Light Relics

Cynthia Trendafilova
Maps to Power Spectra Working Group

CMB-S4 Spring Collaboration Meeting - March 11th, 2021

CMB-S4

Overview

- Our key cosmological parameter and focus is **N_{eff}** (“effective number of neutrino species”).
- Overview of DRAFT tool
- N_{eff} constraints from DRAFT tool
- Update on beam studies
- Join us for the Maps2Cell parallel session (12:30pm PST)

Neff

- $\mathbf{N_{eff}}$ - contribution of light relics to the energy density of the universe
- An important goal of CMB-S4 is to set stringent constraints on light relics.
- CMB-S4 target is $\boldsymbol{\sigma}(N_{eff}) = 0.03$: *"SR2.0: CMB-S4 shall determine N_{eff} with an uncertainty ≤ 0.06 at the 95% confidence level."*

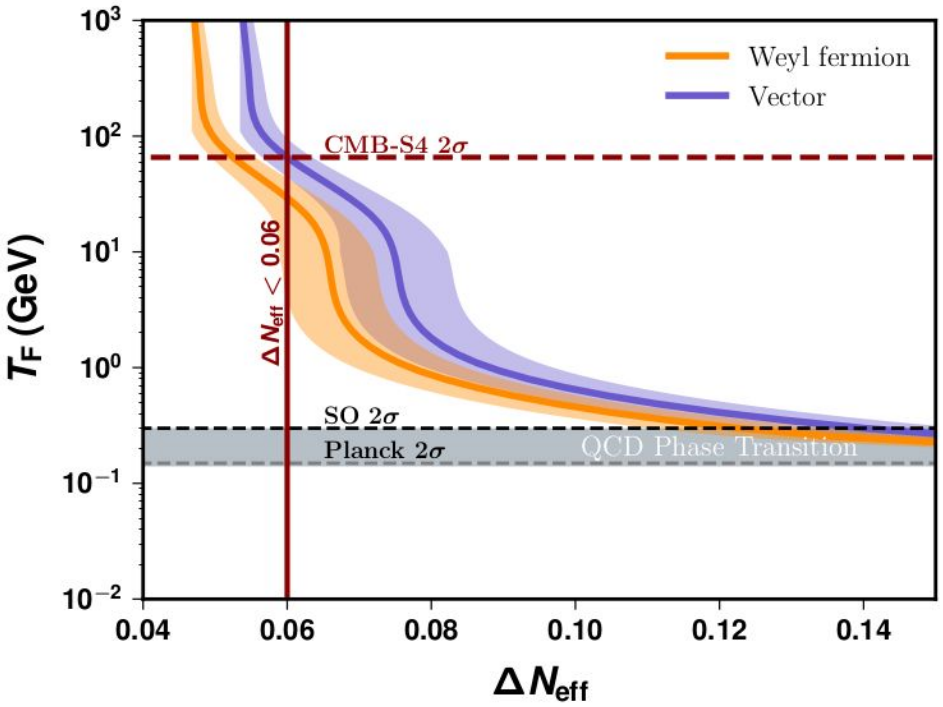
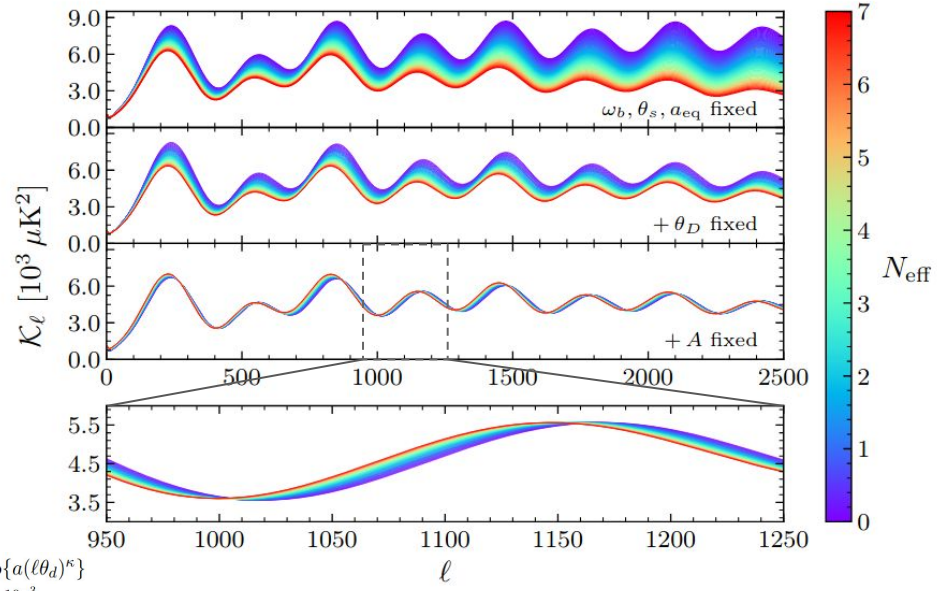


