Can dark energy emerge from a varying G and spacetime geometry?

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- Energy of the quantum vacuum is many magnitudes off
- Renormalization to a small (but non-zero) value required

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Formulate dark energy as the spacetime response to variation of G.

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Assuming Hubble flow, this tensor can be written in terms of only two scalar functions, $\Phi(t) + \Psi(t)$,

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Using the usual FLRW metric we get the cosmological equations:

$$H^2 = \frac{8\pi G\rho}{3} + \frac{8\pi\Phi}{3} - \frac{\kappa}{a^2}, \qquad \frac{\ddot{a}}{a} = -\frac{4\pi G}{3}(\rho + 3p) - \frac{4\pi}{3}(\Phi + 3\Psi)$$

Obtaining Φ and Ψ

Bianchi identitiy gives a relation between $\Phi(t)$ and $\Psi(t)$.

$$\mathrm{D}_\mu S^{\mu\nu} = -T^{\mu\nu}\partial_\mu G \quad \Rightarrow \quad \dot{\Phi} + 3H(1 + \tfrac{\Phi}{\Psi})\Phi = -\dot{G}\rho$$

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Define $w(t) = \Phi(t)/\Psi(t)$, and $\xi(t)$ as a function satisfying $\dot{\xi}/\xi = 3H(1+w)$.

$$\dot{\Phi} + 3H(1+w)\Phi = -\dot{G}\rho \quad \Rightarrow \quad \tfrac{d}{dt}(\Phi\xi) = -\dot{G}\rho\xi$$

Obtaining Φ and Ψ

At $t = 0$, $\rho \to \infty$ but we can integrate these at the lower limit $t = \varepsilon$.

$$\Phi(t)\xi(t) = \lim_{\varepsilon \to 0} \left(\Phi(\varepsilon)\xi(\varepsilon) - \int_\varepsilon^t \dot{G}\rho\xi dt \right)$$

$$\xi(t) = \lim_{\varepsilon \to 0} \left[\xi(\varepsilon) \frac{a(t)^{3(1+w(t))}}{a(\varepsilon)^{3(1+w(\varepsilon))}} \exp\left(-3 \int_\varepsilon^t \dot{w} \ln(a) \, dt \right) \right]$$

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Ansatz for G

$G(a) = G_0\left(1 + \sum_{n=1}^{\infty} b_n (1-a)^n\right)$. We take only the first few terms.

Assuming flat universe $\kappa = 0$ allows determining one of the b_n in terms of the others.

Late Universe Data

- Type Ia Supernovae (JLA)
  i. $L \propto M_{Ch} \propto G^{-1.5}$
  ii. $L \propto G^{1.46}$ [1,2]

- Baryon Acoustic Oscillations (6dFGS, SDSS-MGS, BOSS DR12, eBOSS DR14)

[1] B. S. Wright and B. Li, Phys. Rev. D97, 083505
[2] J. Sakstein, et al. Phys. Rev. D53

Results

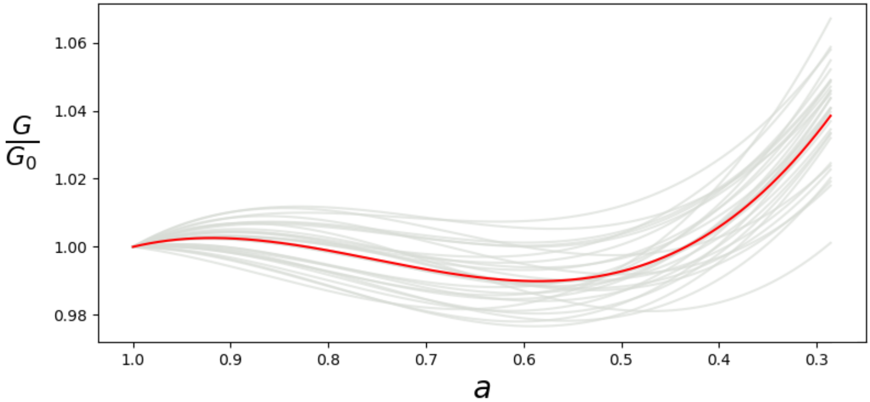
We obtain the model parameters with a χ^2 minimization analysis.

Model	χ^2	d.o.f.
ΛCDM	698.05	749
Varying G	697.73	747

b_1	b_2	b_3
0.07 ± 0.15	-0.51 ± 0.33	0.679 ± 0.094

Ω_m	Ω_r	$H_0 r_d$ [km s^{-1}]
0.284 ± 0.017	$(0.0 \pm 7.0) \times 10^{-3}$	$(101.7 \pm 1.3) \times 10^2$

Results



$$G(a)/G_0 = \left(1 + b_1(1-a) + b_2(1-a)^2 + b_3(1-a)^3\right)$$

Conclusion and Outlook

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- This type of a model is consistent with the late-time expansion data.
- The predicted variation of G is small.

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- What about the early Universe?
- The bounds of G variation from CMB are theory dependent. Requires analysis of perturbations.
- A different G value at the early universe can lead to a different H_0.

Thank you for listening!

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