Searching for physics beyond the standard model

with Planck, SPT, and ACT data.

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20/06/2022

Image Credit:
Aman Chokshi

Content

- Introduction
- Constraining Physics Beyond the Standard Model
  - Primordial Magnetic Fields
  - Early Dark Energy
- New Results from the South Pole Telescope

CMB Cosmology Overview

- After inflation, early universe is hot and dense, pressure waves permeate
- Cooling through expansion until recombination
- Dynamics of the early universe “frozen” into the CMB
- CMB observations helped establish ΛCDM as the standard model

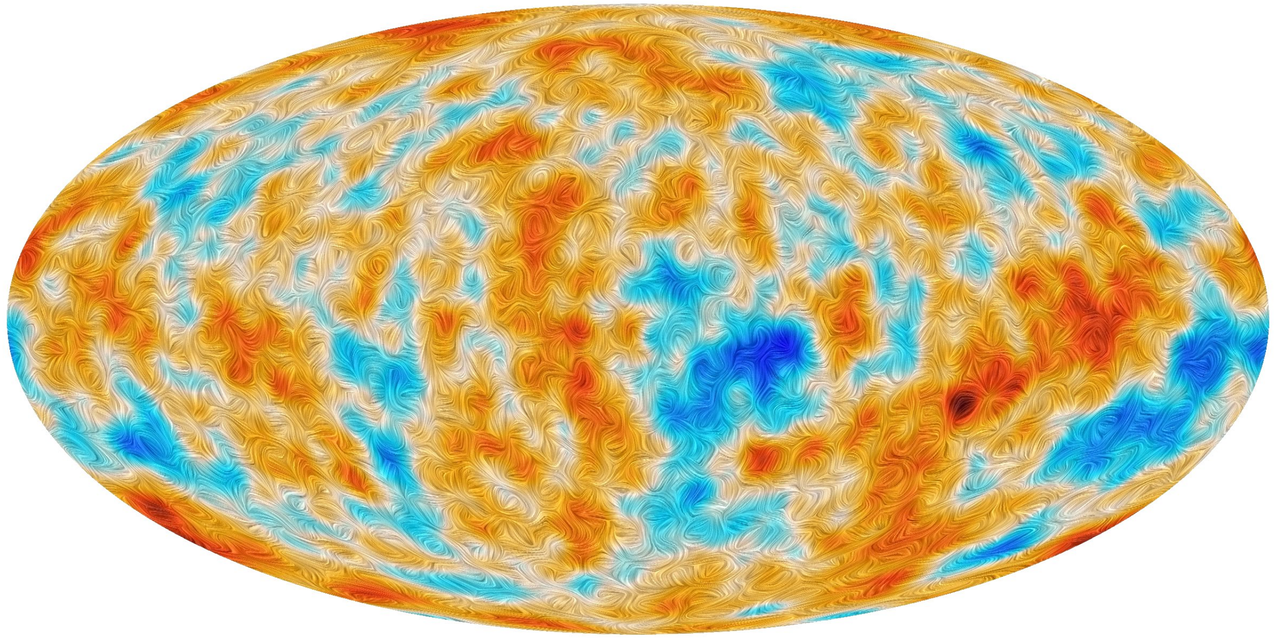


Image Credit: ESA/Planck Mission

ΛCDM **is Insufficient**

- What exactly *are* dark energy and dark matter?
- What is the hierarchy and mass of neutrinos?
- Discordance between different probes

→ **H_0 and S_8 tensions**

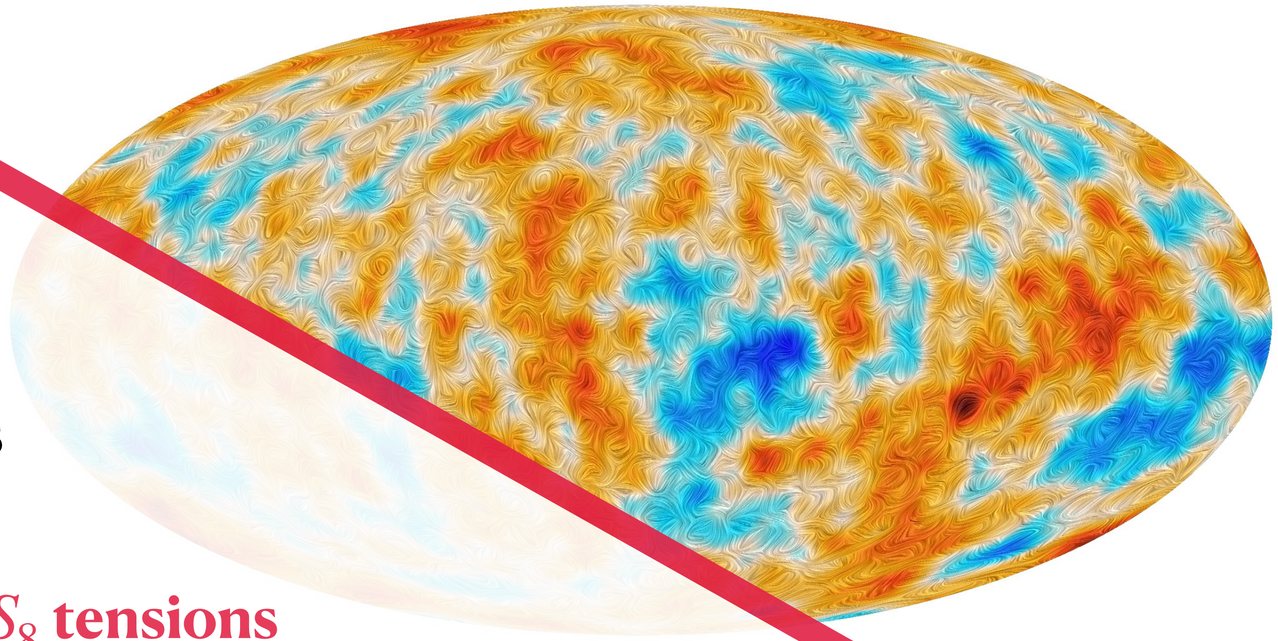


Image Credit: ESA/Planck Mission

Planck

Image Credit:
ESA Enabling & Support
Planck Mission

SPT

Image Credit:
Aman Chokshi

ACT

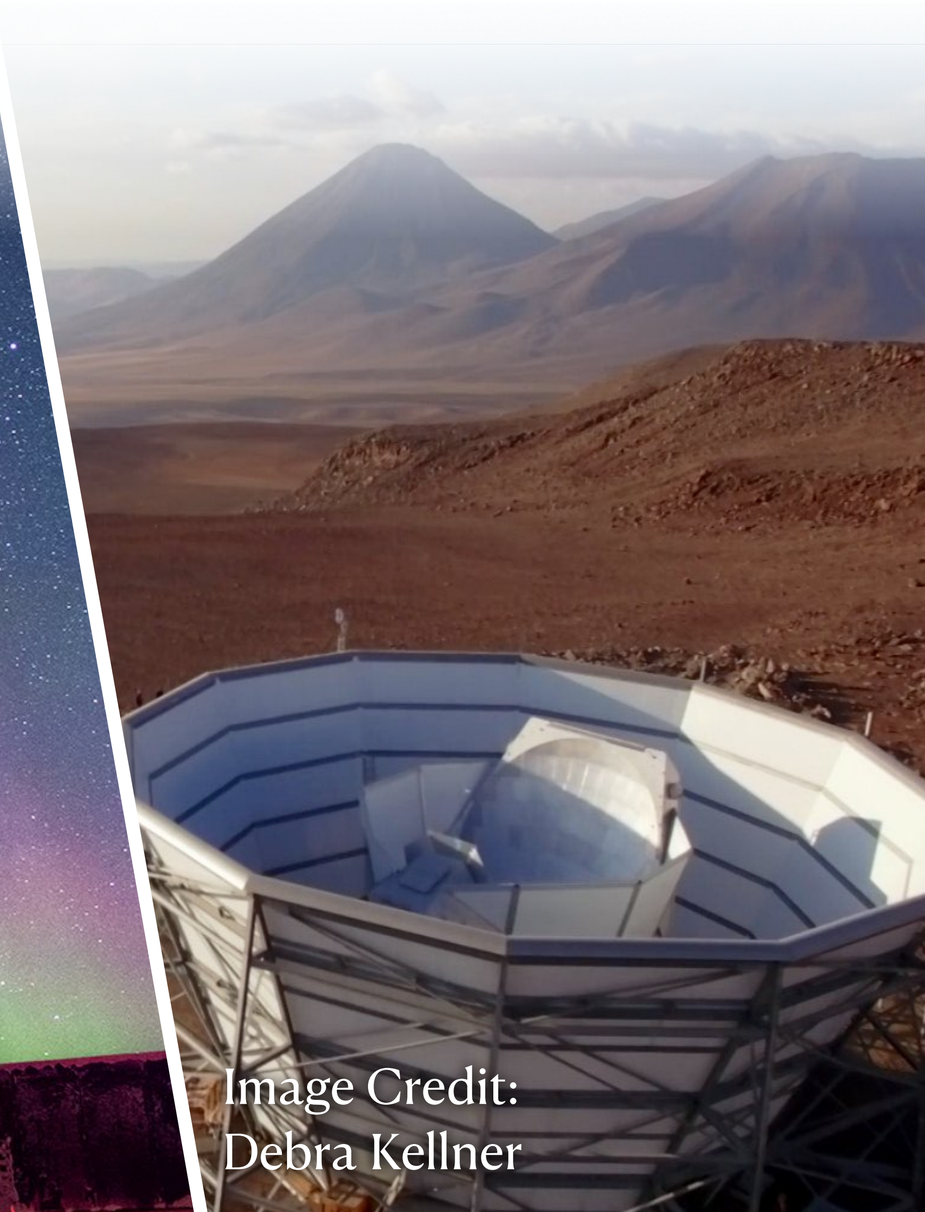
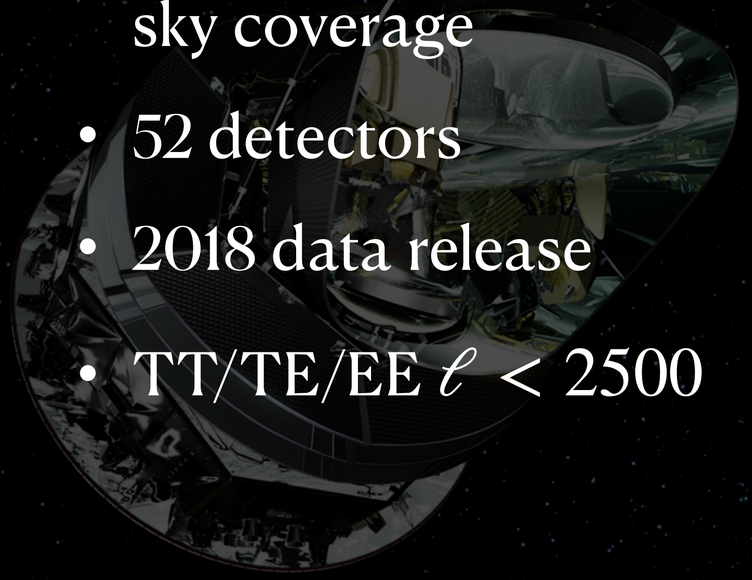


