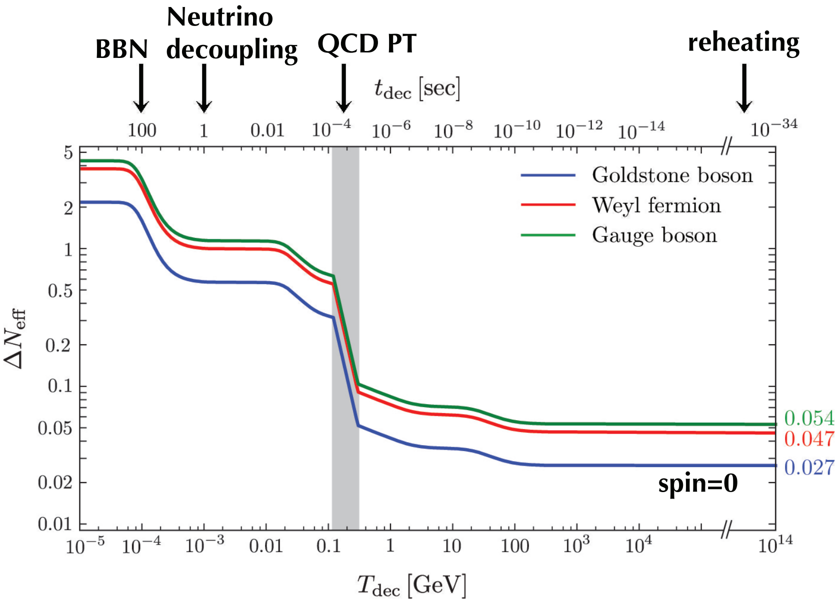
Neutrino signature in the Baryon Acoustic Oscillation spectrum

Florian Beutler

5 July, 2018

Motivation



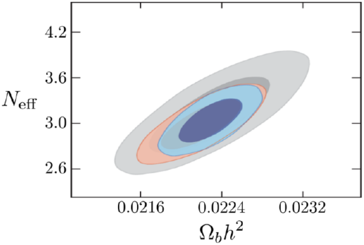
BBN
Neutrino decoupling
QCD PT
reheating
t_{dec} [sec]
100
1
0.01
10^{-4}
10^{-6}
10^{-8}
10^{-10}
10^{-12}
10^{-14}
10^{-34}
Goldstone boson
Weyl fermion
Gauge boson
ΔN_{eff}
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
0.054
0.047
0.027
spin=0
10^{-5}
10^{-4}
10^{-3}
0.01
0.1
1
10
100
10^{3}
10^{4}
10^{14}
T_{dec} [GeV]

Motivation

Relic neutrinos make up 41% of the radiation density

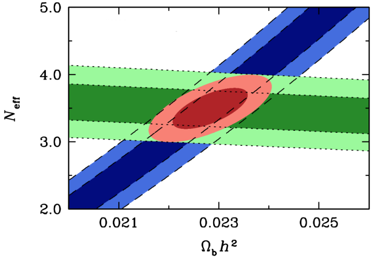
$$\rho_r = \left[1 + \frac{7}{8} \left(\frac{4}{11} \right)^{4/3} N_{\rm eff} \right] \rho_\gamma$$

CMB



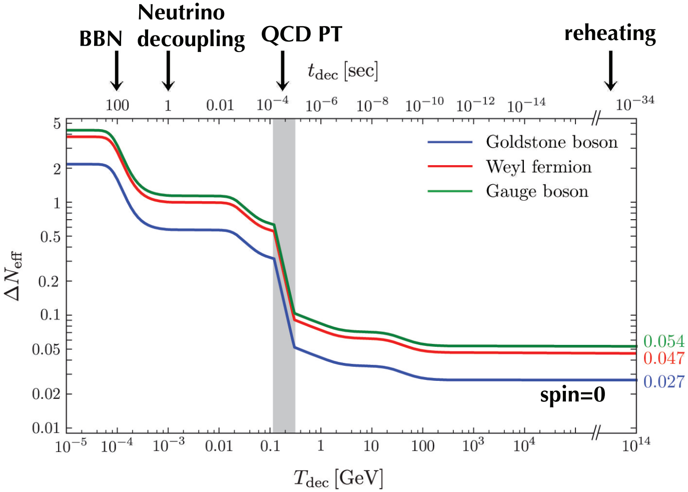
$$N_{\rm eff}^{\rm CMB} = 3.04 \pm 0.18$$

