Isocurvature modes and the intrinsic CMB bispectrum

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Based on arxiv:1803.08939, arxiv:1902.00459
and ongoing work with Karim Malik and David Mulryne

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Contents

- The early Universe
- Isocurvature initial conditions
- Intrinsic Bispectrum of the CMB
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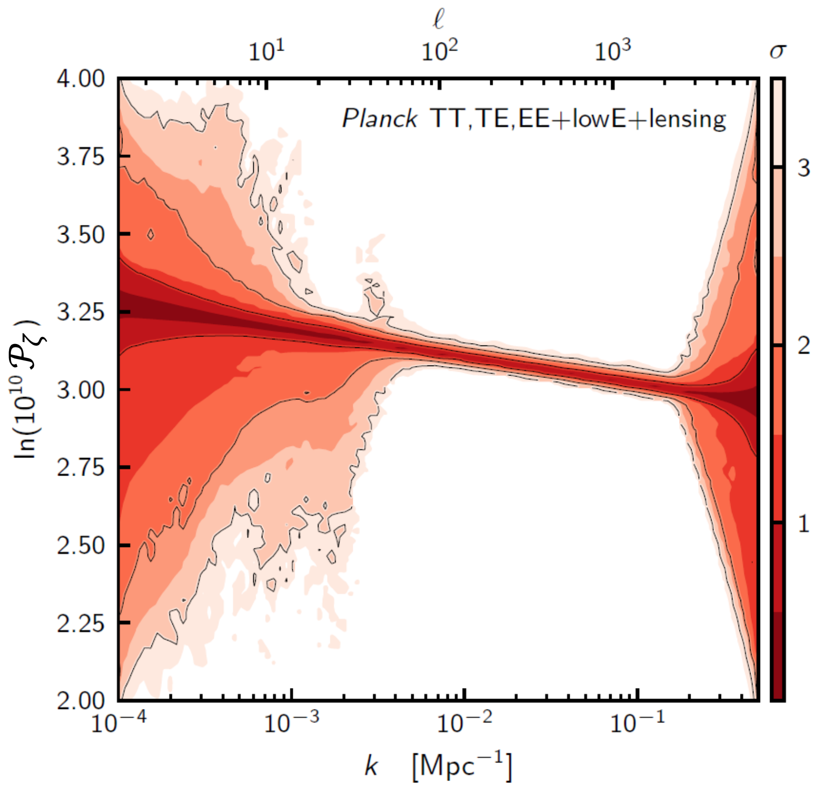
The early Universe

- The physics of the early Universe is not directly observable.
  - Experiments measure only initial conditions;
  - Assuming power law:

$$\mathcal{P}_\zeta(k) = A_s \left(\frac{k}{k^*}\right)^{n_s-1}$$

$$\log(10^{10}A_s) = 3.044 \pm 0.014$$

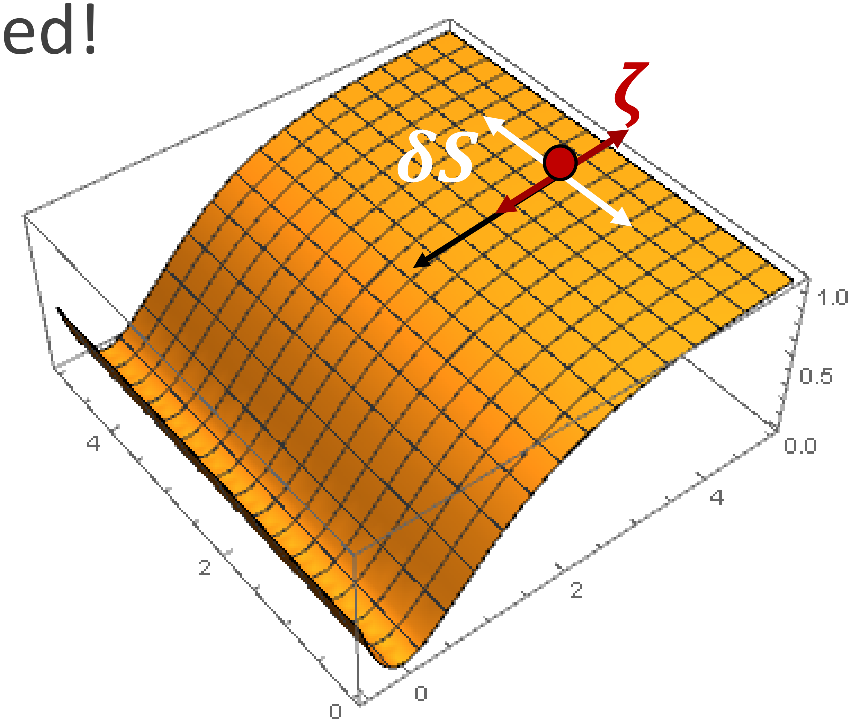
$$n_s = 0.9649 \pm 0.0042$$



[Planck 2018, Constraints on Inflation]

The early Universe

- Single-field, slow-roll inflation is a good fit to observations;
- Multi-field inflation is better motivated!
- Multiple d.o.f. allow for:
  - Non-Gaussianity
  - Isocurvatures



- A detection would increase our knowledge of the early Universe!

Isocurvatures

- What are the properties of each mode after reheating?

