CMB-S4 Preliminary Baseline Design Validation - Measurement to Science: Light Relics

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Work done with: *Joel* **Meyers**, *Cynthia* **Trendafilova**, and *Benjamin* **Wallisch.**

Baseline setup

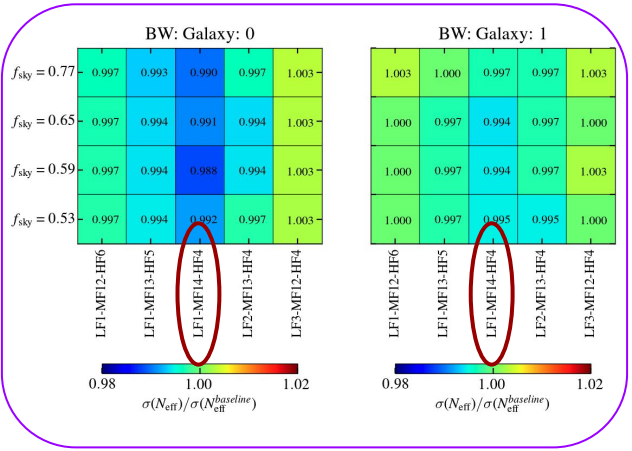
- **Goal:**
  - Developing **Dark Radiation Anisotropy Flowdown Team (DRAFT)** tool to forecast cosmological parameter constraints.
  - Forecast $\boldsymbol{\sigma}(N_{eff})$ from S4-Wide Chilean LAT (+ delensing LAT).
  - N_{eff} as a driver of S4-Wide frequency coverage.
  - Biases from residual foregrounds. (Ben will cover this in the next talk in a bit more detail).
- **Instrument specs:**
  - **S4-Wide (Chilean LAT):**
    https://cmb-s4.org/wiki/index.php/Expected_Survey_Performance_for_Science_Forecasting#Instrument_Definition
    - *We also investigate the importance of using the delensing LAT for* $\boldsymbol{\sigma}(N_{eff})$.
    - https://cmb-s4.org/wiki/index.php/Delensing_sensitivity_-_updated_sensitivities,_beams,_TT_noise
  - **Bands:** 30, 40, 95, 145, 225, 278 GHz.

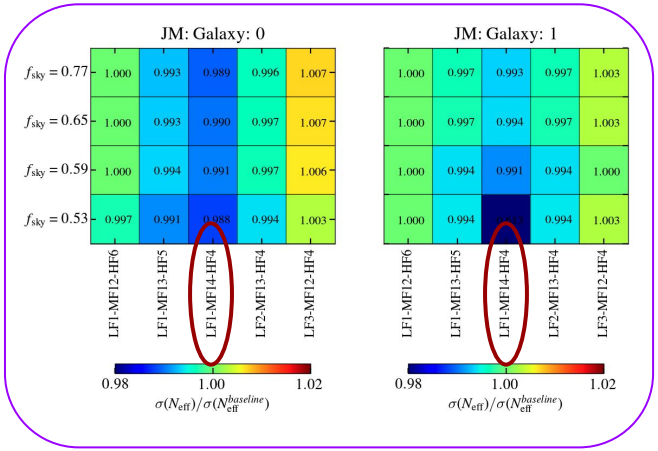
DRAFT tool

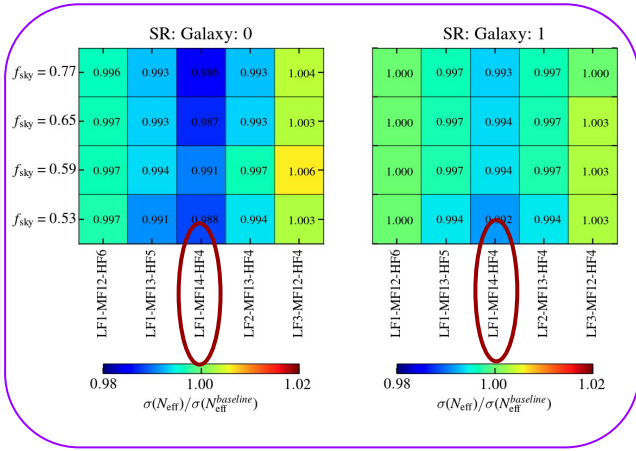
- GitHub repo link:
  - https://github.com/sriniraghunathan/DRAFT
  - https://github.com/sriniraghunathan/cmbs4_fisher_forecasting
  - Delensing code from Joel Meyers (Green et al. 2016, arXiv: 1609.08143).
  - Currently integrating all of this into one.
- **What does the tool do?**
  - Optimally combines data from different bands using noise + foreground signals in different bands.
    - How are the foregrounds modelled?
      - **Extragalactic foregrounds:** Radio, CIB, tSZ and kSZ power spectra from SPT measurements (George et al. 2015, arXiv: 1408.3161 and Reichardt et al. 2020, arXiv: 2002.06197).
      - **Galactic foregrounds:** Dust and Synchrotron power spectra obtained from pySM3 simulations.
  - Computes lensing noise curves using residual noise.
  - Combines delensed CMB spectra and lensing spectra to forecast cosmological parameter constraints using Fisher formalism.
  - Estimates biases in cosmological parameters due to residual foregrounds also using Fisher formalism.