Figure 1-11 of PBDR

Neff as the high-\ell Science Driver



$$\mathcal{K}_\ell = \mathcal{D}_\ell^{TT} \exp\{a(\ell\theta_d)^\kappa\}$$
$$\theta_d \approx 1.6 \times 10^{-3}$$
$$a \approx 0.68,\ \kappa \approx 1.3$$

Wallisch (2018)

- Improving constraints on N_{eff} requires good measurements of the primary CMB (in particular TE and EE) at high ℓ.
- Other science that relies on high ℓ measurements also benefits from these improvements.

Forecasting Neff constraints for CMB-S4 surveys -- the DRAFT tool

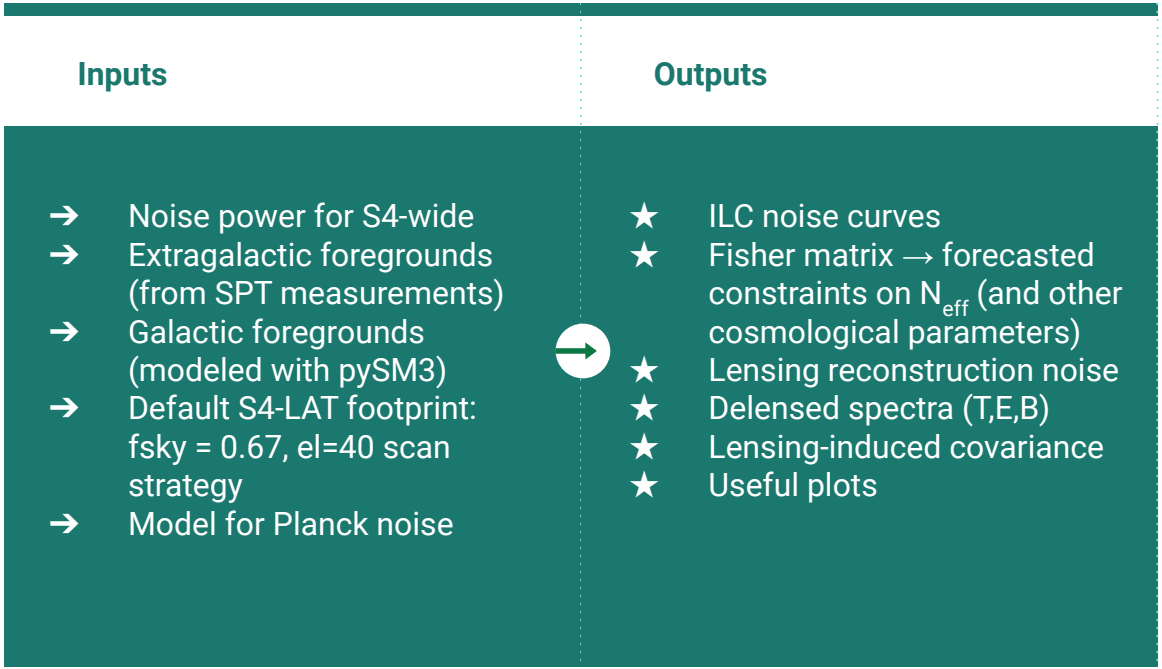
- Dark Radiation Anisotropy Flowdown Team (DRAFT)
  - foreground modeling and component separation: Srini Raghunathan
  - Fisher forecasting: S.R., Benjamin Wallisch, Joel Meyers
  - bias estimation: S.R., B.W., Cynthia Trendafilova, J.M.
  - beam effects: Dan Grin, Francis-Yan Cyr-Racine

- Modular design:
  - Internal Linear Combination (ILC) code from Srini
  - delensing Fisher code from J.M. & co.
    (based on arXiv:1609.08143 w/ Daniel Green, Alexander van Engelen)

- Plan to release a user-friendly wrapper incorporating both components.