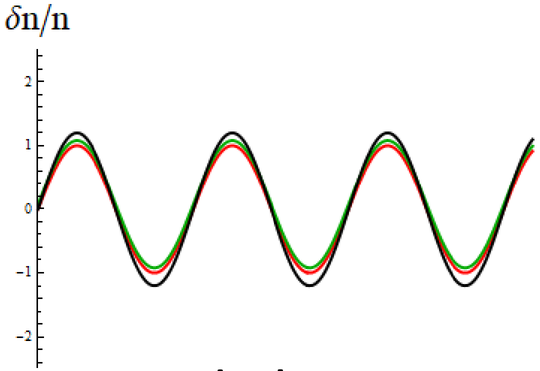
- Adiabatic mode:

$$\zeta \neq 0 \qquad S_{ij} = \frac{\delta_i}{1+w_i} - \frac{\delta_j}{1+w_j} = 0$$

- Isocurvature modes:

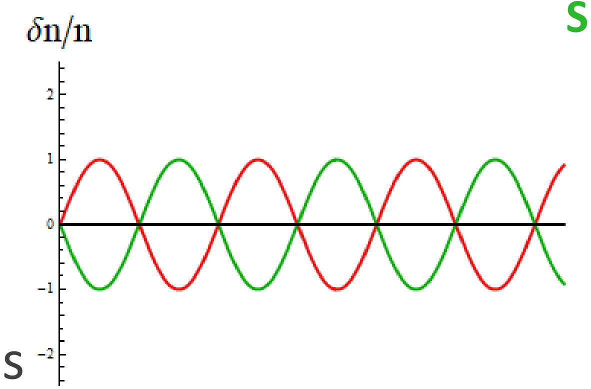
$$\zeta = 0 \qquad S_{ij} = 0 \qquad S_{iso} \neq 0$$

- 4 types at first order:
  - Baryon, CDM, ν density and ν velocity modes



Adiabatic

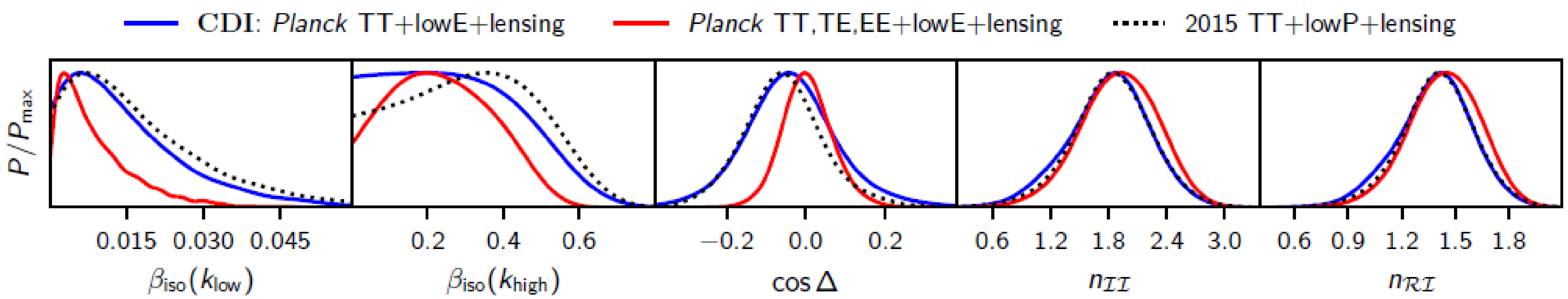
Species 1
Species 2
Total



Isocurvature

Isocurvatures

- Constraints on matter isocurvatures from Planck 2018



- Low amplitude, $\lesssim 1\%$ contribution to CMB variance.

- If present, correlation with adiabatic mode is very small.

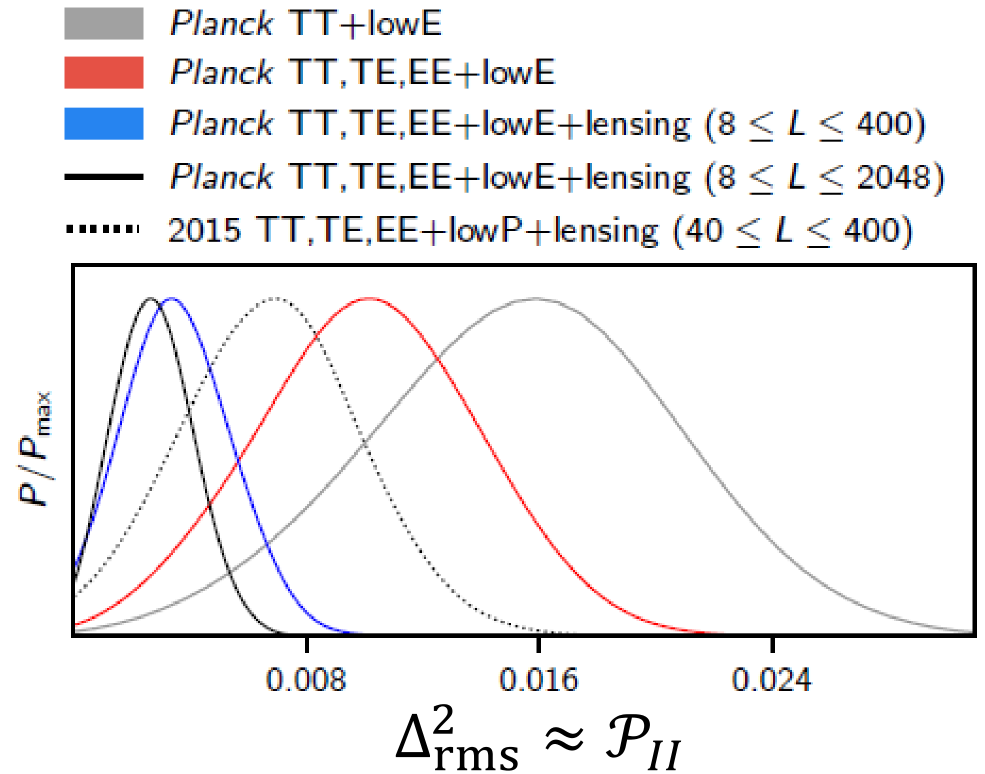
$$\beta_{iso} \equiv \frac{\mathcal{P}_I}{\mathcal{P}_\mathcal{R} + \mathcal{P}_I} \qquad \cos\Delta \equiv \frac{\mathcal{P}_{RI}}{\sqrt{\mathcal{P}_\mathcal{R}\mathcal{P}_I}}$$

