Cosmology from SKA Observatory precursors

Jacobo Asorey
Universidad Complutense de Madrid

In collaboration with:
Benedict Bahr-Kalus (KASI), Stefano Camera (UoT), Catherine Hale (ROE), David Parkinson (KASI), Ignacio Sevilla-Noarbe (Ciemat), Fei Qin (KASI) and members of the EMU and RACS collaborations

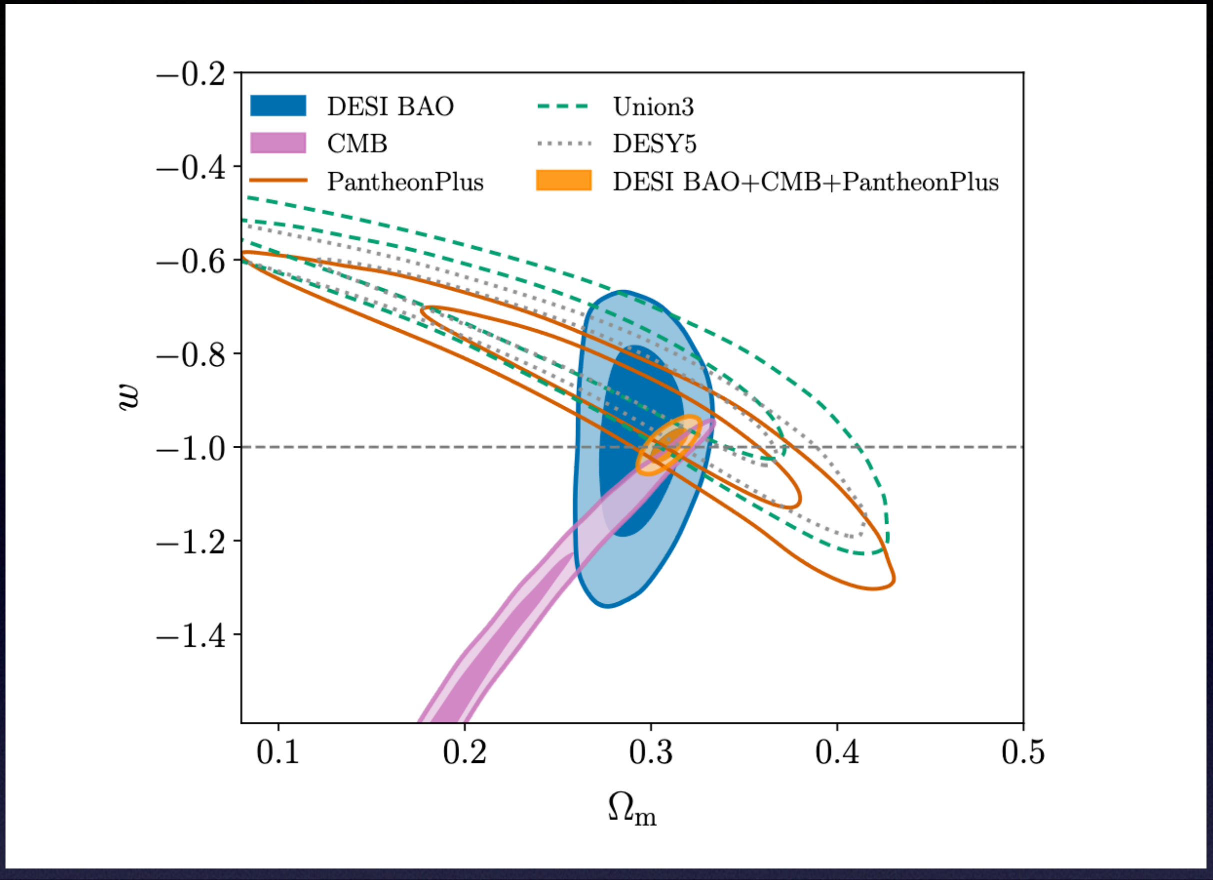
B. Bahr-Kalus, D. Parkinson D., JA, S. Camera, C. Hale, F. Qin, 2022, MNRAS

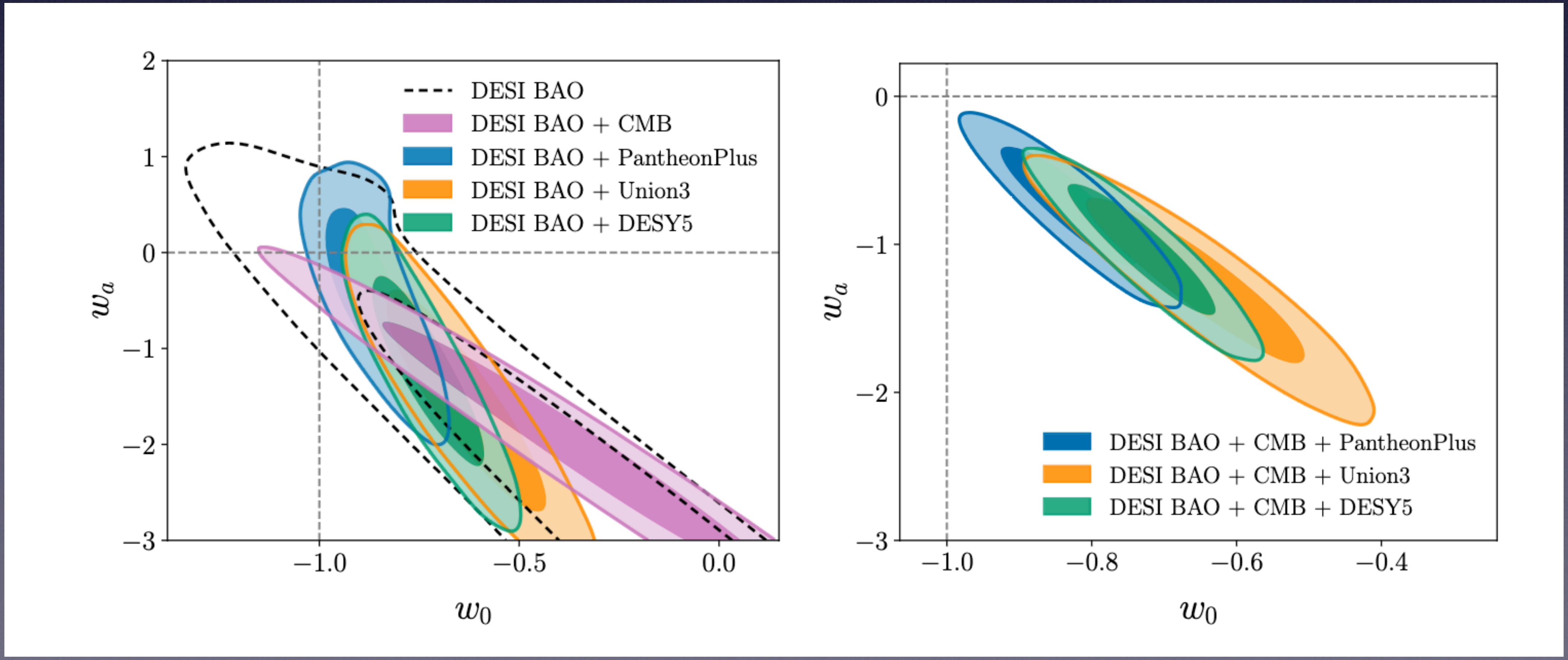
1ª Reunión Nacional Planes Complementarios de Astrofísica y Altas Energías

GOBIERNO DE ESPAÑA
MINISTERIO DE UNIVERSIDADES
Plan de Recuperación, Transformación y Resiliencia
Financiado por la Unión Europea
NextGenerationEU

Universidad de Zaragoza, 6/6/2024

Λ or not Λ?

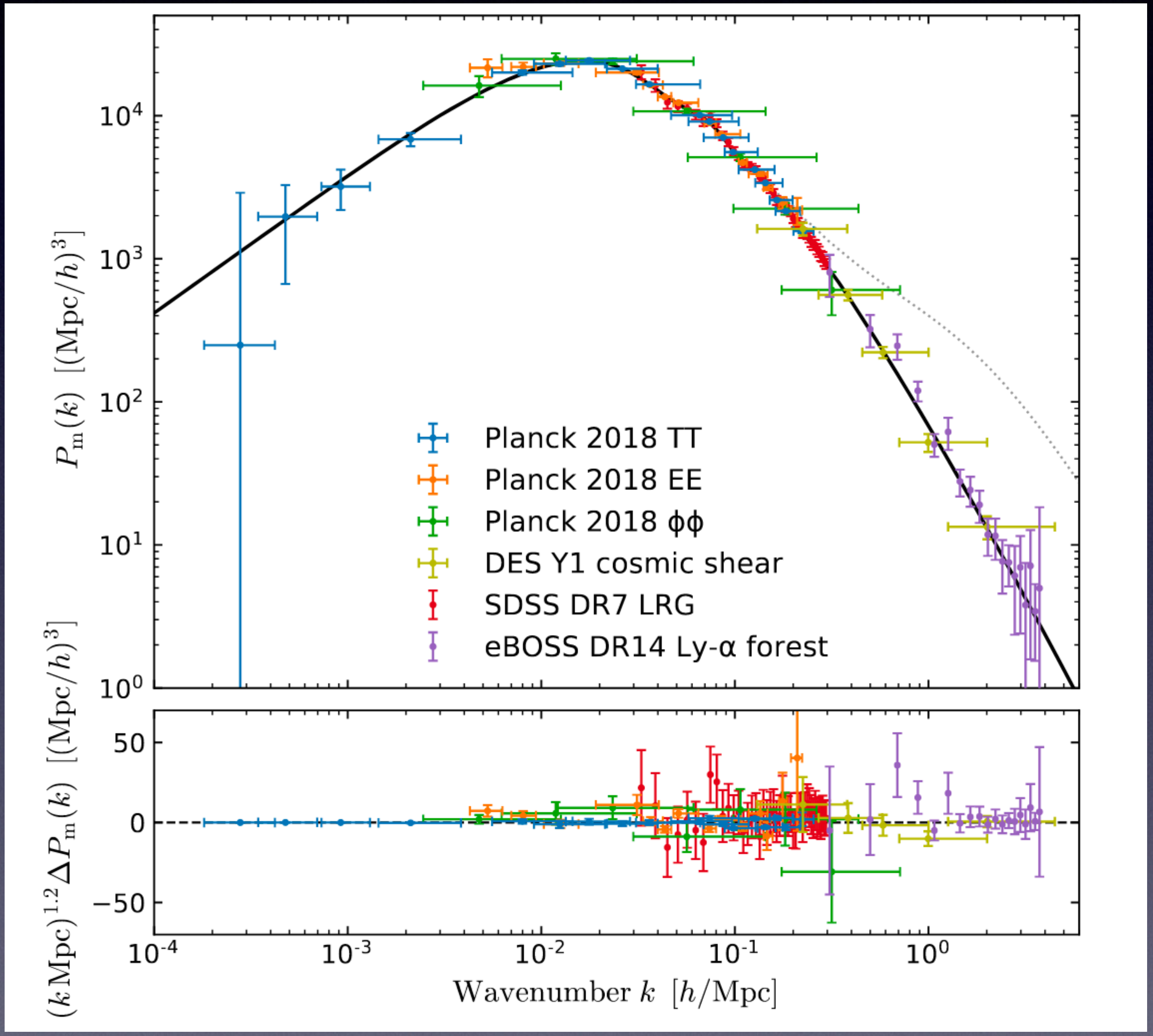




DESI Collaboration: 2404.03002

Large-scale structure

- Universe filled with density fluctuations
- Structure only only visible through galaxies (distribution) and photons (weak lensing)
- Galaxies and photons here are functioning as test particles - tracing out the gravitational field
- Most low-redshift surveys have measured the transfer function.
- Need very large volumes to measure primordial power spectrum and determine initial conditions (independently from CMB)



Chabanier et al., 2019

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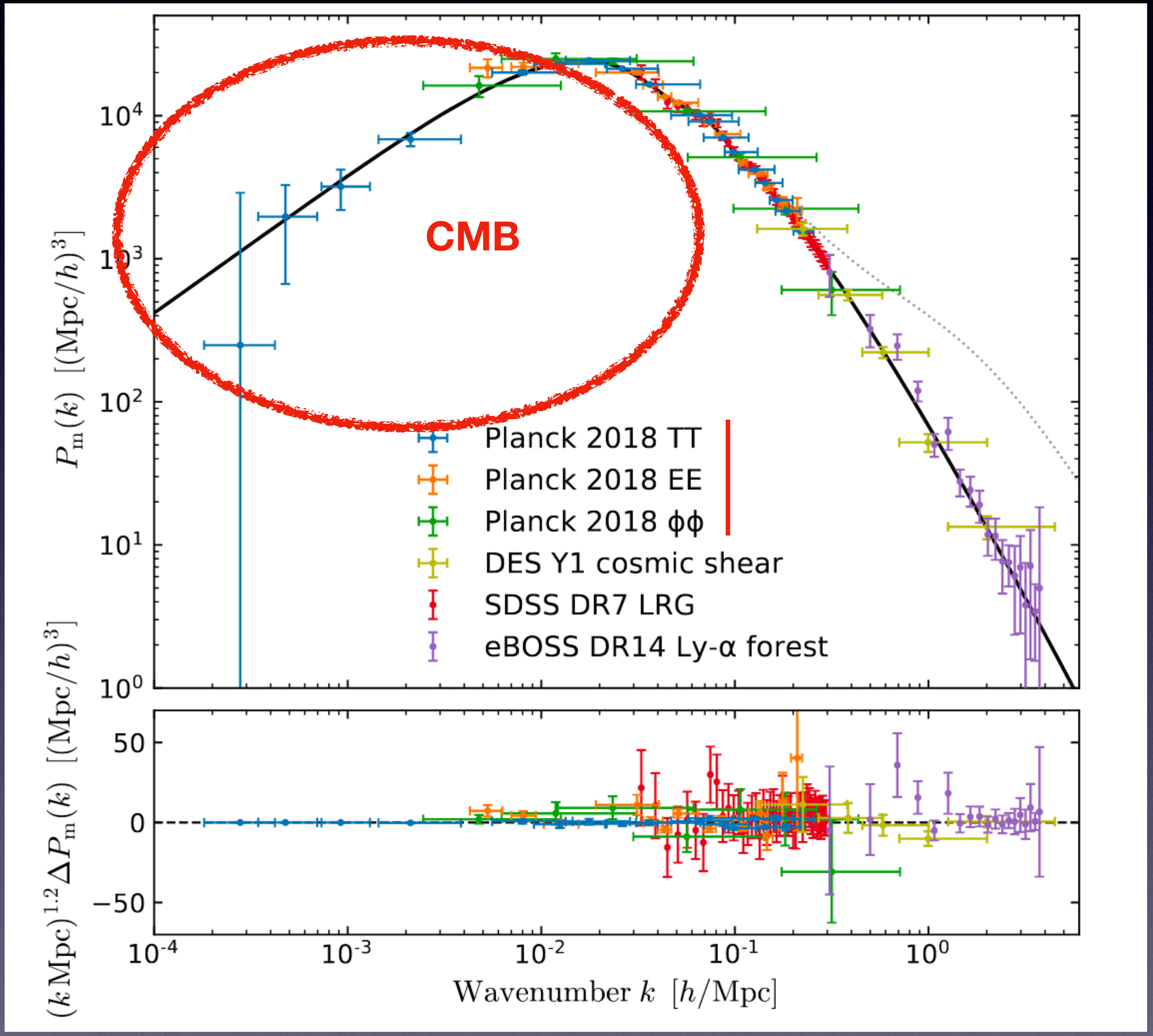

