IRENE ABRIL-CABEZAS

THE ATACAMA COSMOLOGY TELESCOPE & THE SIMONS OBSERVATORY

Cosmoglobe Collaboration Meeting 2024

SCIENCE CASES

primordial fluctuations

large scale B-modes
➔ tensor-to-scalar ratio (BB)
➔ primordial power at small scales (TE, TT, EE)

relativistic species

damping tail
➔ N_{eff} (TE, TT, EE)

reionization

sources
➔ width of reionization (kSZ)
➔ mean free path of photons (kSZ)

neutrino mass

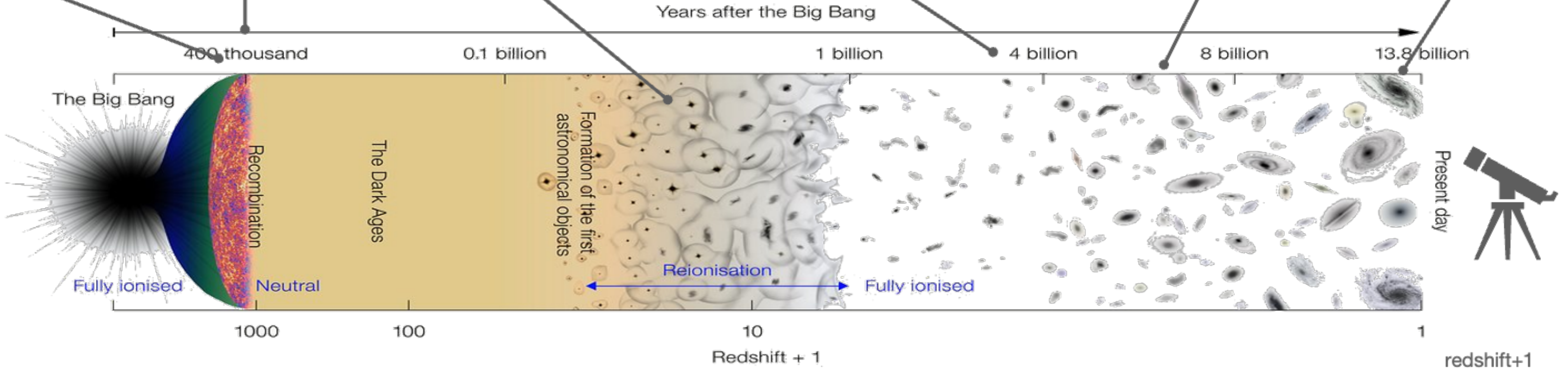
lensing potential (TT+EB), tSZ
➔ Σm_ν

galaxy evolution

tSZ, kSZ
➔ non-thermal pressure (tSZ+kSZ)
➔ feedback efficiency (tSZ+kSZ)

dark energy

tSZ, lensing
➔ σ_8 at z=2-3 (lensing, tSZ)
➔ growth of structure (kSZ)



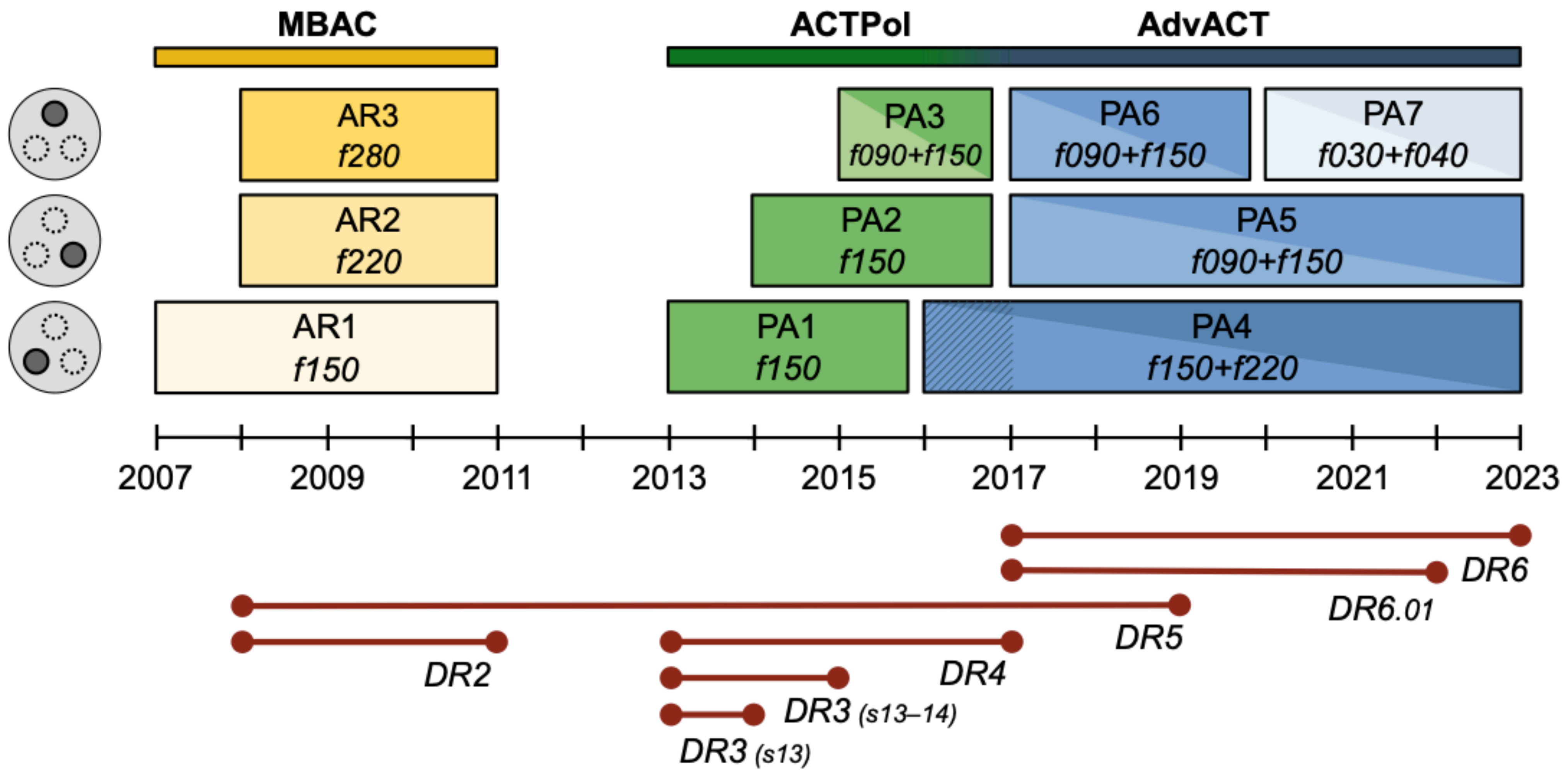
credits: ESO and Josquin Errand

CERRO TOCO, LLANO CHAJNANTOR, ATACAMA DESERT, CHILE

- ✅ 5200m altitude
- ✅ PWV ~1.2mm
- ✅ Low latitude (-23°)
- ✅ Excellent site for CMB observations

THE ATACAMA COSMOLOGY TELESCOPE

- Commissioned in 2008 – First instrument not sensitive to polarization
- 6-metre primary mirror: requirement for arcminute resolution
- Data Release 6: observations at 90, 150 and 220 GHz



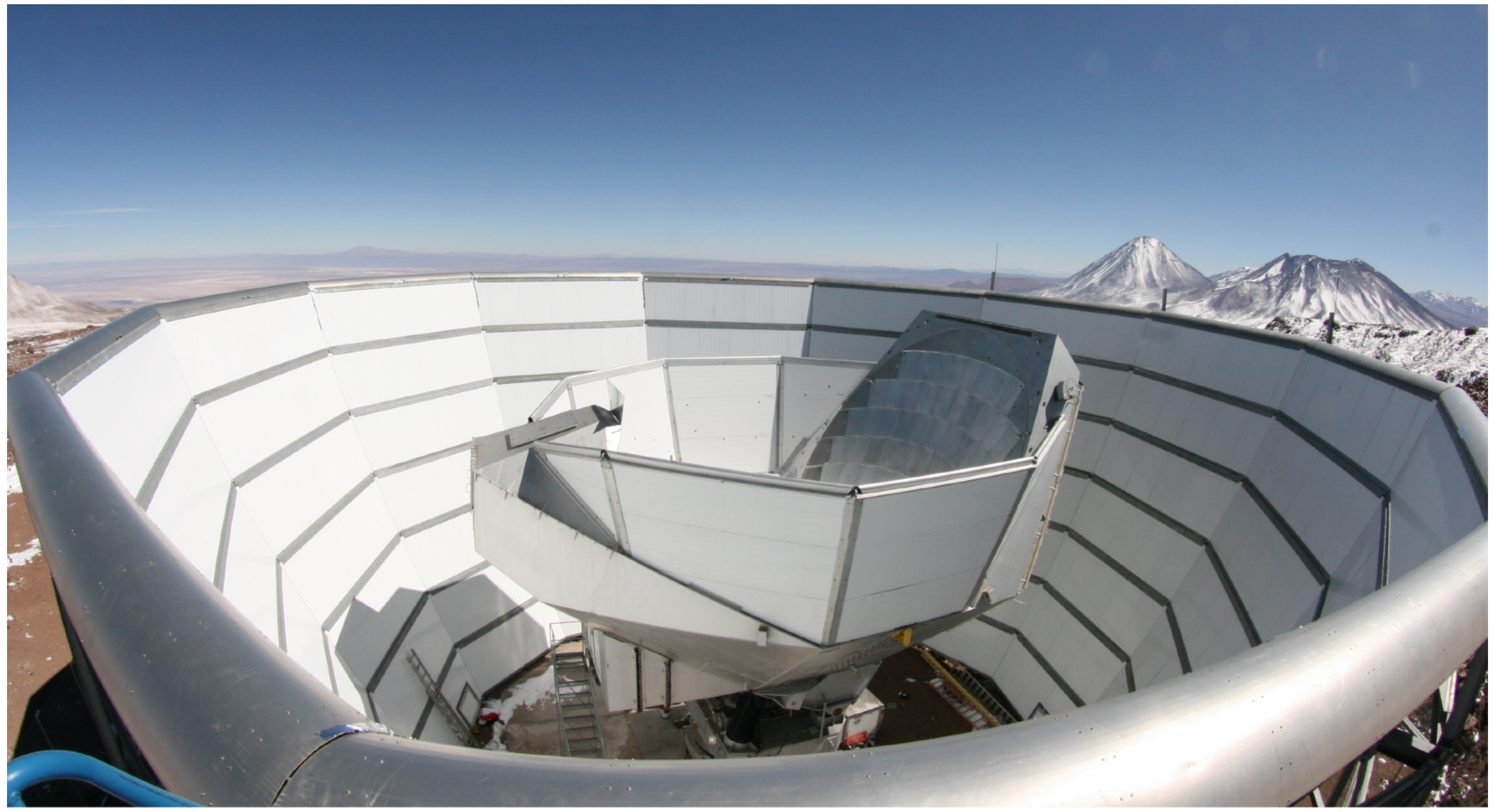
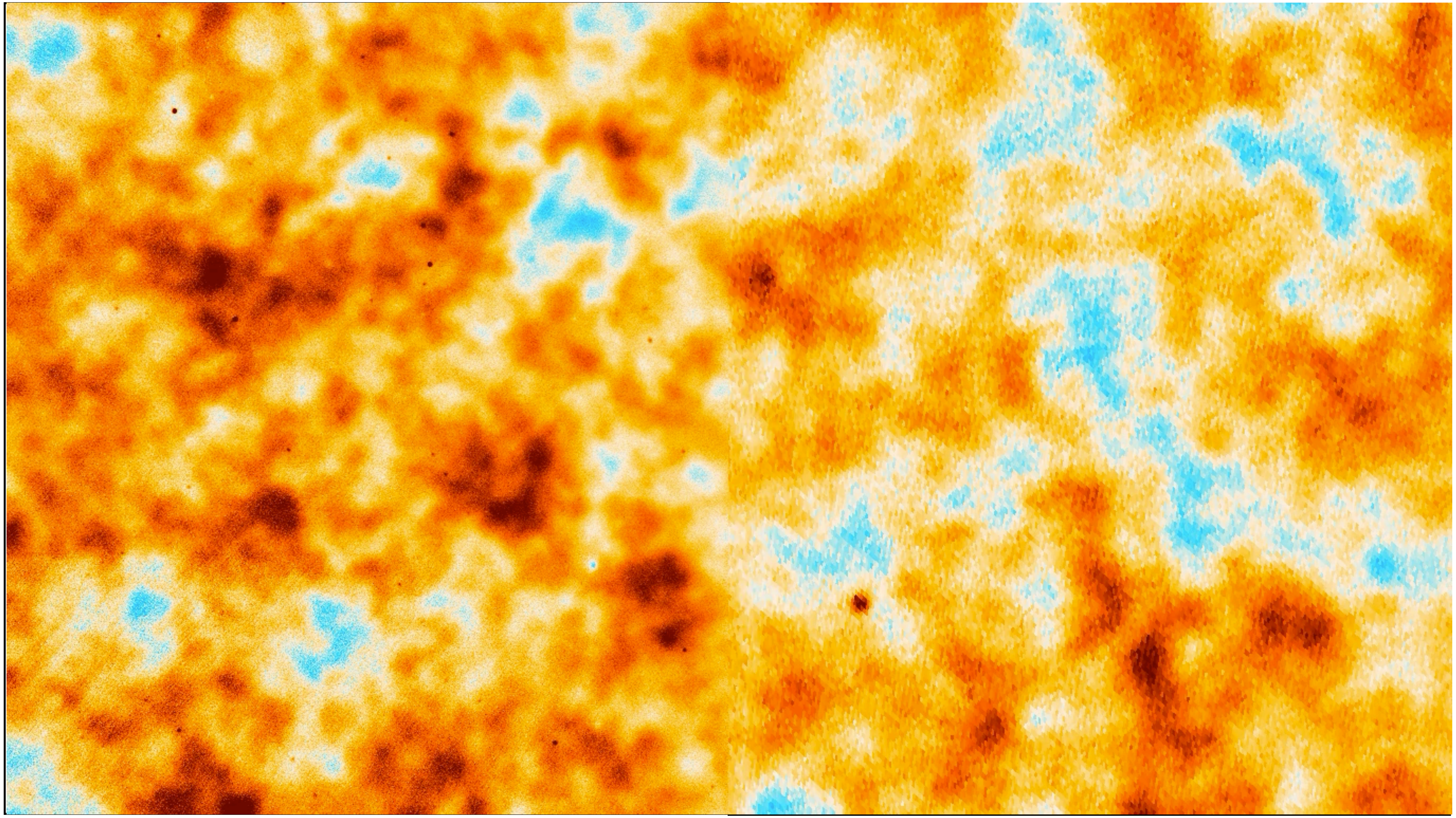


