Cosmology from LoTSS DR2

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On behalf of the LOFAR surveys KSP cosmology team

SKA Cosmology SWG 2023

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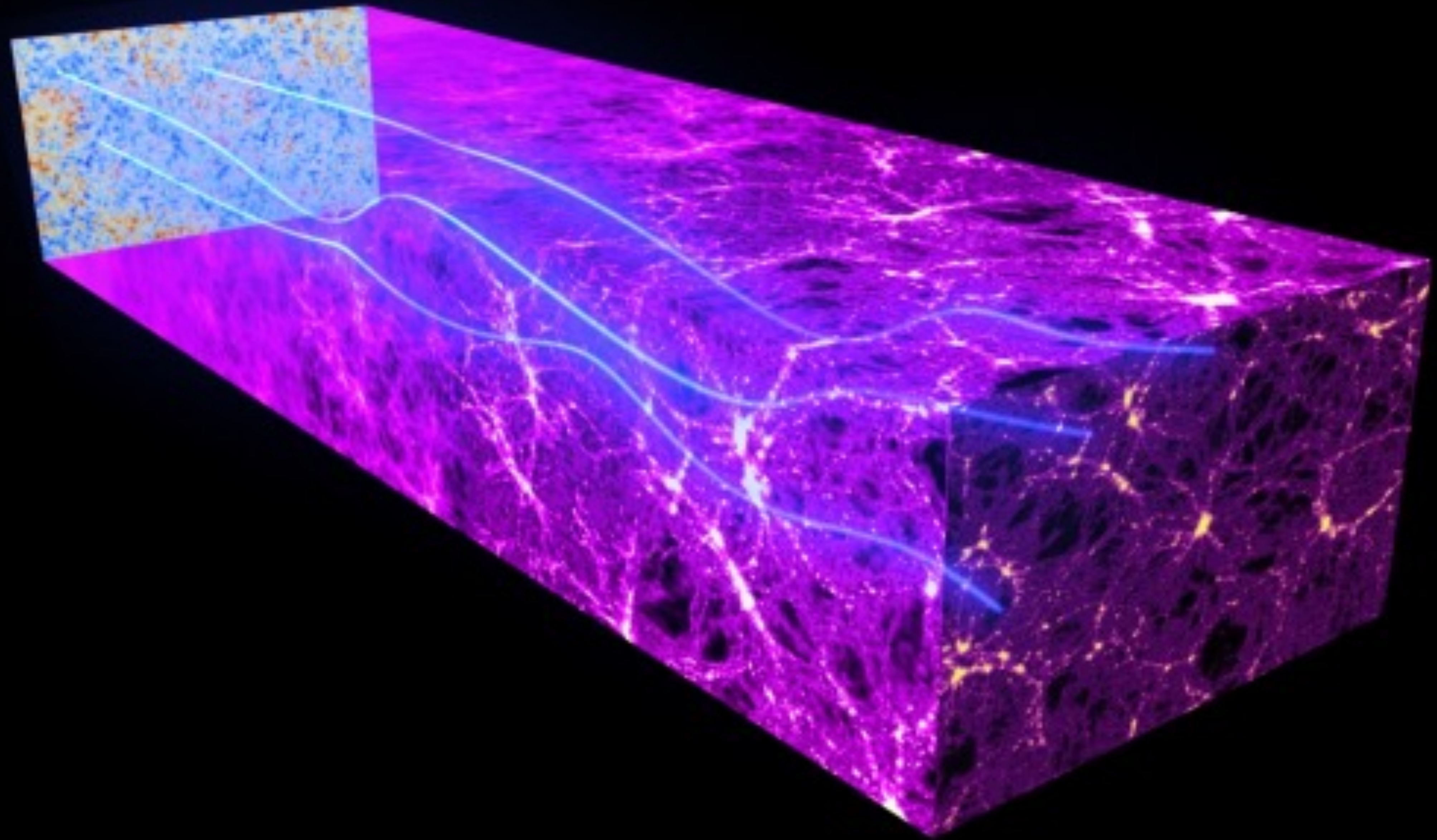
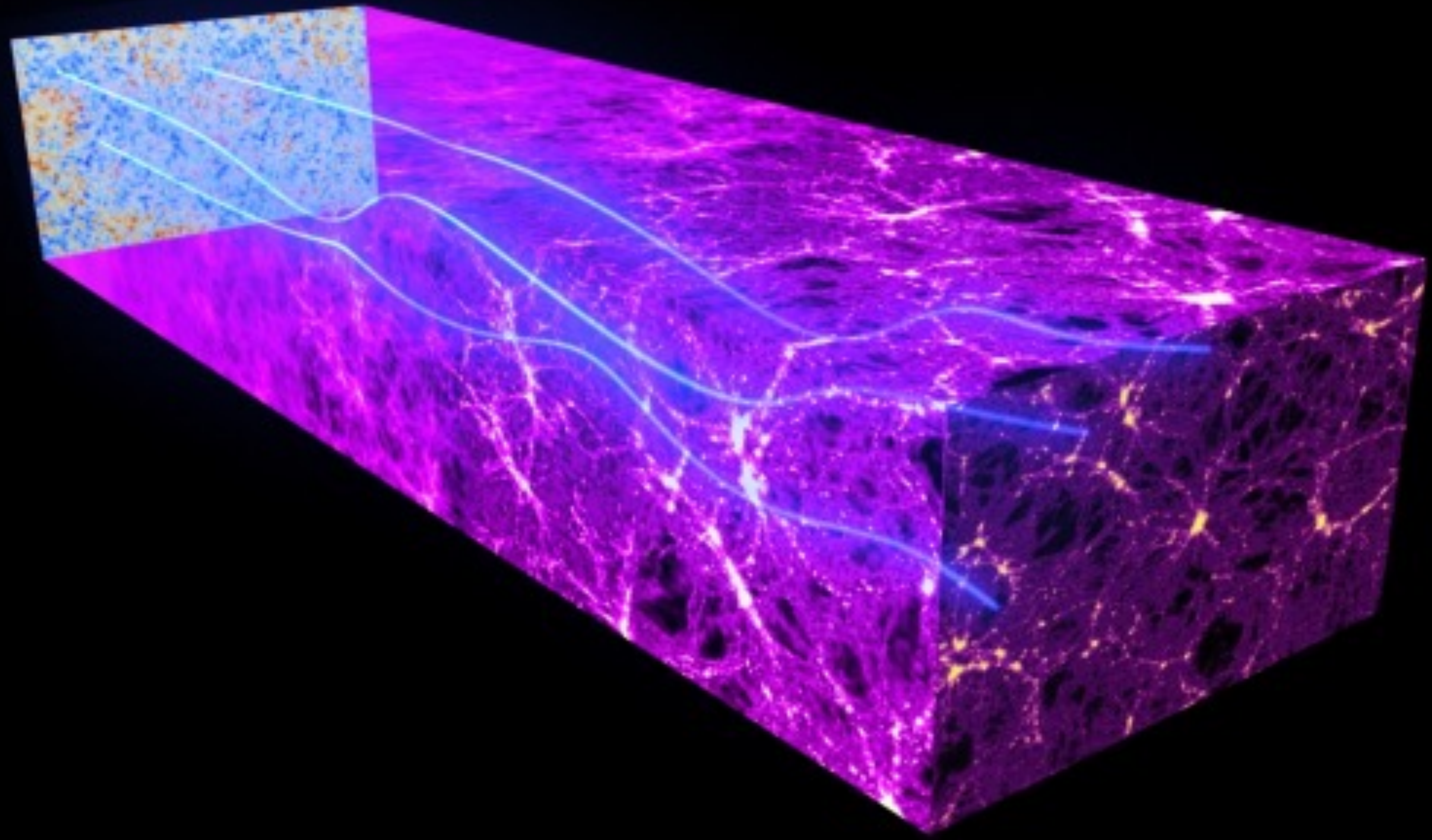