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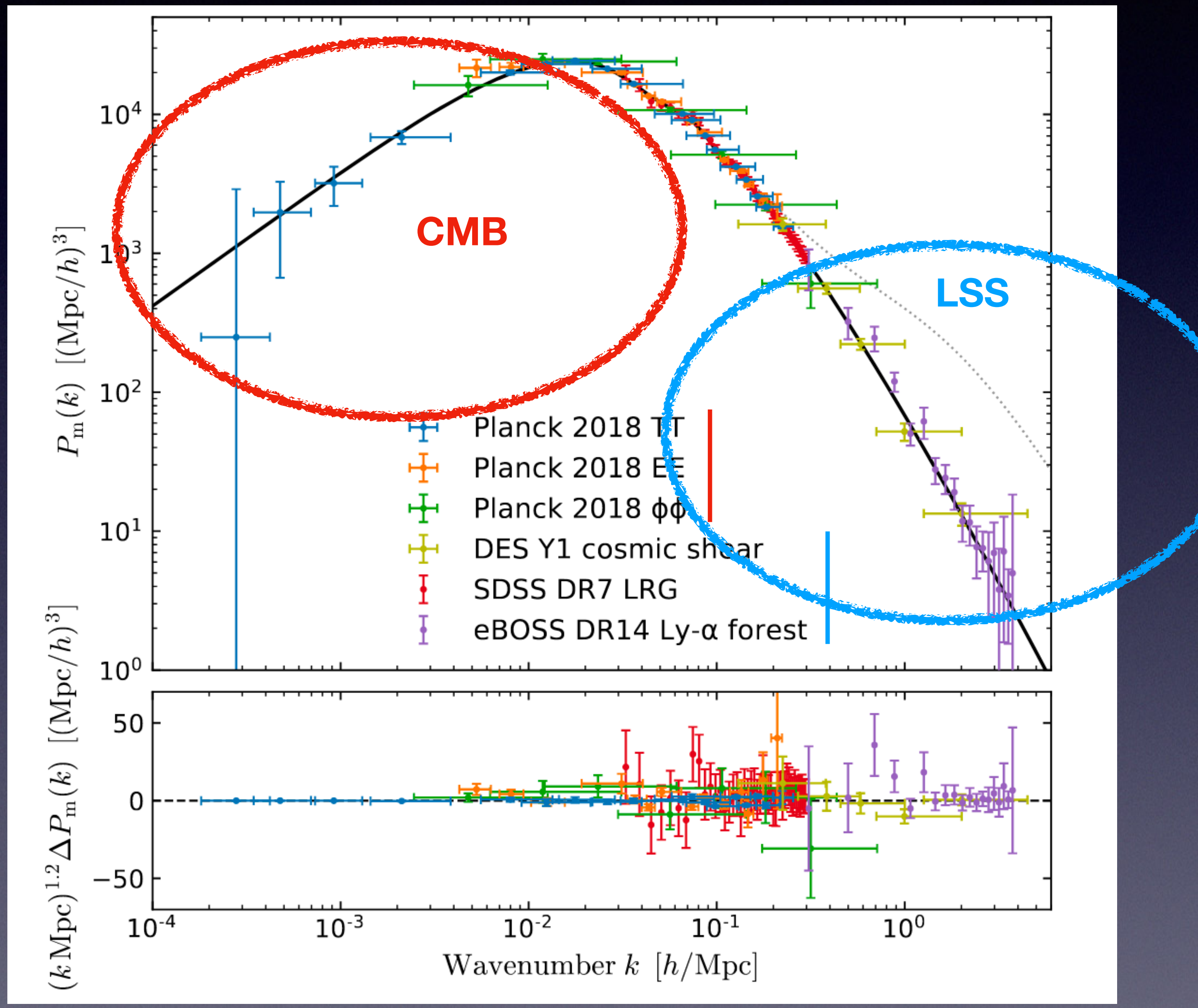
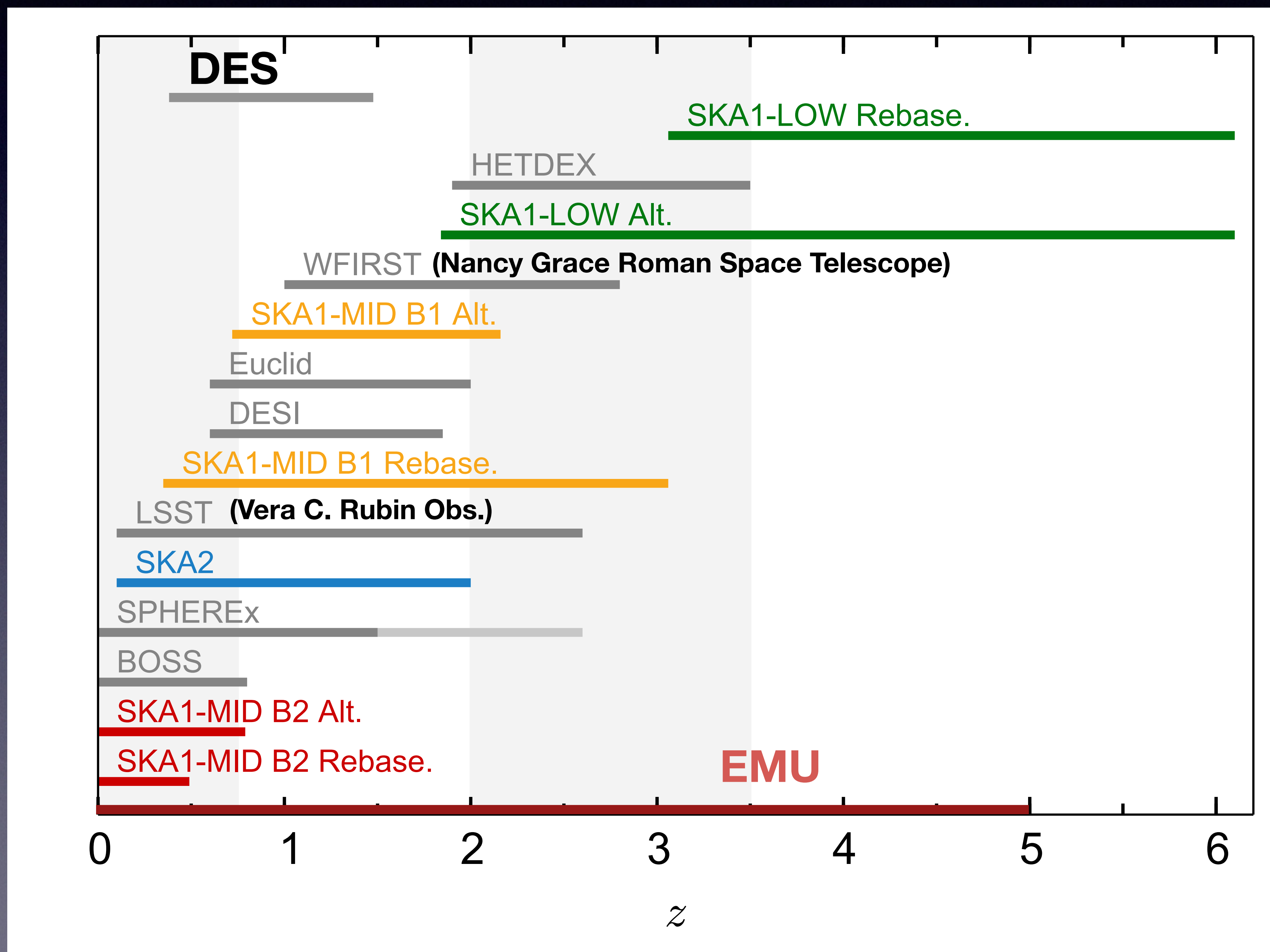


Chabanier et al., 2019

Sampling the redshift desert

- In the near future, we will sample the "redshift desert" with different missions and surveys.



Optical
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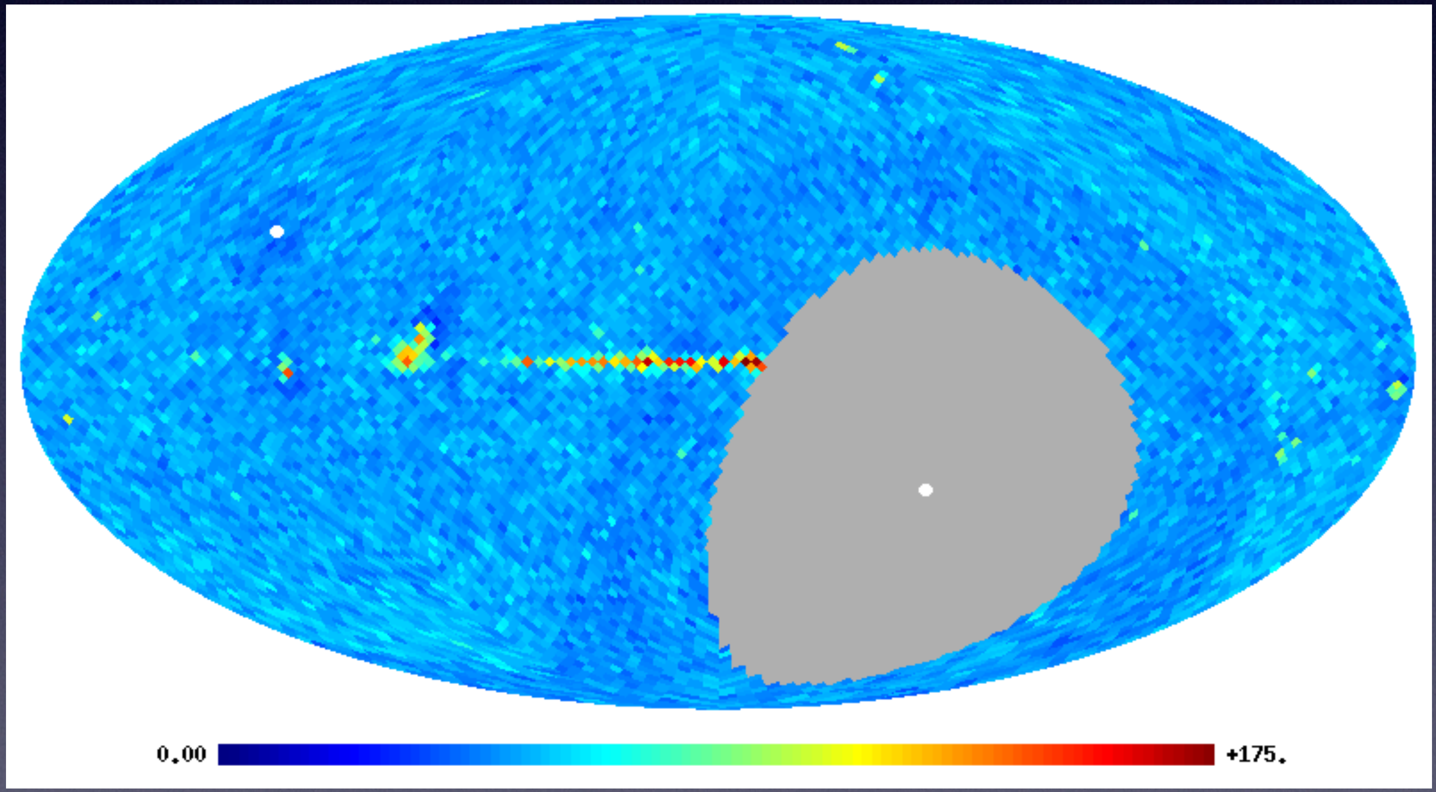
Bull (2016)

