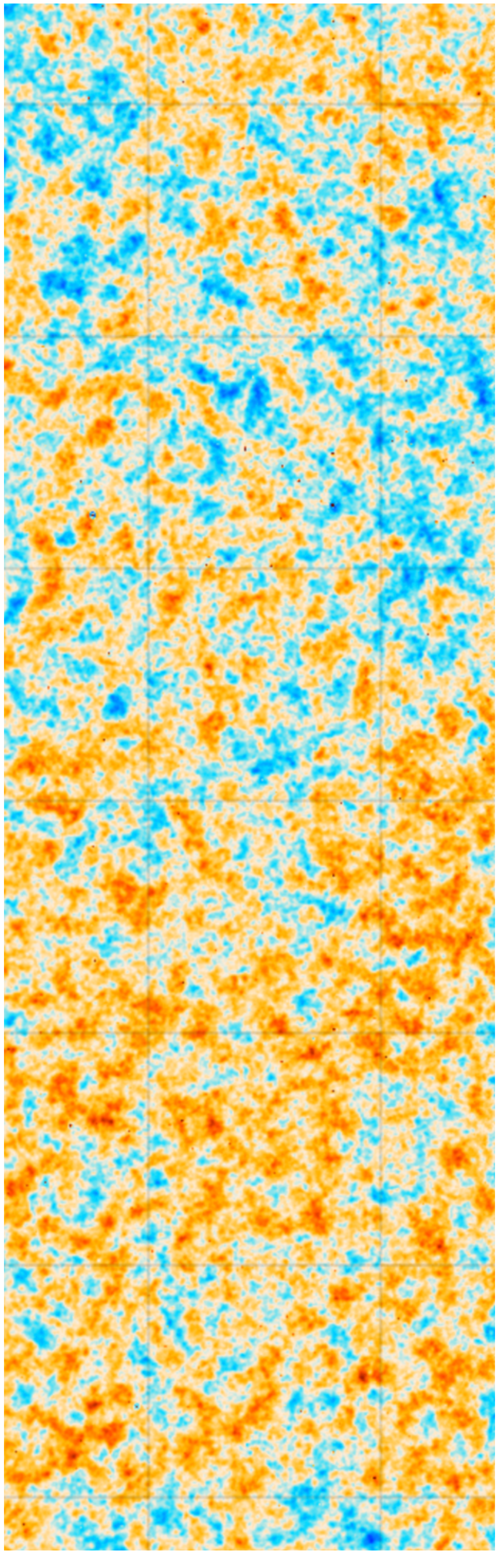
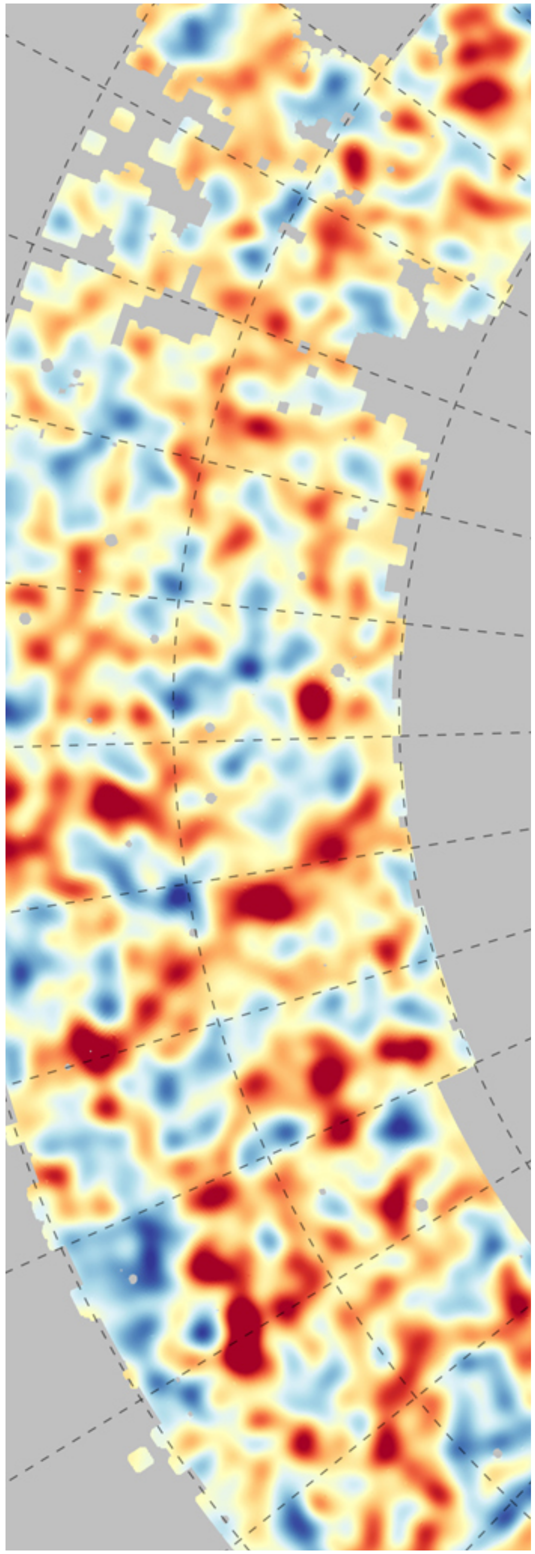