Image Credit:
Debra Kellner

Planck



- Satellite mission w/ full sky coverage
- 52 detectors
- 2018 data release
- TT/TE/EE $\ell < 2500$

Planck Collaboration 2018, arXiv:1907.12875

SPT

- Current survey SPT-3G covering 1500deg^2
- SPT-3G: 15,000 detectors
- 2018 data (released 2021)
- TE/EE $300 < \ell < 3000$

Dutcher et al. 2021 arXiv:2101.01684

ACT

- Power Spectra from 5400deg^2
- ACTpol: 3068 detectors
- Data release 4 (2020)
- TT/TE/EE $325 < \ell < 7550$*

Aiola et al. 2021 & Choi et al. 2021 arXiv:2007.07288 & 2007.07289

Primordial Magnetic Fields

Consistency of Planck, ACT and SPT constraints
on magnetically assisted recombination
and forecasts for future experiments
S. Galli, L. Pogosian, K. Jedamzik, L. Balkenhol 2021,
Phys. Rev. D 105, 023513 , arXiv:2109.03816

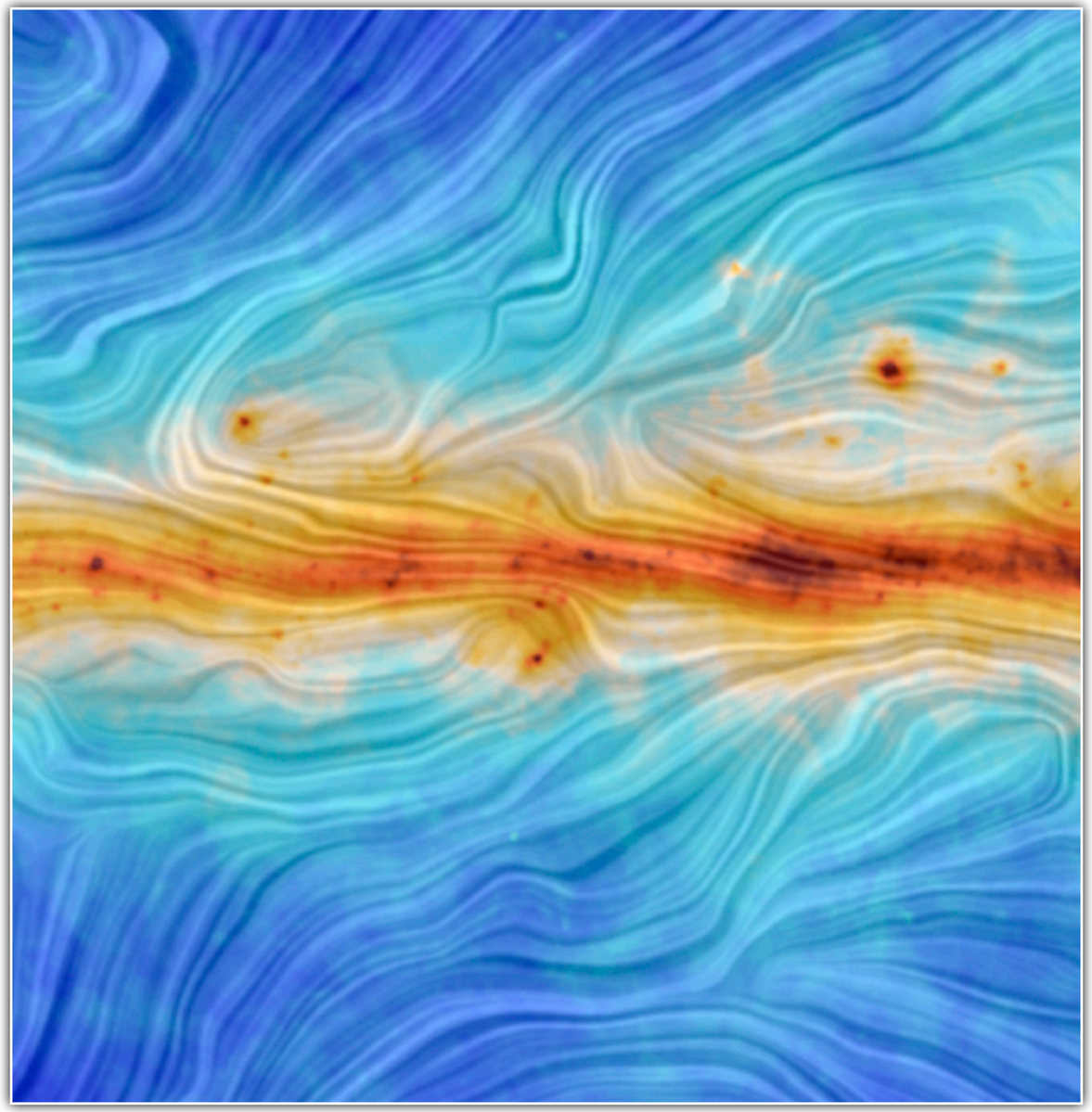


Image Credit: ESA/Planck Mission

Primordial Magnetic Fields

- Magnetic fields are ubiquitous… so why not?
- PMFs lead to inhomogeneities:

  baryon clumping factor, b
- Inhomogeneities lead to earlier recombination

Higher H_0 inferred from CMB observations

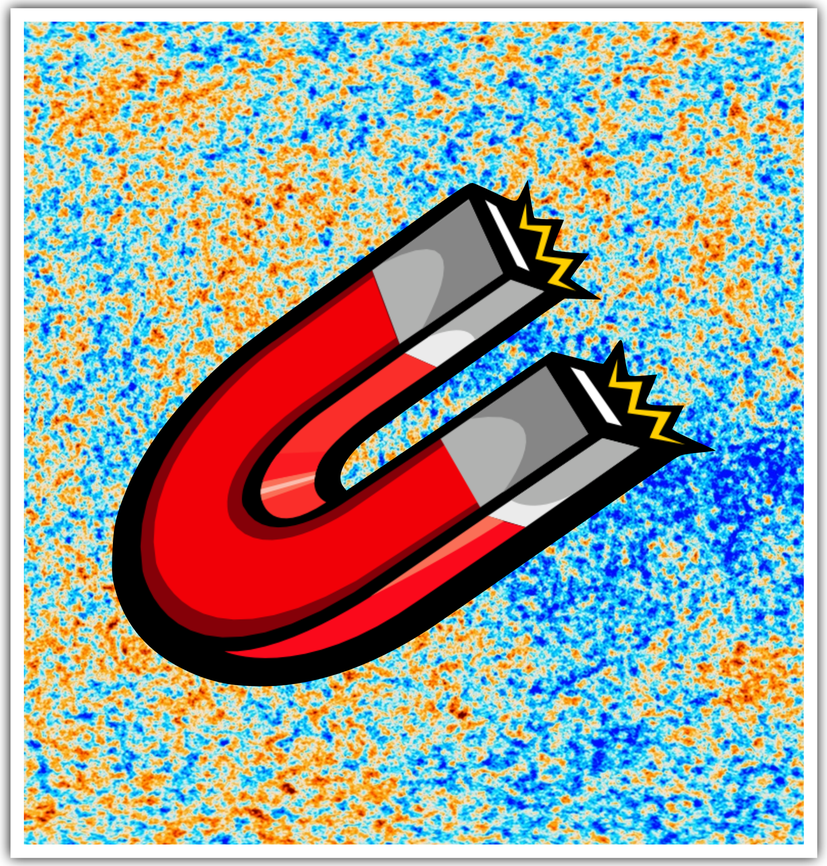
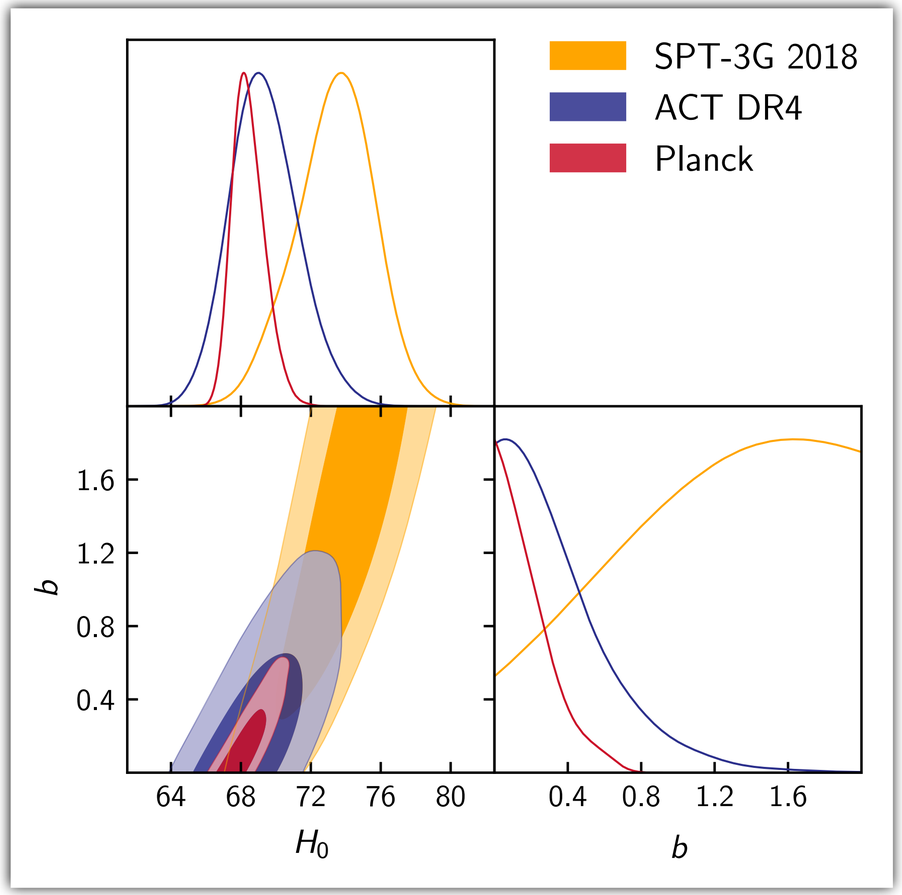


