Constraints On Gravity from CMB data: an Effective Field Theory approach

Valentina Salvatelli

Rencontres de Moriond 2016, 24th March
Outline:

- Why cosmologists challenge the general relativity?
A matter-of-fact: the universe is accelerating

Nobel Prize

Physics 2011

Models with no lambda are ruled out

© High-Z Supernova Search Team

Planck 2015 results.
What is sourcing the cosmic acceleration?

\[ G_{\mu\nu} = 8\pi G T_{\mu\nu} + \Lambda g_{\mu\nu} \]

- **Cosmological Constant**
  (a good fitting solution so far)

- **Dark Energy ?**

- **Modified gravity ?**
On-going and short coming experiments have discriminating sensitivity to test gravity effects on cosmological scales.
Which strategy to test gravity?

**Theoretical approach:**
Given a theoretical set up, specify the action of the theory, derive the background and perturbation equations in that framework, compare observables with data.

**Phenomenology approach:**
Construct functions that map closely onto cosmological observables of gravity, parametrize the functions and look for deviations from standard.

\[ \mu(a, k) \equiv \frac{G(a, k)}{G_N}, \quad \gamma(a, k) \equiv \frac{\Psi}{\Phi} \]

**Effective Field Theory approach:**
Parametrize the action in terms of a set of effective time-dependent functions.

( F. Piazza’s talk)
How the CMB probes gravity

- Position of the peaks ↔ Background history
- Amplitude of peaks ↔ Growth of structure
- ISW effect ↔ Gravitational potentials
- Lensing ↔ Gravitational potentials

Constraints on gravity: an EFT approach
Results from Planck-15

✓ No evidence for deviation from $\Lambda$CDM at the background level.

✓ Some tensions emerge in the perturbations, when the phenomenological approach is considered.

✓ No evidence for deviations when considering specific models, (but very unpractical to test models one by one)

Evidence of deviations ??

arXiv:1502.01590 - Planck Collaboration (including VS)
EFT of DE, a short reminder:


✓ It describes all the possible effects on gravity of an additional scalar degree of freedom

✓ Theory parametrized in terms of time-dependent functions

✓ Separation between functions acting on the background and on the perturbations is possible

Set of EFT functions

\[ \bar{w}(t), \mu(t), \mu_3(t), \epsilon_4(t) \]

Background  Perturbations
Methodology of this analysis

- Gravity phenomenological functions, expressed in terms of the functions that appear in the EFT action (Perenon et al. 2015).

\[
\mu_{MG} \equiv \frac{G_{eff}}{G_N} = \mathcal{F}_1(\mu, \mu_3, \epsilon_4, H, \dot{\mu}_3, \dot{\epsilon}_4, \Omega_m^0)
\]

\[
\gamma_{MG} \equiv \frac{\dot{\Psi}}{\dot{\Phi}} = \mathcal{F}_2(\mu, \mu_3, \epsilon_4, H, \dot{\mu}_3, \dot{\epsilon}_4, \Omega_m^0)
\]

- Temporal evolution of EFT functions encoded in a set of parameters.

  - **3D–Model** (0th-order Taylor expansion):
    \[\{p_1, p_3, p_4\}\]
  
  - **5D–Model** (1th-order Taylor expansion):
    \[\{p_1, p_3, p_4, p_3^{(1)}, p_4^{(1)}\}\]

- Background fixed to $\Lambda$CDM.

- Dataset: CMB temperature, polarization and lensing from Planck

![Graph](image-url)

Time variable going to 1 at early times

\[
\mu(x) = (1-x) \left[p_1 + p_1^{(1)}(x-x_0)\right] H(x),
\]

\[
\mu_3(x) = (1-x) \left[p_3 + p_3^{(1)}(x-x_0)\right] H(x),
\]

\[
\epsilon_4(x) = (1-x) \left[p_4 + p_4^{(1)}(x-x_0)\right],
\]

EFT free parameters
Theoretical viability conditions

Main advantage of this approach: keeping under control the health of the models we are considering.

3 scenarios considered:

1. Stability = no ghosts and gradient instabilities (Always enforced)

2. Stability + Cs < 1 = above and scalar perturbations propagate not superluminally

3. Stability + Cs < 1 + Ct < 1 = above and tensor perturbations propagate not superluminally
Results (3-D model):

$p_1, p_3, p_4$ are the parameters characterizing each of the EFT functions.

- Viability conditions strongly reduce the allowed parameter space.
- Health theoretical criteria compensate for the observational unsensitivity.

*arXiv:1602.08283 VS, Piazza, Marinoni*
Results (3-D model):

- No deviations from GR in p3 and p4
- A negative p1 is favoured by current measurements?

... Not really.

The chi-square do not improve with respect to Λ CDM.

*arXiv:1602.08283 VS, Piazza, Marinoni*
Results (5-D model):

✓ More freedom  ➔ larger contours

✓ Degeneracies are the same ➔ not due to the parametrization

✓ No evidence of deviation from $\Lambda$CDM

$\text{arXiv:1602.08283 VS, Piazza, Marinoni}$
What about the observables?

- Only models with an effective Newton constant greater than in General Relativity are stable!
- If also subluminarity is imposed $\gamma_{MG}(z = 0) \leq 1$.
- No healthy theories, that add one scalar degree of freedom, lie in the region preferred in the phenomenological approach.

(See also the poster by Louis Perenon) arXiv:1602.08283 VS, Piazza, Marinoni
Summary:

- Rapidly growing possibility to test gravity on cosmological scales.

- A unified language is convenient: so far phenomenological parametrizations have been extensively used with this aim.

- The Effective Field of Dark Energy has being developed as new attractive unified framework. Main advantage: a clear control of the underlying theory and its health.

- The use of the EFT framework shows that:
  - Theoretical viability condition significantly improve the constraints.
  - Phenomenological results have to be cautiously interpreted.