Image credits: Debra Kellner (top), Mark Devlin (bottom)

SMALL-SCALE MILLIMETRE SKY WITH THE ATACAMA COSMOLOGY TELESCOPE

ACT + Planck

Planck



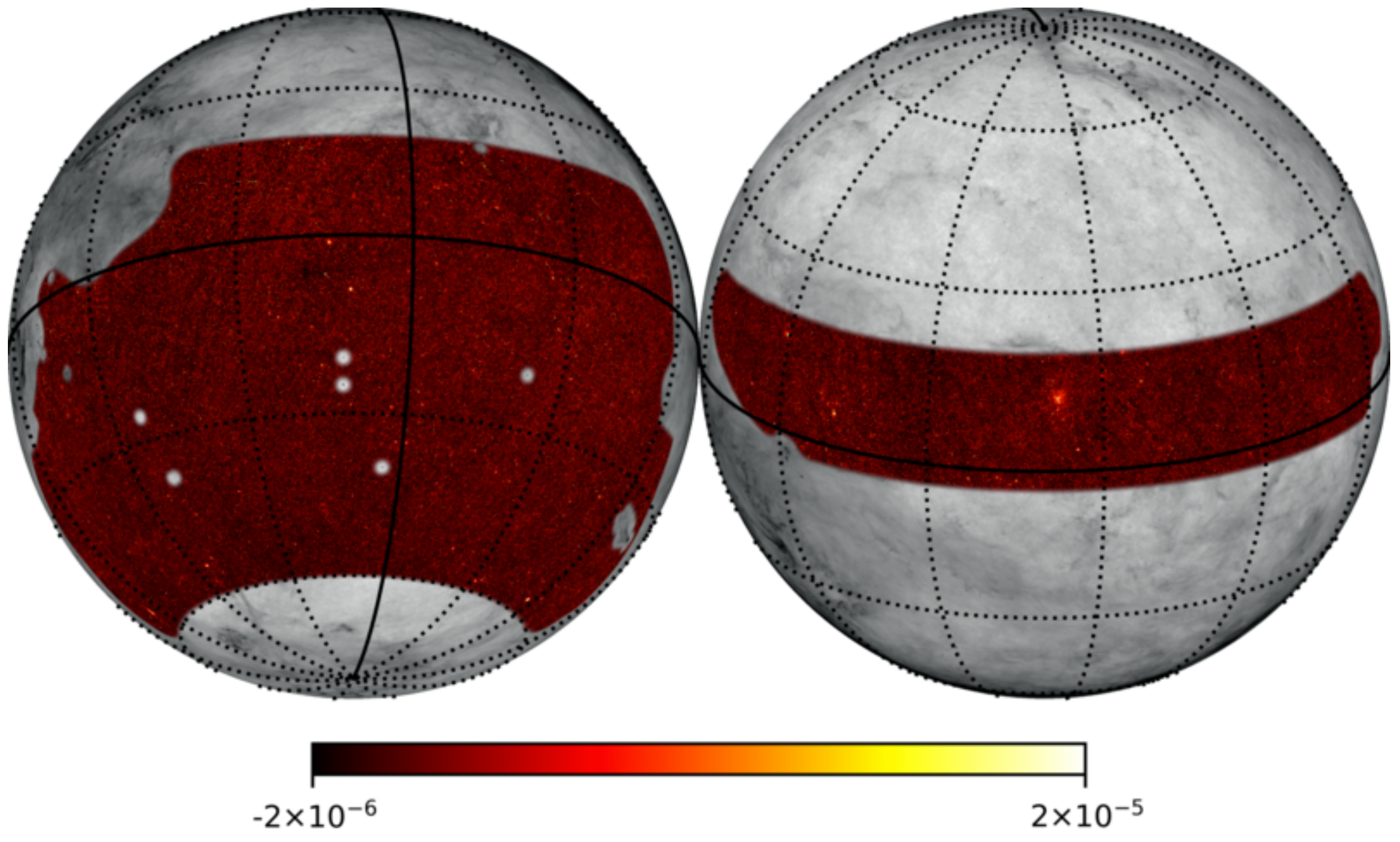
Source: Sigurd Naess and the ACTPol Collaboration

ACT multi-frequency observations vital for separating sky signals

- Example: thermal SZ effect

Problem:

- Isotropic signals best treated in harmonic space
- Inhomogeneous noise and Galactic signals better described in real space
  - *Wavelets are localised in both harmonic and real space!*

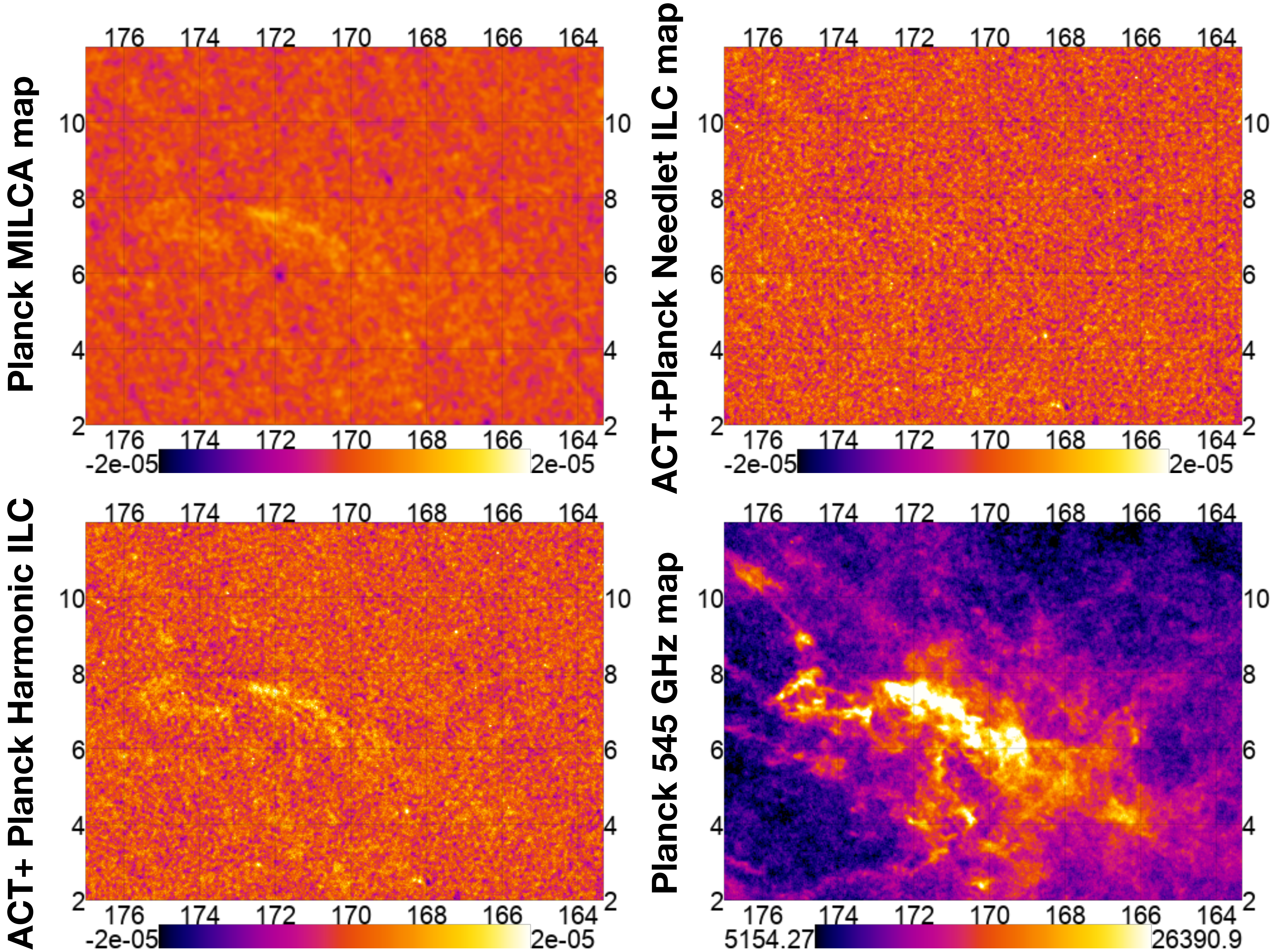


ACT & *Planck* NILC Compton-y map.