Image Credit: ESA/Planck Mission

New Limits on Primordial Magnetic Fields

- Data consistent with no PMFs: $b < 0.54$
- Signs of internal inconsistency in ACT EE/TE data?
- SPT data lacks TT information , fits well-known features in power spectrum
- Planck and SPT are consistent, ACT marginally



Galli et al. 2021, arXiv:2109.03816

Weird ACT Constraints

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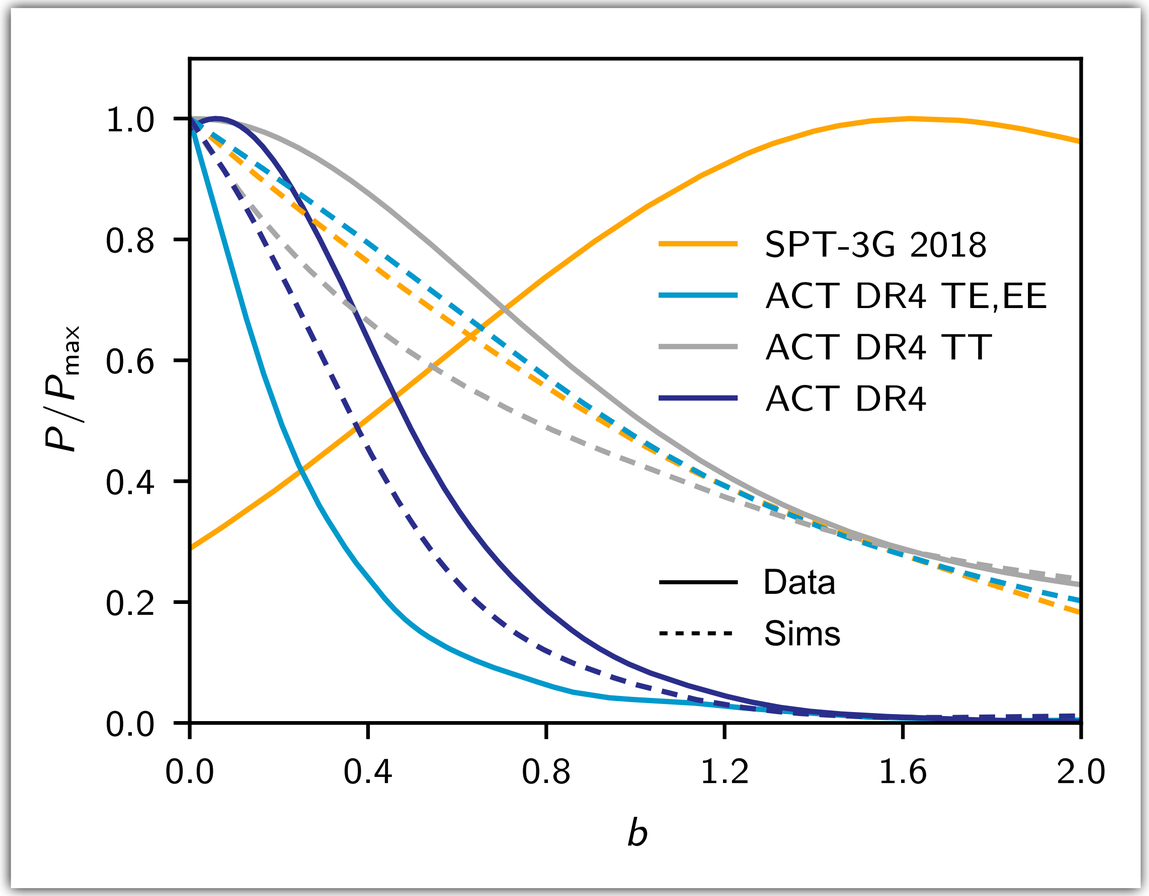

Galli et al. 2021, arXiv:2109.03816

TT crucial to constrain PMFs

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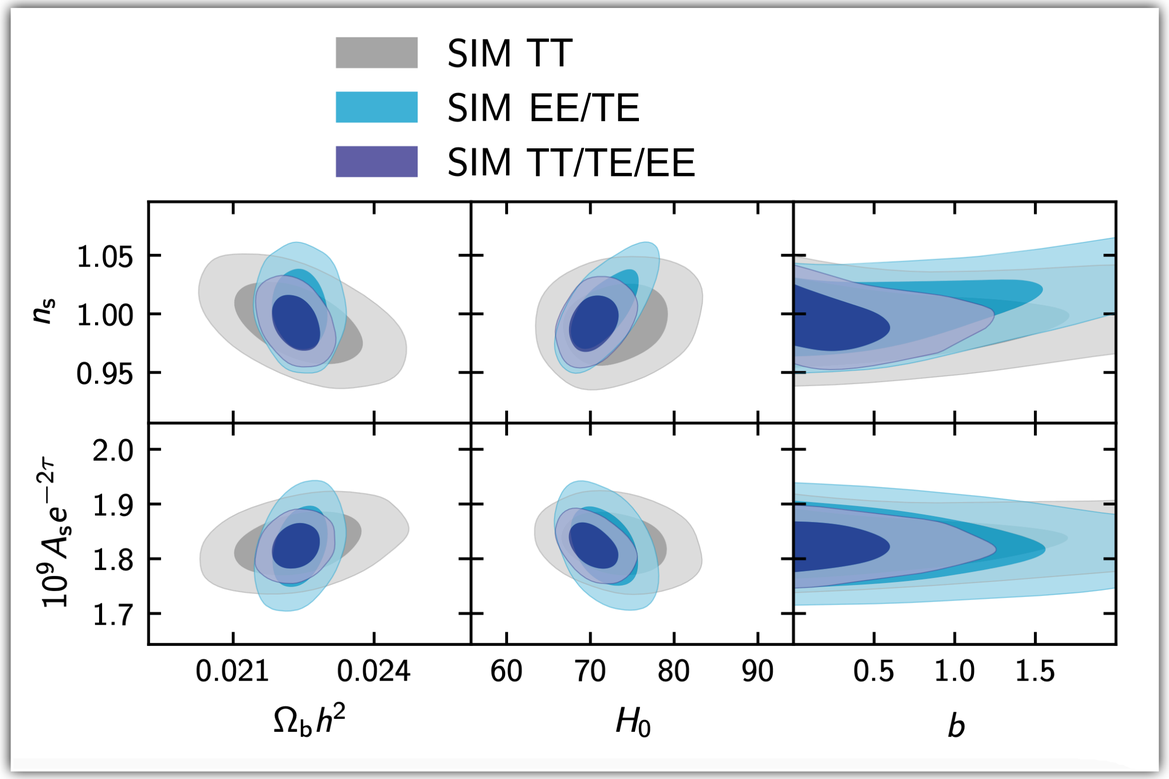

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Consistency of Planck, ACT, SPT

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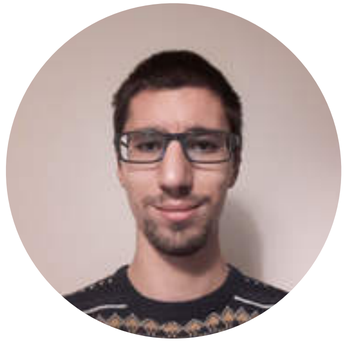
	ΛCDM	ΛCDM + b
Planck - SPT	**12% (1.2σ)**	**6% (1.8σ)**
Planck - ACT	**0.5% (2.7σ)**	**1.5% (2.4σ)**
SPT - ACT	**0.5% (2.7σ)**	**0.8% (2.6σ)**

