Cosmology with SPT-3G

Cail Daley
CosmoStat, CEA Paris-Saclay

on behalf of the SPT-3G collaboration

ESLAB Euclid Symposium
March 25, 2025

Outline

- Cosmology with the Cosmic Microwave Background (CMB)
- The South Pole Telescope (SPT) and the SPT-3G camera

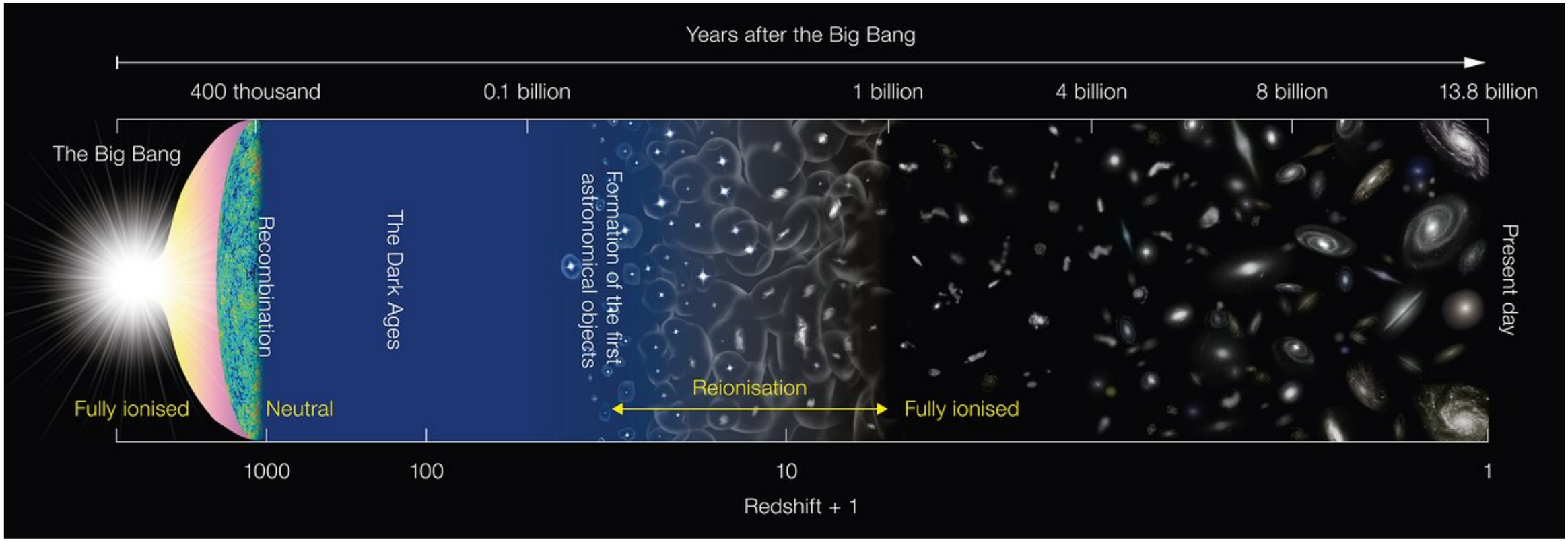
- Recent and upcoming 2019+2020 SPT-3G results:
  - **Three analyses:** MUSE, TT/TE/EE, and CMB lensing ($\phi\phi$)
- Beyond 2019+2020: the Ext-10k survey

- SPT-3G and Euclid

Cosmology with the CMB

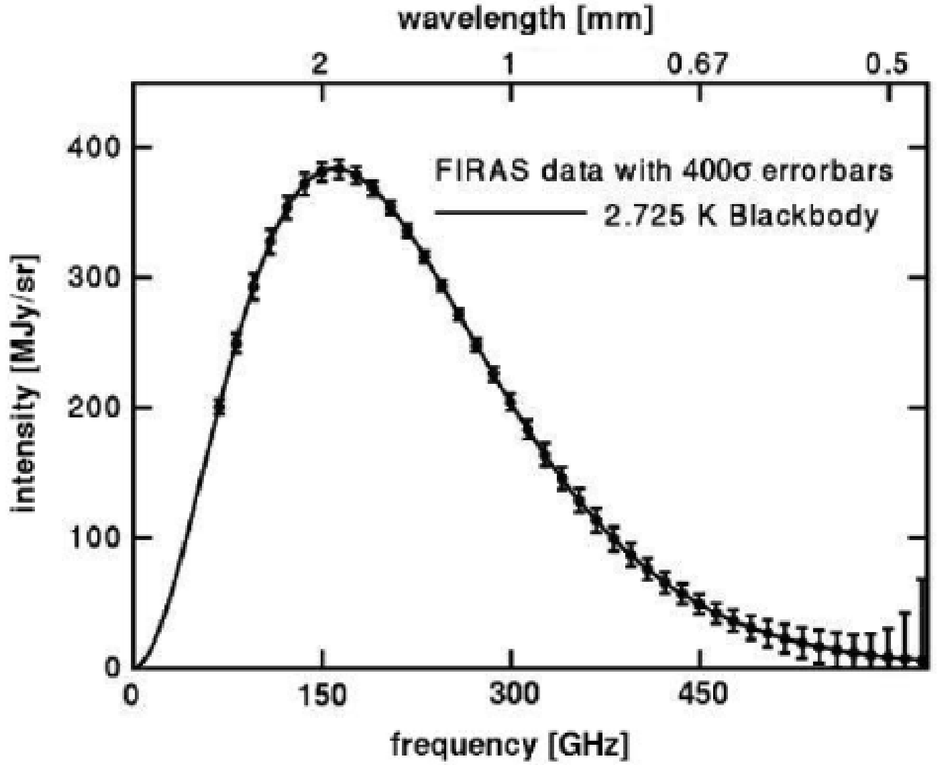
most distant observable electromagnetic radiation $\Longrightarrow$ early-Universe physics

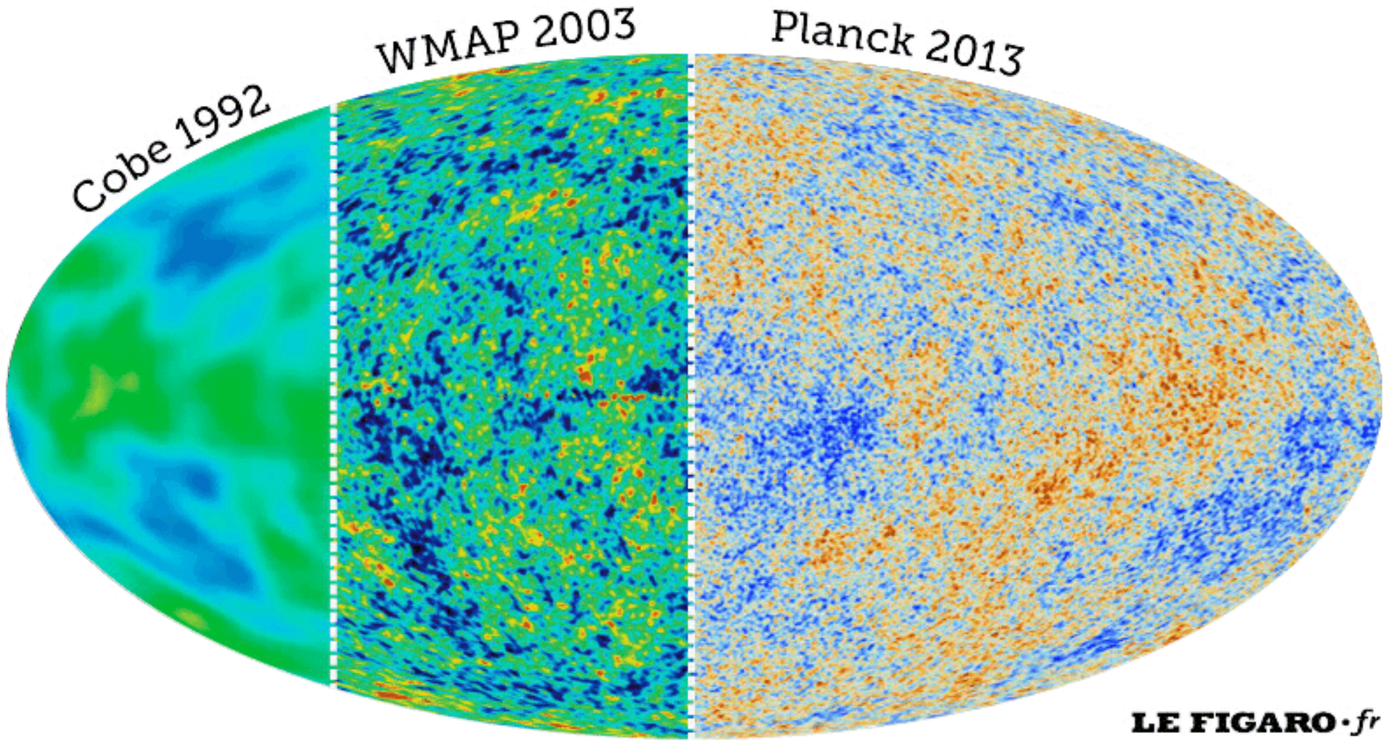
illuminates the Universe's evolution: reionization, structure growth, astrophysics..



NAOJ

Cosmology with the CMB

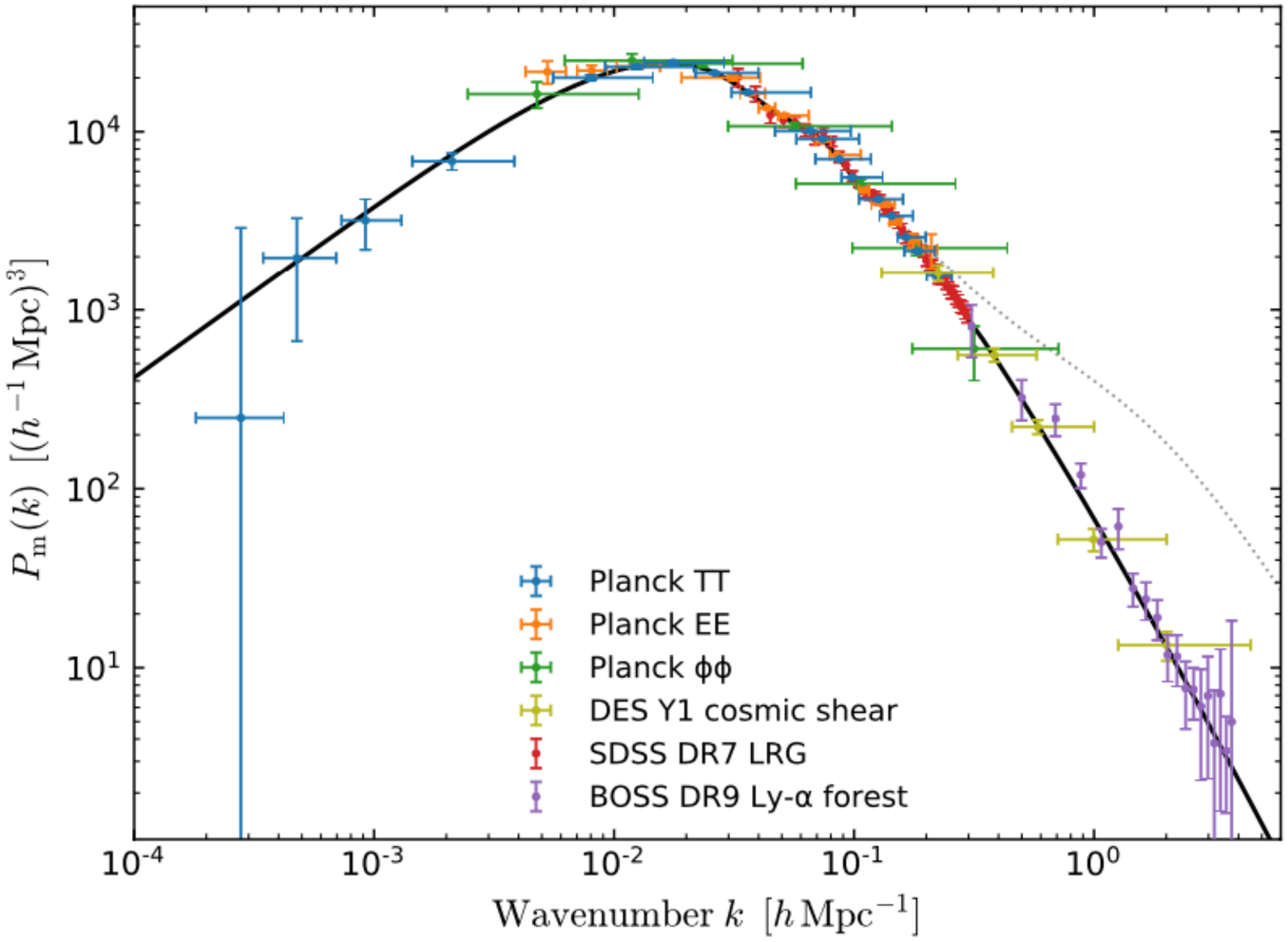




Turner (2022): The Road to Precision Cosmology

ΛCDM Concordance

six-parameter model predicts a wide range of cosmic observables:

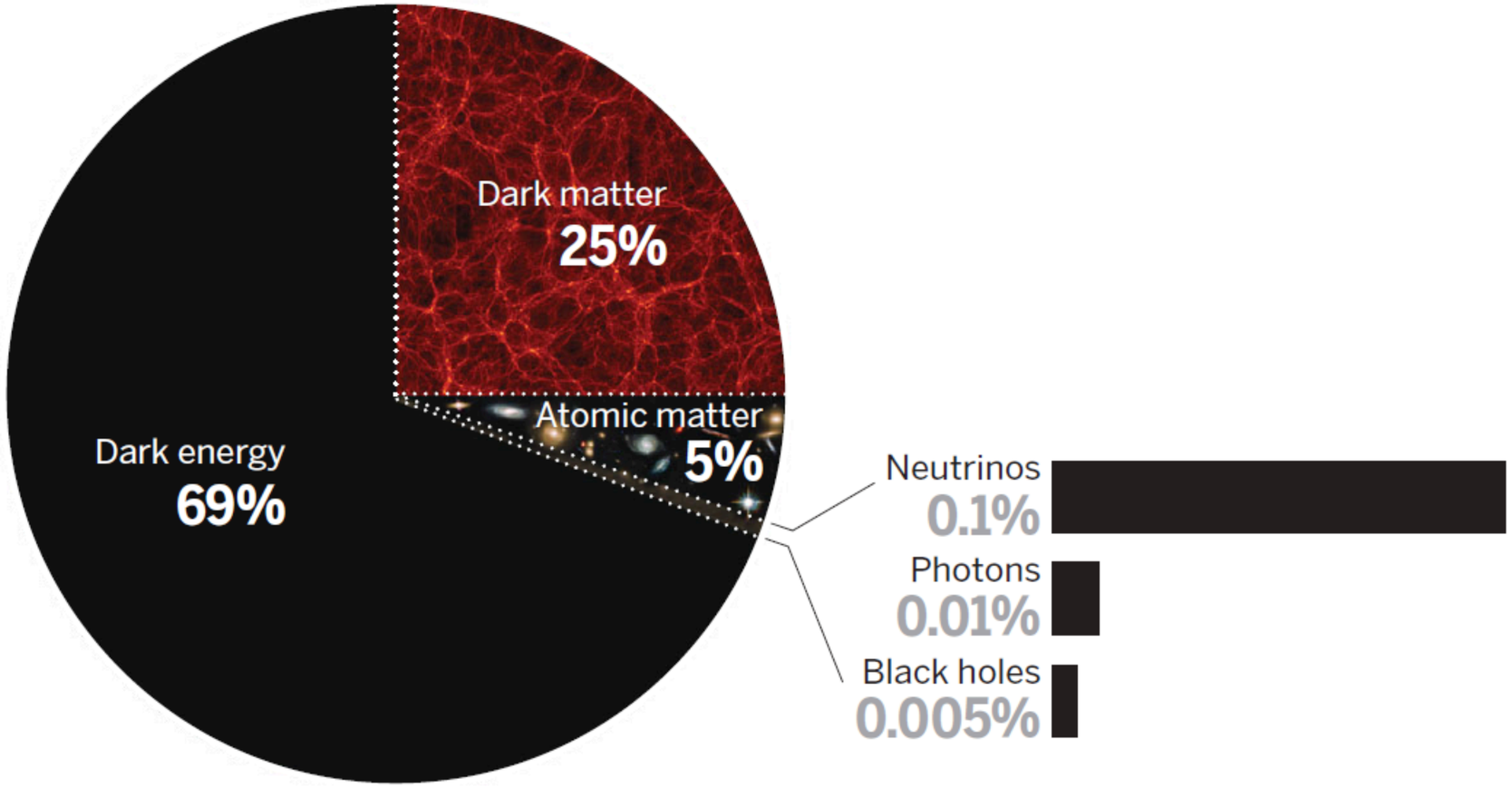


Planck Collaboration (2018)

ΛCDM Phenomenology

The multiple components that compose our universe

Current composition (as the fractions evolve with time)