N_{eff} as a driver of S4-Wide frequency coverage

Datasets: Delensed S4 `TT/EE/TE` + *Planck* + lensing: $\sigma(N_{eff})/\sigma(N_{eff}^{baseline})$: Ben, Joel, and Srini



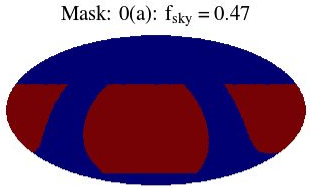


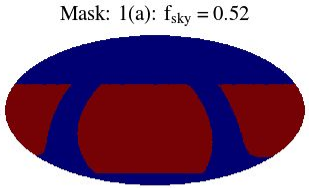


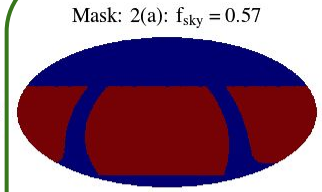
- Legend: LF**X**-MF**Y**-HF**Z** → X low freq. 30/40 GHz tubes; Y medium freq. 90/150 GHz tubes; Z high freq. 220/270 GHz tubes.
  - Baseline DSR configuration: LF2-MF12-HF5.
- LF1-MF14-HF4, highlighted with a circle, gives the best result for all authours.
- LF3-MF12-HF4 is the worst. **Adding more LF detectors does not help.**
- All configurations but LF3-MF12-HF4 are better than the baseline configuration.
  - But the difference in performance is at sub-per cent level (even for LF1-MF14-HF4).
  - Furthermore, from SZ study, which cares mostly about temperature and hence CIB, we know that reducing the number of HF detectors is sub-optimal.