BBN



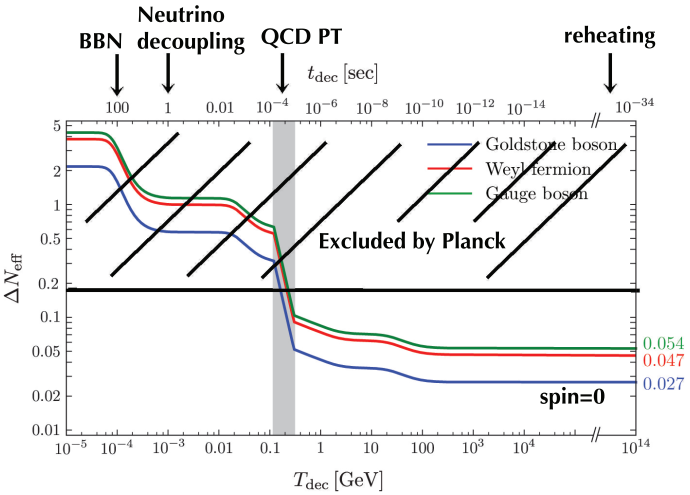
$$N_{\rm eff}^{\rm BBN} = 3.28 \pm 0.28$$

Planck (2015), Cooke et al. (2015)



$\sigma(N_{eff}) = 0.030$ (CMB-S4)

$\sigma(N_{eff}) = 0.027$ (CMB-S4 + Euclid)



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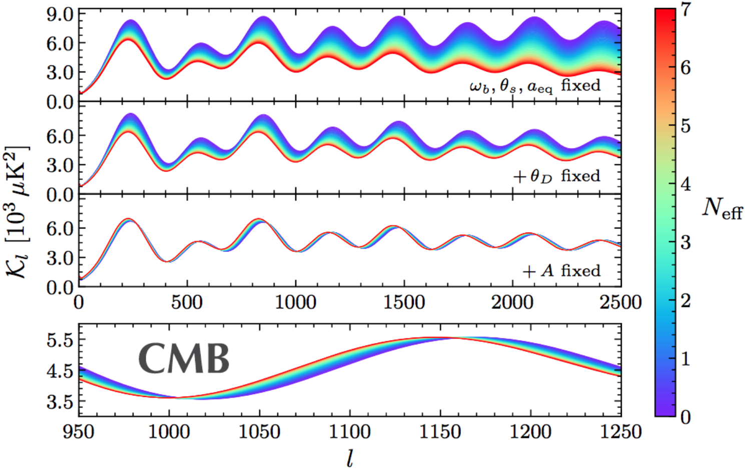
Neutrinos in the CMB Spectrum

The main effect of neutrinos is to increase the damping of the power spectrum (degenerate with helium fraction).



D. Baumann, D. Green & B. Wallisch (2017)

The oscillation have been imprinted during radiation domination

$$\ddot{\delta}_{b\gamma} - c_s^2\nabla^2\delta_{b\gamma} = \nabla^2\Phi$$

with solutions (Φ sourced by γ, DM, baryons)

$$\delta_{b\gamma} = A\cos(kr_s)$$

- The gravitational sources on the right only impact A, but they cannot change the phase (Bashinsky & Seljak 2003, Baumann et al. 2015).
- Any fluctuation in the grav. potential which travels faster than the baryon-photon plasma can generate a phase shift (free streaming neutrinos $c_\nu > c_\gamma$).

Evolution of density perturbations

The oscillation have been imprinted during radiation domination

$$\ddot{\delta}_{b\gamma} - c_s^2 \nabla^2 \delta_{b\gamma} = \nabla^2 \Phi$$

with solutions (Φ sourced by γ, DM, baryons $+ \nu$)

$$\begin{aligned} \delta_{b\gamma} &= A\cos(kr_s) + \delta B \sin(kr_s) \\ &= A\cos(kr_s + \phi) \end{aligned}$$