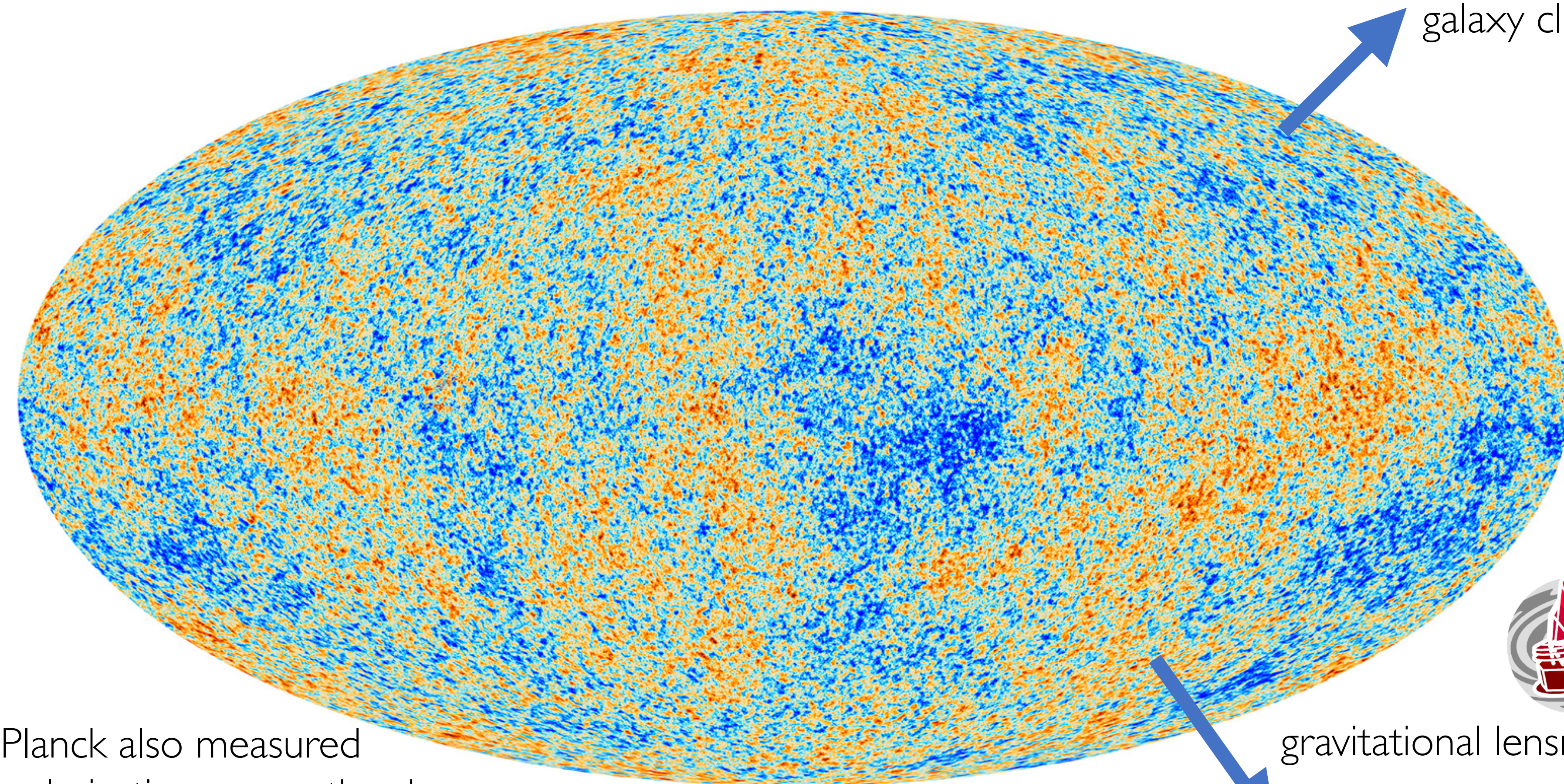


Synergy between next generation CMB and LSS probes of cosmology

Jo Dunkley
Princeton University

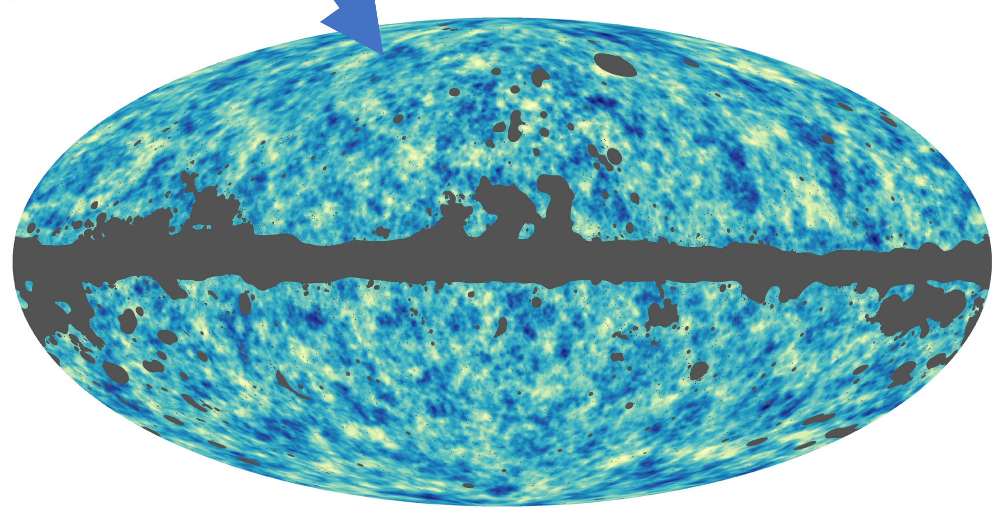
Current CMB

SZ effect: ~1000 galaxy clusters



Planck also measured polarization across the sky

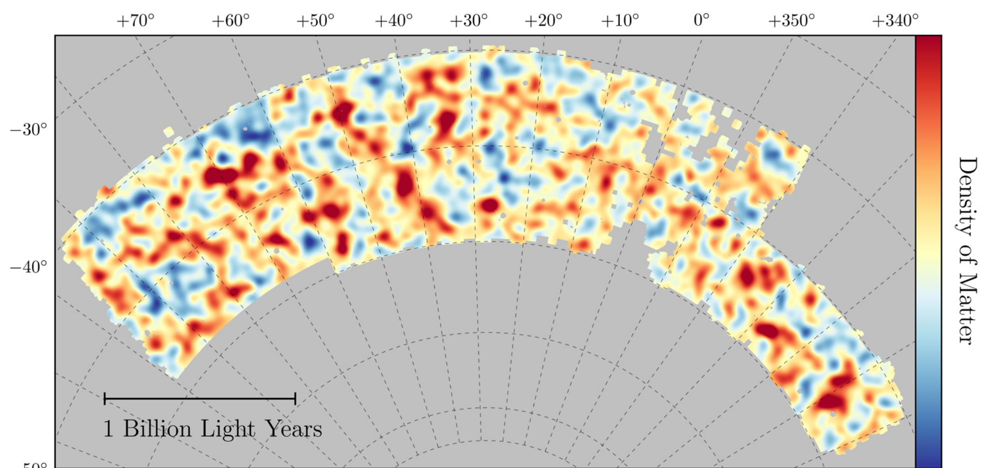
gravitational lensing



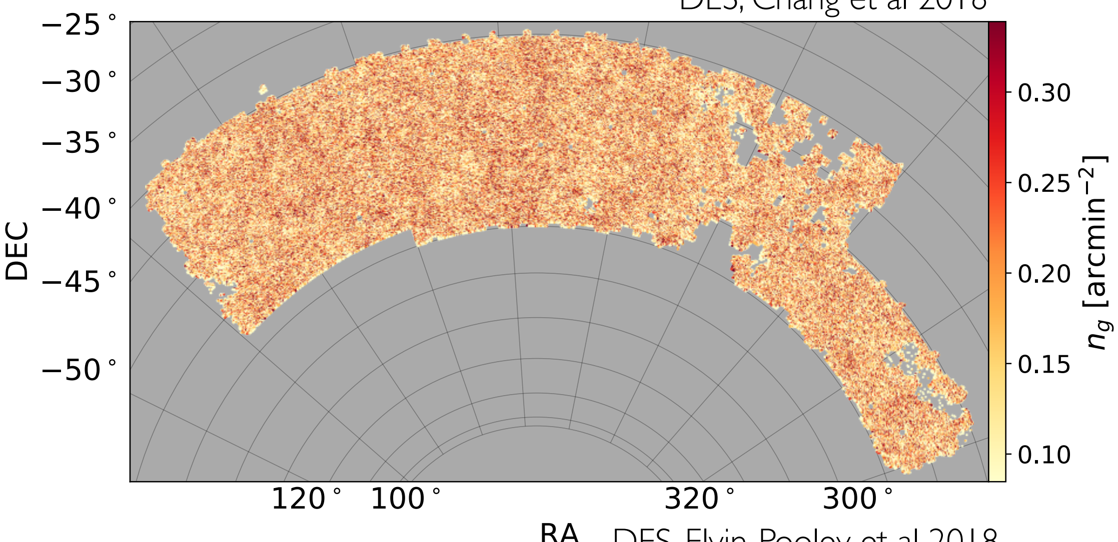
Much ground-based data too

(Some) current Large-Scale Structure

Photometric surveys:
HSC (1400 deg^2), KiDS (1400 deg^2), DES (5000 deg^2)
Map the density and lensing of galaxies

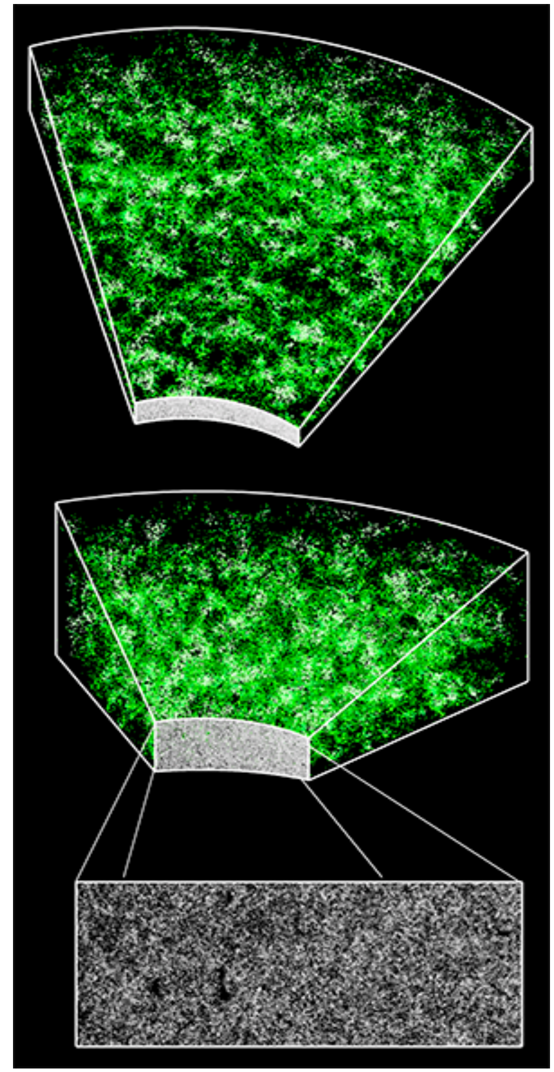


DES, Chang et al 2018



DES, Elvin-Pooley et al 2018

Spectroscopic: BOSS
Galaxy clustering, redshift-space distortions



Tinker for SDSS-III

plus 21cm, IR, X-ray…

What's coming in next decade?

CMB:

Ground-based from Chile and South Pole

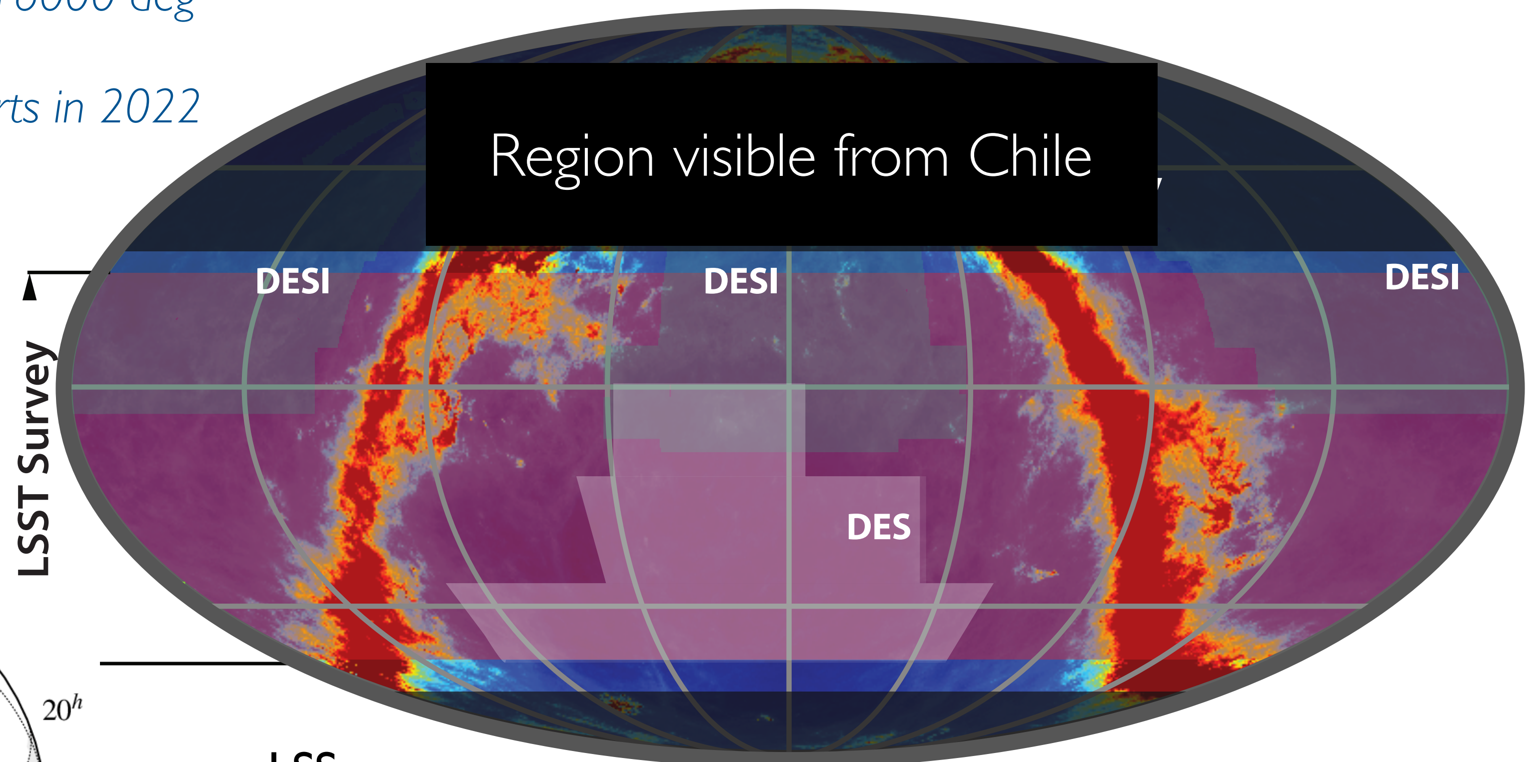
Higher resolution and sensitivity than Planck

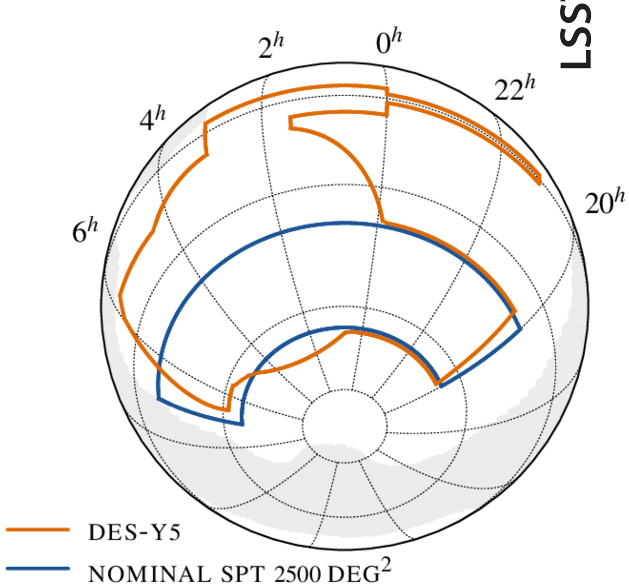
ACT: data thru 2021, ~16000 deg^2

SPT: ~ 2500 deg^2

Simons Observatory: starts in 2022

S4: late 2020s





LSS:

Deeper photo and spectro surveys

DESI ~2019-24

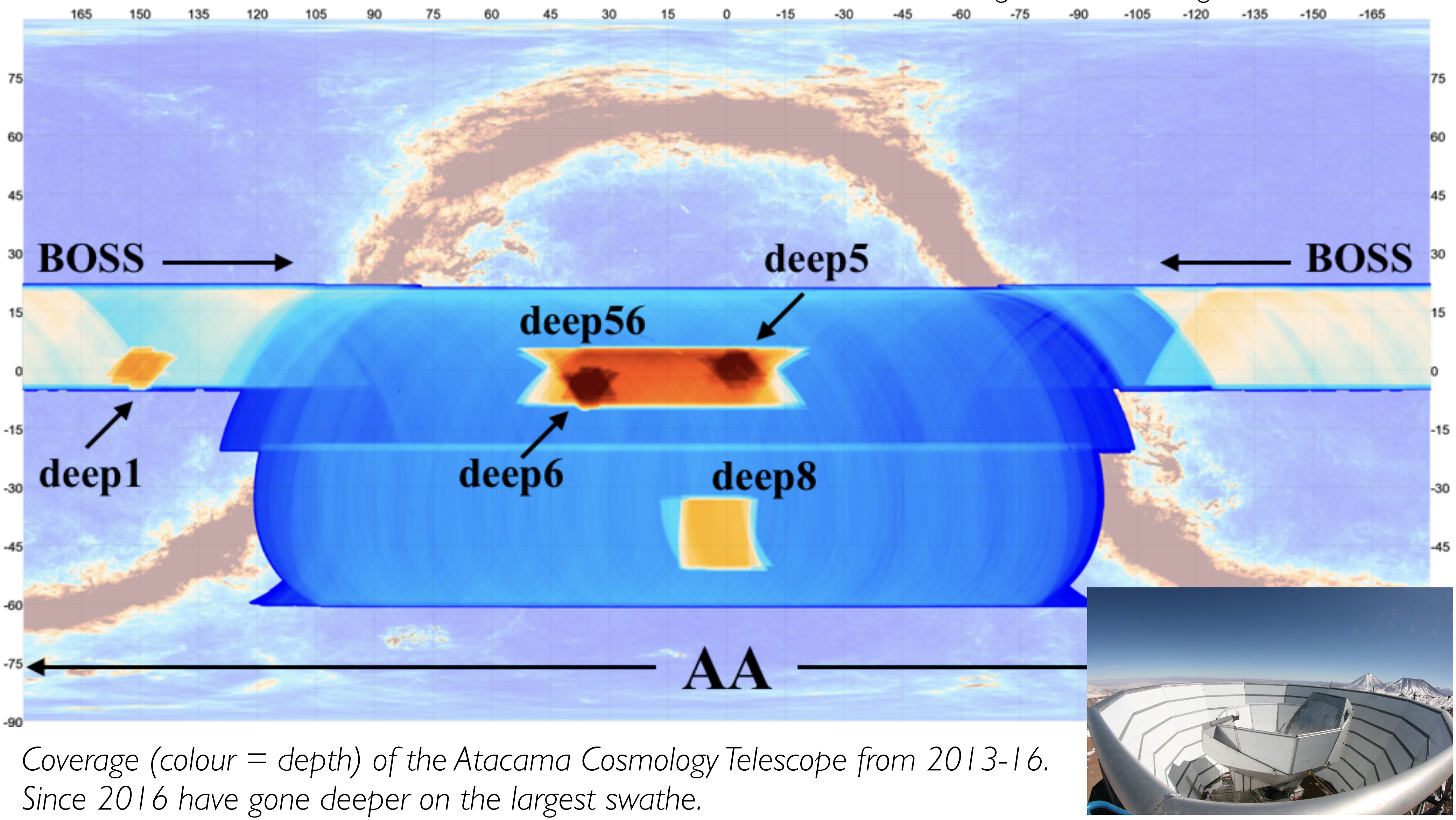
LSST ~2022-32

Euclid ~ 2022 launch

SPHEREx ~2023 launch, WFIRST launch ~2025, plus more

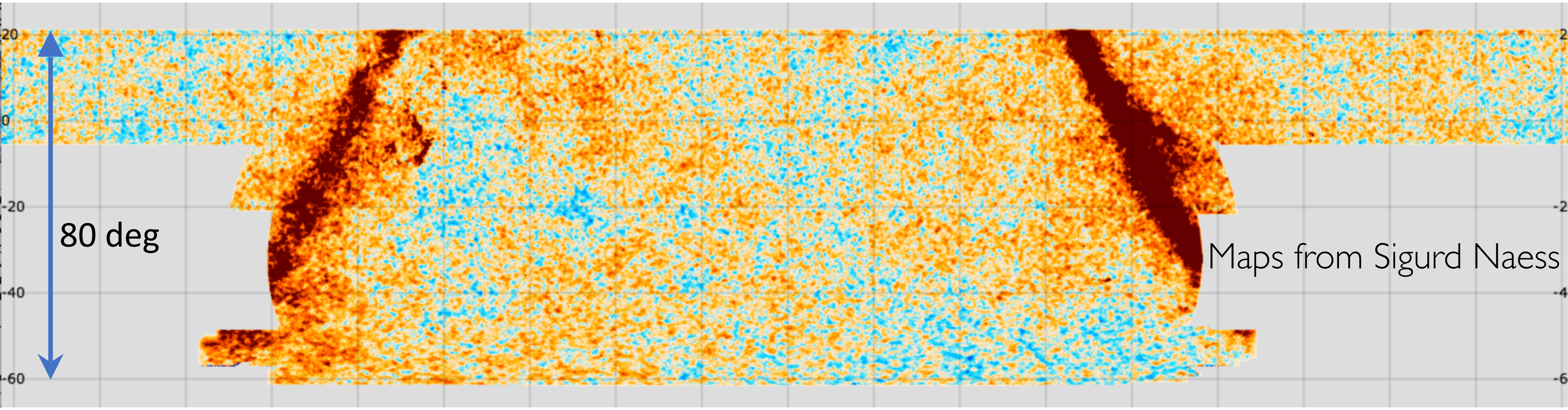
More area - in practice (CMB)

