Who needs a model? Cosmological tests of model independent modified gravity

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Why do we need to go beyond Einstein?

- Quantum Gravity
- Dark stuff $T_{\mu\nu} \sim G_{\mu\nu}$

- Being a good scientist
Models vs model independent

- Doesn't rely on us having come up with correct model
- No clearly leading alternative; No fundamental theory from complete Quantum Gravity
- No need for model selection criteria
- Answers could lead us to correct theory
What is GR in Cosmology?

- FRW metric: expanding homogeneous and isotropic (flat) spacetime with perturbations
  \[ ds^2 = -(1 - 2\Psi)dt^2 + a^2(t)(1 - 2\Phi)\left( dx^2 + dy^2 + dz^2 \right) \]
  \[ k^2 \Psi = -4\pi G a^2 \rho \delta(a, k) \quad \text{Fourier space: } \nabla^2 \to -k^2 \]
  \[ k^2 (\Phi - \Psi) = -32\pi G a^2 \rho \Pi \]
Parameterisation

- \( \mu: k^2 \Psi = -4\pi G a^2 \mu(a, k) \rho \delta(a, k) \)
- \( \eta = \Psi / \Phi \)
- Both have value 1 in GR
- This work: single value \( \neq 1 \), switches on at redshift 30
Power Spectrum of anisotropies of background radiation

Notably ISW effect, generated at late time by evolution of both potentials

Calculated by Boltzmann code MGCAMB$^1$

$^1$Zhao et al 0809.3791
Observables-Weak Lensing

- Correlations in small scale distortions of galaxy images
- Depends on sum of potentials

![Diagram showing Correlations in small scale distortions of galaxy images](image.png)
Large dark matter halos full of hot gas

Number of clusters at different redshifts very sensitive to \( \Psi \) only

Halo Mass functions: prescriptions for calculating number density of objects with mass \( M \) from linear matter power spectrum
Fisher Matrix

- Examine change in observables as parameters vary
- Compare this to noise of experiment
  \[ \Rightarrow \text{forecasted } 1\sigma \text{ constraints on the parameters} \]
3-4 years time

Figure: $\mu$ vs $\eta$ from CMB+WL, then CMB+WL+counts
10 years time

Figure: $\mu$ vs $\eta$ from CMB+WL, then CMB+WL+counts
Combining experiments allows us to constrain *model independent* Modified Gravity.

Adding cluster counts into the mix is a good idea...

...but we could do with understanding clusters better.

Next: Time and scale dependent $\mu$ and $\eta$.