Constraining non-Gaussianity: current LSS and ISW data and outlook for the DES

Tommaso Giannantonio
LMU Munich & Excellence Cluster

Saturday, 21 April 2012
Outline

• Large-scale structure and **Primordial non-Gaussianity** (PNG)

• Scale-dependent, **non-local** bias

• LSS & correlation with the CMB: the **integrated Sachs-Wolfe (ISW) effect**

• Updates on combined LSS+ISW data: the **Luminous Red Galaxies from BOSS**

• Combined measurement of PNG from LSS+ISW data

• PNG with **DES** and Euclid

• Conclusions

**Collaborators:** R. Crittenden, B. Nichol, W. Percival, A. Ross, C. Porciani, J. Weller, M. Kilbinger
Theory
Constraining the early universe

- Many models available
  - single field
  - many fields
  - slow or fast decay
  - various possible kinetic terms
  - cyclic/ekpyrotic models...

- Simplest models predict:
  1. near-flatness ✓
  2. nearly scale-invariant power spectrum ✓
  3. curvature perturbations only ~ [Valiviita & TG 09]
  4. nearly Gaussian distribution ?

- Other models: many configurations: kernel $W$. 
  $\Phi$: primordial potential; $\varphi$ Gaussian. Amount of NG: $f_{NL}$

$$\Phi(x, z_*) = \varphi(x, z_*) + (f_{NL} \ast W \ast \varphi \ast \varphi)(x, z_*)$$

Saturday, 21 April 2012
Non-Gaussianity and the LSS

- Dark matter perturbations $\delta_m > d.m.$
  haloes $\delta_h >$ galaxies $\delta_g$
  - halo mass function:
    halo bias, $\delta_h = b_h \delta_m$
  - halo occupation distribution:
    galaxy bias, $\delta_g = b_g \delta_m$

- PNG: strongly scale-dependent $b$

- Spectra $\langle$gal-gal$\rangle \sim b^2$ and $\langle$gal-CMB$\rangle \sim b$: constraints on PNG! [Slosar et al 08, ...]

- Also small effect on $P_{\text{matter}}$ from bispectrum [Taruya et al 08]
Scale-dependent, non-local bias

(Dalal et al 07, Slosar et al 08, Verde et al 09, TG & Porciani 09...)

- Split $\varphi = \varphi_{\text{short}} + \varphi_{\text{long}}$ + PNG definition: $\Phi = \varphi + f_{\text{NL}} \varphi^2$
  - $\Phi_l$, $\Phi_s$, $\Phi_{\text{mixed}}$
  - coupling from double product in $\varphi^2$

- Halo formation:
  - collapse when: $\delta_s (1 + 2 f_{\text{NL}} \varphi_l) > \delta_c$
  - with r.m.s.: $\sigma_{\text{NG}} = \sigma (1 + 2 f_{\text{NL}} \varphi_l)$

- Halo density perturbation: $\delta^L_h = \frac{n(M) - \bar{n}}{\bar{n}}$, $n \propto f ((\delta_c - \delta_l) / \sigma_{\text{NG}})$

- Taylor-expanded in both variables!

\[
\delta^L_h(q) = \sum_{j,m=0}^{\infty} \frac{b^L_{jm}}{j! m!} \delta^j_l(q) \varphi^m_l(q)
\]

1st order:

$\delta^L_h = b^{-10}_l \delta_l + b^{-01}_l \varphi_l$

- $\delta_l$, $\varphi_l$ related by Poisson eq, but non-local

With PNG, extra bias from the potential!
Power spectra and Effective bias

- $b_{ij}$: from NG halo mass function (e.g. LoVerde et al.)
  - 1st order: $\delta_h = b_{L10} \delta_l + b_{L01} \varphi_l$
  - $b_{L01} \propto b_{L10} f_{NL}$
- Fourier space:
  - $\varphi(k) \rightarrow \delta(k) / \alpha(k)$
- Power spectra: $P_{hm}(k) = \langle \delta_h(k) \delta(k) \rangle$
- Effective $b = P_{hm} / P_{mm}$

Physical meaning: large-scale $\delta_h$ traces $\varphi$, not $\delta$!
Current data: LSS & ISW
LSS tomography & Correlation with the CMB: The ISW effect  
[Sachs & Wolfe 67]

- Integrated Sachs-Wolfe: Secondary effect on the CMB:
  \[ \frac{\delta T}{T} = 2 \int_\gamma \dot{\Phi}[r(t), t] dt \]

- No effect in matter domination as
  \[ \delta_m \propto a \Rightarrow \dot{\Phi} = 0 \]

- **Late** ISW if dark energy dominates

- Probe of Dark Energy

**BUT:** signal is small! \( \sim 10\% \) of primary CMB \( <TT> \) spectrum
The cross-correlation method [Crittenden & Turok 95]

• Total observed CMB: sum of primary + secondary

Noise! $z = 1100$

Signal! $z < 3$

• Primary: uncorrelated with large-scale structure, $z$ too high!