- The gravitational sources on the right only impact A, but they cannot change the phase (Bashinsky & Seljak 2003, Baumann et al. 2015).
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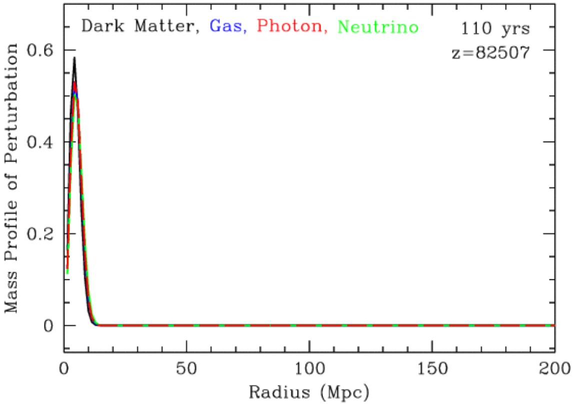
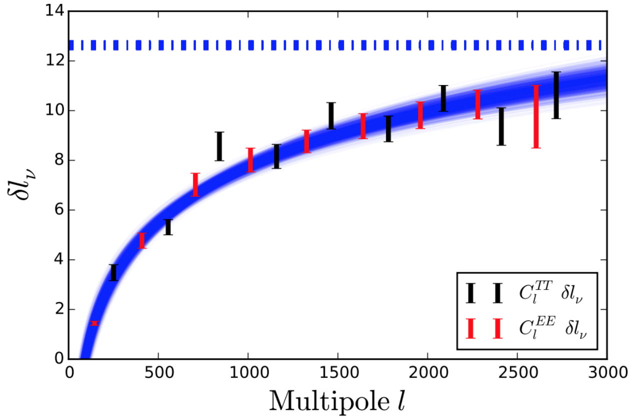
Free-streaming neutrinos overtake the photons, and pull them ahead of the sound horizon.



D. Eisenstein, H.-J. Seo & M. White (2007)

Phase shift detection in the CMB

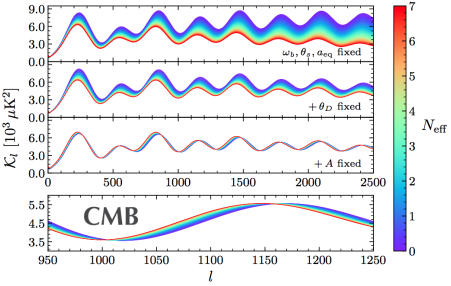
The Phase shift has recently been detected in the temperature and polarisation CMB spectrum.



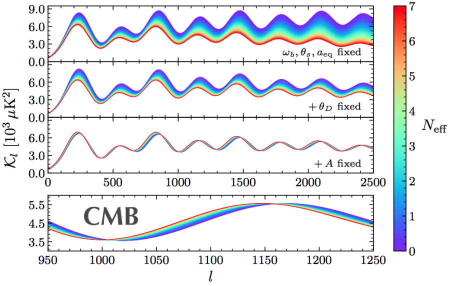
$$N_{\rm eff} = 2.8^{+1.1}_{-0.4}$$

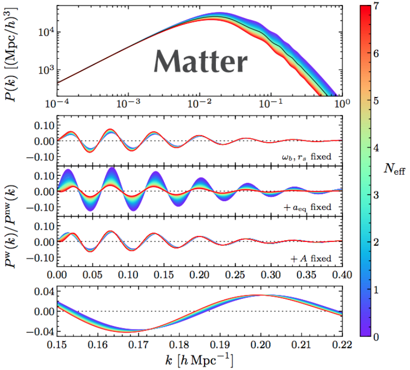
Follin, Knox, Millea & Pan (2015)

Neutrinos in the BAO Spectrum

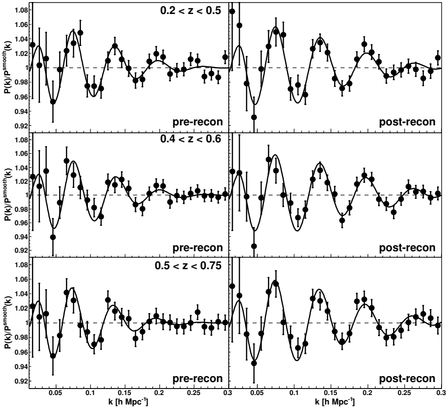


Neutrinos in the BAO Spectrum





D. Baumann, D. Green & B. Wallisch (2017)



Beutler et al. (2017)

$$D_A \sim 1.5\%$$
$$H \sim 2.5\%$$
$$D_V \propto \left[D_A^2/H\right]^{1/3} \sim 0.9\%$$

