Constraining gravity on the largest scales with CMB lensing and galaxy velocities

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AP, S. Alam, and S. Ho, arXiv:1412.4454 (MNRAS)
AP, S. Alam, S. He, and S. Ho - *soon on arXiv!*

LSS of the Universe, Garching
Friday, July 24, 2015

E_G = Gravity Probe

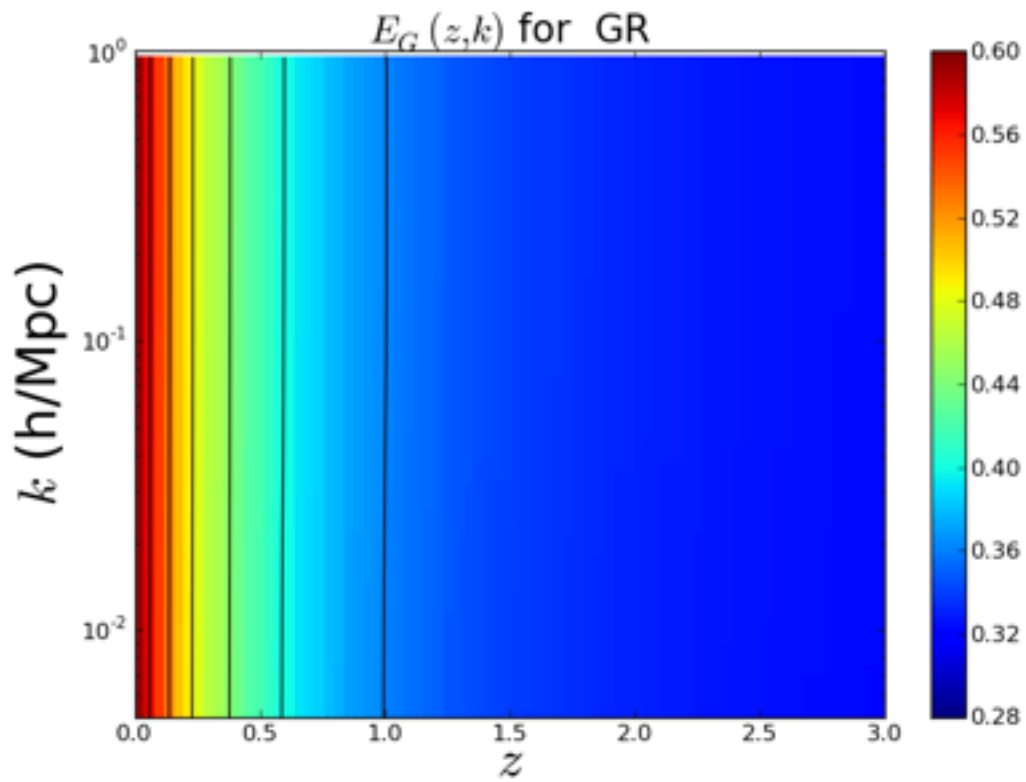
- E_G - Combines lensing, clustering, and RSD; *bias-independent*
- Probes expansion & growth rate; *breaks dark energy - gravity degeneracy!*
- Discriminates GR vs. modified gravity
- Previously measured using galaxy-galaxy lensing
- CMB lensing: no intrinsic alignments; precise, well-defined source plane

