Numerical Problems in Perturbed Coupled Quintessence

Alex Leithes

in collaboration with Karim A. Malik*, David J. Mulryne*, Nelson J. Nunes**

Queen Mary University of London

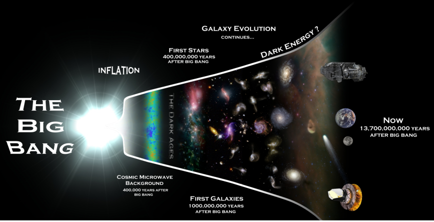
*Queen Mary, University of London, **Universidade de Lisboa

Overview

Overview

- Beyond Lambda - Why Coupled Quintessence?
- Work to date - general perturbation equations, PYESSENCE code
- Results and future work

Beyond Lambda - Why Coupled Quintessence?



Why Coupled Quintessence?

- Late time accelerated expansion - simplest solution: Cosmological Constant, Λ, "Dark Energy?" - problems e.g. coincidence
- Alternatives: one or more scalar fields
- Coupled Quintessence: Canonical scalar field(s), ϕ, with potential $V(\phi)$, interacting gravitationally with all components, and through couplings between DE and CDM components - solves problems e.g. coincidence (Quintessence alone), breaking tracking (when Coupled)
  $$\nabla_\mu T^{\mu(\phi)}_\nu = \kappa \mathbb{C} T_{(M)} \nabla_\nu \phi \quad , \quad \nabla_\mu T^{\mu(M)}_\nu = -\kappa \mathbb{C} T_{(M)} \nabla_\nu \phi$$
- Potential examples: Exponential, $V_0 e^{-\lambda\kappa\phi}$, Freezing, e.g. $M^{4-n}\phi^{-n}$, $(n>0)$, Thawing, e.g. $M^4 \cos^2(\frac{\phi}{f})$, etc., a "potential" glut

Beyond Lambda - Why Coupled Quintessence?

Questions of Coupled Quintessence

- Need a generalised code to test any given coupled quintessence model and allow comparison with observations
- We are developing code, PYESSENCE, to do this
- Background evolution of a model must match observations (CMB, SN data)
- If background satisfies this, is the perturbed model stable (under what range of couplings/no. of fields etc.)?
- If perturbations are stable do they match observations from large scale structure surveys e.g. BOSS, DES, eBOSS, DESI, Euclid, SKA?

Work to date - perturbed equations

The key equations

- Perturbed around FLRW to derive the perturbed equations for multiple CDM fluids and DE fields (Assisted Coupled Quintessence), fully general, gauge unspecified, allowing for pressure (c.f. 1407.2156 Amendola, Barreiro, Nunes for earlier work)
- Allows us to write completely general code for the community to test wide range of models under differing conditions

Work to date - PYESSENCE code

Work to date

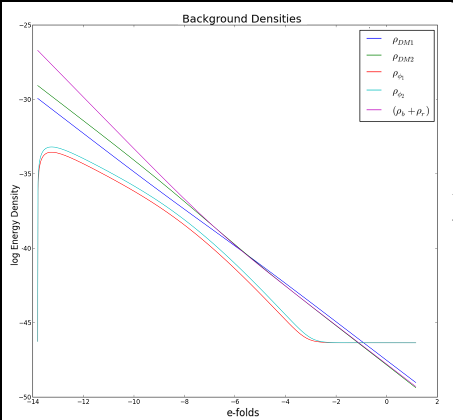
- Code designed to step through parameter space of couplings, determine region of parameter space for stable perturbations
- By repeating for different k modes can build power spectrum for comparison with observations
- First working implementation in Flat gauge
- Code to be used for N fields, M fluids
- Initial testing for 2 fields and 2 fluids
- Also for testing, sum of exponential potential chosen

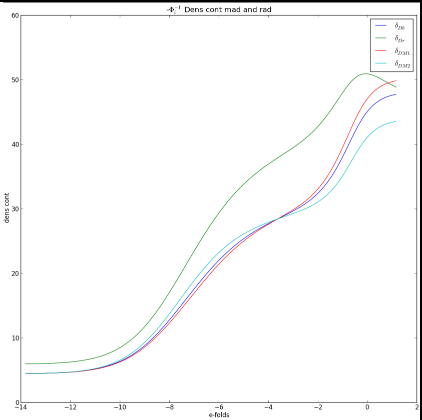
$$V(\phi_1 ... \phi_n) = M^4 \sum_I e^{-\kappa \lambda_I \phi_I}$$

PYESSENCE code - Work to date

Work to date

- Plotted evolution of perturbations to this 2 fluid, 2 field, sum of exponentials model, for a point in coupling constant space, in fourier space. For the plot below $k = H_0$ (flat gauge)