• ISW: highly correlated through the gravitational potential $\Phi$

**ISW signal**: Detectable cross-correlating $\langle \text{CMB} \times \text{LSS} \rangle$

• linear, large-scale effect: need wide and deep density maps

• non-zero signal ONLY with dark energy (or K)

Observations match LCDM, low S/N ~ 2: combine! [TG et al 08, Ho et al, 08]
Combined LSS+ISW analysis, updated [TG 08, TG 12 et al, submitted]

- **data maps**, pixellated resolution = 0.9 deg
  - **density**: 6 galaxy catalogues: 2MASS, SDSS (main gal DR8, LRG DR7-8, QSO DR6), NVSS, HEAO
  - **temperature**: now WMAP7 (ILC, Q, V, W)

- **masks**
  - survey geometry (DR8: 24% increase)
  - foregrounds:
    - **extinction**, galactic plane cut + bright sources (NVSS, HEAO)

Saturday, 21 April 2012
Measured correlations

- Covariance: Monte Carlos
- highly correlated
- mostly agreeing with older data
- **Total S/N = 4.4 \sigma (\pm 0.3)** (single amplitude fitting LCDM template)

Independent evidence for Dark Energy at >4\sigma

[TG et al. 12a, MNRAS submitted]
Systematics

- **WMAP3 → 7**: little change, NVSS closer to LCDM
- **CMB-Frequency** independent: no evidence for contamination, SZ, etc.

[TG et al. 12a, MNRAS submitted]
New data: consistent with old

- **Main galaxies** SDSS DR8:
  - 24% extra sky area, in S
  - $0.1 < z < 0.9$; $\sigma(z) < 0.5 \, z$
  - $18 < r < 21$
  - Now ~40 Million gals!
  - Reddening mask $A_r > 0.18$
  - no difference in CCF

- **LRG** [Thomas et al. 10] DR7: more excess
  - 10% area increase
  - completeness cut: $i < 19.8$
  - Star-gal separation: $\delta_{sg} > 0.2$
  - 1.4 Million LRGs, some difference in large-scale CCF (mostly due to change in WMAP and mask)

- Even better **LRG** data [Ross et al. 11] DR8...
LRG comparison
[TG et al. 12b, in prep.]

- Thomas et al. 10 MegaZ vs Ross et al. 11 SDSS DR8 CMASS

- Similar redshift range, Ross et al. South coverage (DR8)

- Ross et al.: correction for stellar systematics!
  - Fewer galaxies observed where lots of stars!
  - Large proportion (15%) with BOSS spectra

- ACF: Thomas et al. show more excess power on large scales --> stars?

- CCF: Ross et al. lower, in agreement with LCDM! :-)

- If no star correction, same area: higher CCF

---

Saturday, 21 April 2012
LRG systematics
[TG et al. 12b, in prep.]

- N/S divide
  - Ross et al. in N: higher CCF
  - possibly statistical fluke
  - (S alone too noisy)

- Frequency independence:
  - Very stable CCF, with all WMAP bands!
  - Evidence for superior quality of Ross et al. data

- Stellar contamination negligible

Total ISW S/N down to 4.1; even better agreement with LCDM
Full bias analysis of LSS + ISW data & $f_{\text{NL}}$

- Measure (local) $f_{\text{NL}}$ via $b$
- Not only $\langle T_g \rangle \propto b$, but also ALL $\langle g g \rangle \propto b^2$ correlations
- Data: all 27 2-pt functions!
- For each catalogue we model $b_i(k,z) = b_{i0}(z) + \Delta b (k,z)$
- Several models for Gaussian $b_0$:
  - constant $b_i(z) = b_{0i}$
  - evolving $b_i(z) = 1 + (b_{0i} - 1) / D(z)$

Effect of $f_{\text{NL}}$:

- large-scale excess power $\langle T_{gi} \rangle$ $\langle g_i g_i \rangle$ $\langle g_i g_j \rangle$
Monte Carlo likelihood analysis

- Full Covariance Matrix (351x351) from 10,000 Monte Carlo mocks
- Theory models: with modified Camb code
- Monte Carlo likelihood analysis, marginalising over (nestled sampling)
  - cosmology (7 params)
  - 6 nuisance parameters $b_{0i}$
  - 3 nuisance parameters $\kappa_i$: stellar contamination

Results: (mostly from QSO ACF: high b)

preliminary, $16 < f_{NL} < 60$ @ 95% c.l.
Systematics!