Galli et al. 2021, arXiv:2109.03816

Early Dark Energy

Hints of Early Dark Energy in Planck, SPT, and ACT data: new physics or systematics?
T. Smith, M. Lucca, V. Poulin, G. F. Abellan, L. Balkenhol, K. Benabed, S. Galli, R. Murgia,
Submitted to PRD, arXiv:2202.09379


+ G. F. Abellan,

+ R. Murgia

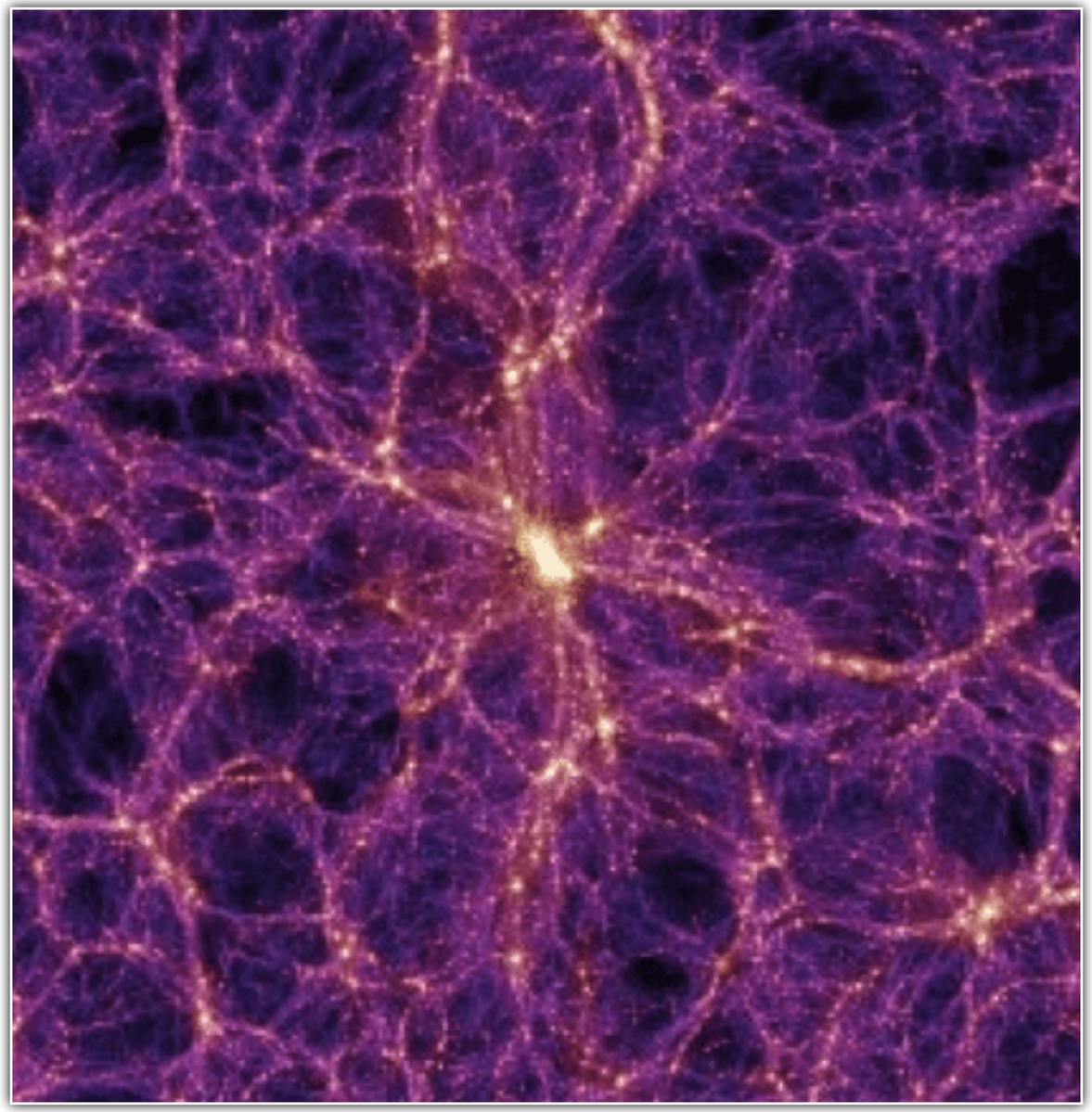


Image Credit: Millennium Simulation

Early Dark Energy

- Some component that behaves like dark energy at around matter-radiation equality
- Introduce three new model parameters:

$$z_c \qquad f_{\rm EDE}(z_c) \qquad \theta_i$$

- Shortens the sound horizon at recombination
- Momentum from Hill et al. 2021, Poulin et al. 2021, La Posta et al. 2021

Higher H_0 inferred from CMB observations

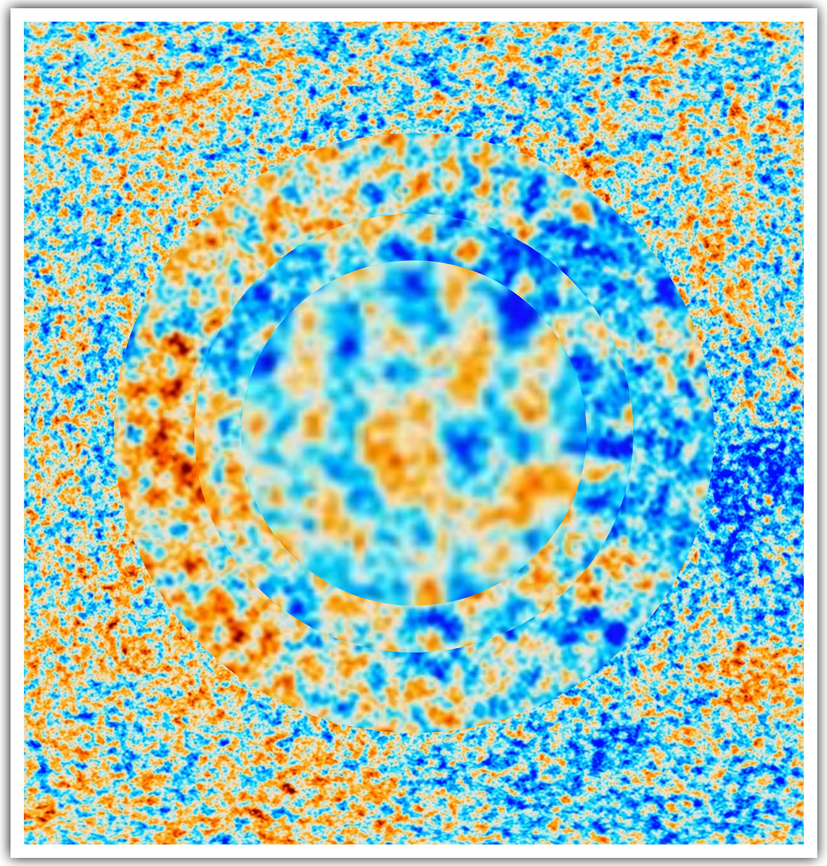


Image Credit: ESA/Planck Mission

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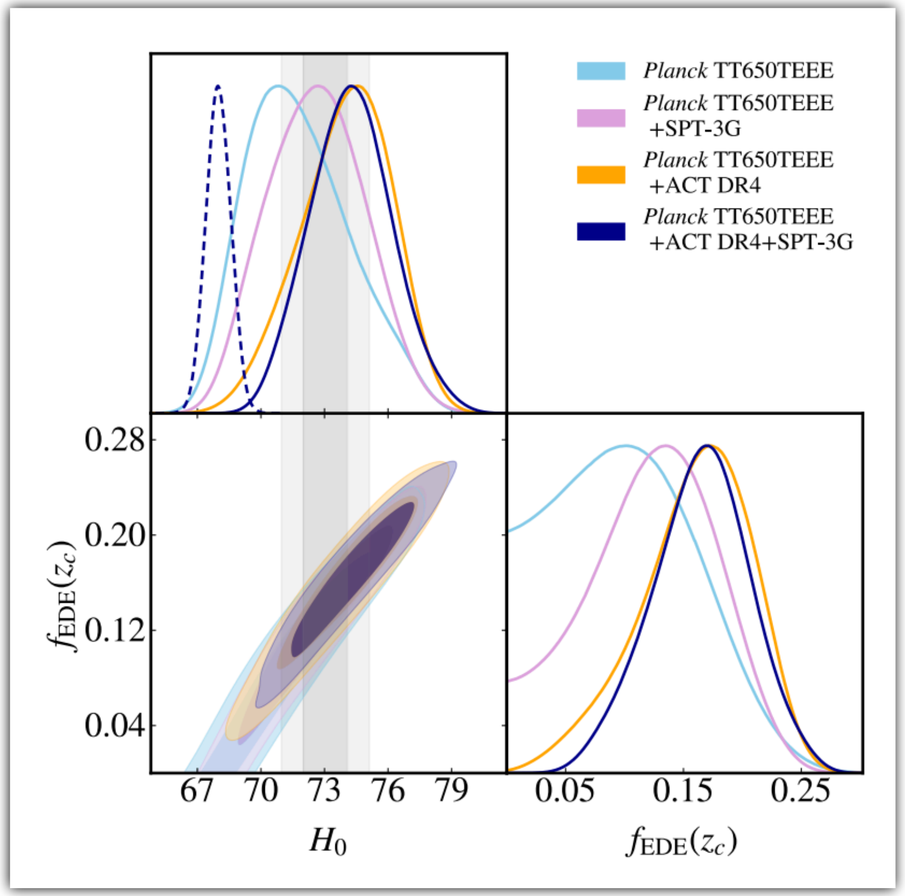
Higher H_0 inferred from CMB observations