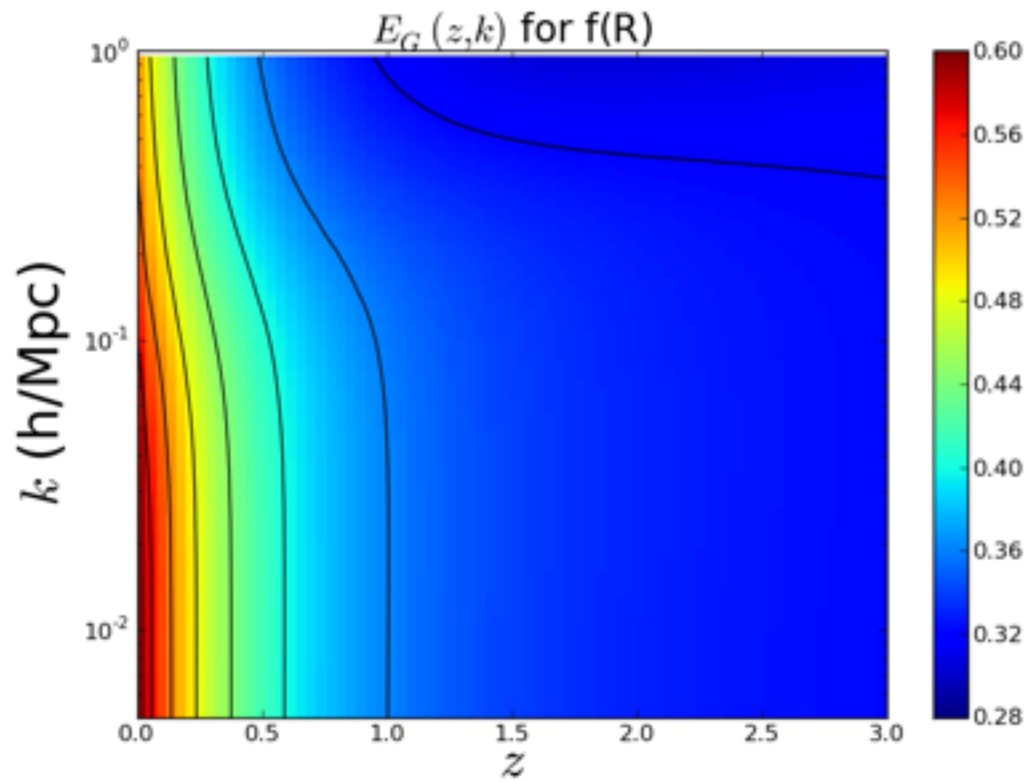
$$E_G(\ell) = \Gamma \frac{C_\ell^{\kappa g}}{\beta C_\ell^{gg}}$$

$$E_G[\mathrm{GR}] = \frac{\Omega_{m,0}}{f(z)}$$

Peebles & Ratra 2003, Dvali et al. 2000, Zhang et al. 2007, Reyes et al. 2010, Pullen et al. 2015

E_G - GR vs f(R)



