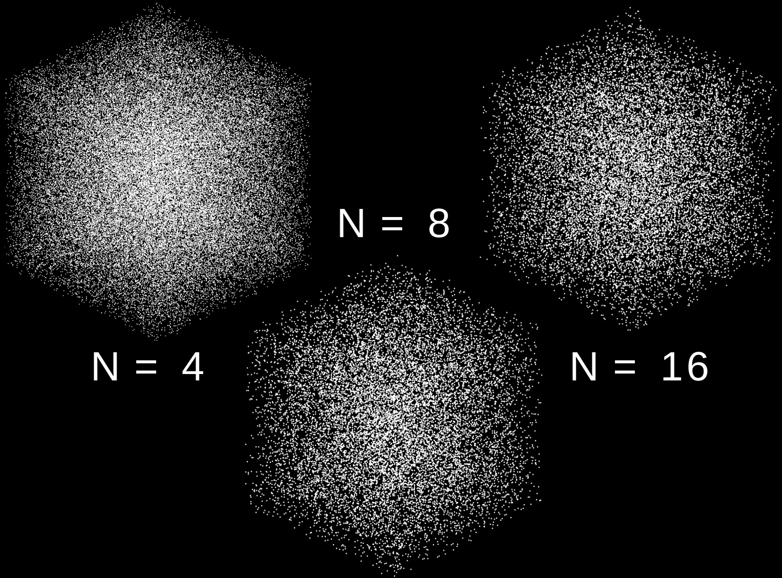
Structure formation - only visible matter



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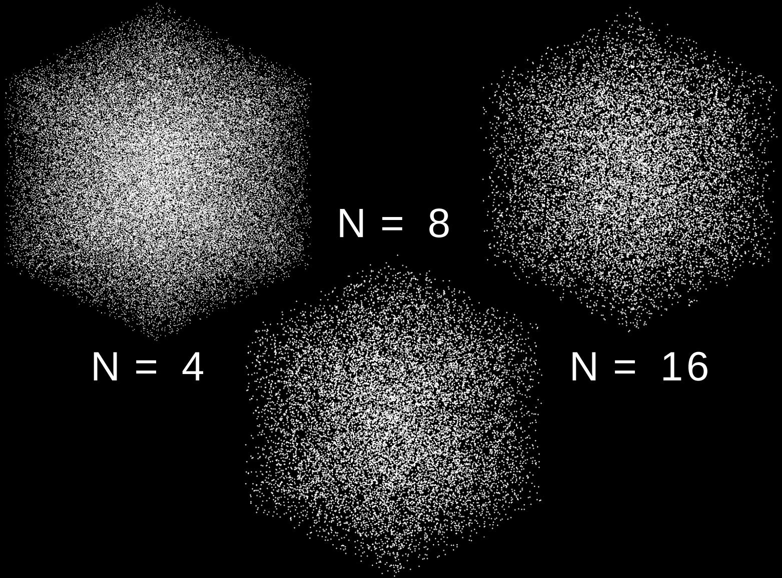

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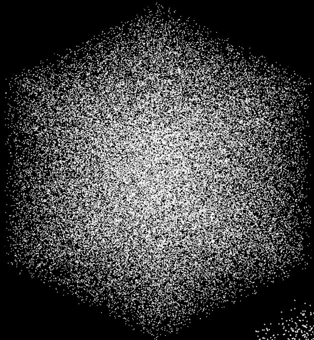

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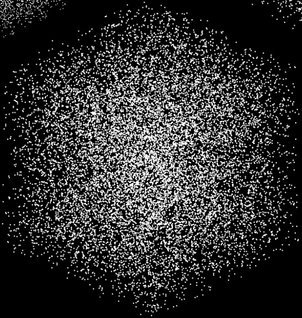

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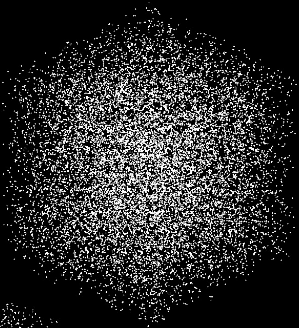

