LSS constraints with controlled theoretical uncertainties

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Moriond Cosmology, March 2016
"The future of precision cosmology is in LSS"

\[ N_{\text{CMB}} \approx l_{\text{max}}^2 \sim 10^7 \]

\[ N_{\text{LSS}} \approx \left( \frac{k_{\text{max}}}{k_{\text{min}}} \right)^3 \]

Galaxies
Ly\(\alpha\)
21cm
...
How much information can we get from a LSS survey? (including “theoretical errors”)

— Can we reach some (theoretically interesting) thresholds?

\[ \sigma(M_\nu) \sim 60 \text{ meV} , \quad \sigma(f_{\text{NL}}) \sim 1 \]

(many talks about neutrinos this afternoon)
(BAO peak position, weak lensing, DE equation of state, anomalies…)

— Data analysis: constraints on cosmological parameters
Fisher matrix

— Uncertainties taken into account

  statistical errors

  nuisance parameters such as bias parameters

— Additional systematic errors due to the theoretical uncertainties

  Usually neglected!

  they are largish ~1%, and can change the constraints significantly

  present in PT and simulations

  even with the full nonlinear DM field, usual bias models are perturbative
Theoretical errors in PT

— Increase $k_{\text{max}}$ as much as possible

— Gravitational nonlinearities become large

$$P_{\text{NL}}(k) = P(k) + P^{1-\text{loop}}_{\text{SPT}}(k) + P_{\text{ct}}(k) + \cdots$$

$$P_{\text{ct}}(k) = -2R_{p}^{2}k^{2}P(k)$$
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— Higher order terms are estimate of the error

\[ P(k) \propto k^n \]

\[ P^{1-\text{loop}}(k)/P(k) \propto (k/k_{\text{NL}})^{(3+n)l} \]

\[ k_{\text{NL}} \sim 0.3 \, h\text{Mpc}^{-1} \quad n \sim -1.5 \]
Theoretical errors in PT

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Fisher matrix with theoretical errors

marginalize over all possible models with given $E(k)$ and $\Delta k$

$$L_e = \frac{1}{\sqrt{(2\pi)^N|C_d|}} \exp \left[ -\frac{1}{2} (d - t_f - e) C_d^{-1} (d - t_f - e) \right]$$

$$\times \frac{1}{\sqrt{(2\pi)^N|C_e|}} \exp \left[ -\frac{1}{2} e C_e^{-1} e \right]$$

$$L = \frac{1}{\sqrt{(2\pi)^N|C|}} \exp \left[ -\frac{1}{2} (d - t) C^{-1} (d - t) \right]$$

$$C = C_d + C_e \quad (C_e)_{ij} = E_i \rho_{ij} E_j$$

$$\rho_{ij} = \begin{cases} 
\exp \left[ -\frac{(k_i - k_j)^2}{2\Delta k^2} \right] & P, \\
\prod_{\alpha=1}^{3} \exp \left[ -\frac{(k_{i,\alpha} - k_{j,\alpha})^2}{2\Delta k^2} \right] & B.
\end{cases}$$

A different proposal (without coherence length)
Audern, Lesgourgues, Bird, Haehnelt, Viel, JCAP 1301, 026 (2013)
Results

— The model is one-loop power spectrum + one-loop bispectrum

\[ P(k) + P^{1-\text{loop}}(k) \]

\[ B^{\text{tree}}(k_1, k_2, k_3) + B^{1-\text{loop}}(k_1, k_2, k_3) \]

two joint analyses

— Bias model \( \delta_g = b_1 \delta + \frac{b_2}{2} \delta^2 + b_{G_2} G_2 + \cdots \)

— The set of parameters in the model

\[ p = \{ f_{NL}, M_\nu, A, R_p, R_b, b_1, b_2, b_{G_2}, b_{\Gamma_3} \} \]

— \( f_{\text{sky}}=0.5, \; 0<z<5, \; \)constant nuisance parameters (very optimistic)

— Our choice of coherence length \( \Delta k = 0.05 \; h \text{Mpc}^{-1} \)
Results — neutrinos

— Without marginalization over nuisance parameters

\[ \sigma(M_\nu) \text{[meV]} \]

- \( n_0 = 10^{-2} \), \( \alpha = 0 \)

- \( 5(Gpc/h)^3 \) to \( 100(Gpc/h)^3 \)

- \( k_{\text{max}} \) [h Mpc\(^{-1}\)]

\[ n_0 = 10^{-2}, \alpha = 0, z_{\text{max}} = 2 \]
Results — neutrinos

— Marginalizing over all nuisance parameters

with theoretical error

without theoretical error

<table>
<thead>
<tr>
<th>Theory</th>
<th>with theoretical error</th>
<th>without theoretical error</th>
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<tbody>
<tr>
<td>$P_{\text{lin}}$</td>
<td>$P_{\text{lin}} + B_{\text{lin}}$</td>
<td>$P_{1L}$</td>
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<tr>
<td>$n_0 = 10^{-2}$, $\alpha = 0$</td>
<td>$n_0 = 10^{-2}$, $\alpha = 0$</td>
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Results — neutrinos

— 1-loop enough for S3
— 2-loops enough for S4
— Results strongly depend on priors for the amplitude

\[ \sigma(M_\nu) \sim 30 \text{ meV} \]
\[ \text{with} \]
\[ \sigma_A = 0.5\% \]
Results — equilateral NG

\[
\frac{B_{\text{eq.}}(k)}{P^2(k)} \sim f_{\text{NL}} \frac{9H_0^2\Omega_m}{k^2T(k)D_+(0)} \quad \text{vs.} \quad \frac{B_{\text{grav.}}^{l-\text{loop}}(k)}{P^2(k)} \sim (k/k_{\text{NL}})^{(3+n)l}
\]

— Hard to improve the CMB limits! (important for future surveys, like SPHEREx)
Results — local NG

— Local NG have characteristic shape protected by the Equivalence Principle
Conclusions

— Theoretical errors present in PT and simulations, $O(1\%)$
— They should be included in the likelihood as any other uncertainty
— Consistent way to include relevant systematics
— Consistent way to avoid biased results in data analysis
— A more detailed study needed
  more realistic forecasts
  the real size of errors in the bispectrum
  different shapes of primordial NG
  the correct coherence length
  how well simulations do?