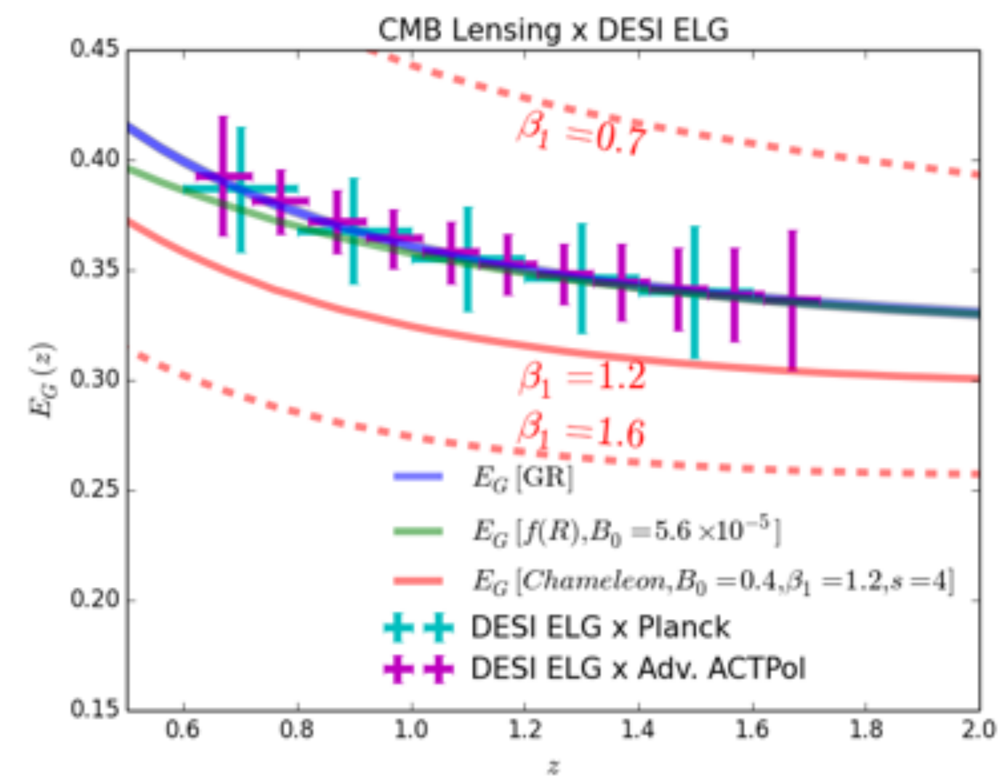


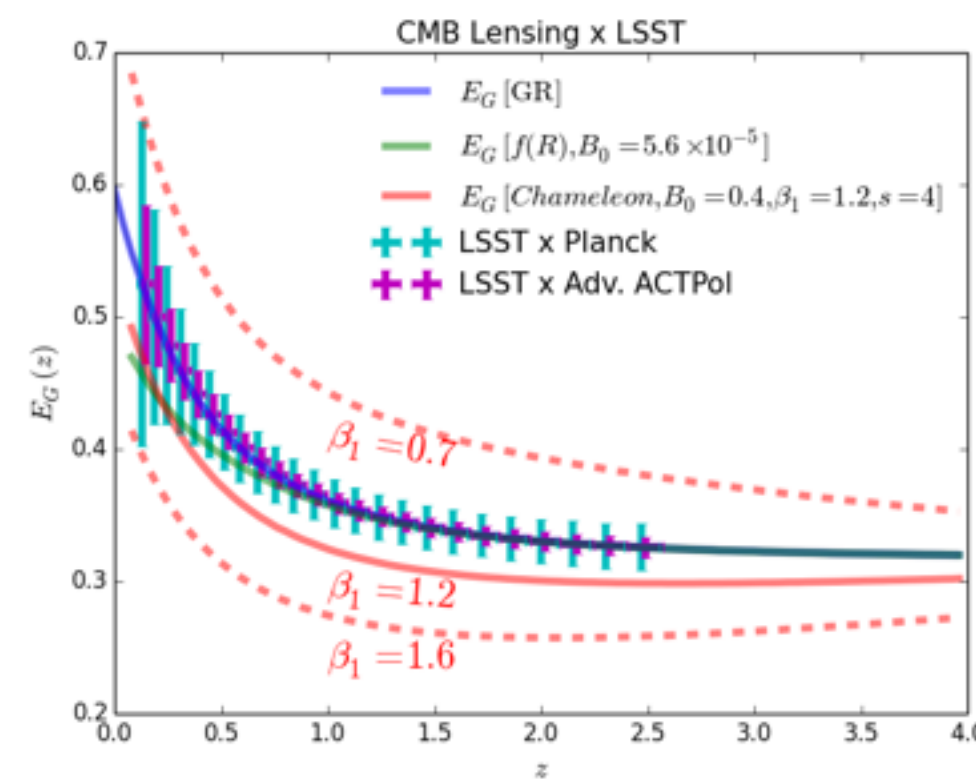
E_G for modified gravity tends to be scale-dependent.

Pullen et al. 2015, Carroll et al. 2004, Song et al. 2007

Forecasts

- Spectro surveys - E_G errors of 2% (Planck) or 1% (Adv. ACTPol)
- Photo surveys - E_G errors of 1% (Planck) or less (Adv. ACTPol); discriminate current *f(R)* by 15σ!
- Assumes photo RSD errors of ~8% over $\Delta z \sim 0.1$.
- **Challenges:** photo-RSD, foregrounds, quasi-linear scales





Pullen et al. 2015, Ross et al. 2011, Asorey et al. 2014

E_G Measurement

Measure E_G using current data.