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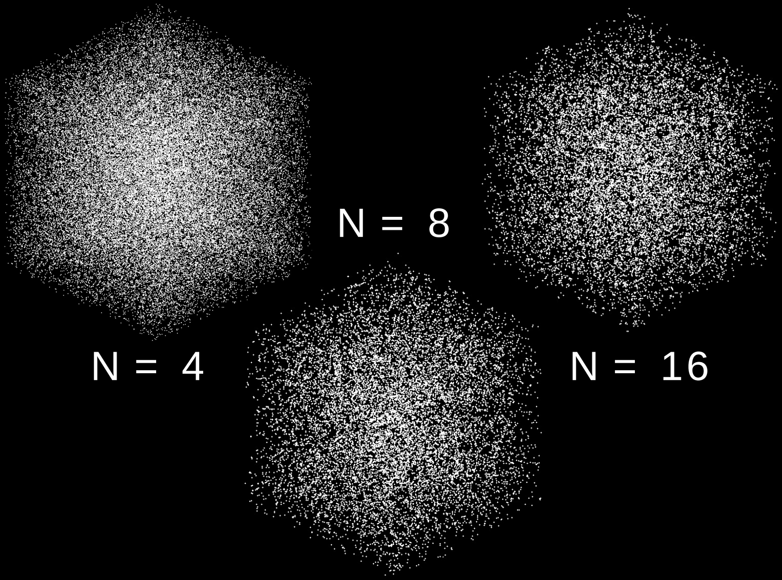

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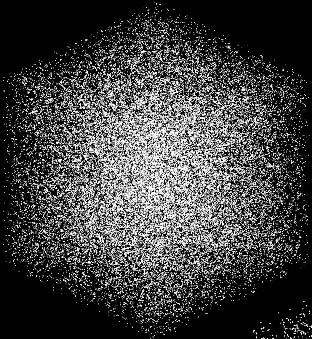

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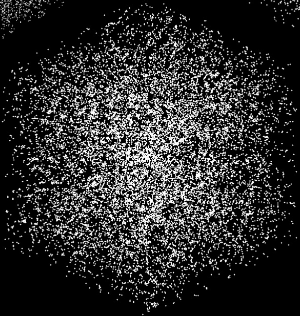

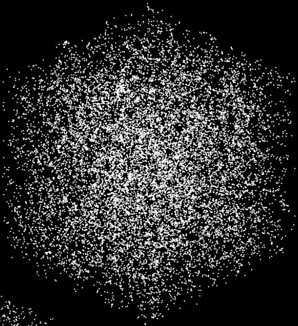

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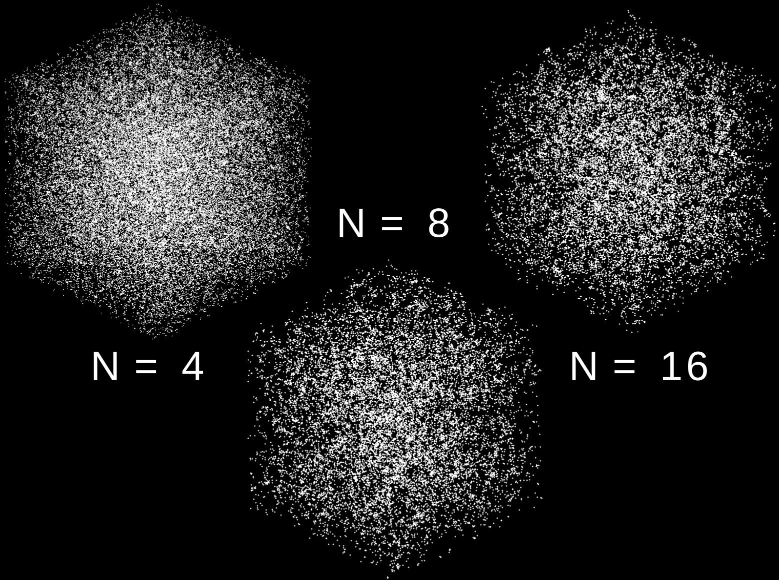