Image Credit: ESA/Planck Mission

Hint of EDE in Planck, SPT, and ACT Data

- All data sets show preference for EDE over ΛCDM:

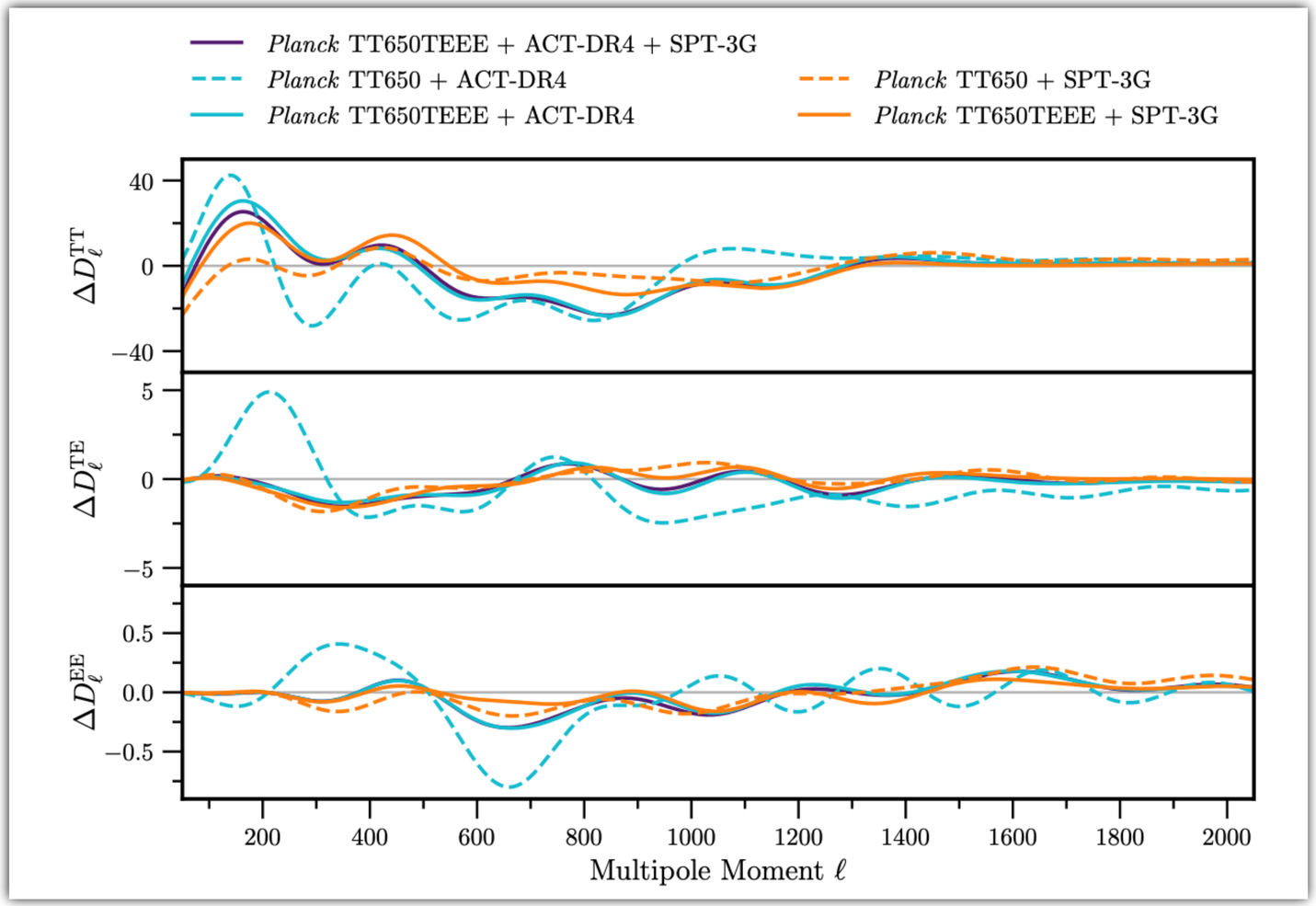
Planck TT (l < 650) /TE/EE	2.2σ
+ SPT	2.4σ
+ ACT	3.3σ
+SPT + ACT	3.3σ



Smith et al. 2021, arXiv:2202.09379

Consistent EDE Signal Across Data Sets

- Same signatures of EDE in best-fit spectra for data sets
- Planck polarisation pulls SPT and ACT together
- Different mode of EDE than ACT-alone fit (Hill et al. 2021)



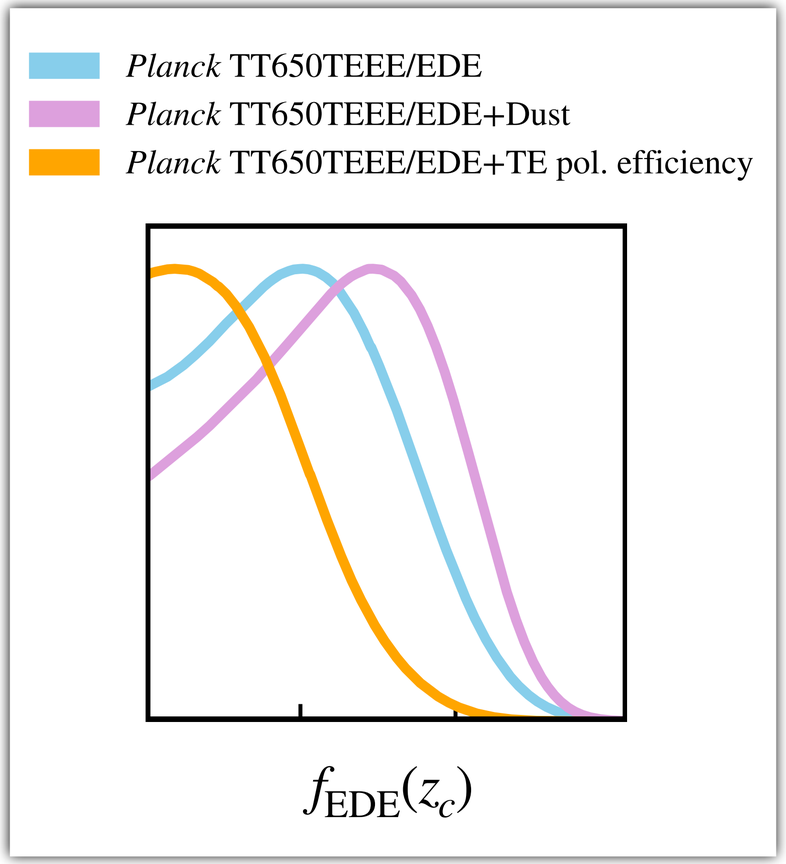
Smith et al. 2021, arXiv:2202.09379

EDE Preference Robustness

- Preference for EDE:
  - increases with relaxed gal. dust priors
  - decreases with alternative TE calibration
- Planck TT $\ell \gtrsim 1200$ kills EDE:

  Planck TT/TE/EE + ACT + SPT: 2.3σ

  c.f. La Posta et al. 2021
- Lensing and BAO mildly reduce preference from 3.3σ to 2.6-3.0σ



Smith et al. 2021, arXiv:2202.09379

Planck high ℓ TT disfavours EDE

- Preference for EDE:
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  - decreases with alternative TE calibration
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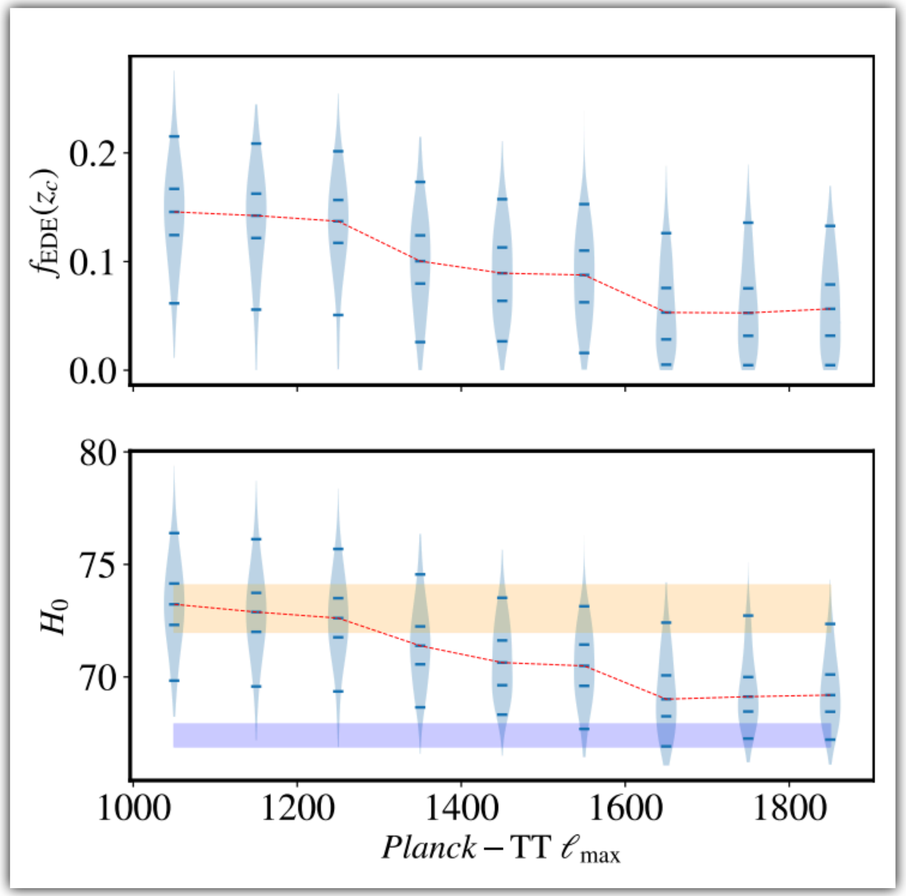