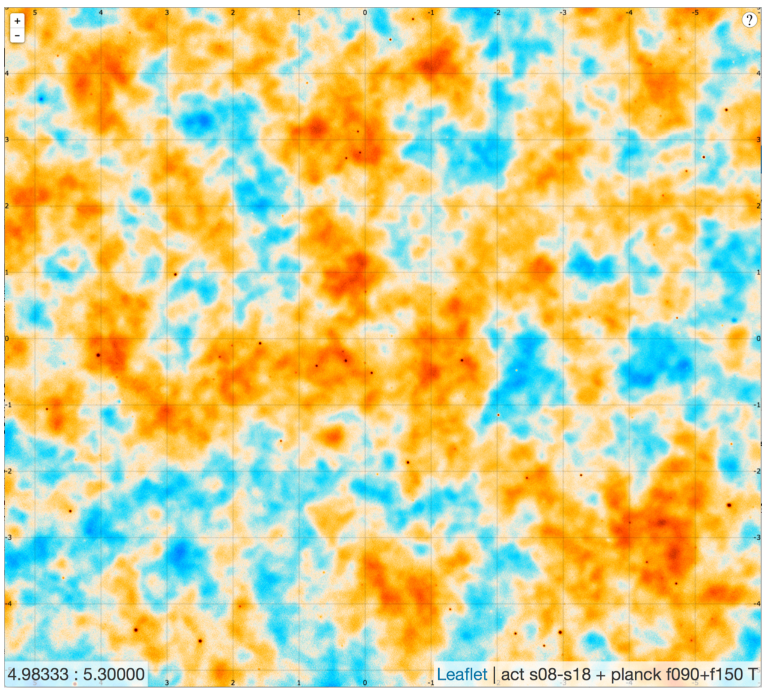
Fig: Simone Aiola, Sigurd Naess for ACT

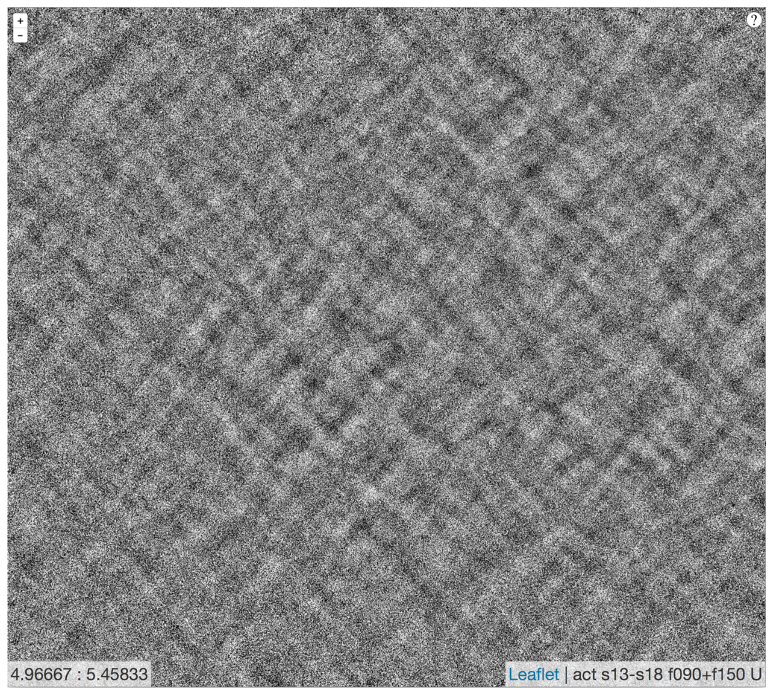


Coverage (colour = depth) of the Atacama Cosmology Telescope from 2013-16.
Since 2016 have gone deeper on the largest swathe.

Map of CMB from ACT+Planck (preliminary)







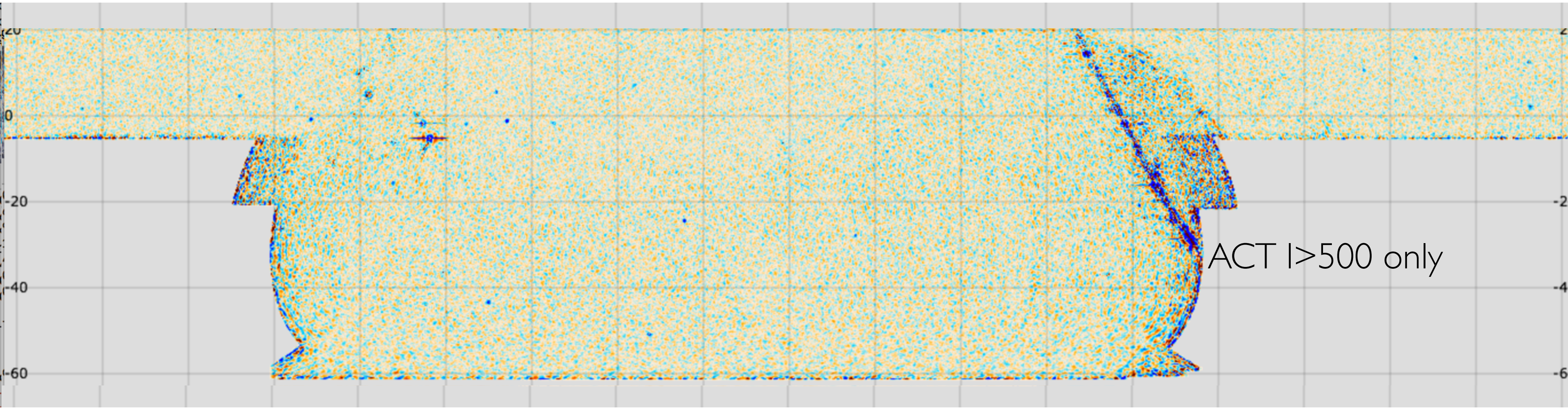
T ~20,000 deg^2

Aiola et al in prep
Naess et al in prep

100 deg^2 Intensity zoom

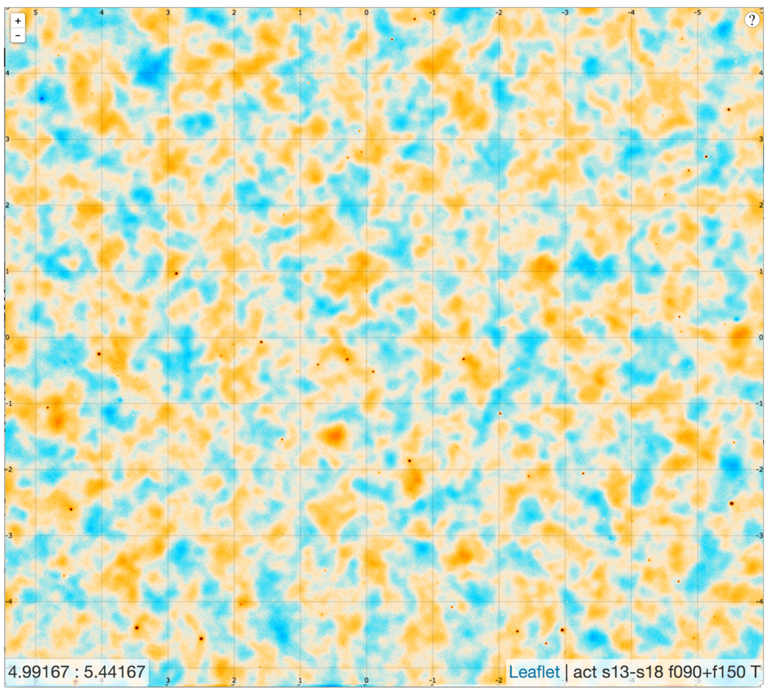
100 deg^2 polarization (U) zoom

Map of CMB from ACT+Planck (preliminary)