David Spergel / AAAS / Science

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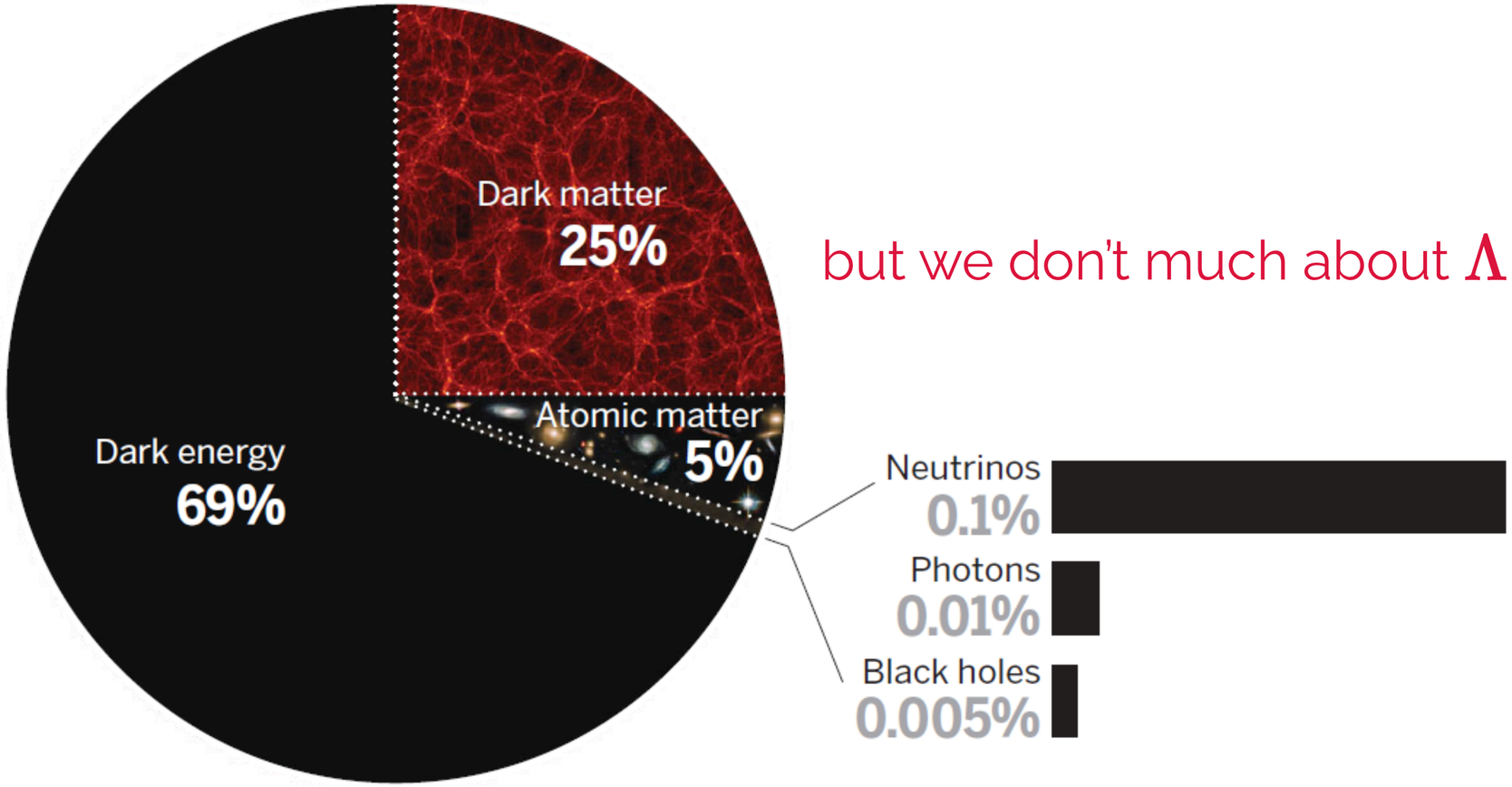
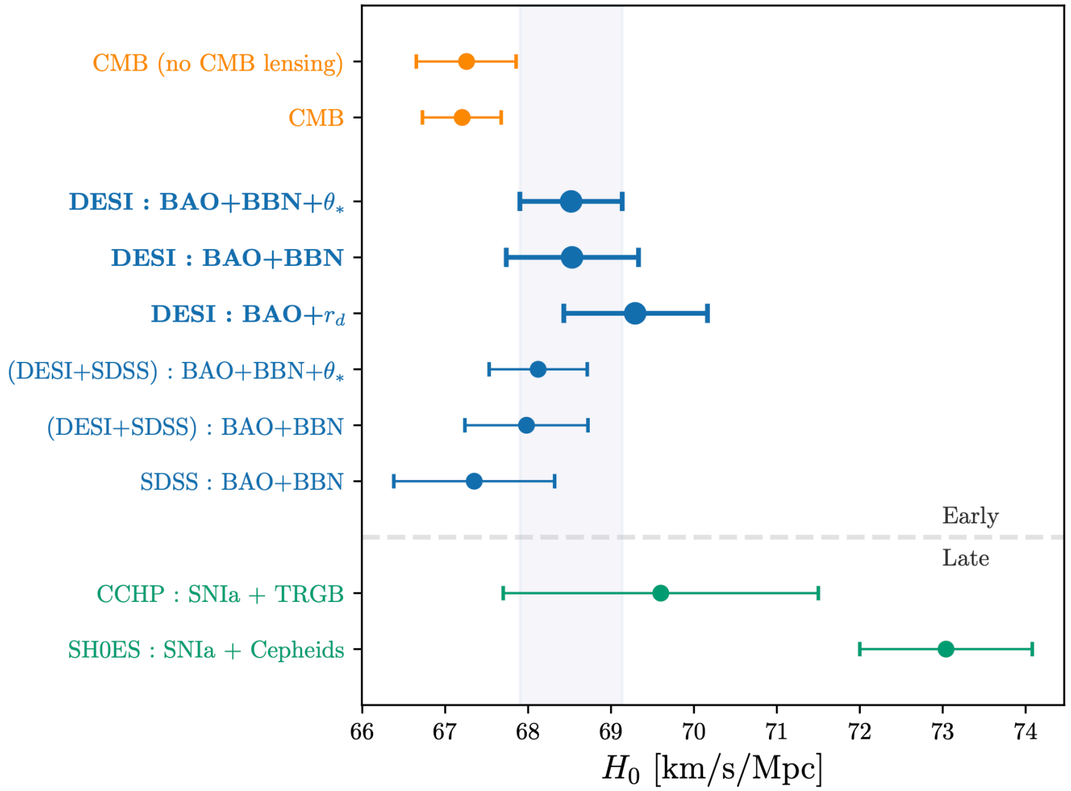


but we don't much about Λ *or* CDM!

David Spergel / AAAS / Science

ΛCDM Cracks

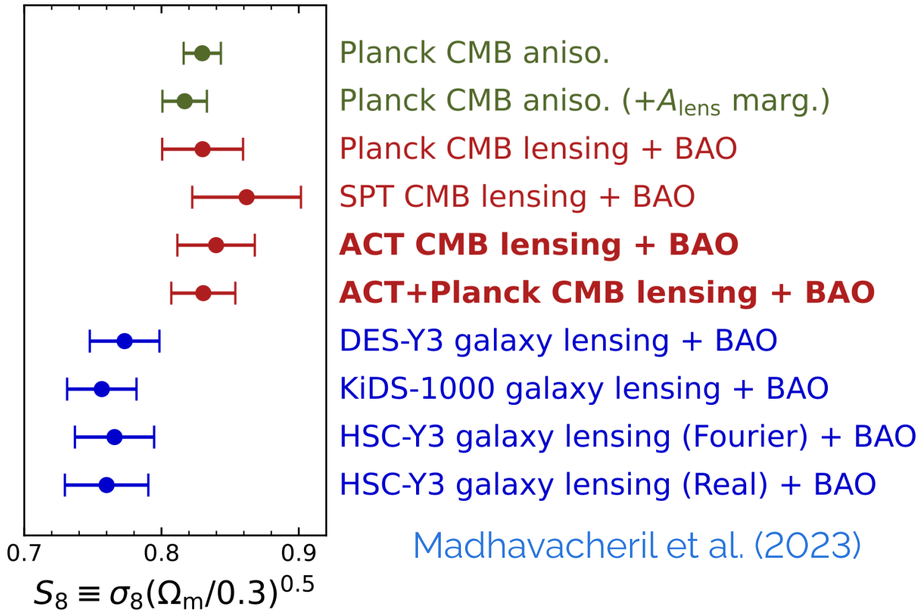
- Tensions between early- and late-time measurements of H_0



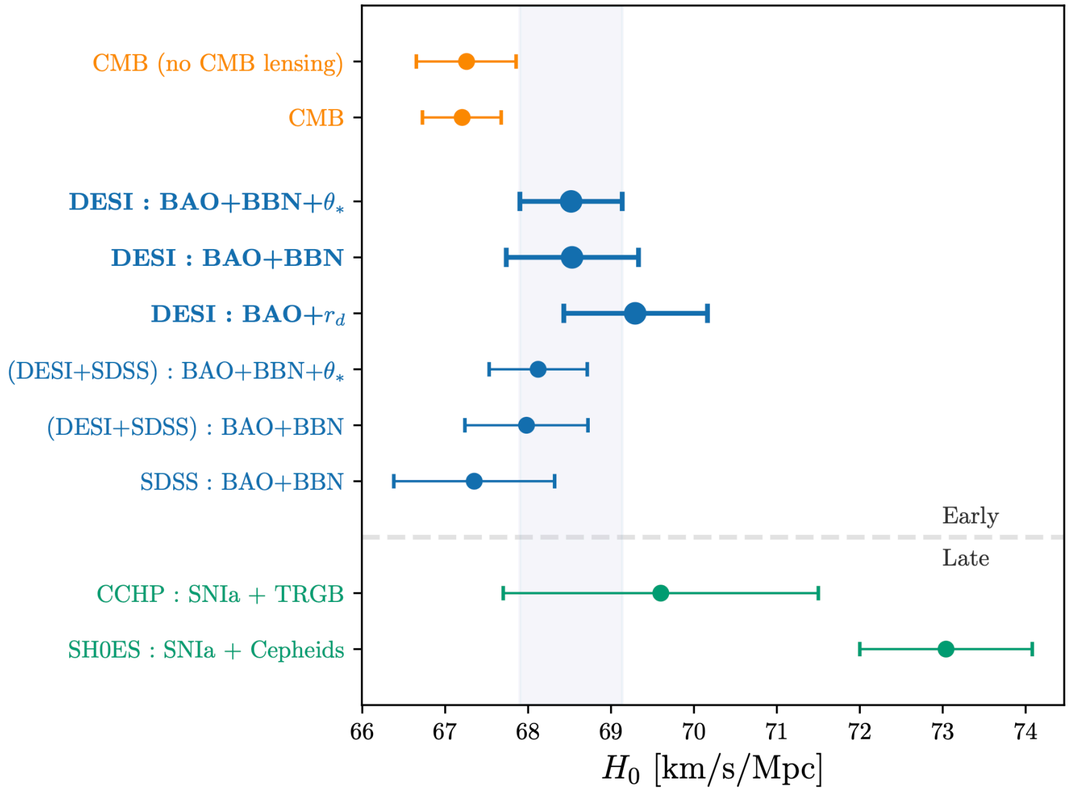
DESI Collaboration (2024)

ΛCDM Cracks

- Tensions between early- and late-time measurements of H_0 and S_8:



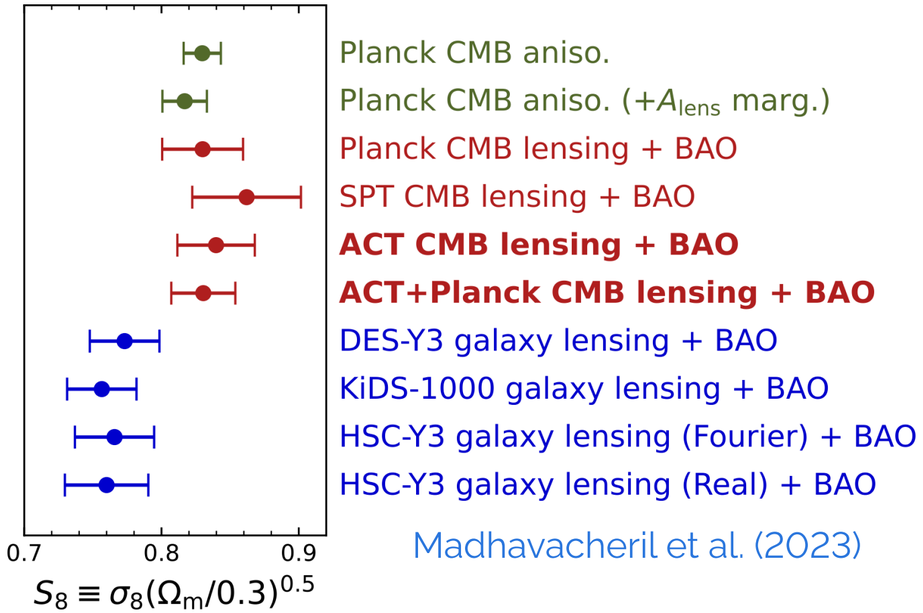
Madhavacheril et al. (2023)



DESI Collaboration (2024)

ΛCDM Cracks

- Tensions between early- and late-time measurements of H_0 and S_8:
- Low neutrino masses?



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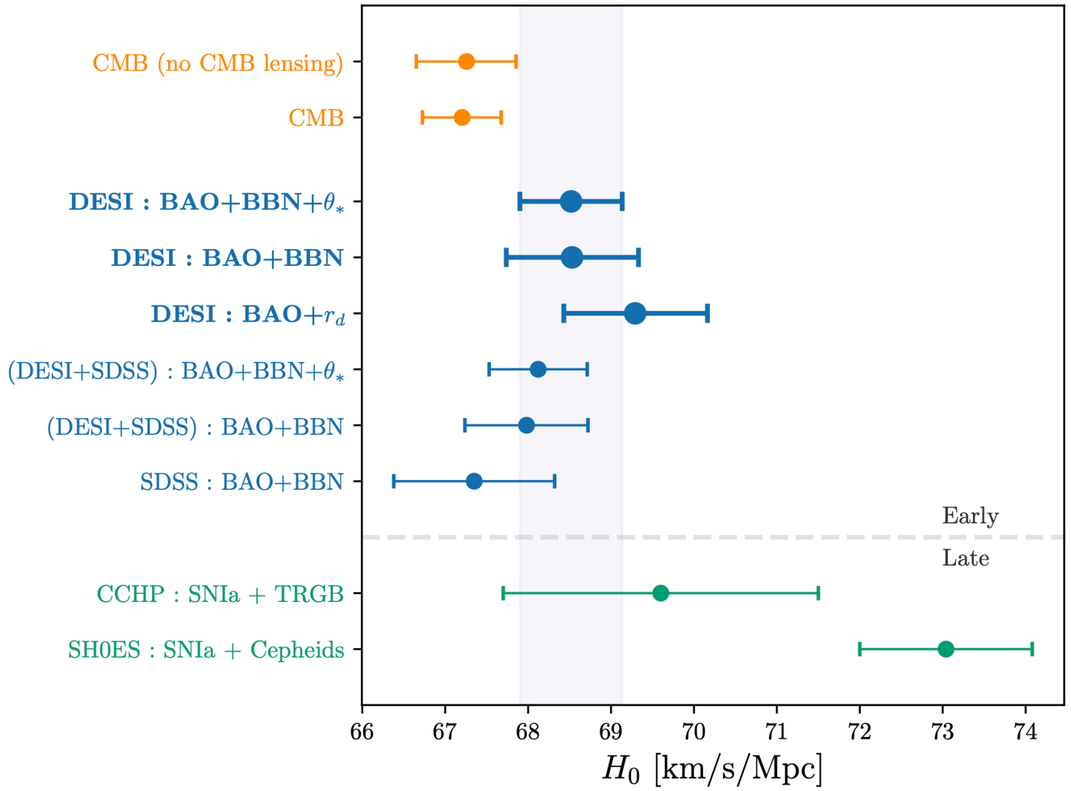

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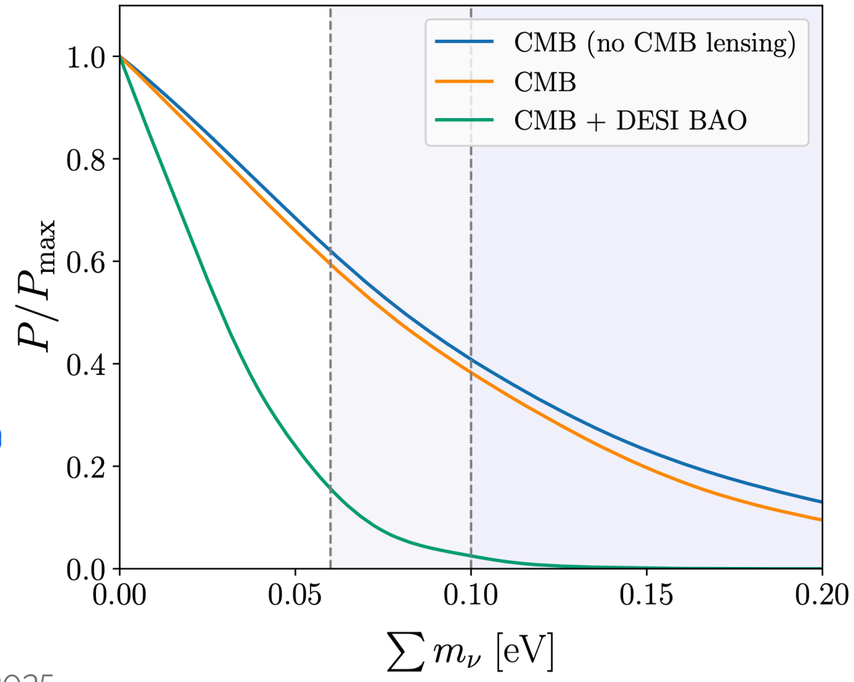
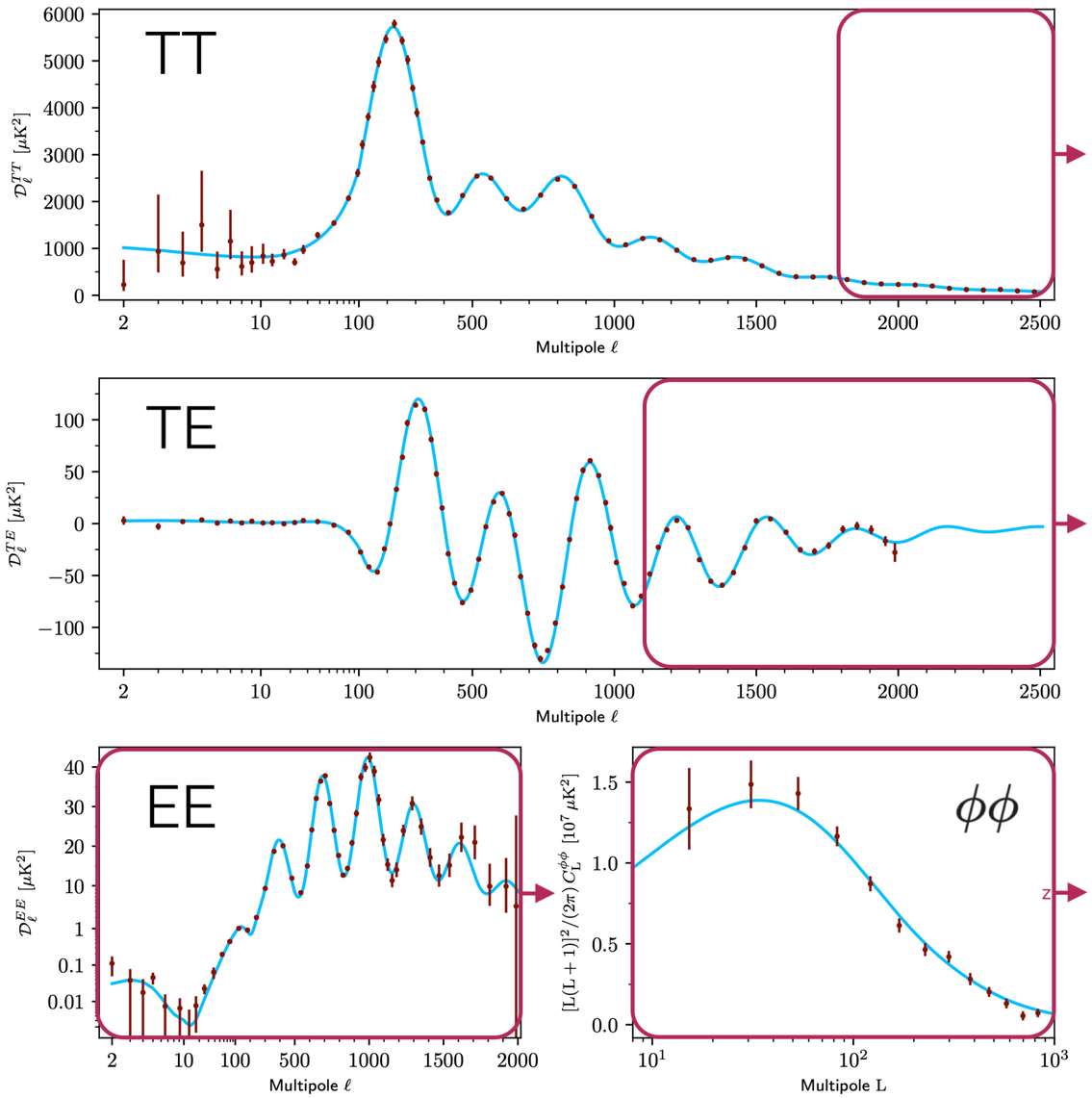


The CMB Beyond Planck

Planck is noise-variance-limited beyond:

- $\ell > 1800$ in TT, $\ell > 1100$ in TE;
- **everywhere** in EE and lensing ($\phi\phi$).



