The Atacama Cosmology Telescope:

cosmology from DR6 CMB lensing and cross-correlations with unWISE

Gerrit S. Farren

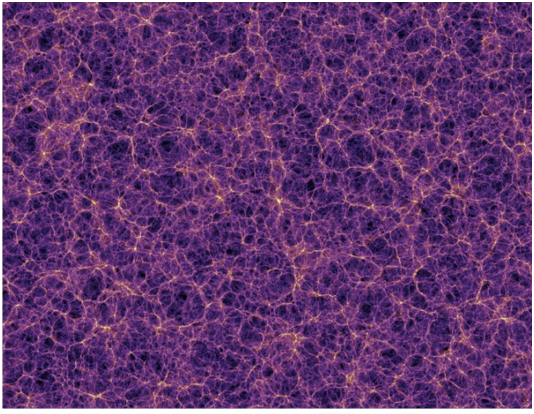
Department of Applied Mathematics and Theoretical Physics, University of Cambridge, Cambridge, UK
Kavli Institute for Cosmology Cambridge, Cambridge, UK

based on work with Alex Krolewski, Frank Qu, Niall MacCrann, Boris Bolliet, Simone Ferraro, Blake Sherwin and the ACT Collaboration presented in arXiv:2309.05659 and arXiv:2311.04213

LBNL, Physics Division Research Progress Meeting, Dec 7 2023

The large scale structure of the universe

Learning from the distribution of matter in the universe:

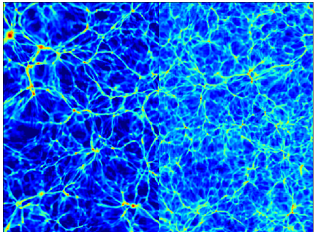


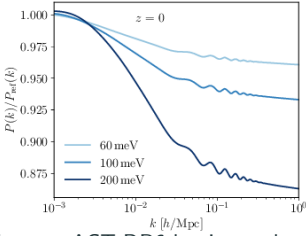
- What is the nature of *dark matter* and *dark energy*?
- Is GR is the correct theory of gravity on all scales?
- What is the mass of the neutrinos?
- ...

Fundamental physics in the large scale structure

neutrinos

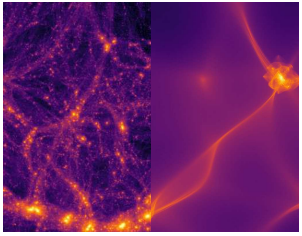
massless massive

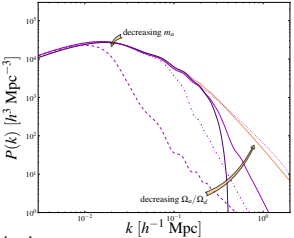




nature of dark matter

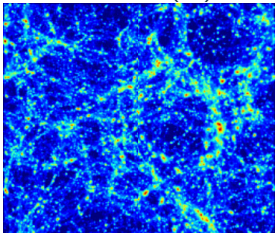
CDM FDM





modified gravity

GR $f(R)$



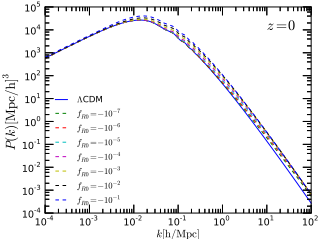
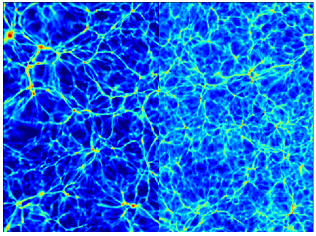


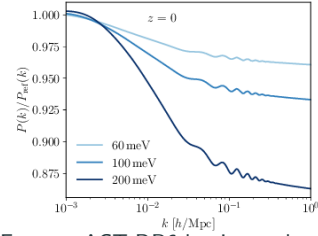
Image Credit: (*nu*): Agarwal & Feldman, Gerbino et al.; (ULAs): Mocz et al., Marsh et al.; ($f(R)$): He et al.

Fundamental physics in the large scale structure

neutrinos

massless massive





nature of dark matter

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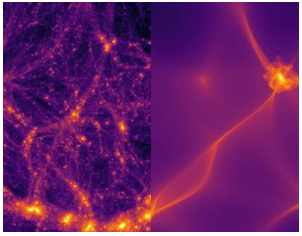

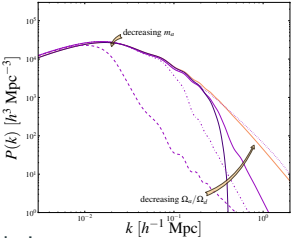

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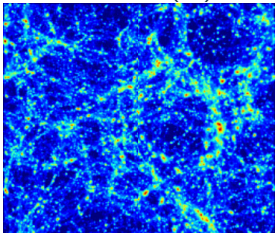

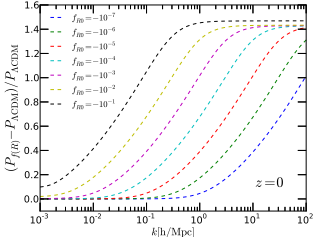

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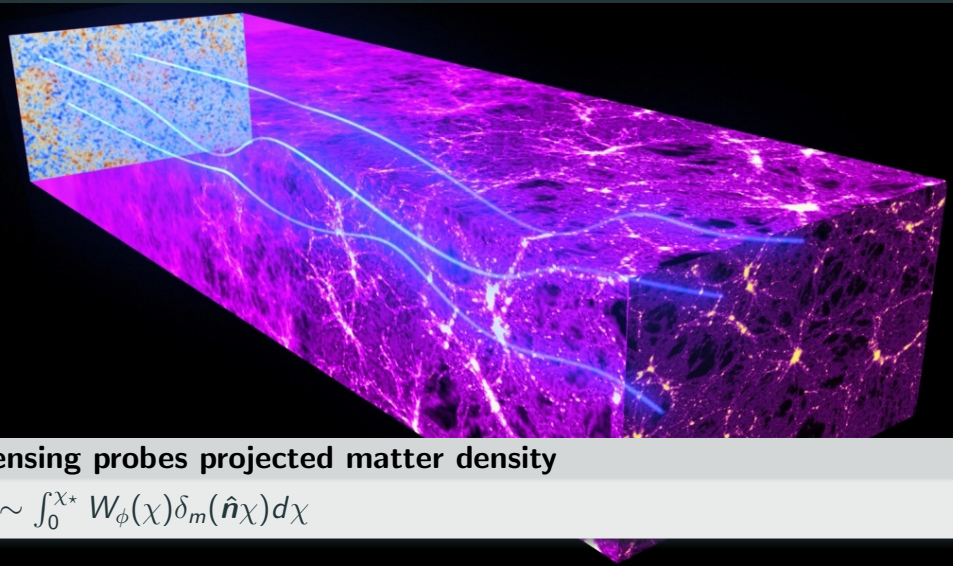
Introduction to CMB lensing

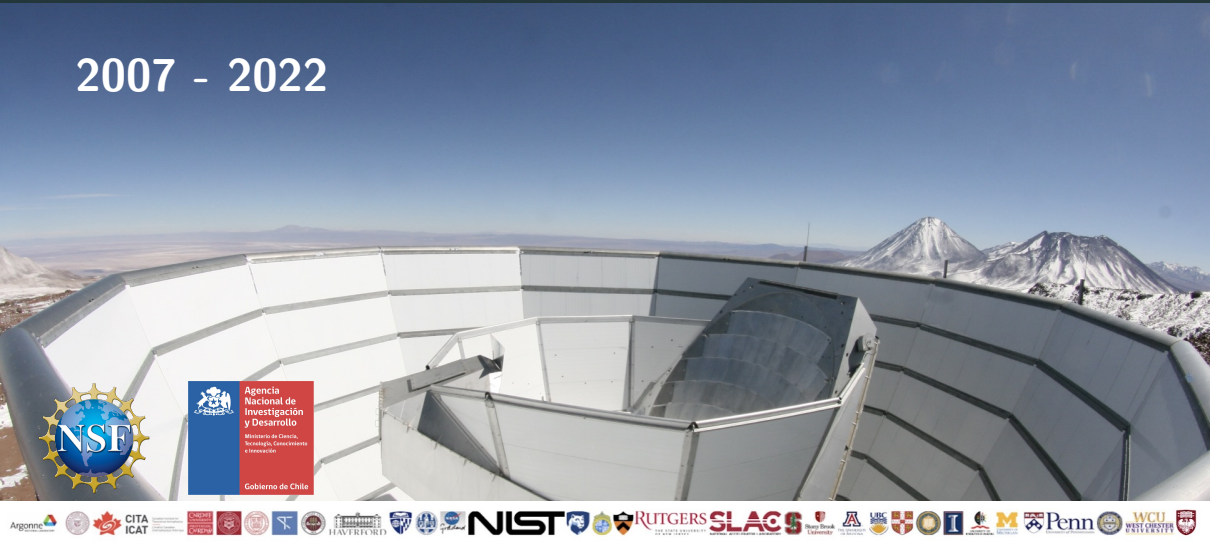


Lensing probes projected matter density

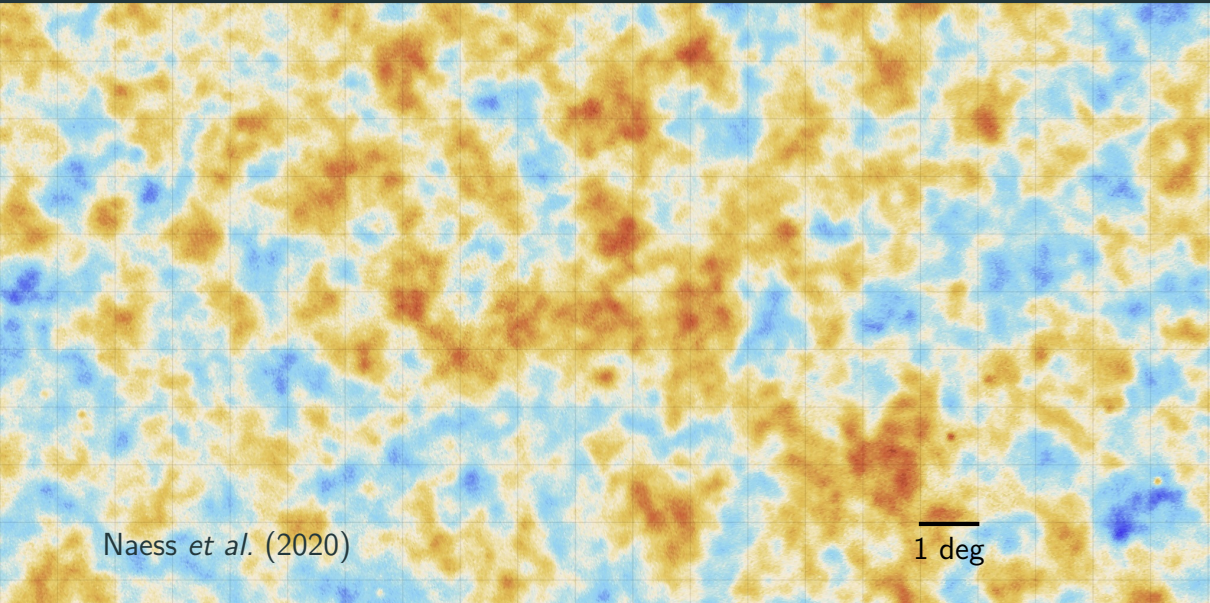
$\phi \sim \int_0^{\chi_\star} W_\phi(\chi)\delta_m(\hat{\boldsymbol{n}}\chi)d\chi$