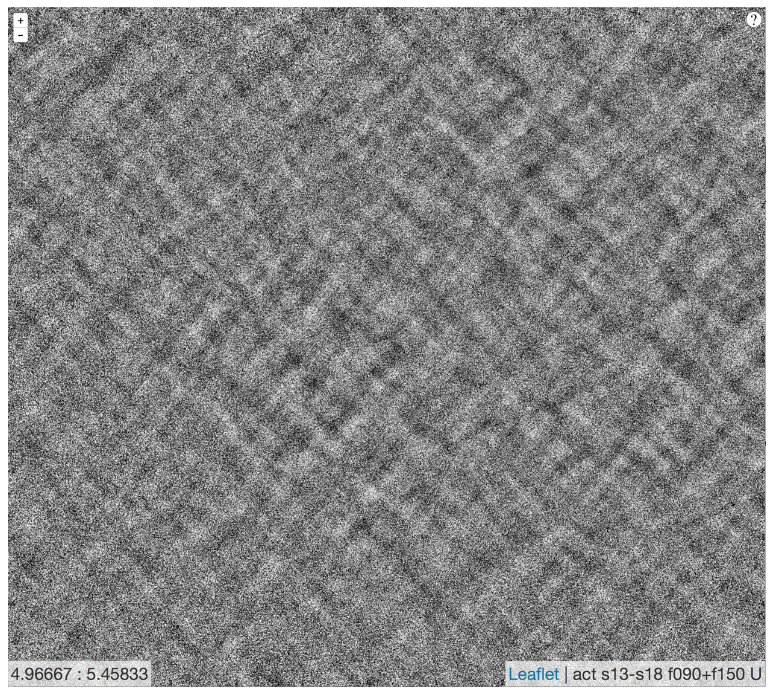


T ~20,000 deg²

Aiola et al in prep
Naess et al in prep



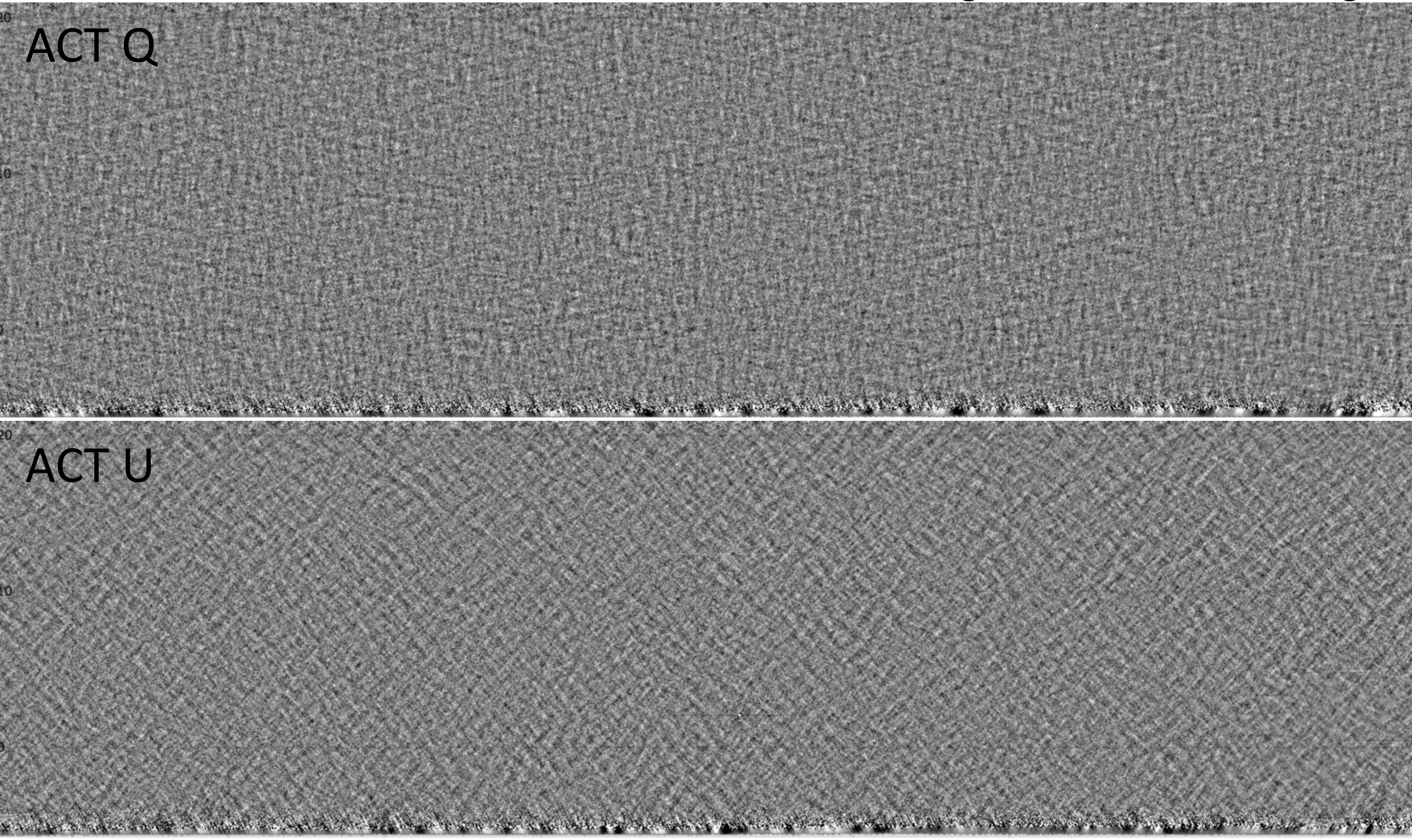
100 deg² Intensity zoom



100 deg² polarization (U) zoom

Polarization of the CMB from ACT (preliminary)

2200 deg^2 zoom in 'BOSS-N' region



PRELIMINARY **~25 x 85 deg**

RA=180

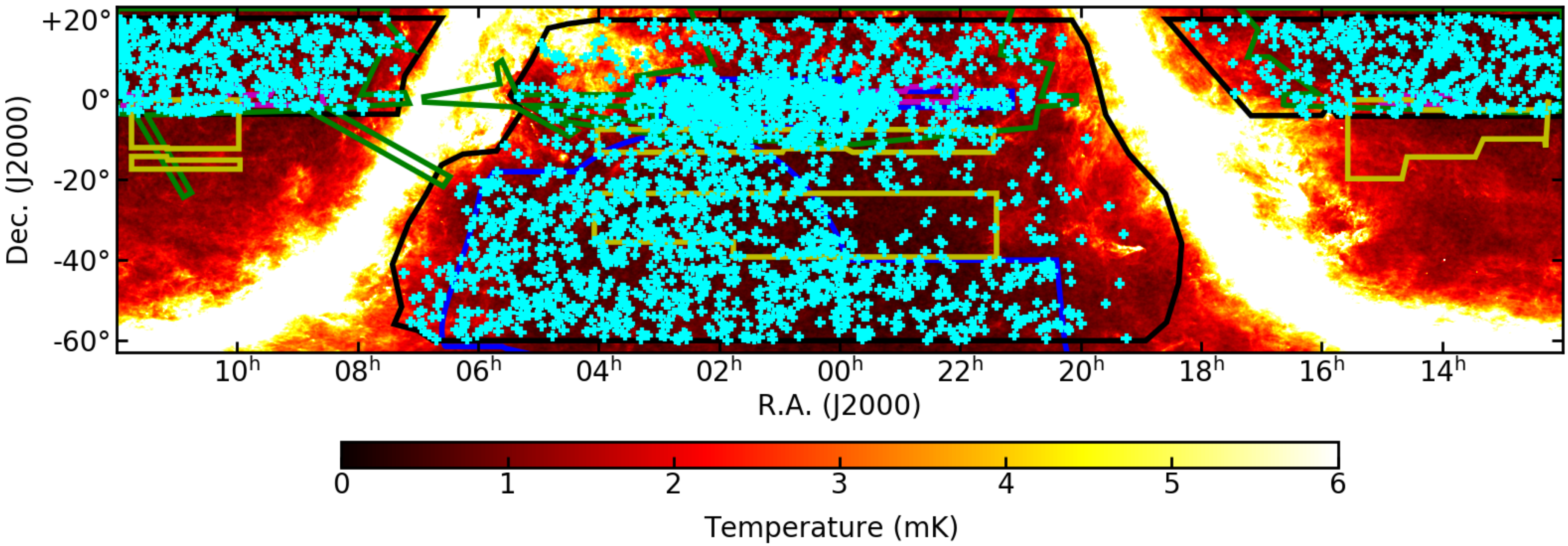
90+150 GHz

Aiola et al in prep

The field is moving: SZ clusters

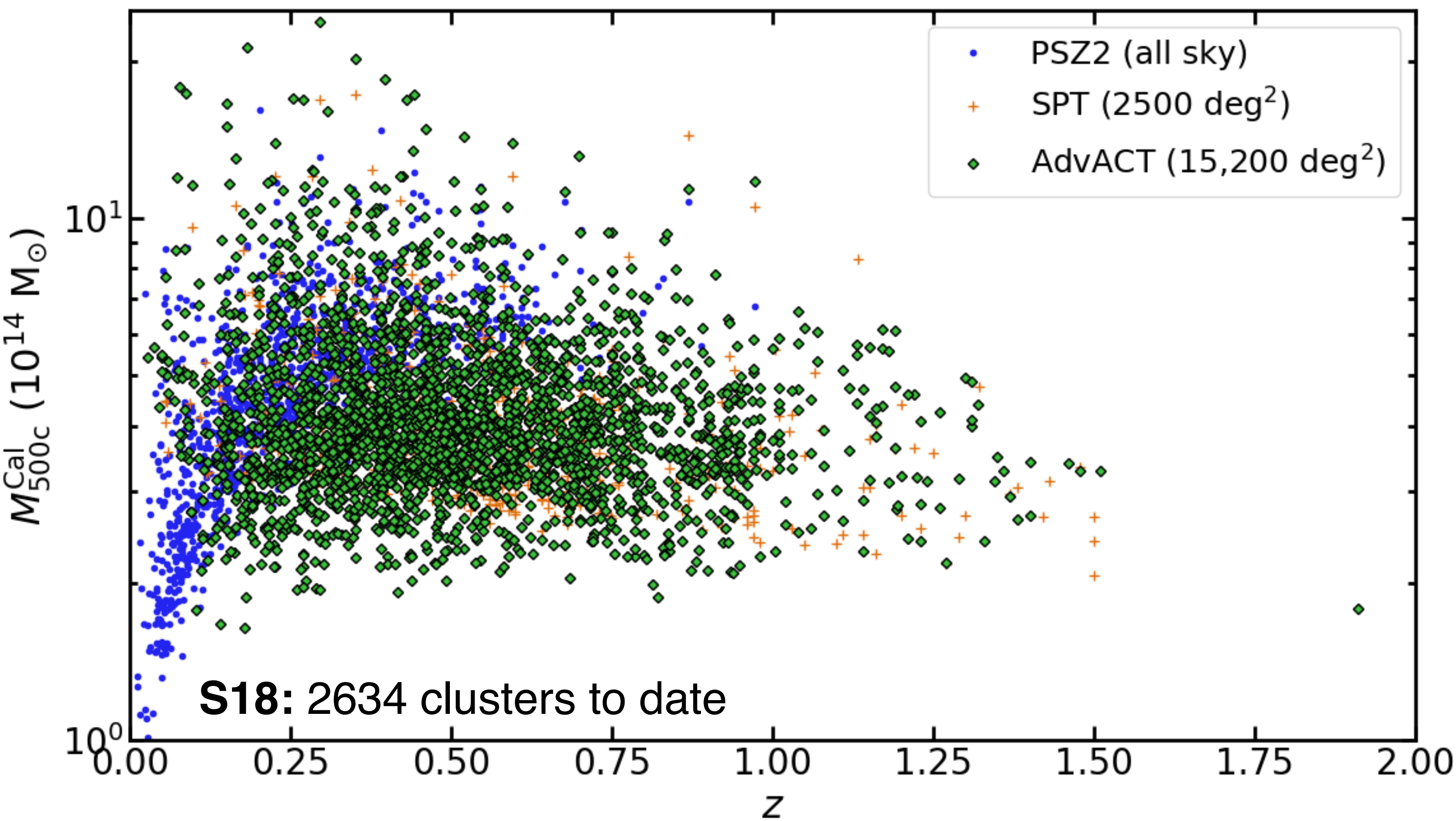
- Find clusters through thermal Sunyaev Zel'dovich effect: hot electrons
- Atacama Cosmology Telescope data taken through 2018 (at 90, 150 GHz)
- **2634** confirmed clusters with redshifts to date. *Also see SPT talk.*