Radio Continuum Surveys

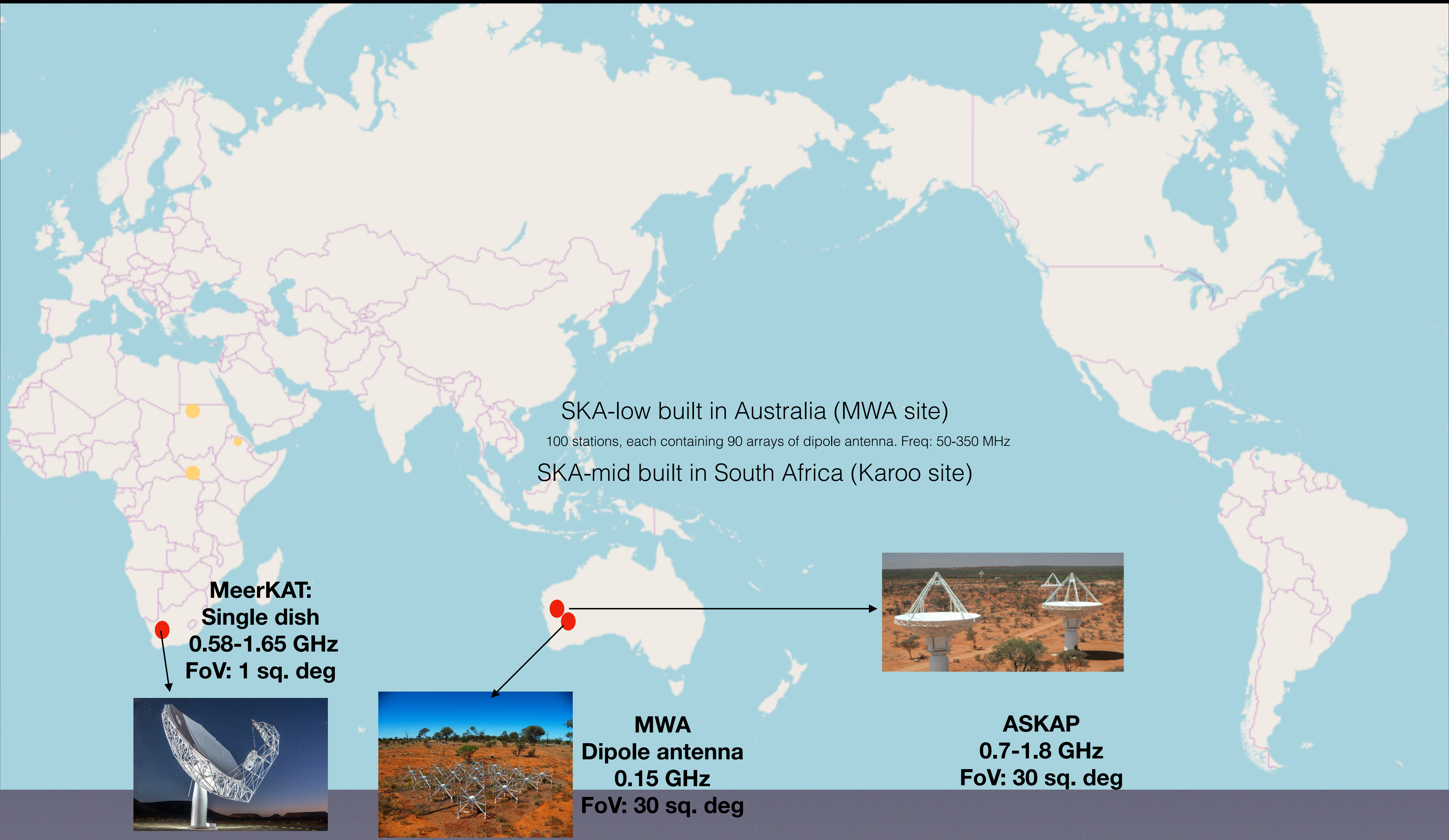
- Continuum surveys measure intensity of total radio emission, across waveband
- Emission dominated by synchrotron, so spectrum (almost) featureless
- Measure **RA** and **Dec** of sources, but need other information for redshift

NVSS Healpix map



Chen & Schwartz (2016)

SKA precursors



Australian Square Kilometre Array Pathfinder (ASKAP)

- 36 12-metre antennas spread over a region 6 km in diameter
- frequency band of 700–1800 MHz, with an instantaneous bandwidth of 300 MHz
- FoV ~ 30deg^2, pointing accuracy > 30 arcsec
- Angular resolution ~ 10 arcsec
- **75% of the time: Survey projects**

EMU: Continuum

RACS: Continuum

DINGO: HI evolution

POSSUM: MW magnetic fields

WALLABY: Spectroscopy 21cm

FLASH: HI absorption

CRAFT: Fast transients

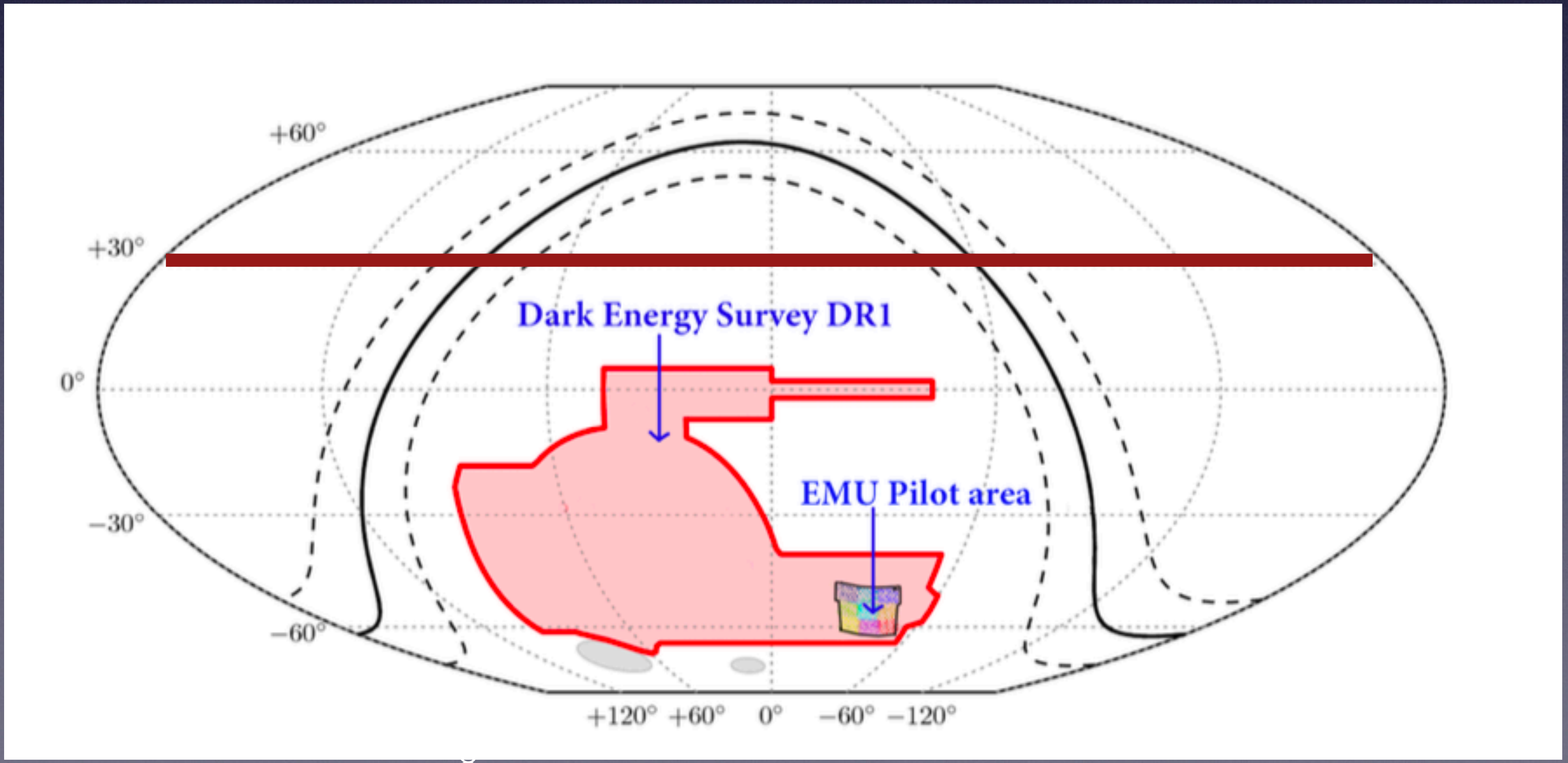
COAST: PTA

VAST: Slow transients

VLBI: long baseline

Evolutionary Map of the Universe (EMU)

- Main continuum survey with ASKAP
- Covering up to declination +30 degrees (30000 sq. deg)
- Expected noise of 15 μJy.
- Resolution of ~12″ to 15″ FWHM
- Expected 70 million sources



Cosmological observables

1. Angular correlation function of radio galaxies
2. Cosmic Magnification of high-z radio galaxies by low-z optical foreground galaxies
3. Cosmic Magnification of CMB by radio galaxies
    - Cross-correlation between radio density and CMB on small scales
4. Integrated Sachs-Wolfe effect
    - Cross-correlation between radio density and CMB on large scales

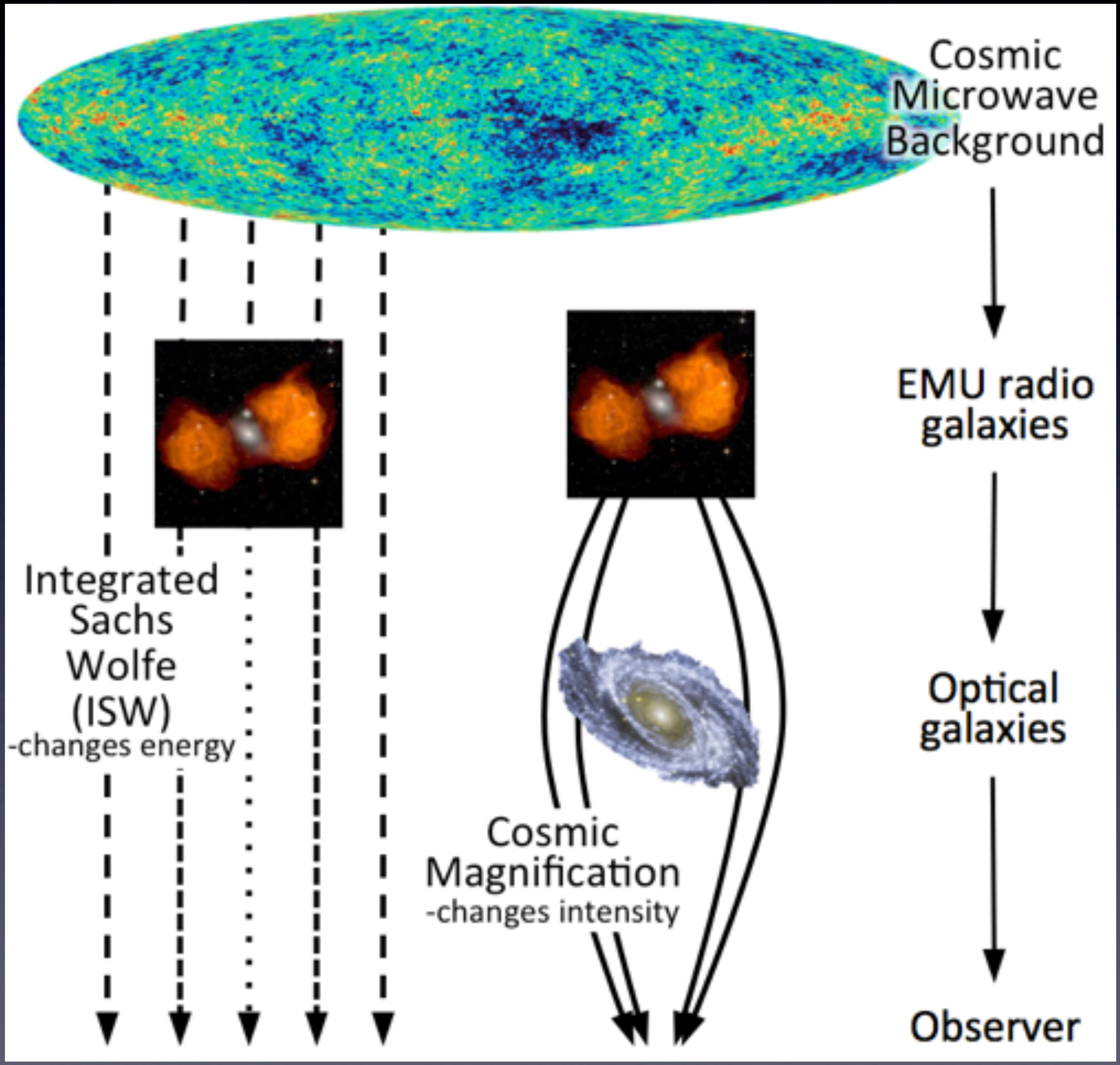
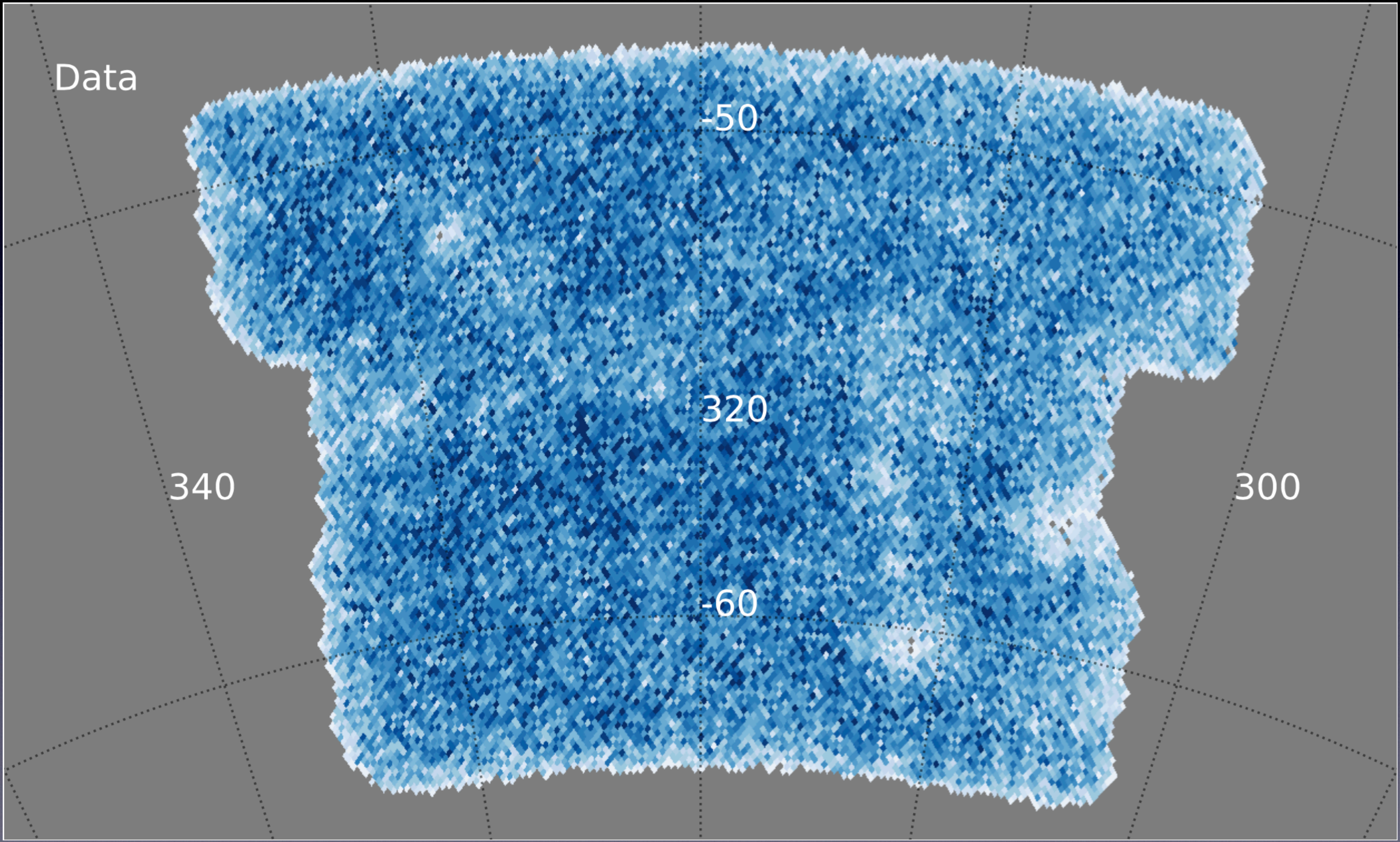


