Testing Unified Dark Matter-Energy models in the non-linear regime

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We study the dynamical evolution of the universe, by solving Einstein equations of G.R. for the FLRW metric, with the friedmann equations.

$$R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R = 8\pi G T_{\mu\nu}$$

$$H^2 = \frac{8\pi G}{3}\rho$$

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3P)$$

$$\frac{d}{dt}(a^3\rho) + p\frac{d}{dt}(a^3) = 0$$

$$\rho(a) = \rho(a_0) e^{-\int_{a_0}^{a} 3(1+w(a))a^{-1}da}$$

$$w = \frac{p}{\rho}$$

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Cosmological constant challenges:

-Fine-tuning problem

-Coincidence problem

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Unified dark matter-energy models

- Generalised Chaplygin Gas
  - Characterised by a sound speed bigger than zero, preventing structure formation
  - Only viable if indistinguishable from CDM

- Alternatives
  - Silent Chaplygin
  - Decomposition models
  - **Backreaction**

    Avelino+ 2014
  - **Fast transition**

    Bruni+ 2013

Generalised Chaplygin Gas

$$p_{cg} = -\frac{A}{\rho_{cg}^{\alpha}}$$

From the continuity equation:

$$\rho_{cg}(a) = \rho_{cg(0)} \left[\bar{A} + (1 - \bar{A})a^{-3(1+\alpha)}\right]^{\frac{1}{1+\alpha}}$$

With:

$$\bar{A} = A/\rho_0^{1+\alpha}$$

Equation of state:

$$w_{cg} = \frac{p}{\rho} = -\frac{A}{\rho_{cg}^{1+\alpha}}$$

Sound speed:

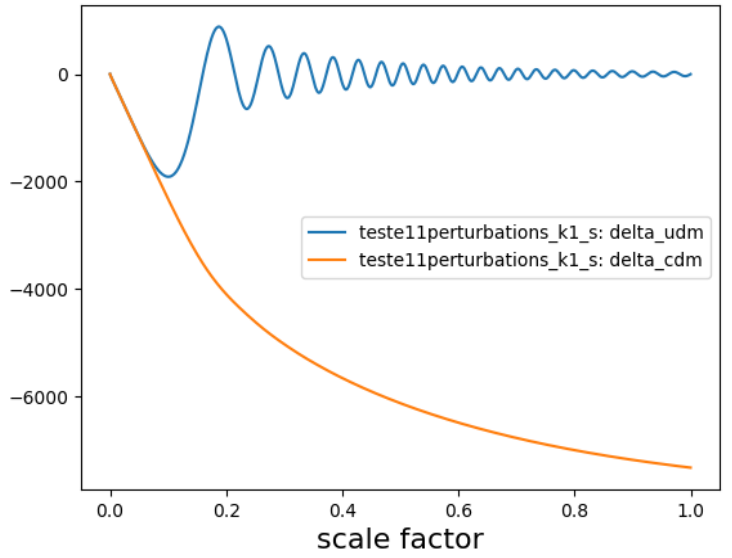
$$c_{s,cg}^2 = \frac{dp}{d\rho} = -\alpha w_{cg}$$

