Bi-Poisson: a RAMSES implementation of two coupled Poisson equations

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Based on 2102.08834, `https://github.com/cspotz/RAMSES_Bi-Poisson`
Collaborators: G. Chardin, Y. Dubois, G. Manfredi, B. Miller.

Two coupled Poisson equations

Assumptions

Consider two matter species which have two different matter densities (ρ_1, ρ_2). Consider also that those two species couple differently to gravity through two coupled Poisson equations. Let (ϕ_1, ϕ_2) be two gravitational potential for each Poisson equations and f_i $(i = 1, 2)$ are two real valued functions.

Dynamics

Then, `BiPoisson`, my patch of `RAMSES` can simulate the following dynamics:

$$\Delta\phi_1 = f_1(\rho_1, \rho_2) \tag{1}$$

$$\Delta\phi_2 = f_2(\rho_1, \rho_2) \tag{2}$$

I have duplicated all the relevant gravity routines and use the tag to differentiate the two matter species and how they couple to gravity.

Application to Dirac-Milne cosmology

For $f_1 \propto \rho_1 - \rho_2$ and $f_2 \propto -\rho_1 - \rho_2$ we obtain the equations governing the Dirac-Milne cosmology. There the two species are dubbed **matter** and **antimatter**.

Dirac-Milne: an invitation to reinterpret cosmological observations

- Ambitious framework without dark energy and dark matter.
- Exotic gravity with

$$\Delta\phi_1 = 4\pi G(\rho_1 - \rho_2) \tag{3}$$

$$\Delta\phi_2 = 4\pi G(-\rho_1 - \rho_2) \tag{4}$$

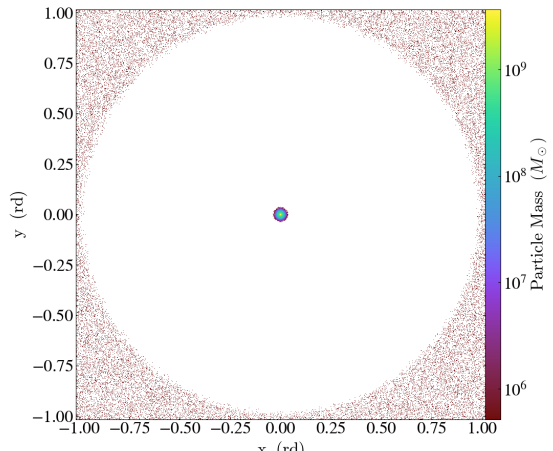
  Repulsion between matter and antimatter. Antimatter *antigravitates*.
- Solve in passing the matter-antimatter asymetry problem.
- Milne cosmology :

$$a(t) \propto t \tag{5}$$

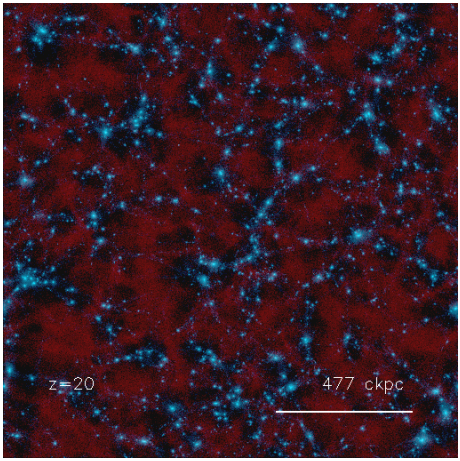
  On large scales: void universe: $\bar{\rho}(t) = 0$. Only coordinate expansion.

- See Levy 1110.3054 for a discussion on nucleosynthesis, the position of the first peak of the CMB and supernovae IA in Dirac-Milne cosmology.
- In Manfredi 1804.03067 and Manfredi 2010.07776 structure formation was studied using a N-body code which assumes spherical symmetry.

- Start from disjoint quasi homogeneous supports for Virialized matter and antimatter at redshift 1080. Density contrast between matter and antimatter are of order 1. Let the system evolve.
- Matter rapidly collapses into structures.
- Antimatter spreads around.
- But antimatter does not come very close from structures as it repels with matter. $\rightarrow$ creation of a *buffer* (depletion) zone which is totally void.



Our Simulation



Numerical setup:

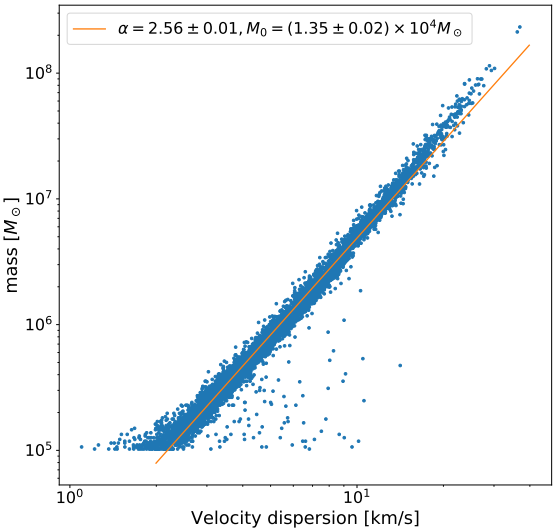
Grid: 256^3, BoxSize$= 1\ h^{-1}$ cMpc, Total mass in the box : $3.3 \times 10^{10} M_{\odot}$.

Assumption:

Matter is in the form of stars: particle sector of `RAMSES`, no hydro.

Main results: scaling relation (Tully-Fisher)

Tight scaling relation, slope closer from 3 than 4. See discussion in Lelli 1901.05966 or Ponomareva 1711.09112.



Main results: modified gravity

- Define $\vec{g}_m = -\vec{\nabla}(\phi_1 - \phi_2)/2$ and $\vec{g}_+ = -\vec{\nabla}\phi_1$.
- The matter field feels an extra force due to the coupled Poisson equations.

- Rich interesting phenomenology at galactic scales
- Need to move to baryons and feedback.
- May allow to perform global fit to galactic observables.
- Prediction 1: acceleration scale of MOND is time dependant $a_0(z)$. $\rightarrow$ rotation curves of galaxies at high redshift.
- No known linear regime in Dirac-Milne cosmology. Need resolution of 100 ckpc. $\rightarrow$ computationally expensive to simulate the largest scales.
- Prediction 2: More small scales structures at high redshift (non-linear regime all the way from $z = 1080$). $\rightarrow$ observation of high redshift quasars.
- Prediction 3: Antimatter *antigravitates*. $\rightarrow$ Gbar, ALPHA-g and AEgIS @CERN
- Do you know other setups where `BiPoisson` may be useful?

Thank you for your attention