Image credit: Tamara Davis

PIlot survey



Pilot survey

- We create the random catalogue that matches the observing conditions given by the RMS map.
- RMS of about 30 μJy

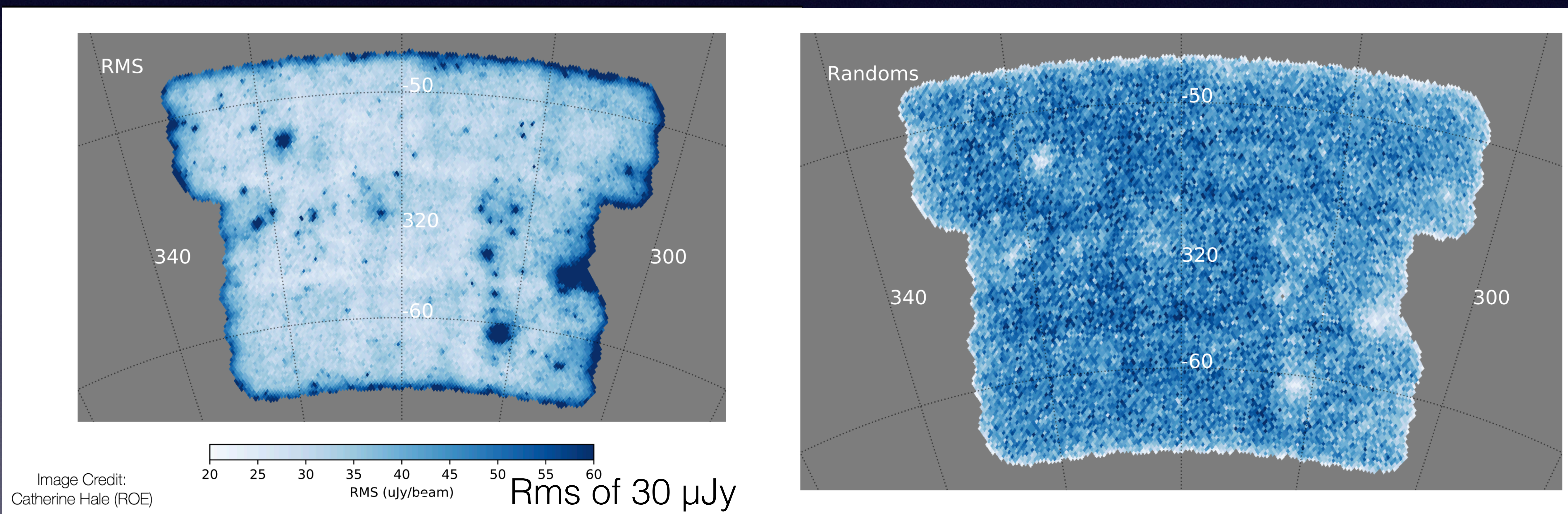
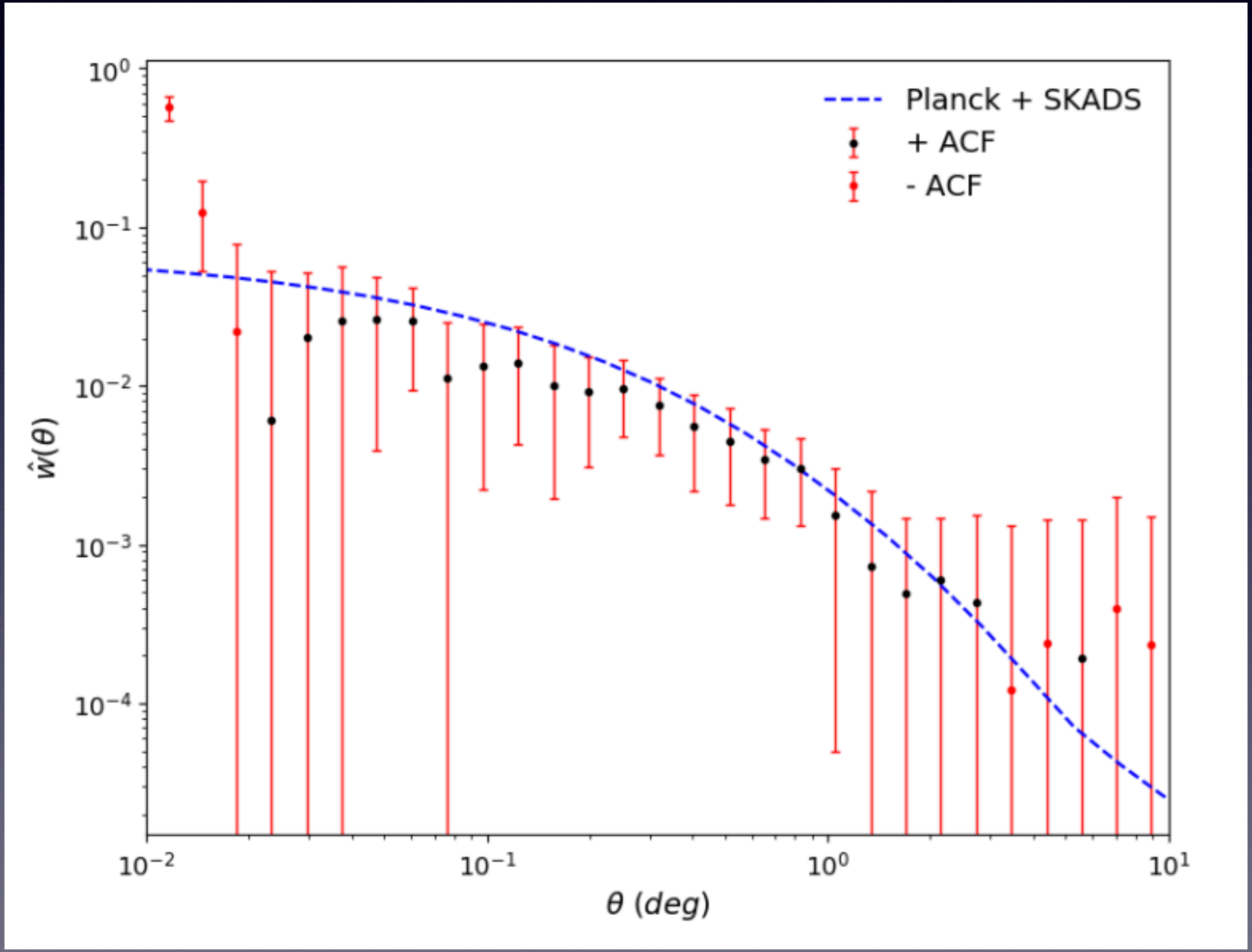


Image Credit:
Catherine Hale (ROE)

Clustering of the EMU pilot survey

- By eye, reasonable fit to prediction from Planck + SKADS (Wilman, 2009)
- Relative amplitude shift between islands and components



Norris et al. 2021, PASA

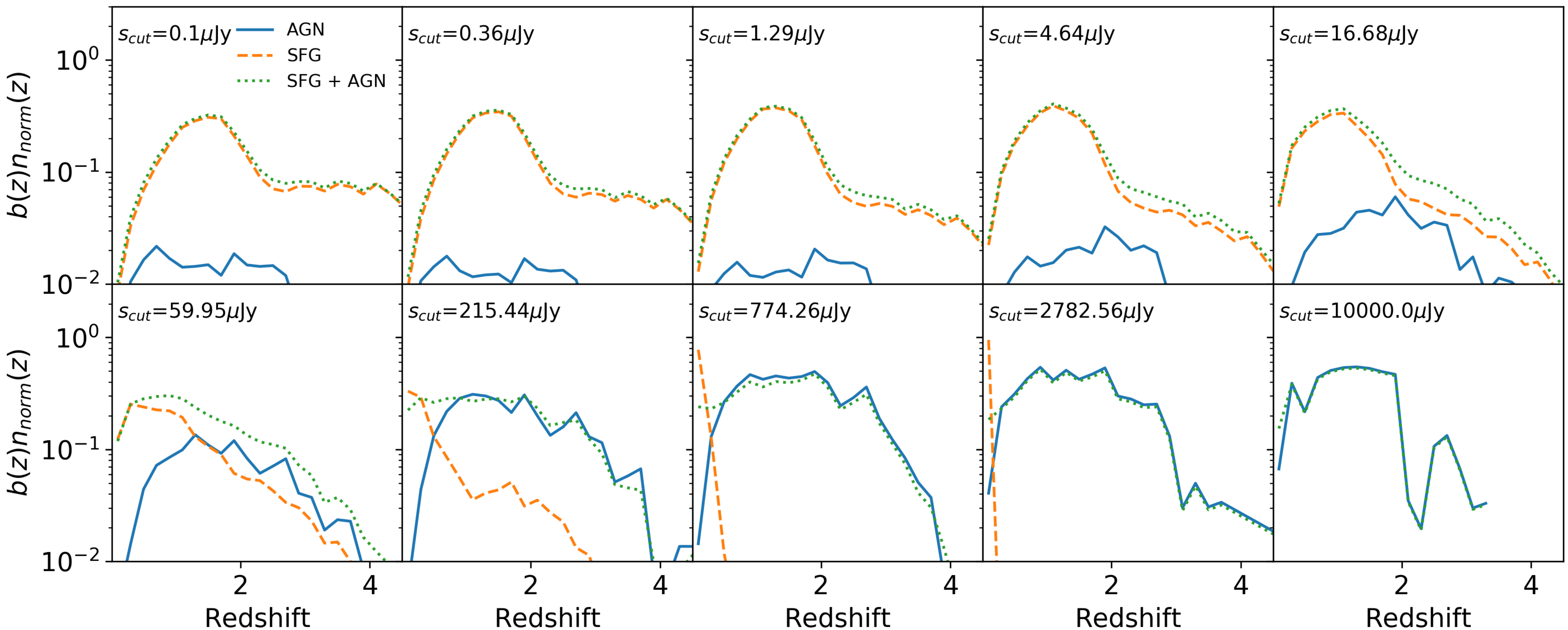
Clustering statistics

- The error depends on the sample variance and on the shot noise.
- Angular clustering depends on the redshift distribution N(z) and the galaxy bias.
- N(z) from T-RECS simulation (Bonaldi et al., 2016) and theoretical prescription for the bias.

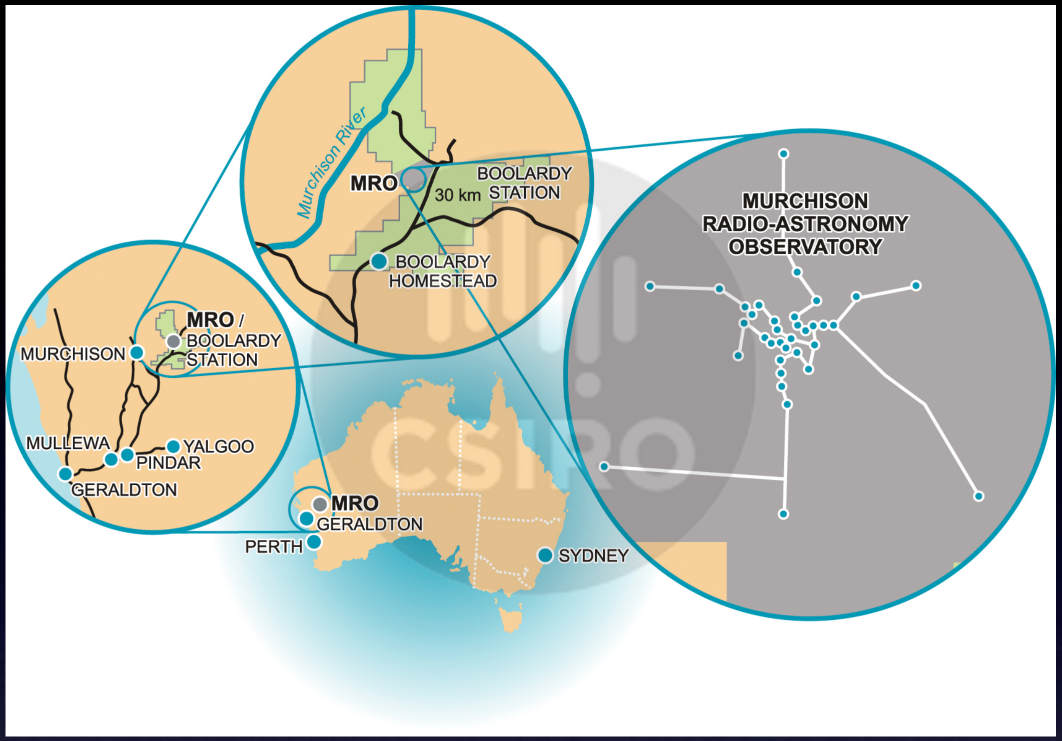
Angular power spectrum:

$$C_\ell = 4\pi \int \frac{dk}{k} \Delta^2(k) [W_\ell^g(k)]^2 ,$$

$$W_\ell(k) = \int \frac{dN(\chi)}{d\chi} b(z) D(z) j_\ell [k\chi] d\chi .$$



Rapid ASKAP Continuum Survey (RACS)