Smith et al. 2021, arXiv:2202.09379

SPT-3G 2018 TT/TE/EE

Work in progress!
SPT-3G collaboration, with crucial contributions from
C. L. Reichardt, S. Galli, K. Benabed,
N. Goekner-Wald, D. P. Dutcher





Image Credit: Aman Chokshi

TT/TE/EE Needed for ΛCDM+

- Need temperature and polarisation to tightly constrain ΛCDM extensions
- Cross-checks with other experiments at high signal-to-noise
- Use all available data

Add TT data to SPT-3G 2018
to learn about ΛCDM extensions
and pave the way for future analyses

PMF, EDE,

$N_{\rm eff}, \Sigma m_\nu, A_L, \ldots$

SPT-3G 2018 TT/TE/EE - Status

- Check null tests
- Produce 2018 band powers
- Check inter-frequency consistency
  - Minimum-variance contribution
  - Difference spectra
- Write likelihood code

Null-tests for TT 150GHz:

(1)	Azimuth	37%
(2)	Chronological	73%
(3)	Scan-direction	59%
(4)	Moon	57%
(5)	Saturation	91%
(6)	Wafer	72%

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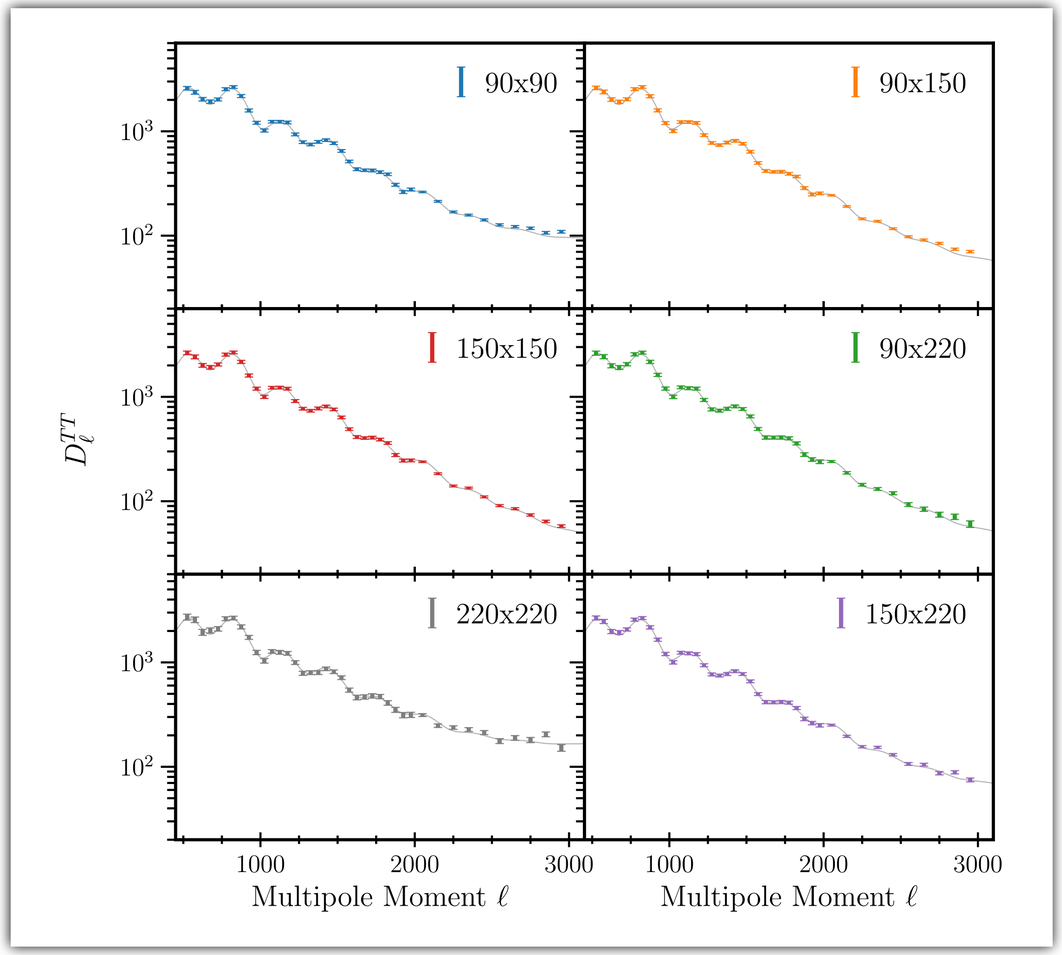

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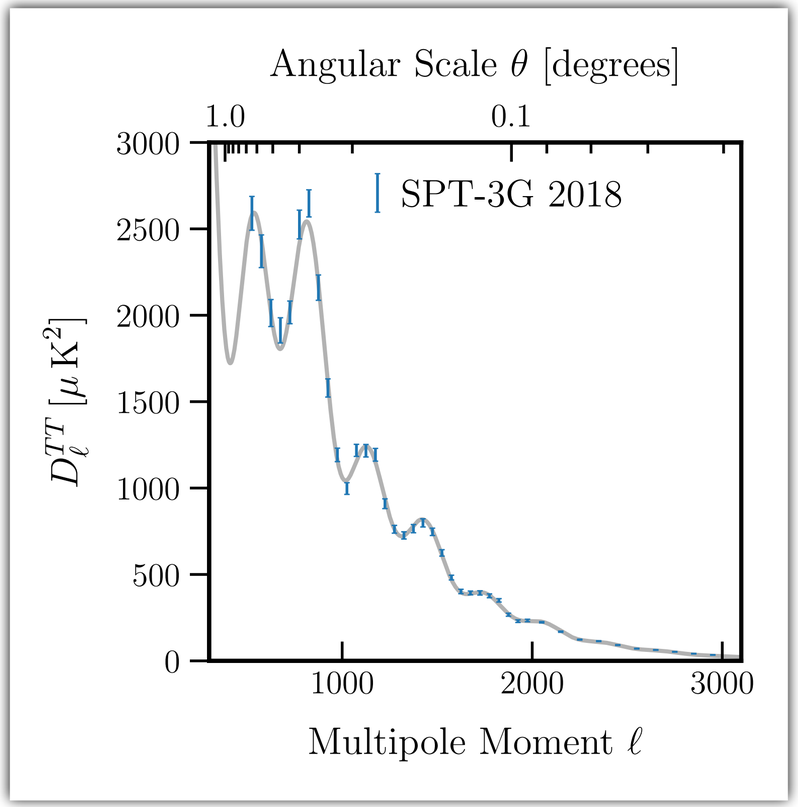

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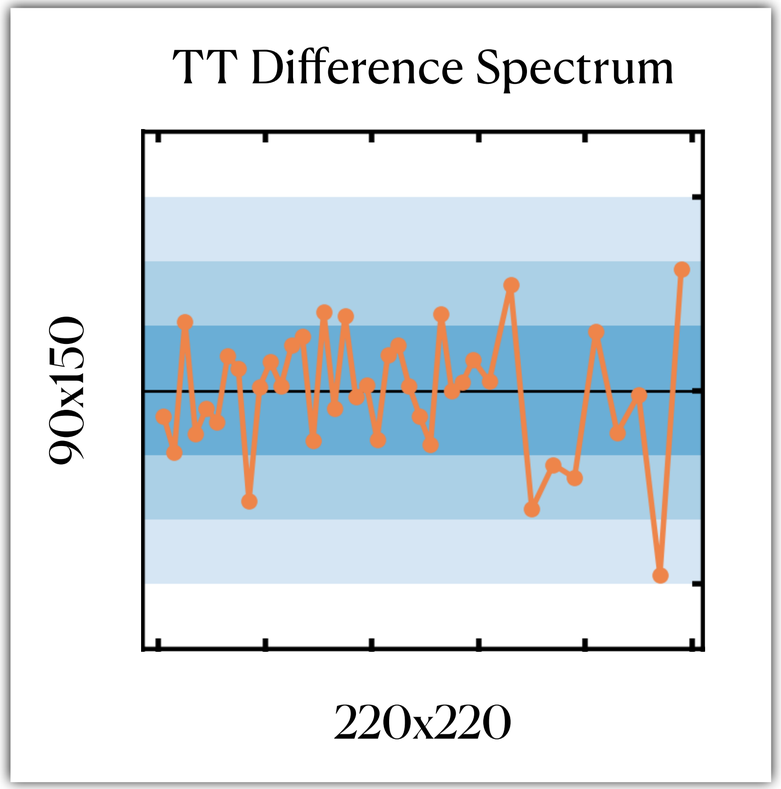

SPT-3G 2018 TT/TE/EE - Status

- Check null tests
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```
subroutine likelihood(…):
```

$$-\ln L \propto \Delta D_b C^{-1}_{bb'} \Delta D_{b'} + \ln |C|$$