The CMB Beyond Planck

Planck is noise-variance-limited beyond:

- $\ell > 1800$ in TT, $\ell > 1100$ in TE;
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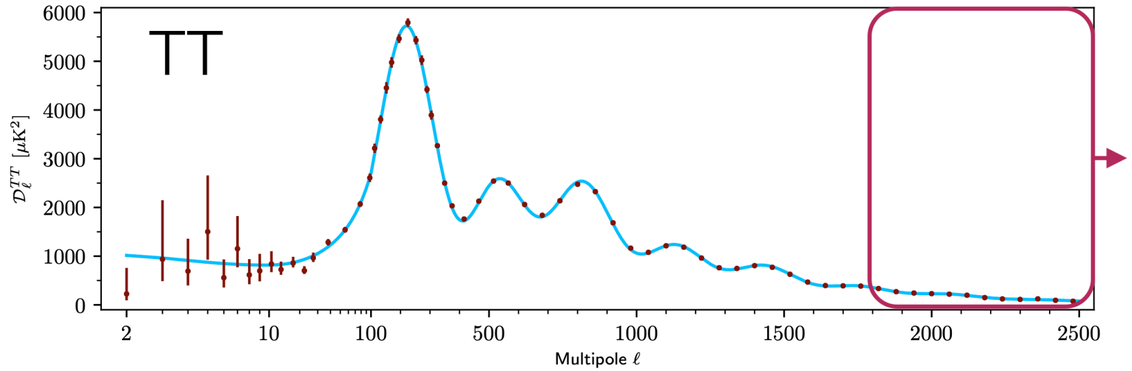
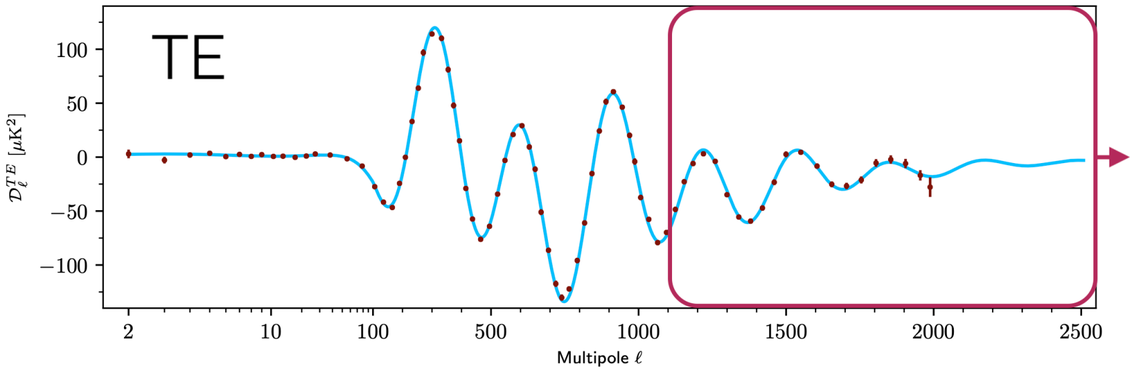
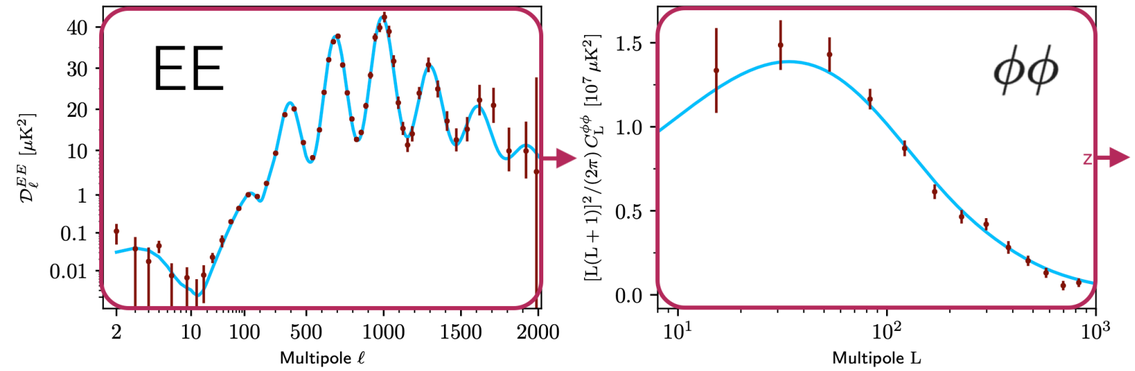
CMB experiments filling this niche:

SIMONS OBSERVATORY

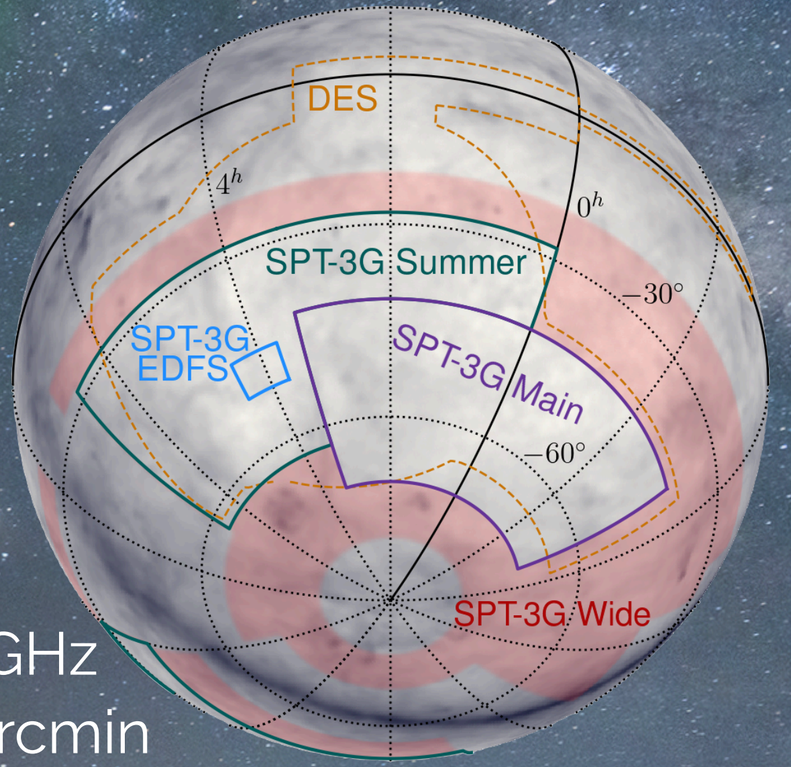
CMB-S4
Next Generation CMB Experiment







The South Pole Telescope



3 bands: 95, 150, 220 GHz

resolution: 1.6, 1.2, 1.0 arcmin

SPT-SZ (2007) ~1000 detectors

SPTpol (2012) ~1500 detectors

SPT-3G (2017) ~16,000 detectors

Photo Credit: Aman Chokshi

SPT-3G 2019+2020 Analyses

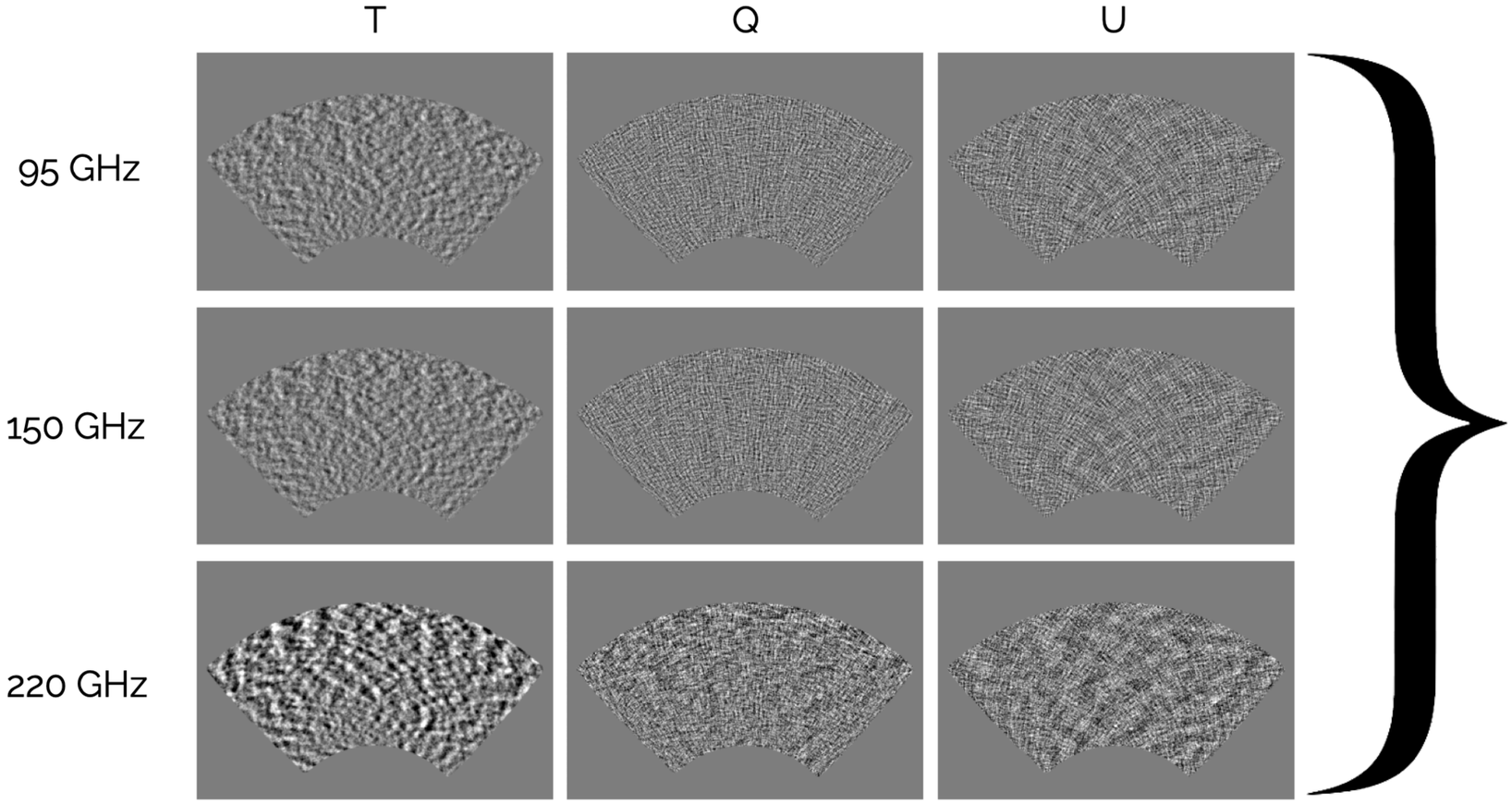
Kevin Zagorski

SPT-3G 2019+2020 Analyses

*successful cosmology analyses already published with SPT-3G 2018 data

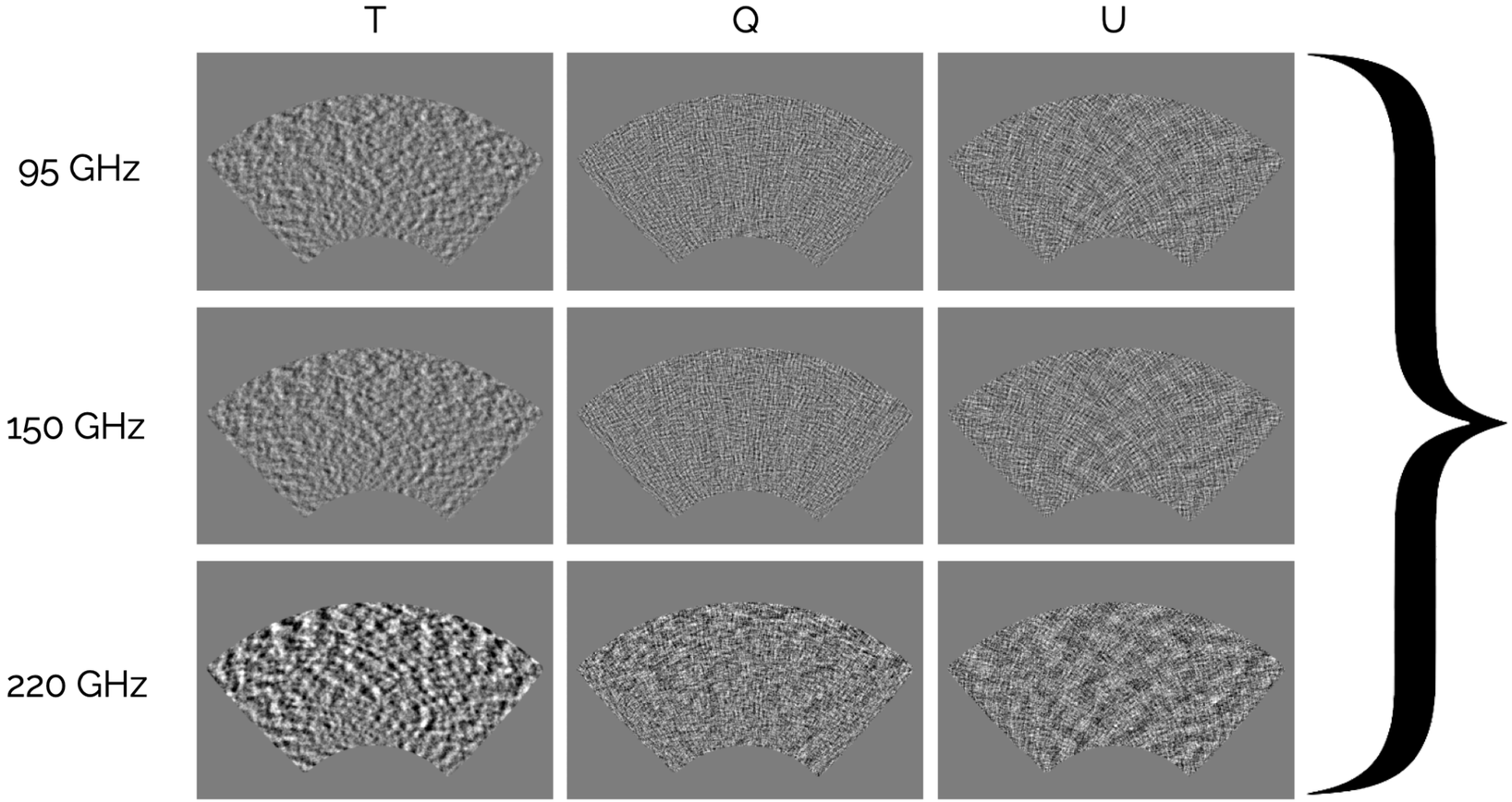
Kevin Zagorski

2019+2020 Analyses



Same 9 maps used by three independent pipelines:

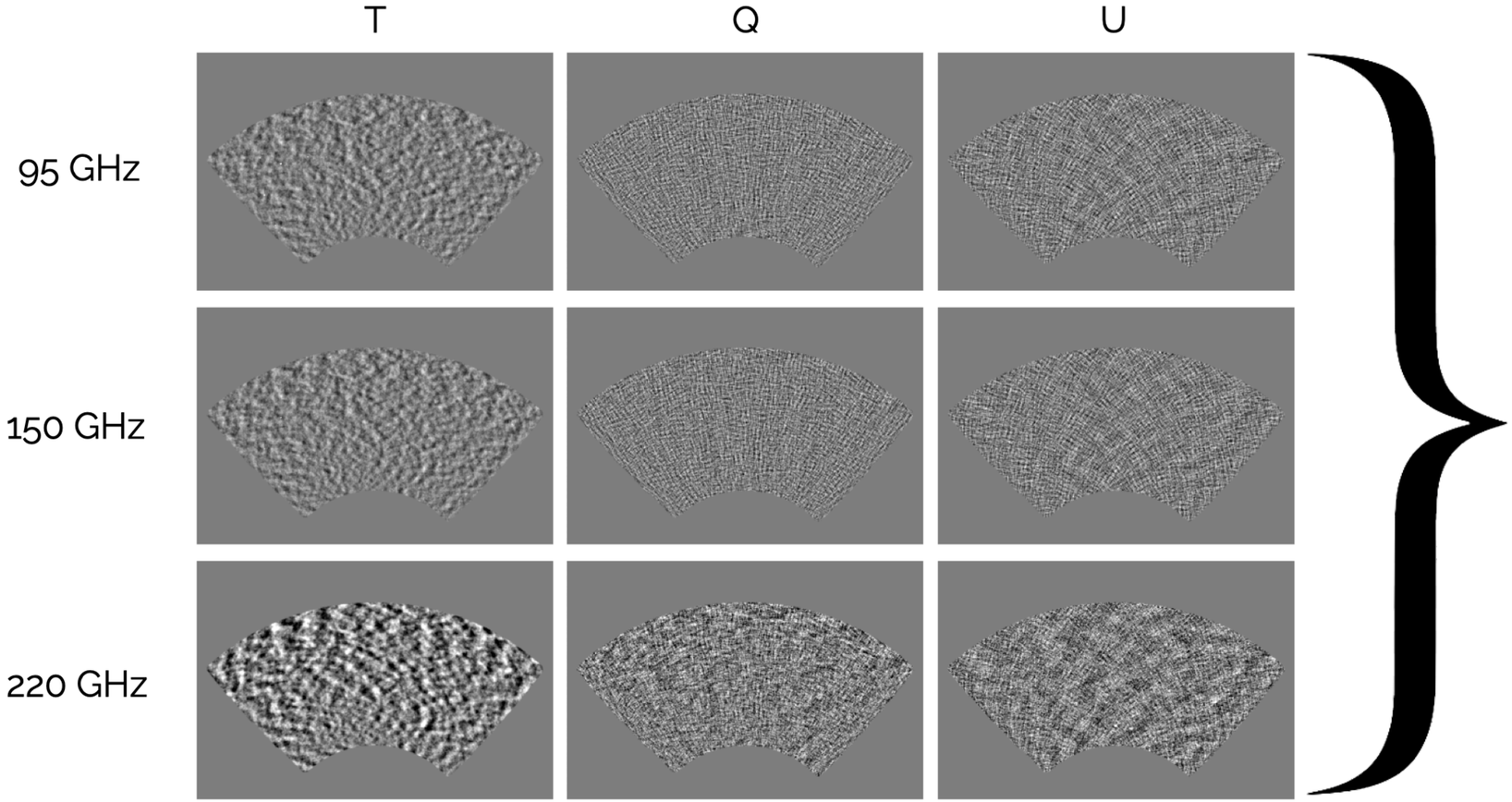
2019+2020 Analyses



Same 9 maps used by three independent pipelines:

1. MUSE: Bayesian joint inference of cosmology, systematics, and pixels

2019+2020 Analyses



Same 9 maps used by three independent pipelines:

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2. Traditional TT/TE/EE power spectrum

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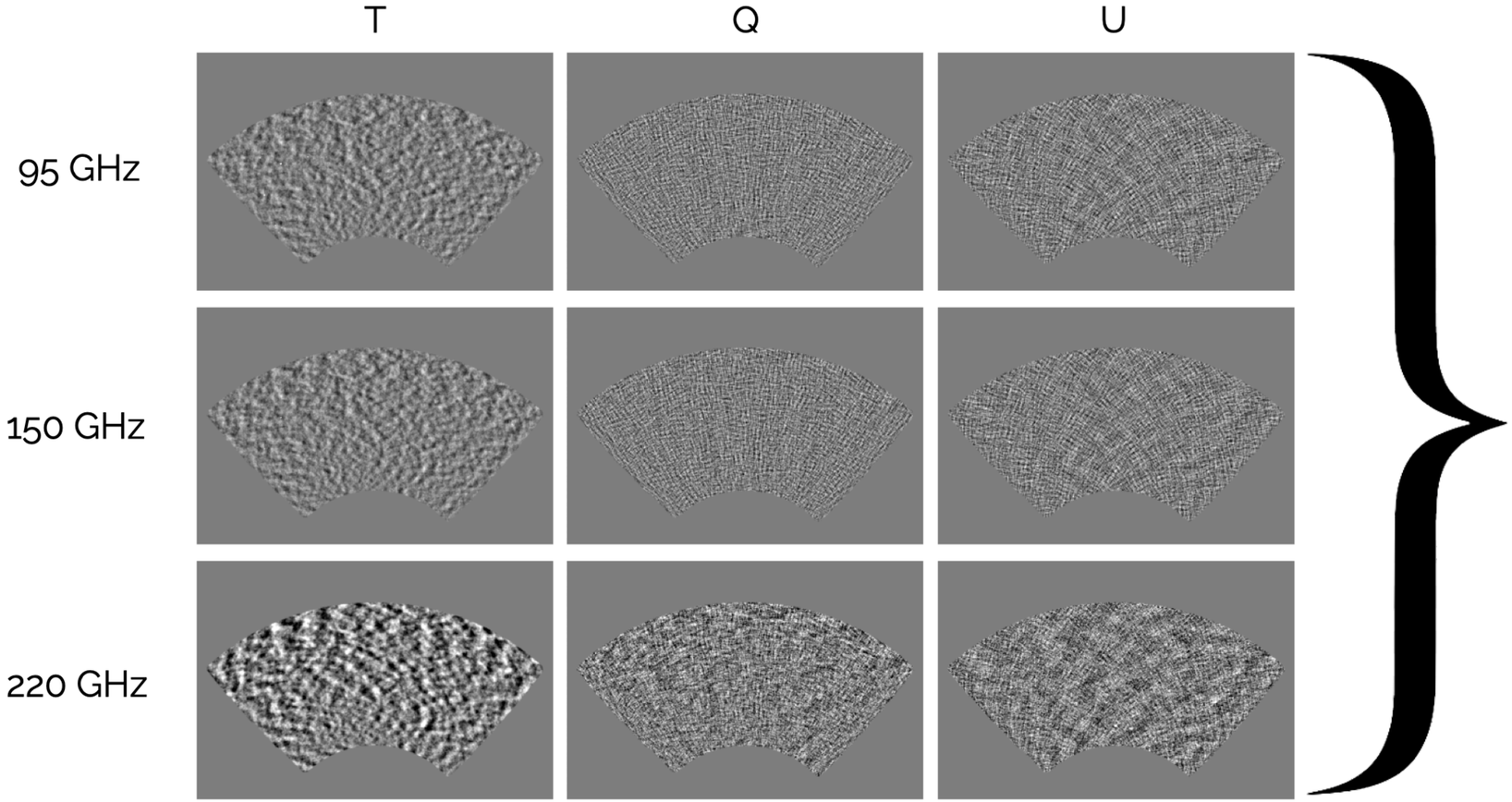