The Atacama Cosmology Telescope

2007 - 2022



Observing the CMB with ACT



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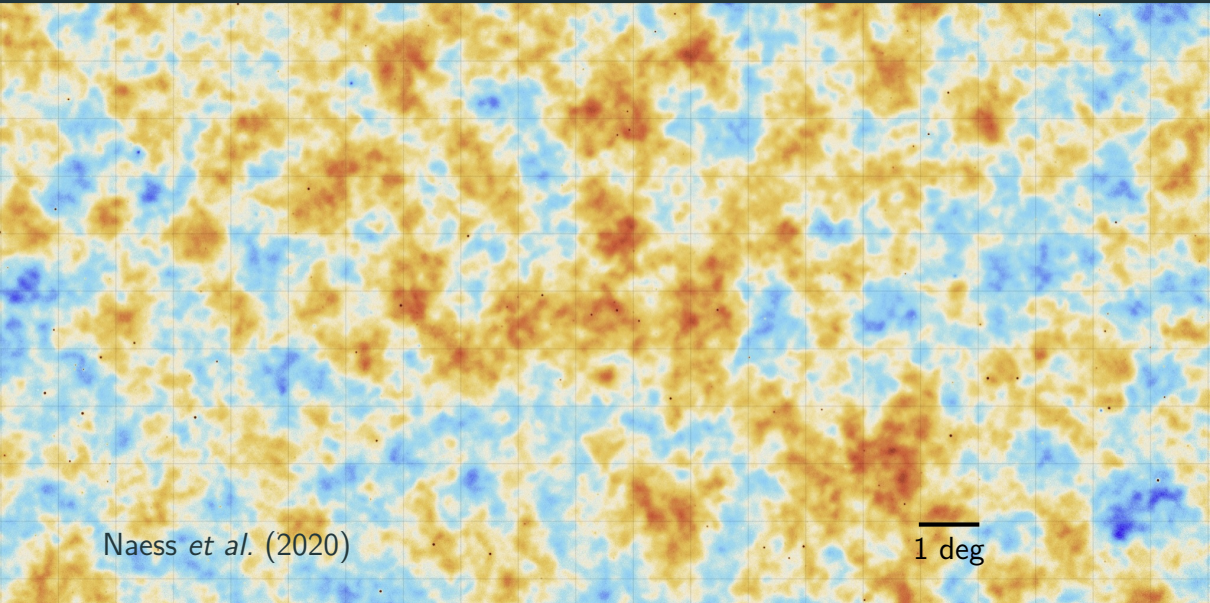

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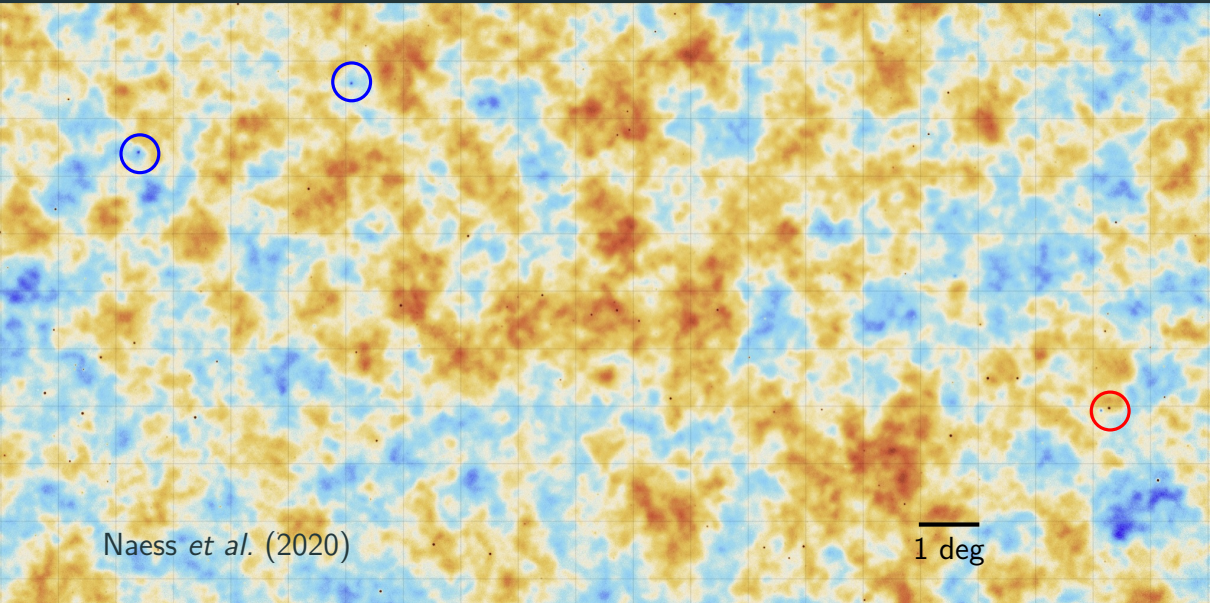
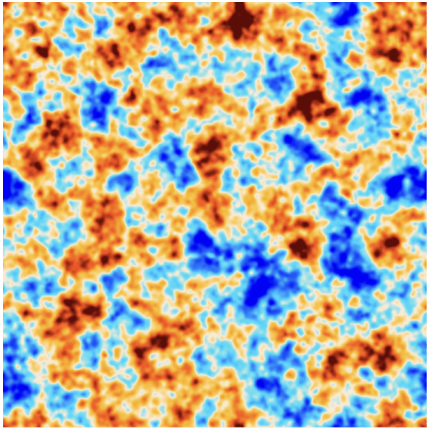


The effect of CMB lensing

unlensed



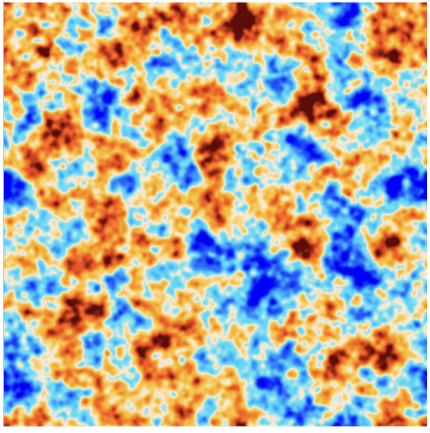
- observed field = unlensed field evaluated at a different position

$$\tilde{\Theta}(\hat{\boldsymbol{n}}) = \Theta_0(\hat{\boldsymbol{n}} + \boldsymbol{\nabla}\phi) \approx \Theta_0(\hat{\boldsymbol{n}}) + \boldsymbol{\nabla}\phi \cdot \boldsymbol{\nabla}\Theta_0$$

- small-scale ($\mathcal{O}$(arc-minute)) deflections described by a deflection potential ϕ
- coherent over larger, $\mathcal{O}(\mathrm{degree})$, scales
- lensing convergence $\kappa = -\frac{1}{2}\boldsymbol{\nabla}^2\phi$

The effect of CMB lensing

lensed



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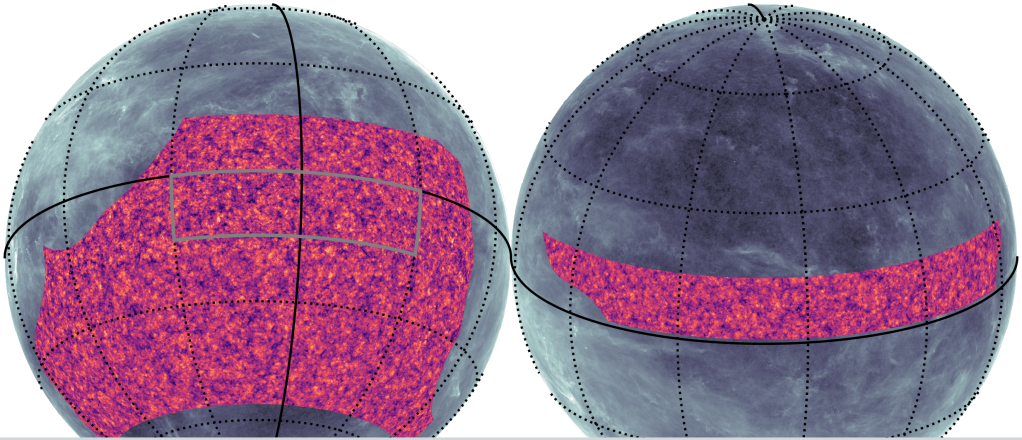
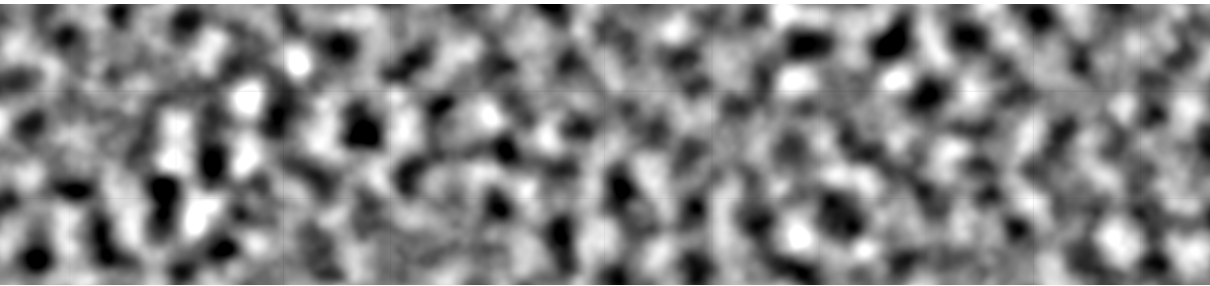
Lensing reconstruction