Solution: Internal Linear Combination with Wavelets

Coulton+23

COMPONENT SEPARATION WITH THE ATACAMA COSMOLOGY TELESCOPE

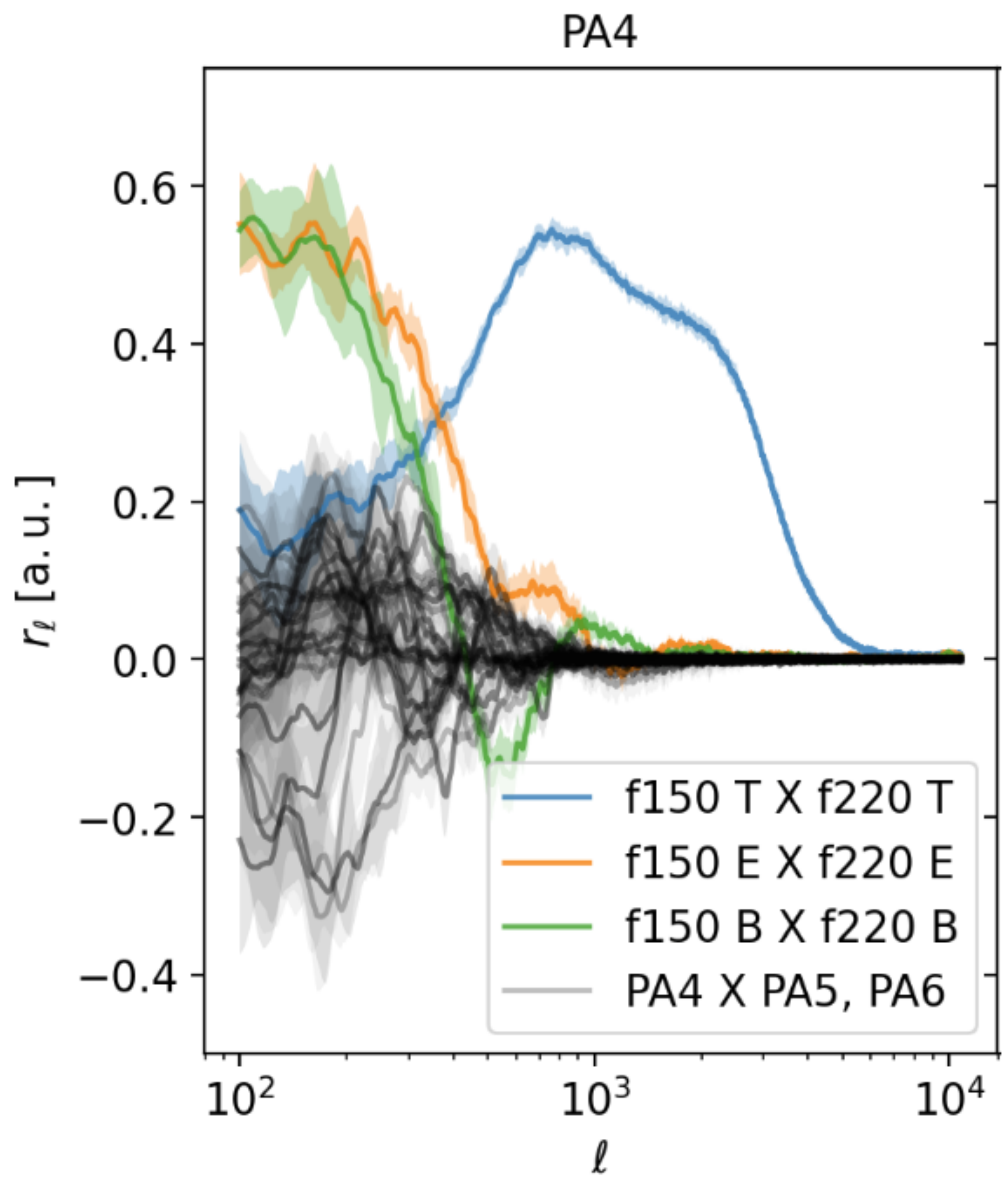


Coulton+23

THE ATACAMA COSMOLOGY TELESCOPE: COMPLEX NOISE STRUCTURE

Ground-based CMB maps have complicated noise properties from atmosphere and scanning strategy:

- 1/f correlated atmospheric noise
- Same-array frequency-frequency correlations
- Inhomogeneous & scale-dependent map depth
- Spatially-varying noise stripiness



Atkins+23

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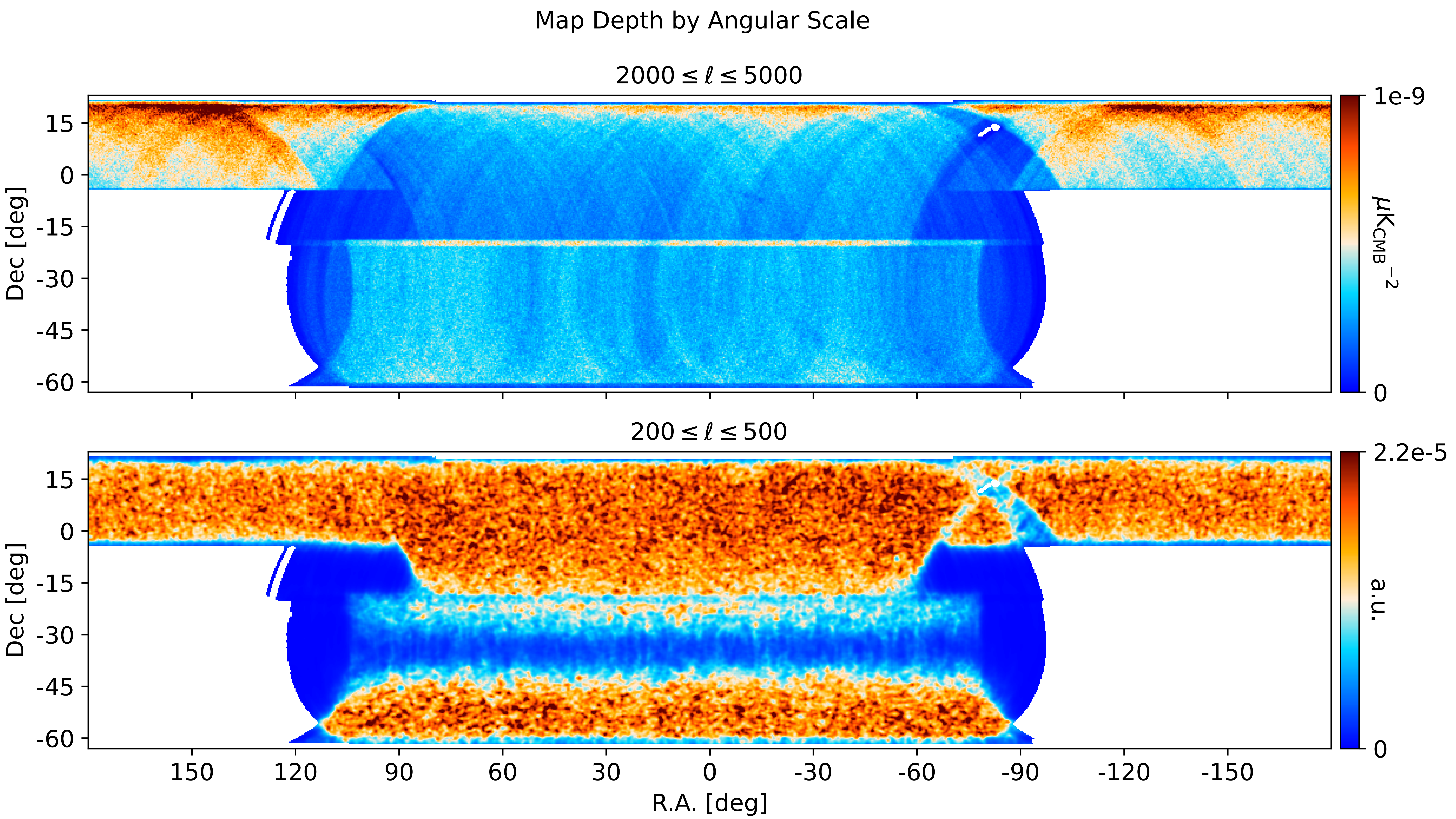

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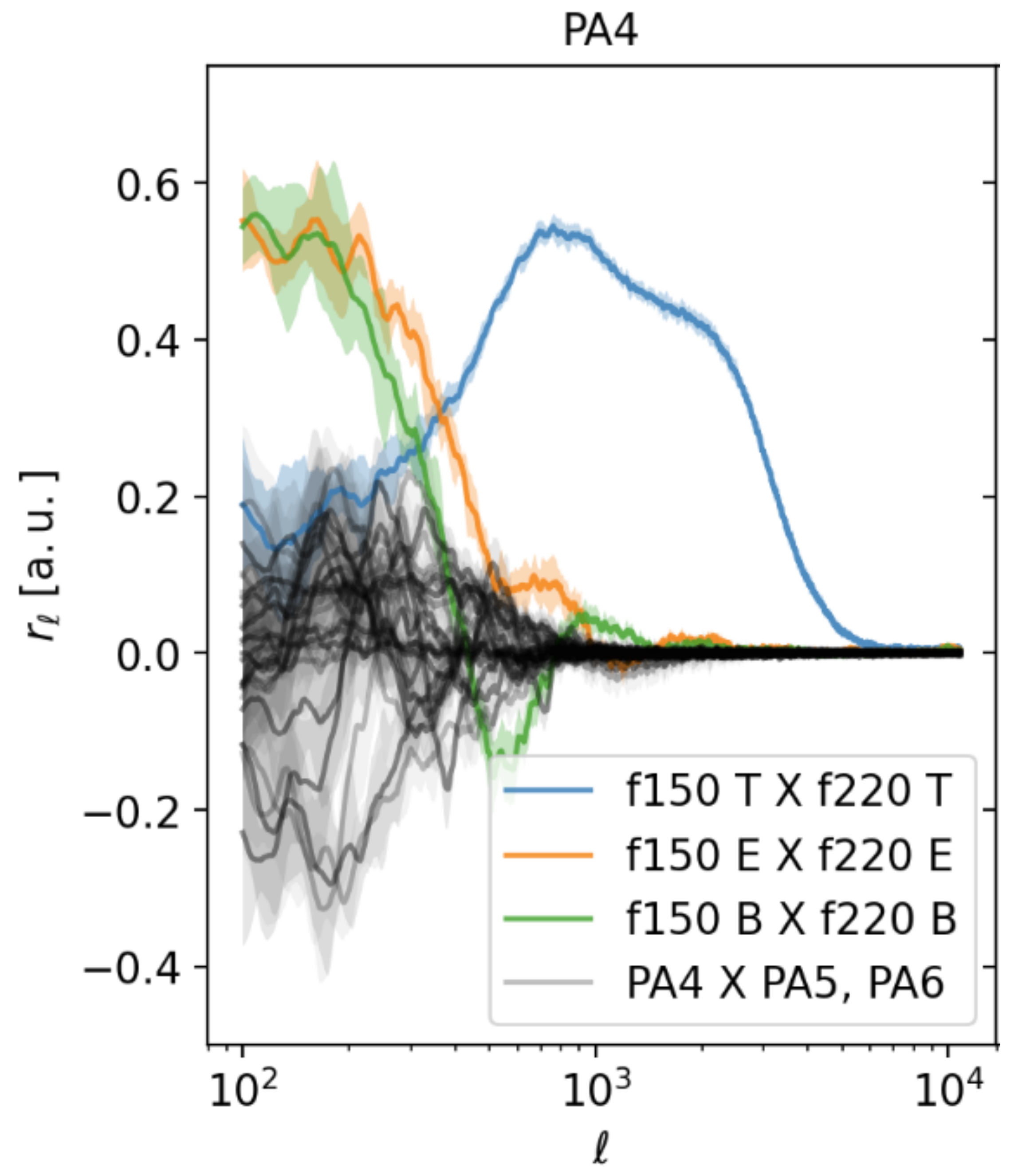
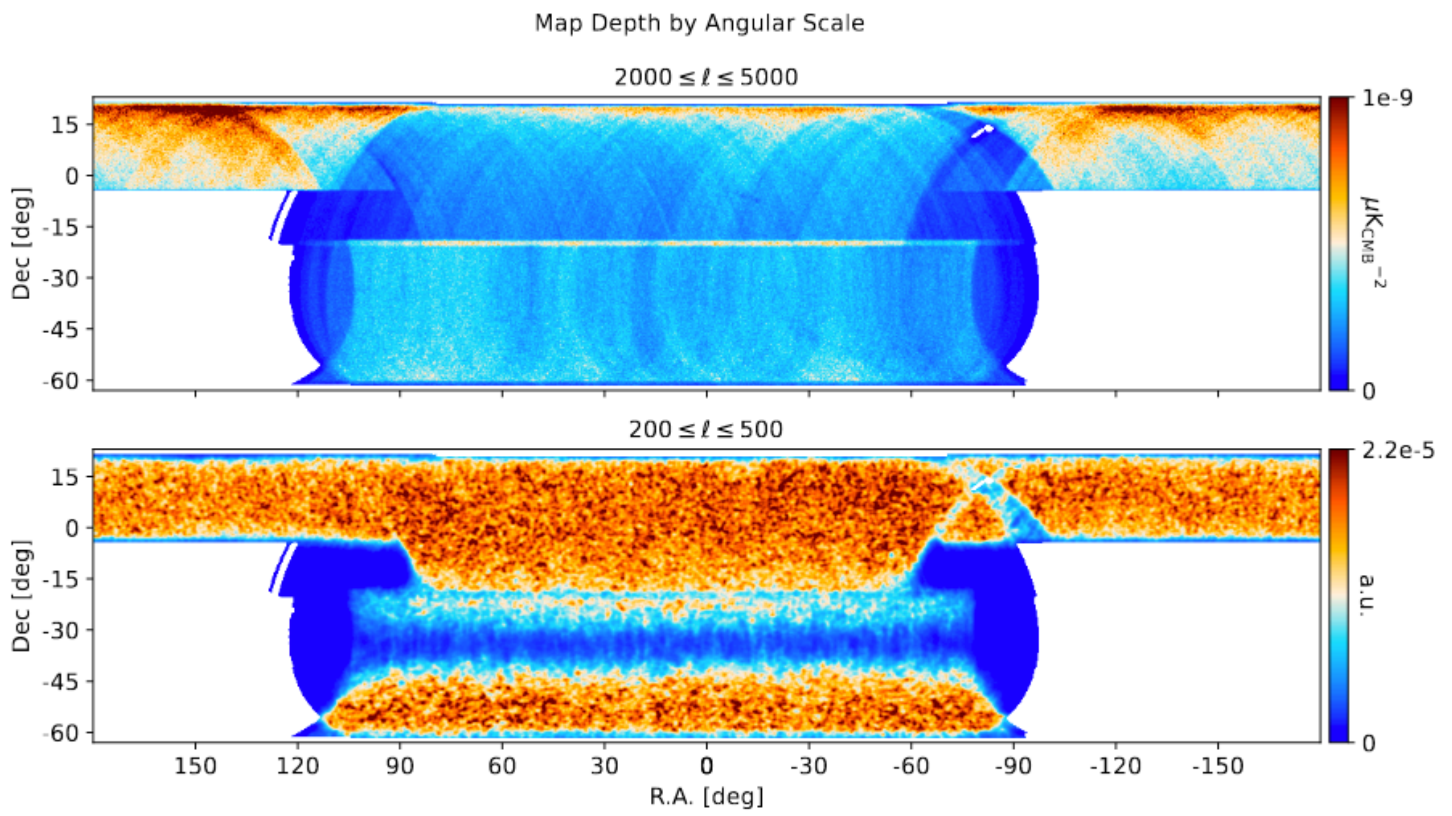
Map-based noise simulations: Atkins+ (2303.04180)