Same 9 maps used by three independent pipelines:

1. MUSE: Bayesian joint inference of cosmology, systematics, and pixels
2. Traditional TT/TE/EE power spectrum
3. Traditional quadratic estimator (QE) lensing

1. MUSE

Recently accepted! arxiv:2411.06000

- Likelihood publicly available:
  https://pole.uchicago.edu/public/data/ge25/index.html

Fei Ge

Marius Millea

1. MUSE

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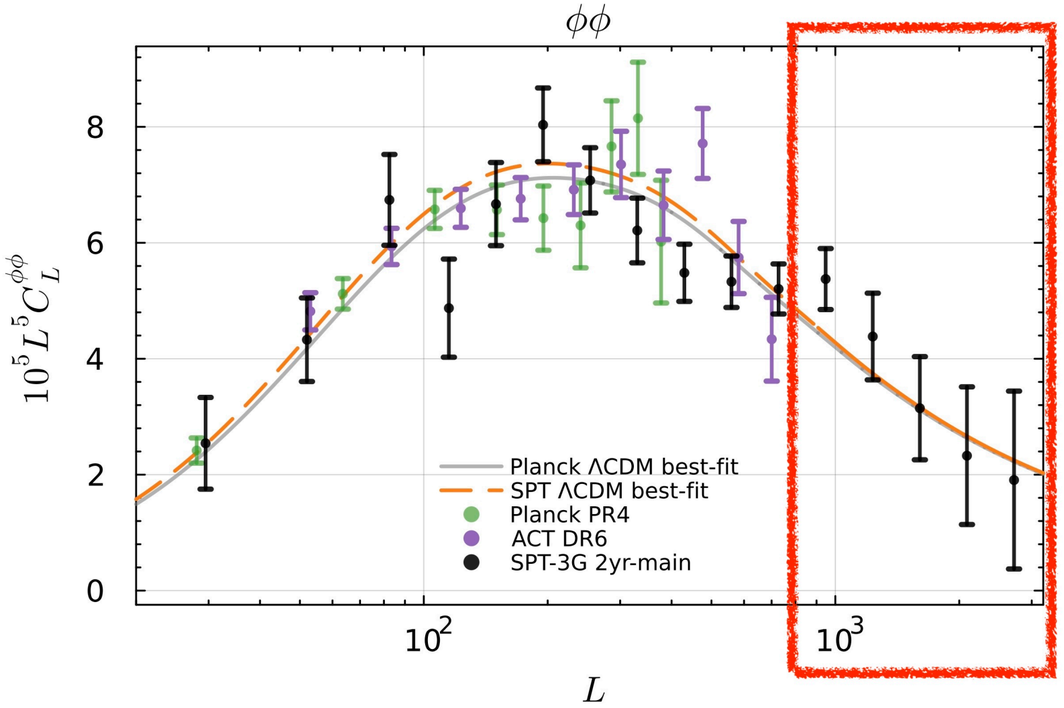
Fei Ge

Marius Millea

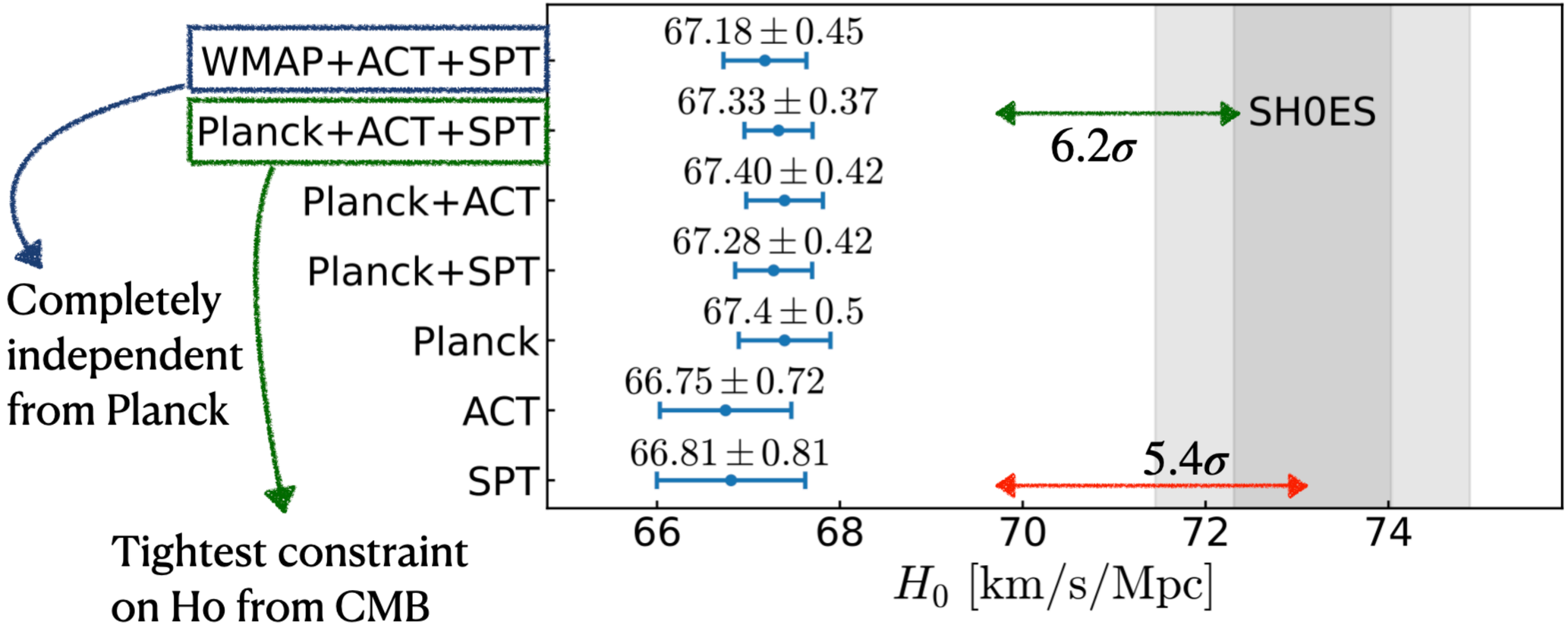
Methods in the spirit of
simulation-based inference (SBI).

EE & $\phi\phi$ bandpowers *probe new scales*
and are in agreement with Planck ΛCDM:



1. MUSE Results: H_0

WMAP:	TT+TE	[9yr]
Planck:	TT+TE+EE+ϕϕ(T&P)	[Plik/PR4]
ACT:	TT+TE+EE+ϕϕ(T&P)	[DR4/DR6]
SPT:	EE+ϕϕ(P)	[2yr-main]



1. MUSE Results: S_8

WMAP:	TT+TE	[9yr]
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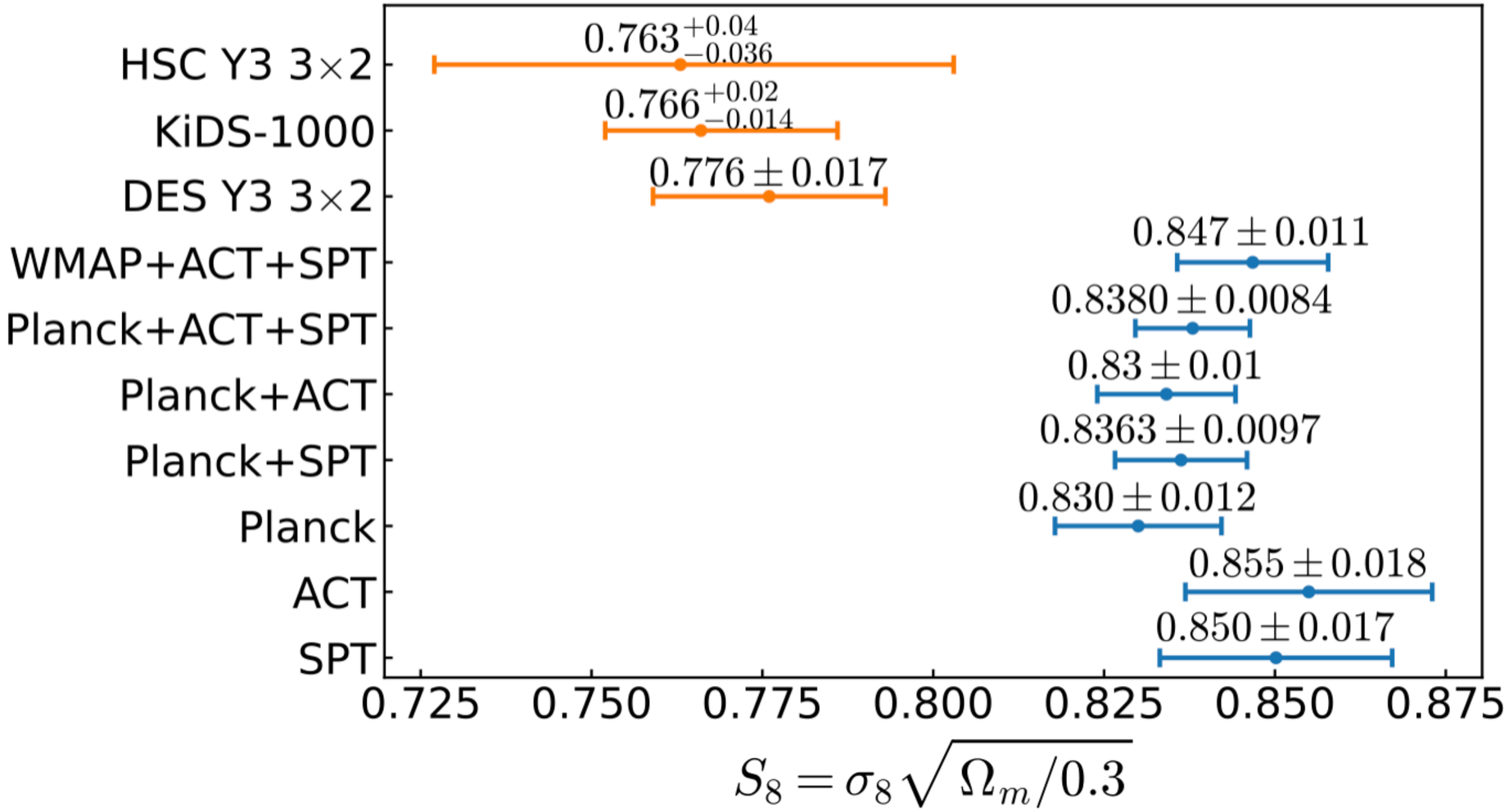
ACT:	TT+TE+EE+ϕϕ(T&P)	[DR4/DR6]
SPT:	EE+ϕϕ(P)	[2yr-main]



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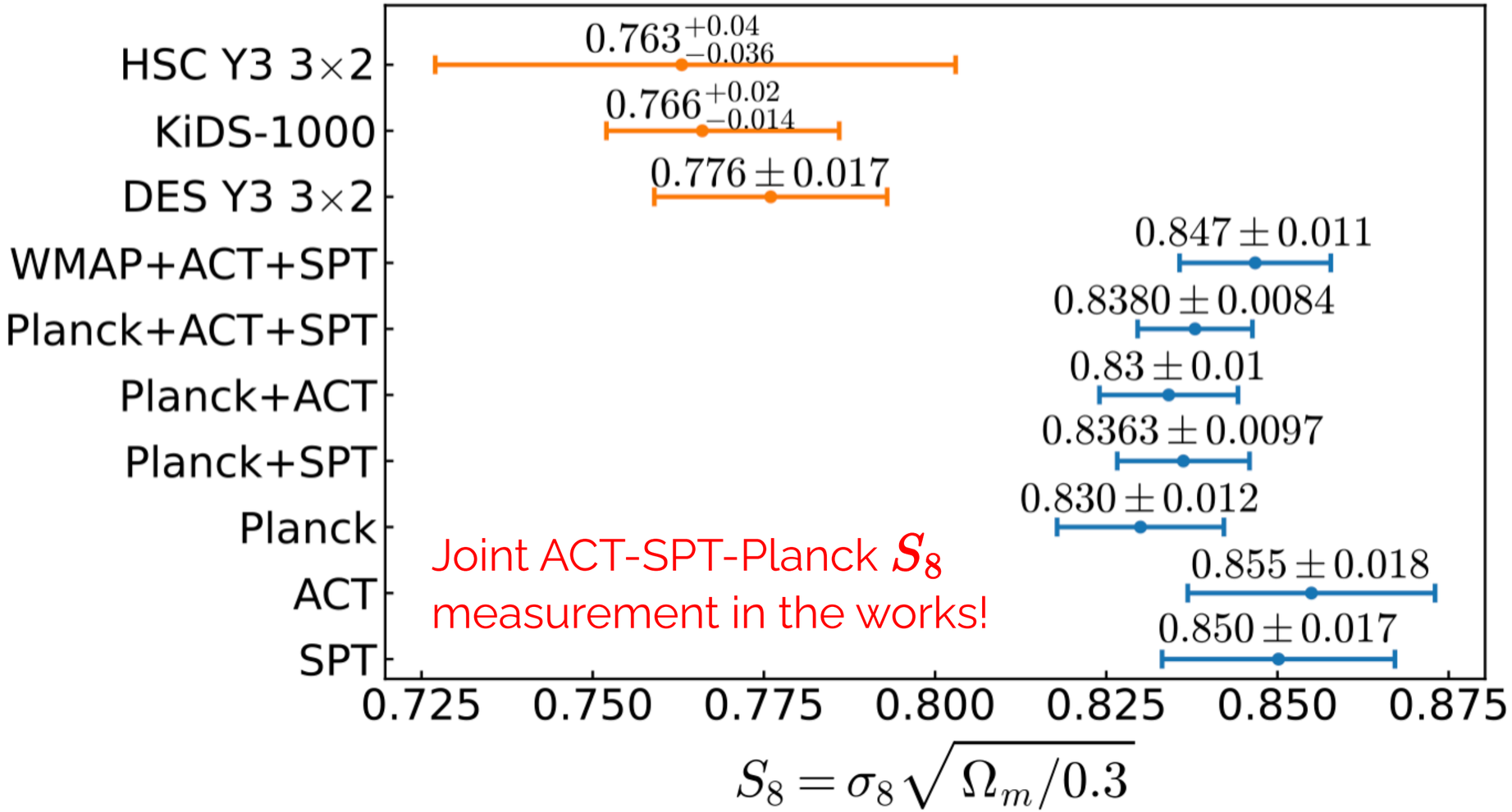
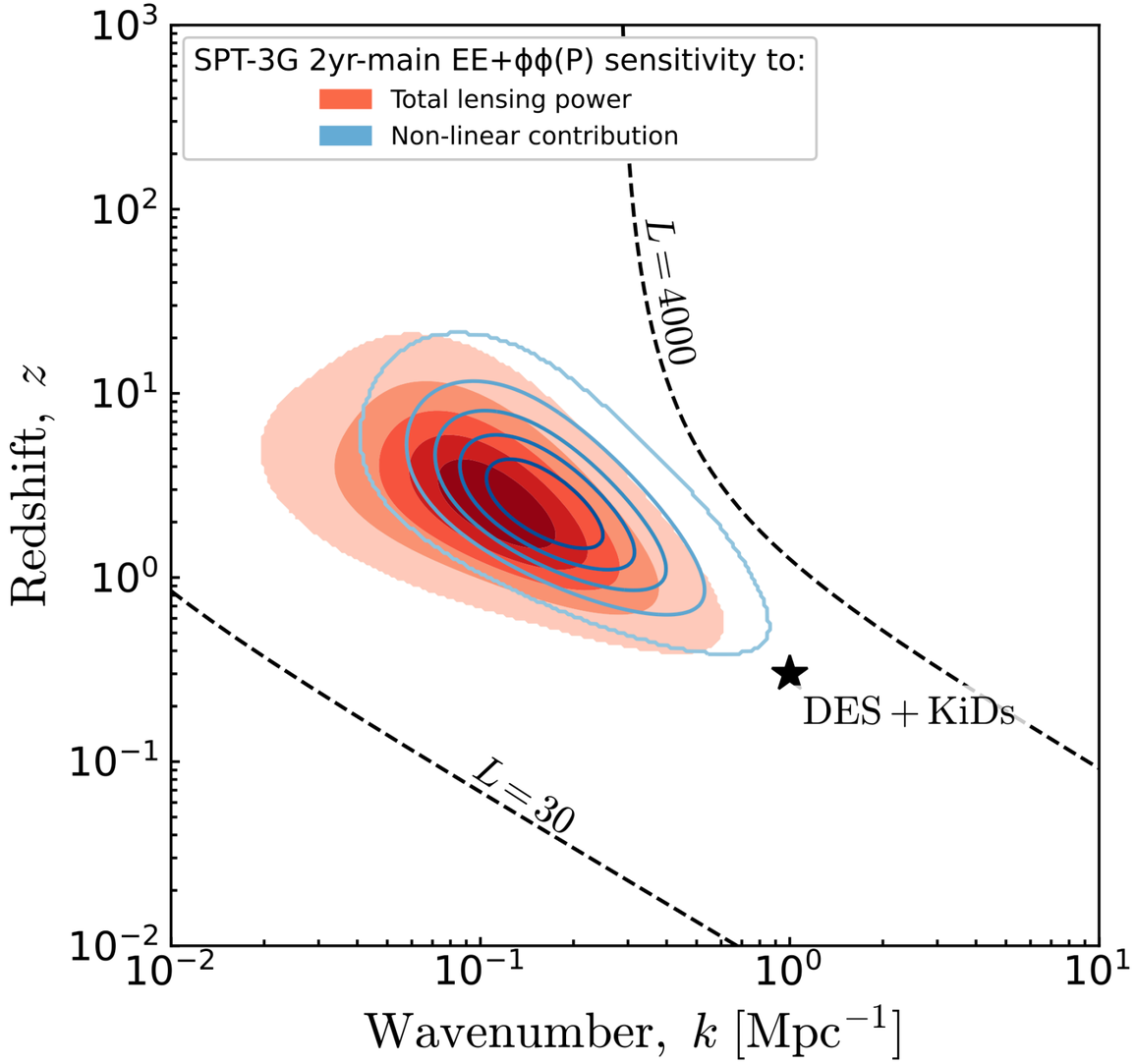


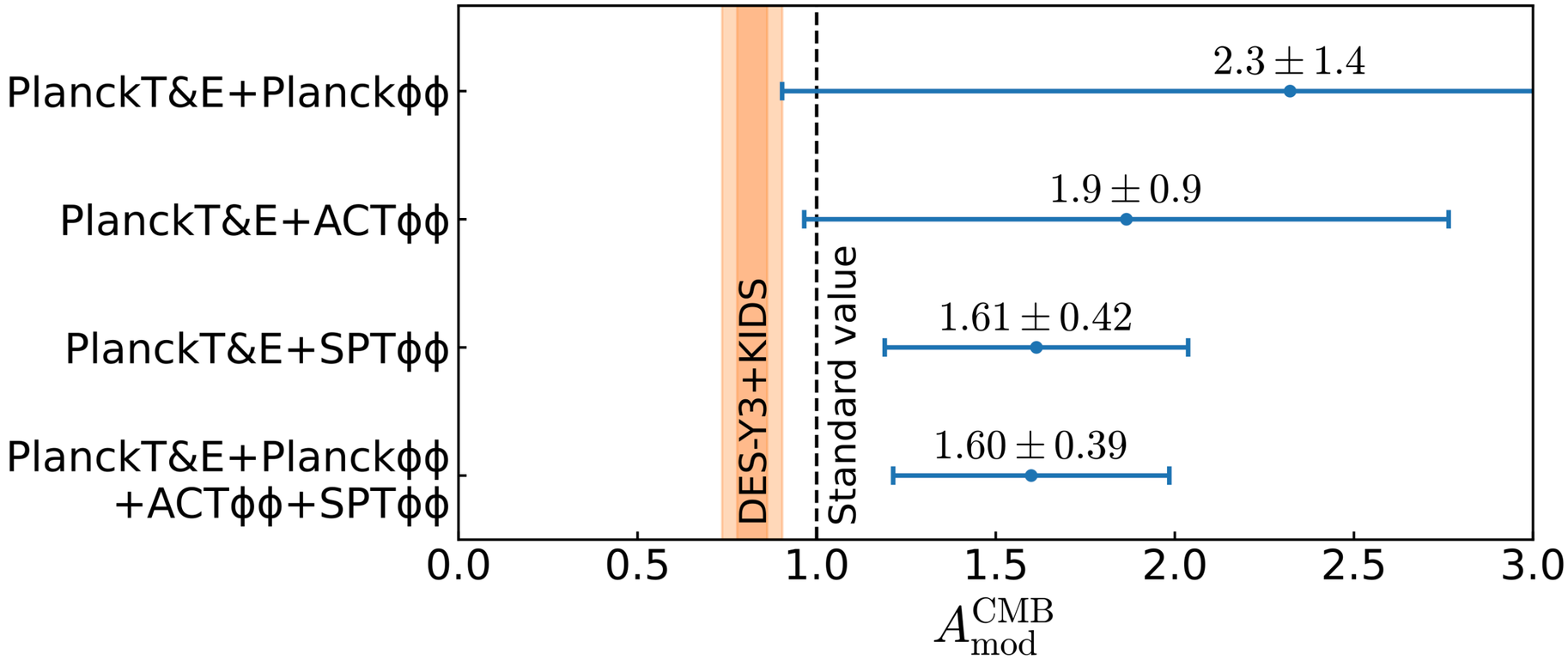
1. MUSE Insights on Structure Growth

Scales and **redshifts** that contribute to MUSE constraints: total and non-linear contributions.