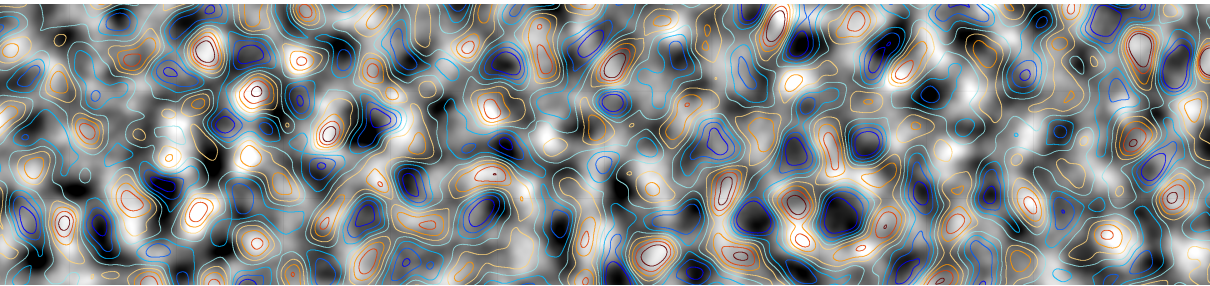
Reconstruct lensing from off-diagonal correlations in CMB

$$\hat{\phi}(\boldsymbol{L}) \sim \int d^2\boldsymbol{l}\tilde{\Theta}(\boldsymbol{l})\tilde{\Theta}(\boldsymbol{l}-\boldsymbol{L})g(\boldsymbol{l},\boldsymbol{L})$$

Lensing reconstruction



Lensing reconstruction



Lensing reconstruction

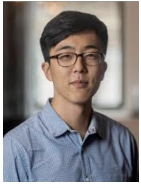
Presented in ...

- **Qu et al.** (arXiv:2304.05202): lensing power spectrum + lensing-only param.
- **Madhavacheril et al.** (arXiv:2304.05203): lensing map
  + comb. w/ external data + extended models
- **Mac Crann et al.** (arXiv:2304.05196): lensing systematics investigation

Frank Qu
(Cambridge)

Mat Madhavacheril
(UPenn)

Niall MacCrann
(Cambridge)

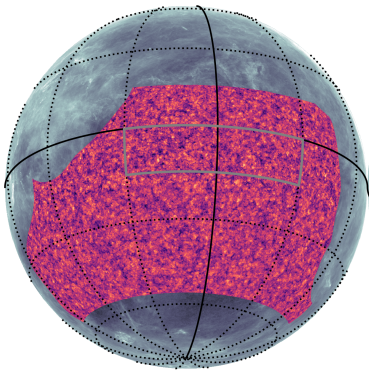


Dongwon Han
(Cambridge)

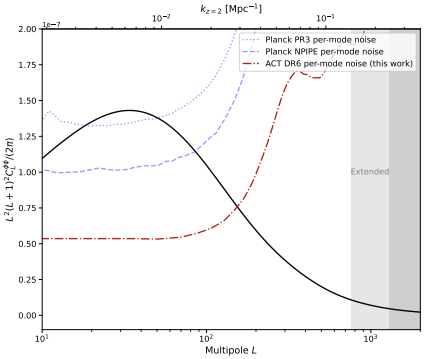
Key results from the ACT DR6 CMB lensing auto-spectrum

structure growth and neutrinos

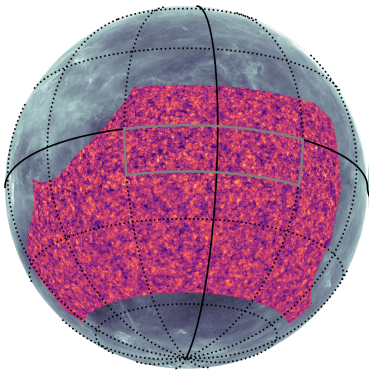
The lensing power spectrum



$$\hat{C}_\ell^{\phi\phi} \sim \langle \hat{\phi}_{\ell m} \hat{\phi}^*_{\ell m} \rangle$$



The lensing power spectrum



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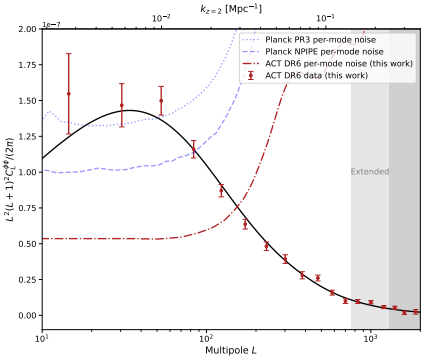
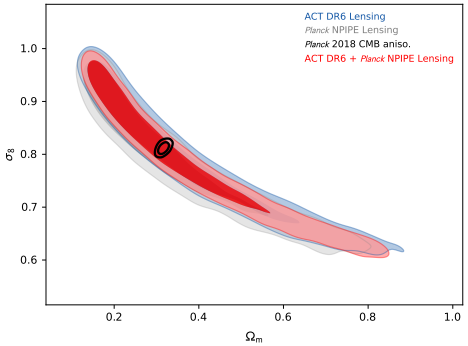


Constraints on structure growth

Best constrained parameter

$$S_8^{\rm CMBL} = \sigma_8 \left(\frac{\Omega_m}{0.3}\right)^{0.25}$$



ACT DR6 Lensing

$\mathbf{S_8^{\rm CMBL} = 0.818 \pm 0.022}$

ACT DR6 + Planck PR4 Lensing

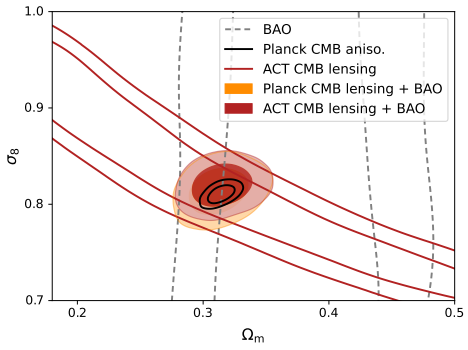
$S_8^{\rm CMBL} = 0.813 \pm 0.018$

cf. primary CMB aniso.

$S_8^{\rm CMBL} = 0.823 \pm 0.011$ (Planck 2018)

$S_8^{\rm CMBL} = 0.828 \pm 0.022$ (ACT+WMAP)

Constraints on structure growth



ACT DR6 Lensing + BAO

$\sigma_8 = 0.819 \pm 0.015$

ACT DR6 + Planck PR4 Lensing

$\sigma_8 = 0.812 \pm 0.013$

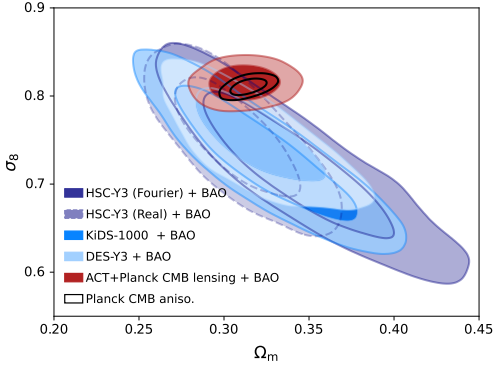
cf. primary CMB aniso.

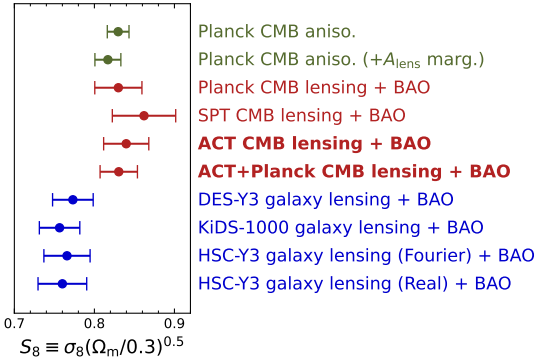
$\sigma_8 = 0.811 \pm 0.006$ (Planck 2018)

$\sigma_8 = 0.822 \pm 0.012$ (ACT+WMAP)

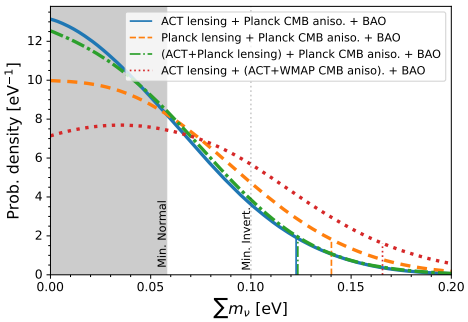
Constraints on structure growth - comp. to galaxy weak lensing

ACT CMB lensing is **consistent** with (at $1.7 - 2.1\sigma$) but **consistently higher** than galaxy weak lensing shear





Constraints on Neutrinos



ACT DR6 Lensing + Planck PR4 CMB + BAO

$\sum \mathbf{m_\nu} < \mathbf{0.12\ eV}$; 95% c.l.