Isocurvatures

- Compensated Isocurvature
  - Mode with

$$S_{M\gamma} = \Omega_b S_{b\gamma} + \Omega_c S_{c\gamma} = 0$$

$$S_{c\gamma} \neq 0 \qquad S_{b\gamma} \neq 0$$



[Planck 2018, Constraints on Inflation]

  - No linear effect on CMB;
  - Similar effect to lensing;
  - Amplitude can be $10^6 \times$ larger than adiabatic mode!

Isocurvatures

- 2^{nd} order Boltz. codes need new initial conditions for isocurvatures;

- Ex: mix between CI and adiabatic:

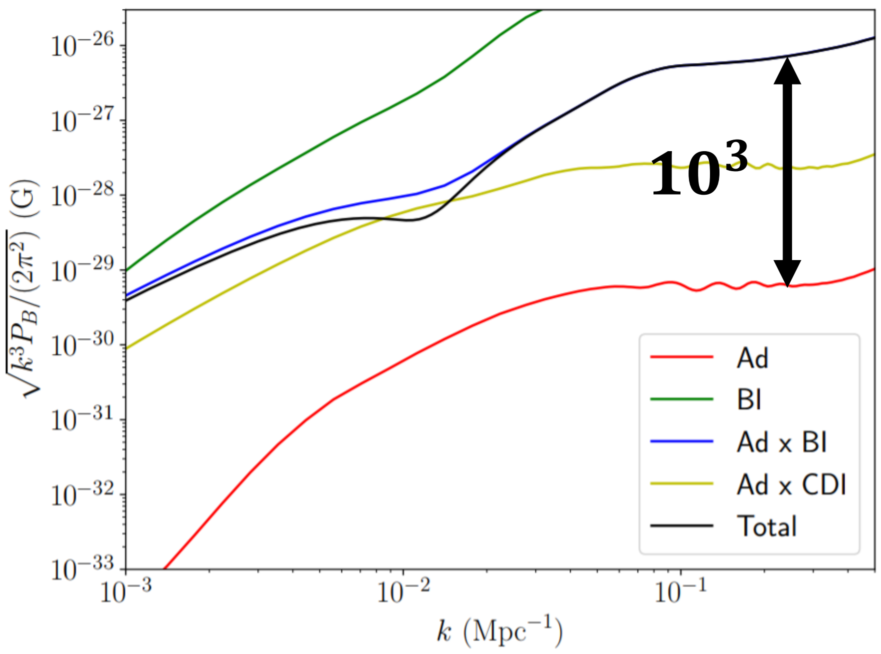
$$v_{\gamma b} = \frac{\Omega_c}{\Omega_\gamma} \frac{k^2 + k_1^2 - k_2^2}{96k^2} \, {k_2}^2 \omega \tau^4 \, \delta^0_{CI,k_1} \psi^0_{k_2}$$

$$\delta_b = \frac{\Omega_c}{20\Omega_b} (5 - \omega\tau)\, (k_2\tau)^2 \, \delta^0_{CI,k_1} \psi^0_{k_2}$$

$$\delta_c = -\frac{1}{20} (5 - \omega\tau)\, (k_2\tau)^2 \, \delta^0_{CI,k_1} \psi^0_{k_2}$$

10 more solutions in **arXiv:1803.08939**

- CI enhances magnetogenesis:



Other modes in **arXiv:1902.00459**

Bispectrum of the CMB

- The CMB bispectrum offers a window into the non-linear physics of the early Universe

$$\langle TTT \rangle \sim \langle \zeta\zeta\zeta \rangle$$

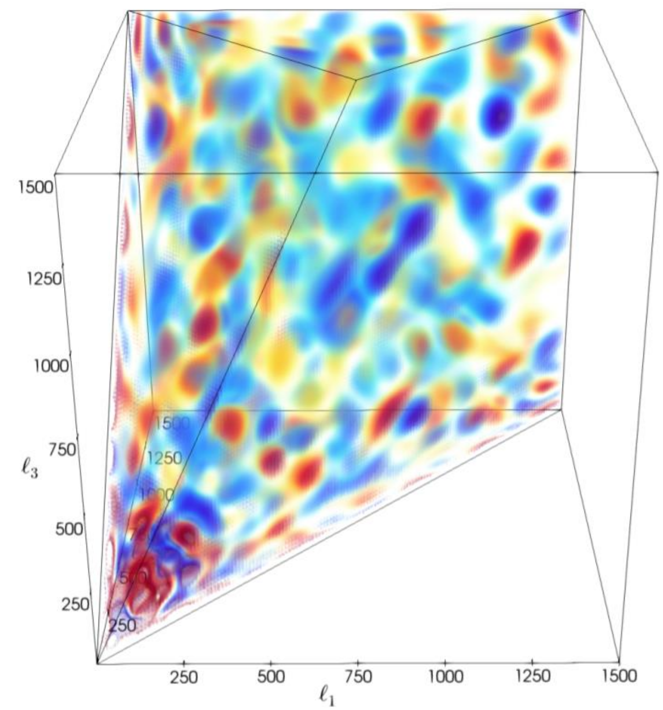
- Planck has constrained 3 templates:

$$f_{NL}^{local} = -0.9 \pm 5.1$$

$$f_{NL}^{equil} = -26 \pm 47$$

$$f_{NL}^{ortho} = -38 \pm 24$$

- But no primordial signal found yet!



[Planck 2018, Constraints on non-Gaussianity]

Bispectrum of the CMB

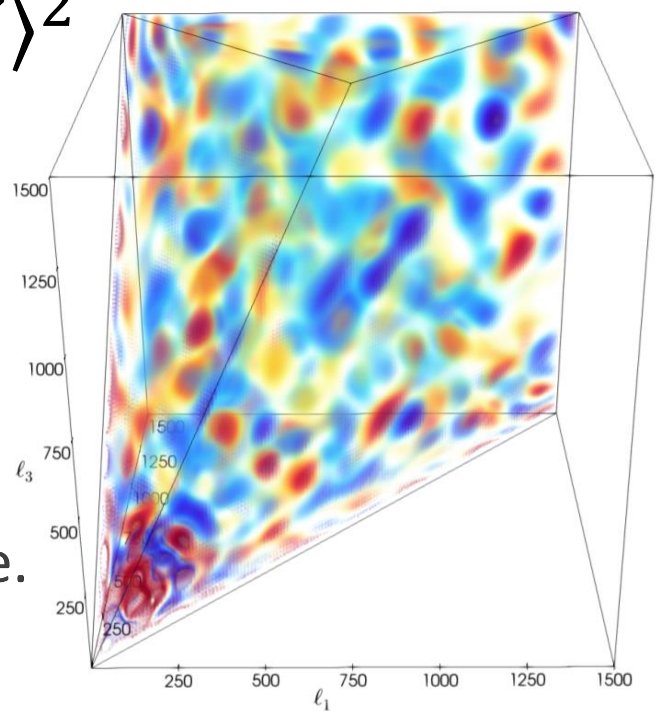
- But it also probes the non-linear evolution after inflation, even with Gaussian initial conditions:

$$\langle TTT\rangle \sim {\mathcal{T}^{(1)}}^3\langle\zeta\zeta\zeta\rangle + \mathcal{T}^{(2)}{\mathcal{T}^{(1)}}^2\langle\zeta\zeta\rangle^2$$

- Lensing-ISW contribution detected:

$f_{NL}^{lensing} = 0.90 \pm 0.26$ $\Delta f_{NL}^{local} = 5.0$

- Large bias must be subtracted!
- Other contributions may be found in future.
- **Aim:** Compute signal from isocurvatures!



[Planck 2018, Constraints on non-Gaussianity]

Bispectrum of the CMB

- We compute the bispectrum numerically using SONG (no lensing).

$$B_{\ell_1\ell_2\ell_3} \propto \int \mathcal{T}_i^{(1)}\mathcal{T}_j^{(1)}\mathcal{T}_{kl}^{(2)} P_{ik} P_{jl}$$

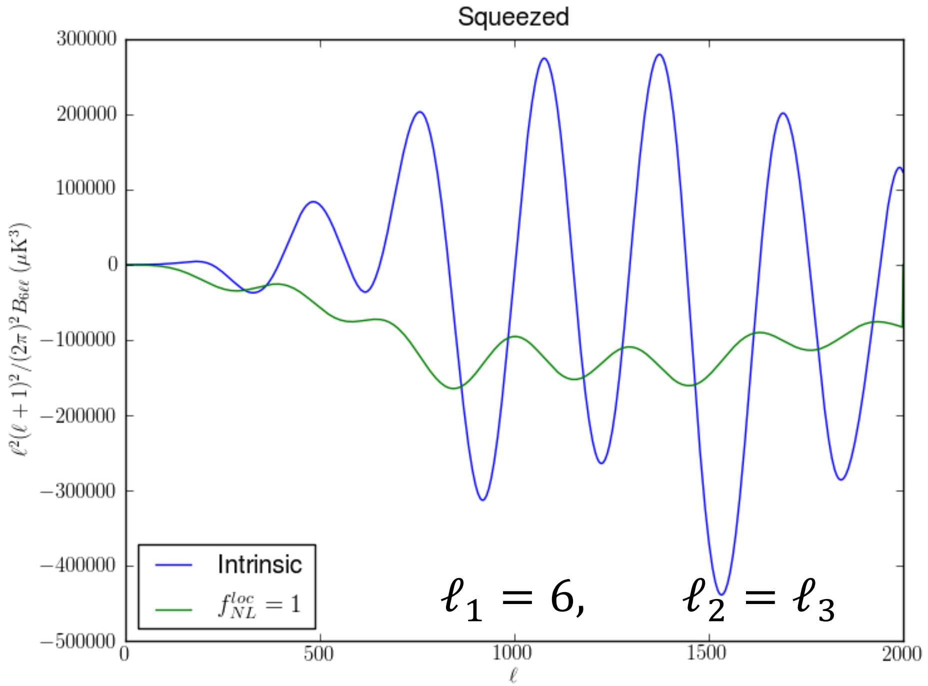
$i, j, k, l =$ Ad, BI, CDI, etc

- Adiabatic result [Huang et al (2013), Su et al (2013), Pettinari et al (2013), etc]:
  - Mostly squeezed;
  - For Planck