```
end subroutine
```

Summary

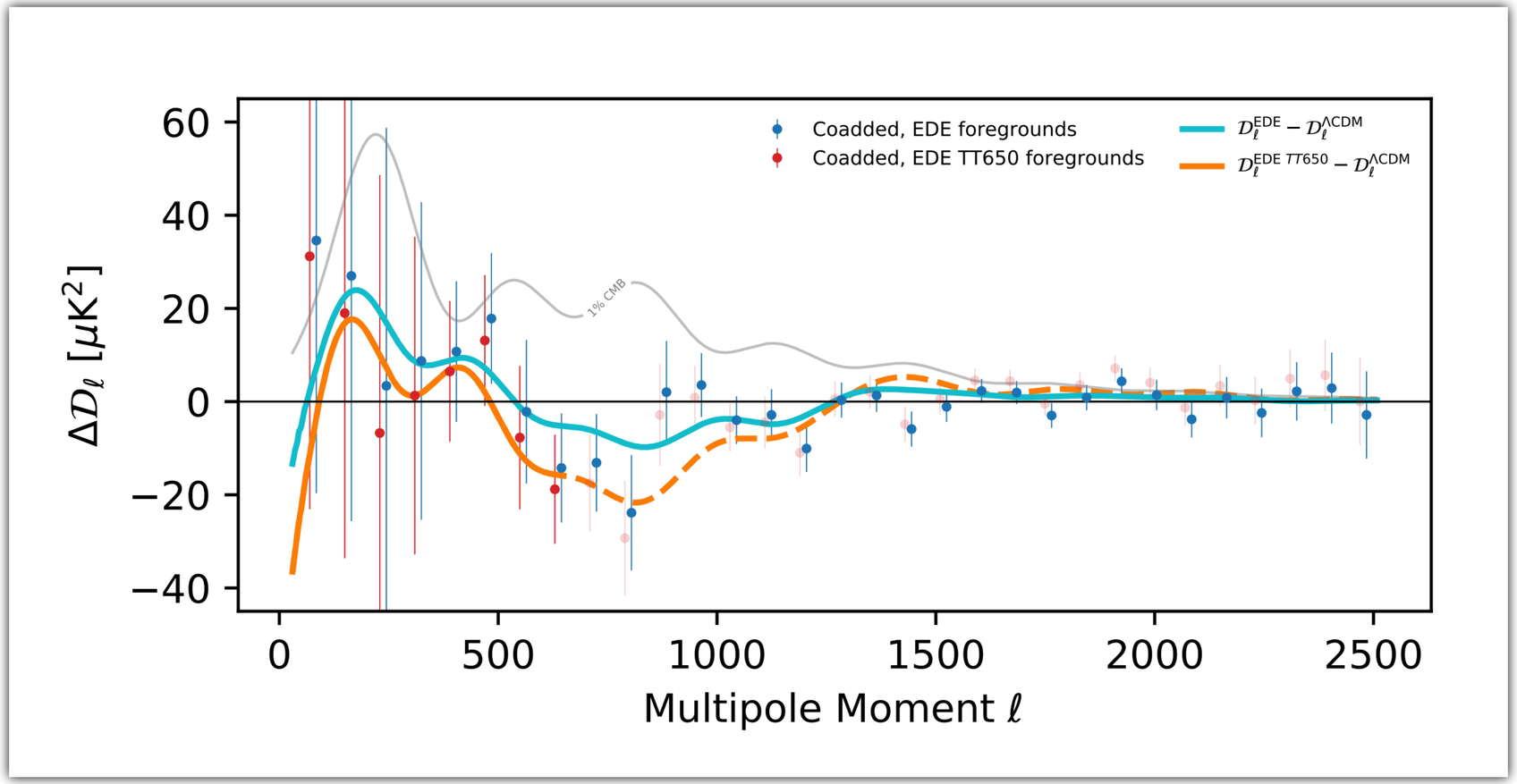
- Use Planck, SPT, and ACT data to constrain PMF and EDE
- Independent probes and full primary power spectrum information crucial
- SPT-3G 2018 TT data is internally consistent - cosmological results coming soon!

Image Credit: Aman Chokshi - Twitter/Instagram: aman_chokshi

Backup Slides

EDE - Planck high ell foregrounds

- Planck FG models at high ell similar - it really is the data driving EDE preference



Smith et al. 2021,
arXiv:2202.09379

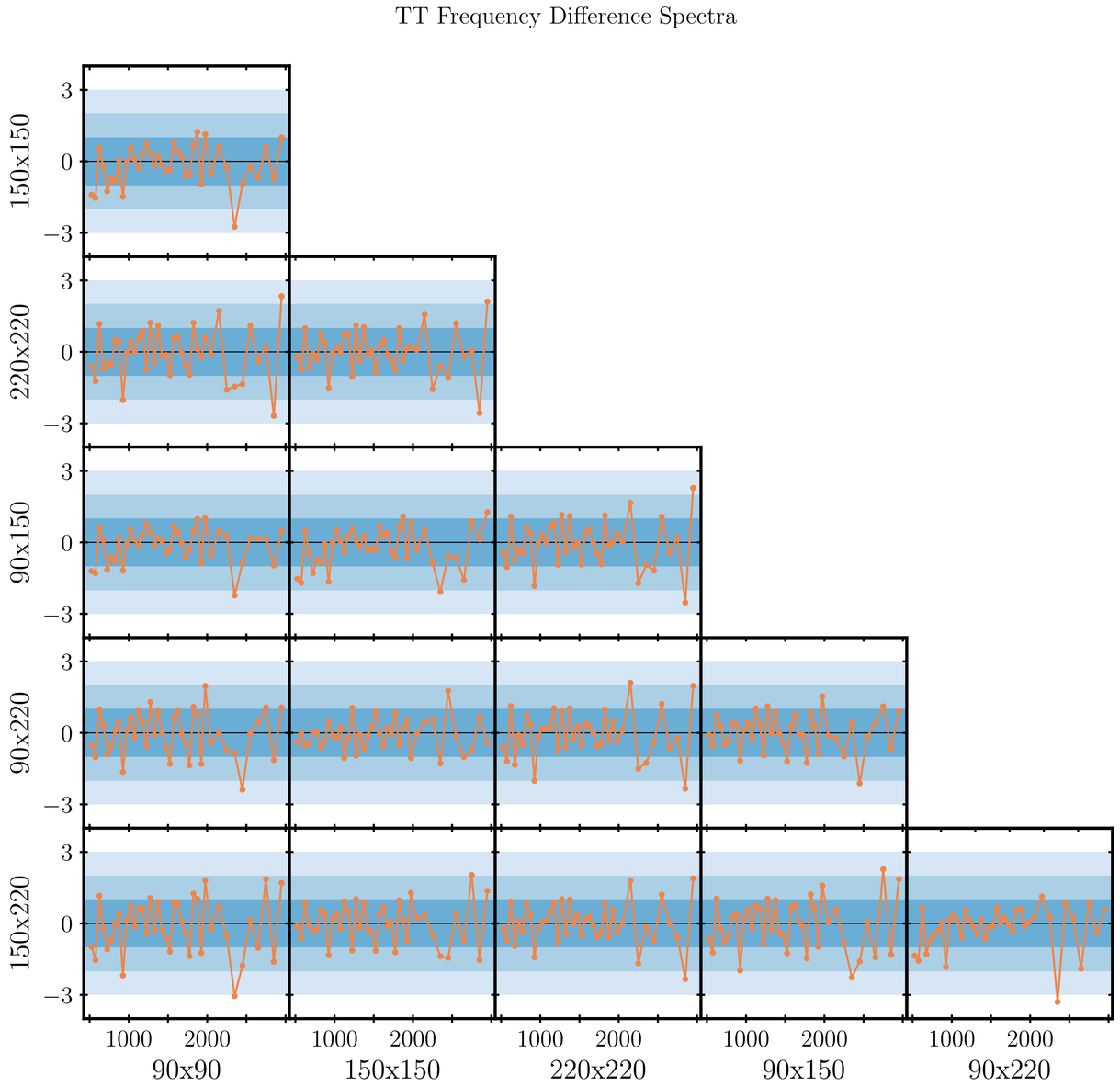
EDE: S_8 gets worse

- Planck 2018 TT/TE/EE+lensing ΛCDM:
  - $S_8 = 0.830 \pm 0.013$
- DES Y3:
  - $S_8 = 0.776 \pm 0.017$

Model	ΛCDM	EDE
$f_{\rm EDE}(z_c)$	–	$0.163(0.179)^{+0.047}_{-0.04}$
$\log_{10}(z_c)$	–	$3.526(3.528)^{+0.028}_{-0.024}$
θ_i	–	$2.784(2.806)^{+0.098}_{-0.093}$
m (eV)	–	$(4.38 \pm 0.49) \times 10^{-28}$
f (Mpl)	–	0.213 ± 0.035
H_0 [km/s/Mpc]	$68.02(67.81)^{+0.64}_{-0.6}$	$74.2(74.83)^{+1.9}_{-2.1}$
$100\ \omega_b$	$2.253(2.249)^{+0.014}_{-0.013}$	$2.279(2.278)^{+0.018}_{-0.02}$
$\omega_{\rm cdm}$	$0.1186(0.1191)^{+0.0014}_{-0.0015}$	$0.1356(0.1372)^{+0.0053}_{-0.0059}$
$10^9 A_s$	$2.088(2.092)^{+0.035}_{-0.033}$	$2.145(2.146)^{+0.041}_{-0.04}$