Sky coverage / masks: el_40 footprint

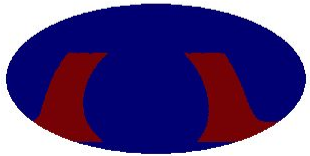
Clean masks

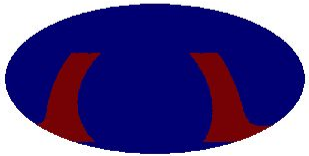


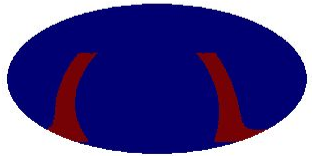




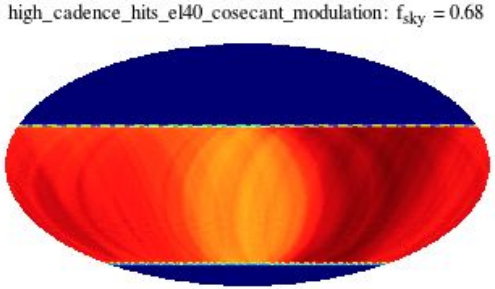
Dirty masks





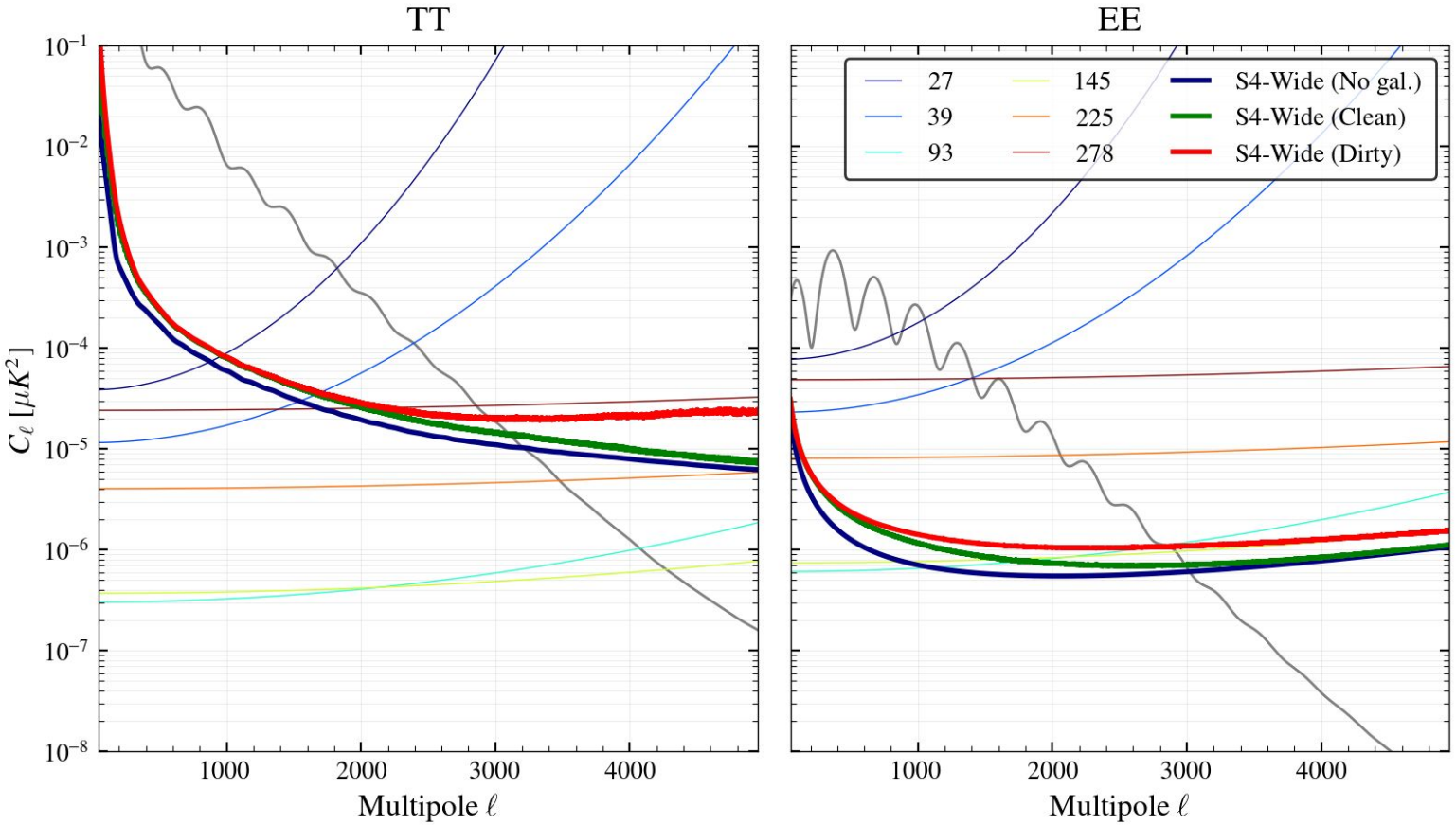


Clean + dirty = full S4 footprint

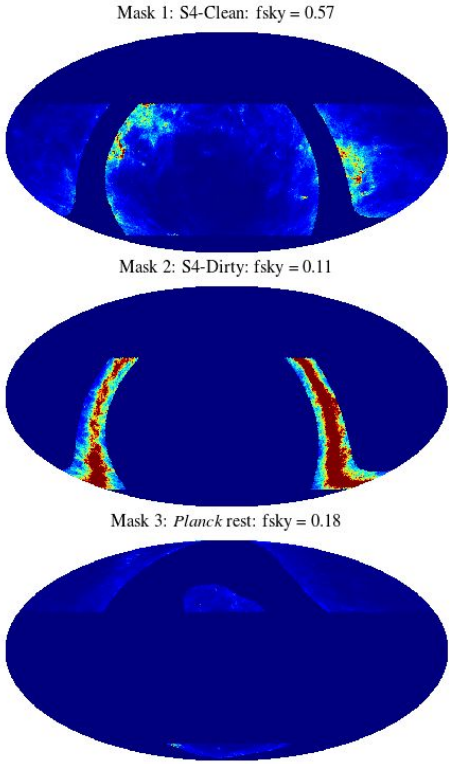


Baseline masks: *Maximises the "Clean" sky area.*

S4-Wide: ILC residuals



Constraints with S4-Wide: $\sigma(N_{eff})$



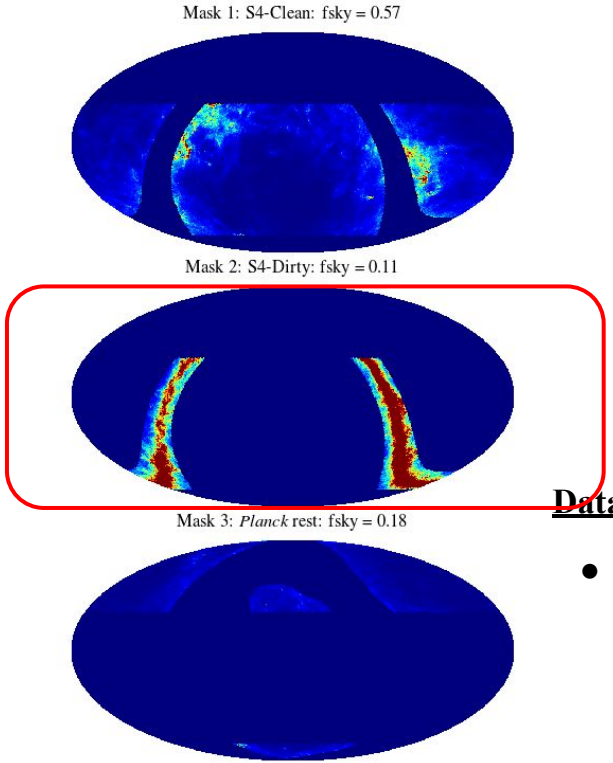
S4/*Planck* masks overlayed on galactic dust emission at 145 GHz.