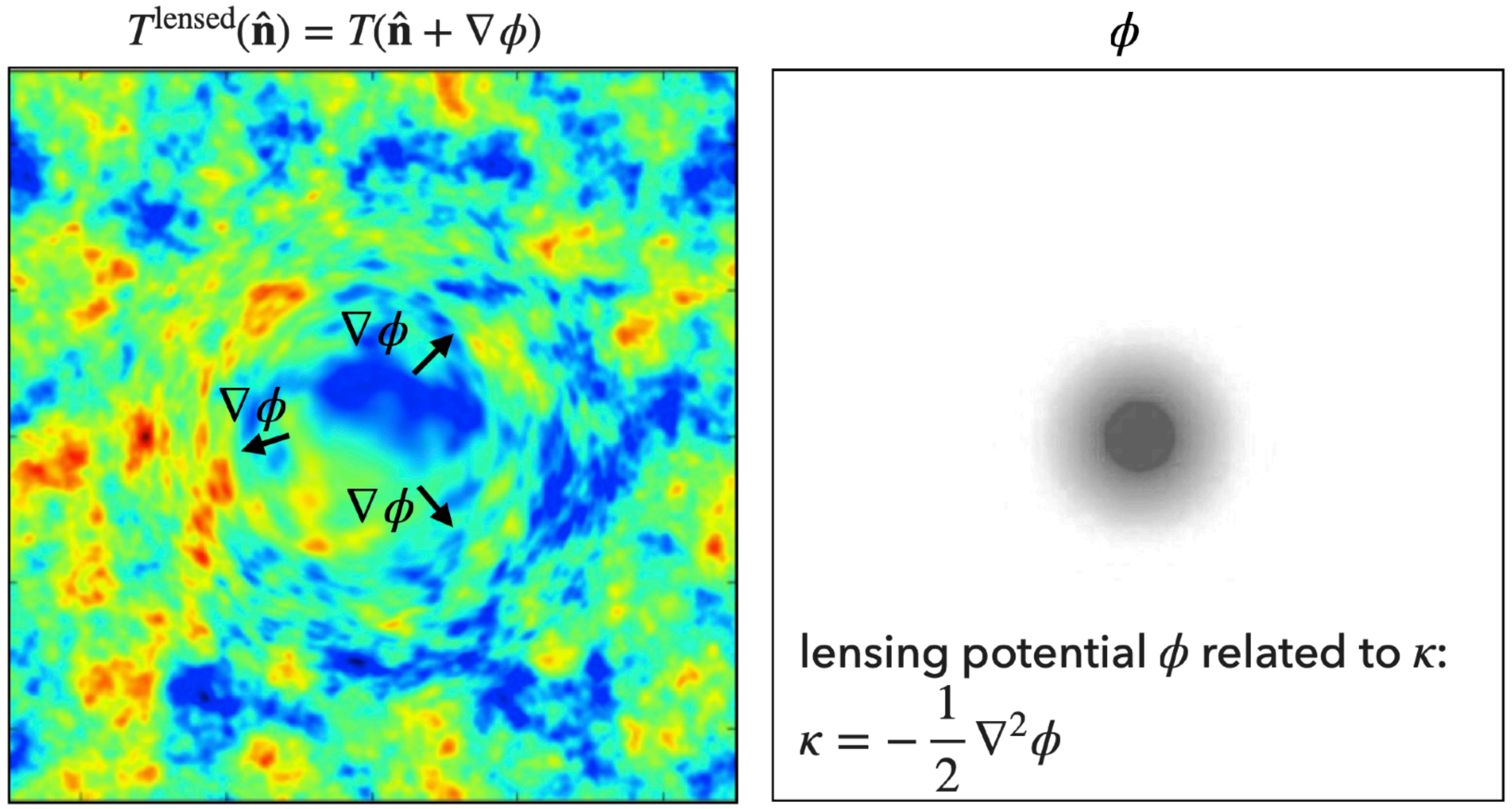


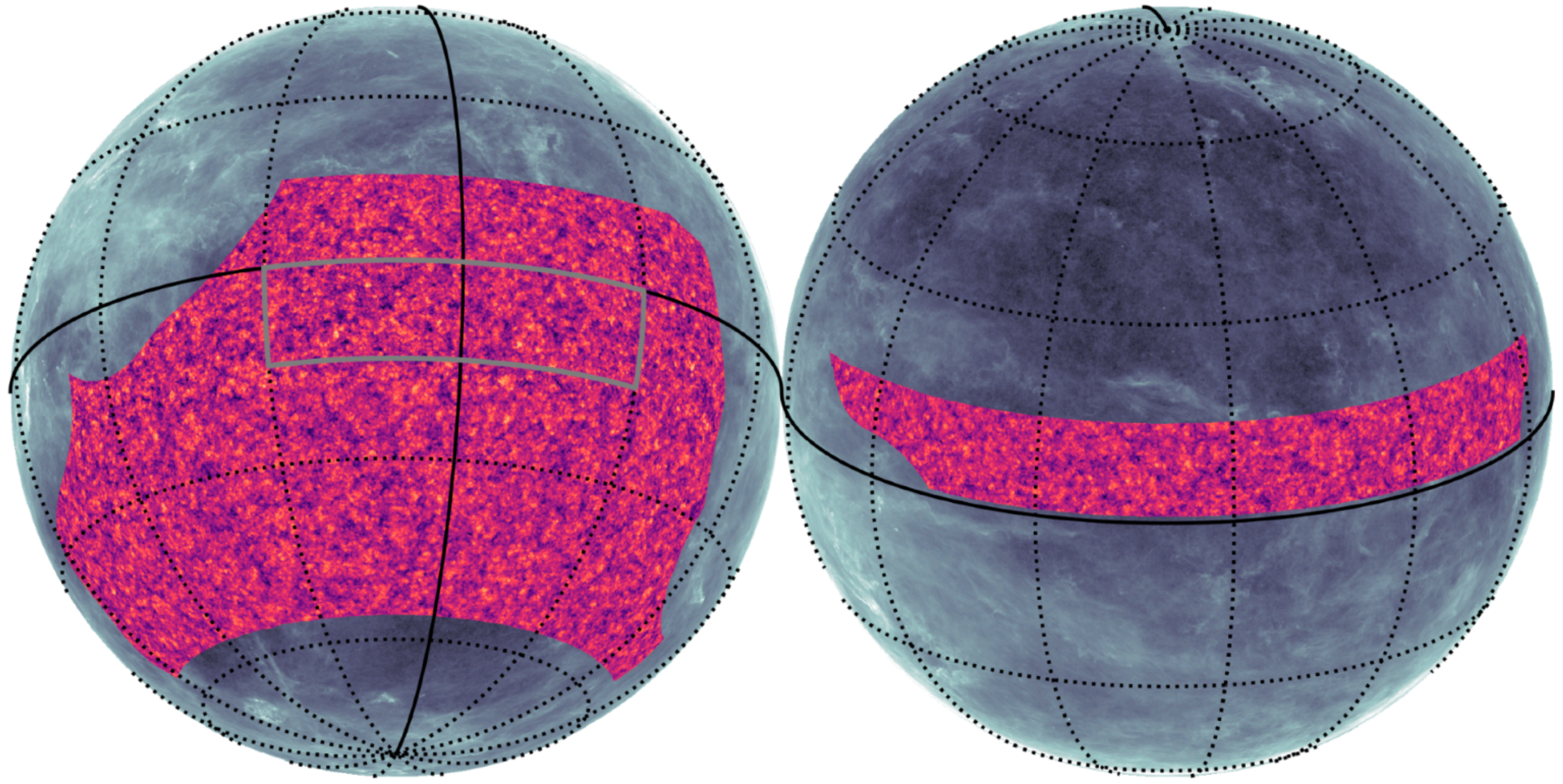
Atkins+23

Gravitational lensing of the CMB depends on the total matter over-density integrated along the line of sight:

$$\kappa(\vec{n}) = \int \mathrm{d}z W(z)\delta_m\left(\chi(z)\vec{n}, z\right)$$

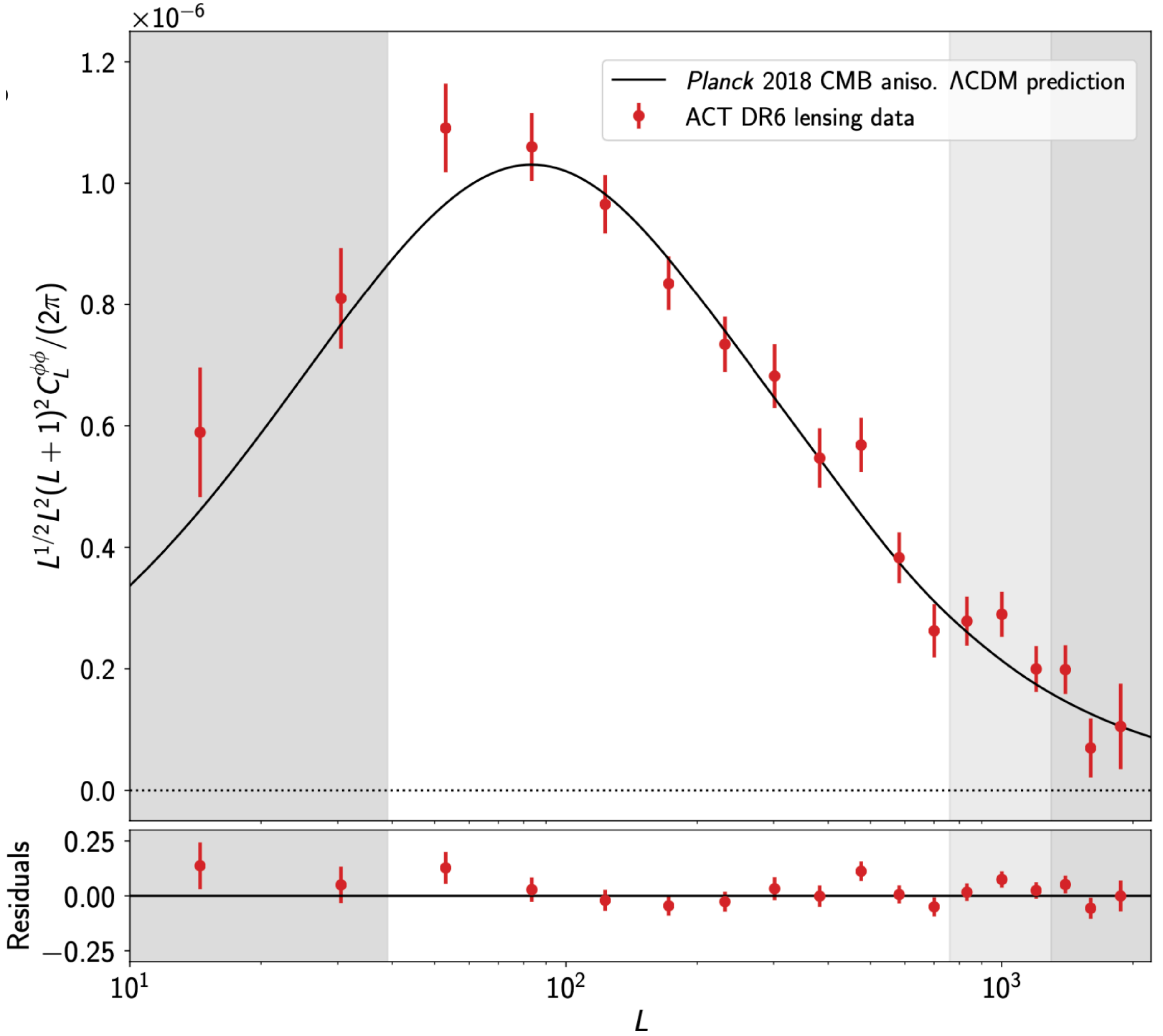
- For a fixed ϕ field, the lensed CMB becomes statistically anisotropic. Use this to find ϕ
- Algorithm: quadratic estimator
  $\hat{\phi}(L) \sim \int \mathrm{d}^2\mathbf{l}\; T(\mathbf{l})\, T^*(\mathbf{l} - \mathbf{L})$