1. MUSE Insights on Structure Growth

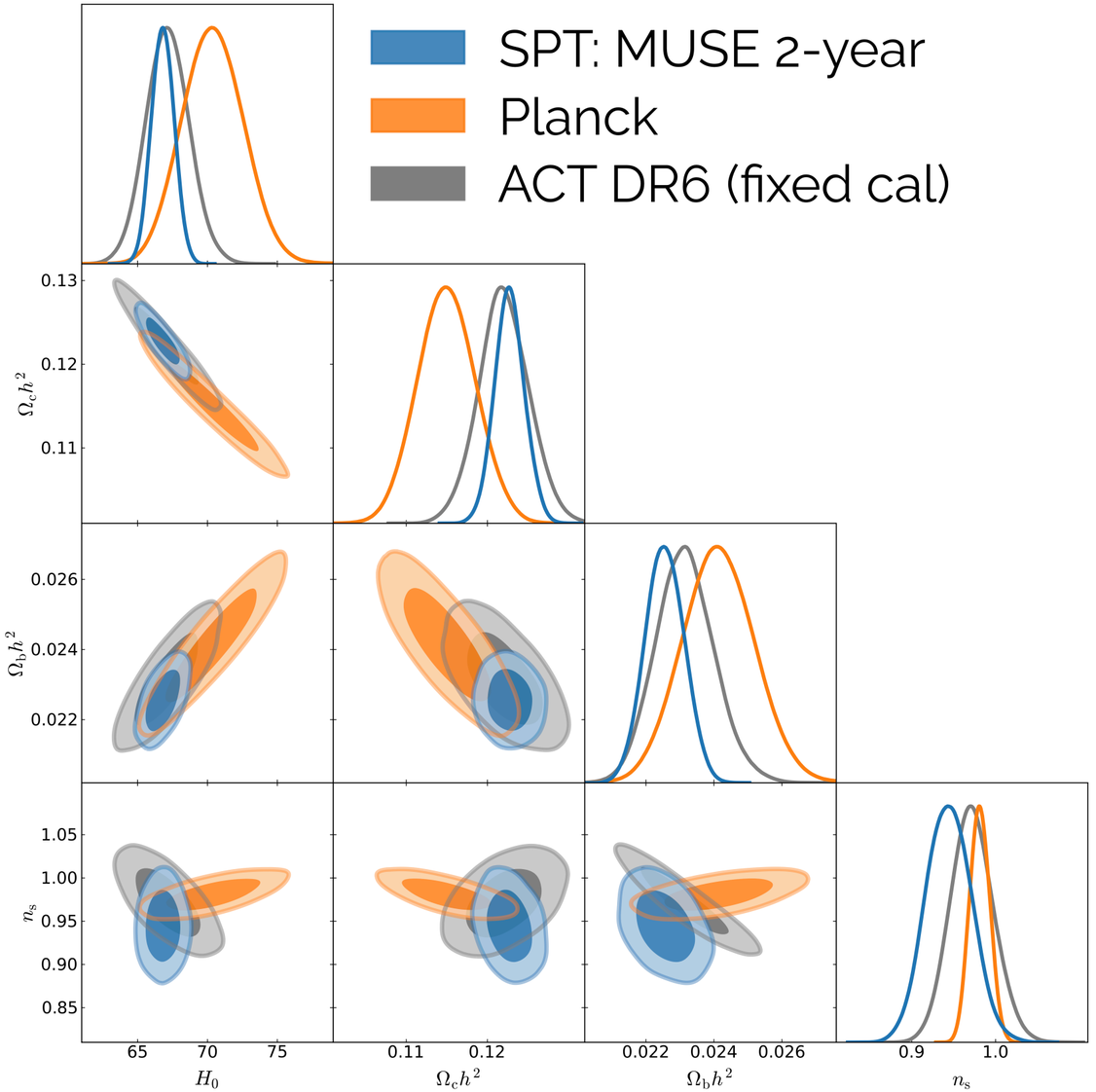
$A_{\rm mod}$ to scale the non-linear matter power spectrum:



Planck T&E + SPT$\phi\phi$ gives first 3σ detection of non-linear structure with CMB lensing!

1. MUSE vs. Planck and ACT

Comparison of **polarization-only** (EE + $\phi\phi_{\rm pol}$) constraints from SPT, Planck, and ACT:



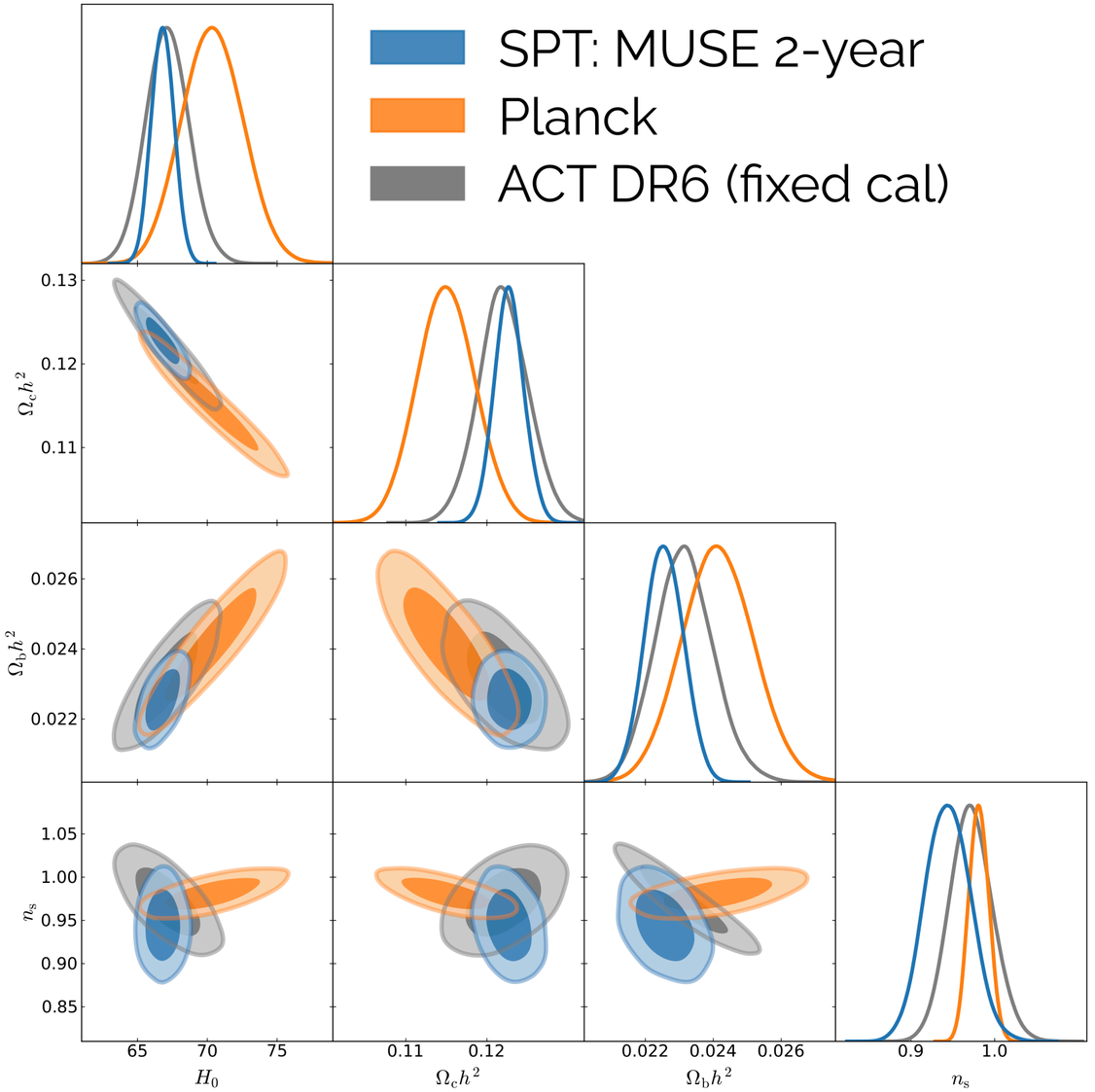
1. MUSE vs. Planck and ACT

Comparison of **polarization-only** (EE + $\phi\phi_{\rm pol}$) constraints from SPT, Planck, and ACT:

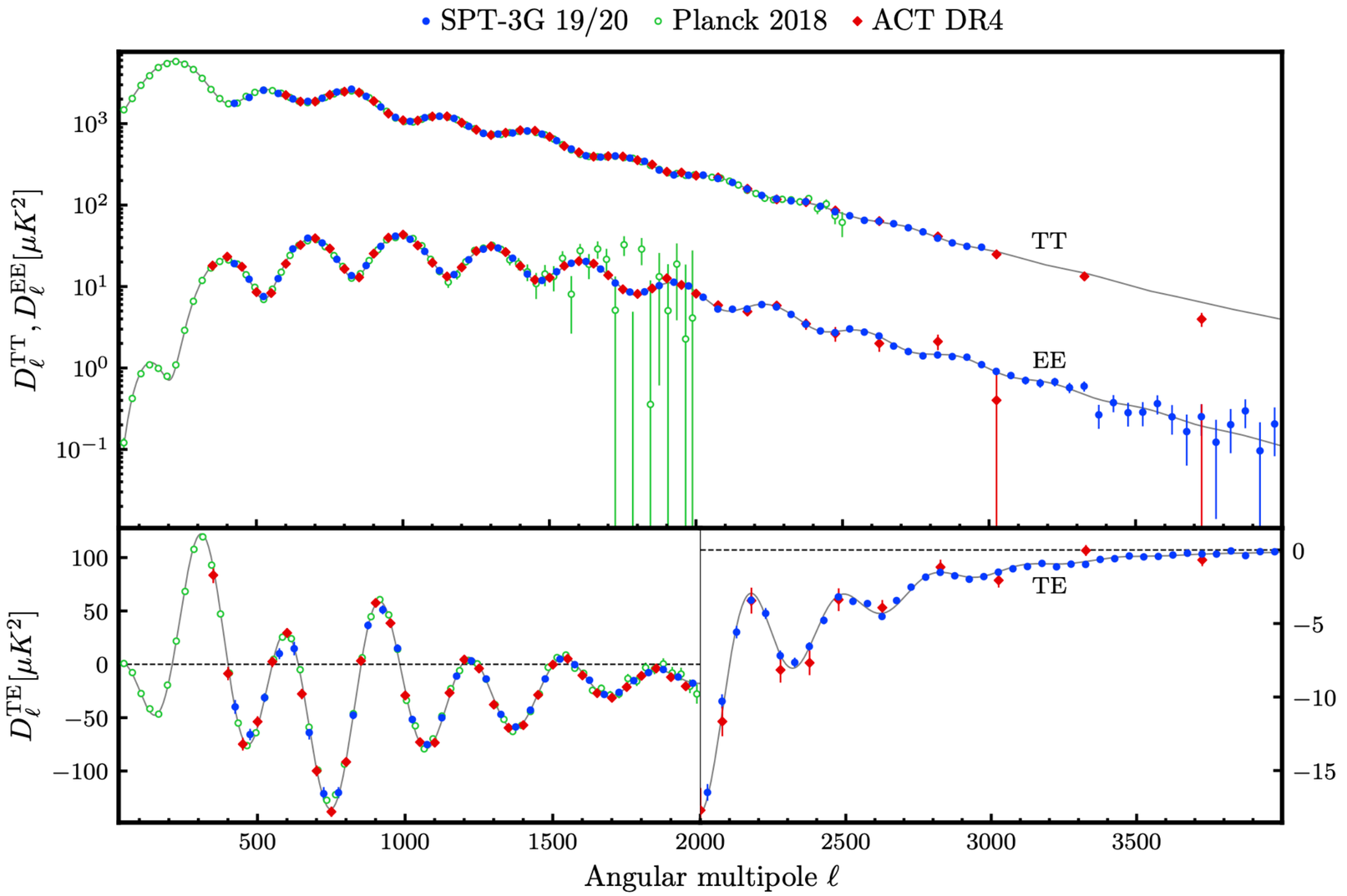
SPT-3G polarization data is incredible!

but, this isn't a complete picture of the constraining power of these instruments:

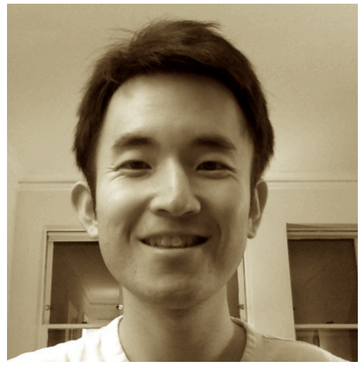
$\Longrightarrow$ upcoming SPT TT/TE/EE/$\phi\phi$



2. Upcoming 19+20: TT/TE/EE



Etienne Camphuis



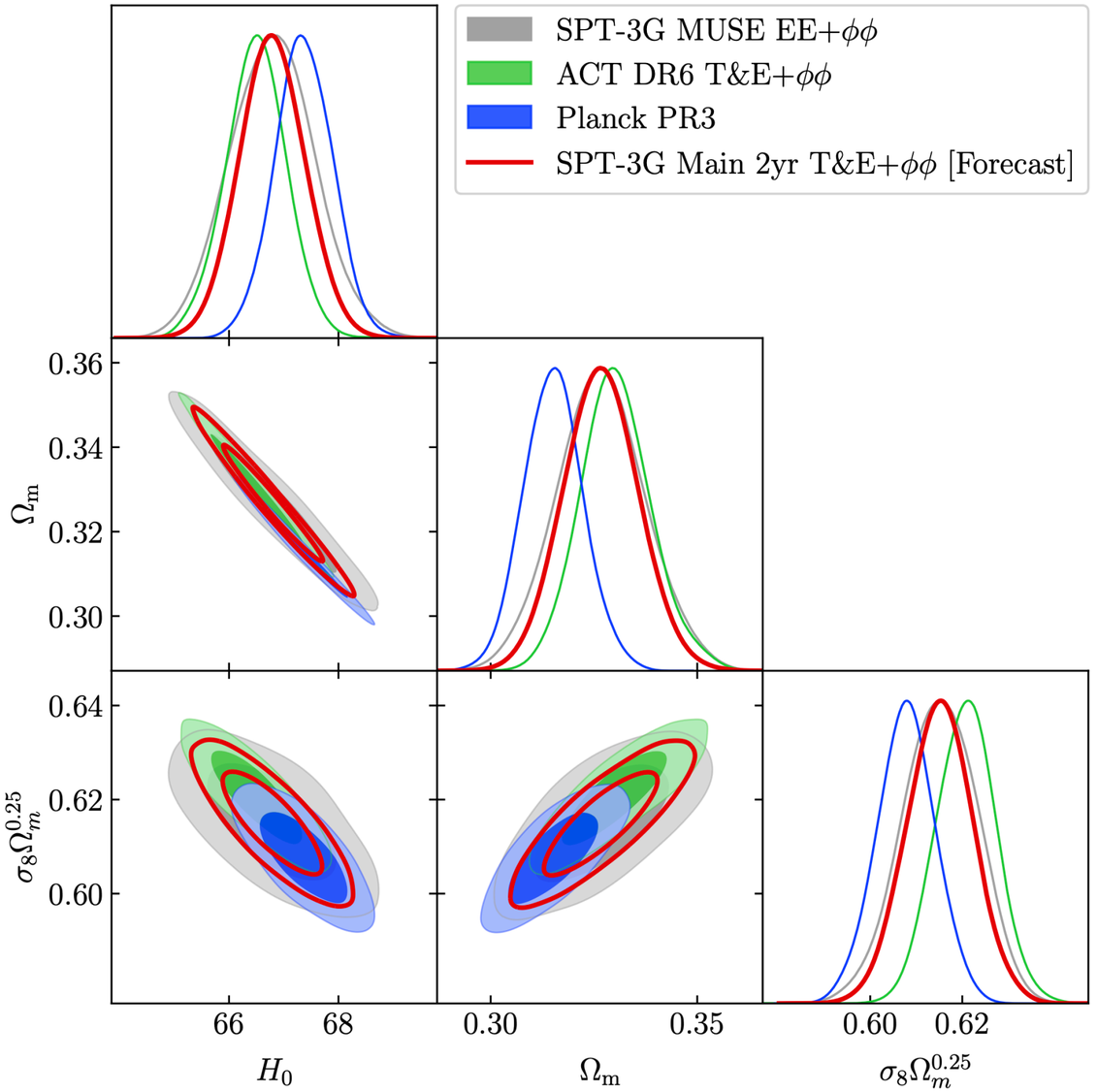
Wei Quan

2. Upcoming: TT/TE/EE + MUSE $\phi\phi$

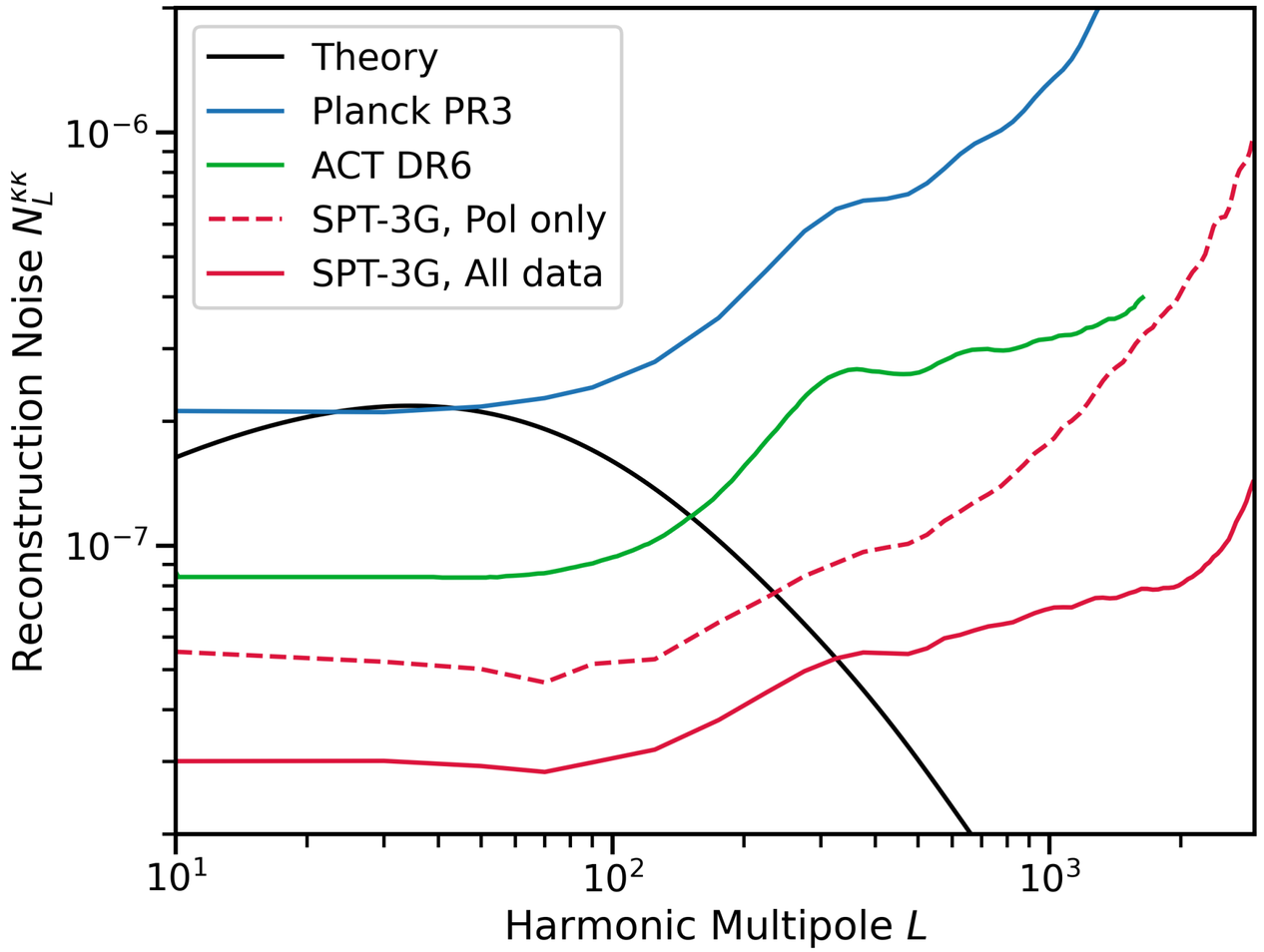
Targeting publication this summer.