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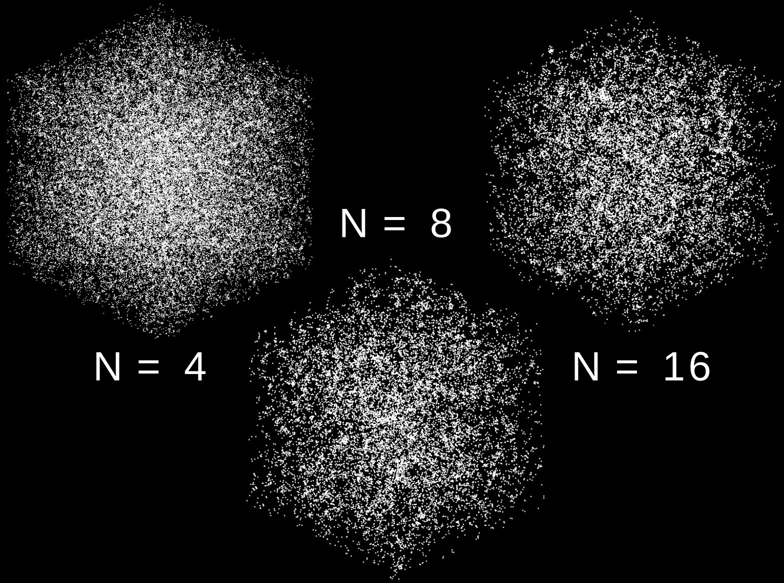

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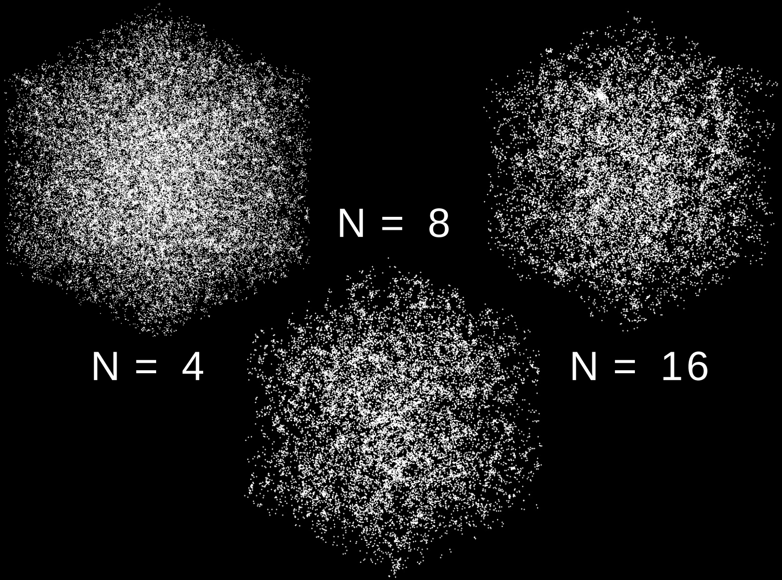

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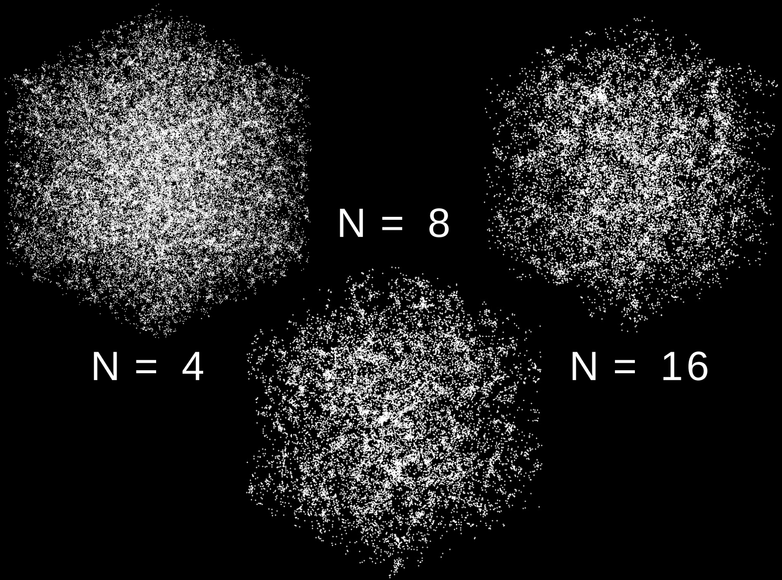