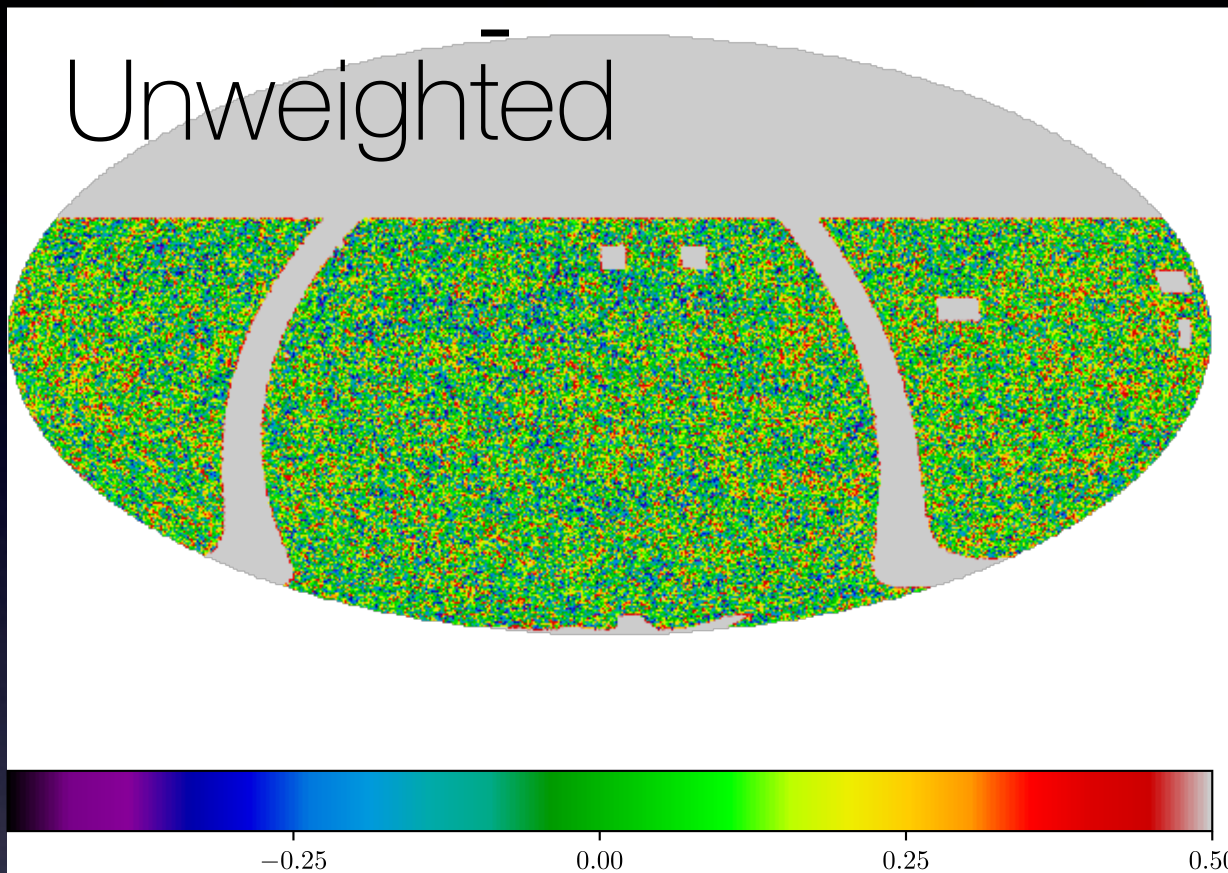


- Rapid ASKAP Continuum Survey (RACS, fast)
  - Technology demonstration, no major science goals
- We acknowledge the Wajarri Yamatji people as the traditional owners of the Observatory site.

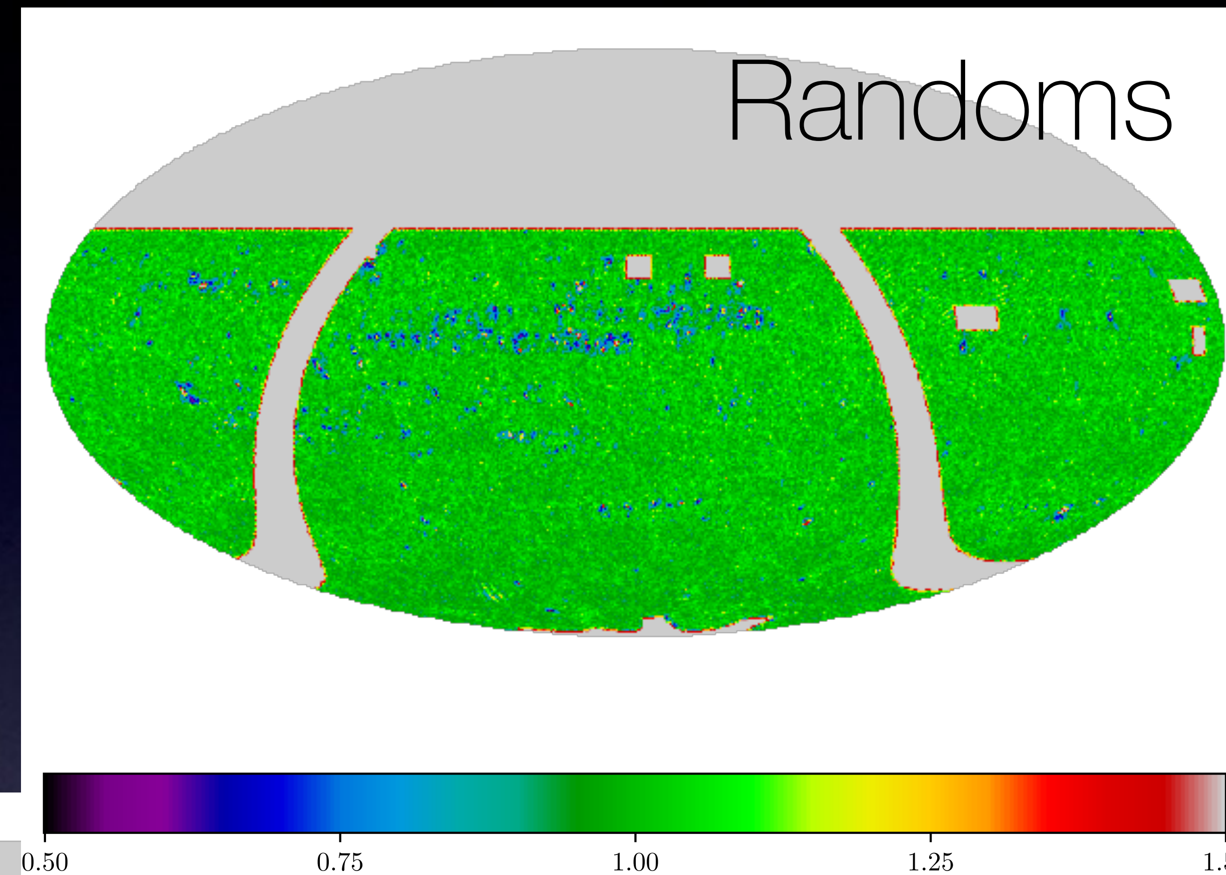
Baselines	22m - 6400m	All 36 antennas
Resolution	15 arcsec	
Frequencies	700-1800 MHz	288 MHz bandwidth
Integration	15 minutes	
Polarization	I, Q, U, V	
Image noise	~250 μJy	
Sky coverage	$-90° < \delta < +40°$	903 tiles