ACT DR6 + Planck PR4 Lensing + Planck PR4 CMB + BAO

$\sum \mathbf{m_\nu} < \mathbf{0.12\ eV}$; 95% c.l.

cf. primary CMB aniso. + BAO

$\sum \mathbf{m_\nu} < \mathbf{0.16\ eV}$; 95% c.l. (Planck PR4)

Cosmology from the ACT DR6 CMB lensing $\times$ unWISE galaxies

structure growth at low redshift

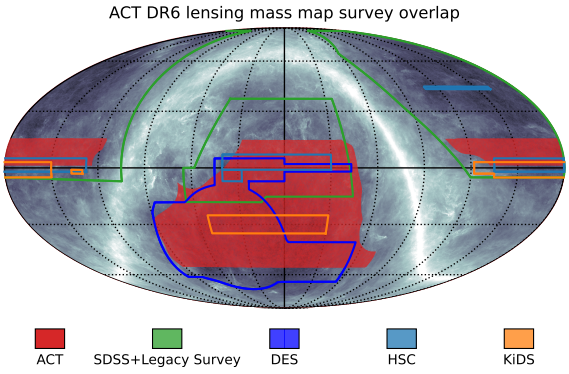
Cross-correlation science with ACT DR6 lensing

Large sky overlap with:

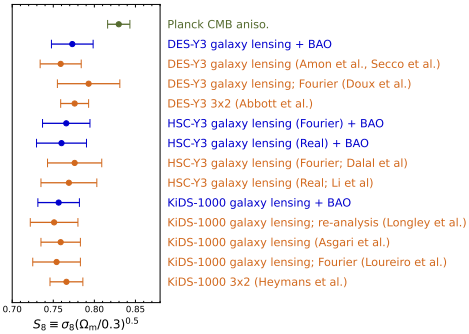
- DESI
- DES
- HSC
- KiDS

Science cases:

- tomographic structure formation: $\sigma_8(z)$
- primordial non-Gaussianity: $f_{\rm NL}$



Narrowing in on the S_8 tension

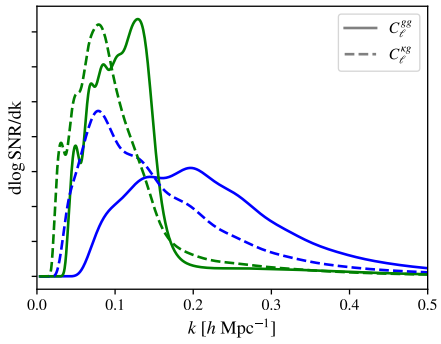


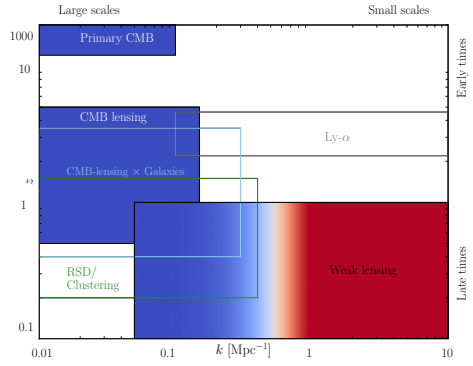
Two possible resolutions?

- scale dependent suppression of power
  - non-linear structure growth
  - (stronger than expected) baryon feedback
  - ...
- redshift dependent suppression of power
  - dark energy evolution
  - ....

Probing different scales and redshifts

- $C_\ell^{\phi\phi}$: $z \gtrsim 1.0$ & $k \lesssim 0.2h\,\mathrm{Mpc}^{-1}$



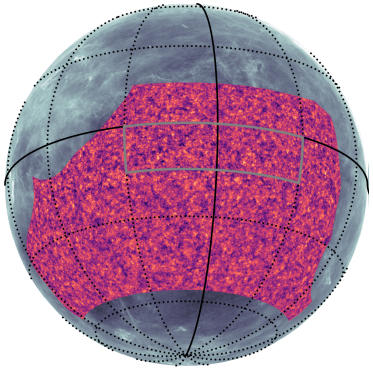


from Preston *et al.* (2023)

- $C_\ell^{\phi g}$: $z \simeq 0.2 - 1.6$ & $k \lesssim 0.3h\,\mathrm{Mpc}^{-1}$

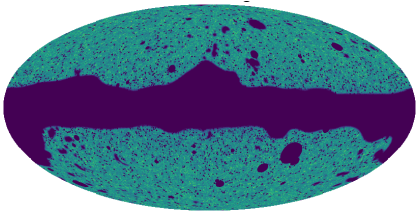
Cross-correlation between ACT DR6 lensing and unWISE

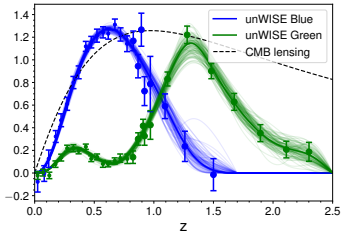
CMB Lensing reconstruction



×

Galaxy number density

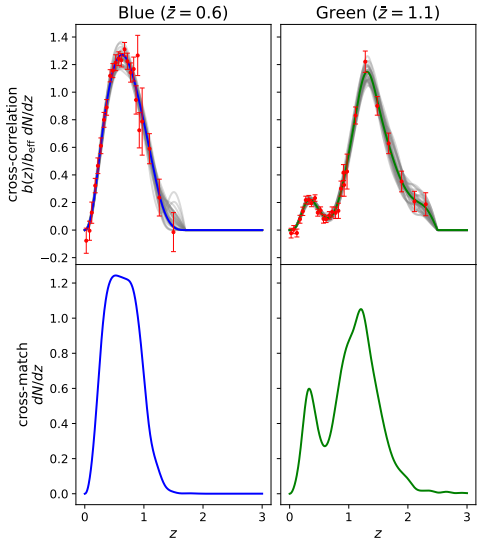




The unWISE samples

- galaxies from the WISE survey
- including 2 years of post-cryogenic observations (at 3.4 and 4.6 μm)
- $>$500 million galaxies
- $0 \lesssim z \lesssim 2$
- color selection for two samples

sample	$\bar{z}$	$\bar{n}$
Blue	0.6	$\sim$3400
Green	1.1	$\sim$1800



Redshifts for unWISE

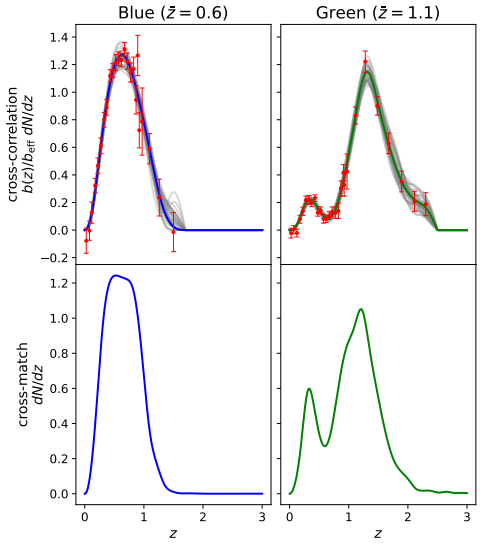
dN/dz from ...

- cross-correlating with spectroscopic surveys (BOSS, eBOSS)

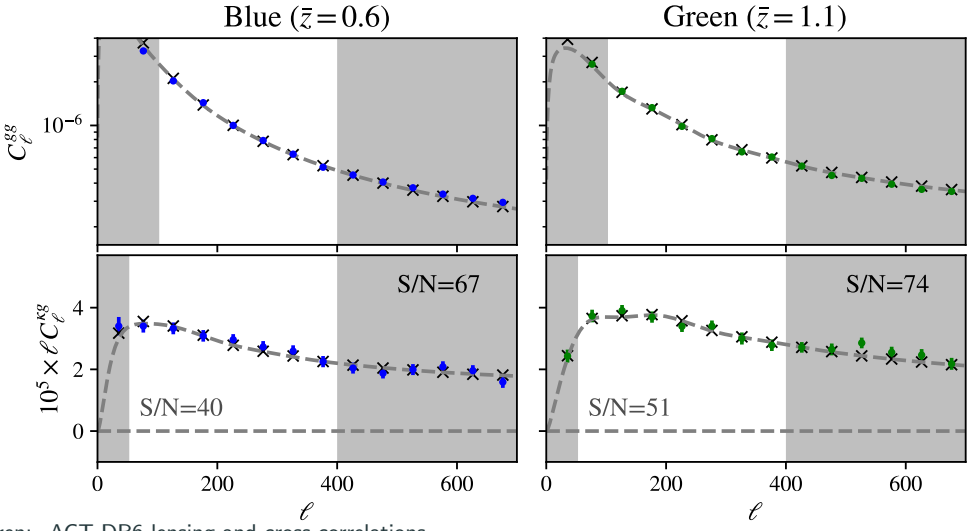
$$b_{\text{photo.}}\widehat{\frac{dN_{\text{photo.}}}{dz}} \propto \frac{w^{\text{spec.}\times\text{photo.}}(z)}{\sqrt{w^{\text{spec.}\times\text{spec.}}(z)}}$$

(Ménard *et al.*, 2013)

- cross matching with photometric redshifts on smaller field (COSMOS)



ACT DR6 lensing × unWISE - spectra

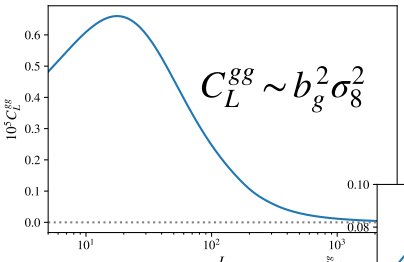


Measuring S_8 with galaxy - CMB lensing cross-correlations

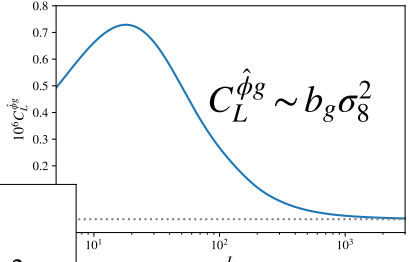
interested in

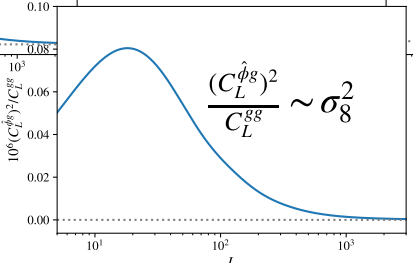
$\sigma_8^2 \sim \langle \delta_m^2 \rangle$

from galaxies



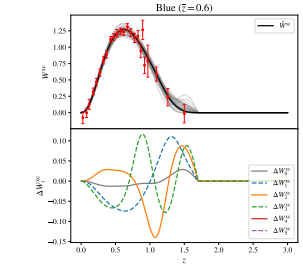
from galaxies × lensing

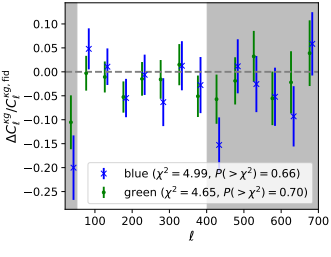




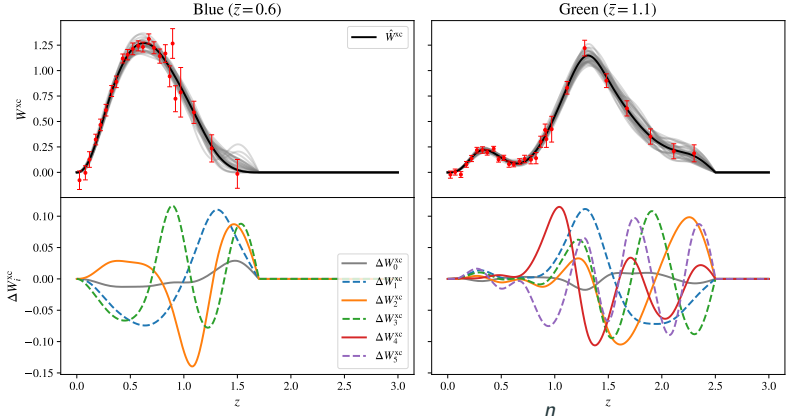
Highlights of ACT DR6 CMB lensing × unWISE analysis