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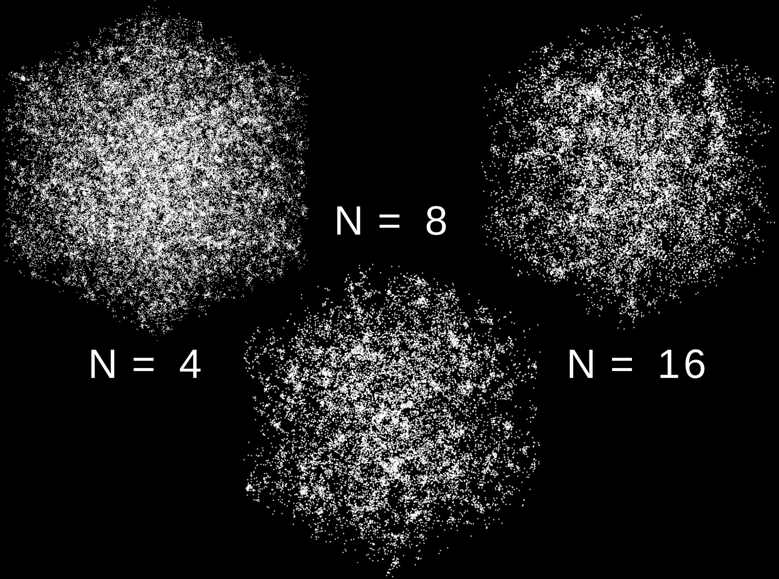

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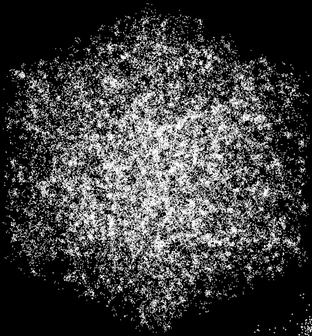

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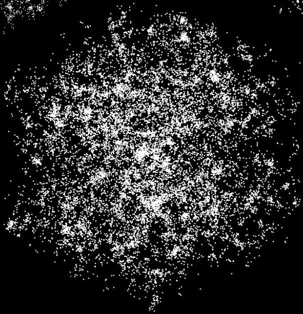

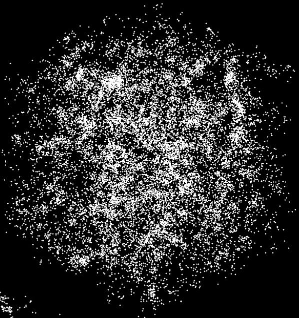

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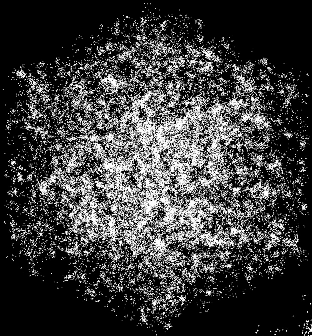

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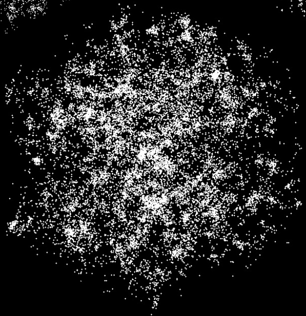