RACS Source density

1.26 Million galaxies (EMU will have 40 Million).

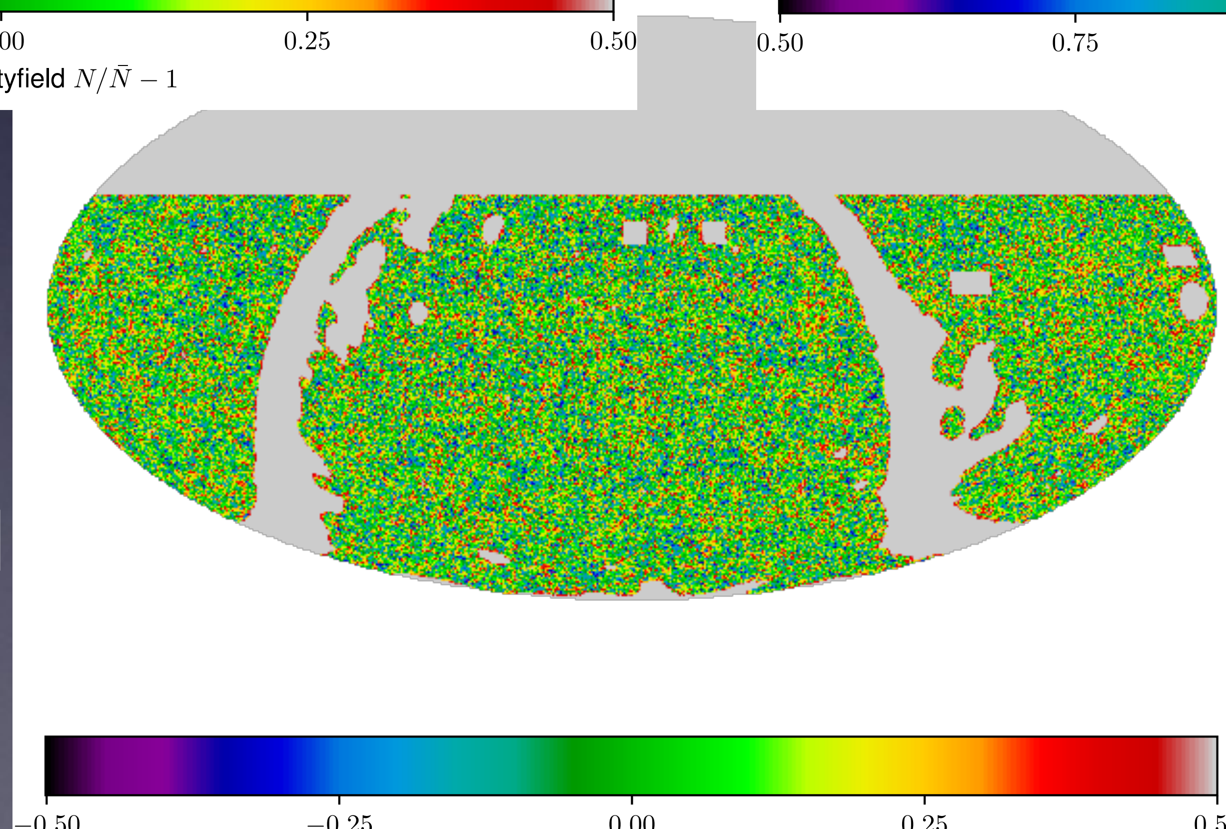


(b) raw densityfield $N/\bar{N} - 1$



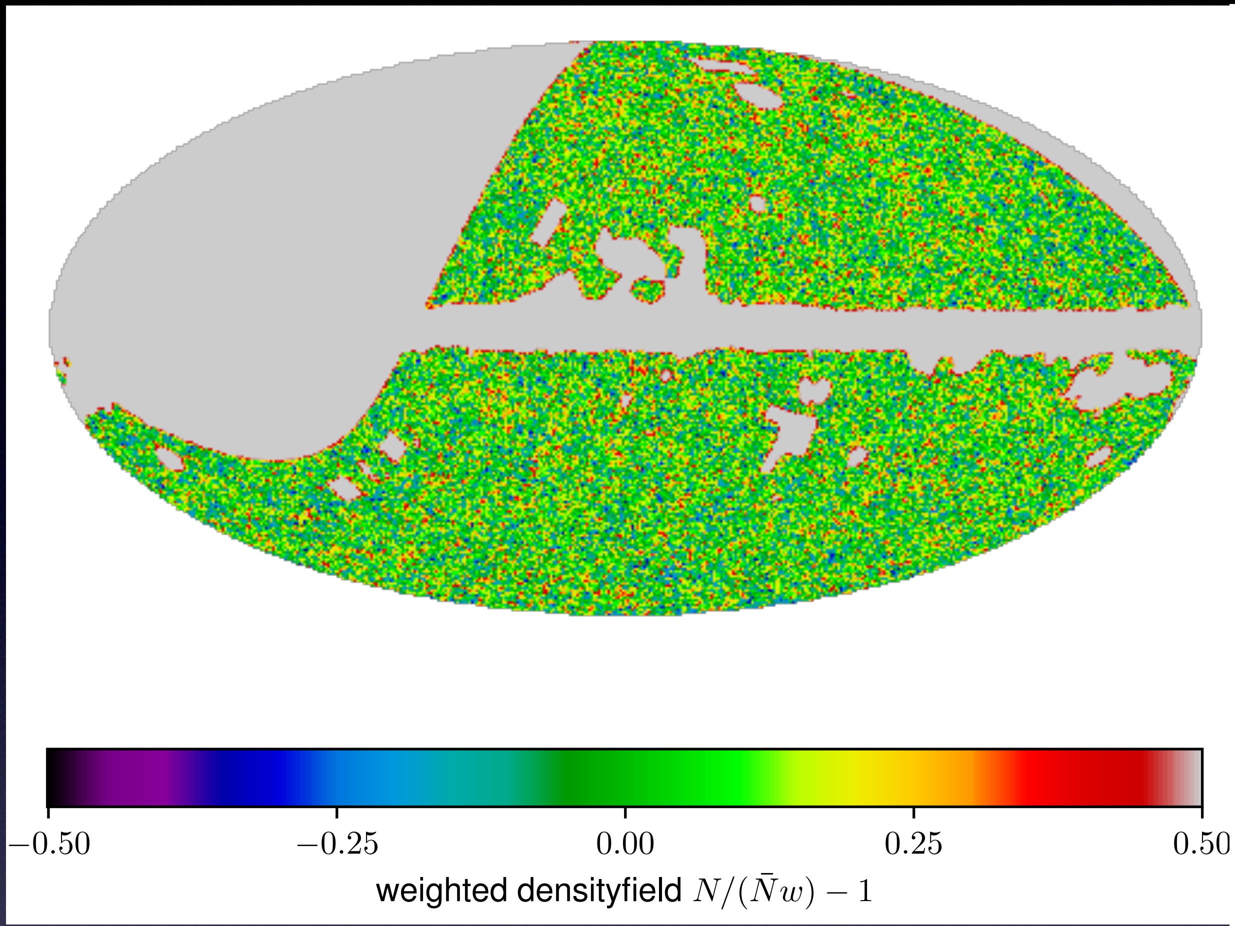
(a) weights w

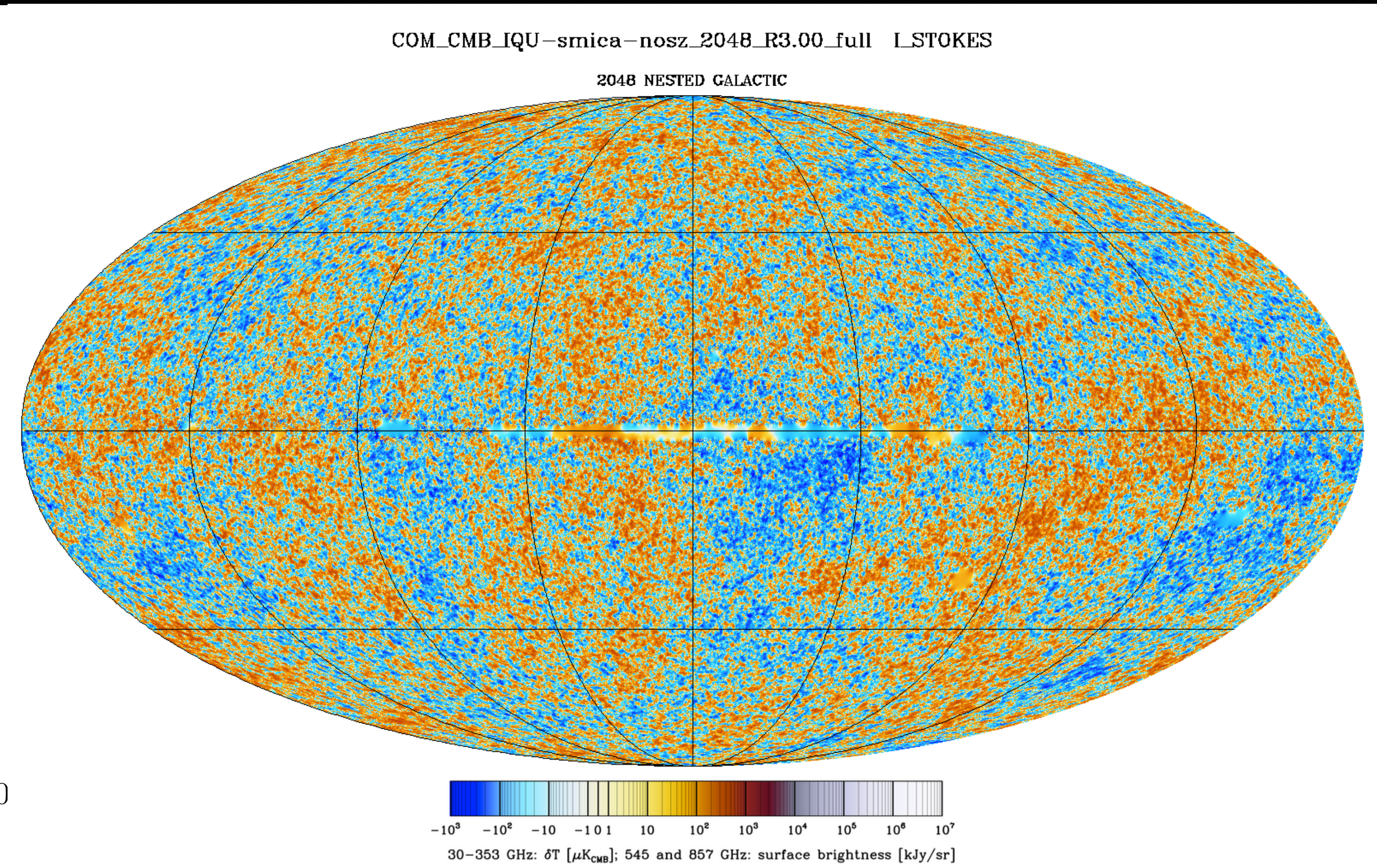
Weighted, and CMB mask applied



(c) weighted densityfield $N/(\bar{N}w) - 1$

RACS x Planck SMICA R3



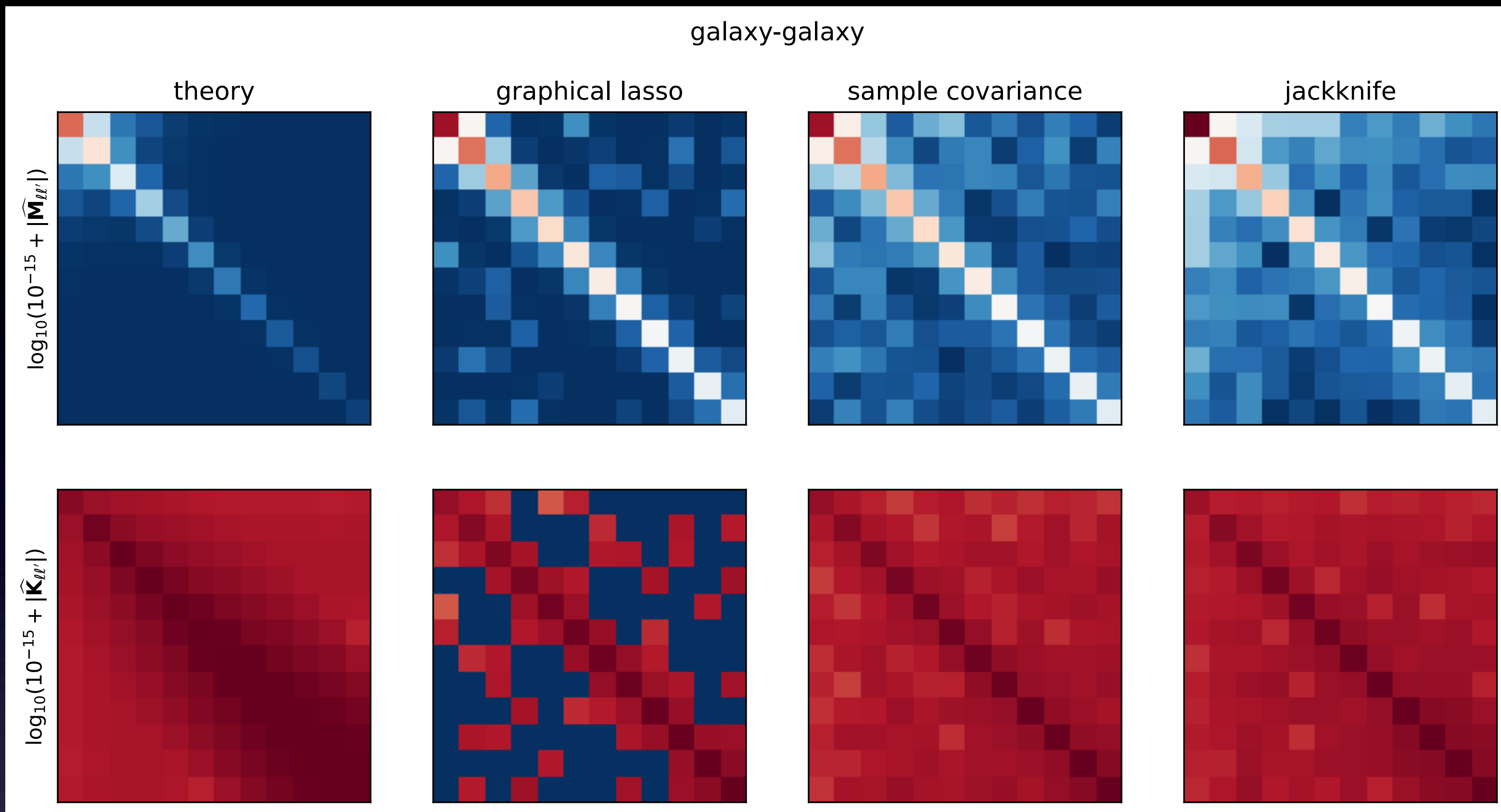


- Removed Galactic plane ($|b| < 5°$)
- Flux cut of 4 mJy
- Construct weight map w using SKADS simulations
- Apply Planck mask
- Cut regions with w < 0.5
- Apply weights to number count and obtain over-density field

B. Bahr-Kalus, D. Parkinson D., JA, S. Camera, C. Hale, F. Qin, 2022, MNRAS

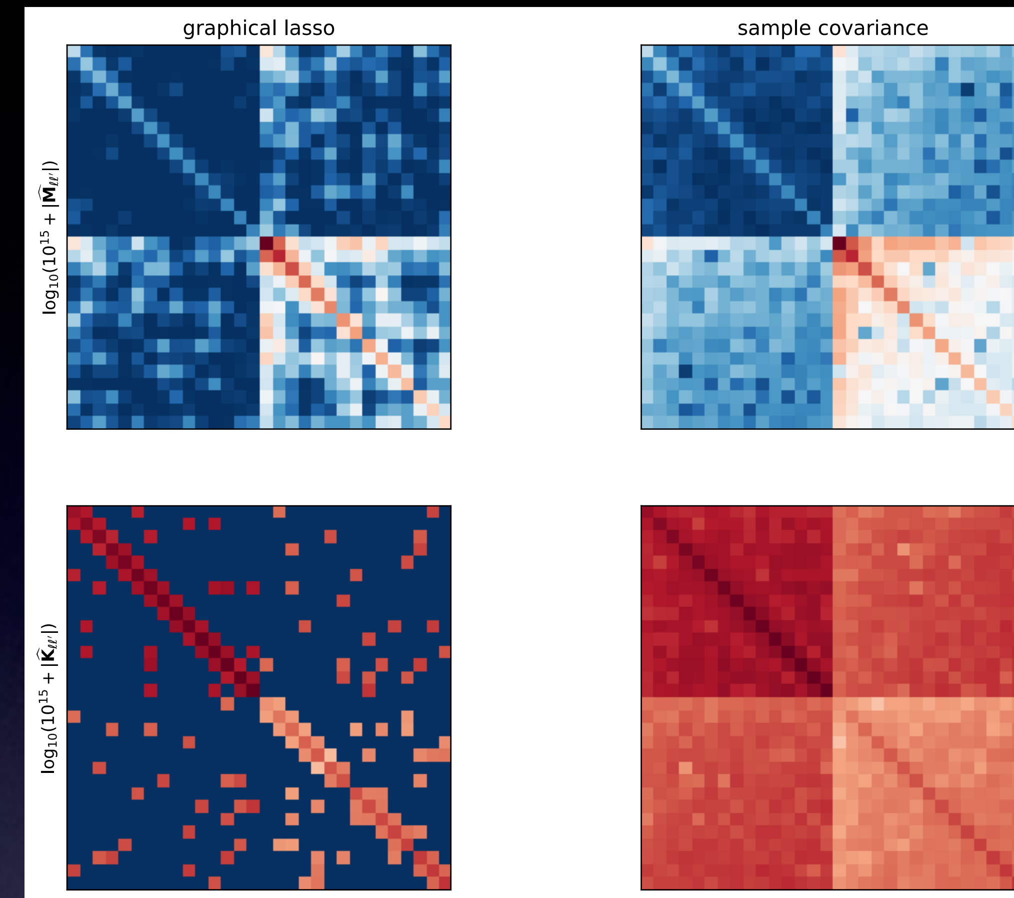
Covariance matrices

gg



- We use 4 different methods to obtain the gg covariance matrix: analytic, graphical lasso, sample covariance from 3000 Flask simulations and jackknife resampling from the data.

