Non-Gaussianity discussion
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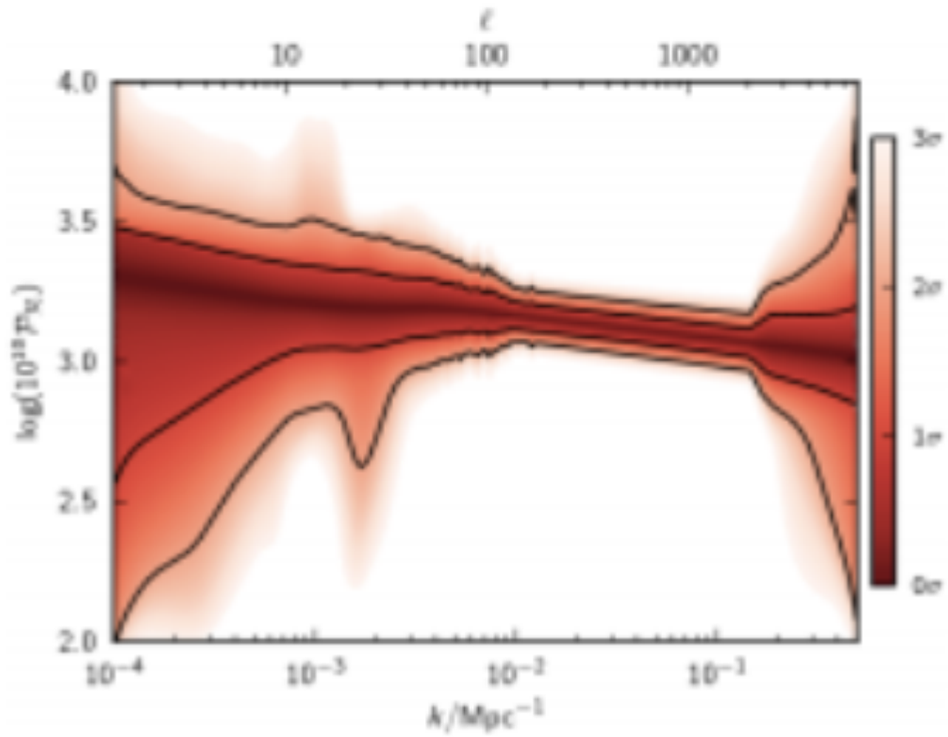
Inflation: We observe so much yet see so little…

- It is remarkable and disappointing that we can explain the statistical property of 10^7 CMB pixels with just two primordial numbers (+ background parameters)
- We have only measured the amplitude and spectral index of the power spectrum
- Is this evidence that inflation was simple? Bayesian model comparison is inconclusive.
- We need more data => go to smaller scales