As a taste, SPT-3G TT/EE/TE + MUSE $\phi\phi$ (**mock!**) vs. ACT DR6, MUSE and Planck.

With the addition of full QE $\phi\phi$ (see following slides), **joint constraints on ΛCDM parameters will be comparable to Planck!**



3. Upcoming 19+20: QE Lensing




Yuuki Omori

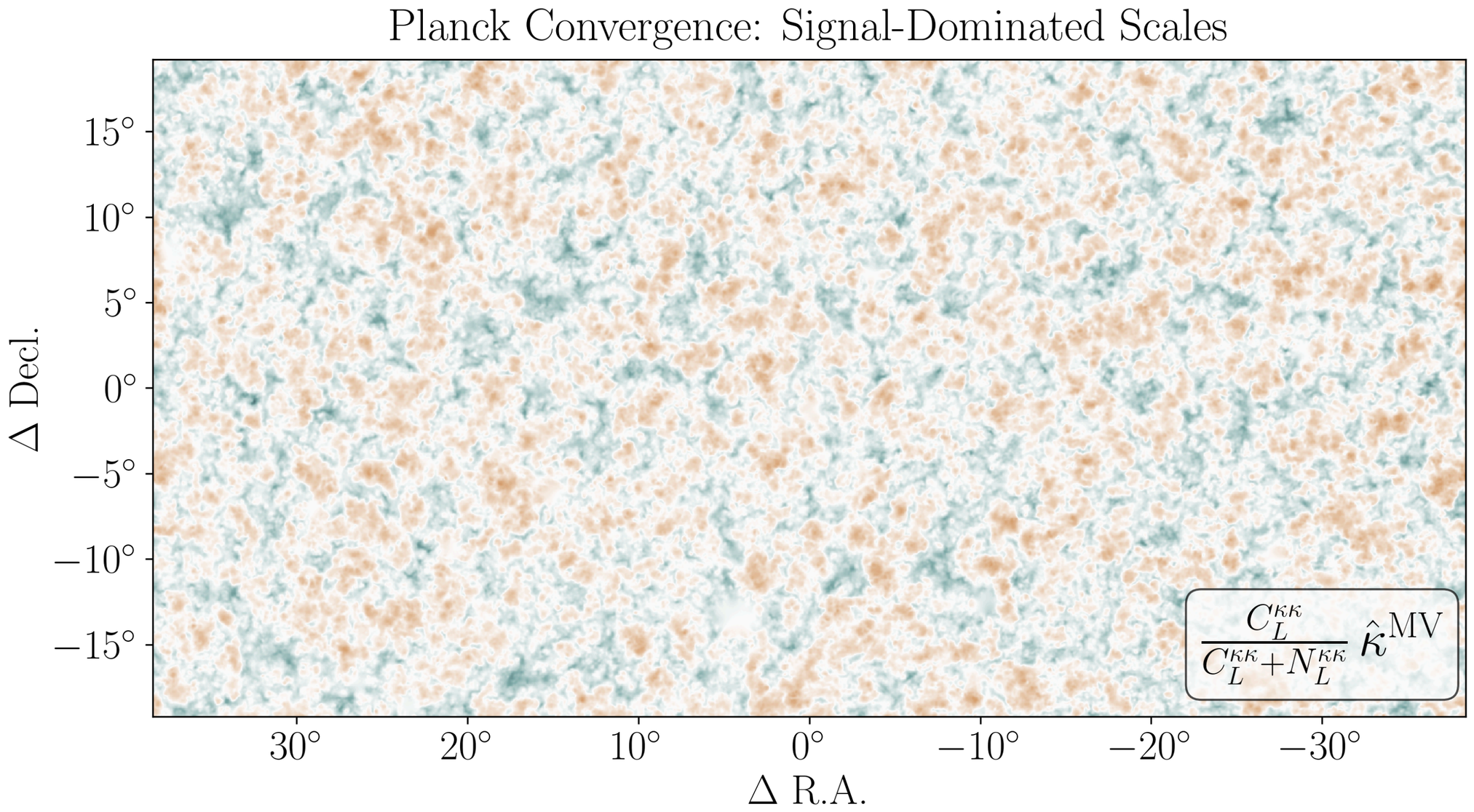

Myself


Federico Bianchini


Yuka Nakato

forecast: 1.5% measurement $\sigma_8\Omega_m^{0.25}$ from SPT-3G lensing alone!
vs. 2.7% for Planck lensing

3. Upcoming 19+20: QE Lensing



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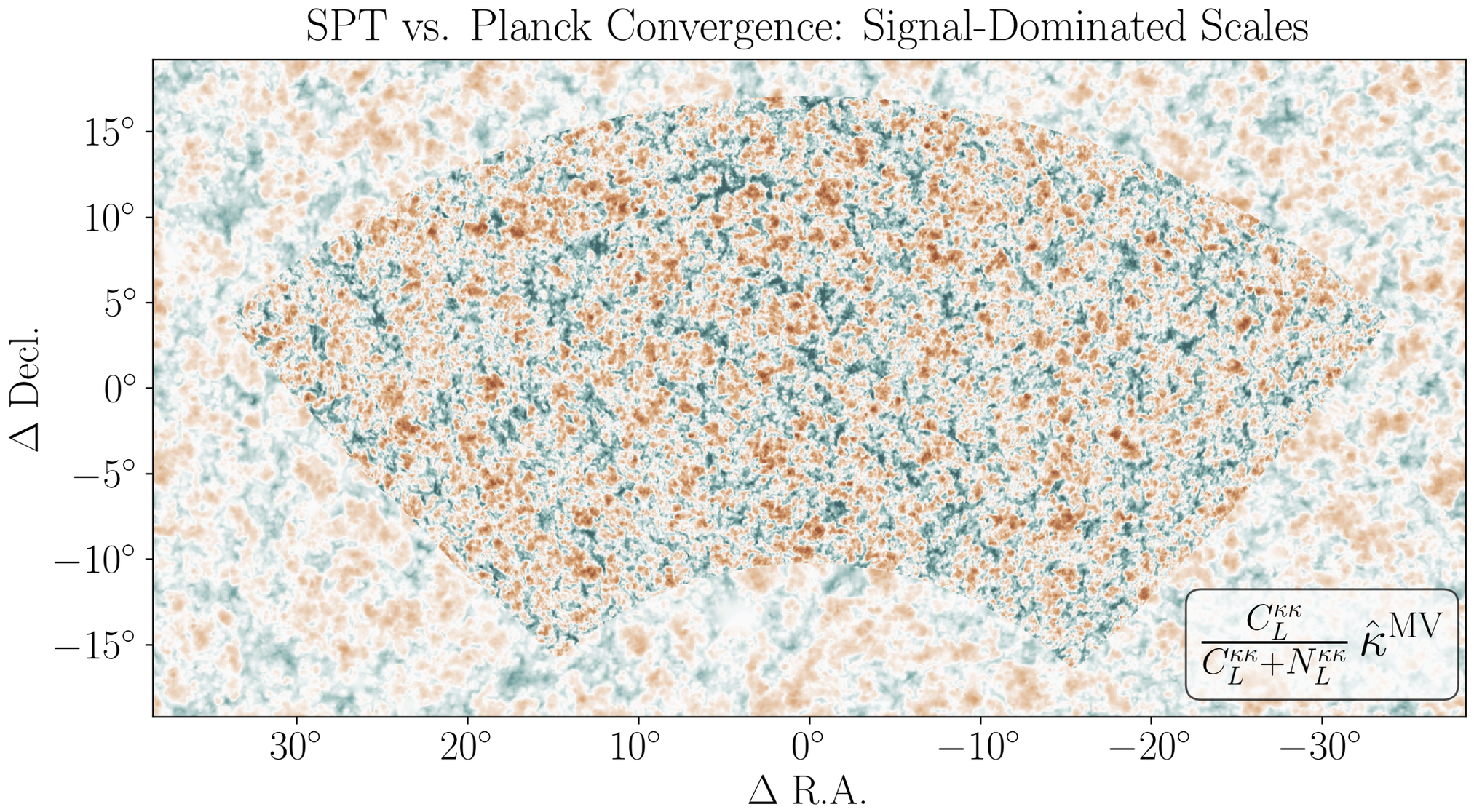
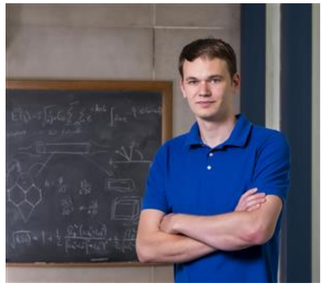


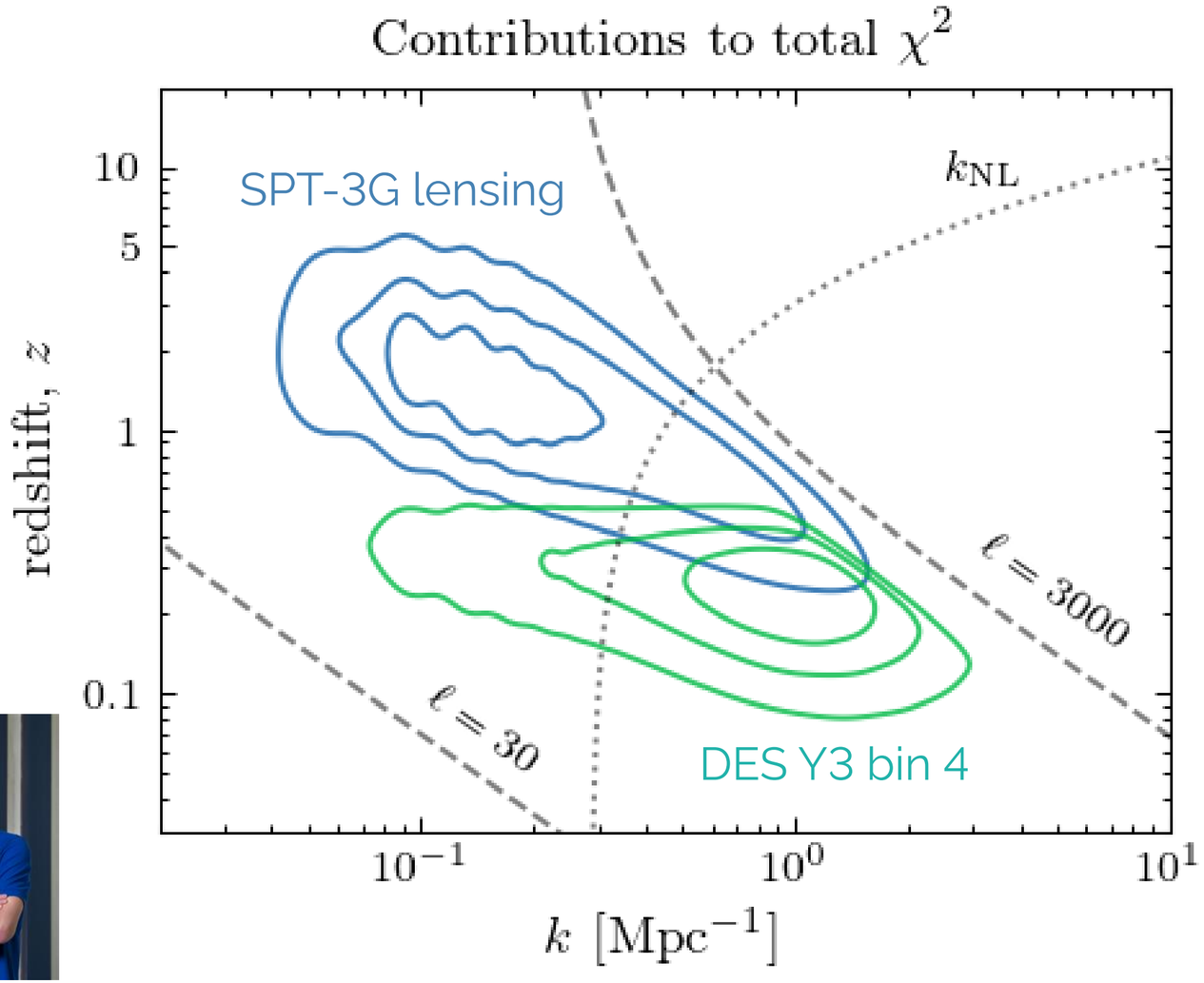
3. Upcoming 19+20: Cross-correlations

SPT-3G lensing: large scales, high z (mostly linear)

Cosmic shear: smaller scales, low z (mostly non-linear)



Aaron Ouellette



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SPT-3G lensing: large scales, high z (mostly linear)

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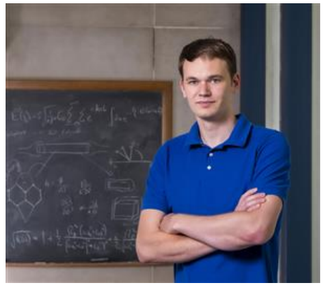
Cross-correlation bridges the gap



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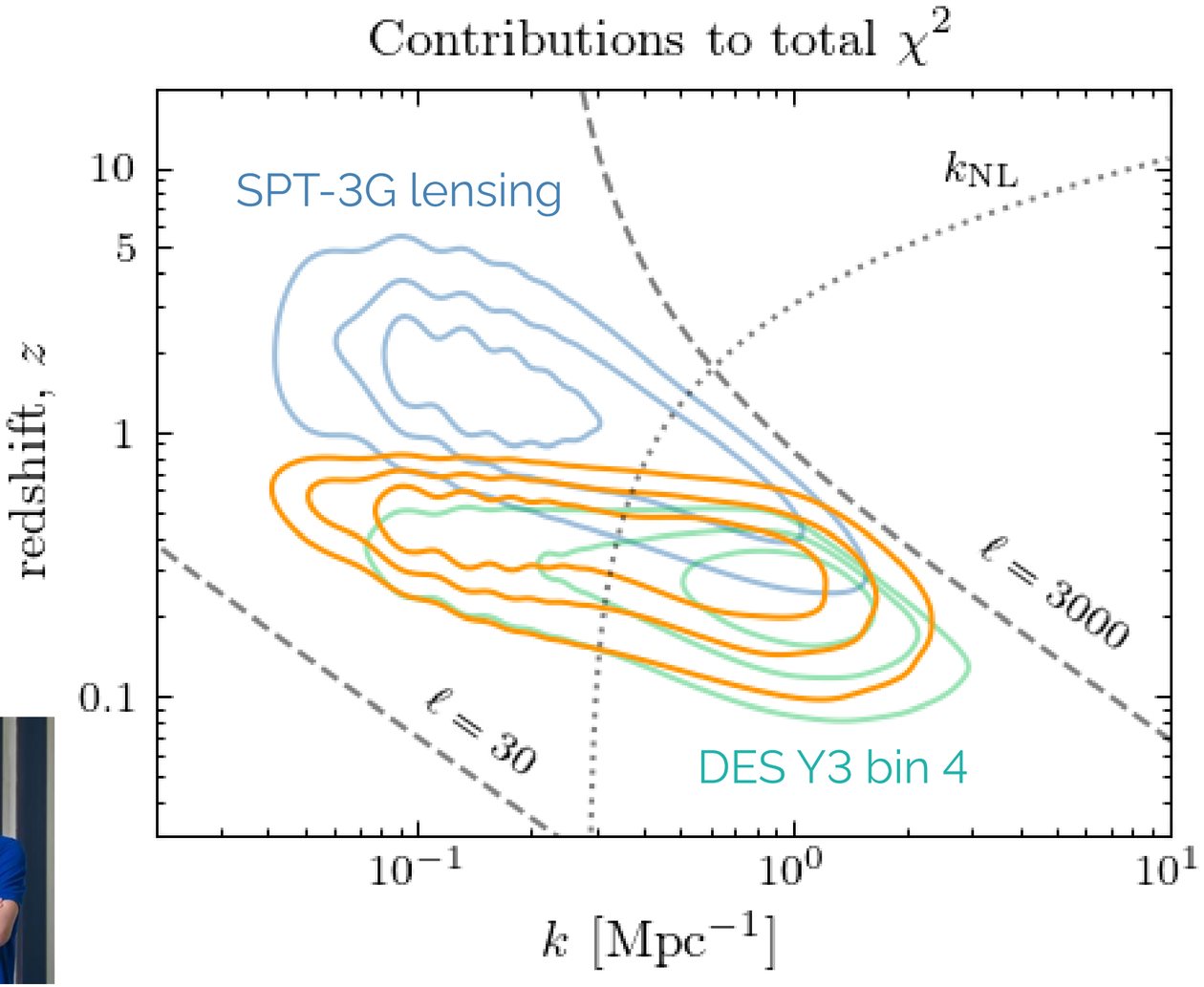