Preliminary, from Matt Hilton for ACT



Black *= cluster search area; Pink = HSC (s18a); Blue = DES; Green = SDSS; Yellow = ESO/VST*

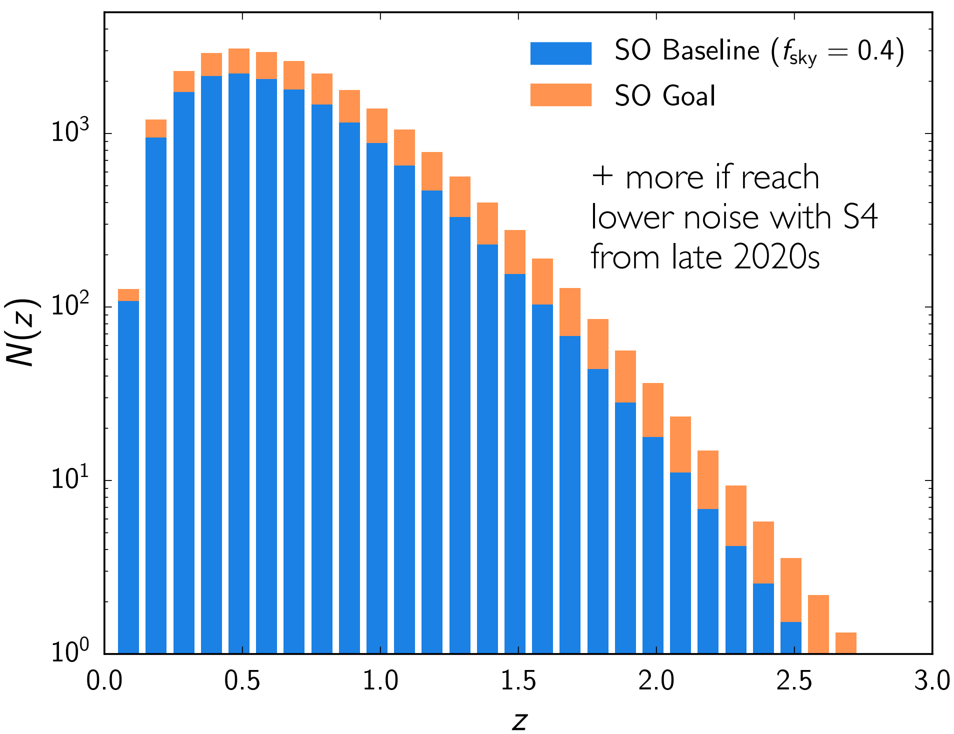
A larger SZ cluster sample than ever before



Preliminary, from Matt Hilton for Atacama Cosmology Telescope

(1) Weighing SZ clusters using weak lensing

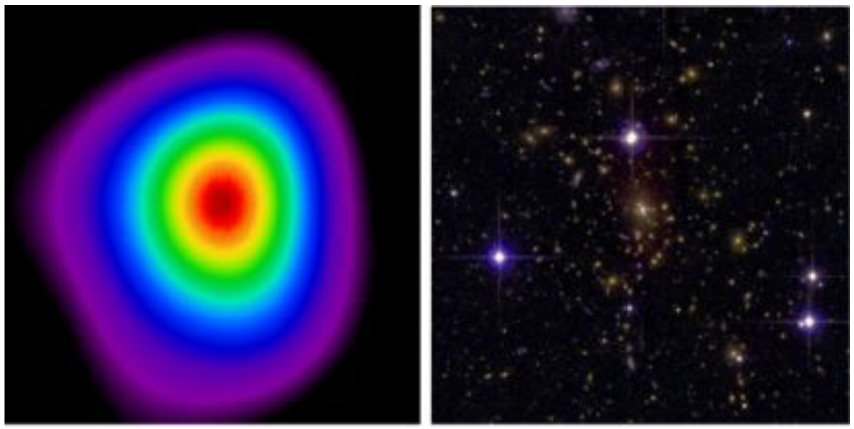
~20k SZ clusters coming from SO!



Higher neutrino mass —> fewer massive clusters

CMB needs optical data: calibrate masses

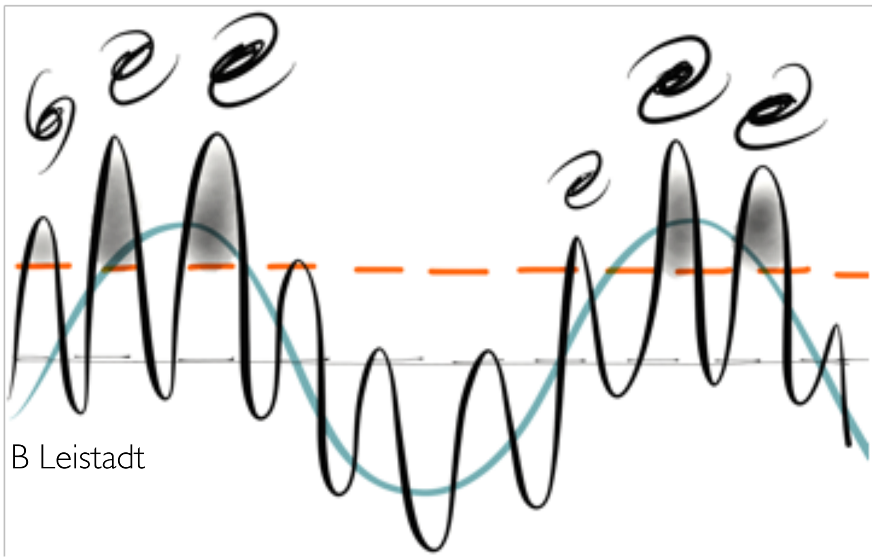
Planck/ACT w HSC - Miyatake et al 2018
ACT w KiDS - Robertson et al in prep, 20σ
SPT w Magellan/HST - Boquet et al 2019

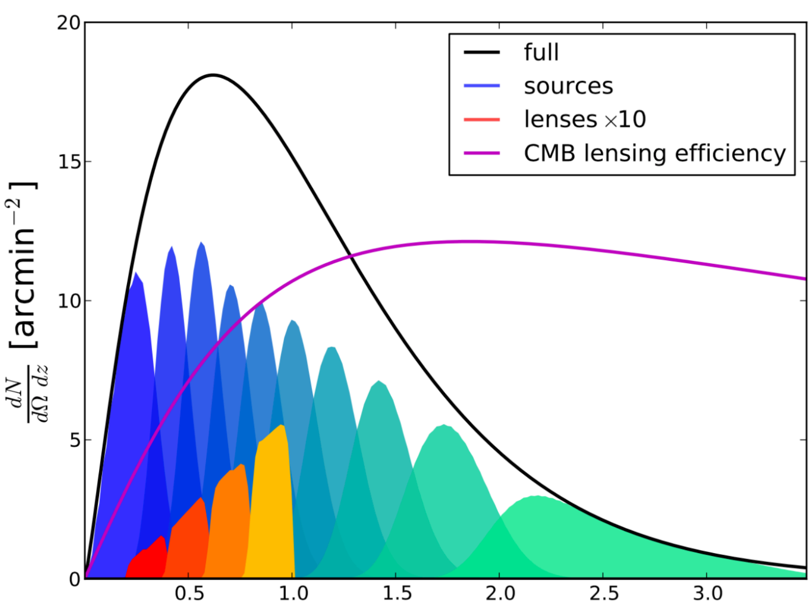


SO+LSST: measure neutrino mass sum
$\sigma(\Sigma M_\nu)$ = 0.03 eV, and σ_8 to 2% at z=1-2
(SO Collaboration 2019)

