Chameleon in the Early Universe

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CITA people aren't taking G2000 seriously...

1pm today, MP 1404D:

Zhiqi: Oh you are giving a G2000 talk, too?

Evan: Yeah...

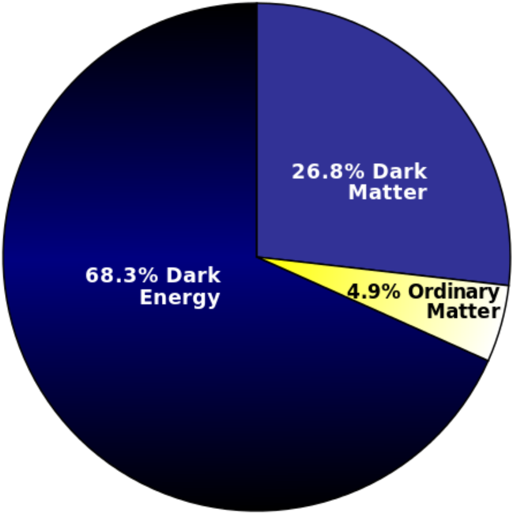
Zhiqi: And you just started making the slides now?

Evan: Ehuh, yeah...

Zhiqi: Guess I need to start, too. Oh no, I need to get the lunch first...

Outline

The Cosmic Pie after Planck



The Chameleon Model for Dark Energy

GR:

$$\mathcal{L} = \frac{M_p^2}{2} R\left(g_{\mu\nu}\right) + \mathcal{L}_{\rm matter}\left(g_{\mu\nu}, \psi_m\right) \ .$$

Chameleon field ϕ:

$$\mathcal{L} = \frac{M_p^2}{2} R\left(g_{\mu\nu}\right) + \mathcal{L}_{\rm matter}\left(\tilde{g}_{\mu\nu}, \psi_m\right) + \frac{g^{\mu\nu}}{2} \partial_\mu \phi \partial_\nu \phi - V(\phi) \,,$$

where $\tilde{g}_{\mu\nu} \equiv e^{\frac{2\beta}{M_p}\phi} g_{\mu\nu}$.

Chameleon coupling

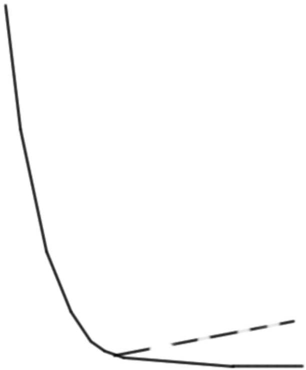
The e.o.m. for Chamaleon field:

$$\partial^2\phi = -\frac{dV}{d\phi} + \frac{\beta}{M_p} T^{\mu}_{\mu} \, ,$$

where T^{μ}_{μ} is the trace of energy momentum tensor of the matter fields in Einstein frame.

species	T^{μ}_{μ}
radiation	0
non-relativistic fluid	energy density ρ

The non-relativistic ρ raises the effective potential



$$V_{\mathrm{eff}}(\phi) = V(\phi) + \frac{\beta \rho_{\mathrm{non-rel}}}{M_p}\phi$$

The "kickers" before BBN

Contributions to Σ

fermions			bosons		
particle	g	m (GeV)	particle	g	m (GeV)
before QCD phase transition					
top	12	172	Higgs	1	125
bottom	12	4.2	Z	3	91
charm	12	1.3	$W^{\pm}$	6	80
tau	4	1.8			
after QCD phase transition					
muon	4	0.106	π^0	1	0.140
electron	4	5.11×10^{-4}	$\pi^{\pm}$	2	0.135

TABLE I: The numbers of degrees of freedom (g) and the masses (m) of the particles that we include in the kick function $\Sigma(T)$. For the fermions, the contributions from antiparticles are included in the number of degrees of freedom for each species.

How linear perturbation theory works?

1. Solve the background equations and compute $m^2(t) = d^2V/d\phi^2$.
2. Solve the linear perturbations using the known $m^2(t)$:

$$\delta\left(\partial^2\phi\right) + m^2(t)\delta\phi = 0$$

.

When does linear perturbation theory fail?

Linear perturbation theory assumes that we can replace the local $d^2V/d\phi^2$ with its background value. This assumption fails when

- The mass $d^2V/d\phi^2$ is very sensitive to a tiny shift of ϕ. That is, we have a huge $d^3V/d\phi^3$. (Chameleon models)
- In a chaotic system, tiny differences in the initial conditions can lead to significantly different background trajectories. A typical example is the modulated preheating (Bond, Frolov, Huang, Kofman 2009.)

The methods beyond linear perturbation theory

- For classical particle production (modulated preheating), we can use lattice simulations.
- For quantum particle production (Chameleon models), a full calculation is very difficult. However, we can include the lowest-order backreaction from $d^3V/d\phi^3$:

$$\partial_t^2\phi = -V'(\phi) - \frac{1}{2}V'''(\phi)\int_{2\pi/L}^{\infty}\frac{k^3 d\ln k}{2\pi^2}\left[\frac{-\delta\omega_k}{2\omega_k(\omega_k+\delta\omega_k)}\right]$$

The energy dumped into fluctuations

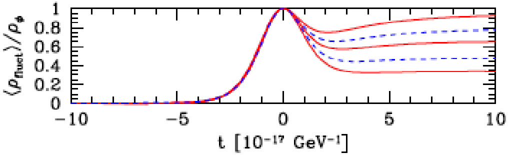


FIG. 11: The evolution of the energy density in fluctuations, $\langle\rho_{\rm fluct}\rangle$, as a fraction of the total energy density of the chameleon field $\rho_\phi \simeq \dot\phi_M^2/2$. In this figure, $\dot\phi_M = -100\,\mathrm{GeV}^2$, and $V(\phi)$ is given by Eq. (9) with $n = 2$ and $M = 10^{-3}$ eV. The different curves show different $k_{\rm IR}$ values: from bottom to top, $k_{\rm IR} = 10^{13}, 10^{14}, 10^{14.7}, 10^{15}$, and $10^{15.3}$ GeV. In all cases, $k_{\max} = 10^{18}$ GeV. The spatially averaged field turns around at $t = 0$.

$$V(\phi) = M^4 \exp\left(\frac{M}{\phi}\right)^2$$

Conclusions and Outlook

- For a large portion of the parameter-space ($\beta \gtrsim O(1)$), Chameleon condensate can be destroyed before BBN.
- Higher-order corrections from $d^4V/d\phi^4$, $d^5V/d\phi^5$ ... might also be relevant. Further calculations is needed in order to fully understand this problem.