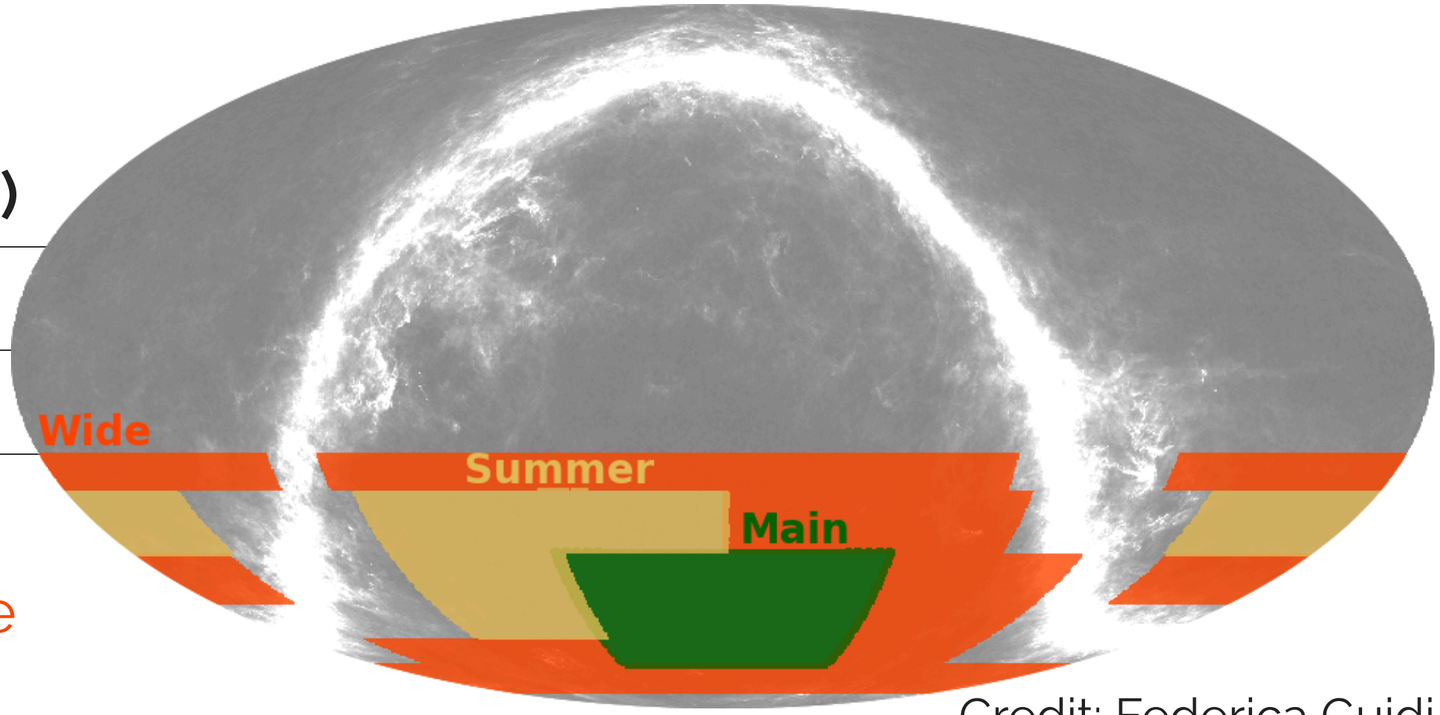
Beyond 2019+2020: the Ext-10k survey

Kevin Zagorski

Beyond 2019+2020: the Ext-10k survey

Survey	Area (deg^2)	Depth (μK-arcmin)
Main	1,500	2.1
Summer	2,600	9
Wide	6,000	12

Ext-10k = Main + Summer + Wide



Credit: Federica Guidi

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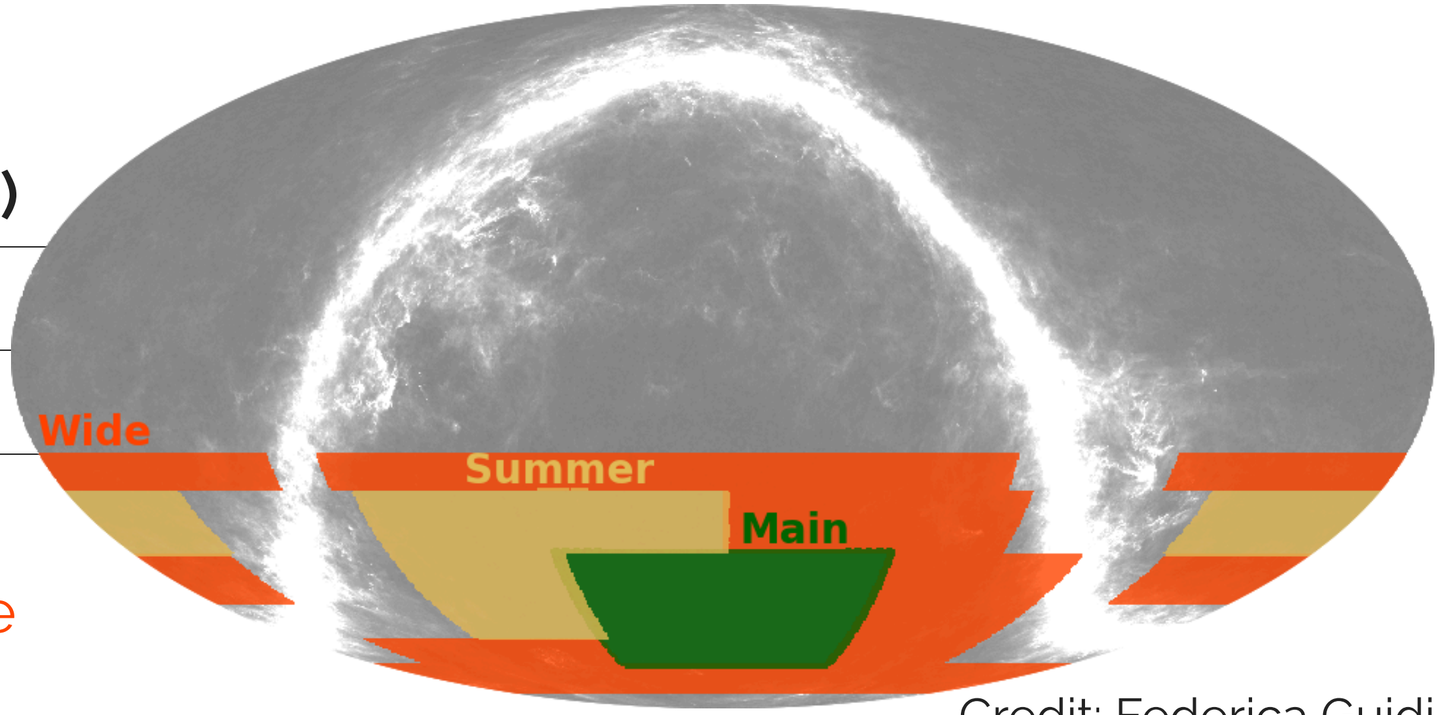


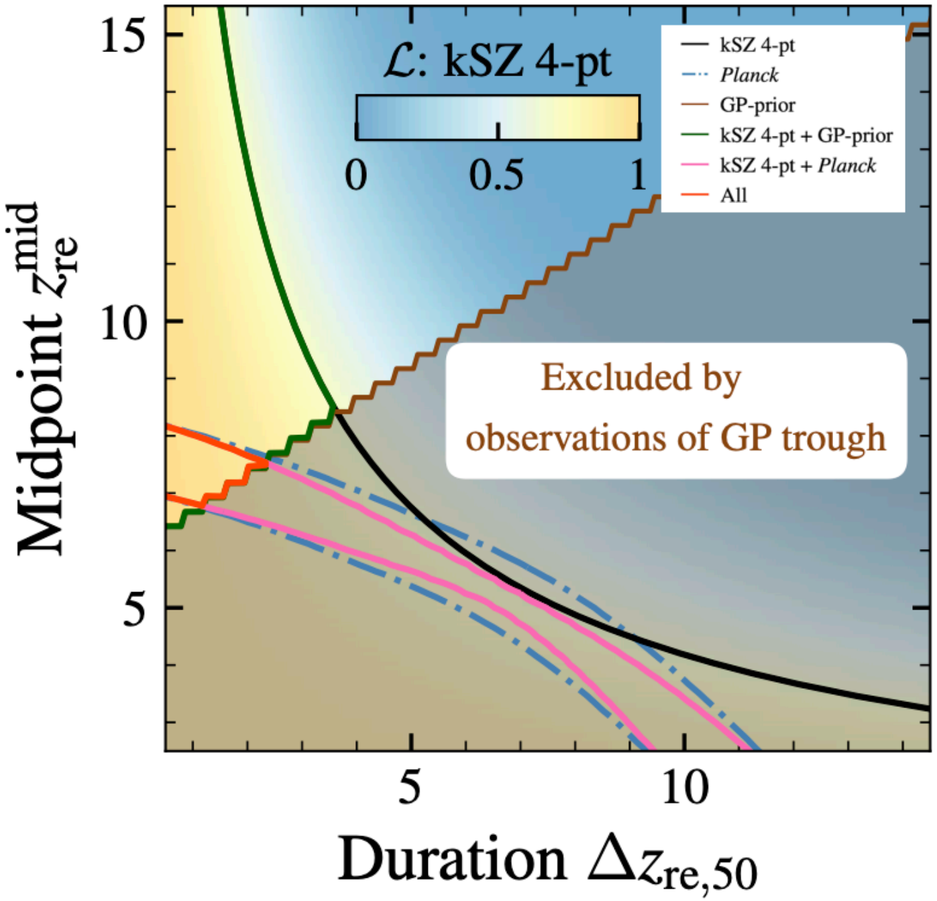
Credit: Federica Guidi

Combined Ext-10k survey will improve on Planck constraints by as much as:
2x for ΛCDM parameters, 3x for single-parameter extensions!

Cosmology from CMB Secondaries

Foreground signals also contain rich cosmological information.

SPT has provided the best constraints on the Epoch of Reionization to-date from kinetic Sunyaev-Zel'dovich 4-pt:



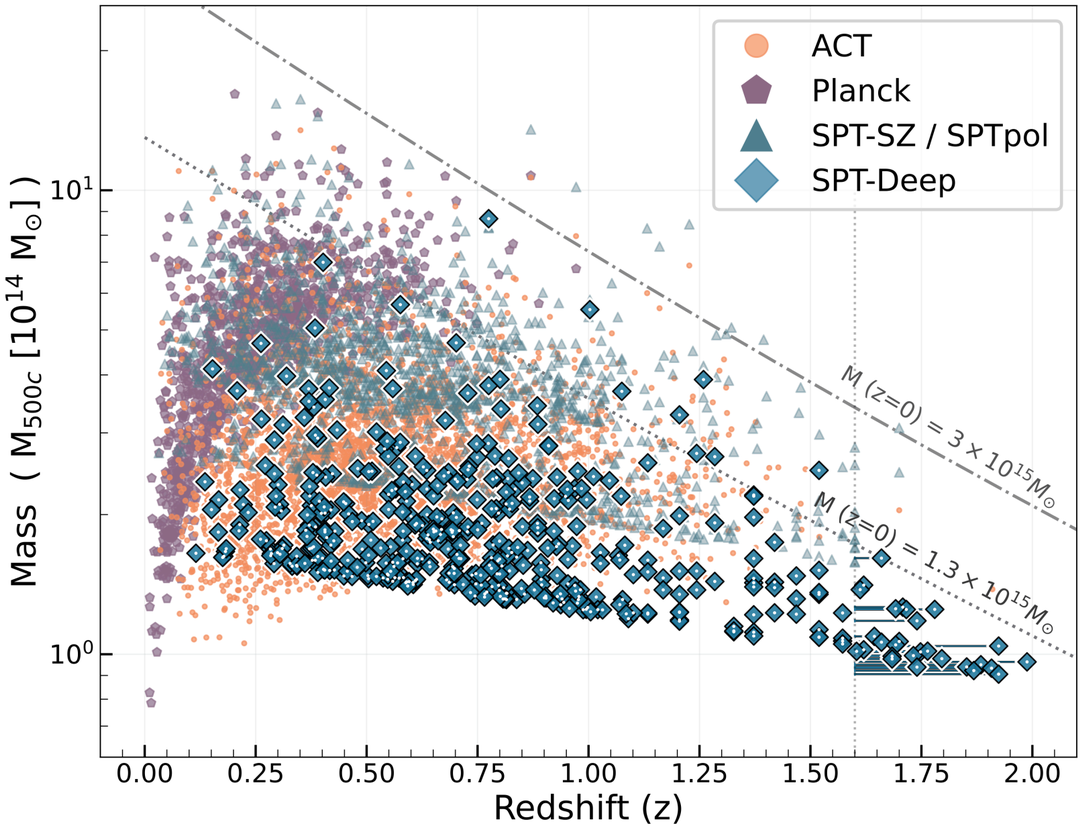
Raghunathan et al. (2024)

Cosmology from CMB Secondaries

Foreground signals also contain rich cosmological information.

100 deg² SPT-deep cluster catalog on arXiv as of last week: arXiv:2503.17271

Looking forward to cluster cosmology with SPT-3G + Euclid!



Kornoelje et al. (2025)

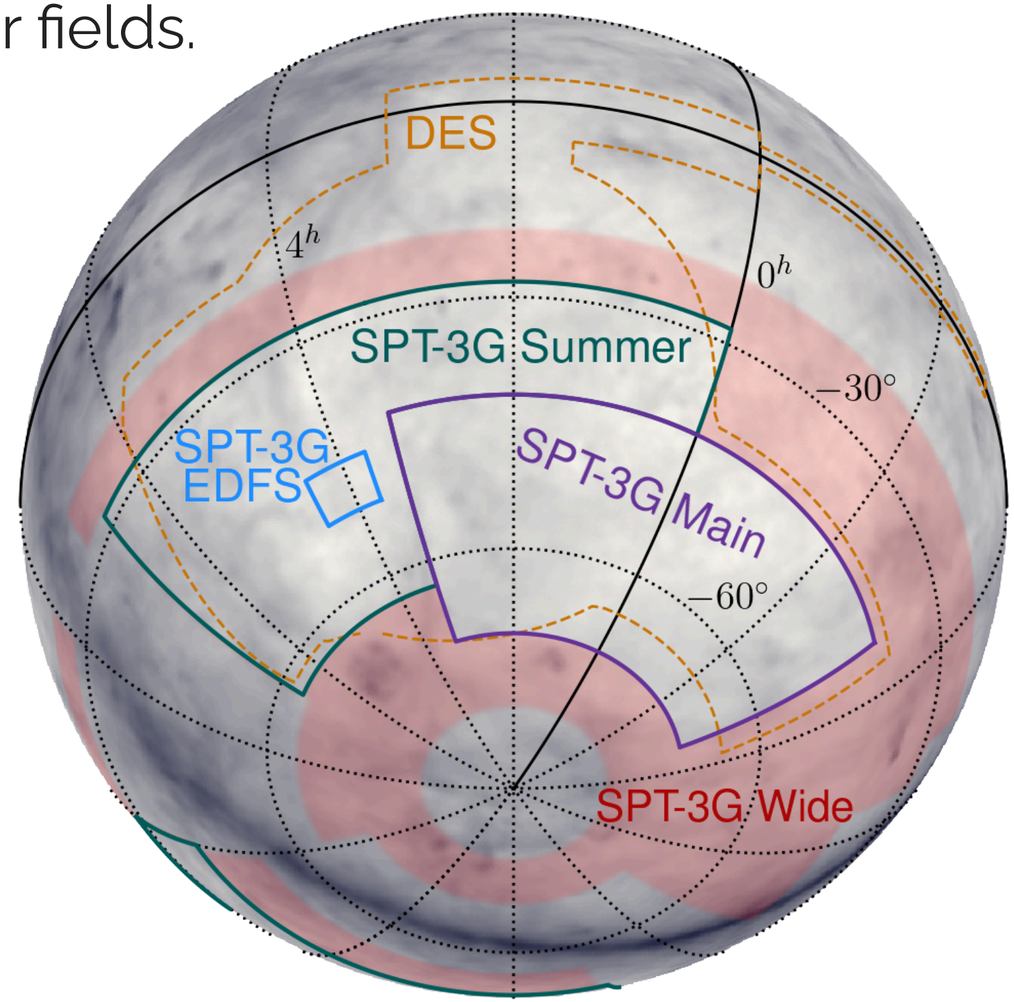
SPT-3G and Euclid

Kevin Zagorski

SPT-3G and Euclid

Joint analyses of SPT-3G and Euclid data will be incredibly powerful!

- DR1 largely overlaps SPT-3G Main and Summer fields.



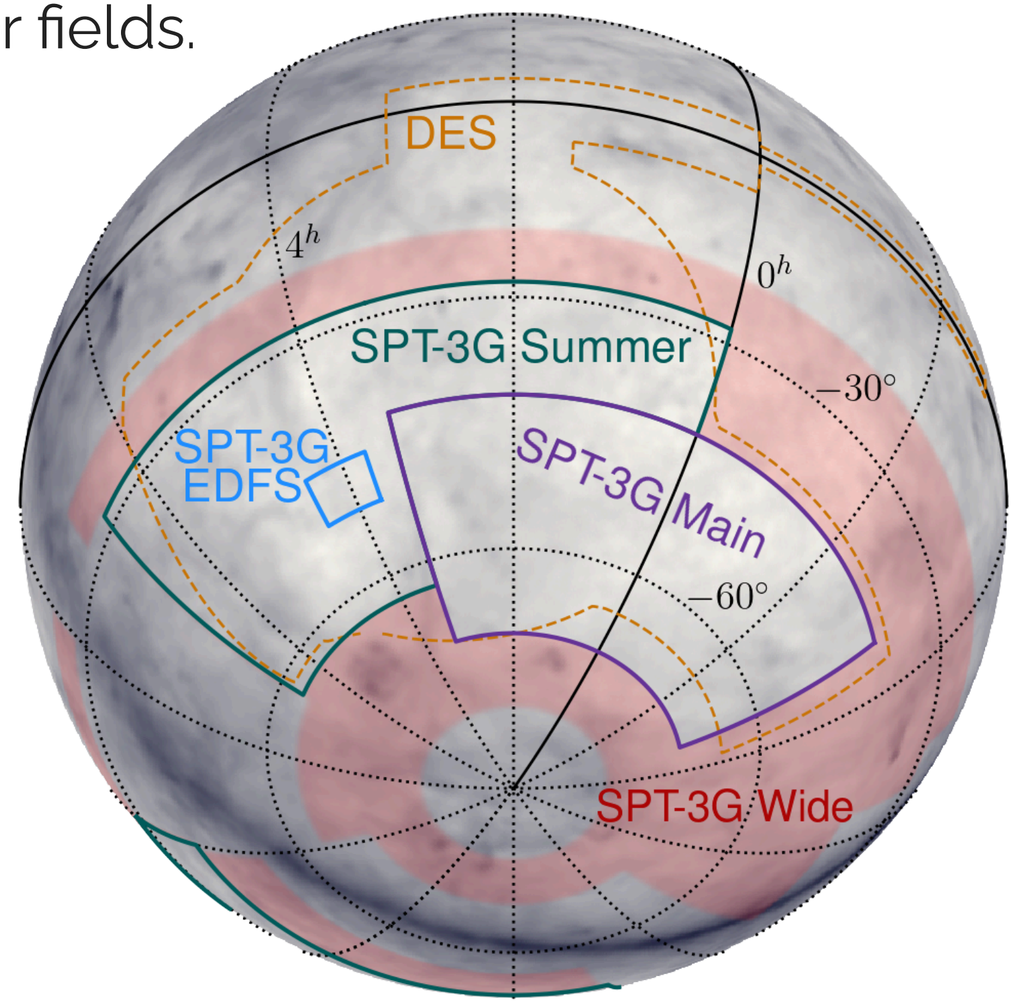
SPT-3G and Euclid

Joint analyses of SPT-3G and Euclid data will be incredibly powerful!

- DR1 largely overlaps SPT-3G Main and Summer fields.

SPT has conducted dedicated observations of Euclid Deep Field South (EDFS) and is planning a release of:

- temperature maps & analysis products
- emissive source catalogs
- cluster catalogs.

