Second Order Non-Gaussianity - SONG

in collaboration with GW Pettinari, R Crittenden, D Wands and K Koyama

Institute of Cosmology and Gravitation

Christian Fidler

Today

What is SONG ?

SONG is CMB code like CMBFAST, Camb, CLASS, but at second order in cosmological perturbations.

Seljak & Zaldarriaga, 1996; Lewis, Challinor & Lasenby, 2000; Blas, Lesgourgues & Tram, 2011

It is used to compute effects that are absent at first order:

- Mode coupling
  - ➔ Non-Gaussianity
- Scalar-Vector-Tensor mixing
  - ➔ B-mode polarisation
- Spectral distortions generated by second order collision term. Detectable by PIXIE, PRISM?
- Magnetic fields generated during recombination

How does SONG work?

SONG is

- based on CLASS
  - ➔ Written in C, inheriting the structure of CLASS
    Evolver is optimised for stiff problems
    MCMC and Phyton frontend
- fast and efficient
  - ➔ OpenMP parallelisation
    Uses novel numerical methods for integration of Bessel functions and the bispectrum integration
    Takes 8 hours to compute the second order Bispectrum on a single core
- easy to use
  - ➔ Modular structure
    More than 10.000 lines of comments

What does SONG do?

1) We solve the full differential system including photons, neutrinos, dark matter and baryons from the deep radiation era, till last scattering
2) We build the line-of-sight sources for photon perturbations using the result of the differential system
3) The line-of-sight integration is used to evolve the photon perturbations until today
4) We compute the bispectrum on a three dimensional grid and interpolate using an interpolation based on a tetrahedral base
5) We compare the shape against the templates for local, equilateral and orthogonal shapes and compute the f_{NL} contamination and the signal to noise

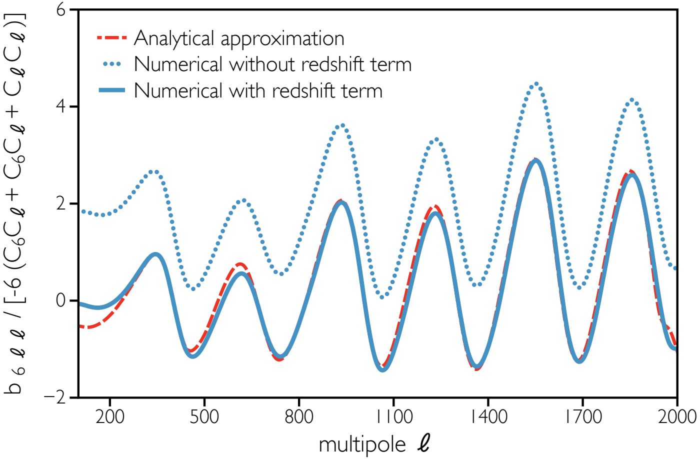
Is SONG numerically stable?

The second order computations are very complicated needing a lengthy code. To reduce the risk of mistakes we performed many test with SONG:

- We match many analytical limits for the sub horizon transfer functions
  Goroff, Grinstein, et al., 1986; Makino, Sasaki & Suto, 1992; Jain & Bertschinger, 1994; Bernardeau et al., 2002; Bartolo, Matarrese & Riotto 2006; Matarrese, Mollerach & Bruni 1998; Boubeker et al. 2009
- Match to the squeezed limit analytic approximation for the bispectrum (Assumes CDM domination and instantaneous recombination)
  Creminelli et al. 2011; Bartolo et al. 2011; Lewis 2012
- Performed detailed convergence and consistence checks
- Code is double checked by a second independent code based on Green functions
  Beneke, Fidler & Klingmuller 2011

Is SONG numerically stable?

Analytic squeezed limit



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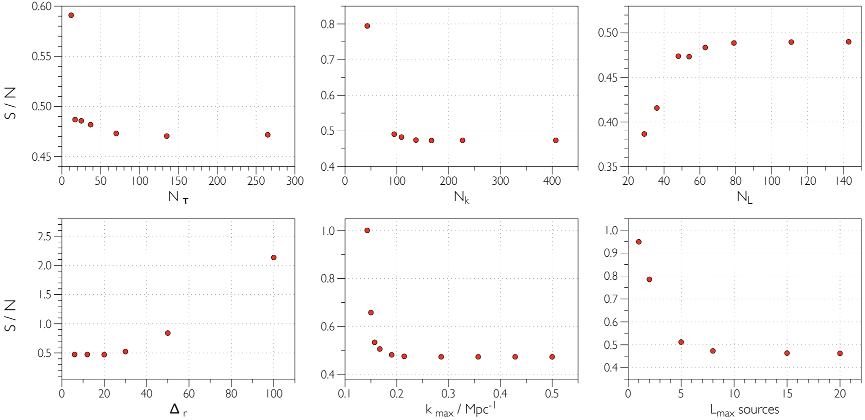
Convergence tests



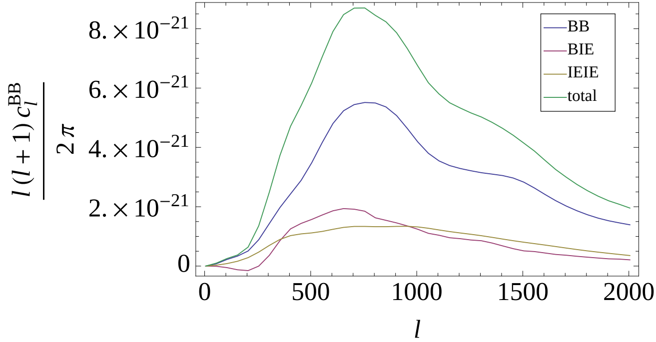
Non-Gaussianity

Model	B^R	B^{R+Z}	B^{R+Z+M}	S/N
Local	2.5	0.57	0.50	0.24
Equilateral	6.7	4.7	4.3	0.018
Orthogonal	-5.1	-1.13	-1.05	0.037
S/N	0.77	0.47	0.47	—

Pettinari, Fidler, Crittenden, Koyama, Wands 2013

- Non-Gaussianity from scattering contaminates f_{NL} by a few
- This contamination is largely cancelled by the redshift effect
- Second order metric perturbations $\mathcal{M}$ are subdominant

B-mode polarisation (preliminary!)



to be published: Fidler, Pettinari, Beneke, Crittenden, Koyama, Wands 2013

- Second order B mode polarisation is comparable to a tensor-to-scalar ratio of 10^{-5}
- To be published soon

Outlook

- Good news for PLANCK: Contaminations to $f_{\rm NL}^{\rm local}$, $f_{\rm NL}^{\rm equilateral}$ and $f_{\rm NL}^{\rm orthogonal}$ are small, but it's still worthwhile to clean PLANCK data
- Good news for PRISM: B-mode contamination comparable to that of a tensor-to-scalar ratio of 10^{-5}
- Future work:
  - ➔ Include lensing and time delay contributions
  - ➔ Compute magnetic fields generated during recombination
  - ➔ Compute y-type spectral distortions form recombination and reionisation
  - ➔ Compute initial conditions for N-body simulations
    Hidalgo, Christopherson & Malik 2013
  - ➔ Large $f_{\rm NL}$ in some models of modified gravity
    Gao X., 2011
  - ➔ More possible applications?
  - ➔ Make SONG public

Thank you for your attention!