- Improved clustering redshifts for unWISE galaxies
- **PCA based marginalisation over redshift uncertainties**
- imaging systematics mitigation
- **Hybrid `HMCode` + LPT model**
- **simulation based foreground tests**
- **extensive null- and consistency tests**
- fully blind analysis





PCA based dN/dz marginalisation



$$W^{\rm xc}(z) = \hat{W}^{\rm xc}(z) + \Delta W_0^{\rm xc}(z) + \sum_{i=1}^{n} c_i \Delta W_i^{\rm xc}(z)$$

Modelling: Projected power spectra

Model $\hat{C}_\ell^{gg}$ and $\hat{C}_\ell^{\kappa g}$ using Limber approximation

$$C_\ell^{XY} = \int d\chi \overbrace{\frac{W_X(\chi) W_Y(\chi)}{\chi^2}}^{\text{projection kernels}} \underbrace{P_{XY}\left(\frac{\ell + 1/2}{\chi}, \chi\right)}_{\text{3D clustering power spectrum}}$$

Observed spectra:

$$\hat{C}_\ell^{gg} = C_\ell^{gg} + \underbrace{2C_\ell^{g\mu} + C_\ell^{\mu\mu}}_{\text{lensing magnification}} + N_\ell^{\text{shot}} \qquad \hat{C}_\ell^{\kappa g} = C_\ell^{\kappa g} + C_\ell^{\mu g}$$

Modelling: 3D power spectra

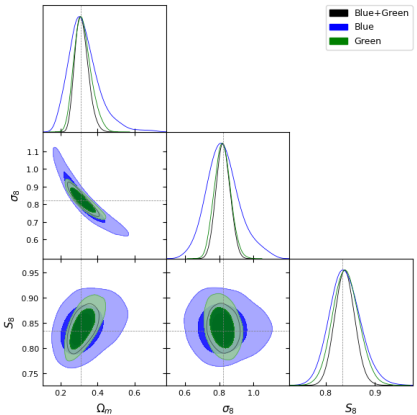
- Power spectrum model: Hybrid `HMCode` + LPT

$$
\begin{aligned}
P_{gg}(k,z) &= b_{1,E}^2(z)P_{mm,\mathrm{HM}} + b_{2,L}(z)P_{b_2}(k,z) + b_{s,L}(z)P_{b_s}(k,z) \\
&\quad + b_{1,L}(z)b_{2,L}(z)P_{b_1 b_2}(k,z) + \cdots + P_{\text{shot noise}} \\
P_{gm}(k,z) &= b_{1,E}(z)P_{mm,\mathrm{HM}} + \frac{b_{2,L}(z)}{2}P_{b_2}(k,z) + \frac{b_{s,L}(z)}{2}P_{b_s}(k,z) \\
P_{mm}(k,z) &= P_{mm,\mathrm{HM}}(k,z).
\end{aligned}
$$

- higher order biases set by co-evolution relations + free offset (co-evolution and priors from simulations)

$$b_{X,L} = b_{X,L}^{\mathrm{co-evol.}}(b_{1,E}^{\mathrm{fid}}(z)) + c_{b_{X,L}}^{\mathrm{offset}}$$

Modelling: Model verification

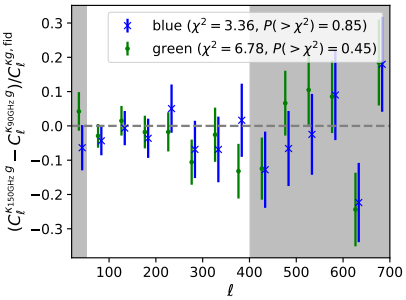


- N-body sims populated with HOD tuned to reproduce unWISE samples (from Krolewski *et al.*, 2021)

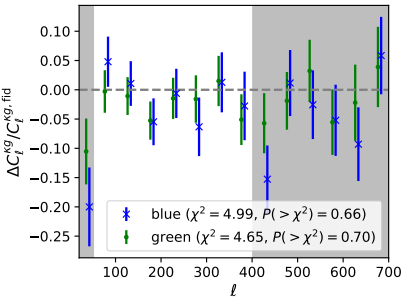
	$\Delta\Omega_m/\sigma_{\Omega_m}$	$\Delta\sigma_8/\sigma_{\sigma_8}$	$\Delta S_8/\sigma_{S_8}$
Blue	0.18	-0.07	0.28
Green	0.18	-0.14	0.07
Joint	0.19	-0.16	0.08

Series of systematics tests: Data null-tests

frequency comparison



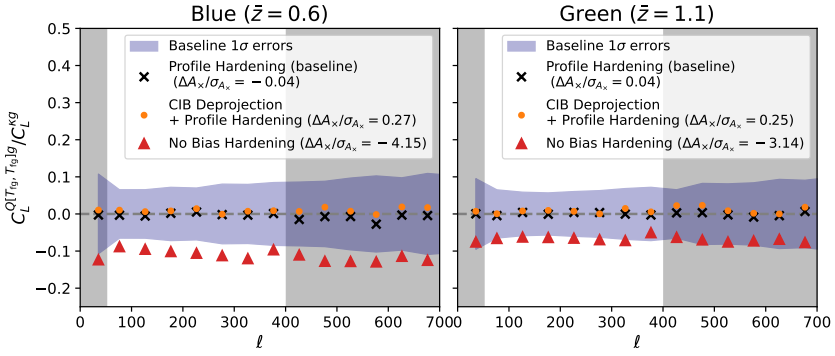
galactic mask comparison



And many more ...

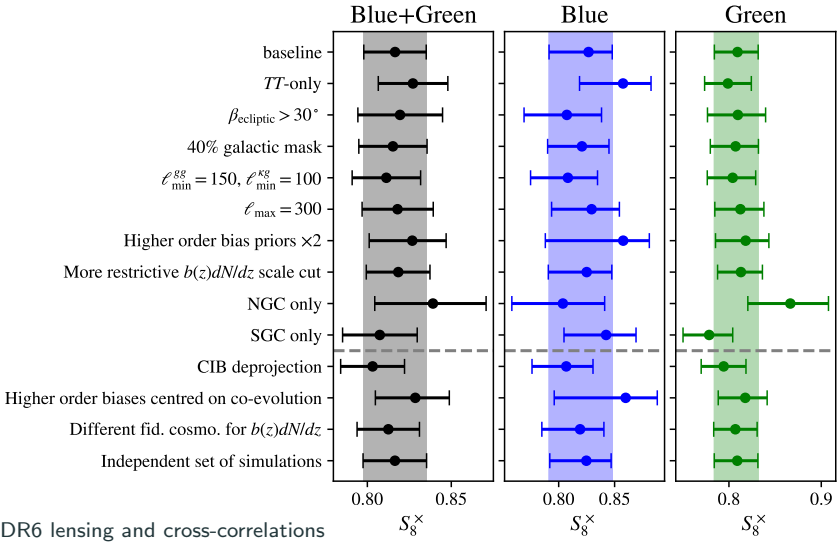
- different reconstruction and bias mitigation strategies
- various different masks

Series of systematics tests: Simulation driven tests

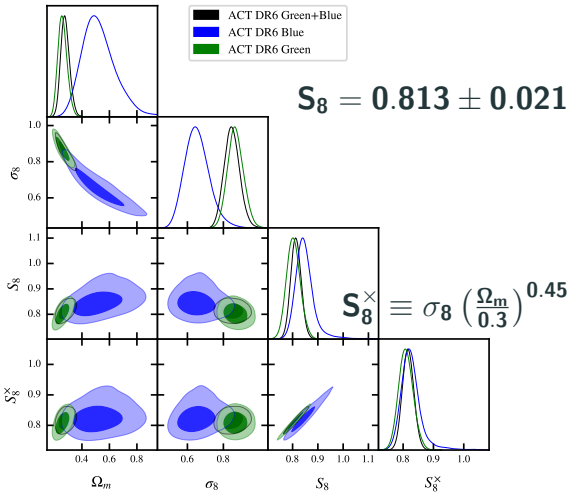


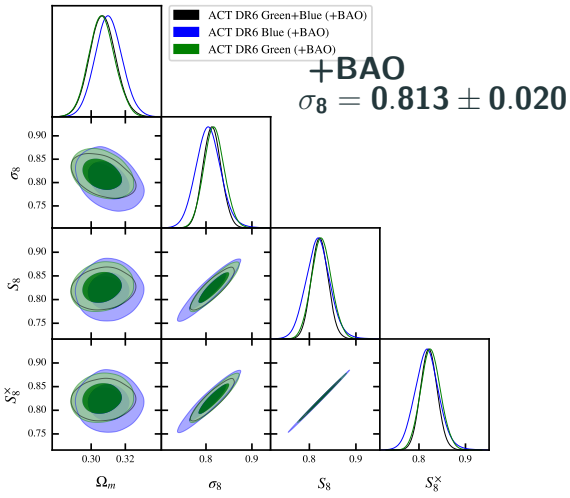
- extragalactic foreground maps from WebSky simulations
- galaxy sample generated using unWISE HOD on WebSky halo catalog
- measure lensing signal induced by foregrounds