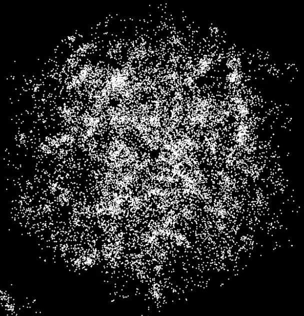

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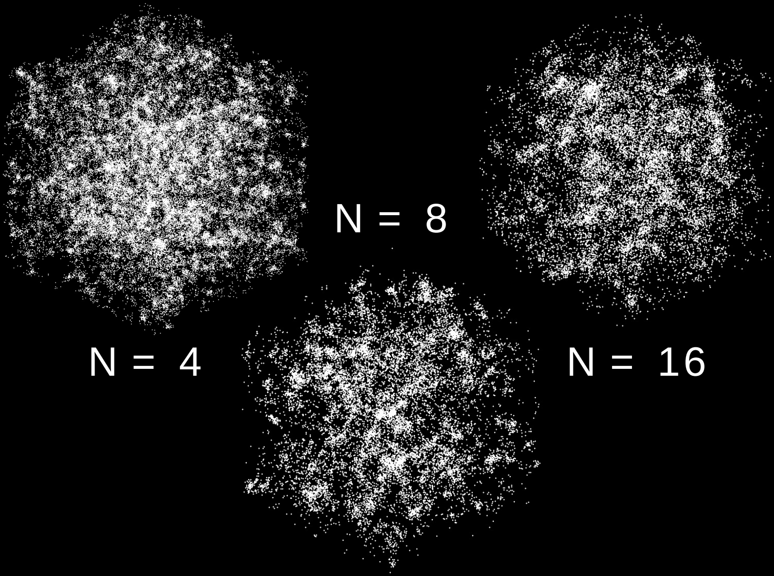

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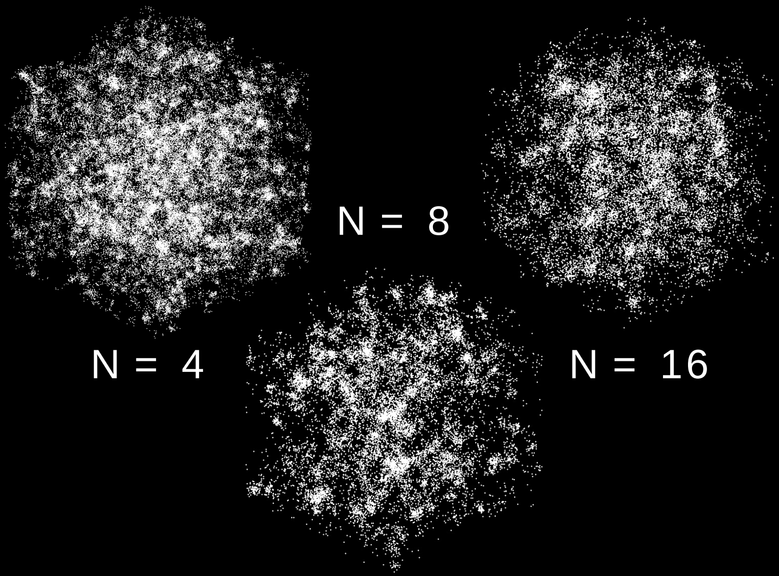

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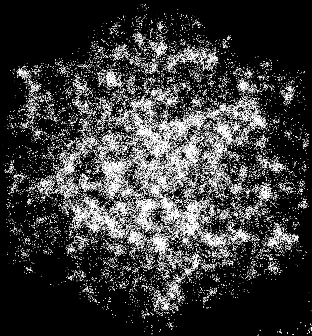

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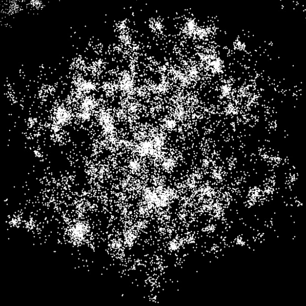

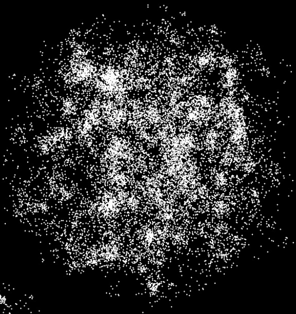

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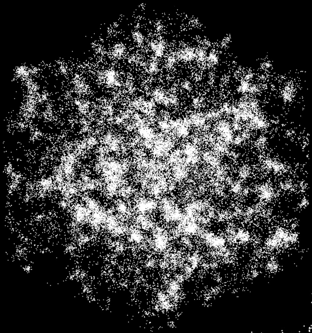

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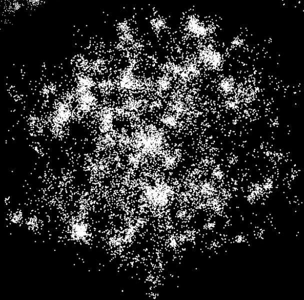

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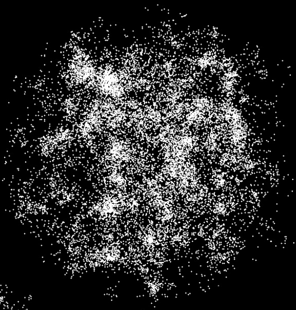