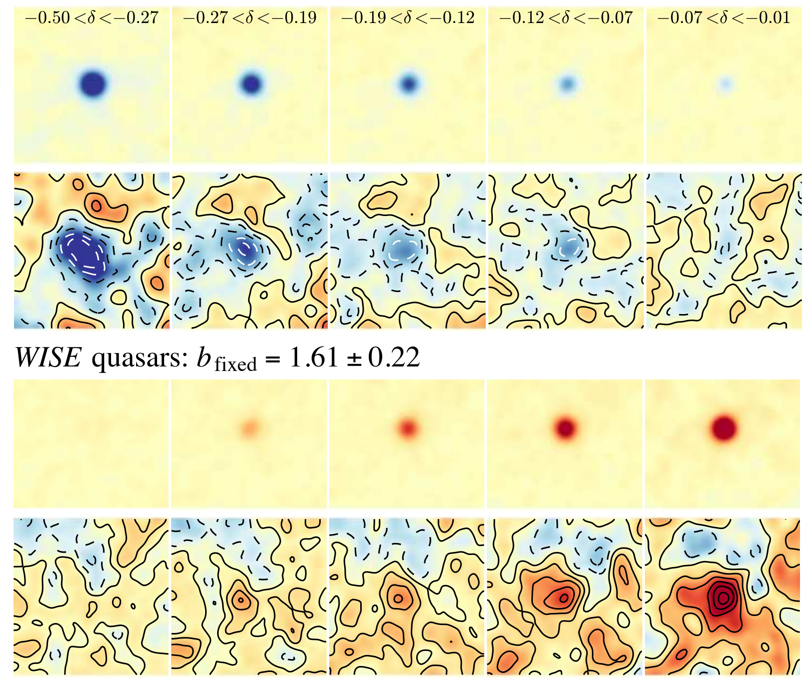
Dark energy above z=1
Neutrino mass
(also galaxy evolution)

(2) Tracing matter with CMB lensing and galaxy densities





Schaan et al 2016



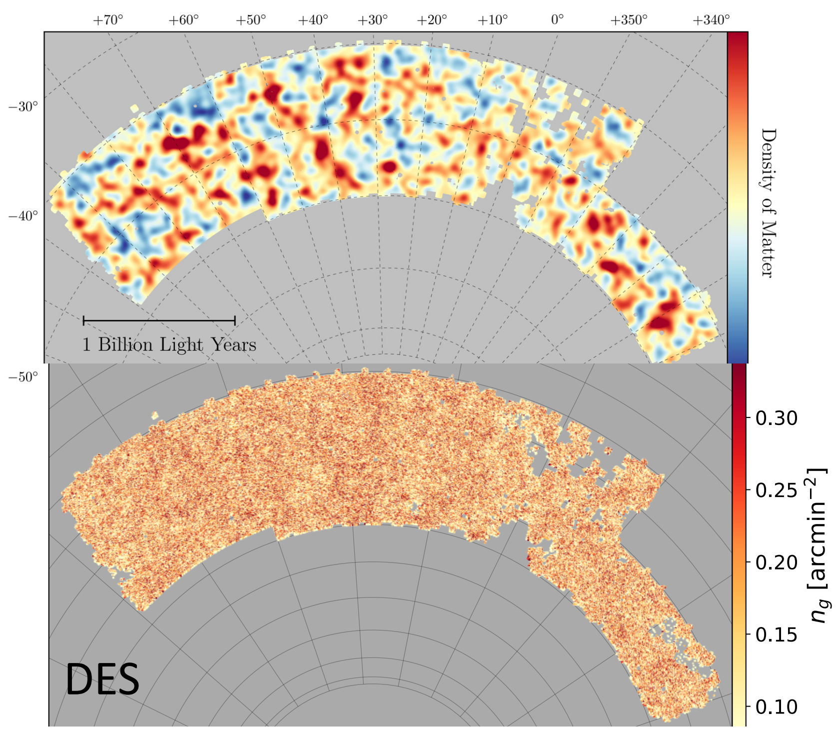
SPTPol, Geach et al 2013

Non-Gaussian fluctuations predict a scale-dependent bias at large scales.
Measure f_{NL} to $\sigma \sim 1$ from SO x LSST (*Schmittfull & Seljak 2018*).

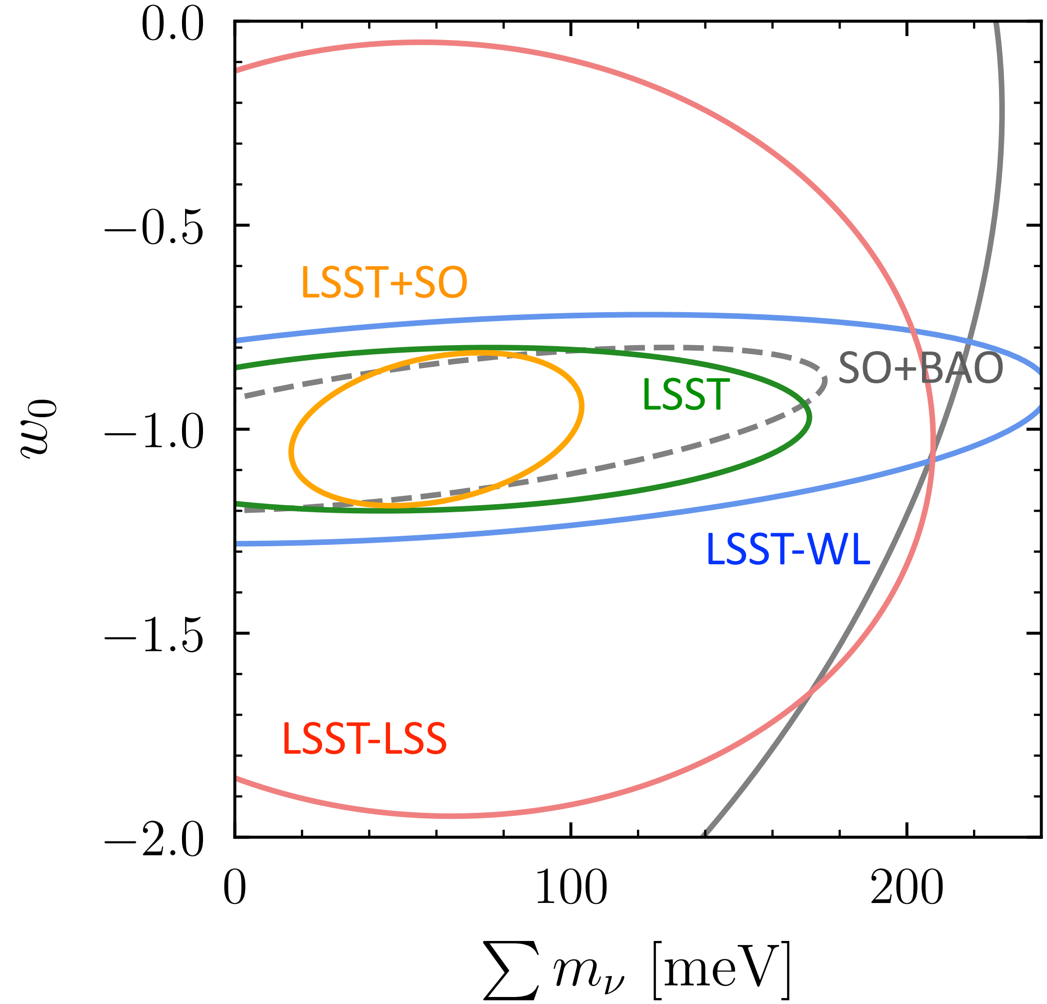
galaxy bias
f_{NL}
dark energy above z=1
neutrino mass

(3) … and including galaxy lensing too

Galaxy lensing and density maps in redshift bins, correlated with CMB lensing
e.g. Abbott et al 2018 for DES/SPT.



Mishra-Sharma et al 2018



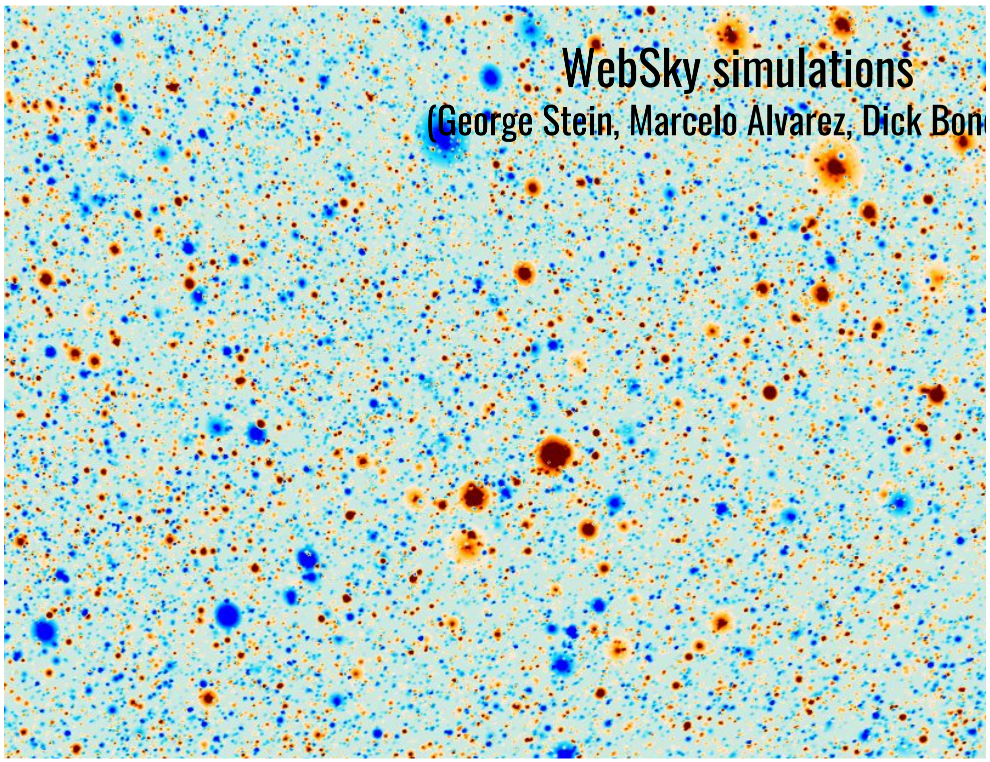
With multiple redshifts and probes can disentangle neutrino mass, w and curvature.