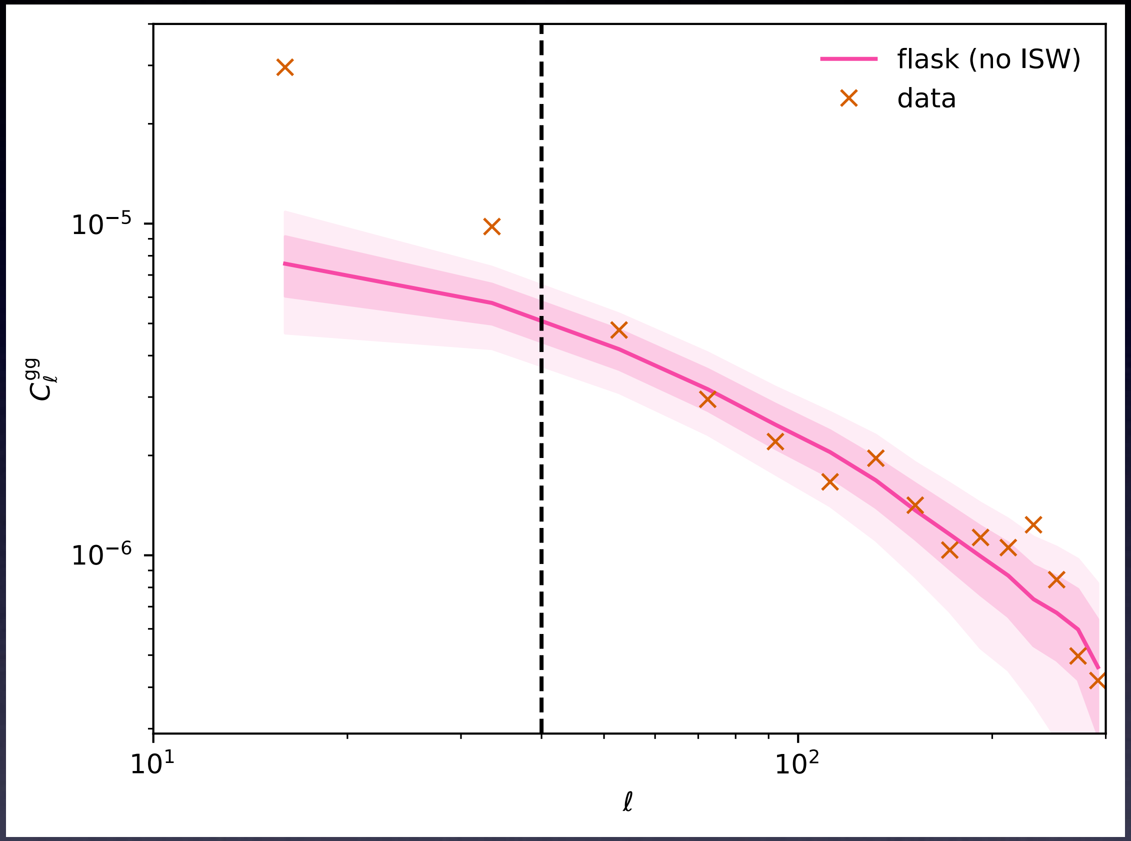
$\mathrm{gg} \times \mathrm{gT}$



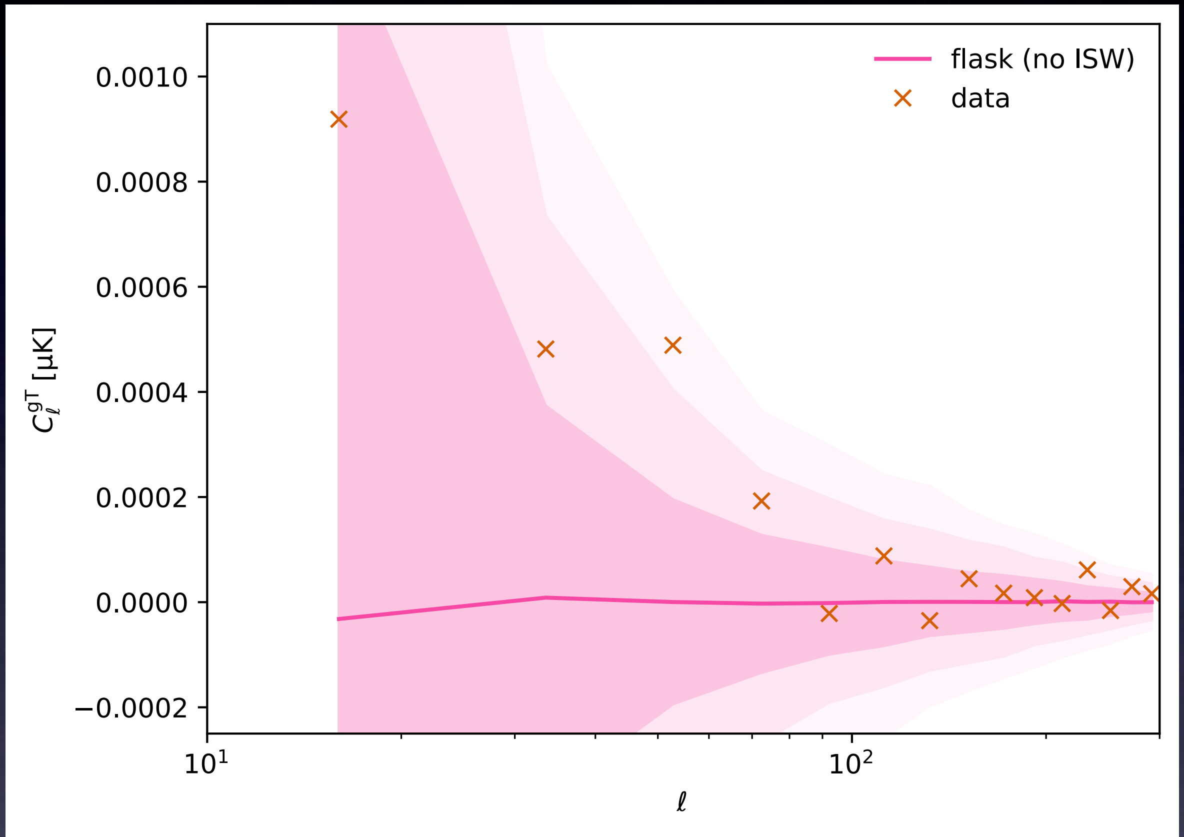
- Same for **gT** spectrum
- $\mathrm{gg} \times \mathrm{gT}$ from mocks only
- Use of sample cov for the main results
- $\mathrm{gg} \times \mathrm{gT}$ cov does not contribute to χ^2

RACS measurements

gg



gT



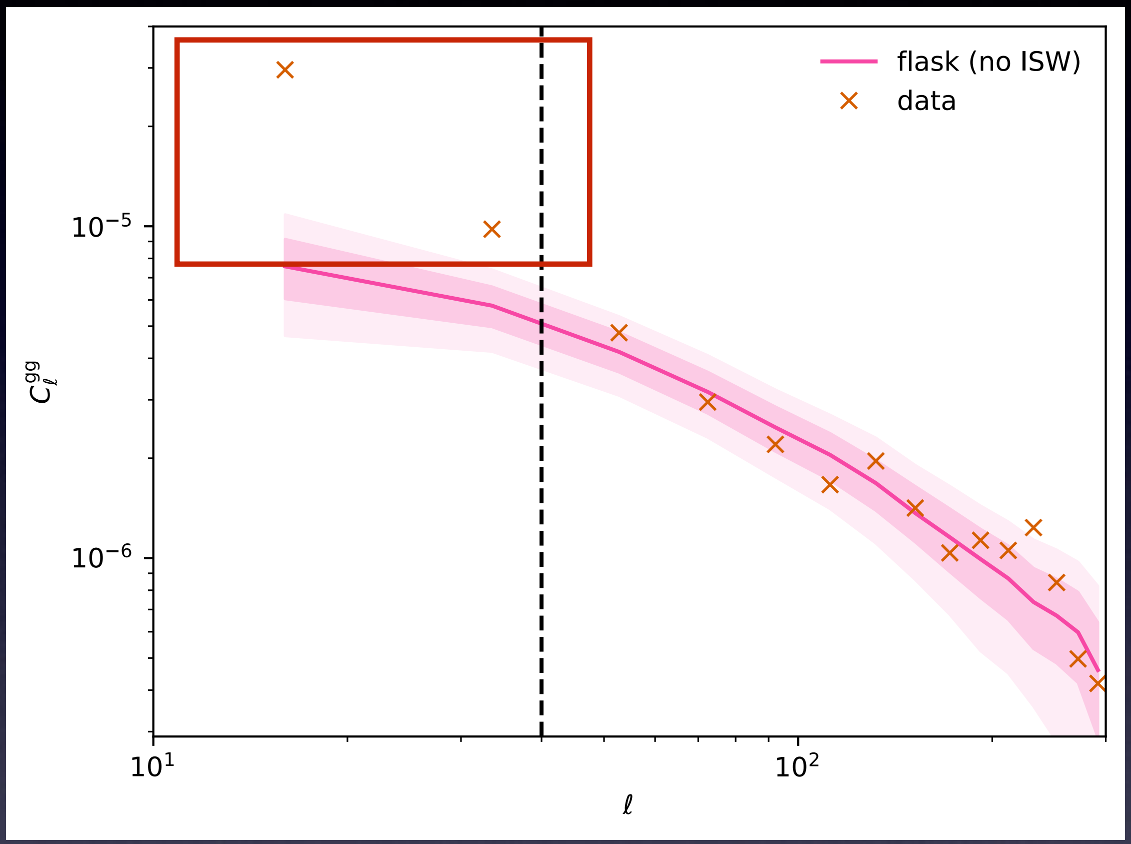
Good agreement at small scales,
Large scale power offset
(Galaxy power spectra information at ℓ >
40 not included in analysis)

$$\frac{S}{N} = \frac{\sum_{\ell,\ell'} C_\ell^{(\mathrm{data})} \mathbf{K}_{\ell\ell'} C_{\ell'}^{(\mathrm{model})}}{\sqrt{\sum_{\ell,\ell'} C_\ell^{(\mathrm{model})} \mathbf{K}_{\ell\ell'} C_{\ell'}^{(\mathrm{model})}}} \approx 2.8$$

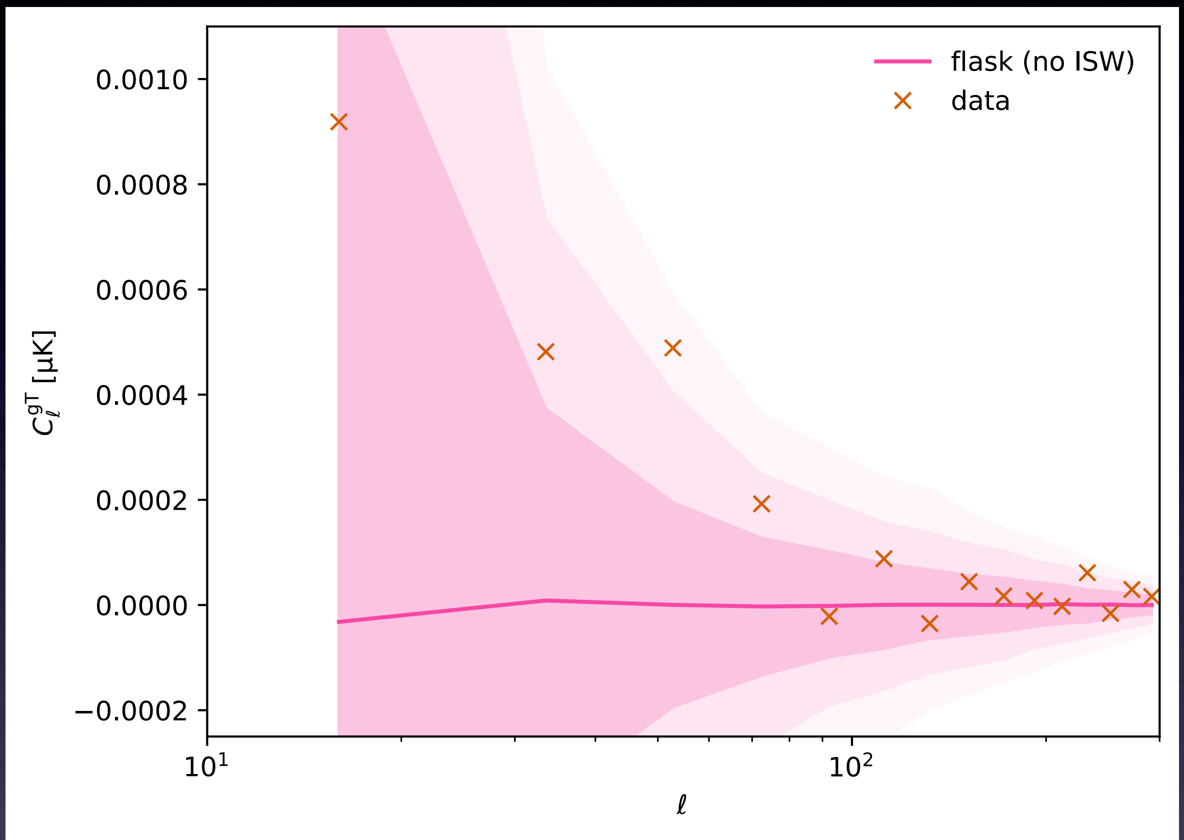
relative to null hypothesis of no correlation

RACS measurements

gg



gT



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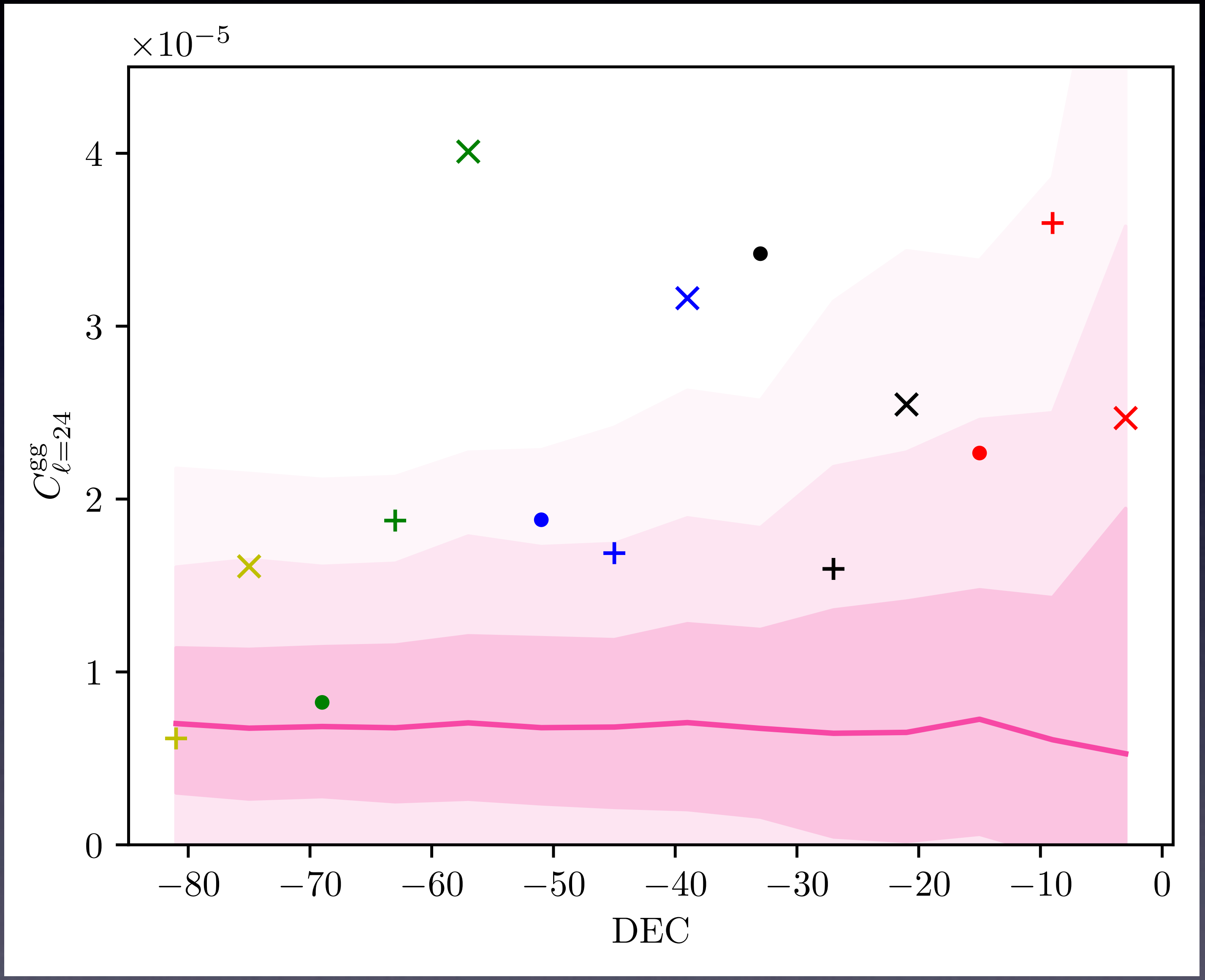
relative to null hypothesis of no correlation

Some systematics

- Large scale power excess seems to be correlated with declination
  - Close to south pole errors smaller, and mean close to predicted value
  - Close to equator number of counts smaller and sky noise large, power is higher than expected
- Hypothesis is that power excess is **not** non-Gaussianity causing scale-dependent bias, but a systematic caused by data reduction procedure