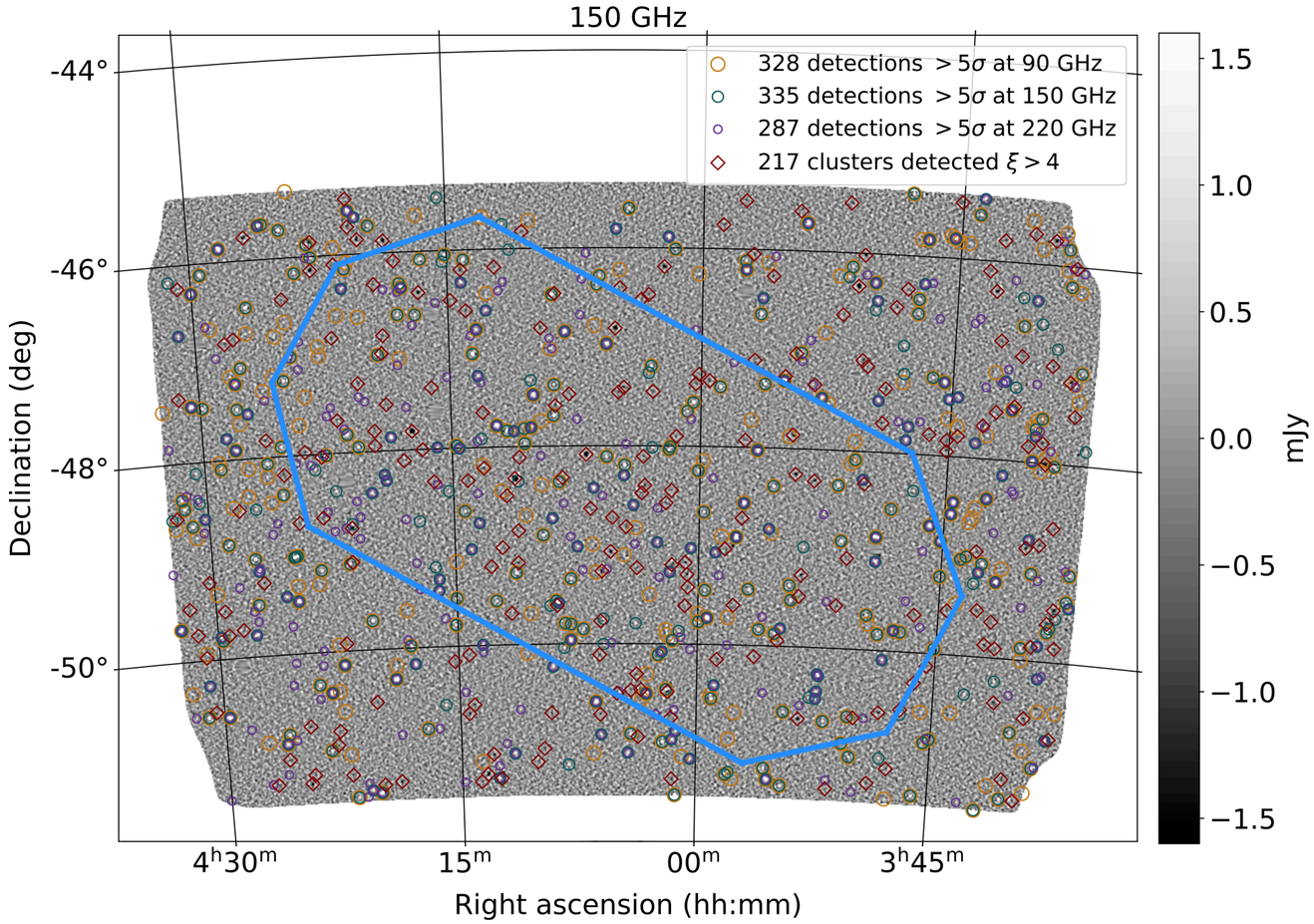


SPT-3G and Euclid

Joint analyses of SPT-3G and Euclid data will be incredibly powerful!

- DR1 largely overlaps SPT-3G Main and Summer fields.

Check out Melanie Archipley's talk **tomorrow at noon** to learn more about our upcoming data release and other SPT science!

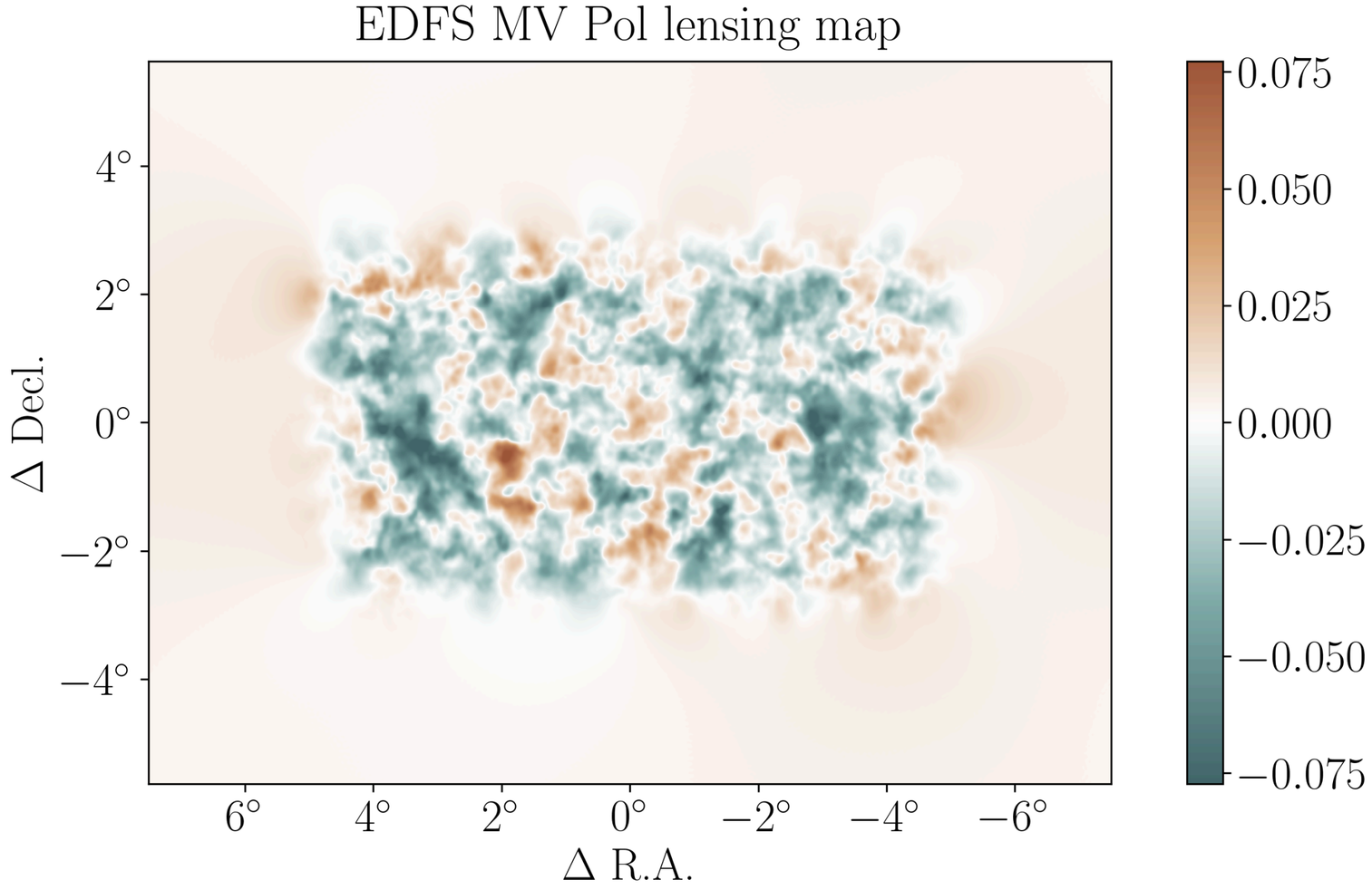


SPT-3G and Euclid

I am working on EDFS lensing maps to be cross-correlated with Euclid Q1 data:

Will provide useful pathfinding for Euclid DR1 × CMB analyses.

Euclid-CMB $\mathbf{6} \times \mathbf{2}$pt will be among Euclid's most powerful cosmological probes.



Summary & Looking Forward

- The CMB still has a lot to tell us about the Universe:
  - **small scales, polarization, & lensing.**

- SPT-3G Main 2019+2020:
  - MUSE polarization-only results probe new scales & are consistent with ΛCDM
  - **coming temperature+polarization constraints will be comparable to Planck!**

- SPT-3G Ext-10k will improve on Planck constraints by as much as **2x for ΛCDM parameters, 3x for single-parameter extensions.**

- Joint SPT-3G + Euclid cosmology constraints will be incredible!

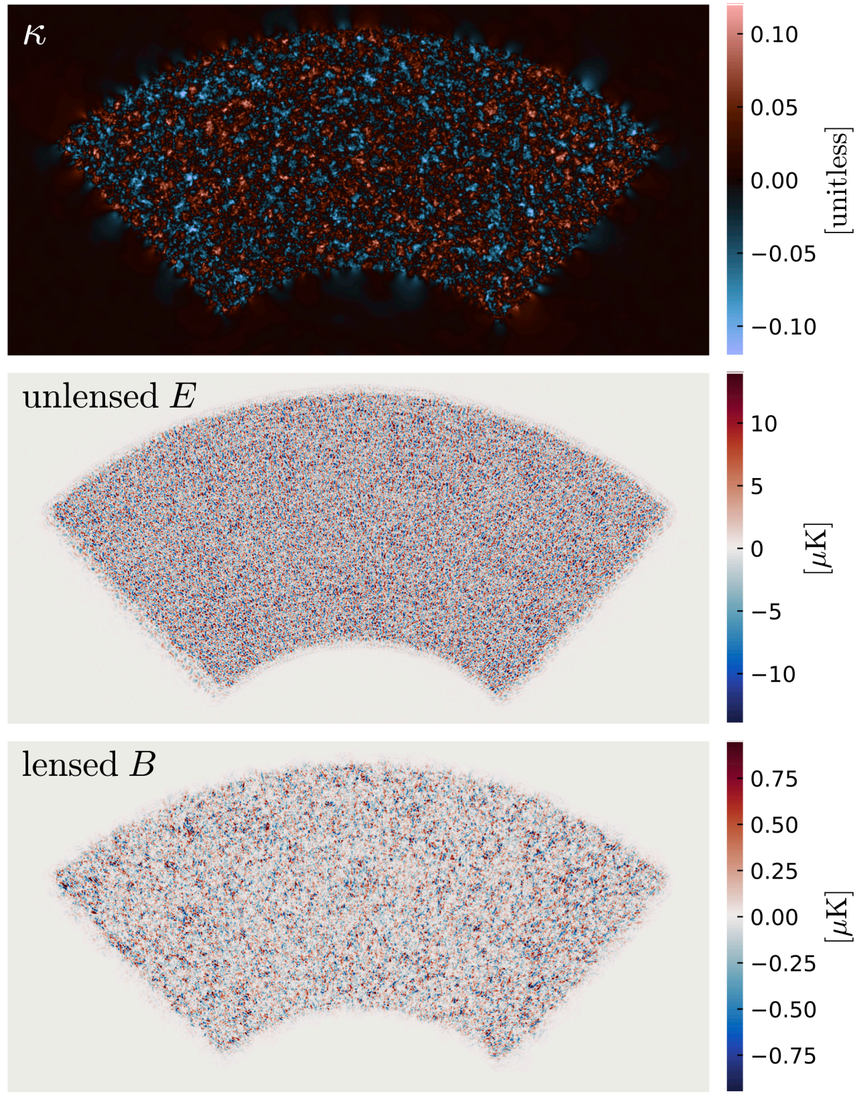
Thank You!

Backup

MUSE Algorithm

Marginalize over CMB f and lensing ϕ maps/pixels to determine parameters θ:

$$\mathcal{P}(\theta \mid d) = \int \mathrm{d}f \, \mathrm{d}\phi \, \mathcal{P}(f, \phi, \theta \mid d)$$

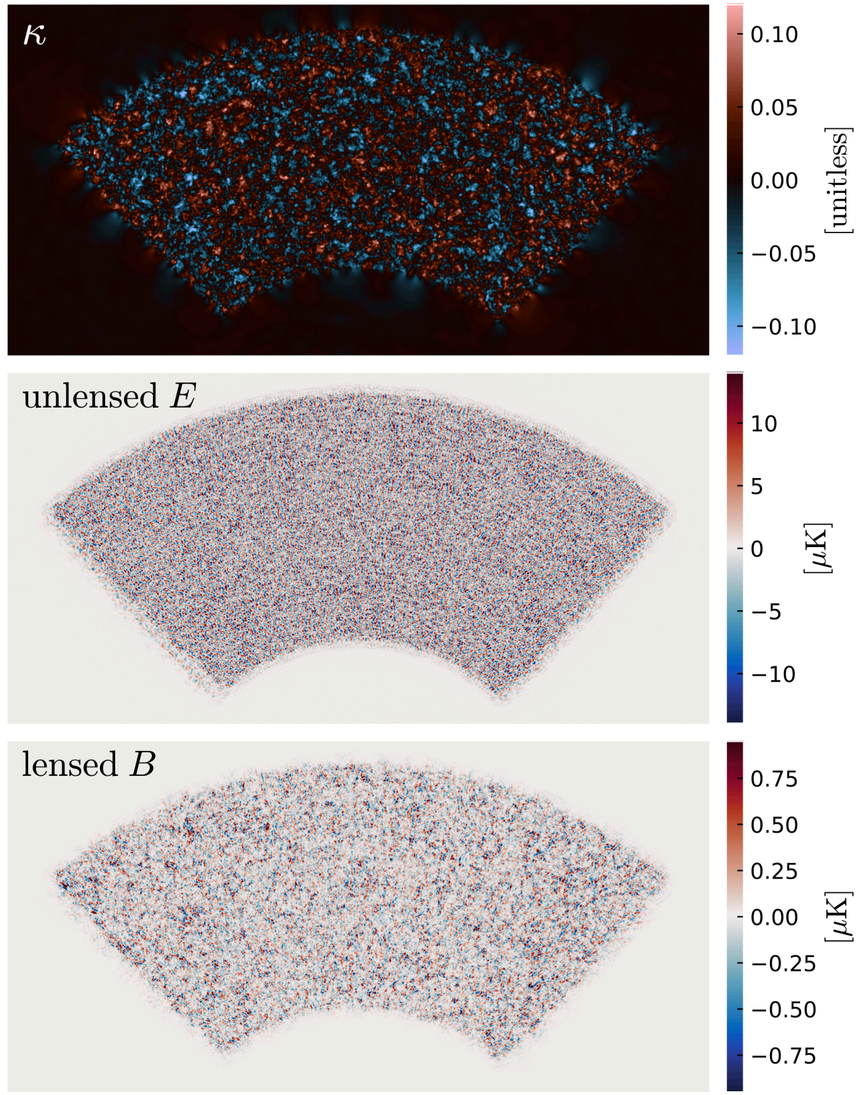


MUSE Algorithm

Marginalize over CMB f and lensing ϕ maps/pixels to determine parameters θ:

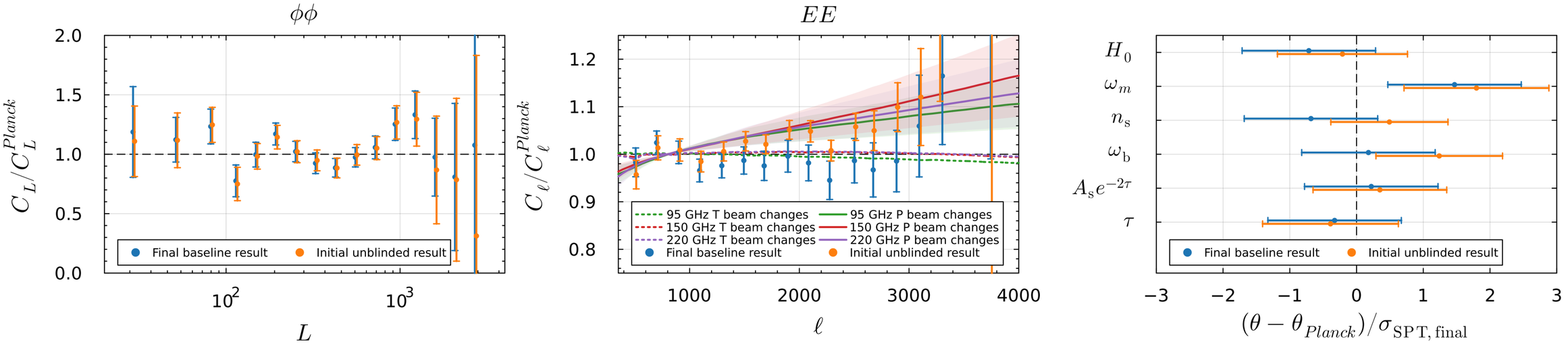
$$\mathcal{P}(\theta \mid d) = \int \mathrm{d}f \, \mathrm{d}\phi \, \mathcal{P}(f, \phi, \theta \mid d)$$

Algorithm similar to simulation-based inference (SBI) with semi-analytic compression statistic.



MUSE Blinding

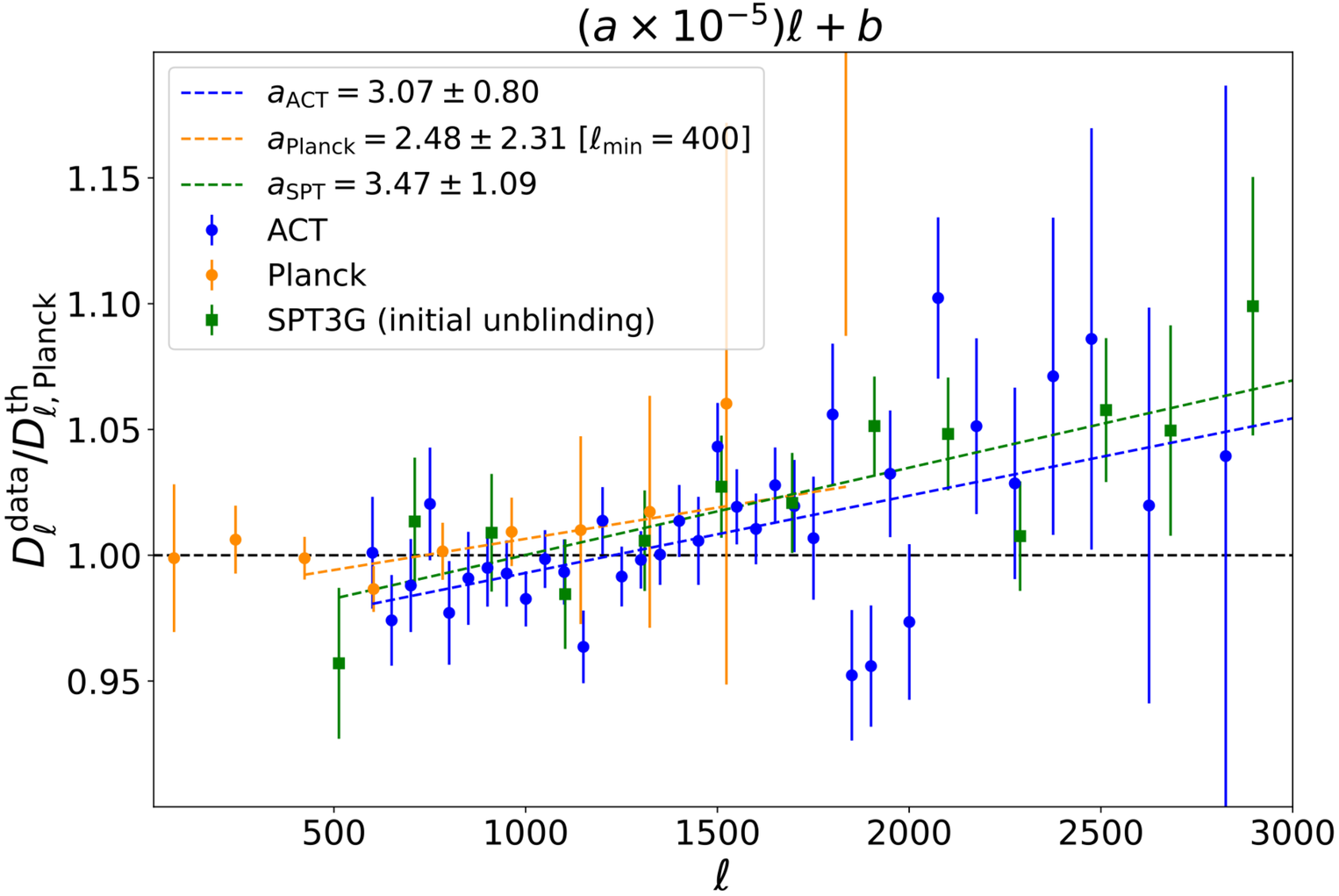
Blinded analysis with post-unblinding beam change:



- Evidence for different beam in polarization.
  - constrained by inter-frequency agreement.
- Shifted cosmological parameters by up to 1σ (not necessarily closer to Planck).

MUSE Blinding

Similar slope seen by ACT DR6:



MUSE Insights on $A_{\rm lens}$

Decreasing neutrino mass **enhances** structure (measured by $\phi\phi$).

CMB prefers more lensing power than predicted by ΛCDM given BAO.

$\implies$ low $\sum m_\nu$ when allowed to vary.

- $A_{\rm recon}$: scales lensing power used to predict lensed CMB power spectra
- $A_{\rm 2pt}$: scales lensing power used to predict lensed CMB power spectra
- $A_{\rm lens}$: if $A_{\rm recon} = A_{\rm 2pt}$