Series of systematics tests: Parameter consistency tests

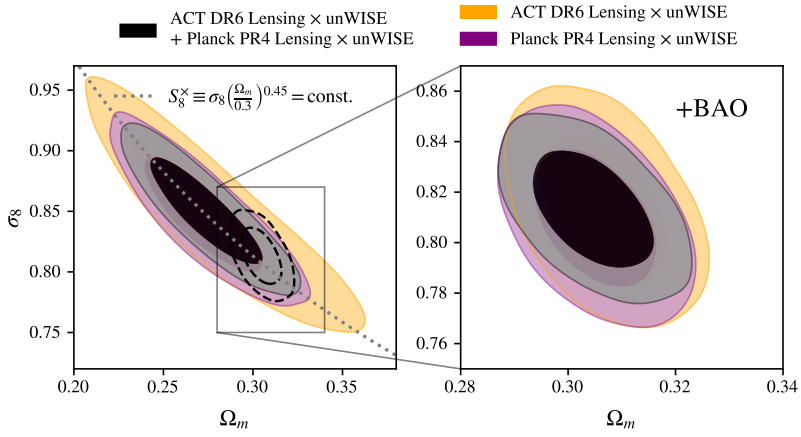


Cosmology from ACT DR6 Lensing × unWISE





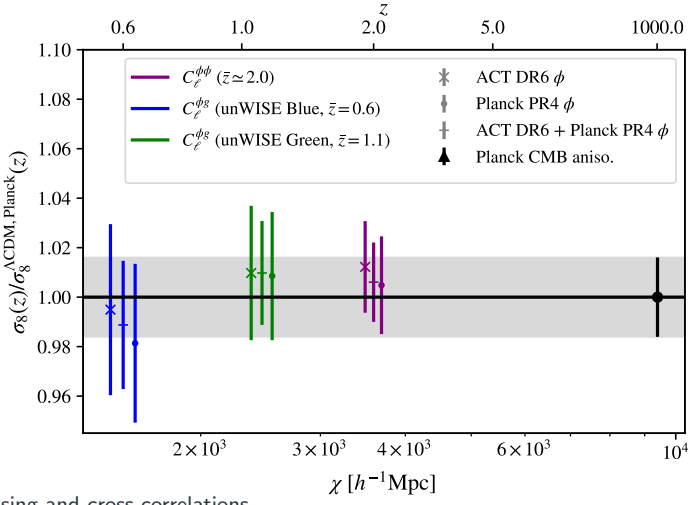
Combining with Planck PR4 × unWISE



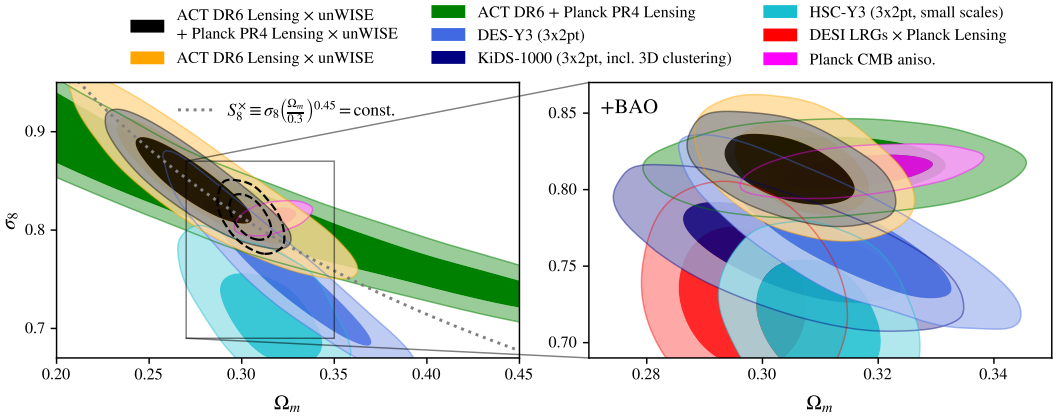
ACT + *Planck* × unWISE:

$$\mathbf{S_8 = 0.810 \pm 0.015} \qquad \sigma_8 = \mathbf{0.813 \pm 0.015}$$

Tomographic structure growth - $\sigma_8(z)$



Comparing to other analyses



Summary and looking ahead

ACT DR6 $C_\ell^{\phi\phi}$ and $C_\ell^{\phi g}$ with unWISE are **consistent with primary CMB**:
no evidence for suppression of structure growth for $z \gtrsim 0.2$ & $k \lesssim 0.3h\,\mathrm{Mpc}^{-1}$

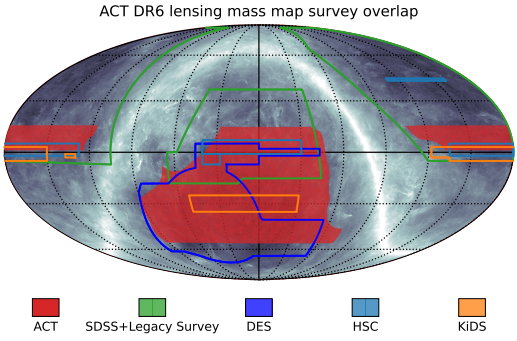
Looking ahead

- 3x2pt analysis: $C_\ell^{\phi\phi} + C_\ell^{g\phi}$ & C_ℓ^{gg}
- 3x2pt + primary CMB: $\sum m_\nu$
- DR6+: additional data (incl. day time), optimal filtering

Other cross-correlations

in preparation:

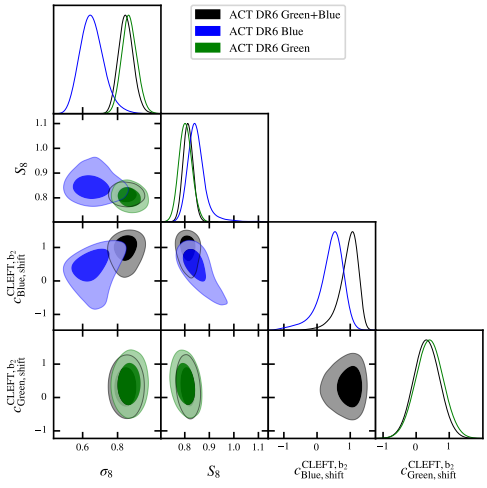
DESI:	Kim & Sailer *et al.*
	Hang & Qu *et al.*
SDSS BOSS:	Wenzl *et al.*
DES-Y3:	Darwish *et al.*
	Shaikh & Harrison *et al.*
	Pitocco *et al.*
	Kim *et al.*
Planck CIB:	Mheta *et al.*
Planck/ACT tSZ :	Bolliet *et al.*
...	



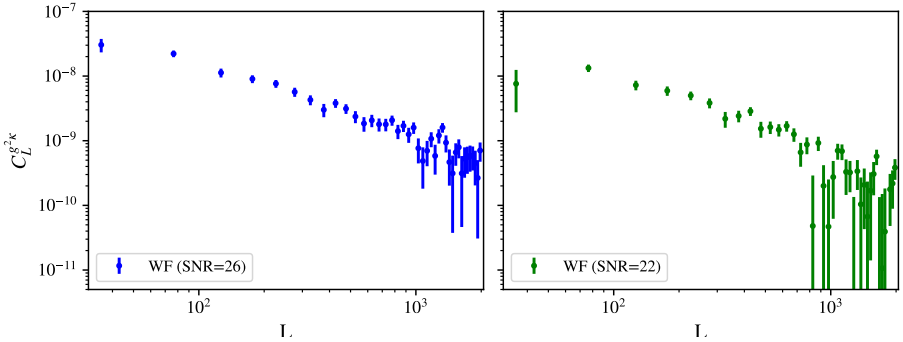
Bonus: Beyond two-point correlations

Information beyond the two-point function

- Cosmology partially degenerate with non-linear bias parameters
- non-linear contributions poorly constraint by power spectrum
- need for priors / risk of projection effects
- $b^{(2)}$ leading-order contribution to bispectrum

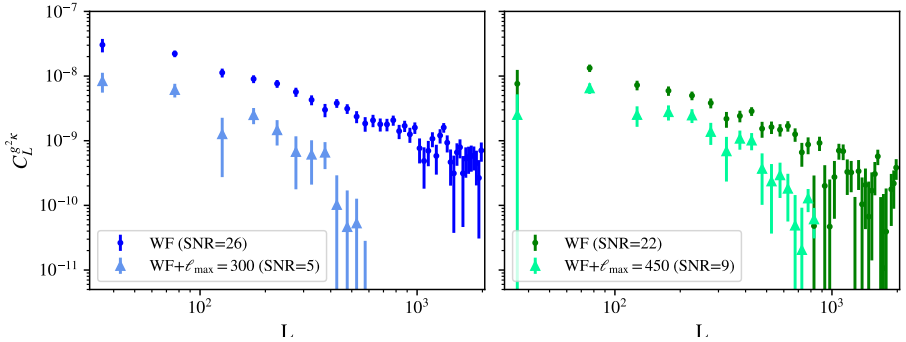


measuring $\langle \delta_g \delta_g \kappa \rangle$-bispectrum



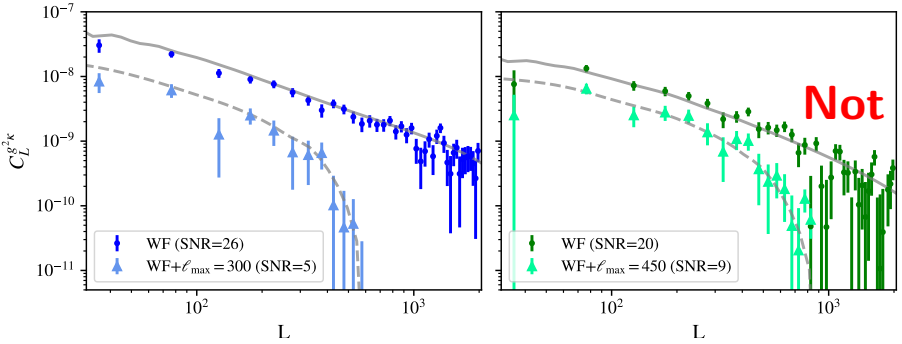
$$\langle (\tilde{\delta}_g^2)_{LM} \tilde{\kappa}^*_{L'M'} \rangle = \delta_{LL'} \delta_{MM'} \underbrace{\sum_{\ell,\ell'} \gamma_{\ell\ell'} B^{gg\kappa}_{\ell\ell' L} \overbrace{w^g_\ell w^g_{\ell'} w^\kappa_L}^{\text{filters}}}_{C_L^{g^2\kappa}}$$

measuring $\langle \delta_g \delta_g \kappa \rangle$-bispectrum



$$\langle (\tilde{\delta}_g^2)_{LM} \tilde{\kappa}^*_{L'M'} \rangle = \delta_{LL'} \delta_{MM'} \underbrace{\sum_{\ell,\ell'} \gamma_{\ell\ell'} B^{gg\kappa}_{\ell\ell' L} \overbrace{w^g_\ell w^g_{\ell'} w^\kappa_L}^{\text{filters}}}_{C_L^{g^2\kappa}}$$

modelling $C_L^{g^2\kappa}$

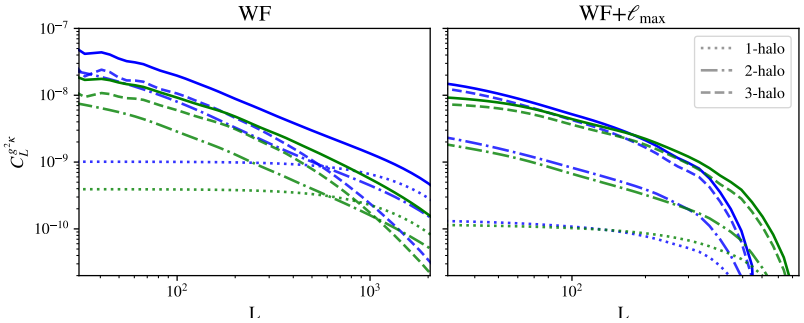


Not a fit!