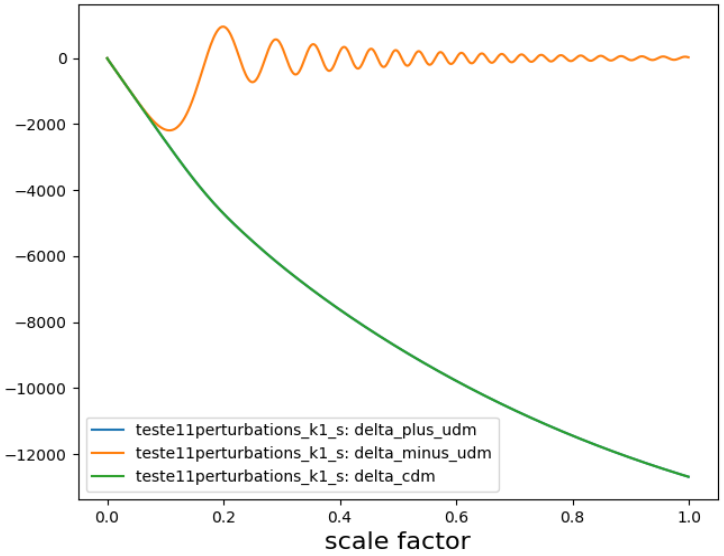
Backreaction

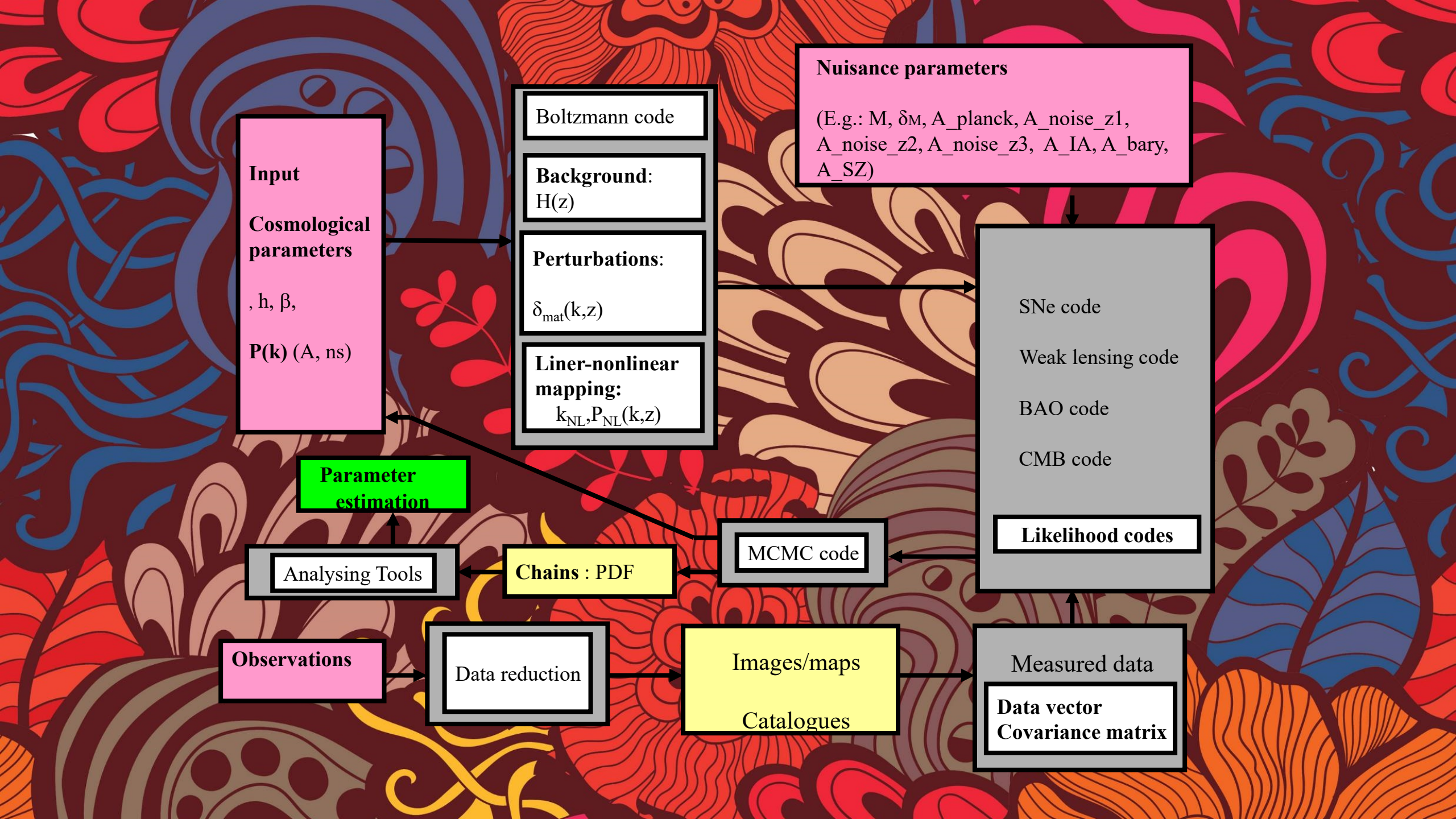
- Collapsed regions $\rho_+ = \frac{E_+}{V} = \epsilon\rho$
- Underdense regions $\rho_- = \frac{E_-}{V} = \frac{E - E_+}{V} = (1-\epsilon)\rho$
- Collapsed fraction $\epsilon = \frac{\epsilon_0\rho_0}{\rho a^3}$