and constrain biases, intrinsic alignment, photo-z uncertainty

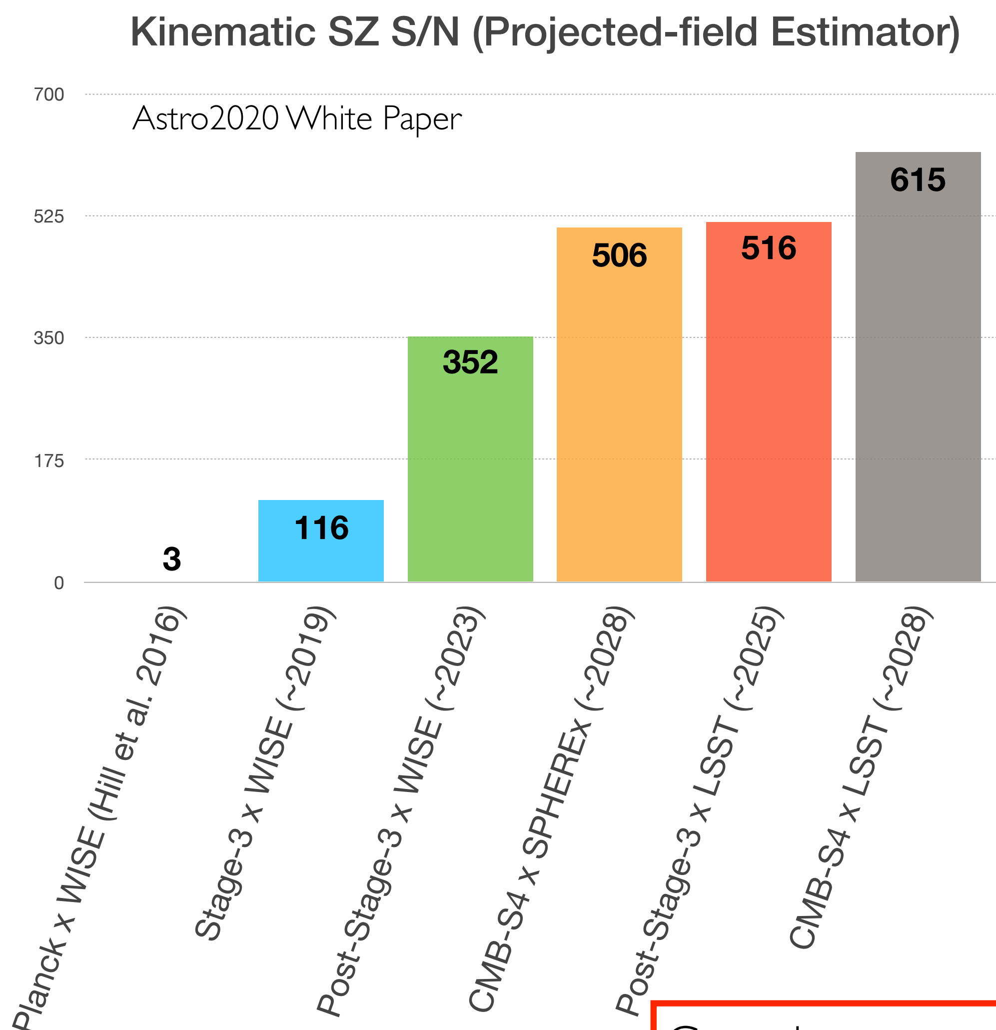
Increased confidence in w
Disentangling neutrino mass, dark energy, curvature

(4) Measuring the motion of electrons (kinetic SZ) located using a galaxy survey

Motion of electrons —> Doppler shift of CMB.

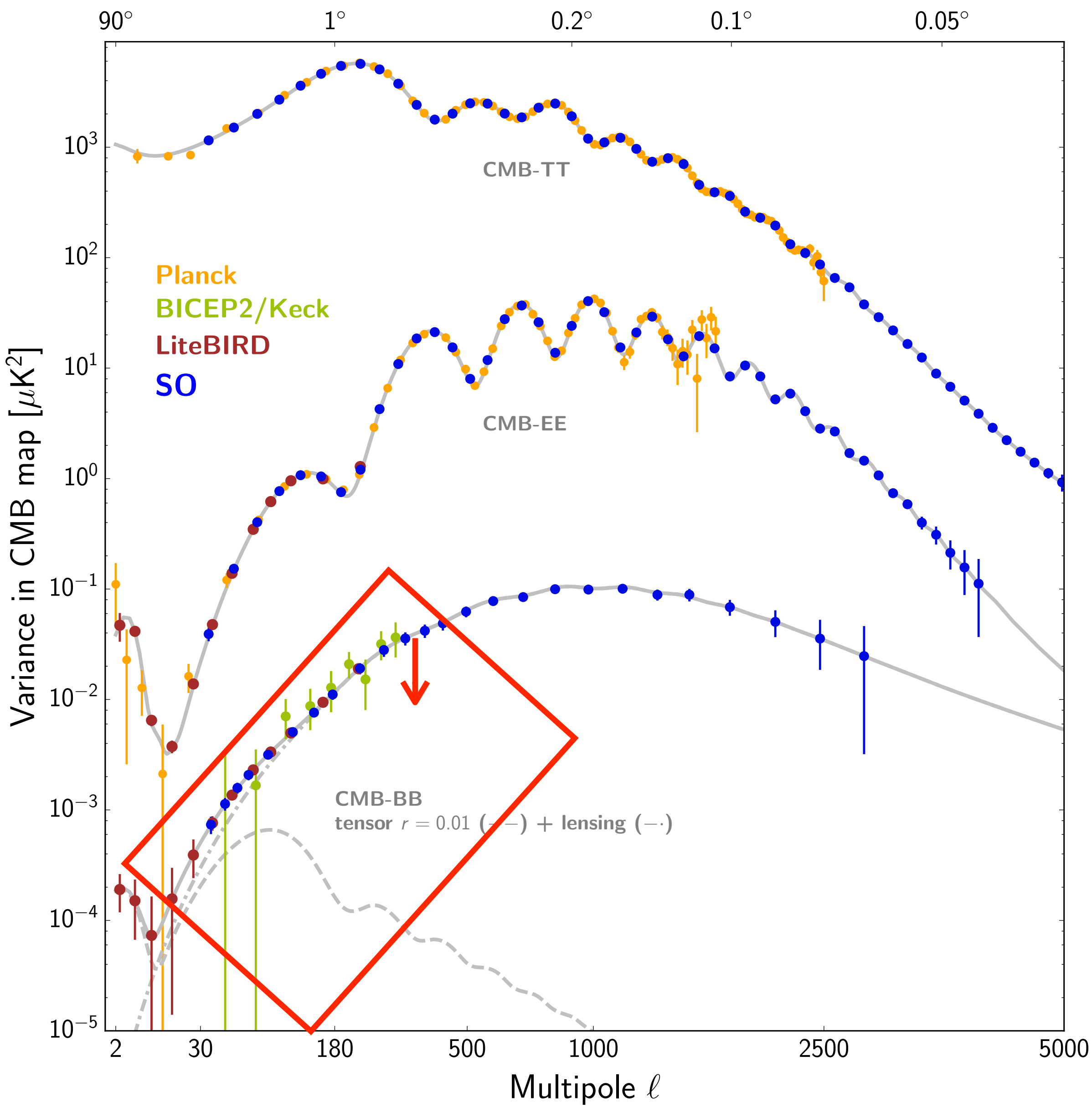


SO x DESI forecast to constrain growth rate to 10% *(Victoria Calafut for SO Collab 2019).*



Growth rate
f_{NL}
Finding the baryons

(5) 'Delensing' of CMB B-mode polarization



SO APC White Paper 2019, figure: E Calabrese

A key goal: measure 'r'.

CMB lensing contaminates: SO needs to remove ~50% of lensing power.

'External' delensing combines CIB, WISE, LSST clustering to make a template lensing map.

Could remove up to 70% of lensing power (see work by Baleato, Namikawa ++) - important for $\sigma(r)$*~0.001 regime.*

$\boxed{\text{tensor-to-scalar ratio}}$

CMB and LSS: we are better together!
But these are all joint analyses, so need commonality in:

Simulations
Data formats
Theory codes
Likelihoods

For this science, new **CMB maps** in coming decade will cover half the sky, and come from ground-based data combined with Planck.

LSS surveys in coming decade: LSST, DESI, Euclid, SPHEREx, WFIRST, eROSITA plus radio and more.

Using data together will improve constraints on **dark energy, neutrino mass, spatial curvature, f_{NL}, tensor-to-scalar ratio**

and probably more importantly, will give confidence that systematic errors are not driving our cosmology.