[Preliminary]

- **Stellar contamination** fraction $\kappa$ (in SDSS samples)

$$\tilde{\xi}^{gg}(\theta) = (1 - \kappa)^2 \xi^{gg}(\theta) + \kappa^2 \xi^{\text{star}}(\theta)$$

- Severe degeneracy: in plateau
  - forcing $\kappa = 0 \%$, $60 < f_{\text{NL}} < 98$
  - forcing $\kappa = 2 \%$, $-6 < f_{\text{NL}} < 37$

- Cleaner, high-bias data needed! e.g. à la Ross et al 11

- Uncertainties in $dN/dz$
  - 15 extra nuisance parameters $b_{ij}$:

$$\xi^{gigj}_{\text{obs}}(\theta) = b_{ij} \xi^{gigj}(\theta)$$

- Weaker bounds: $-2 < f_{\text{NL}} < 186$
Forecasts
Primordial NG with DES and Euclid

[ TG et al. 11 ]

• Combining: lensing + galaxy clustering

• Following Hu & Jain 04

• Including primordial non-Gaussianity

• **DES:**
  • Starting soon!

• **Euclid:** future ESA mission
  • In L2 orbit, launch ~2019
  • Imaging (vis+IR) + spectra
  • Measure $w_0$ to few %!
Specifications

- **Euclid photometric**: Shear & gal 2D spectrum
  - 15,000-20,000 sq. deg
  - shapes of 2 bn galaxies to $z = 2$
  - median $z = 1$, $\sigma_z < 0.05 (1+z)$
  - density 40 / arcmin$^2$

- **Euclid spectroscopic** (slitless): also 3D spectrum + RSD + Alcock-Paczinsky
  - $H_\alpha$ range 1000 - 2000 nm: 0.5 < $z$ < 2
  - 80 M galaxies
  - median $z = 1.1$, $\sigma_z < 0.001 (1+z)$
  - density ~ 1 / arcmin$^2$

- **DES**: photometric: Shear & gal 2D spectrum
  - 5,000 sq. deg
  - shapes of 300 M galaxies to $z=2$
  - median $z = 0.8$, $\sigma_z < 0.1 (1+z)$
  - density 12 / arcmin$^2$
Results

- **Combined** lensing + 2D gal spectrum Fisher forecast:

\[ F_{\alpha \beta} = f_{\text{sky}} \sum_{l=l_{\text{min}}}^{l_{\text{max}}} \frac{(2l+1)}{2} \text{Tr} \left[ D^{-1}_{\alpha \lambda} \left( \tilde{C}^{-1}_{\lambda} \right) D^{-1}_{\beta \nu} \left( \tilde{C}^{-1}_{\nu} \right) \right] \]

[Hu & Jain 04]

- includes \(<\text{lens-gal}>\) spectrum

- **Red**: with Planck TT priors

- **Euclid** accuracy on local \(f_{\text{NL}}\): ±3

- For **DES**: accuracy on \(f_{\text{NL}}\) ~ ±8

- **Running**: \(n_{f_{\text{NL}}} \approx ±0.12\) if \(f_{\text{NL}} = 30\)

- lens+gal matrix sum: worse

---

Critical assumption for \(f_{\text{NL}}\): \(b_{\text{fiducial}}(z) \sim (1+z)^{1/2}\), similar to Orsi et al. 09.
Conclusions & Future Work

- LSS+ISW updated: consistent with older data, still S/N > 4
- Now better systematics control (stars, rotations, ...)
- Likelihood analysis: now better use of ACF (full covariance) and bias (marginalization)
- Non-Gaussianity: $16 < f_{NL} < 60$ @ 95% c.l., but stars are a big issue

- **BOSS**: better systematics control
  - DR8 QSO
  - LSS+ISW analysis with 3D clustering (DR9, DR10)

- **DES**: $f_{NL} \pm 8$
  - gal-gal, CMB-gal, CMB-shear

- **Euclid**: $f_{NL} \pm 3$
Simulation 1 analysis

Mask and Map
(Healpix N\textsubscript{side} = 64)

Joint analysis, VERY PRELIMINARY, margin. Error on local f\textsubscript{NL} ± ~20 @ 95% c.l.
Differences from local approach
Bivariate (or non-local) b vs. local b [Taruya et al. 08, Sefusatti 09]

- At linear order:
  - we recover $\Delta b \propto b^{10-1}$
- No strong dependence on $R$ smoothing at leading order
- in local approach is found $\Delta b \propto b^{20} \sigma^2(R)$
- This is $\propto R$ smoothing
  - equivalent only in particular case: Press-Schechter, high peaks ($\delta_c b_{10}^{L2} \sim b_{10}^{L} b_{20}^{L} \sim \delta_c^3$), smoothing $R =$ halo Lagrangian $R$
  - but then $\sigma \sim 1$, so pert. theory problematic
- Asymptotic $k$-dependence identical
  - so no problem if $b$’s are free fitting parameters, or renormalised a la McDonalds 08
- but non-local (bivariate) method needed for predictive bias theory

Physical meaning: large-scale $\delta_h$ trace $\varphi$, not $\delta$!