- ✦ Planck CMB lensing map
- ✦ BOSS CMASS spectroscopic galaxy sample ($0.43 < z < 0.7$)

Measure RSD from anisotropic clustering.

Test for various observational systematic effects.

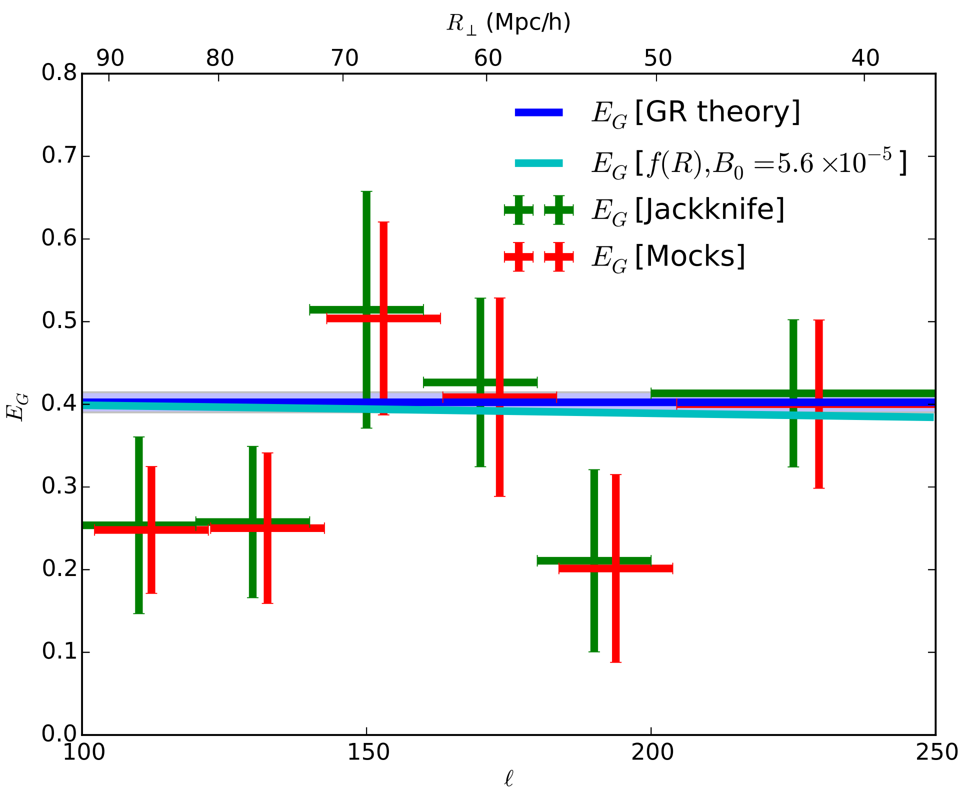
Correct for redshift window functions and nonlinear bias.

Compute errors using jackknife resampling with 37 regions.