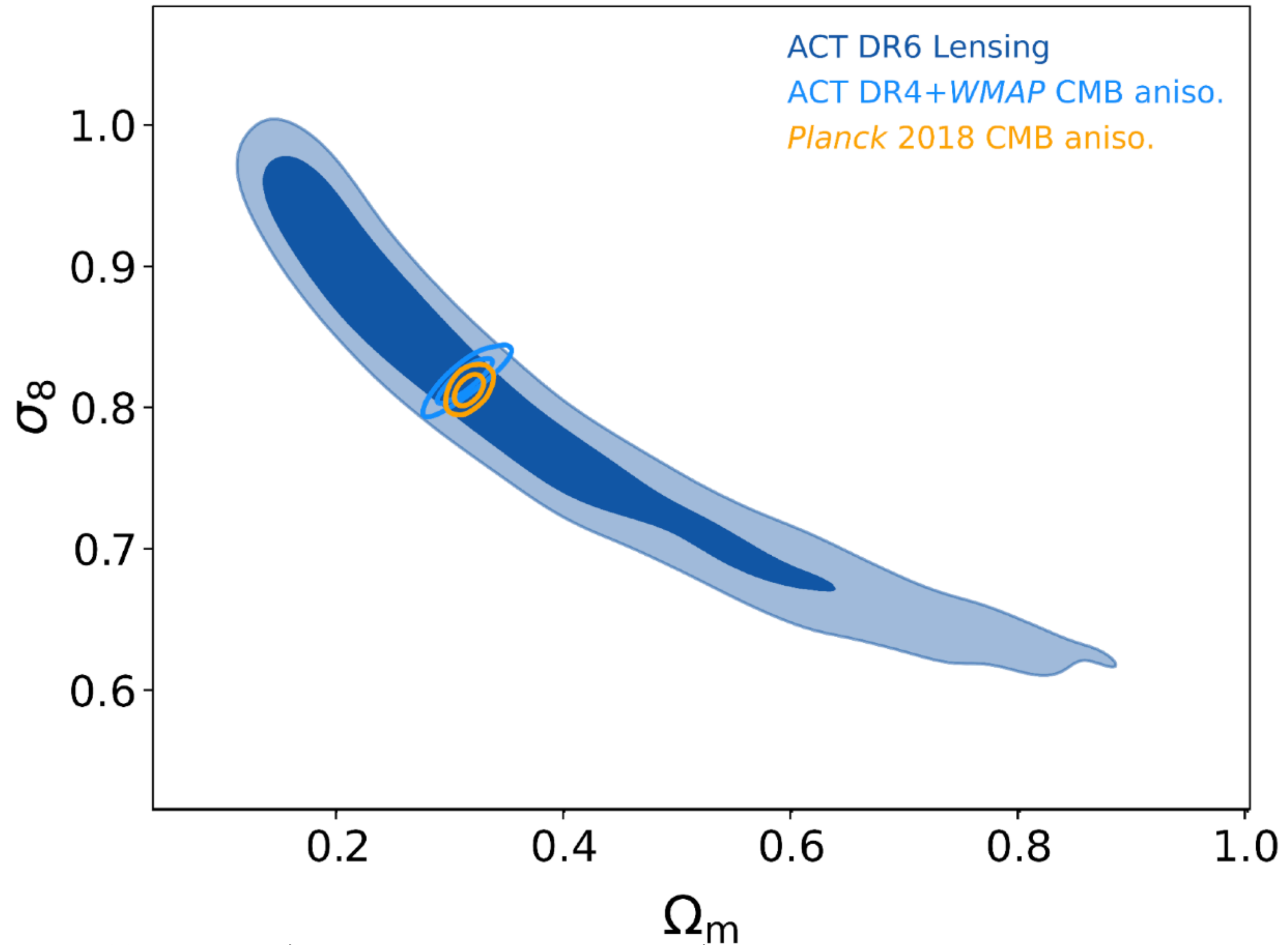


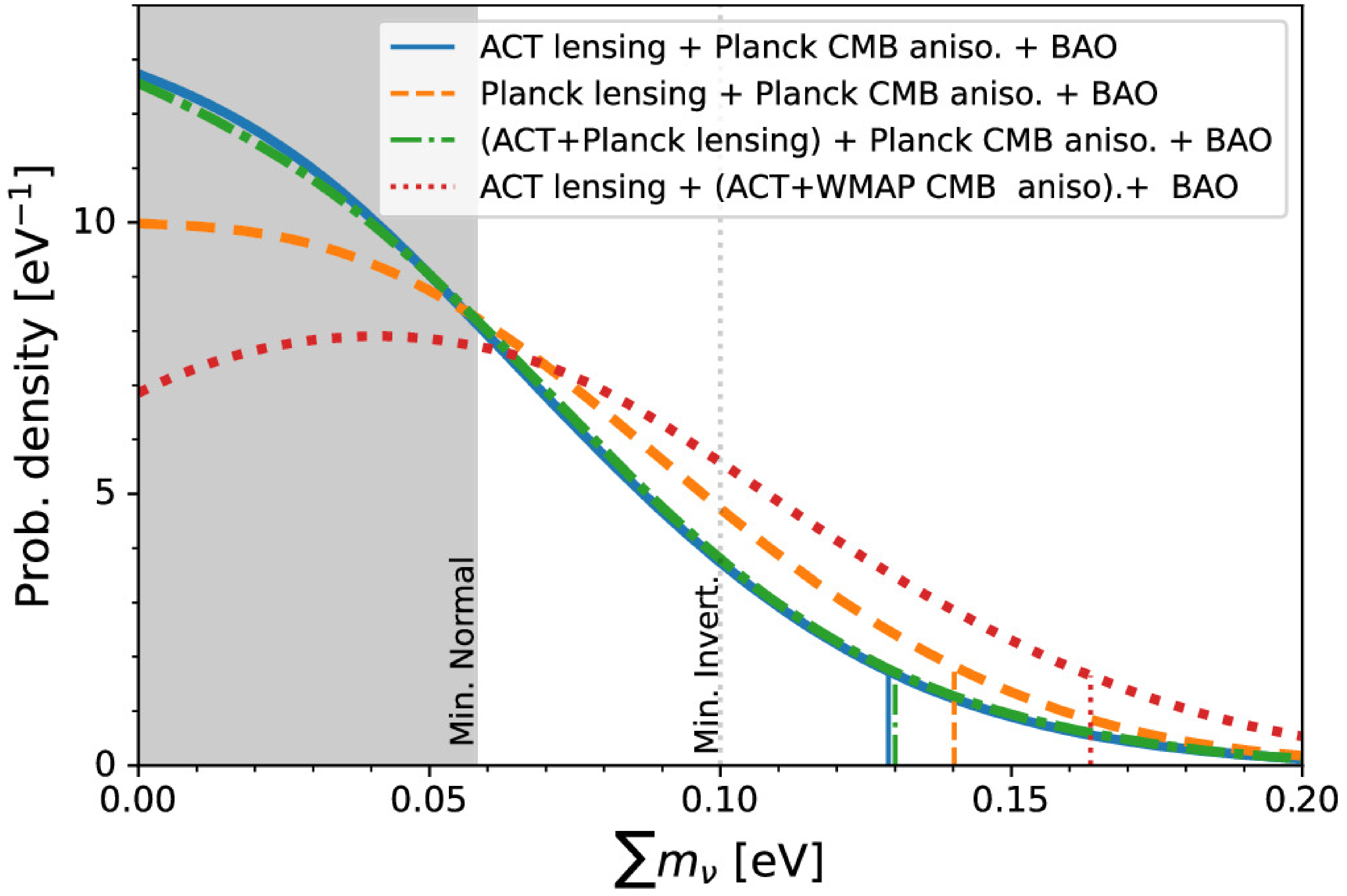


Qu+24, Madhavacheril+24

CMB LENSING WITH THE ATACAMA COSMOLOGY TELESCOPE







Qu+24, Madhavacheril+24

Depth and polarization systematics most important

High resolution and large sky coverage most important

primordial fluctuations

large scale B-modes
➔ tensor-to-scalar ratio (BB)
➔ primordial power at small scales (TE, TT, EE)

relativistic species

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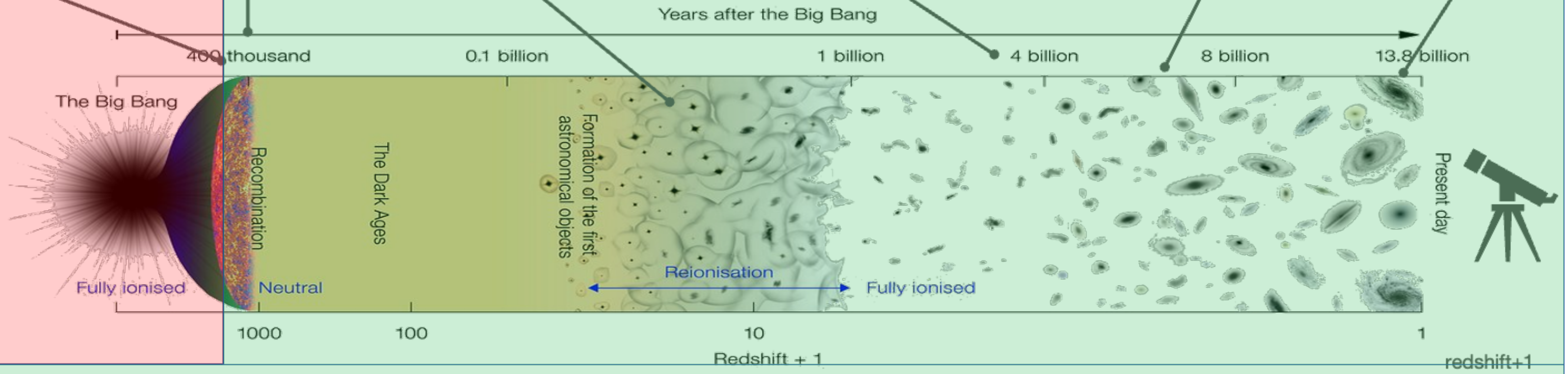


credits: ESO and Josquin Errand

+ transient sources (GRB, TDE, flares), CIB, f_{NL}, cosmic birefringence, solar system (asteroids and planet 9), exo-oort clouds, cluster and AGN catalogs, etc.