$$\delta' + 3\mathcal{H}\left(c_s^2 - w\right)\delta = -\left(1+w\right)\left(\theta + 3\Phi'\right),$$

$$\theta' + \left[\mathcal{H}(1-3w) + \frac{w'}{1+w}\right]\theta = -k^2\left(\frac{c_s^2}{1+w}\delta + \Psi\right)$$






Input
Cosmological parameters
, h, β,
P(k) (A, ns)
Boltzmann code
Background: H(z)
Perturbations:
$\delta_{mat}(k,z)$
Liner-nonlinear mapping:
$k_{NL}, P_{NL}(k,z)$
Nuisance parameters
(E.g.: M, δM, A_planck, A_noise_z1, A_noise_z2, A_noise_z3, A_IA, A_bary, A_SZ)
SNe code
Weak lensing code
BAO code
CMB code
Likelihood codes
Parameter estimation
Analysing Tools
Chains : PDF
MCMC code
Observations
Data reduction
Images/maps
Catalogues
Measured data
Data vector
Covariance matrix

Results

Parameters	Best-Fit	Mean $\pm 1\sigma$	-2σ	$+2\sigma$
ϵ_i	0.9994	$0.9855^{+0.014}_{-0.0088}$	0.9526	0.9999
ϵ_0	0.253	$0.2499^{+0.015}_{-0.014}$	0.2191	0.2777
$\Omega_{b0}h^2$	0.02246	$0.02241^{+0.00038}_{-0.00042}$	0.02174	0.02312
$ln10^{10}A_s$	3.115	$3.124^{+0.058}_{-0.049}$	3.028	3.216
n_s	0.9757	$0.9732^{+0.01}_{-0.0098}$	0.9555	0.9901
H_0	69.51	$69.61^{+1.2}_{-1.3}$	67.32	72.13
τ_{reio}	0.09383	$0.0977^{+0.031}_{-0.024}$	0.04891	0.1447
$\overline{A}$	0.6518	$0.6541^{+0.068}_{-0.059}$	0.5518	0.7577
w_{0-}	-1	$-0.9988^{+0.0061}_{-0.0012}$	-1	-0.9868
σ_8	0.8454	$0.8404^{+0.026}_{-0.025}$	0.7915	0.889

Model constraints from Planck 2015, KiDS-450 and Pantheon.

- Model is viable if we have a collapse fraction of UDM.
  - Motivation to go to non-linear

Simple UDM Lagrangian for non-linear study

Poisson Equation:

$$L(\chi) = P(\chi) = -\rho_\Lambda + \rho_m \alpha \left(\frac{\chi}{\chi_0}\right)^{\frac{1+\alpha}{2\alpha}}$$

$$\rho_\phi = \rho_\Lambda + \frac{c}{\alpha}\chi^{\frac{1+\alpha}{2\alpha}}$$

$$T^\phi_{ab} = \frac{\alpha\rho_m}{\chi_0}\left(\frac{1+\alpha}{2\alpha}\right)\left(\frac{\chi}{\chi_0}\right)^{\frac{1-\alpha}{2\alpha}} \nabla_a\phi\nabla_b\phi + \left[-\rho_\Lambda + \rho_m\alpha\left(\frac{\chi}{\chi_0}\right)^{\frac{1+\alpha}{2\alpha}}\right] g_{ab}$$

$$\frac{\partial^2\Phi}{\partial r^2} = -\frac{3}{2}\Omega_m H_0^2 \alpha \left(\frac{\partial\phi^*}{\partial_r}\right)^{\frac{1+\alpha}{2\alpha}} + \frac{3}{2}\Omega_b H_0^2 \delta_b - 2\frac{\partial\phi^*}{\partial r}$$