$\rightarrow$ The phase is immune to the effects of nonlinear evolution (Baumann, Green & Zaldarriaga 2017)

Fitting the BAO

- Start with linear $P(k)$ and separate the broadband shape, $P^{\rm sm}(k)$, and the BAO feature $O^{\rm lin}(k)$. Include a damping of the BAO feature:

$$P^{\rm sm,lin}(k) = P^{\rm sm}(k)\left[1 + (O^{\rm lin}(k/\alpha) - 1)e^{-k^2\Sigma^2_{\rm nl}/2}\right]$$

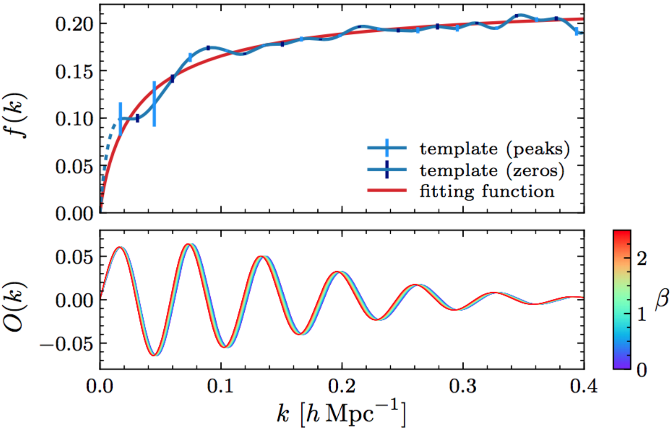
- Add broadband nuisance terms

$$A(k) = a_1 k + a_2 + \frac{a_3}{k} + \frac{a_4}{k^2} + \frac{a_5}{k^3}$$
$$P^{\rm fit}(k) = B^2 P^{\rm sm,lin}(k/\alpha) + A(k)$$

- Marginalize to get $\mathcal{L}(\alpha)$.

Neutrinos in the BAO Spectrum

$$O(k) = O_{\rm lin}(k/\alpha + (\beta - 1)f(k)/r_s^{\rm fid})e^{-k^2\sigma_{\rm nl}^2/2}$$



D. Baumann, F. Beutler, R. Flauger, D. Green, M. Vargas-Magana, A. Slosar, B. Wallisch & C. Yeche (2018)

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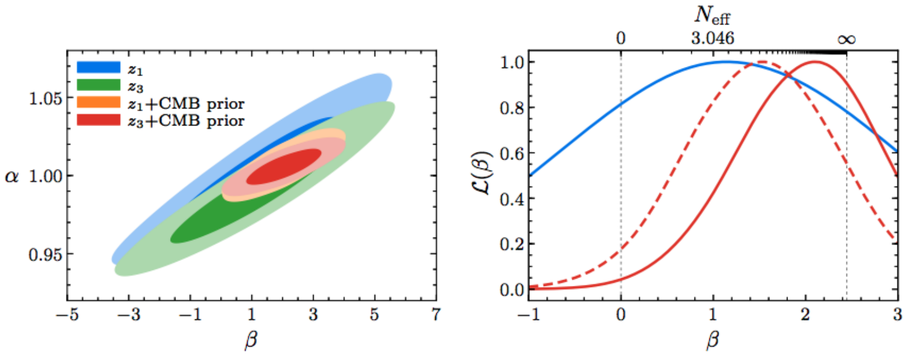

$$\beta(N_{\rm eff}) = \frac{\epsilon}{\epsilon_{\rm fid}} \quad \text{with} \quad \epsilon = \frac{N_{\rm eff}}{8(11/4)^{4/3}/7 + N_{\rm eff}}$$

→ This is a proof of principle for extracting information on light relics from galaxy clustering data.