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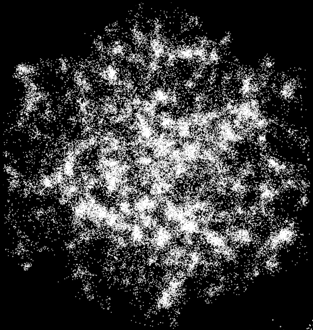

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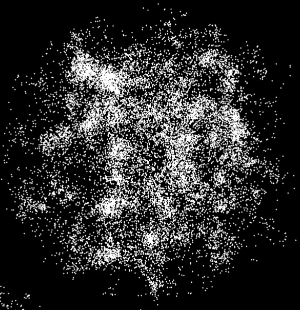

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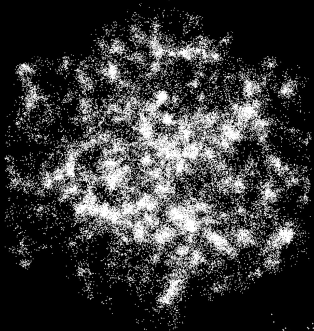

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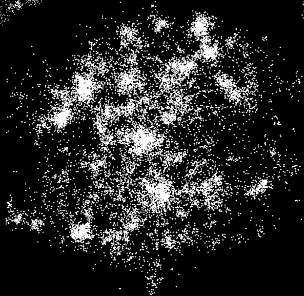

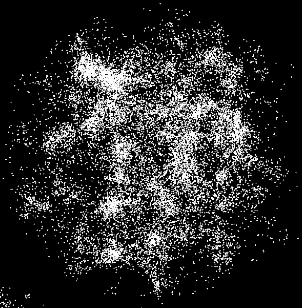

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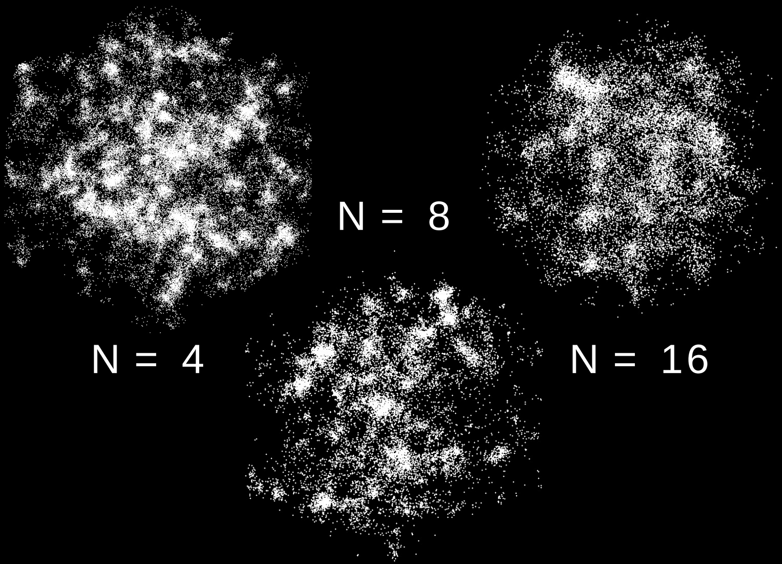

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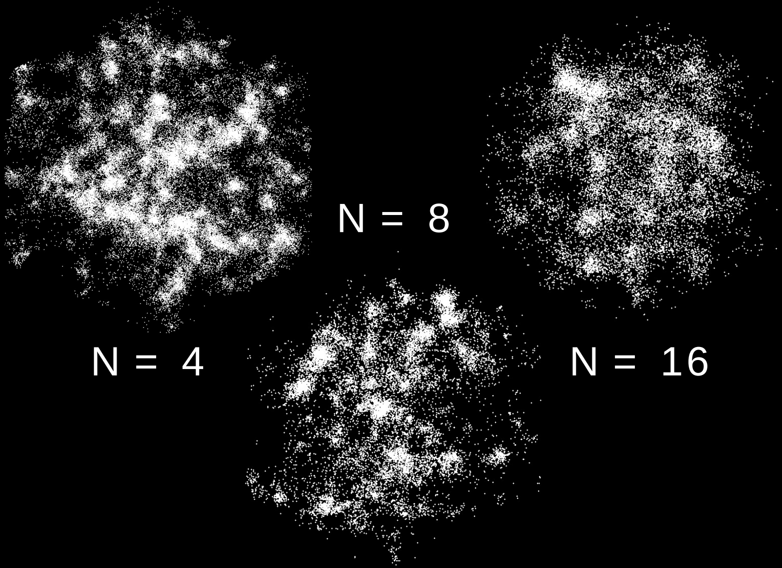