$$C_L^{g^2\kappa} = \frac{1}{2\pi}\int_0^\pi d\theta \int \ell^2 d\ln\ell \; w(L)w(|L+\ell|)I(L,\ell,\theta)$$

$$I(\ell,\ell',\theta) = \int d\chi W_g^2(\chi) W_\kappa(\chi) B^{gg\kappa}\left(\frac{\ell'}{\chi}, \frac{|\boldsymbol{\ell}+\boldsymbol{\ell}'|}{\chi}, \frac{\ell}{\chi}\right)$$

contributions to $C_L^{g^2\kappa}$



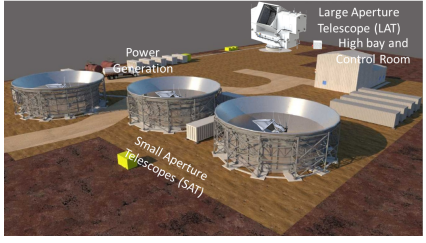
$$
\begin{aligned}
B_{1h}^{gg\kappa} &= \left\langle \hat{u}^g_{k_1} \hat{u}^g_{k_2} \hat{u}^\kappa_{k_3} \right\rangle_n \\
B_{2h}^{gg\kappa} &= \left\langle \hat{u}^g_{k_1} \hat{u}^g_{k_2} \right\rangle_n \left\langle b^{(1)} \hat{u}^\kappa_{k_3} \right\rangle_n P_{\rm lin}(k_3) + \text{perm.} \\
B_{3h}^{gg\kappa} &= 2 \left\langle b^{(1)} \hat{u}^g_{k_1} \right\rangle_n \left\langle b^{(1)} \hat{u}^g_{k_2} \right\rangle_n \left\langle b^{(1)} \hat{u}^\kappa_{k_3} \right\rangle_n F_2(k_1, k_2, k_3) P_{\rm lin}(k_1) P_{\rm lin}(k_2) + \text{perm.} \\
&\quad + \left\langle b^{(1)} \hat{u}^g_{k_1} \right\rangle_n \left\langle b^{(1)} \hat{u}^g_{k_2} \right\rangle_n \left\langle b^{(2)} \hat{u}^\kappa_{k_3} \right\rangle_n P_{\rm lin}(k_1) P_{\rm lin}(k_2) + \text{perm.}
\end{aligned}
$$

The road ahead

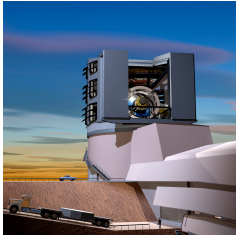
What's next?

- **New data**: SO, DESI, LSST
- **Improved modelling**: Hybrid EFT, joined photo. and spec. x-corr.
- **Bispectra**: fold in non-Gaussian/non-linear info.

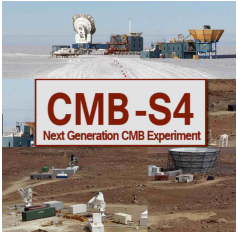
DESI (2021-2026)



Simons Observatory (2024-2029)



VRO/LSST
(2026-2036)



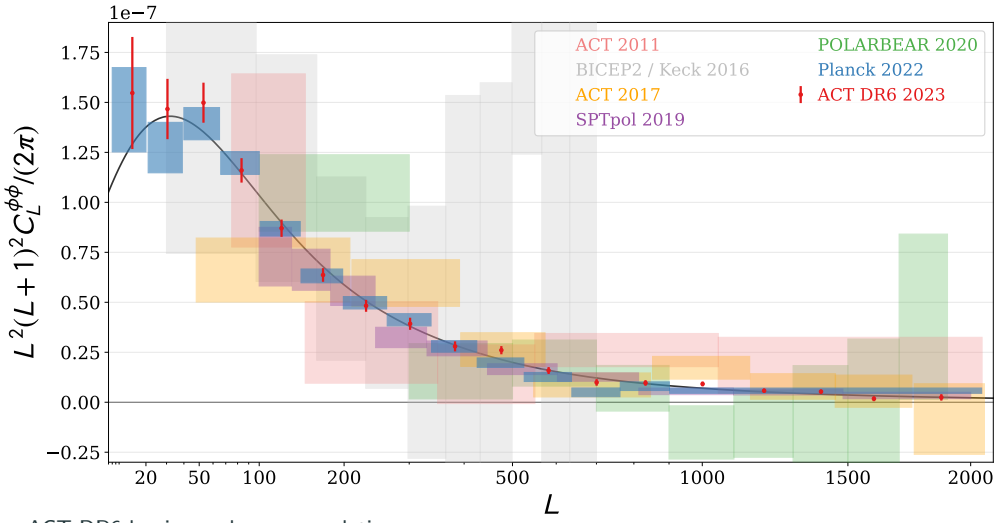
CMB-S4
(2029-????)

Thank you!

Backup slides

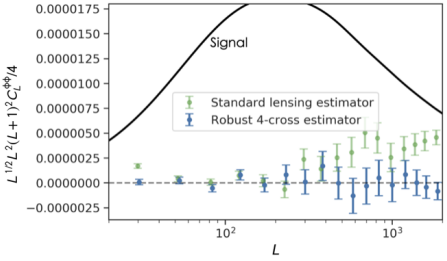
The Atacama Cosmology Telescope

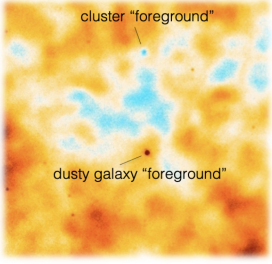
The lensing power spectrum



Highlights of the new ACT DR6 CMB lensing analysis

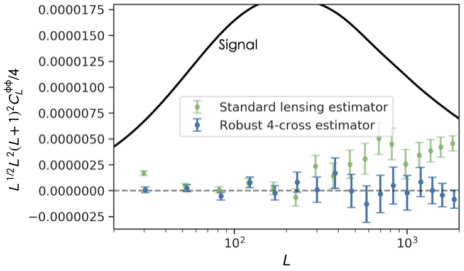
- noise-bias immune cross-correlation based estimator: $\hat{C}_\ell^{\phi\phi} \sim \langle \Theta_A \Theta_B \Theta_C \Theta_D \rangle$
- foreground bias hardened estimator
- simulation based foreground bias investigation
- extensive null-tests
- fully blind analysis





Challenges to measuring the lensing power spectrum: 1) Noise bias subtraction

- Problem: Gaussian lensing bias sensitive to instrumental and atmospheric noise



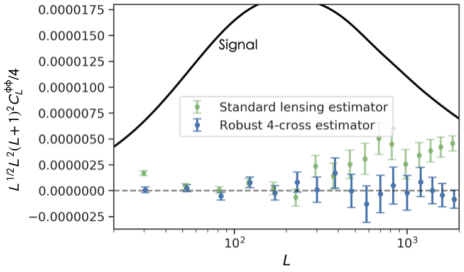
$$\hat{C}_\ell^{\phi\phi} \sim \langle\hat{\Theta}\hat{\Theta}\hat{\Theta}\hat{\Theta}\rangle - \overbrace{\langle\hat{\Theta}\hat{\Theta}\rangle\langle\hat{\Theta}\hat{\Theta}\rangle}^{\text{Gaussian bias}},$$

$$\underbrace{C_\ell^{\Theta\Theta,\mathrm{CMB+FG}} + N_\ell^{\hat{\Theta}\hat{\Theta}}}$$

$$\hat{\Theta} = \Theta_{\mathrm{CMB+FG}}^{T/E/B} + N^{T/E/B}$$

Challenges to measuring the lensing power spectrum: 1) Noise bias subtraction

- Problem: Gaussian lensing bias sensitive to instrumental and atmospheric noise
- Solution: use independent data splits
  $\implies$ no noise contribution to $\langle \hat{\Theta}\hat{\Theta} \rangle$



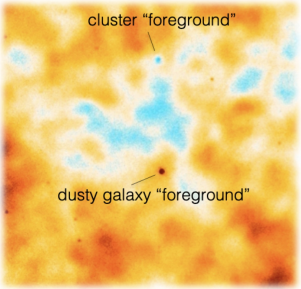
$$\hat{C}_\ell^{\phi\phi} \sim \langle \hat{\Theta}_A \hat{\Theta}_B \hat{\Theta}_C \hat{\Theta}_D \rangle - \overbrace{\langle \hat{\Theta}_A \hat{\Theta}_B \rangle \langle \hat{\Theta}_C \hat{\Theta}_D \rangle}^{\text{Gaussian bias}},$$

$$C_\ell^{\Theta\Theta,\mathrm{CMB+FG}} + \cancel{N_\ell^{\hat{\Theta}\hat{\Theta}}}$$

$$\hat{\Theta} = \Theta_{\mathrm{CMB+FG}}^{T/E/B} + N^{T/E/B}$$

Challenges to measuring the lensing power spectrum: 2) Foregrounds

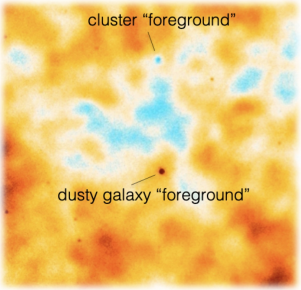
- Problem: Extragalactic foregrounds are non-Gaussian $\implies$ contribute lensing-like signal



$$\hat{\phi}_{\boldsymbol{L}} \sim \int d\boldsymbol{\ell}\, \underbrace{f^{\phi}_{\boldsymbol{L},\boldsymbol{\ell}}}_{\text{mode coupling due to lensing}} \Theta_{\boldsymbol{L}}\Theta_{\boldsymbol{\ell}}$$

Challenges to measuring the lensing power spectrum: 2) Foregrounds

- Problem: Extragalactic foregrounds are non-Gaussian $\implies$ contribute lensing-like signal
- Solution: use bias hardened estimator (explicitly subtract response of lensing estimator to foreground signal)