Planck Collaboration, SDSS Collaboration, Alam et al. 2015, Reyes et al. 2010

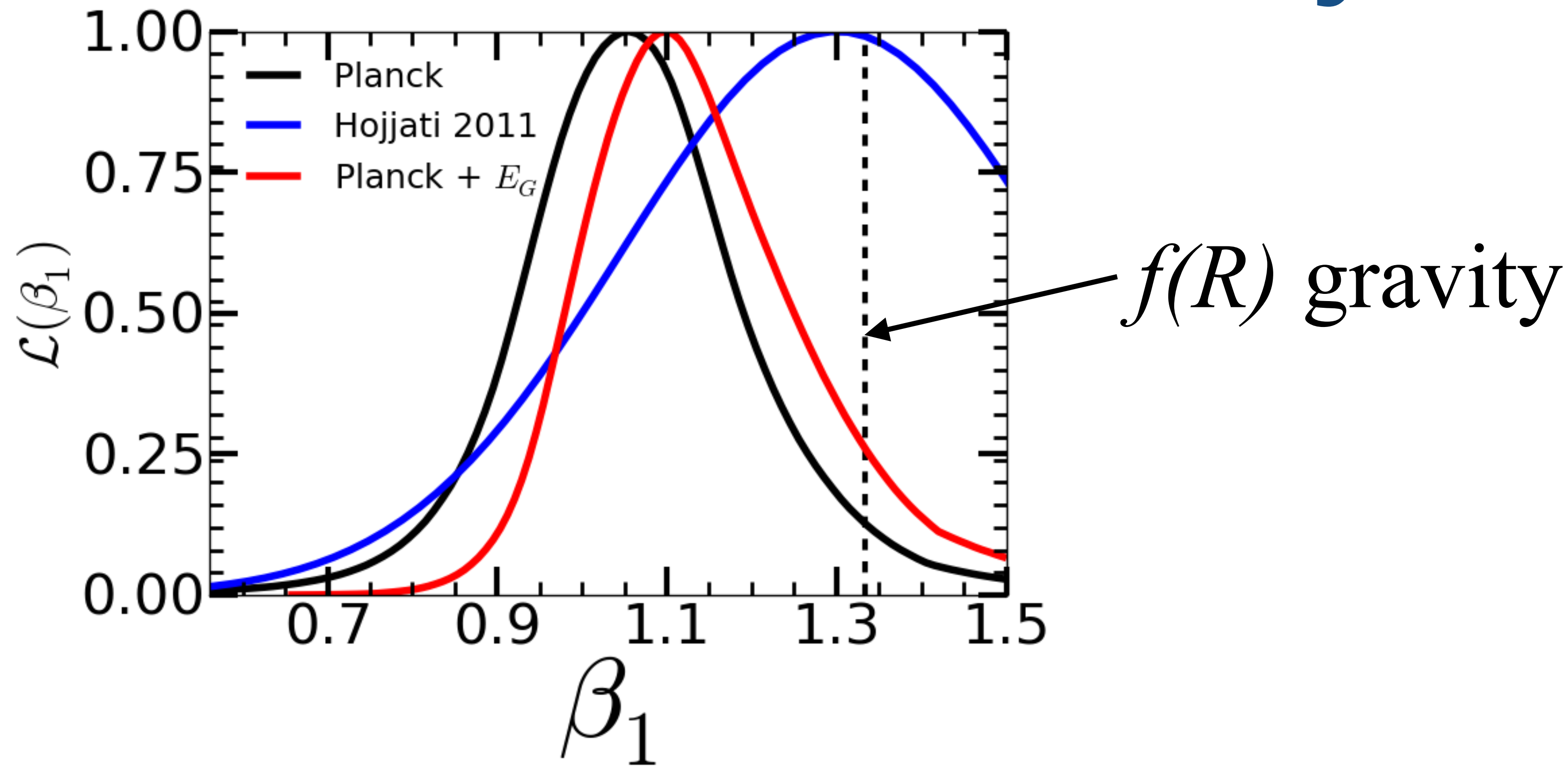
Results

- We estimate E_G in 6 *l*-bins.
- Results using jackknives and mocks agree.
- 4.5σ detection due to *l*-bin correlations
- Consistent with GR (E_G = 0.402) within 2σ
- 3.6% systematic error due to galaxy sample contamination



$$E_G(z = 0.57) = 0.288 \pm 0.064\,(\mathrm{stat})$$

Chameleon Gravity



- β_1 = chameleon gravity coupling (remember forecast plots)
- Compute β_1 likelihood from MCMC analysis
- Planck constraints (C_ℓ^{TT} only) tighter than Hojjati 2011 (WMAP+LSS)
- E_G slightly shifts Planck measurement; consistent with *f(R)* within 2σ

Bertschinger & Zukin 2008, Hojjati et al. 2011

Summary

- CMB lensing measures E_G at larger scales to aid in confirming or ruling out gravity models.
- Upcoming large-area, high-density galaxy surveys could measure E_G to %-level accuracy, potentially ruling out many gravity models.
- Our current E_G measurement is consistent with GR, but greater precision is needed.
- Next steps: Consider DGP constraints, test photo-RSD measurement, design survey- and foreground-specific strategies, synergy with other probes, etc.