Mask	Sky fraction f_{sky}	σ(Neff)
S4-Clean	0.57	**0.0327**
S4-Dirty	0.11	0.0815
S4	0.57 (S4-Clean) 0.11 (S4-Dirty)	0.0303
S4 + *Planck*	0.68 (S4) 0.18 (*Planck*)	0.0299

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.
  - $\ell_{max} = 3000$ (temperature) and 5000 (polarisation) for lensing noise estimation.
- S4-Dirty: delensed S4 TT/EE/TE + lensing: $30 \leq \ell \leq 5000$.
- *Planck:* TT/EE/TE + lensing: $2 \leq \ell \leq 2500$.

Constraints with S4-Wide: $\sigma(N_{eff})$



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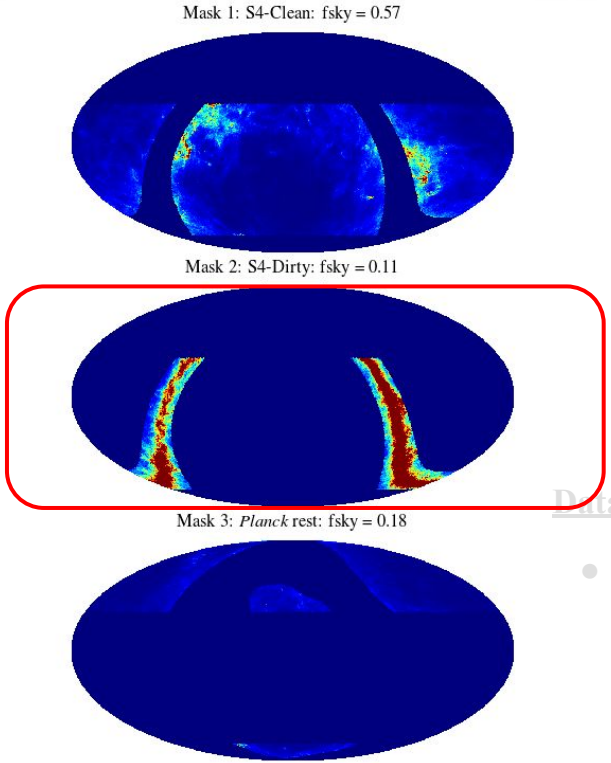