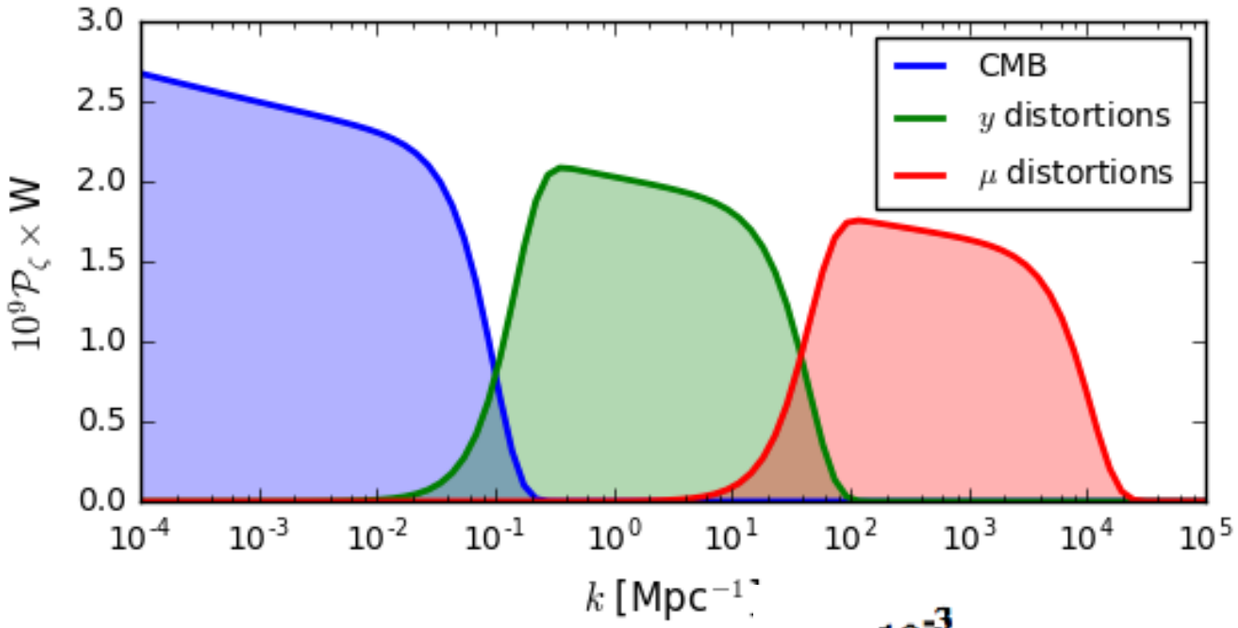
Current power spectrum constraints



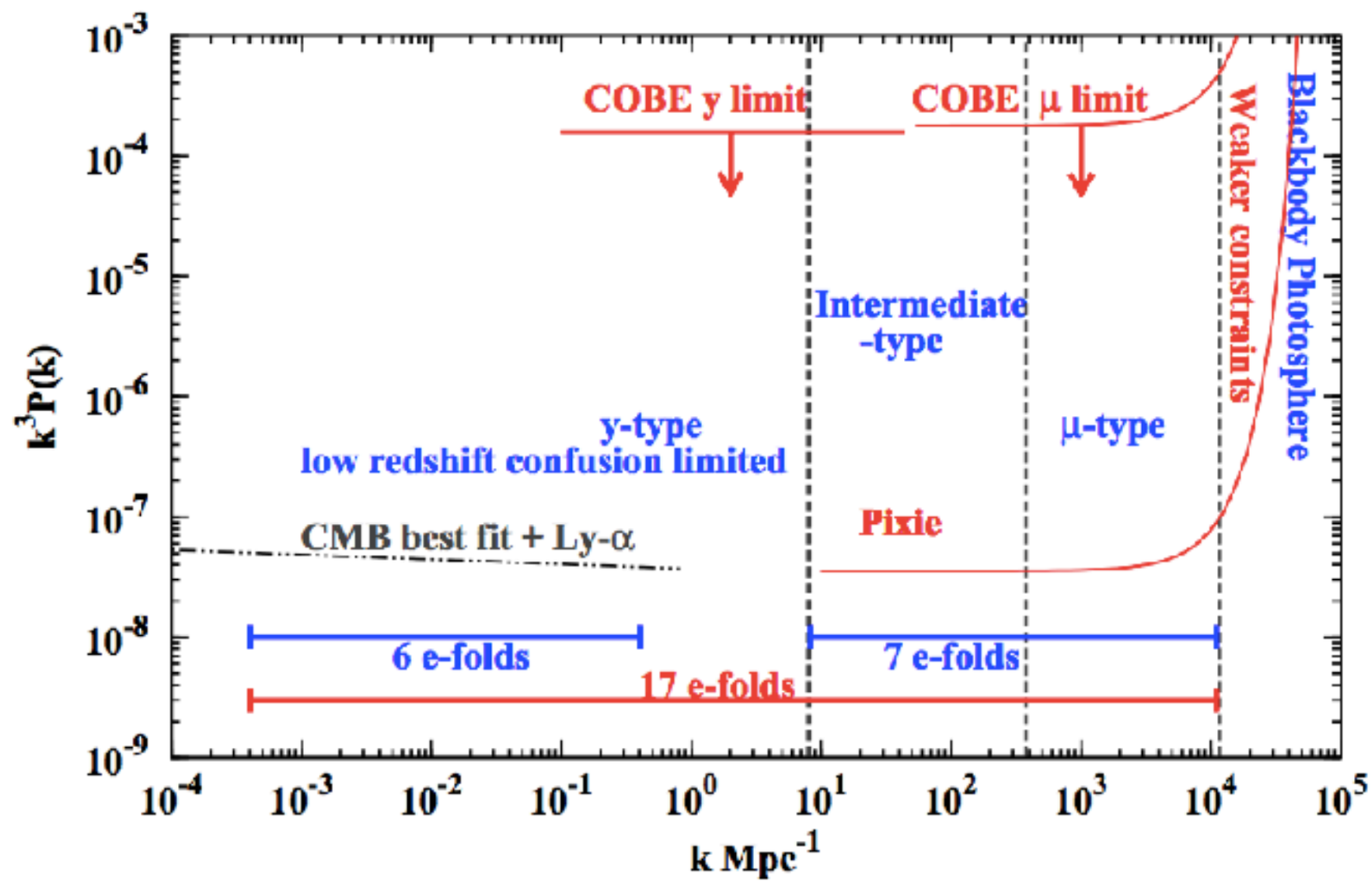
Planck 2015
constraints on inflation

Fig. 26. Bayesian reconstruction of the primordial power spectrum averaged over different values of $N_{\rm int}$ (as shown in Fig. 24), weighted according to the Bayesian evidence. The region $30 < \ell < 2300$ is highly constrained, but the resolution is lacking to say anything precise about higher ℓ. At lower ℓ, cosmic variance reduces our knowledge of $\mathcal{P}_{\mathcal{R}}(k)$. The weights assigned to the lower $N_{\rm int}$ models outweigh those of the higher models, so no oscillatory features are visible here.

- Featureless power law over 1 decade in scales (or log(2300/30)=4.3 efolds)
- Could the perturbations grow dramatically on small scales?