- GitHub repository
  https://github.com/sriniraghunathan/DRAFT

DRAFT Tool


Inputs
Outputs
Noise power for S4-wide
Extragalactic foregrounds (from SPT measurements)
Galactic foregrounds (modeled with pySM3)
Default S4-LAT footprint: fsky = 0.67, el=40 scan strategy
Model for Planck noise
ILC noise curves
Fisher matrix → forecasted constraints on N_{eff} (and other cosmological parameters)
Lensing reconstruction noise
Delensed spectra (T,E,B)
Lensing-induced covariance
Useful plots

Sky masks for $\sigma(N_{eff})$

Inputs:

(A) **Noise power:** 27, 39, 93, 145, 225 and 278 GHz noise curves for S4-wide. Specs obtained from: https://cmb-s4.org/wiki/index.php/Expected_Survey_Performance_for_Science_Forecasting#Instrument_Definition

(B) **Extragalactic foregrounds:** Radio, CIB, tSZ and kSZ power spectra from SPT measurements (George et al. 2015; arXiv: 1408.3161).

(C) **Galactic foregrounds:** Dust and Synchrotron power spectra obtained from pySM3 simulations.

- (a) Default S4-LAT footprint: Covers fsky = 0.67 using el=40 scan strategy.
- (b) Computed and stored the auto/cross spectra for all bands for **clean/dirty masks** corresponding to different levels of galaxy masking.

Outputs:

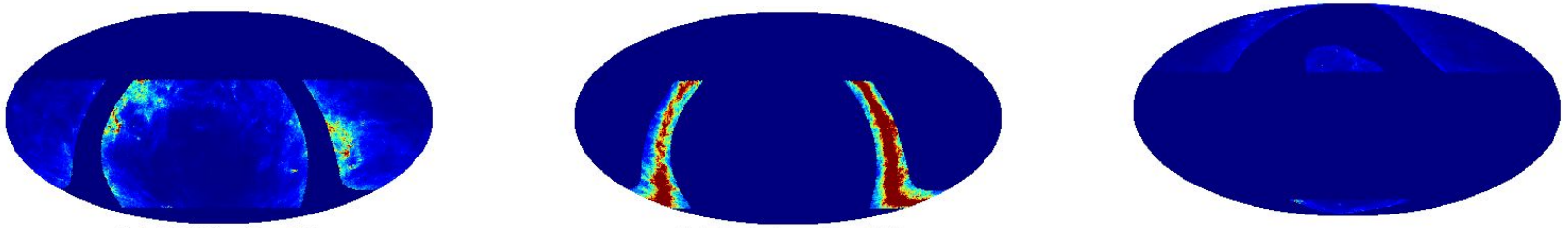
(A) ILC noise curves.

(B) Cosmological parameter constraints using Fisher forecasts: Specifically σ(Neff) for different levels of galaxy masking (fsky).

Mask 1
S4-Clean: fsky = 0.57

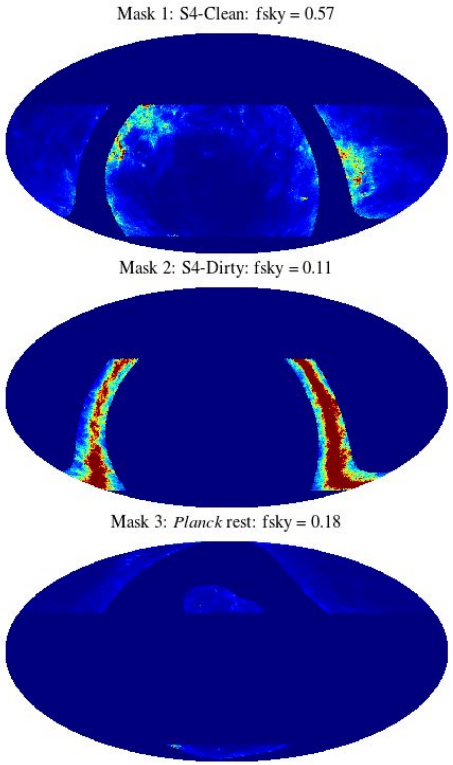
Mask 2
S4-Dirty: fsky = 0.11

Mask 3
Planck rest of sky: fsky = 0.18



S4/*Planck* masks overlayed on galactic dust emission at 145 GHz.