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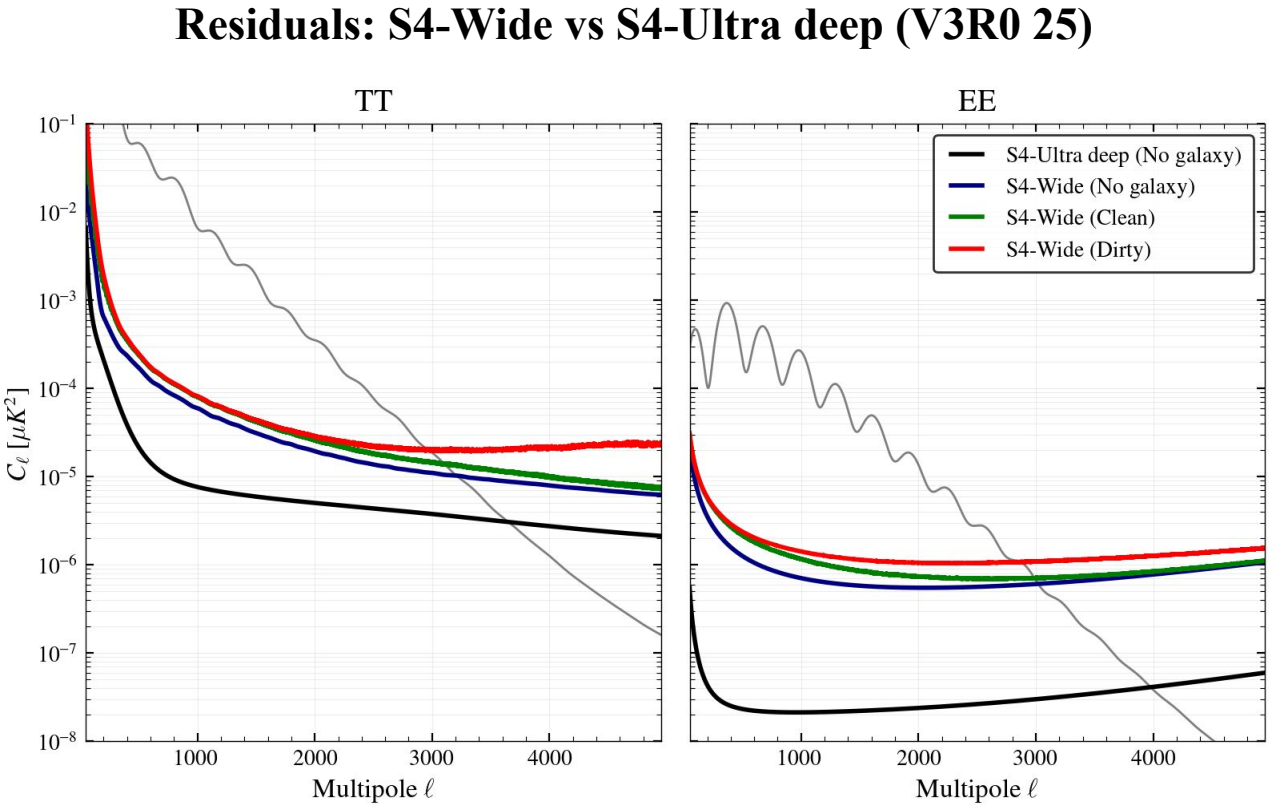
S4-Dirty	0.11	0.0815

But can we trust numbers from the dirty patch?

- How reliable are the galactic emission simulations close to the plane of our galaxy?
- Can we model the residual foregrounds properly to remove any potential bias?

Can the delensing LAT help us remove the dirty patch?