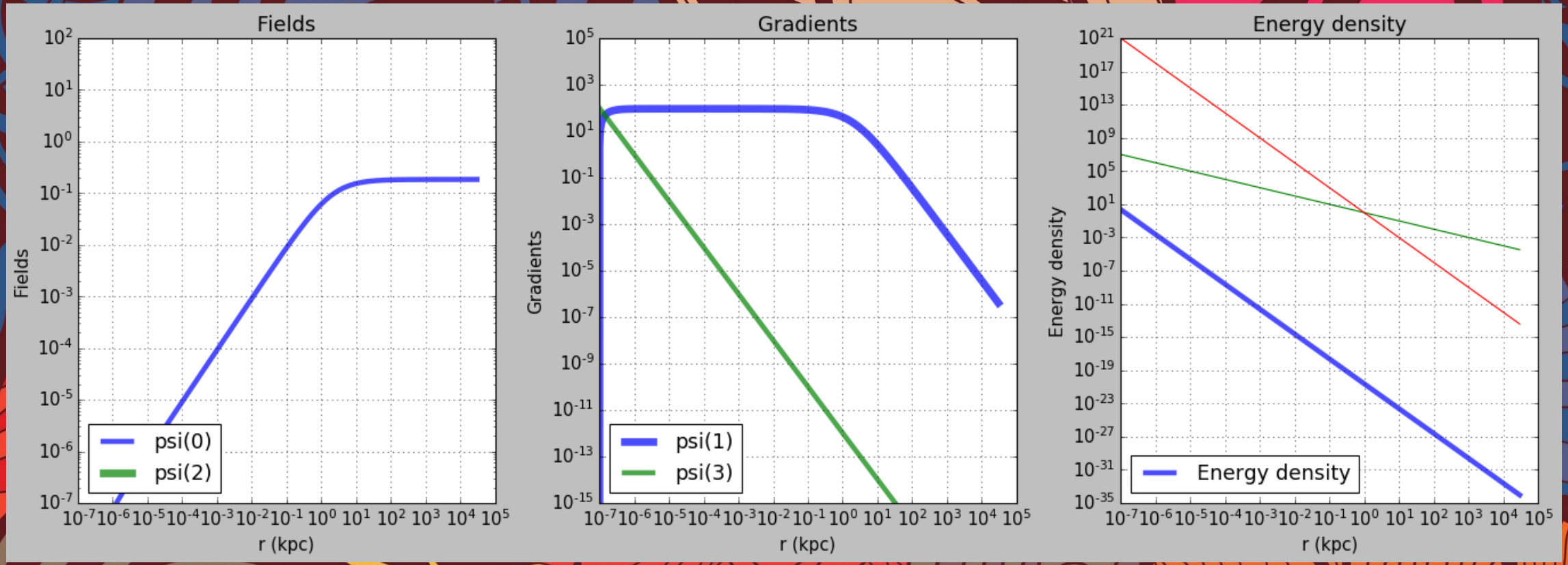
Field Equation:

$$\left[\frac{dL}{d\chi}g^{ab} - \frac{d^2L}{d\chi^2}\nabla^a\phi\nabla^b\phi\right]\nabla_a\nabla_b\phi = 0$$

$$\frac{\partial^2\phi}{\partial r^2} = \frac{\partial\phi}{\partial r}\frac{\partial\Phi}{\partial r}\left(1 - \frac{1}{1 - \frac{1-\alpha^2}{\alpha(\alpha+1)}}\right)$$

$$\left[\left(\frac{1+\alpha}{2\alpha}\right)\rho_m\alpha\chi_0^{-1}\left(\frac{\chi}{\chi_0}\right)^{\frac{1-\alpha}{2\alpha}} g^{ab} - \left(\frac{1-\alpha^2}{4\alpha^2}\right)\rho_m\alpha\chi_0^{-2}\left(\frac{\chi}{\chi_0}\right)^{\frac{1-3\alpha}{2\alpha}}\nabla^a\phi\nabla^b\phi\right]\nabla_a\nabla_b\phi = 0$$

Spherical solution using Hernquist baryon density profile (Ongoing work)



Summary

- UDM models show promising results in the linear regime
- Need to study these models in the non-linear regime
  - To match future observations
  - To account for the backreaction effect
- Spherical solution as a first test and constraint
- Implementation in N-Body code (testing phase)
  - Including backreaction