Spectral distortions
Testing inflation with 17 efoldings



Khatri 2013

The slow-roll hierarchy is not observationally required

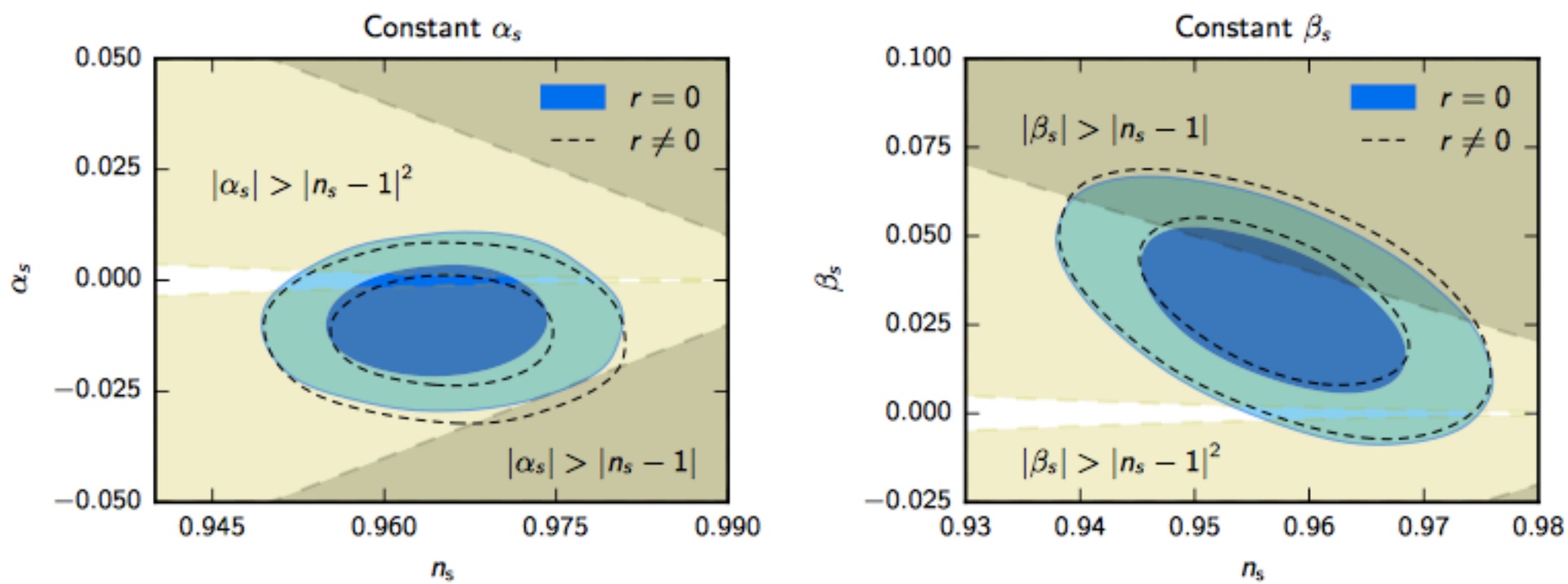


Figure 1. Constraints from *Planck* 2015 TT+lowTEB [1] and BICEP-Keck [22] on a constant α_s (left) and a constant β_s (marginalized over α_s at the pivot scale; right), both against n_s at the pivot scale. Dashed black contours assume a null tensor-to-scalar ratio, r, whereas blue contours marginalize over it. The light shaded region corresponds to the part of the parameter space where the quantity in the vertical axis becomes greater than $|n_s - 1|^2$ and the dark shaded region is where it becomes greater than $|n_s - 1|$. The naive expectation is that the true value of α_s (left) should be close to the boundary of the unshaded region and far away from the dark shaded region, whereas that of β_s (right) should be well inside the unshaded region. Current constraints allow a much greater area of the parameter space.