Summary about $\sigma(N_{eff})$



S4/*Planck* masks overlayed on galactic dust emission at 145 GHz.

Mask	**Sky fraction f_{sky}**	**σ(Neff)**
S4-Clean	0.57	0.0327
S4 + *Planck*	0.57 (S4) 0.18 (*Planck*)	0.0324

Datasets used:

- S4-Clean: delensed S4+*Planck* TT/EE/TE + lensing: $2 \leq \ell \leq 5000$.
  - Here *Planck* is added to S4-CMB data using inverse variance weighting. This helps to remove the S4 1/f noise.
- *Planck:* TT/EE/TE + lensing: $2 \leq \ell \leq 2500$.
- If we trusted pySM in the dirty patch (but we don't), we would hit the target.

Combining S4-Wide with S4-Ultradeep

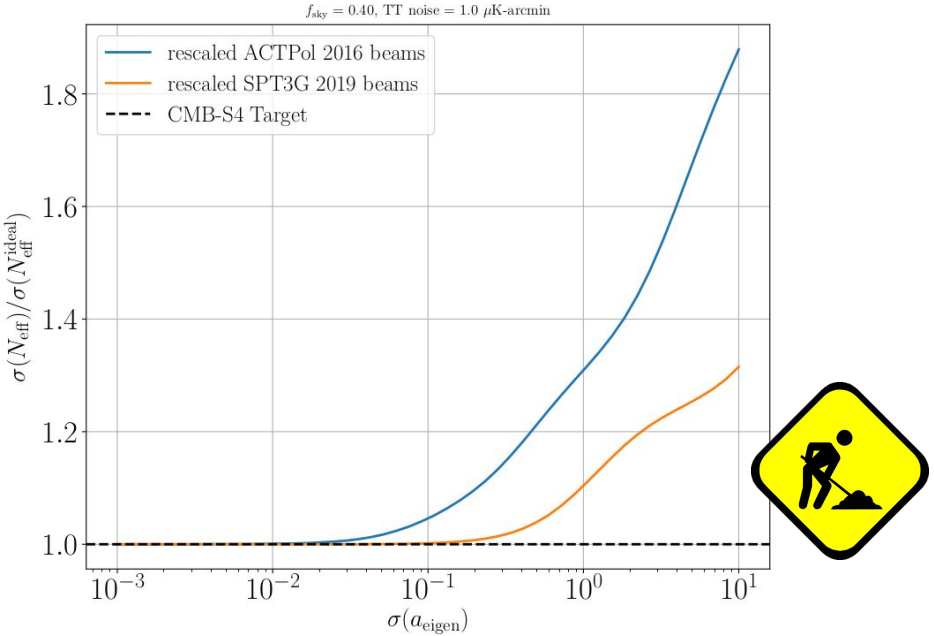
Mask	**Sky fraction f_{sky}**	**σ(Neff)**	**Comments**
S4-Clean	0.57	0.0327	S4-Clean: Patch with low galactic emission.
S4-Ultra deep	0.03	0.0829	S4-Ultra deep: Assume zero galactic emission.
S4-Clean + S4-Ultra deep	0.57	0.0309	Combining S4-Clean and S4-Ultra deep. ***(Conservative: overlapping region is removed.)***
S4-Clean + S4-Ultra deep + *Planck*	0.57 (S4) 0.18 (*Planck*)	0.0307	S4-Clean, S4-Ultra deep, and *Planck*.

Beams

- We are investigating the impact of beam uncertainties on meeting our science goals (led by Dan Grin and Francis-Yan Cyr-Racine).
- Because we rely on information from small scales, beam uncertainty will impact the N_{eff} constraints.
- What have current experiments achieved, and how well do we need to do in comparison?

CMB-S4 will require improvements to beams

- Preliminary results: achieving the desired $\sigma(N_{eff})$ requires eigenmode amplitudes (beam noise levels) better than current experiments (Dan Grin and Francis-Yan Cyr-Racine).



Light Relics Summary

- We forecast $\sigma(N_{eff}) = 0.0307$ for clean parts of the S4 survey.
- Under active investigation:
  - Effect of beam errors on N_{eff} constraints
  - Biases from residual galactic foregrounds
- Attend the Light Relics parallel session for further discussion:
  - Thursday, March 11th, 2021
  - 12:30pm PST - 2:00pm PST