$$\Delta f_{NL}^{local} = 0.33$$

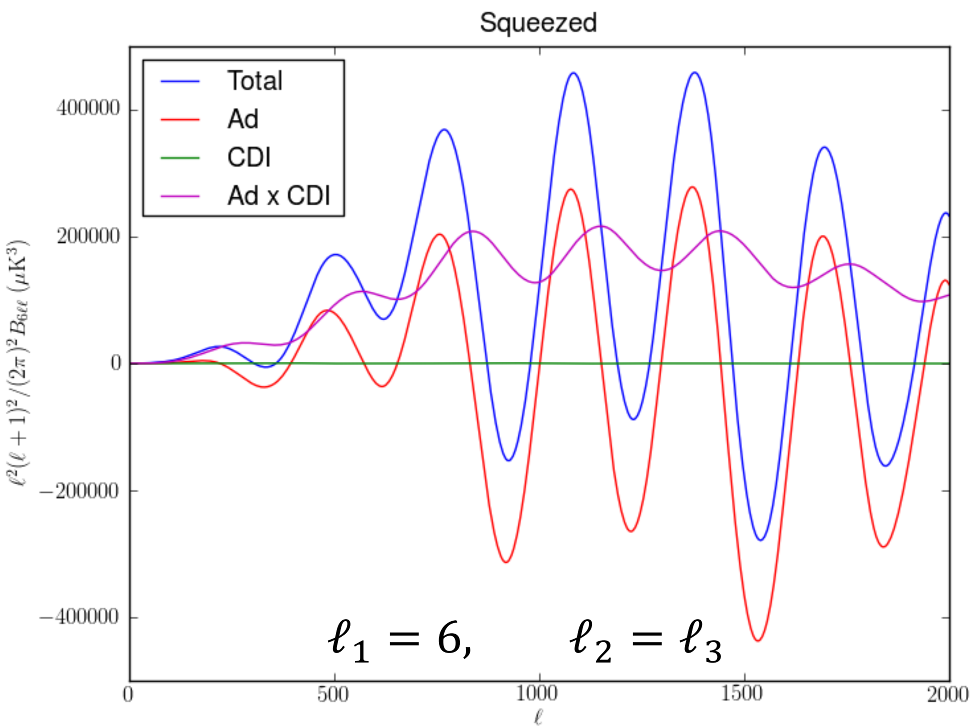
$$S/N = 0.34$$

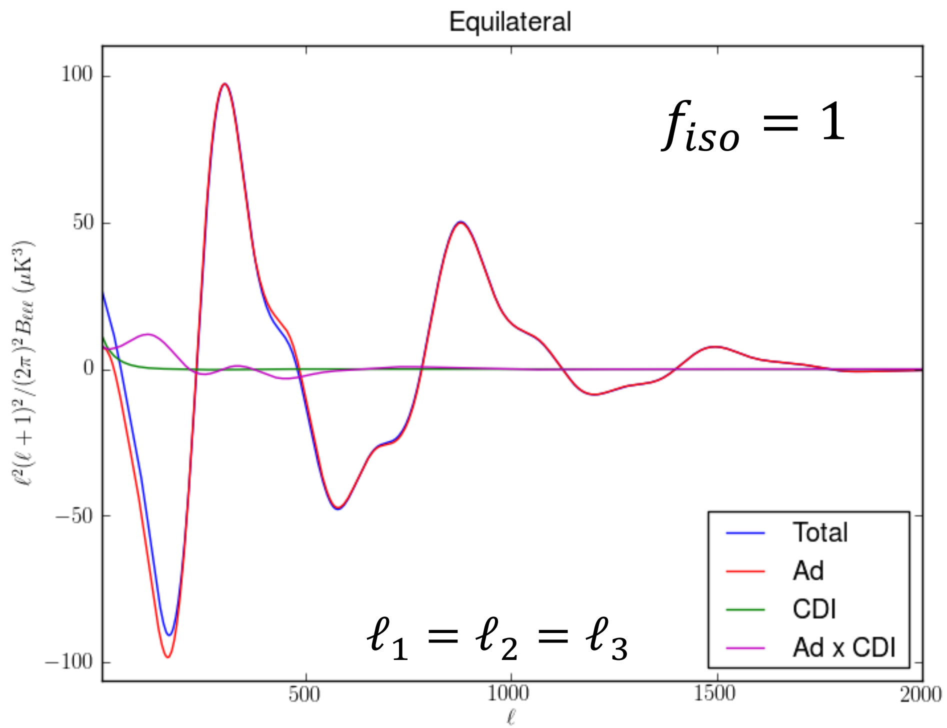
  - $S/N = 1$ for CVL at $\ell_{\max} = 3000$



Bispectrum of the CMB

- Ad + CDM isocurvature ($n_i = 1$) result:

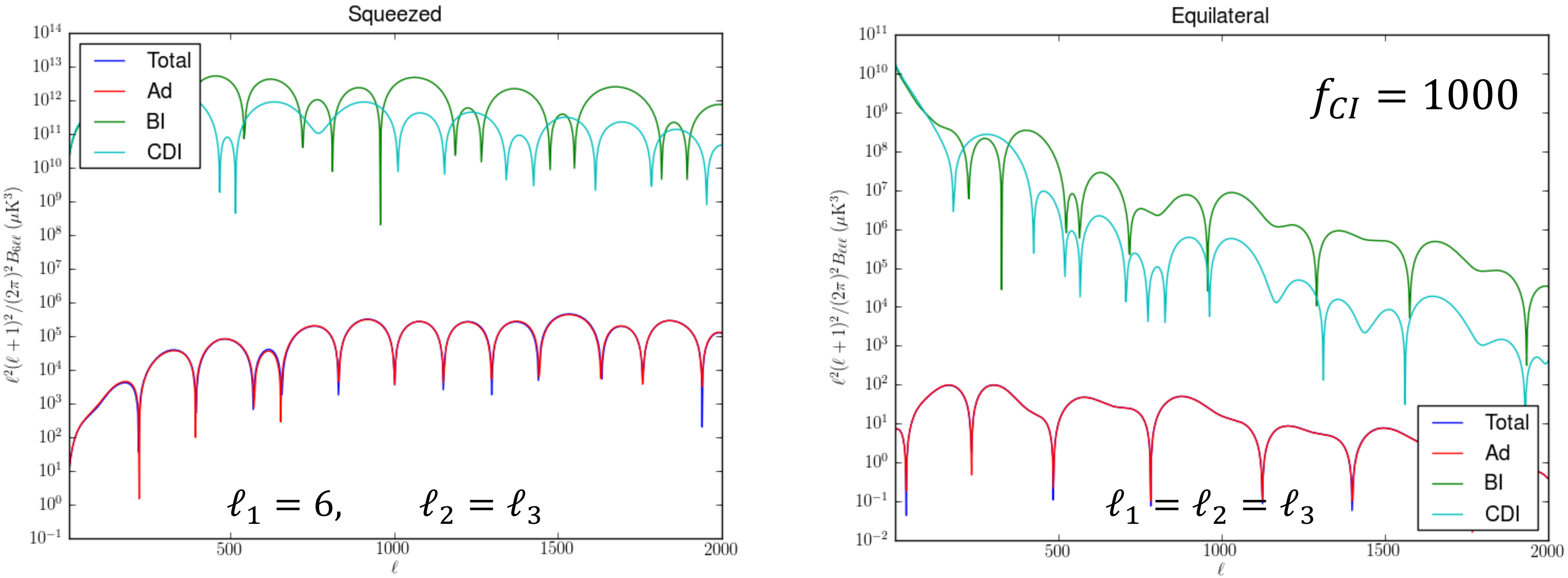




- Strictly positive contribution from Ad x CDI mixed mode.
- Negligible contribution in the equilateral limit.

Bispectrum of the CMB

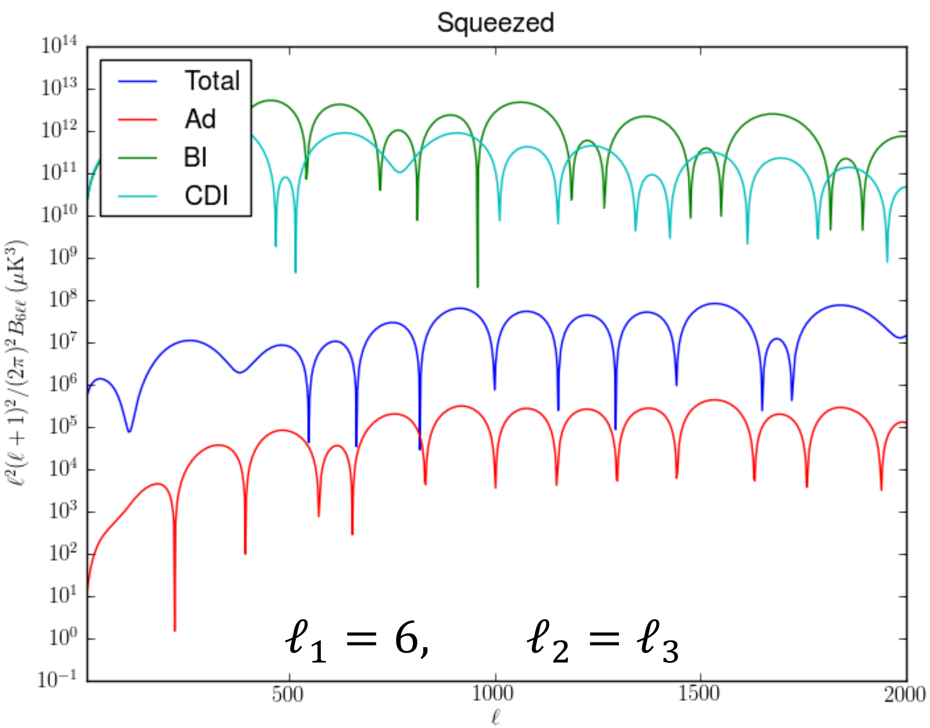
- Ad + compensated isocurvature ($n_{CI} = 1, \cos\Delta_{\zeta CI} = 0$) result:

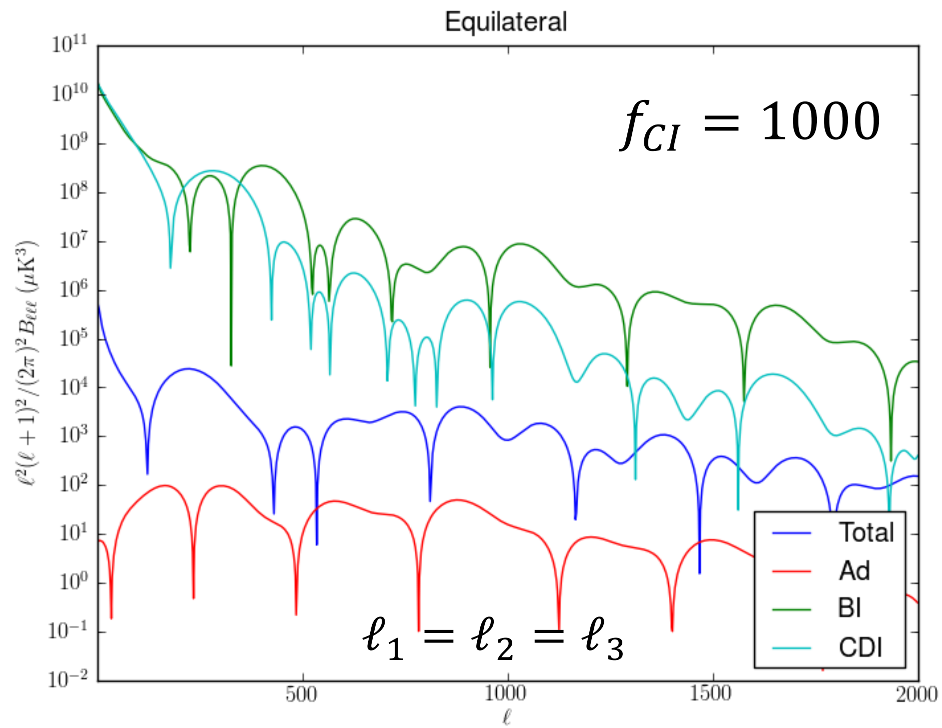


- No signal above adiabatic: $B^{CI}_{\ell_1\ell_2\ell_3} \propto \int \mathcal{T}^{(1)}_{CI} \mathcal{T}^{(1)}_{Ad} \mathcal{T}^{(2)}_{CIAd} P_{CI} P_{Ad} = 0!$
- Allows us to test of the code.

Bispectrum of the CMB

- Ad + compensated isocurvature ($n_{CI} = 1$, $\cos\Delta_{\zeta CI} = \pm 1$) result:

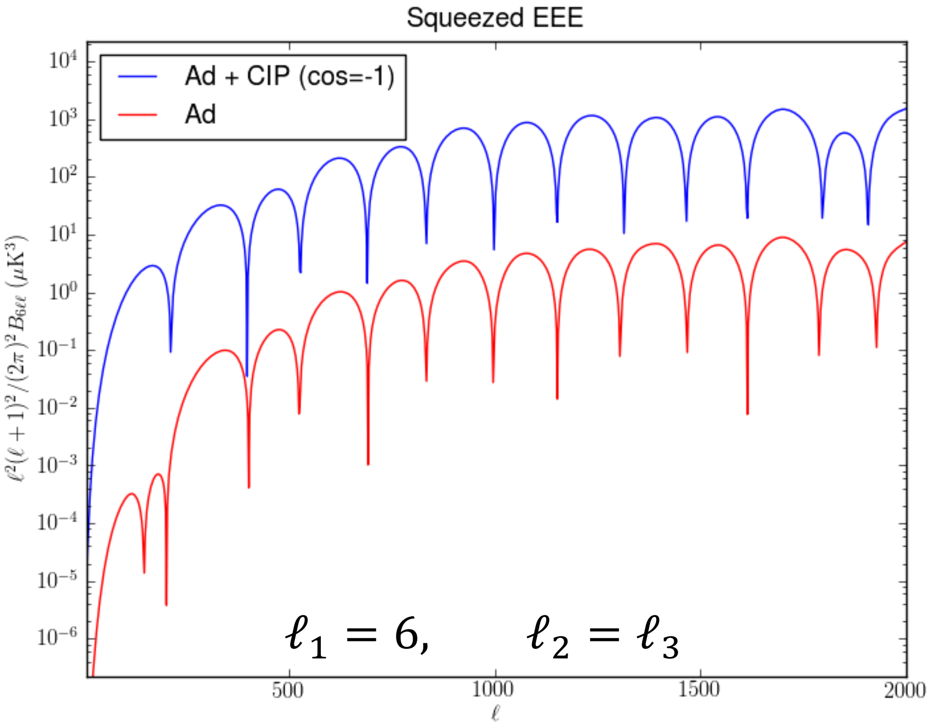


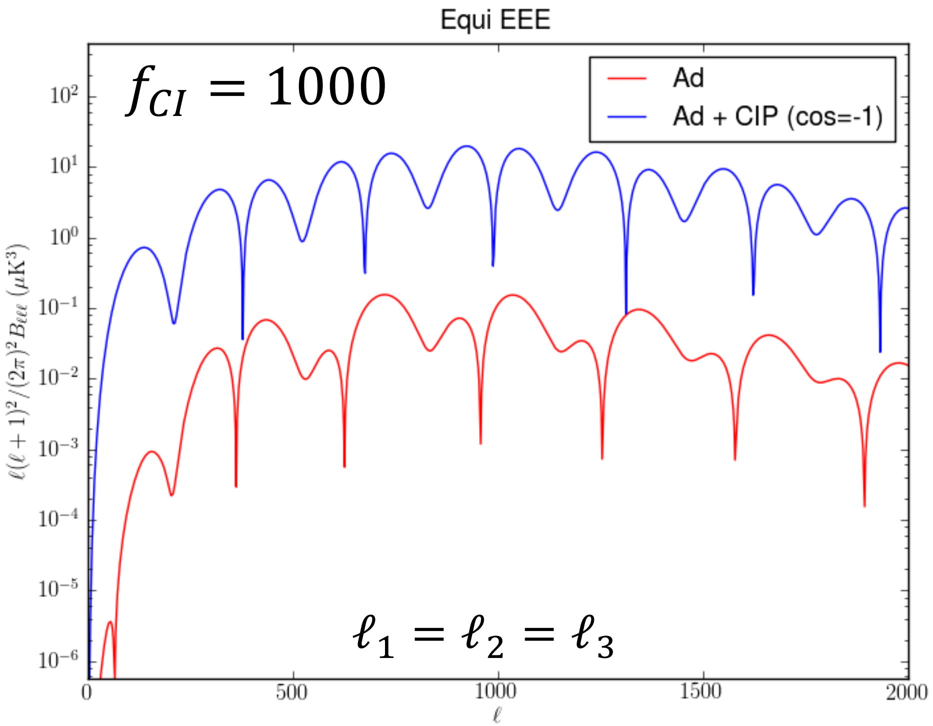


- Bispectrum is amplified by $\sim f_{CI}/5$ from adiabatic!

Bispectrum of the CMB

- Ad + compensated isocurvature ($n_{CI} = 1$, $\cos\Delta_{\zeta CI} = \pm 1$) result:

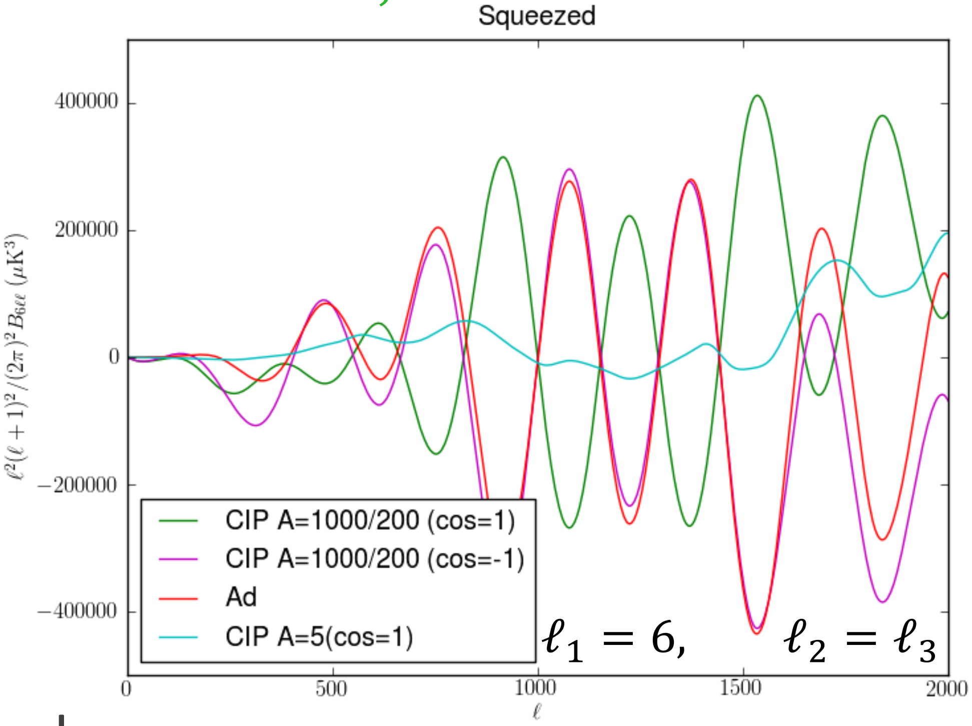




- Polarization bispectrum also amplified by $\sim f_{CI}/5$ from adiabatic!

Bispectrum of the CMB

- Ad + compensated isocurvature ($n_{CI} = 1$, $\cos\Delta_{\zeta CI} = \pm 1$) result:



- Shape of the signal also similar

$$B_T^{CI} \approx -\frac{f_{CI}}{5}\cos\Delta_{\zeta CI}\, B_T^{Ad}$$

- Bias on local template:

$$\Delta f_{NL}^{local} \sim -\frac{f_{CI}}{15}\cos\Delta_{\zeta CI}$$

- Given non-observation of this signal:

$$f_{CI}\cos\Delta_{\zeta CI} \lesssim 75$$

Conclusions

- We can now calculate non-linear effects of isocurvatures!
- Isocurvatures in CMB bispectrum:
  - Small effects for single isocurvatures (but may have increased bias for f_{NL}^{local});
  - Large effect of compensated isocurvature – usable for constraints!
- Future Work:
  - Estimate lensing-ISW contribution for generic isocurvatures;
  - Study of degeneracy between lensing and compensated isocurvature effect.

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QUESTIONS?

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