Vieira, CB, Lewis 2017

Allowed power spectra assuming the "standard" parametrisation

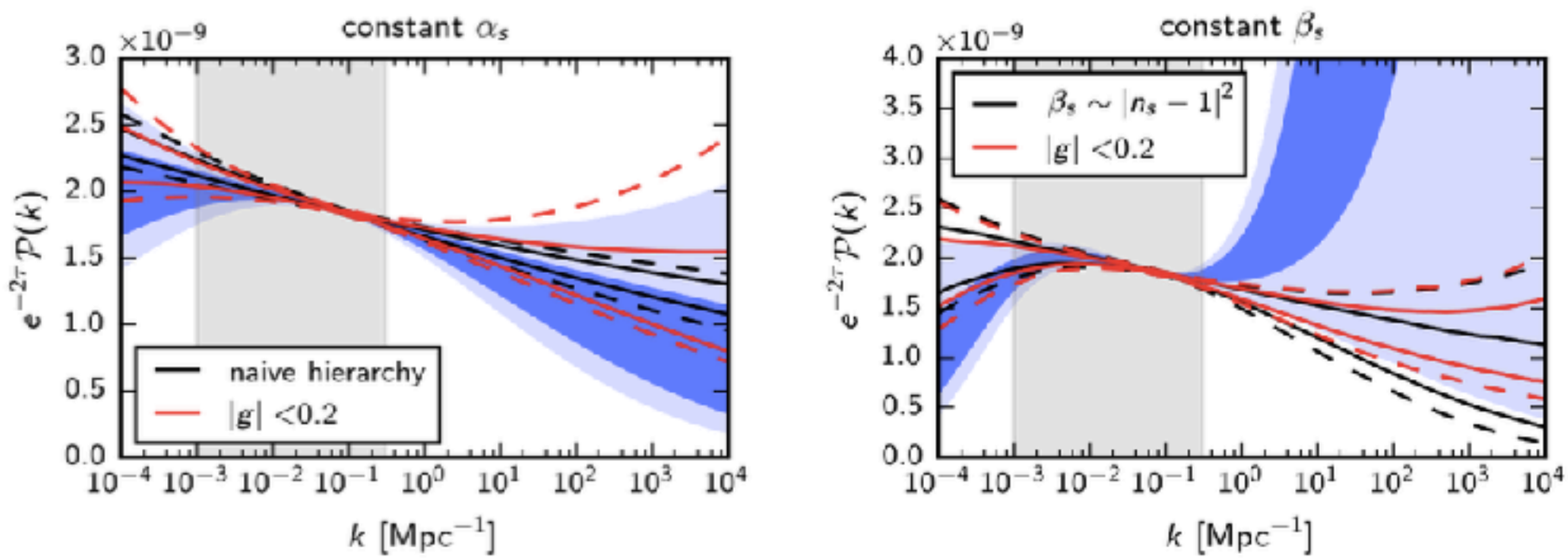
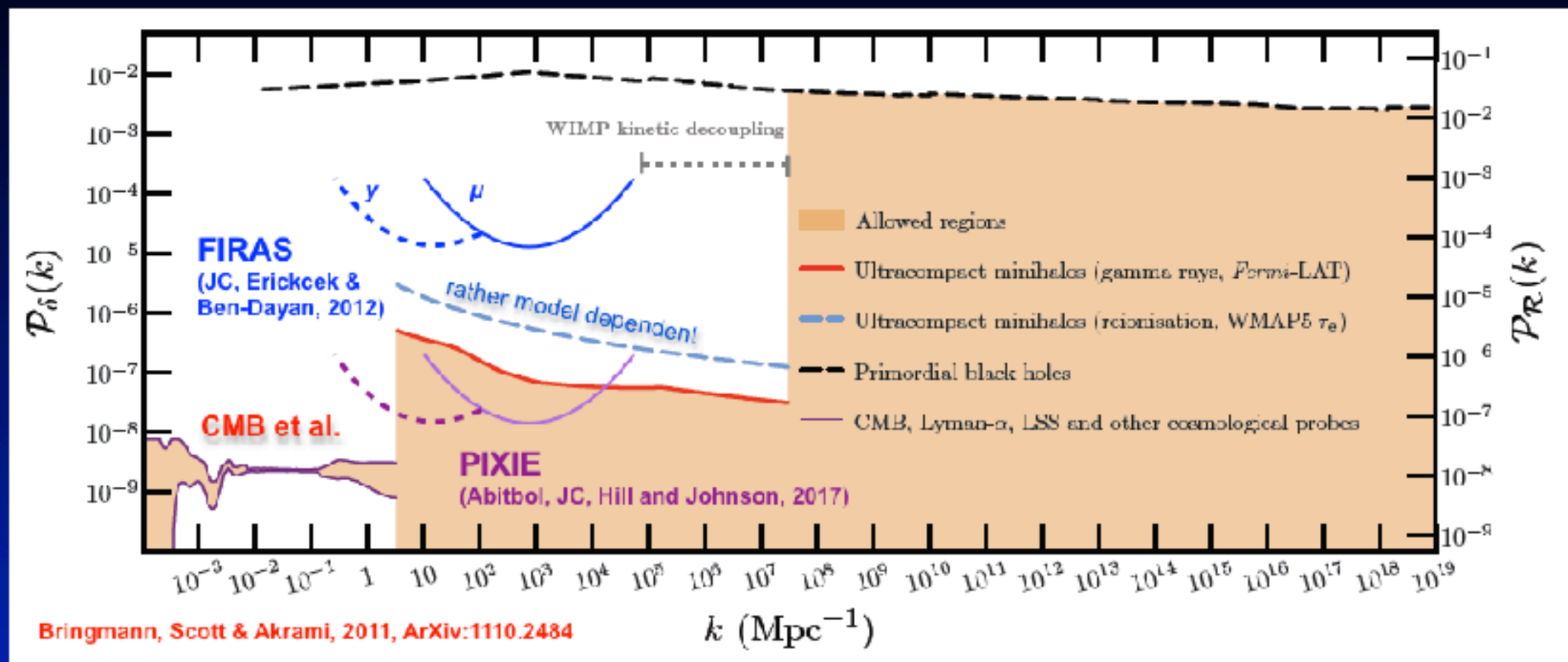


Figure 6. Consequences of the imposition of slow roll (defined by the smallness of g) for the power spectrum scaled by $e^{-2\tau}$, where τ is the optical depth (whose value affects the amplitude of the spectrum, but not its shape). The blue contours represent the 68% (dark blue) and 95% (light blue) limits on the allowed values of the power spectrum (rescaled by a factor of $e^{-2\tau}$) extrapolated from *Planck* 2015 TT | lowTEB constraints (over gray shaded scales) assuming a constant α_s (left) and a constant β_s (right), for different values of k. The solid and dashed red contours represent the 68% and 95% limits on the fraction of these spectra for which $|g| < 0.2$ for the range of scales corresponding to $10^{-3}\mathrm{Mpc}^{-1} < k < 10^{4}\mathrm{Mpc}^{-1}$. The solid and dashed black contours represent the 68% and 95% limits on the fraction of these spectra corresponding to the unshaded regions in figure 1 (note that for the plot on the right the limits of this region already violate the naive expectation for the magnitude of β_s).

