A FIGURE OF MERIT ANALYSIS OF CURRENT CONSTRAINTS ON TESTING GENERAL RELATIVITY USING THE LATEST COSMOLOGICAL DATA SETS.

Jason Dossett
OUTLINE

- Motivations
- Ways to Test Gravity
- Growth Equations
- Modified Growth Equations
- Figures of Merit
- Results
**Motivations**

- Cosmic acceleration

- Proposals of some extensions to general relativity that would manifest themselves at cosmological scales.
WAYS TO TEST GENERAL RELATIVITY

- Looking for inconsistencies in between expansion history and growth of structure
  - The growth rate of large scale structure is coupled to the expansion history via Einstein’s equations. These two effects must be consistent.
- “Trigger parameters”, $\gamma$. The logarithmic growth rate $f = d\ln \delta / d\ln a$ can be approximated by:
  $$f = \Omega_m^\gamma$$
  For different gravity models $\gamma$ has a unique value.
- Gravitational Slip and Modifications to the Poisson Eqn. (We will focus on this)
Growth Equations

Flat Perturbed FLRW Metric.

\[ ds^2 = -a(\tau)^2[1 + 2\psi(x, t)]d\tau^2 + a(\tau)^2[1 - 2\phi(x, t)]dx^2 \]

\[ k^2 \phi = -4\pi Ga^2 \sum \rho_i \Delta_i \]

\[ \psi - \phi = -12\pi Ga^2 \sum_i \rho_i (1 + w_i) \frac{\sigma_i}{k^2} \]

Poisson Eqn.

Anisotropy Eqn.
MODIFIED GROWTH EQUATIONS

Modified Growth Eqns.

Parameterization 1 [Bean]:

\[ k^2\phi = -4\pi G a^2 \sum_i \rho_i \Delta_i Q \]

\[ k^2(\psi - R\phi) = -12\pi G a^2 \sum_i \rho_i (1 + w_i) \sigma_i Q, \]

Parameterization 2 [Zhao]:

\[ k^2\psi = -4\pi G a^2 \sum_i \rho_i \Delta_i \mu(k, a). \]

\[ \frac{\phi}{\psi} = \eta(k, a), \quad \Sigma(k, a) = \frac{\mu(1 + \eta)}{2} \]

Parameters Evolve as:

**Functional form**

\[ Q(a) = (Q_0 - 1) a^s + 1, \]

\[ R(a) = (R_0 - 1) a^s + 1. \]

**Binned**

<table>
<thead>
<tr>
<th>Redshift bins</th>
<th>Scale bins</th>
<th>0.0 &lt; z ≤ 1, 1.5</th>
<th>1.5 &lt; z ≤ 2, 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0 &lt; k ≤ k_x</td>
<td>( \mu_1, \Sigma_1 )</td>
<td>( \mu_2, \Sigma_2 )</td>
<td></td>
</tr>
<tr>
<td>k_x &lt; k &lt; \infty</td>
<td>( \mu_3, \Sigma_3 )</td>
<td>( \mu_4, \Sigma_4 )</td>
<td></td>
</tr>
</tbody>
</table>
FIGURES OF MERIT

- Used previously on the dark energy equations of state parameters.
- Quantifies how well constrained a set of parameters are by a given set of data.

\[ \text{FoM} = (\text{det } C)^{-1/2} \]

\[ \text{FoM} \propto \frac{1}{A_{95}} \]
RESULTS

- Data sets used:
  - WMAP 7 year temperature and polarization spectra
  - Union 2 Supernovae Data
  - BAO from Two-Degree Field and SDSS-DR7
  - Matter Power Spectrum (MPK) from SDSS-DR7
  - ISW-galaxy cross-correlations (SDSS-LRG, 2MASS, NVSS)
  - Refined HST COSMOS 3D weak lensing tomography.

- Used a modified version of the publicly available code CosmoMC, a MCMC sampler.
RESULTS CONT’D

Parameterization 1

<table>
<thead>
<tr>
<th>Data set</th>
<th>FoM</th>
<th>$Q_0$</th>
<th>$R_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMB, MPK</td>
<td>5.53</td>
<td>0.69, 2.79</td>
<td>−0.34, 2.04</td>
</tr>
<tr>
<td>CMB, ISW</td>
<td>6.15</td>
<td>0.70, 2.76</td>
<td>−0.33, 1.85</td>
</tr>
<tr>
<td>CMB, WL</td>
<td>6.44</td>
<td>0.57, 2.54</td>
<td>−0.30, 2.24</td>
</tr>
<tr>
<td>CMB, ISW, WL</td>
<td>8.46</td>
<td>0.67, 2.53</td>
<td>−0.33, 1.84</td>
</tr>
<tr>
<td>CMB, MPK, ISW</td>
<td>7.53</td>
<td>0.80, 2.73</td>
<td>−0.35, 1.62</td>
</tr>
<tr>
<td>CMB, MPK, WL</td>
<td>5.08</td>
<td>0.73, 2.80</td>
<td>−0.34, 2.13</td>
</tr>
<tr>
<td>CMB, MPK, ISW, WL</td>
<td>7.09</td>
<td>0.83, 2.82</td>
<td>−0.37, 1.60</td>
</tr>
</tbody>
</table>
**RESULTS cont’d**

Parameterization 2

| Constraints for $\{\mu_i, \Sigma_i\}$ binned parametrization $0 < z \leq 1, 1 < z \leq 2$ |
|---|---|---|
| $k_\Sigma = 0.01$ | $\mu_1$ | 0.559, 1.567 |
| $\Sigma_1$ | 0.940, 1.138 |
| $\eta_1$ (derived) | 0.281, 2.815 |
| FoM$^1$ | 75.92 | 101.7 | 101.2 |
| Data sets | ISW | ISW, WL |
| $\mu_2$ | 0.614, 1.456 | 0.563, 1.289 |
| $\Sigma_2$ | 0.955, 1.072 | 0.959, 1.075 |
| $\eta_2$ (derived) | 0.376, 2.332 | 0.546, 2.649 |
| FoM$^2$ | 148.9 | 176.3 | 184.2 |
| $\mu_3$ | 0.439, 2.073 | 0.509, 1.588 |
| $\Sigma_3$ | 0.851, 1.321 | 0.708, 1.268 |
| $\eta_3$ (derived) | 0.069, 4.035 | 0.129, 2.889 |
| FoM$^3$ | 18.95 | 22.94 | 25.61 |
| $\mu_4$ | 0.553, 1.754 | 0.588, 1.404 |
| $\Sigma_4$ | 0.887, 1.148 | 0.858, 1.134 |
| $\eta_4$ (derived) | 0.152, 2.708 | 0.376, 2.424 |
| FoM$^4$ | 43.94 | 62.03 | 63.93 |

*Note: The table shows the constraints and FoM for different data sets and parameterizations.*
CONCLUSIONS

- Tensions between the preferred MG parameter values of different datasets cause the constraints to not always get stronger when adding an additional data set.
- The tensions are more pronounced using parameterization 1 possibly due to the functional form imposed.
- The parameter values for general relativity are within 95% confidence level contours for all data sets.
ACKNOWLEDGMENTS

- DOE Office of Science Graduate Fellowship.
- DOE Grant DE-FG02-10ER41310.
- Part of the calculations for this work were performed on Cosmology Computer Cluster funded by Hoblitzelle Foundation.
BIBLIOGRAPHY

ISiTGR

- Software for testing general relativity
  - Available at:
    - http://www.utdallas.edu/~jdossett/isitgr