D. Baumann, F. Beutler, R. Flauger, D. Green, M. Vargas-Magana, A. Slosar, B. Wallisch & C. Yeche (2018)

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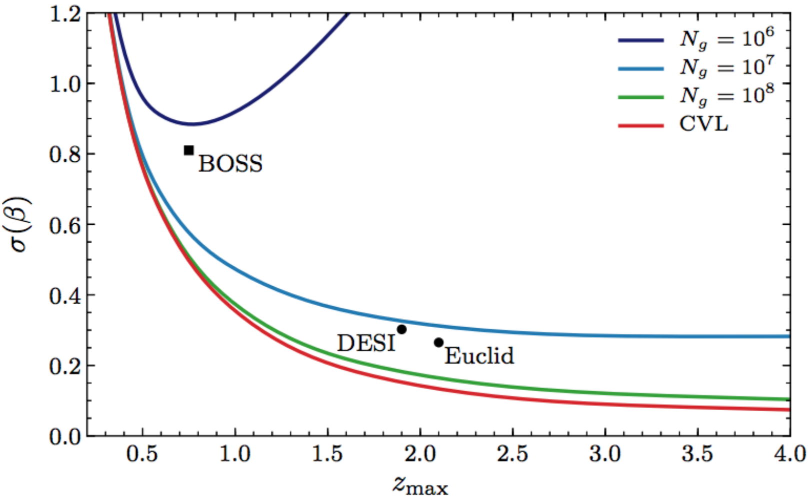
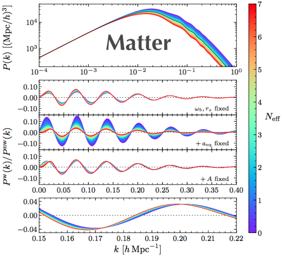
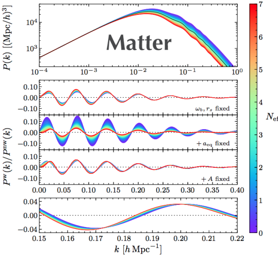


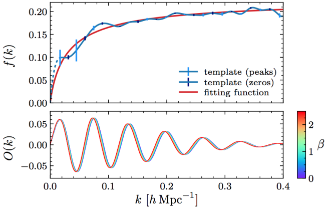
D. Baumann, F. Beutler, R. Flauger, D. Green, M. Vargas-Magana, A. Slosar, B. Wallisch & C. Yeche (2018)

Summary



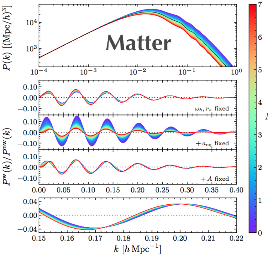
1. The phase of the BAO signature carries information on N_{eff} just as in the CMB. Indirect observable of the cosmic neutrino background.

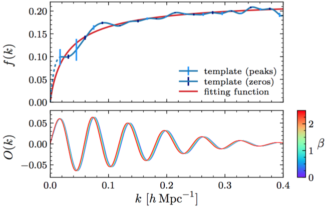


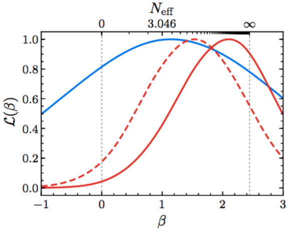


1. The phase of the BAO signature carries information on $N_{\rm eff}$ just as in the CMB. Indirect observable of the cosmic neutrino background.
2. The phase is (at least) as robust as the wavelength of the BAO offering a robust low redshift observable to **directly** constrain $N_{\rm eff}$.

Summary







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3. We have a low significance detection in BOSS and will be able to get $\sim 3-5\sigma$ detections in DESI and Euclid.

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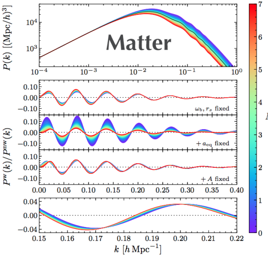

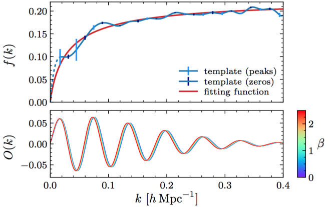

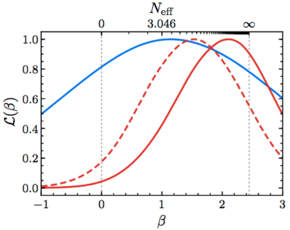

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3. We have a low significance detection in BOSS and will be able to get $\sim 3-5\sigma$ detections in DESI and Euclid.
4. First use of the BAO feature beyond its application as a standard ruler.