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Beyond Lambda: Numerical Problems in Perturbed Coupled Quintessence

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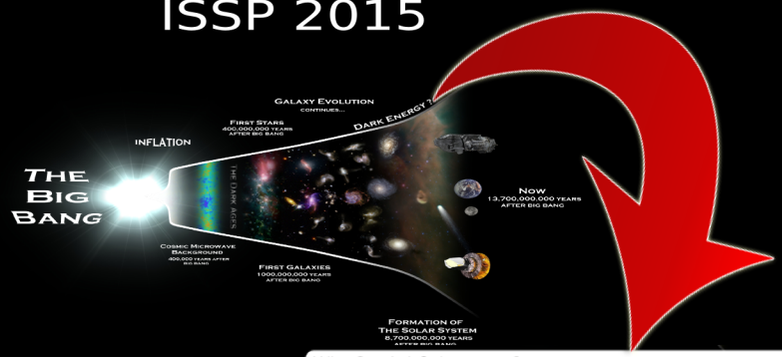


Why Coupled Quintessence?

- 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)
- 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

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 perturbation are stable do they match observations from large scale structure surveys e.g. BOSS, DES, eBOSS, DESI, Euclid?

The key equations

- We perturbed around flat FLRW
- We derived the perturbed equations for multiple CDM fluids and DE fields for first time in full generality, 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
- Finished code will also allow different selections of gauge

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: $\dot{\delta\rho_\alpha} + \left(\frac{\nabla^2 v_\alpha}{a} + \dot{E} - 3\dot{\psi}\right)(\bar{\rho}_\alpha + \bar{P}_\alpha) + 3H(\delta\rho_\alpha + \delta P_\alpha) = -\kappa\sum_I \mathbb{C}_{I\alpha}(\bar{\rho}_\alpha - 3\bar{P}_\alpha)\dot{\delta\phi}_I - \kappa\sum_I \mathbb{C}_{I\alpha}(\delta\rho_\alpha - 3\delta P_\alpha)\dot{\bar{\phi}}_I$
- Field perturbations: $\ddot{\delta\phi}_I + 3H\dot{\delta\phi}_I + V''\delta\phi_I + (\dot{E} - 3\dot{\psi})\dot{\bar{\phi}}_I + \frac{k^2}{a^2}\delta\phi_I + \frac{\dot{\bar{\phi}}_I}{a}k^2 B - \dot{\bar{\phi}}_I\dot{\Phi} + 2V'\Phi - 2\kappa\sum_\alpha \mathbb{C}_{I\alpha}(\bar{\rho} - 3\bar{P})\Phi - \kappa\sum_\alpha \mathbb{C}_{I\alpha}(\delta\rho - 3\delta P) = 0$
- Einstein Field Equations also derived

Work to date

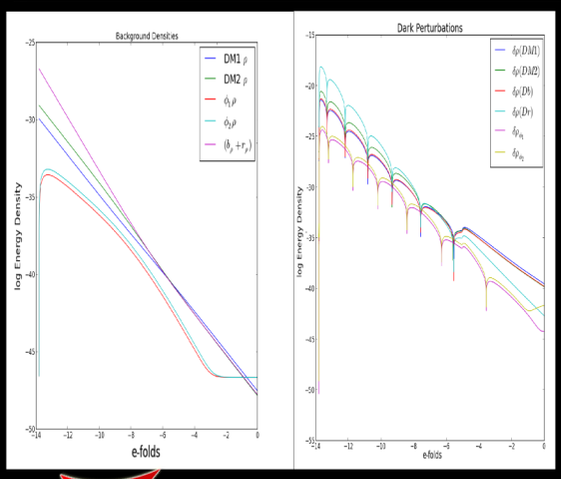
- Code designed to step through parameter space of couplings, slopes of potentials, determine region of parameter space for stable perturbations
- First implementation longitudinal gauge
- Code to be used for N fields, M fluids
- Initial testing for 2 fields and 2 fluids
- Also for testing, sum of exponential potential chosen

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

(gives analytical solution for background evolution)

Work to date

- For first time plotted evolution of stable 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 $k = H_0$



Results and future work

- Forthcoming paper to present these results in full, with maps of stable regions of couplings parameter space, and release PYESSENCE code for community
- Constrain models through stability
- Constrain models through comparison with LSS surveys (Euclid etc.)

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