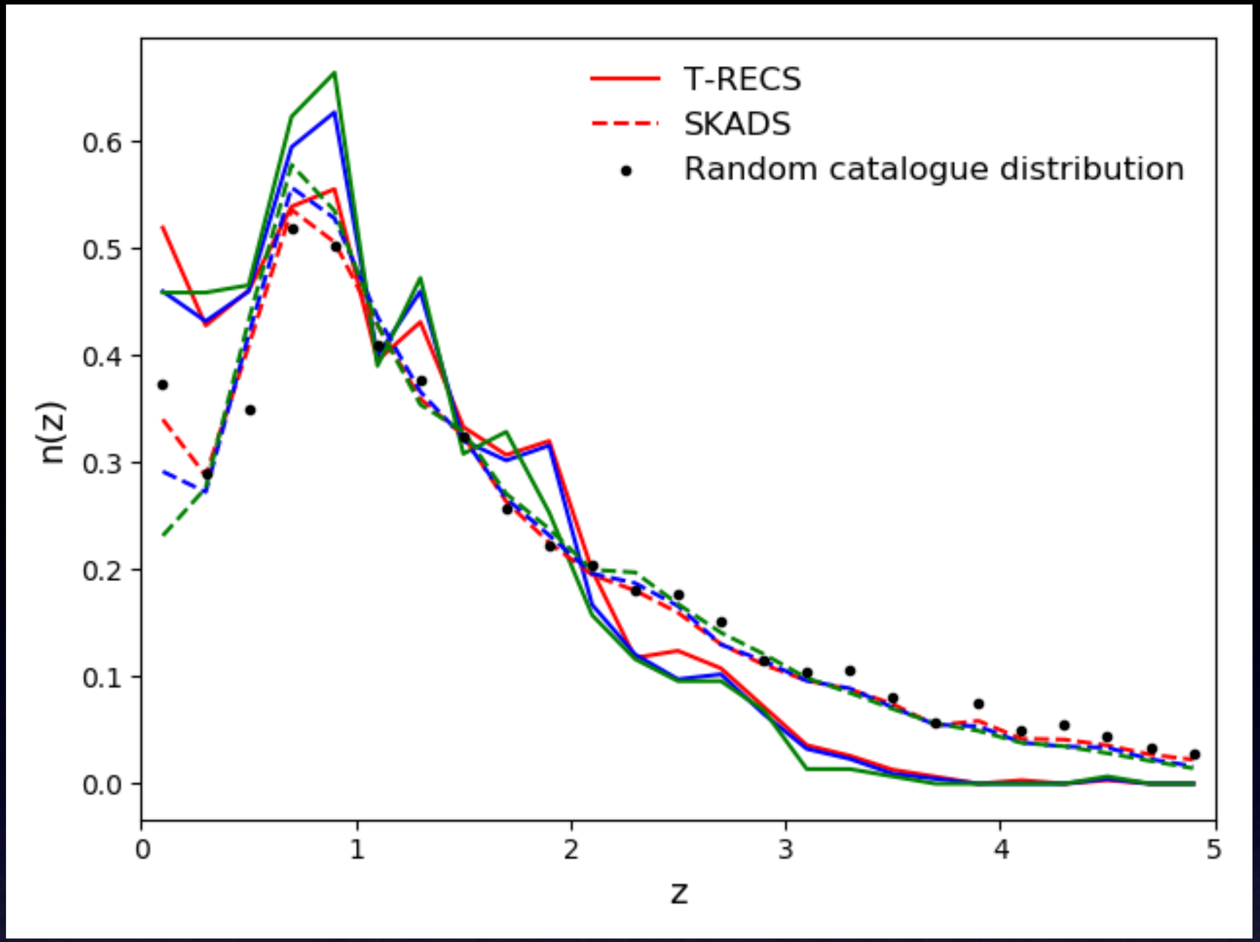


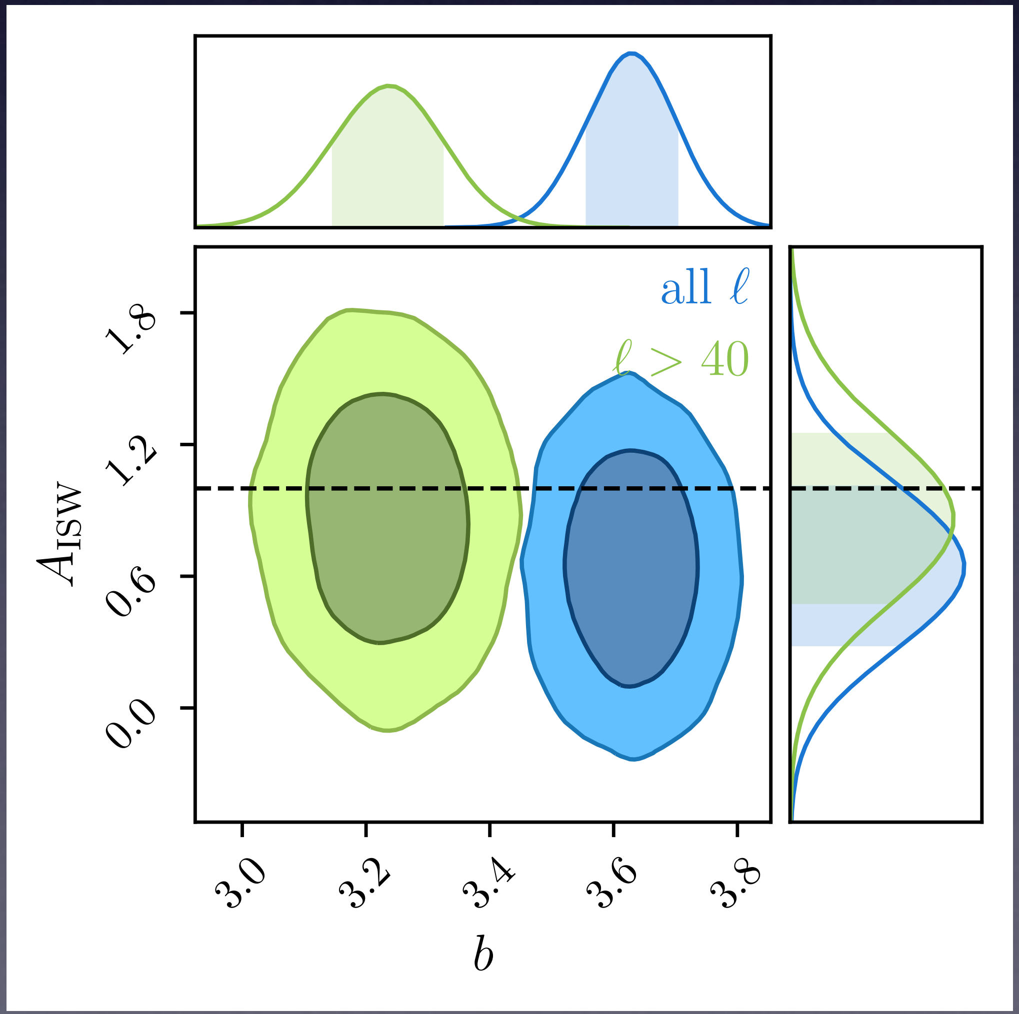
Cosmological constraints

- We vary $b(z)$ and define A_{ISW} such that $C^{gT}_{\ell,\mathrm{measured}} = A_{\mathrm{ISW}} C^{gT}_{\ell,\mathrm{model}}$
- more Bayesian approach to quantify significance of ISW detection
- A_{ISW} and $b(z)$ degenerate in C^{gT}_{ℓ}, broken in combined C^{gg}_{ℓ} and C^{gT}_{ℓ} analysis
- $b(z)$ also degenerate with $\dfrac{dN(z)}{dz}$,
- analysis with $N(z)$ inferred from **SKADS**, as well as from **T-RECS**

$$C_\ell^{ij} = \frac{2}{\pi} \int W_\ell^i(K) W_\ell^j(k) P(k) k^2 dk$$

$$W_\ell(k) = \int j_\ell(kr) b(z) \frac{dN(z)}{dz} dr$$

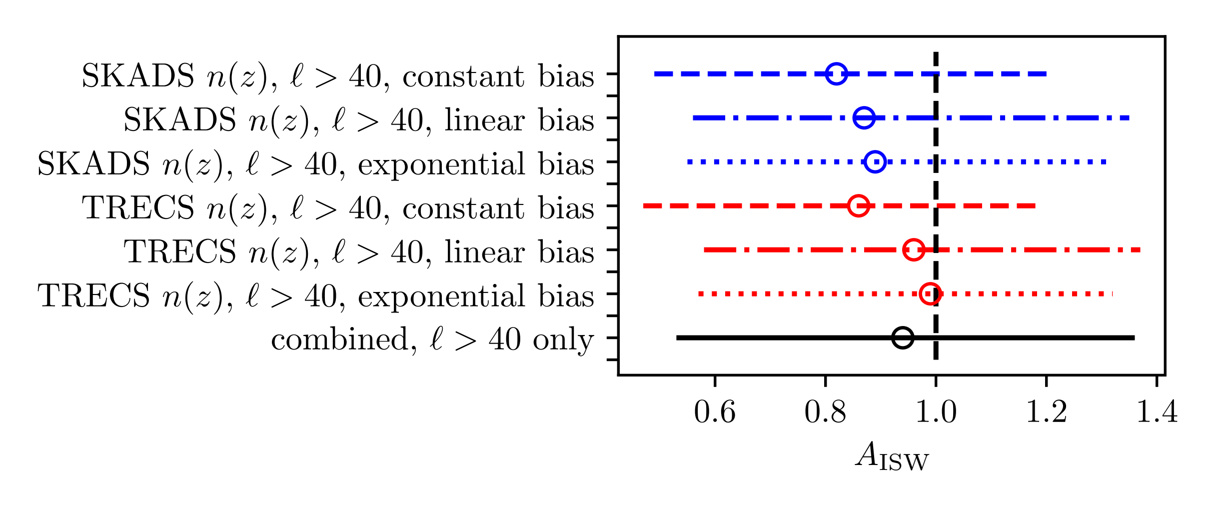


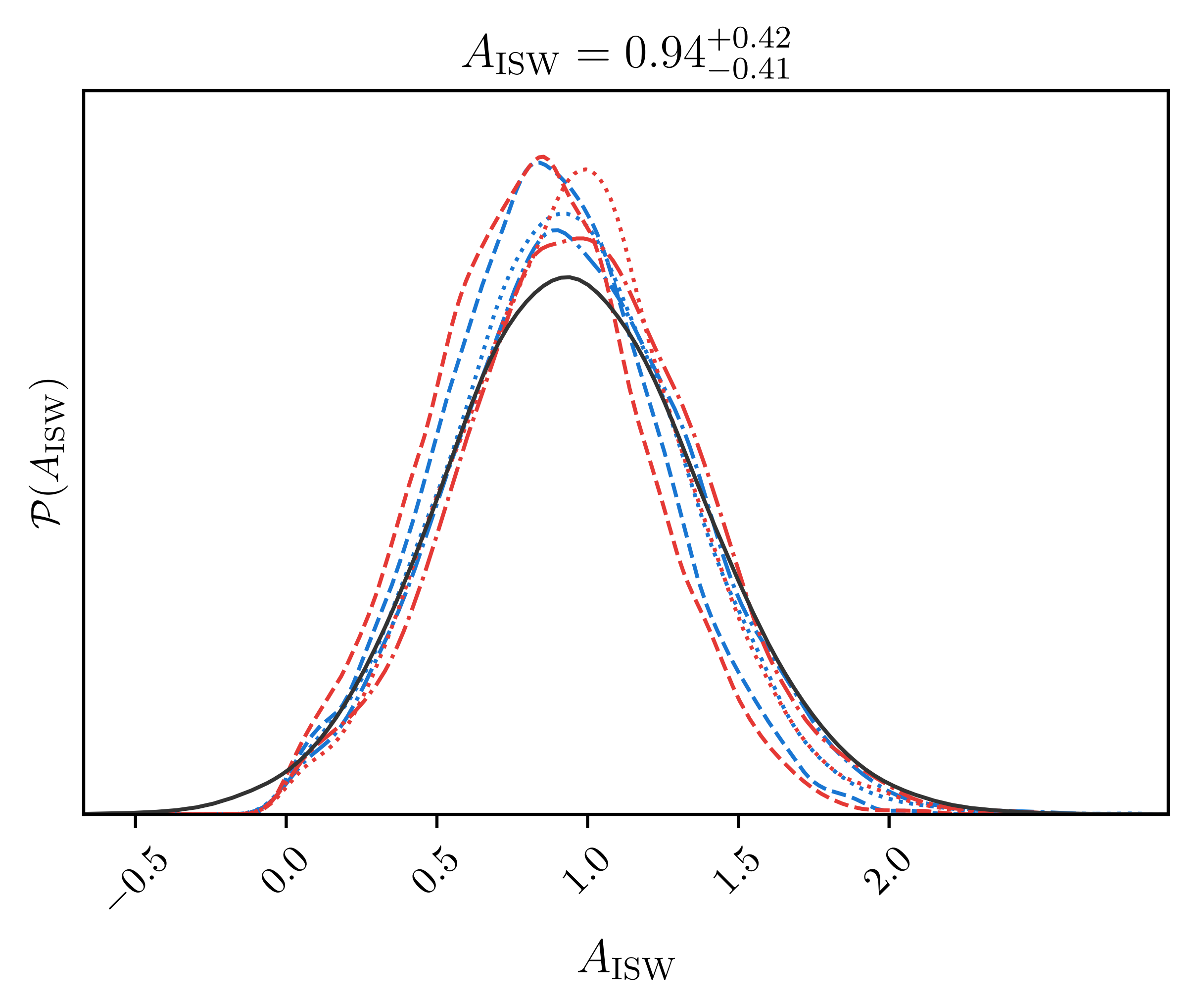


Cosmological constraints

- Consider three bias parameterisations:
  - $b(z)$ constant
  - $b(z) = b_0 + b_1 z$
  - $b(z) = b_0 \exp(\beta z)$
- Always take full ℓ-range into account for C_ℓ^{gT}
- Repeat C_ℓ^{gg} analysis with and without $\ell < 40$
- Use scatter to estimate systematic uncertainty

2.3σ detection of ISW effect with more conservative Bayesian analysis
Probability of $A_{\rm ISW} > 0$ is 98.9%





Summary

- Measurements of the clustering of radio galaxies can be used to determine the bias of radio populations and the cosmological parameters
- The effect of anisotropic noise (location-dependent completeness) can be modelled when generating randoms, to remove any potential bias
- We used FLASK to generate mock catalogues with the same clustering power spectrum as our fiducial cosmology, to test our pipeline and estimate covariance matrix
- We measured angular power spectrum of radio continuum sources detected by RACS at 888 MHz, in auto-and cross-correlation with Planck CMB maps
- Angular power spectra of RACS galaxies consistent with prediction from ΛCDM, except on large scales where we detect an excess.
- Detect cross-correlation between galaxy distribution and CMB temperature distributions. Significant at 2.8σ relative to null hypothesis.
- Parameterise ISW amplitude as $A_{\rm ISW}$. Combining the angular auto- and cross-power spectra, and combining measurements obtained under different assumptions in conservative Bayesian way, we get $A_{\rm ISW} = 0.94^{+0.42}_{-0.41}$ $(2.3\sigma/98.9\%)$

¡Thank you!