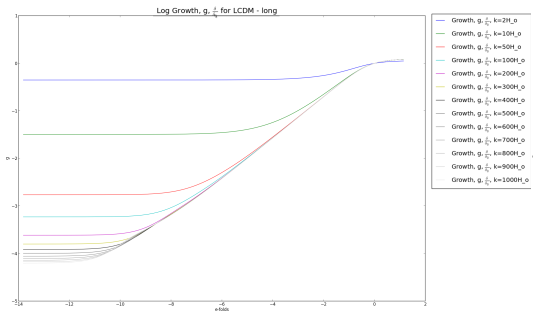


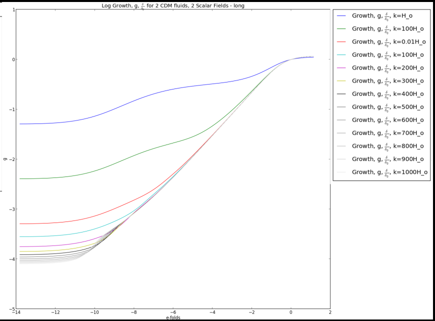


PYESSENCE code - Work to date

Work to date

- Able to plot growth factors g, $\frac{\delta}{\delta_0}$, and f, $\frac{\delta'}{\delta}$, without making approximations for $(k/a)^2 >> aH$ (below: longitudinal gauge)

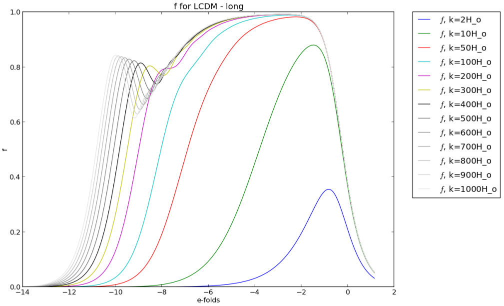


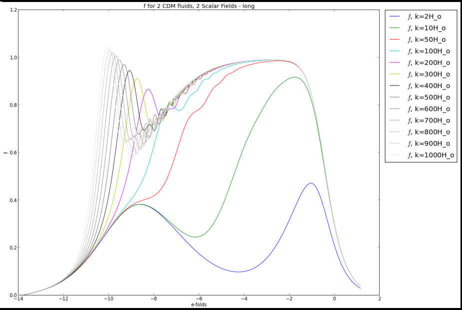


PYESSENCE code - Work to date

Work to date

- Plot growth factors g and f without making approximations for $(k/a)^2 >> aH$ (below: longitudinal gauge)

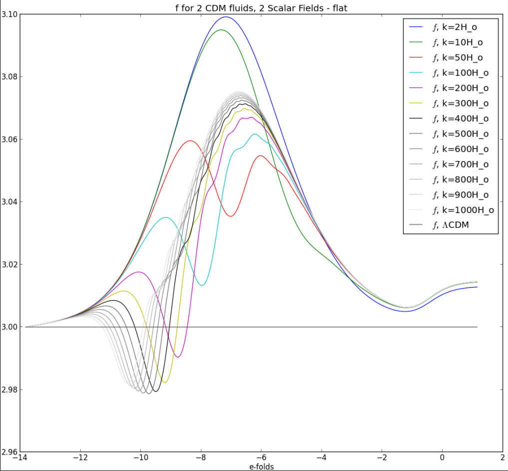




PYESSENCE code - Work to date

Work to date

- Difference in f between LCDM and given Coupled Quintessence model easier to quantify in flat gauge



Results and future work

Results and future work

- Forthcoming paper to present these results in full, and release PYESSENCE code for community
- Constrain models through comparison with LSS surveys (Euclid, SKA etc.)
- Constrain models through stability

Thank you.

Extra Slide - perturbed equations

The key equations

- Perturbed metric,
  $ds^2 = -(1+2\Phi)dt^2 + 2aB_{,i}dtdx^i + a^2\left(\delta_{ij} + 2C_{ij}\right)dx^i dx^j$
- Conservation equation:
  $\dot{\delta\rho}_\alpha + \left(\dot{E} - 3\dot{\psi} - \frac{k^2 v_\alpha}{a}\right)(\bar{\rho}_\alpha + \bar{P}_\alpha) + 3H(\delta\rho_\alpha + \delta P_\alpha) =$
  $-\kappa \sum_I \mathbb{C}_{I\alpha}(\bar{\rho}_\alpha - 3\bar{P}_\alpha)\dot{\delta\phi}_I - \kappa \sum_I \mathbb{C}_{I\alpha}(\delta\rho_\alpha - 3\delta P_\alpha)\dot{\bar{\phi}}_I$
- Field perturbations:
  $\ddot{\delta\phi}_I + 3H\dot{\delta\phi}_I + \sum_J V_{,\phi_I\phi_J}\,\delta\phi_J - (k^2\dot{E} + 3\dot{\psi})\dot{\bar{\phi}}_I + \frac{k^2}{a^2}\delta\phi_I + \frac{\dot{\bar{\phi}}_I}{a}k^2 B -$
  $\dot{\bar{\phi}}_I\dot{\Phi} + 2V_{,\phi_I}\,\Phi - 2\kappa\sum_\alpha \mathbb{C}_{I\alpha}(\bar{\rho}_\alpha - 3\bar{P}_\alpha)\Phi - \kappa\sum_\alpha \mathbb{C}_{I\alpha}(\delta\rho_\alpha - 3\delta P_\alpha) = 0$
- Einstein Field Equations also derived