SIMONS OBSERVATORY

PARQUE ASTRONÓMICO ATACAMA, CHILE

22°57' S, 67°47' W

ELEVATION: 5190m

www.simonsobservatory.org

15+ COUNTRIES

60+ INSTITUTIONS

375+ RESEARCHERS

SIMONS FOUNDATION

HEISING-SIMONS FOUNDATION

BERKELEY LAB · CARDIFF UNIVERSITY PRIFYSGOL CAERDYDD · CITA-ICAT · iPMU · KEK-JAPAN · NASA · NIST · SISSA · SLAC · TEL AVIV UNIVERSITY · TOHOKU · UBC · UNIVERSITY OF KWAZULU-NATAL · MANCHESTER · MELBOURNE · MICHIGAN · OXFORD · UNIVERSITY OF SUSSEX · WCU WEST CHESTER UNIVERSITY

LARGE APERTURE TELESCOPE (LAT) RECEIVER

- 6-metre primary mirror (2′ FWHM)
- Designed for 13 optic tubes. Nominal SO includes 7
- 6 bands (27-280 GHz)
- 30k detectors

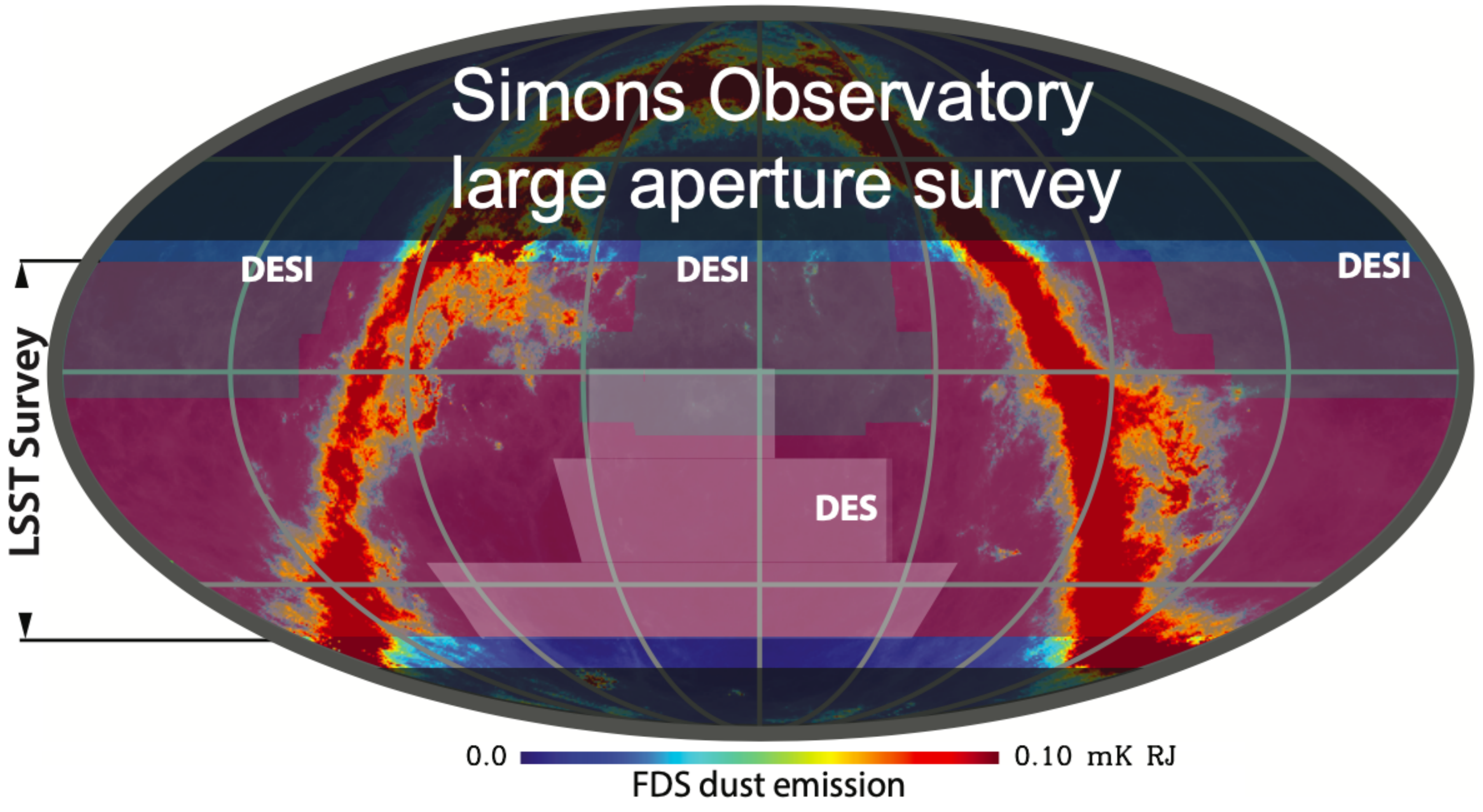
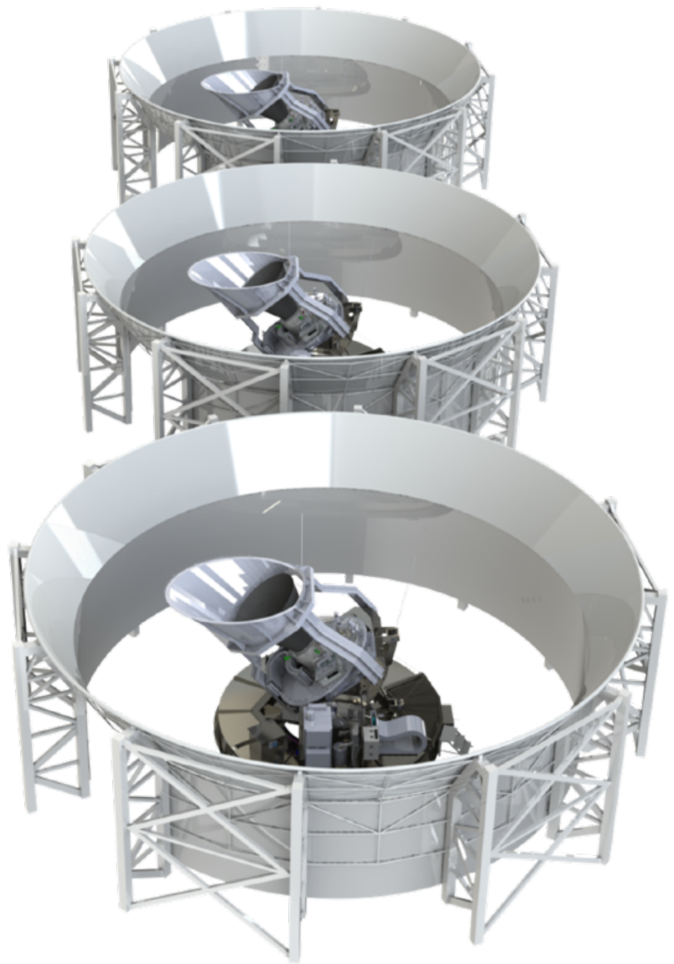


Image credits: Mark Devlin

SMALL APERTURE TELESCOPE (SAT) RECEIVERS

- 3 SATs (2 MF, 1 UHF currently)
- 0.4-metre primary lens (30′ FWHM)
- Cryogenic Half Wave Plates (CHWP)
- 6 bands (27-280 GHz)
- 30k detectors total



May 2022

May 2024

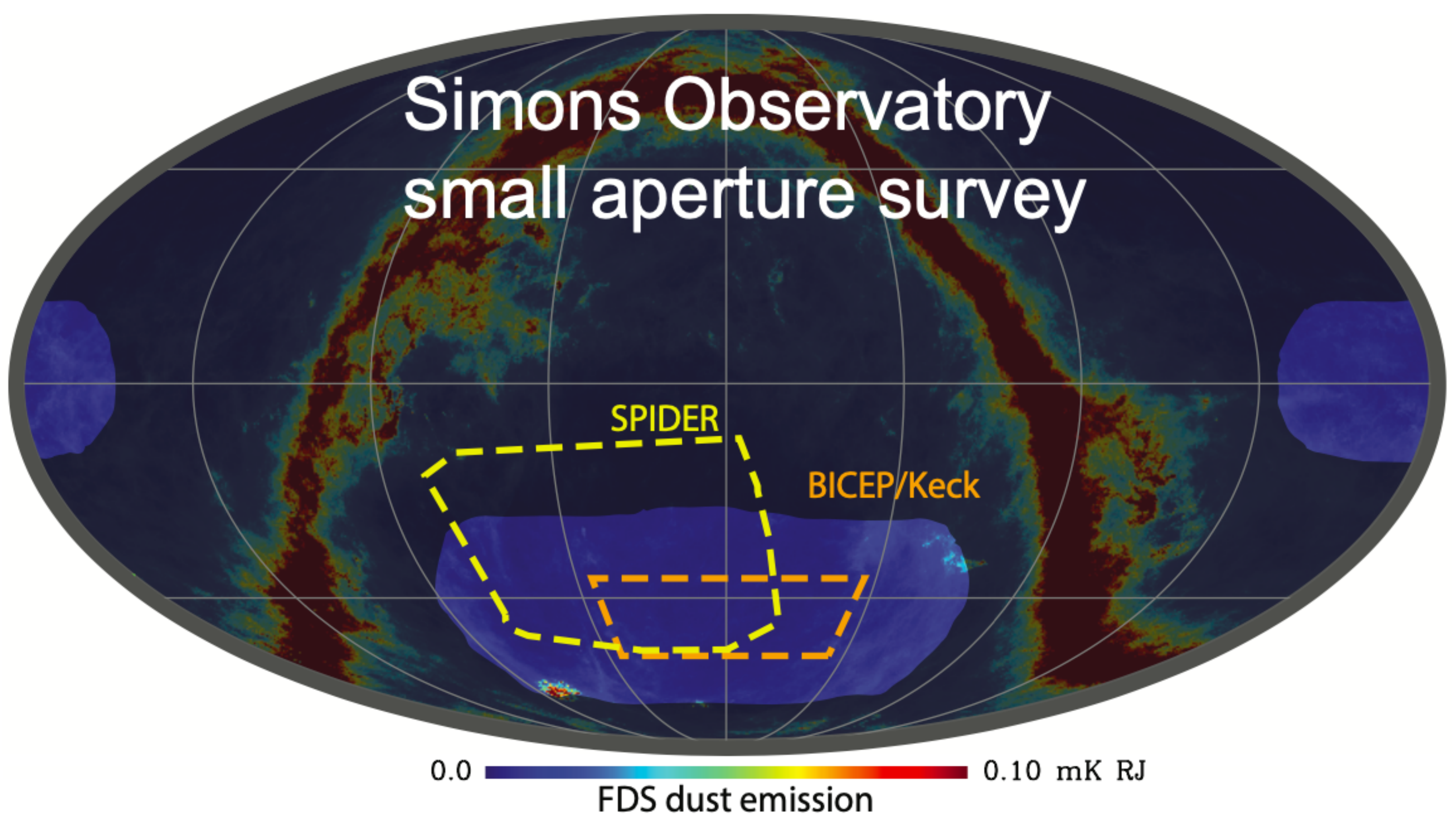


Image credits: Gabriele Coppi, Rolando Dunner, Federico Nati, Matías Rojas

SIMONS OBSERVATORY FORECASTS

Table 9
Summary of SO key science goals[a]

	Parameter	SO-Baseline[b] (no systematics)	**SO-Baseline[c]**	SO-Goal[d]	Current[e]	Method
Primordial perturbations	r	0.0024	**0.003**	0.002	0.03	BB + ext delens
	$e^{-2\tau}\mathcal{P}(k=0.2/\mathrm{Mpc})$	0.4%	**0.5%**	0.4%	3%	$TT/TE/EE$
	$f_{\mathrm{NL}}^{\mathrm{local}}$	1.8	**3**	1	5	$\kappa\kappa\times$ LSST-LSS + 3-pt
		1	**2**	1		kSZ + LSST-LSS
Relativistic species	N_{eff}	0.055	**0.07**	0.05	0.2	$TT/TE/EE + \kappa\kappa$
Neutrino mass	Σm_ν	0.033	**0.04**	0.03	0.1	$\kappa\kappa$ + DESI-BAO
		0.035	**0.04**	0.03		tSZ-N $\times$ LSST-WL
		0.036	**0.05**	0.04		tSZ-Y + DESI-BAO
Deviations from Λ	$\sigma_8(z=1-2)$	1.2%	**2%**	1%	7%	$\kappa\kappa$ + LSST-LSS + DESI-BAO
		1.2%	**2%**	1%		tSZ-N $\times$ LSST-WL
	H_0 (ΛCDM)	0.3	**0.4**	0.3	0.5	$TT/TE/EE + \kappa\kappa$
Galaxy evolution	η_{feedback}	2%	**3%**	2%	50-100%	kSZ + tSZ + DESI
	p_{nt}	6%	**8%**	5%	50-100%	kSZ + tSZ + DESI
Reionization	Δz	0.4	**0.6**	0.3	1.4	TT (kSZ)