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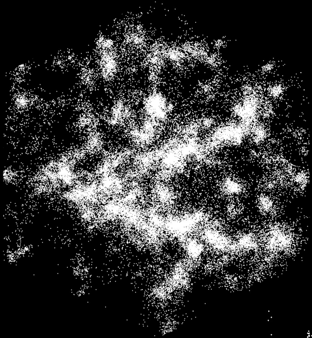

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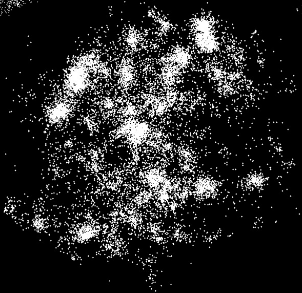

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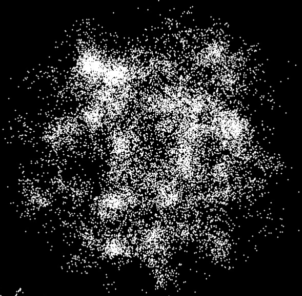
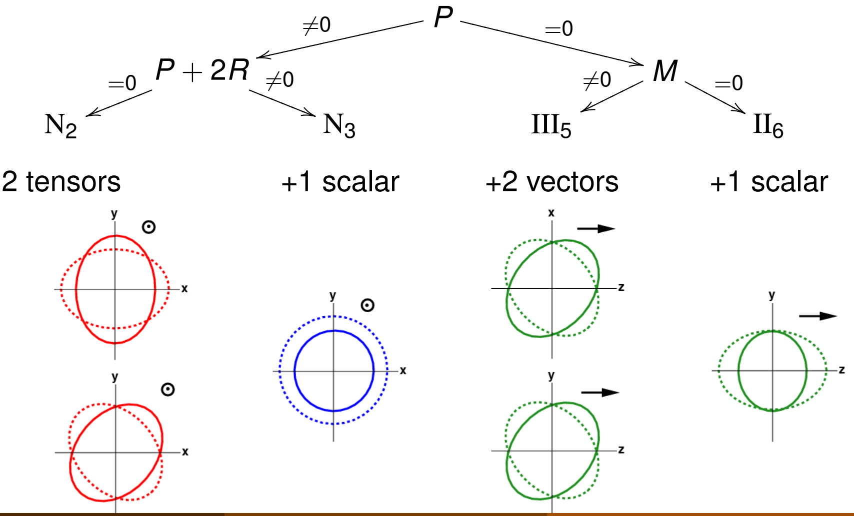


N = 16

Gravitational waves

- Gravitational waves are null. [MH '11]
- Polarizations classified by reps. of E(2). [Eardley, Lee, Lightman *et al.* '73]
- E(2) class of multimetric gravity depends on 3 parameters: [MH '11]



Summary

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

$\Rightarrow$ Linearly PPN consistent multimetric repulsive gravity for $N \geq 3$.

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

$\Rightarrow$ Structure formation features clusters and voids.

$\Rightarrow$ Voids contain repulsive mass concentrations.

$\Rightarrow$ Gravitational waves are null.

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

Outlook

- Solar system physics:
  - Develop full non-linear multimetric PPN formalism.
  - Examine further exact solutions (single point mass…).
- Cosmology:
  - Calculate further cosmological matching parameters.
  - Perform cosmological perturbation analysis to understand CMB.
- Structure formation:
  - Advanced simulation of structure formation including thermodynamics using GADGET-2 (Millennium Simulation).
  - Search for repulsive gravity sources in galactic voids through gravitational lensing.
- Gravitational waves:
  - Emission of gravitational waves from various sources.
  - Shapiro delay of gravitational waves in weak gravitational fields.