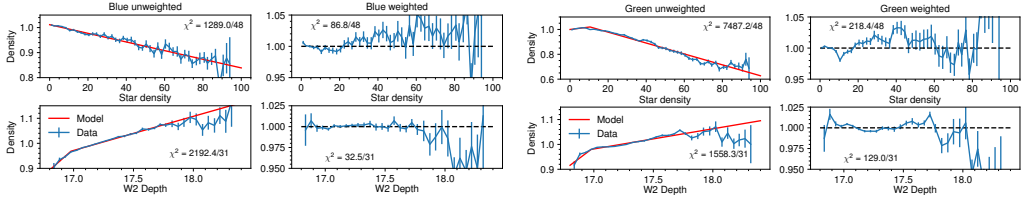


$$\hat{\phi}_{\boldsymbol{L}} \sim \int d\boldsymbol{\ell}\, \underbrace{f^{\phi}_{\boldsymbol{L},\boldsymbol{\ell}}}_{\text{mode coupling due to lensing}} \Theta_{\boldsymbol{L}}\Theta_{\boldsymbol{\ell}} \rightarrow \hat{\phi}^{\rm BH}_{\boldsymbol{L}} \sim \hat{\phi}_{\boldsymbol{L}} - \overbrace{R^{\phi,\rm FG}_{\boldsymbol{L}}}^{\phi \text{ estimator response to foregrounds}} \int d\boldsymbol{\ell}\, \underbrace{f^{\rm FG}_{\boldsymbol{L},\boldsymbol{\ell}}}_{\text{mode coupling due to foregrounds}} \Theta_{\boldsymbol{L}}\Theta_{\boldsymbol{\ell}}$$

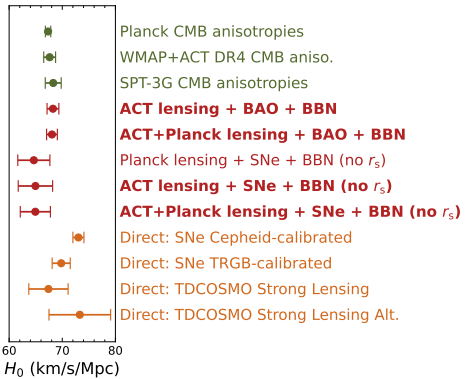
Mitigating systematic density fluctuations

Galaxy density depends on **imaging systematics** as well as real cosmological fluctuations

Fit trends with linear regression and define **imaging weights** to mitigate



Constraints on H_0



ACT DR6 Lensing + BAO + BBN

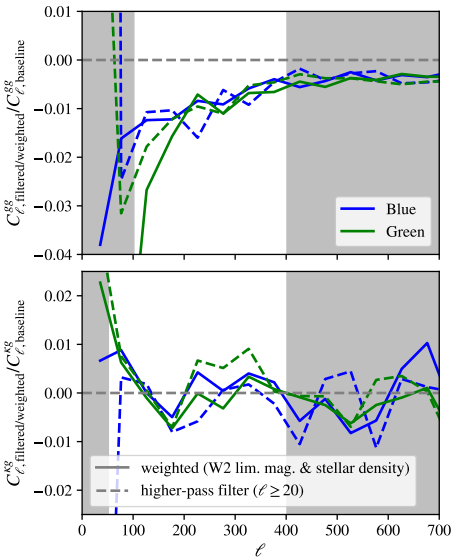
$$H_0 = 68.3 \pm 1.1\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$$

ACT DR6 Lensing + Pantheon (w/o r_s)

$$H_0 = 65 \pm 3.2\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$$

Mitigating systematic density fluctuations

- few percent effect on large scales in C_ℓ^{gg}
- difference to previous analysis $\sim$0.5% (used high pass-filter; $\ell \geq 20$)

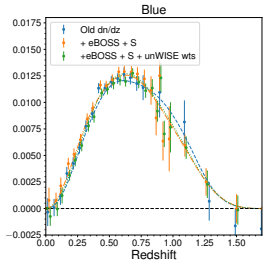


Spec.-z galaxy samples for redshift calibration

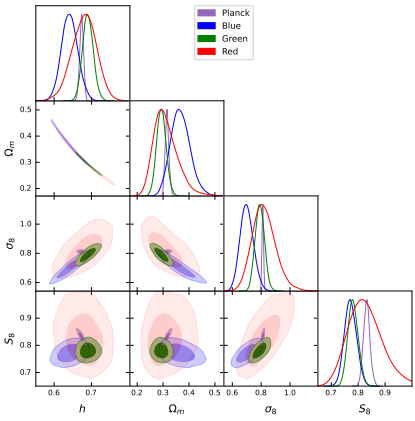
Spectroscopic samples cover the entire unWISE redshift range

- LRGs from LOWZ ($0 < z < 0.5$), CMASS ($0.4 < z < 0.8$), eBOSS (**new**; $0.6 < z < 1.0$)
- QSOs from eBOSS (**updated**; $0.8 < z < 2.2$); BOSS ($2 < z < 2.5$)

We also add spectroscopic data in the South Galactic Cap: $\sim$20% of BOSS/eBOSS area, but better overlap with ACT footprint

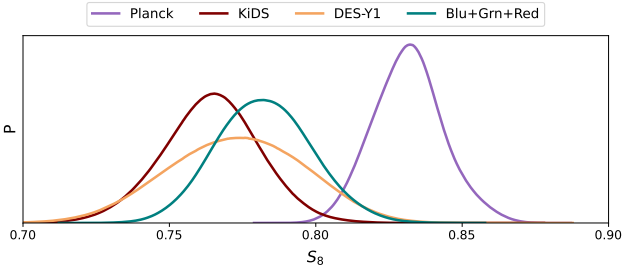


Previous work on Planck lensing x unWISE



Spectra: Krolewski *et al.* (2020)

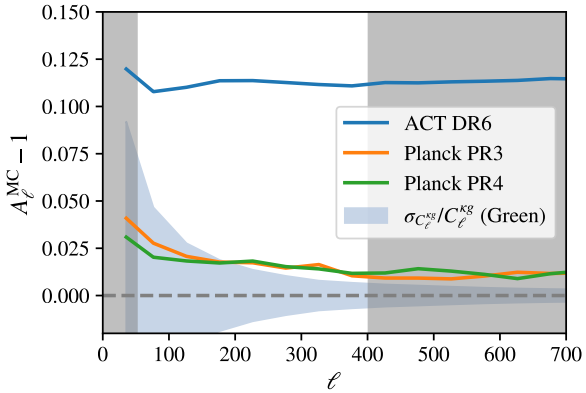
Cosmology analysis: Krolewski *et al.* (2021)



$$S_8 = 0.782 \pm 0.015$$

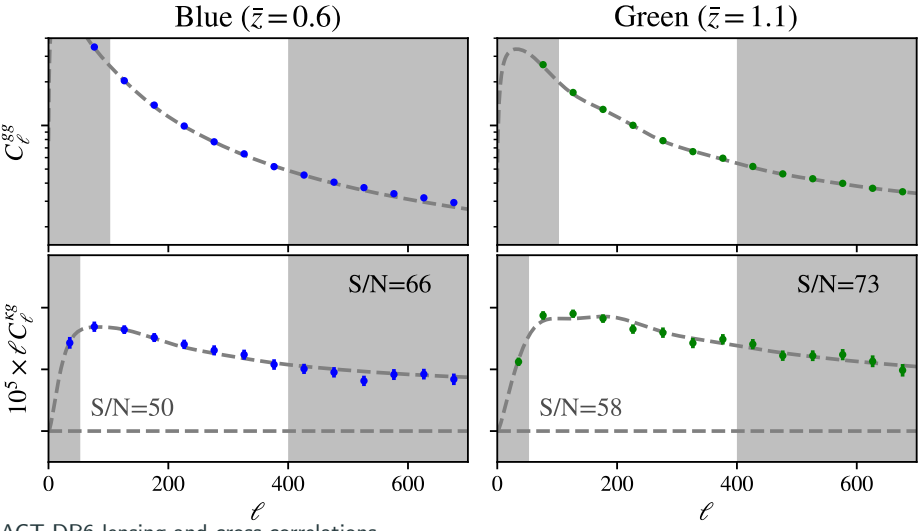
$$\implies \sim 2.4\sigma \text{ tension with Planck 2pt}$$

Reanalysing Planck Lensing × unWISE: MC norm correction



Lensing normalisation correction: $C_\ell^{\hat{\kappa}_{\rm MC} g} = C_\ell^{\hat{\kappa} g} A_\ell^{\rm MC}$

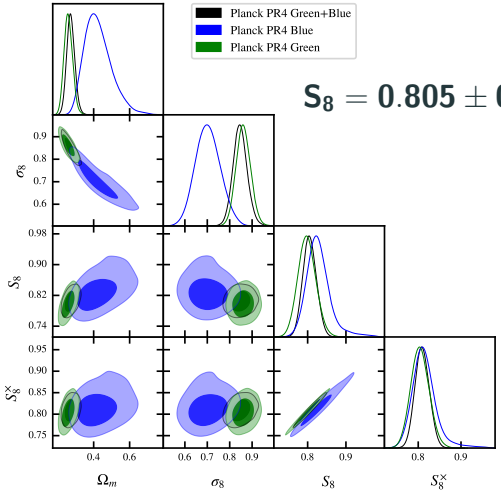
Reanalysing Planck Lensing × unWISE: Planck PR4 lensing

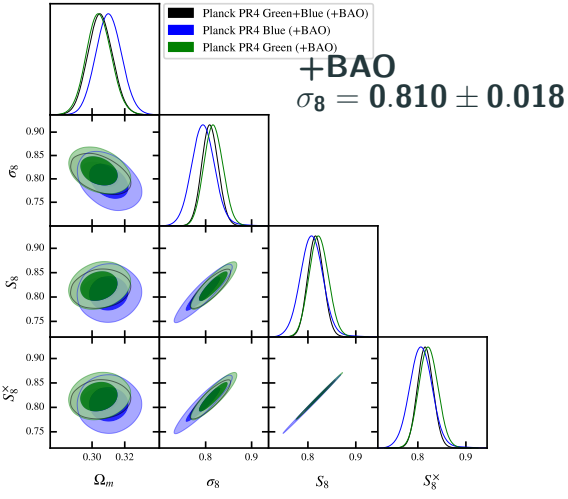


Reanalysing Planck Lensing × unWISE: summary of changes

	Impact on S_8
MC lensing norm correction	$+0.6\sigma$
modelling improvements	-0.5σ
Systematics weighting	$+0.4\sigma$
Additional spectroscopic data	$+0.8\sigma$
PR4 lensing reconstruction	$+0.2\sigma$
PCA dN/dz marginalisation	-0.2σ & $\sim$15% wider posteriors
fid. cosmo. correction	change in degeneracy directions
Total	$+\mathbf{1.3}\sigma$ & $\sim$**15% wider posteriors**

Reanalysing Planck Lensing × unWISE: Cosmology - corner plots





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