# CMB lensing with PICO

#### Alexander van Engelen Canadian Institute for Theoretical Astrophysics University of Toronto

## Lensing/Delensing



# Lensing/Delensing

• Delensing: r, N<sub>eff</sub>

- Large-scale lensing:  $\Sigma m_v$ , w
- Small-scale lensing: w,  $\Sigma m_v$

 Correlation between lensing and tracers: See Marcel's talk (next)







#### Neutrino mass constraints





#### Autospectrum state of the art



#### Updated from Sherwin, AvE, ++2017

# What is possible with PICO? Planck 2015 PICO forecast





# Why is PICO better?

#### Lensing noise vs. instrumental noise



- Polarization rather than Temperature
- Max-like/iterative estimators



# Which CMB modes need to be measured?



#### PICO v3 noise curves



#### Noise levels and delensing

- Lensed B-modes give a noise floor of 5 uK-arcmin
- Hu & Okamoto QE non-optimal
  - Iterate! Reconstruction and Delensing strongly linked

$$\begin{split} N_{\ell}^{\phi\phi} &= \left[ \frac{1}{2\ell+1} \sum_{\ell_{1}\ell_{2}} |f_{\ell_{1}\ell_{2}\ell}^{EB}|^{2} \left( \frac{1}{C_{\ell_{1}}^{B_{\text{res}}} + N_{\ell_{1}}^{BB}} \right) \left( \frac{(C_{\ell_{2}}^{EE})^{2}}{C_{\ell_{2}}^{EE} + N_{\ell_{2}}^{EE}} \right) \right]^{-1} \\ C_{\ell_{1}}^{B_{\text{res}}} &= \frac{1}{2\ell_{1}+1} \sum_{\ell_{2}\ell} |f_{\ell_{1}\ell_{2}\ell}^{EB}|^{2} \left[ C_{\ell_{2}}^{EE} C_{\ell}^{\phi\phi} - \left( \frac{(C_{\ell_{2}}^{EE})^{2}}{C_{\ell_{2}}^{EE} + N_{\ell_{2}}^{EE}} \right) \left( \frac{(C_{\ell}^{\phi\phi})^{2}}{C_{\ell}^{\phi\phi} + N_{\ell}^{\phi\phi}} \right) \right] \end{split}$$

starting by taking  $C_{\ell}^{B_{\text{res}}} = C_{\ell}^{B_{\text{len}}}$  in the first iteration.

#### Noise levels and delensing



#### Delensing



## "Delensing beyond the B modes"

#### **CMB T correlation function**



#### Green, Meyers, AvE 2016

# **Delensing - recent detections**



SPT BB: Manzotti, Story, Wu+2017



Planck TT: Larsen+, ΦPlanck-CIB



#### Planck BB: Carron+, *q*internal



#### Possible concerns

• Dust, synchrotron





-0.00<del>03</del>000<del>2</del>0.00<del>2</del>0.00<del>3</del>0.00<del>3</del>0.000**0**500000.0005

#### Vansyngel+ dust simulation

#### Bias to lensing autospectra from Planck FFP8 sims

CORE lensing paper (Challinor, Allison++2017) arXiv:1707.02259



#### Delensing with dust:

Vansyngel sim in both  $\phi$  and B modes



### Delensing with dust:

Vansyngel sim in both  $\phi$  and B modes



# Summary: PICO would provide unique results for CMB lensing

• Neutrino mass will soon be tau-limited - PICO gives CVL tau

 Lensing sensitivity comparable to ground-based survey on 2030 timescale

- Delensing is crucial for B modes PICO should do this independently
  - Dust/Synchrotron on small scales could be important -> frequency coverage