n_s	$0.9764(0.9747)^{+0.0046}_{-0.0047}$	$1.001(1.003)^{+0.0091}_{-0.0096}$
$\tau_{\rm reio}$	$0.0510(0.0510)^{+0.0087}_{-0.0078}$	$0.0527(0.052)^{+0.0086}_{-0.0084}$
S_8	$0.817(0.821) \pm 0.017$	$0.829(0.829)^{+0.017}_{-0.019}$
Ω_m	$0.307(0.309)^{+0.008}_{-0.009}$	$0.289(0.287) \pm 0.009$
Age [Gyrs]	$13.77(13.78) \pm 0.023$	$12.84(12.75) \pm 0.27$
$\Delta\chi^2_{\rm min}$ (EDE−ΛCDM)	–	-16.2
Preference over ΛCDM	–	99.9% (3.3σ)

Smith et al. 2021, arXiv:2202.09379

SPT-3G 2018 TT/TE/EE - Difference Spectra



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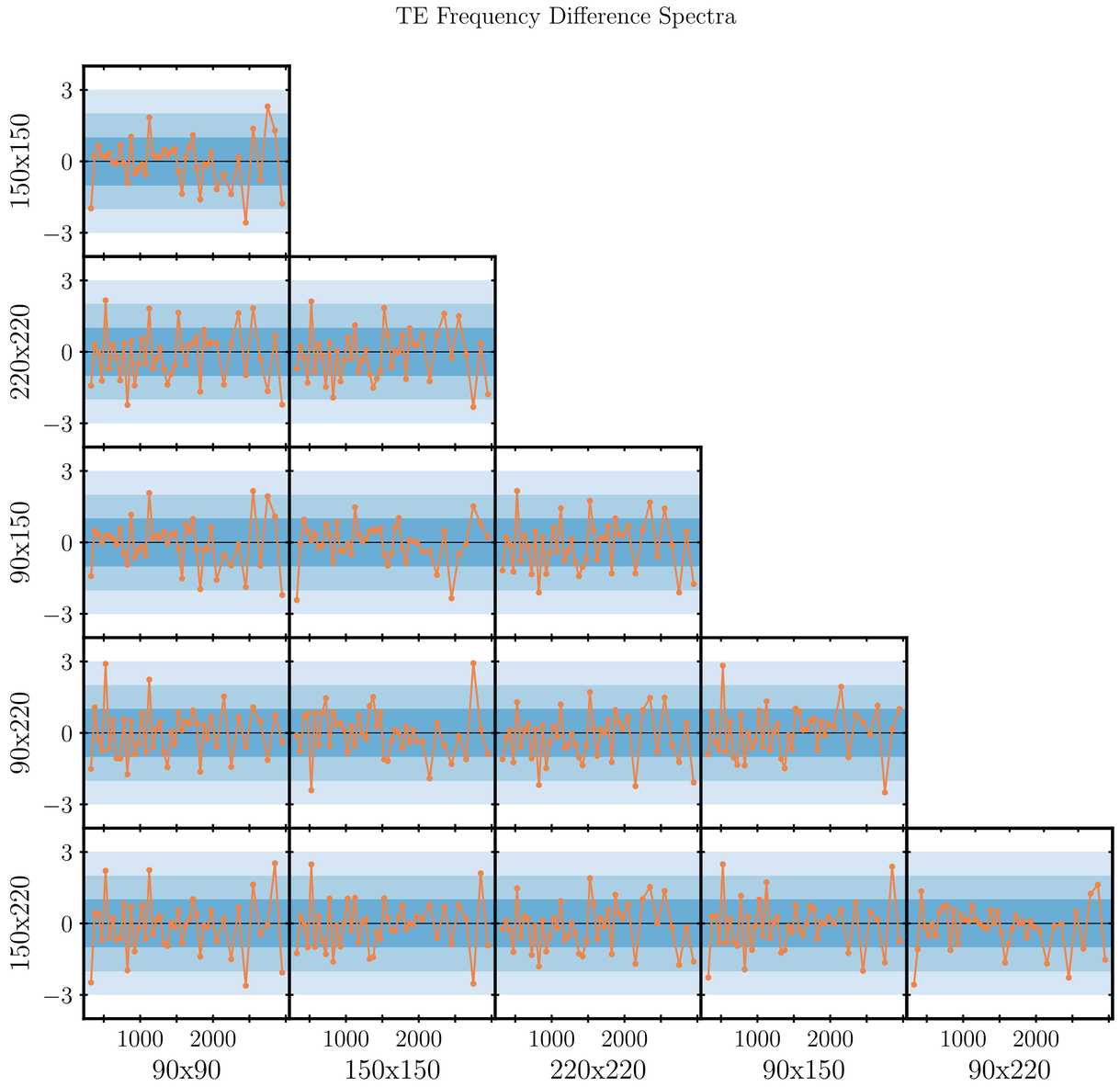

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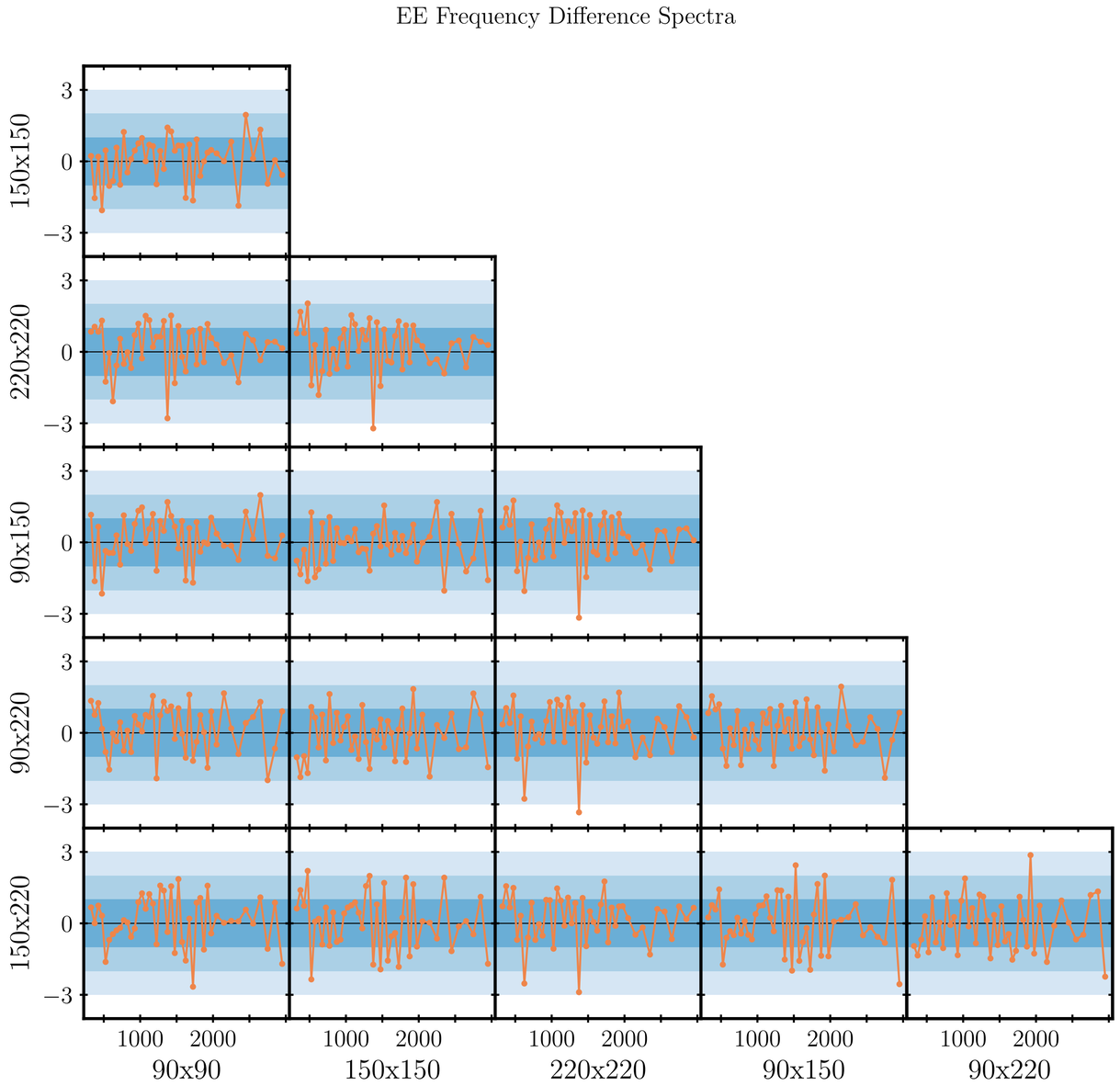

SPT-3G 2018 TT/TE/EE - Forecast

- ΛCDM:
  - 15% better n_s
  - 20% better $10^9 A_s e^{-2\tau}$
- ΛCDM + $N_{\rm eff}$:
  - 50% better $N_{\rm eff}$ and H_0*
- ΛCDM + $N_{\rm eff}$ + Y_P:
  - EE/TE fluctuates away from S.M. by 1.5σ

SPT-3G TT/TE/EE - Full Survey Forecast

Parameter Error	$\Omega_b h^2$	$\Omega_c h^2$	n_s	H_0	S_8
SPT-3G	0.00010	0.0017	0.0073	0.65	0.016
Planck	0.00020	0.0014	0.0044	0.60	0.016
SPT-3G + Planck	0.000090	0.0011	0.0032	0.45	0.0067*

* + lensing

Forecast by Silvia Galli (IAP)