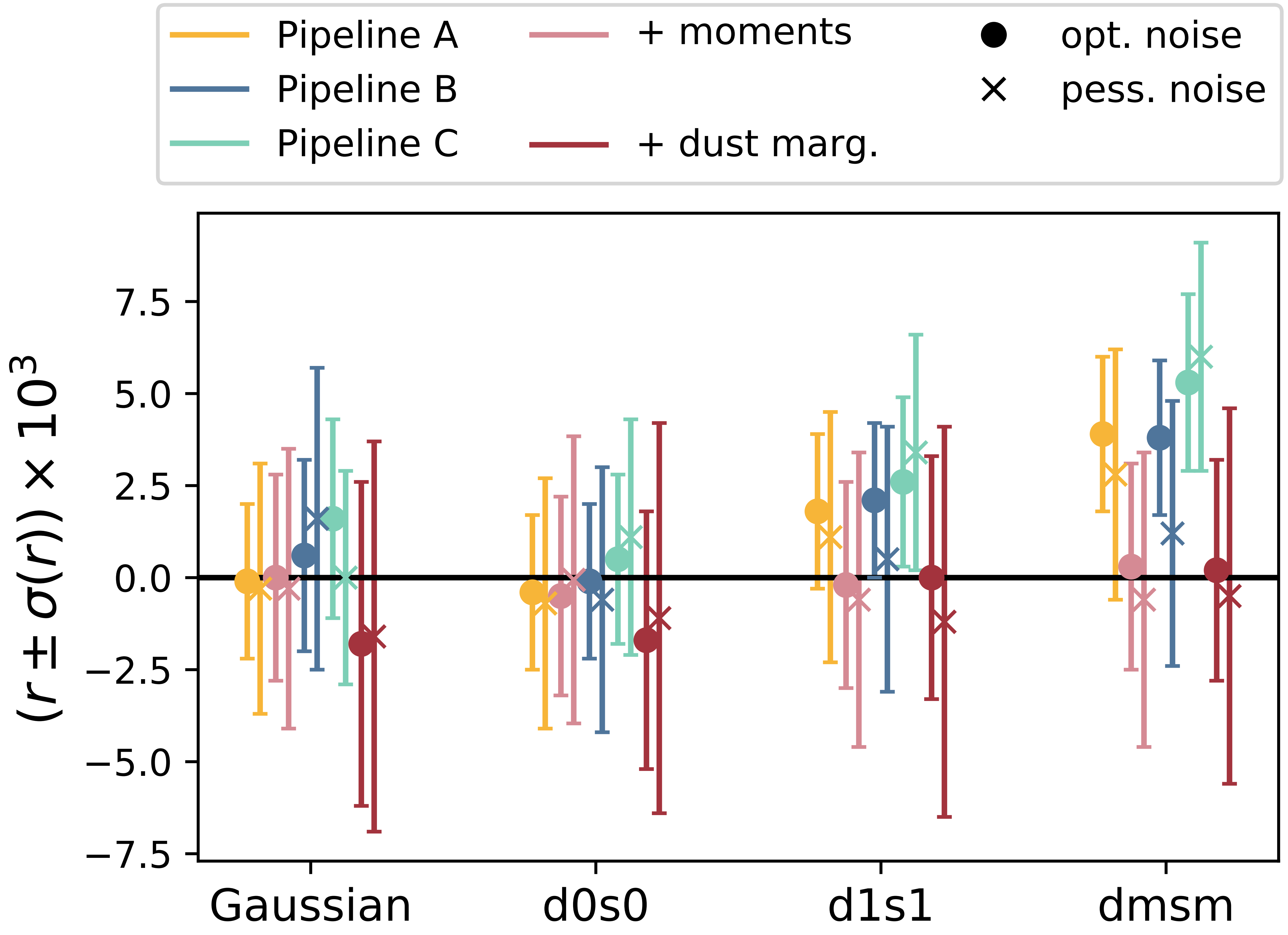
SO Forecasting JCAP (1808.07445)

SIMONS OBSERVATORY: PIPELINE FOR LARGE-SCALE B-MODES

3 different component separation pipelines

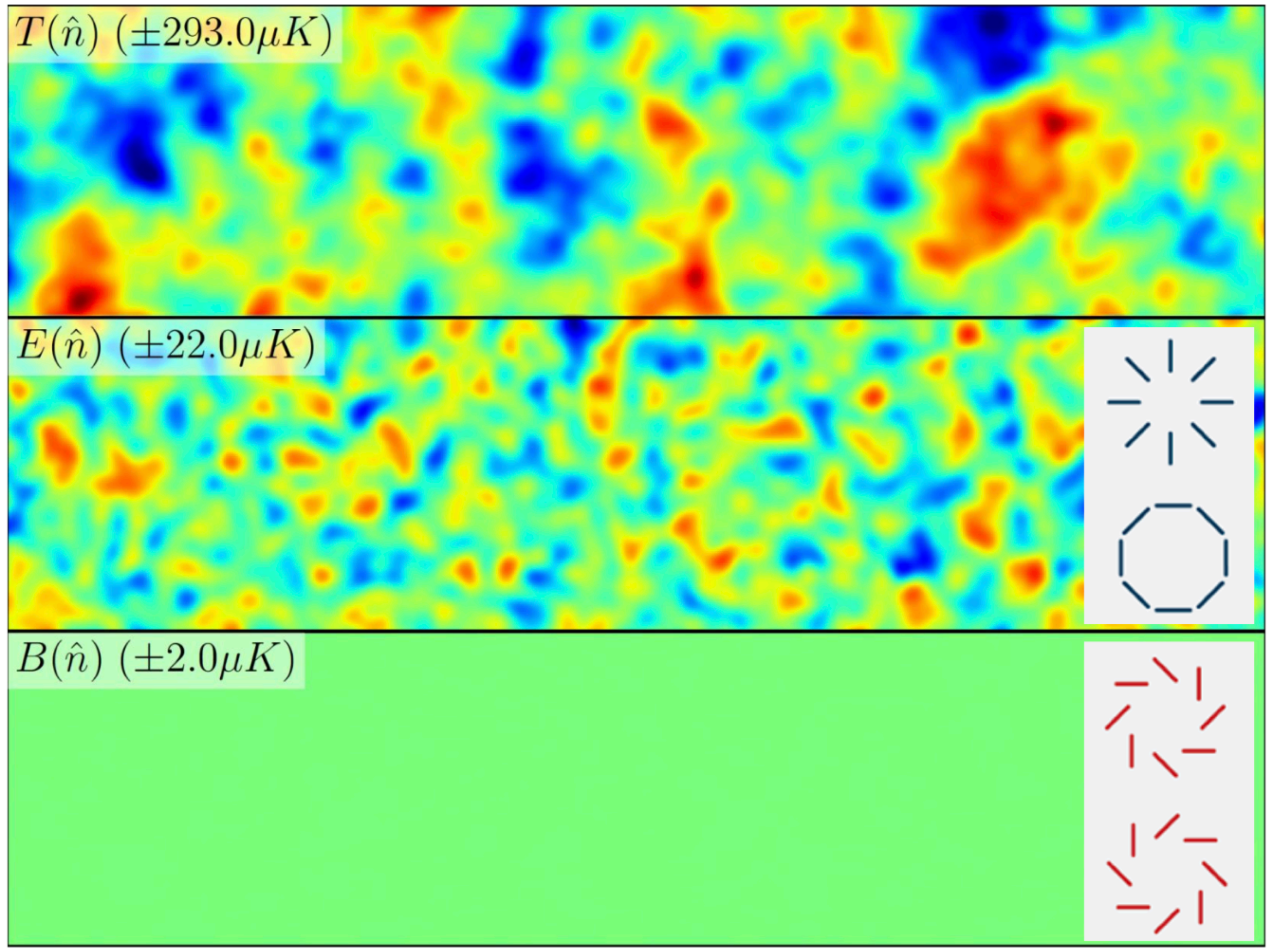
- C_ℓ-based separation: BBPower (includes moments expansion)
- Map-based separation: NILC and FGBuster