Vieira, CB, Lewis 2017

Distortions provide general power spectrum constraints!



- Amplitude of power spectrum rather uncertain at $k > 3$ Mpc^{-1}
- improved limits at smaller scales can *rule out* many *inflationary models*
- CMB spectral distortions would *extend* our *lever arm* to $k \sim 10^4$ Mpc^{-1}
- very *complementary* piece of information about early-universe physics

e.g., JC, Khatri & Sunyaev, 2012; JC, Erickcek & Ben-Dayan, 2012; JC & Jeong, 2013

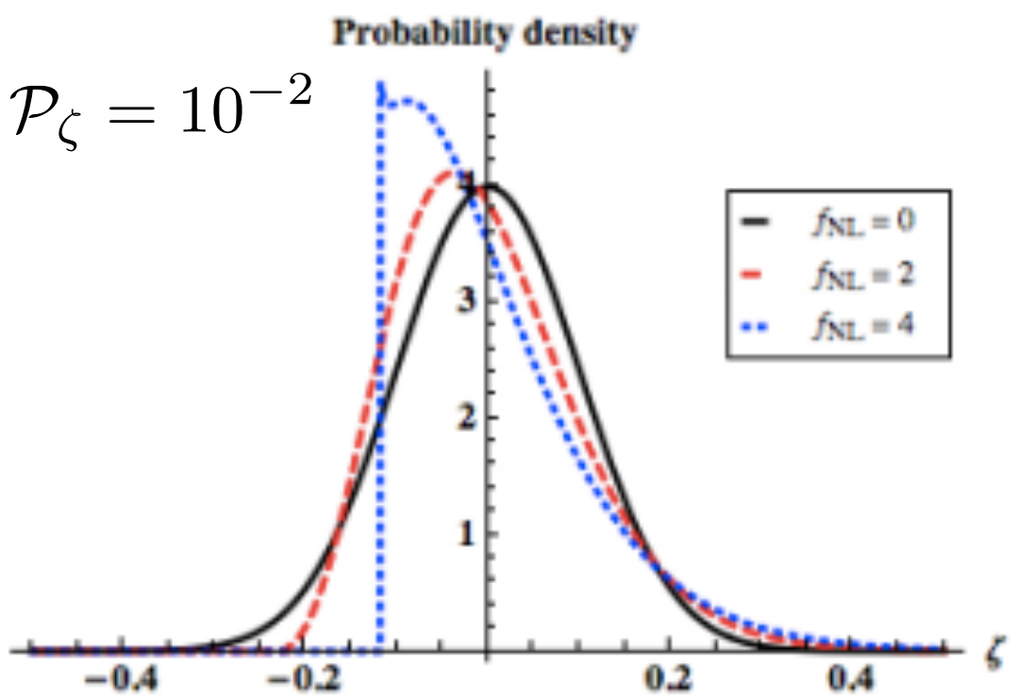
PBHs: Juan and Yacine talks on Thursday

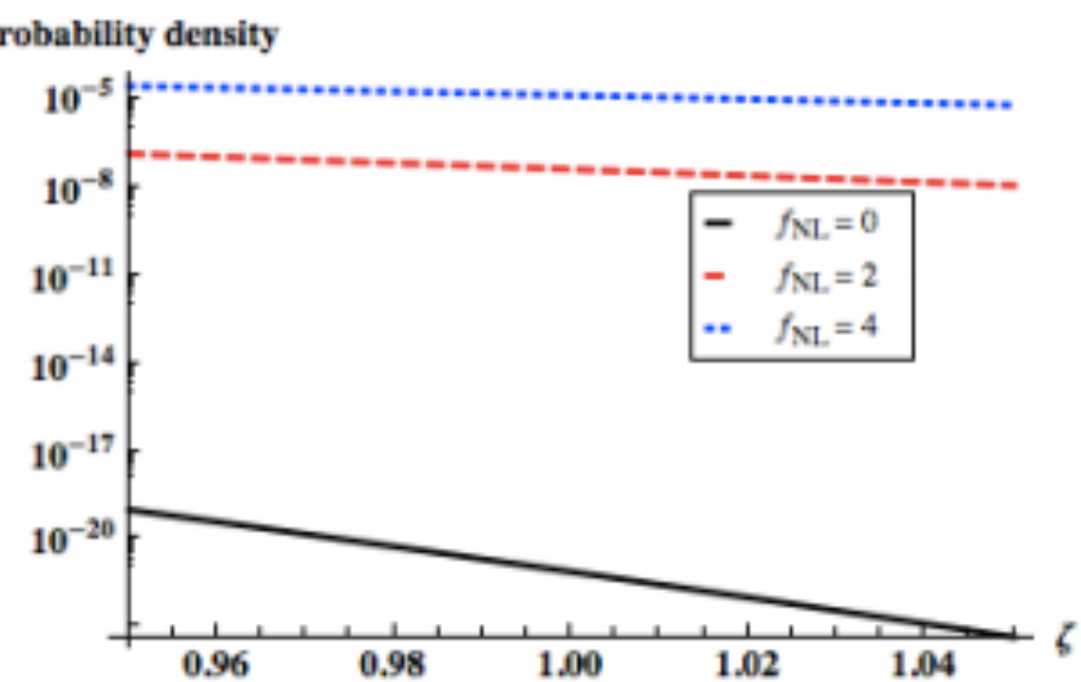
Slide by Jens Chluba - Ultra compact minhalo constraints are unreliable (Gosenca et al, Delos et al, Nakama et al; all 2017). Spectral distortion constraints are tighter than PBH constraints for $M>10^3 M_\odot$
Non-Gaussian perturbations can evade these constraints, e.g. Nakama, Carr & Silk 2017

Probing the tail

Local non-Gaussianity (chi-squared)

$$\zeta = \zeta_g + \frac{3}{5} f_{NL} \left(\zeta_g^2 - \sigma^2\right)$$





Young and CB 2013

Local (squeezed limit) f_{NL} forecasts

$$f_{\rm nl}^{y} \simeq 220 \left(\frac{y_{\rm min}}{2\times 10^{-10}}\right)\left(\frac{\langle y\rangle}{4\times 10^{-9}}\right)^{-1}$$

$$f_{\rm nl}^{\mu} \simeq 220 \left(\frac{\mu_{\rm min}}{10^{-9}}\right)\left(\frac{\langle \mu\rangle}{2\times 10^{-8}}\right)^{-1}$$