Specs: https://cmb-s4.org/wiki/index.php/Delensing_sensitivity_-_updated_sensitivities,_beams,_TT_noise



$\sigma(N_{eff})$: Combining S4-Wide and S4-Ultra deep

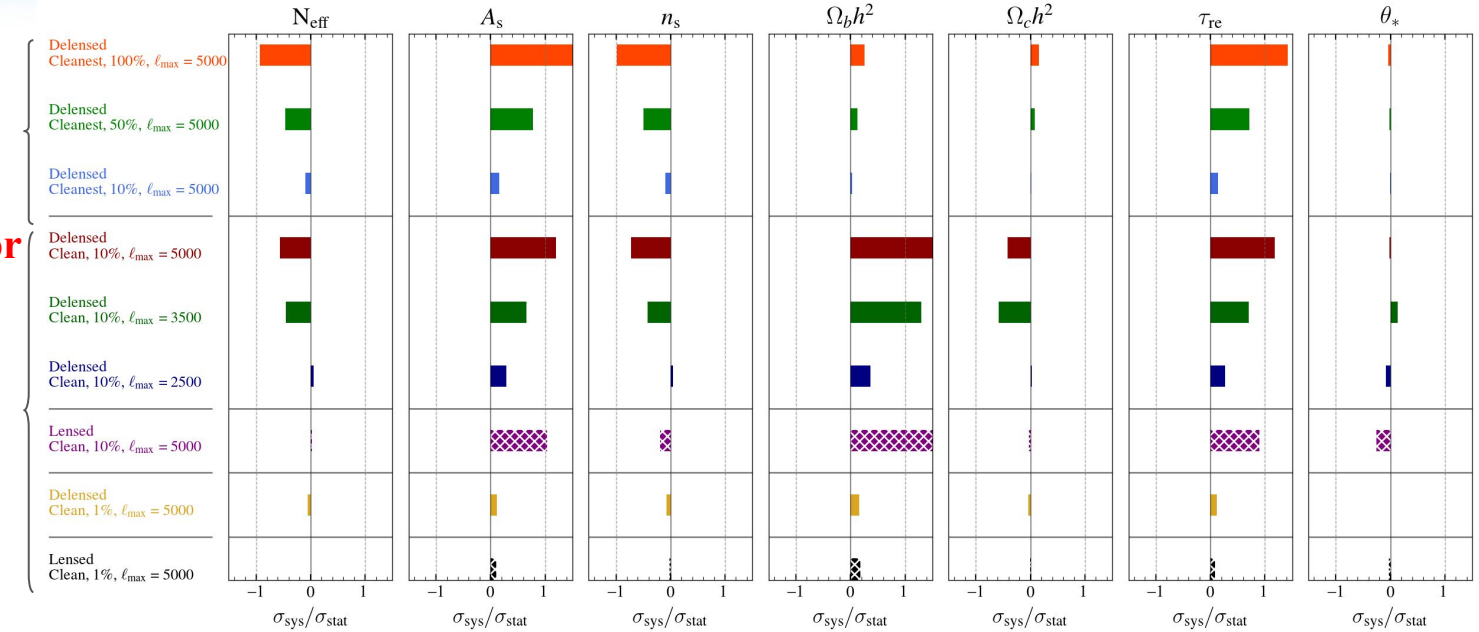
Mask	Sky fraction f_{sky}	σ(Neff)	Comments
S4-Clean	**0.57**	**0.0327**	**S4-Clean: Patch with low galactic emission.**
S4-Clean	0.54	0.0333	S4-Clean: Removing overlap with S4-Ultradeep.
S4-Ultra deep	**0.03** **(0.04)**	**0.0829** **(0.0717)**	**S4-Ultra deep: No galactic emission.**
S4-Clean + S4-Ultra deep	**0.57**	**0.0309** **(0.0302)**	**Combining S4-Clean and S4-Ultra deep.** ***(Conservative: overlapping region removed from S4-Wide.)***
S4-Clean + S4-Ultra deep + *Planck*	0.57 (S4) 0.18 (*Planck*)	0.0307 (0.03)	S4-Clean, S4-Ultra deep, and *Planck*.
S4-Clean + S4-Dirty + S4-Ultra deep + *Planck*	0.68 (S4) 0.18 (*Planck*)	0.0287 (0.0281)	S4-Clean, S4-Dirty, S4-Ultra deep and *Planck*.

Fisher: Biases due to residual galactic foregrounds

Corresponds to emission in BICEP/SPT field

Not likely a problem for current experiments.

Corresponds to emission in the clean region



- We are currently seeing pretty large biases due to residual galactic emissions.
- Solutions:
  - Apply ℓ_{max} cut - but this can increase error bars.
  - Marginalise over residual galactic emission amplitude and spectral tilt. Are there reasonable priors that we can assume?
  - Other techniques - Better component separation, ++
- *More discussion about this in Ben's talk.*