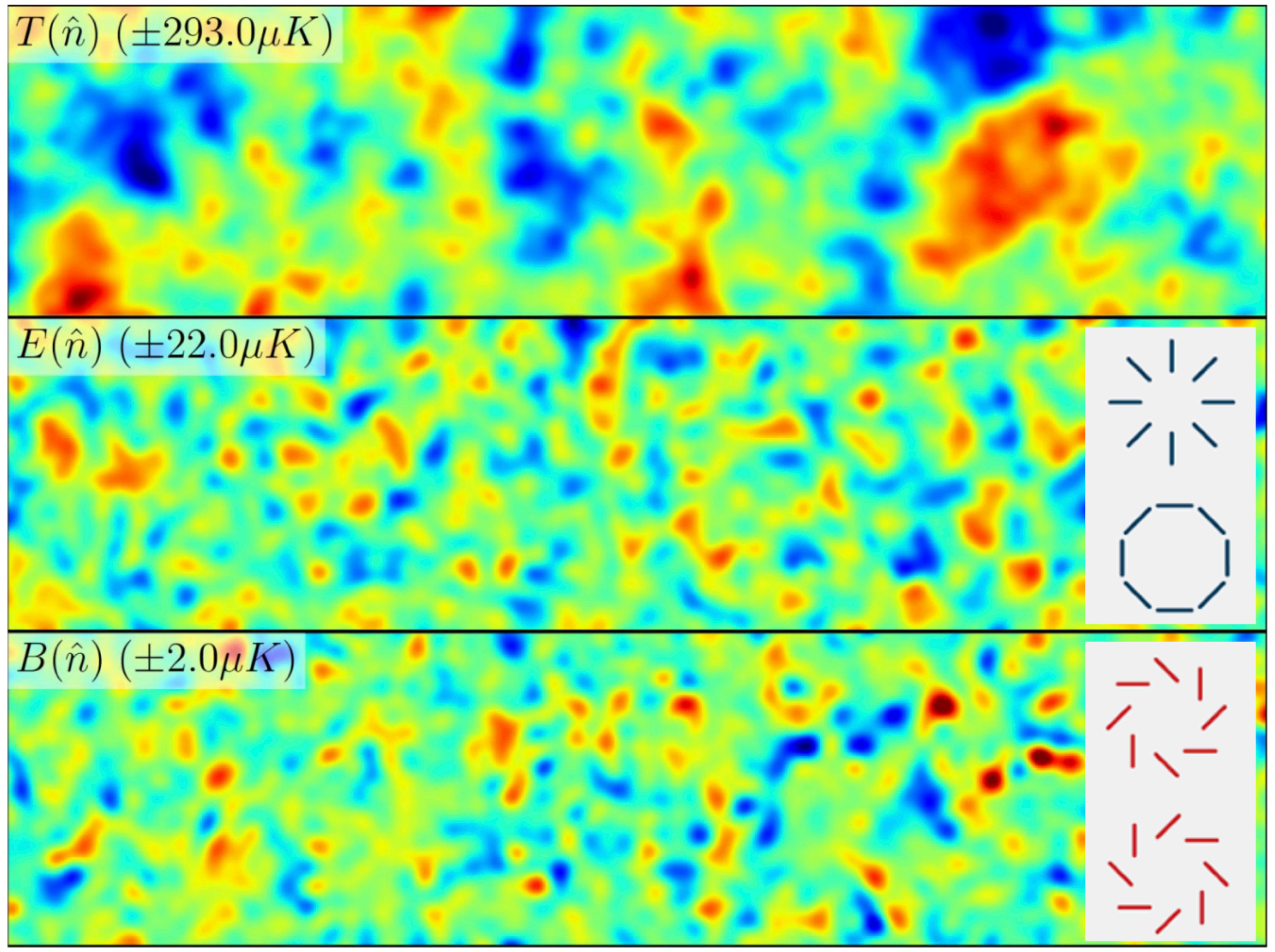
✅ **SO target** $\sigma(r) = 0.003$

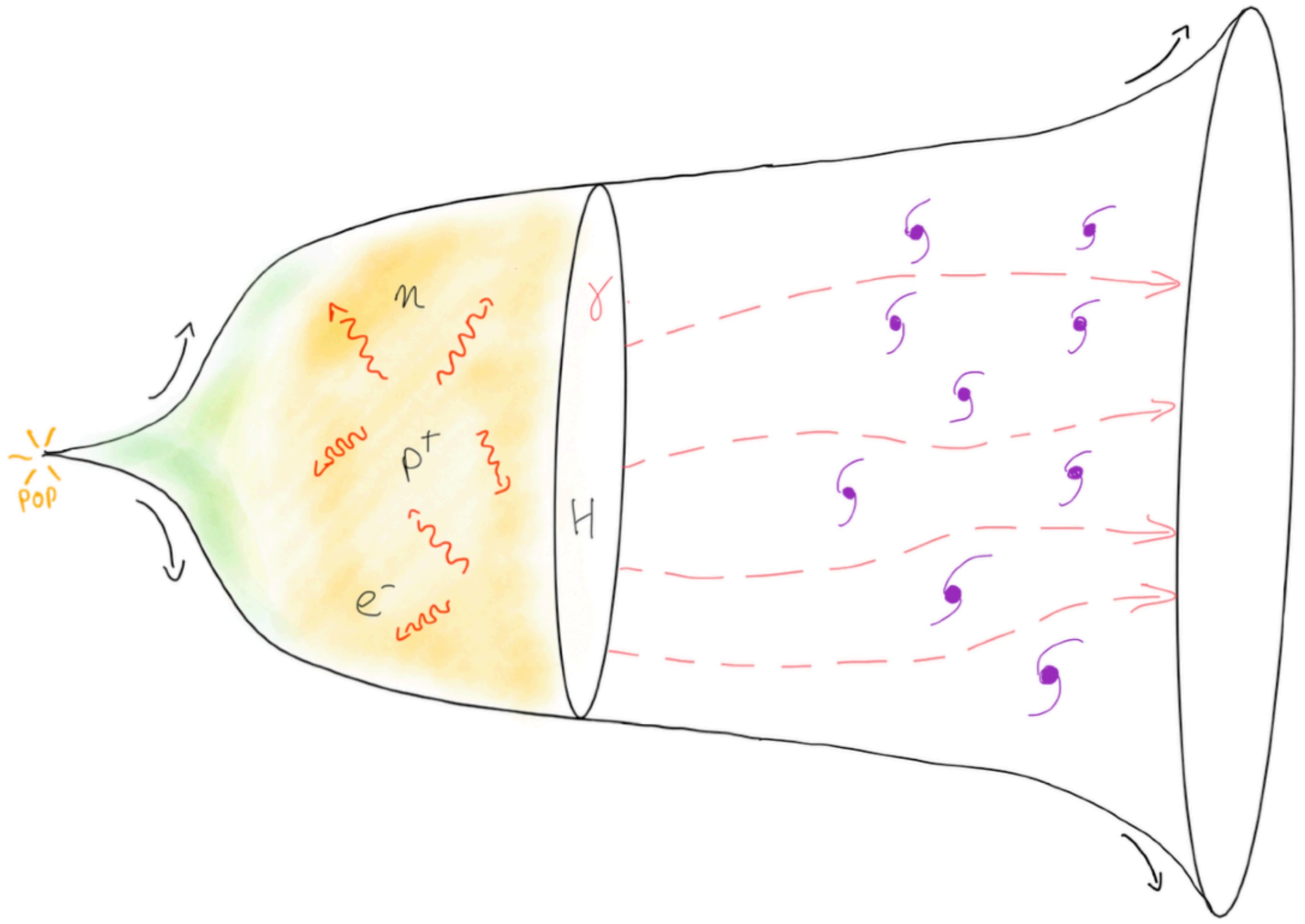


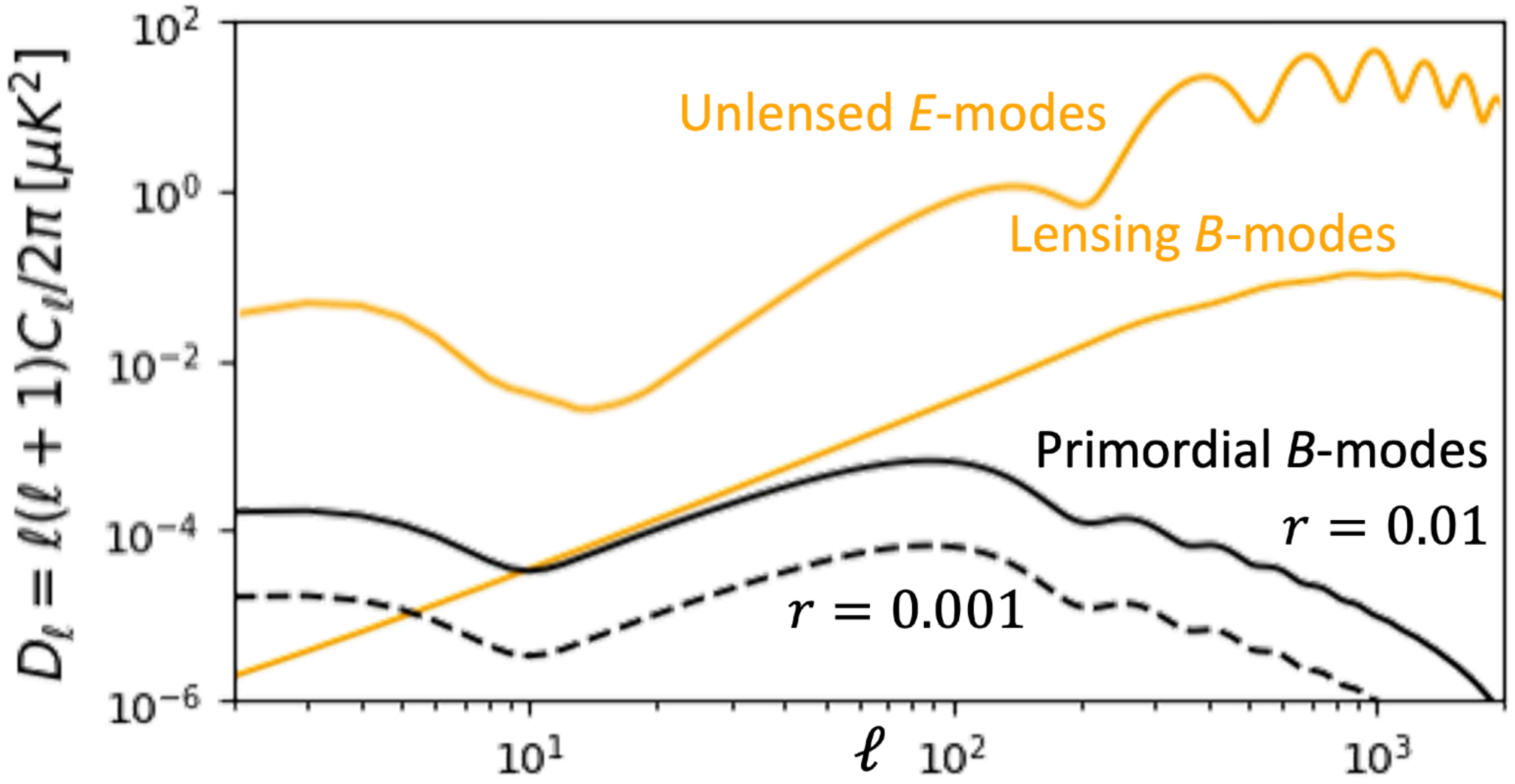
Wolz+24

SIMONS OBSERVATORY: DELENSING FOR IMPROVED CONSTRAINTS





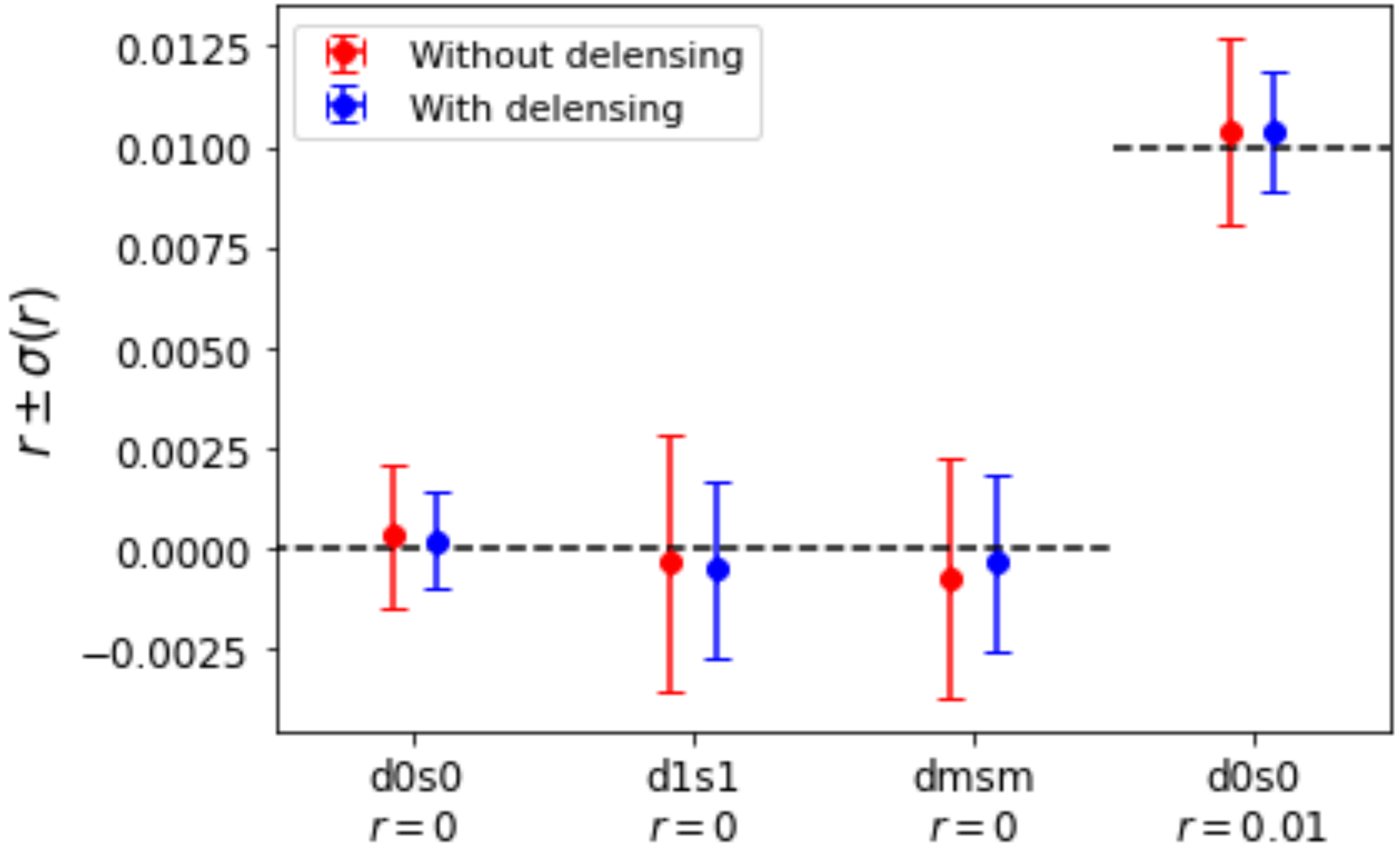




SIMONS OBSERVATORY: DELENSING FOR IMPROVED CONSTRAINTS

First realistic performance forecasts for SO including delensing in the cross-spectral component separation pipeline (BBPower)

- Delensing improvement between 30% and 40%



✅ **SO target** $\sigma(r) = 0.003$

Hertig+24

SUMMARY

- Plenty of lessons learnt from ACT
- Simons Observatory to become the most constraining CMB dataset
- Synergies Cosmoglobe–ACT & Cosmoglobe–SO:

  Component-separation at high resolution? Current NILC in ACT does not provide error estimates

  CMB lensing reconstruction?

  Delensing?

  Complex noise properties?