Emami++ 2015

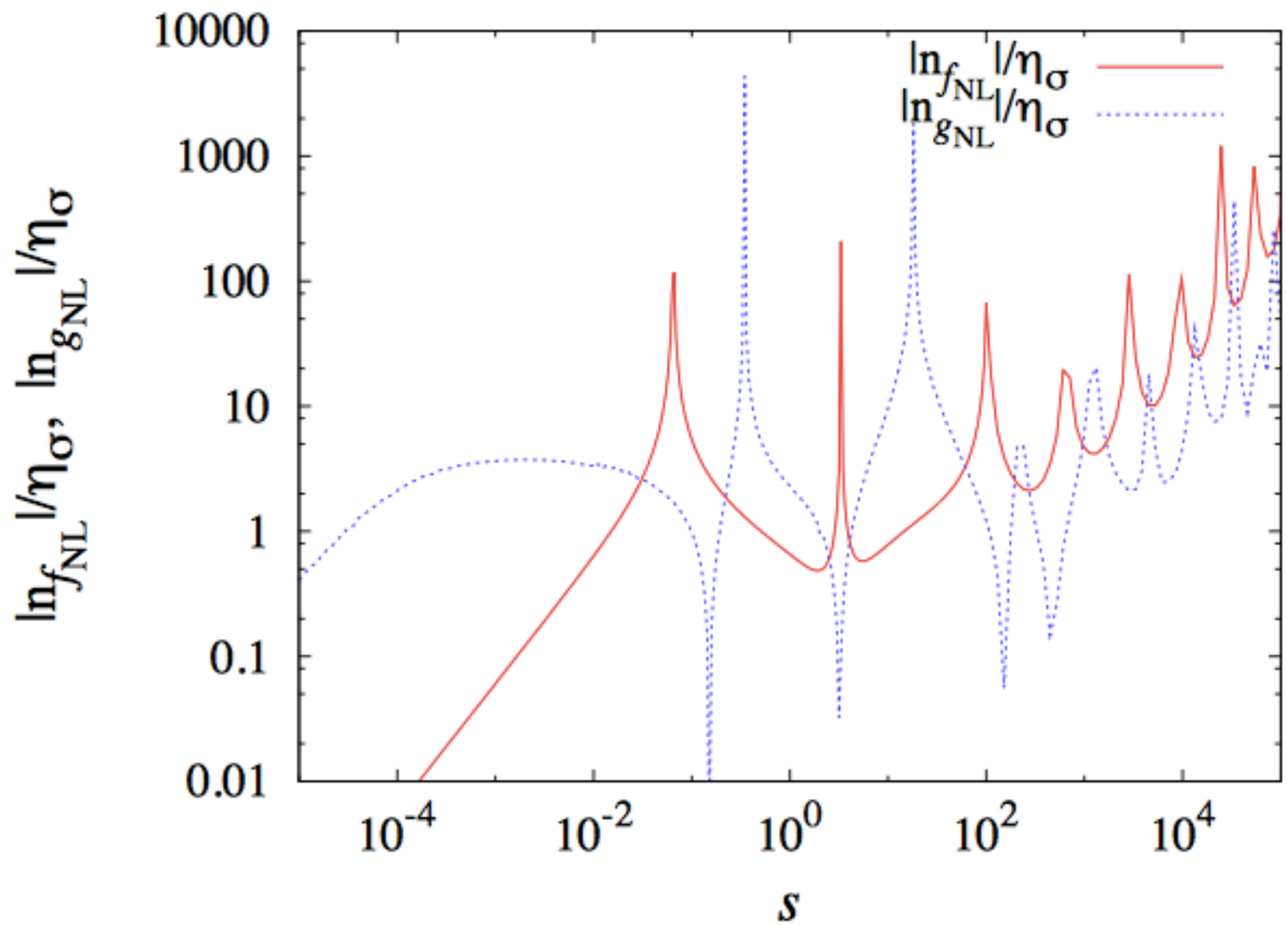
- Assuming scale invariance. If power spectrum grows by 3 orders of magnitude then f_{NL}~1 becomes detectable!
- If ~**any** solar mass PBHs exist then such a growth in the power spectrum is expected, quite possibly accompanied by non-Gaussianity
- Some popular inflationary models generate scale independent f_{NL} even if the power spectrum amplitude massively changes
- Hence if power spectrum grows by more than 220/5 on relevant scales then distortions provide the best constraint on scale-invariant f_{NL}

Scale dependent non-Gaussianity

- Just like the primordial power spectrum, non-Gaussianity is generically expected to have some scale dependence
- This is typically slow-roll suppressed but can be made arbitrarily large (in which case using a spectral index is inadequate)
- Scale dependence can arise from:
    1. Self-interactions of a spectator field
    2. Multiple-field perturbations present in the power spectrum
    3. A non-trivial field space metric
    4. Non-canonical kinetic term with a scale/time dependent sound speed

Strongly self-interacting curvaton scenario

$$n_{f_{\rm NL}} = \frac{{\rm d}\ln|f_{\rm NL}|}{{\rm d}\ln k}\,, \qquad n_{g_{\rm NL}} = \frac{{\rm d}\ln|g_{\rm NL}|}{{\rm d}\ln k} \qquad \eta_\sigma = \frac{m_\sigma^2}{3H^2} \simeq 10^{-2}$$



CB, Enqvist, Nurmi, Takahashi 2011

Elevator pitch?

- Lots of science can be done with distortions
- But what are the key selling points?
  Much harder to summarise than the search for primordial tensors!
- If Pixie flew and did not detect any primordial distortions, what have we learnt?
  Is the situation similar to DE/MG experiments, loads will be learnt if the cosmological constant is ruled out, but not so much if everything remains consistent with the simplest models.