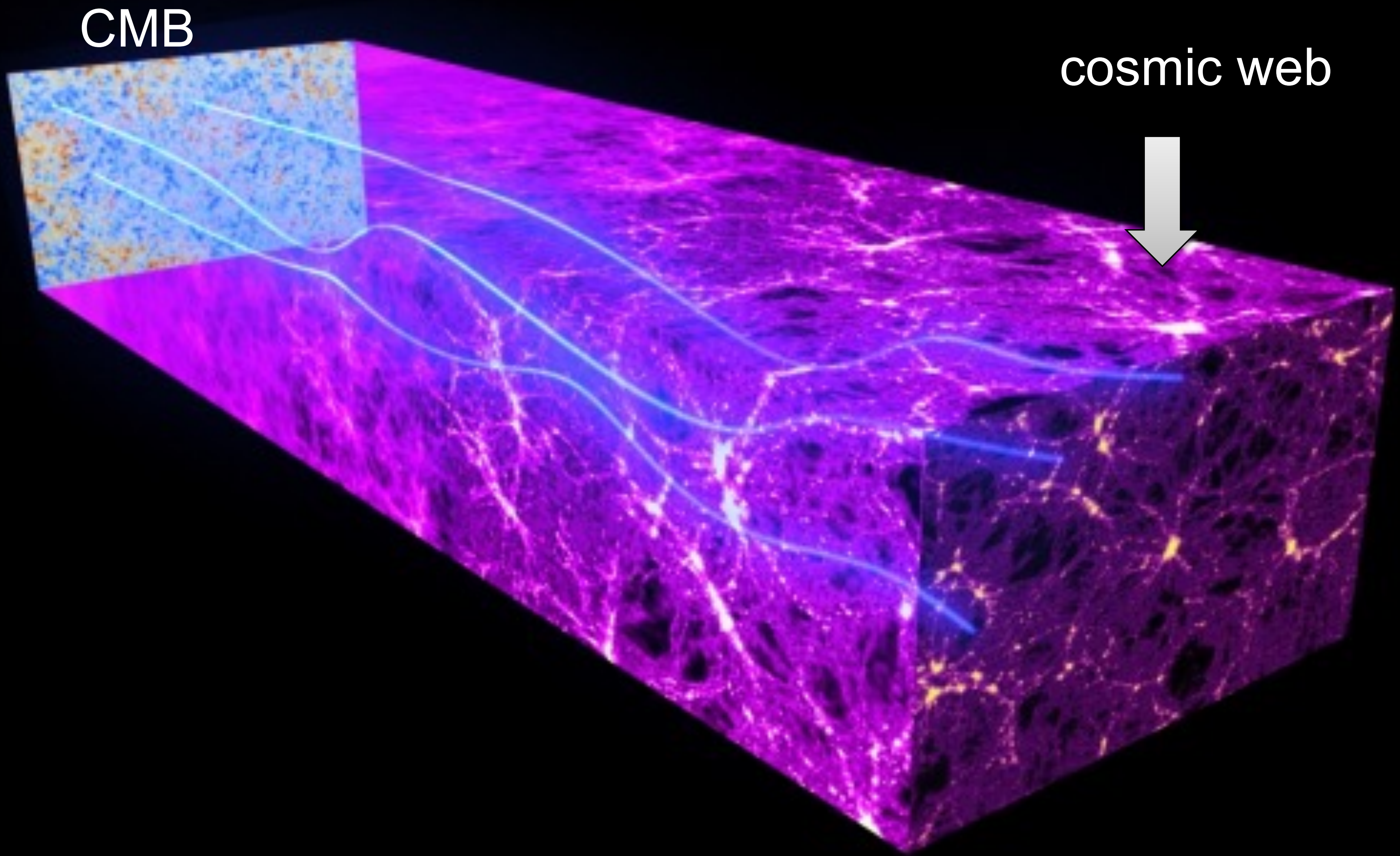


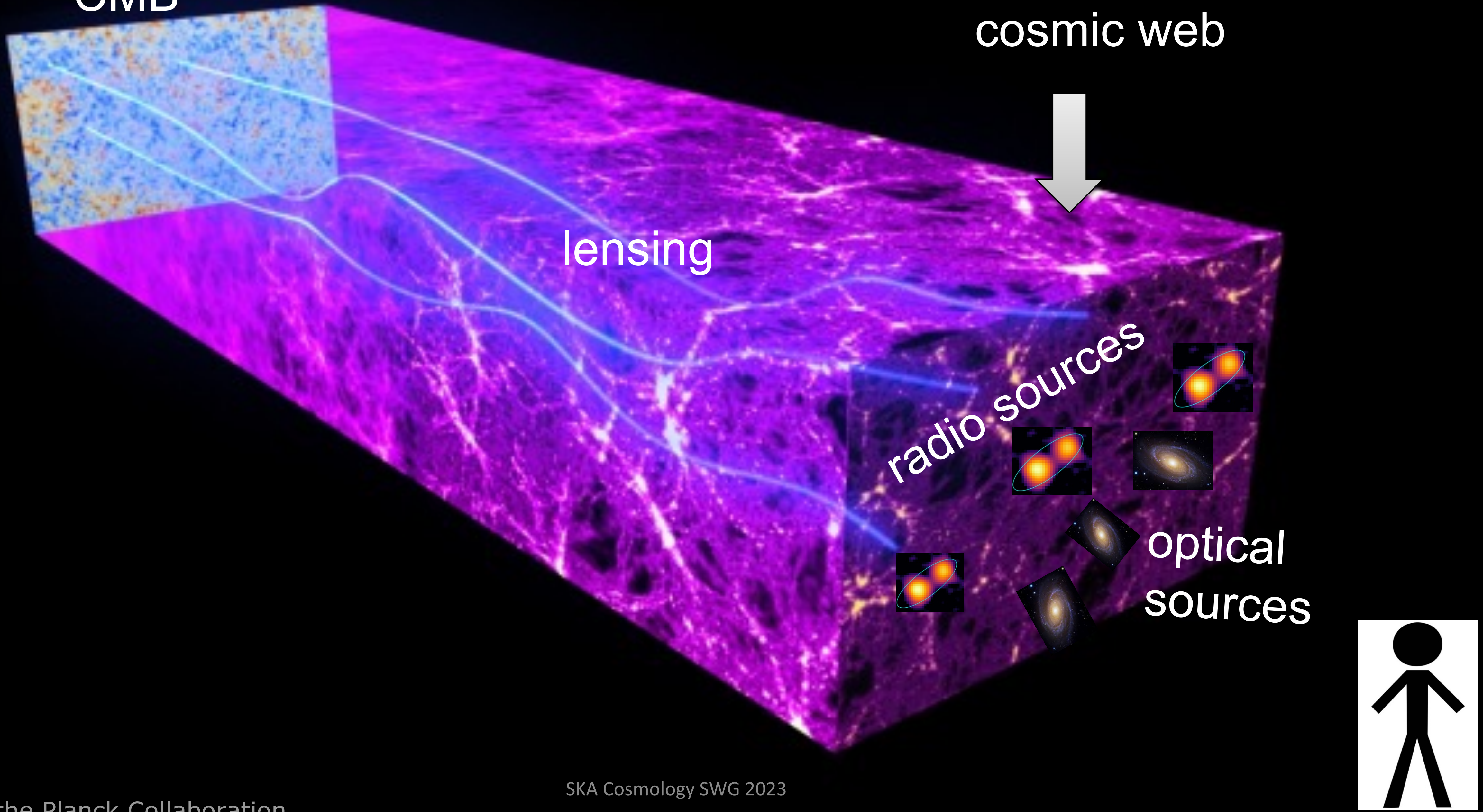
ESA and the Planck Collaboration



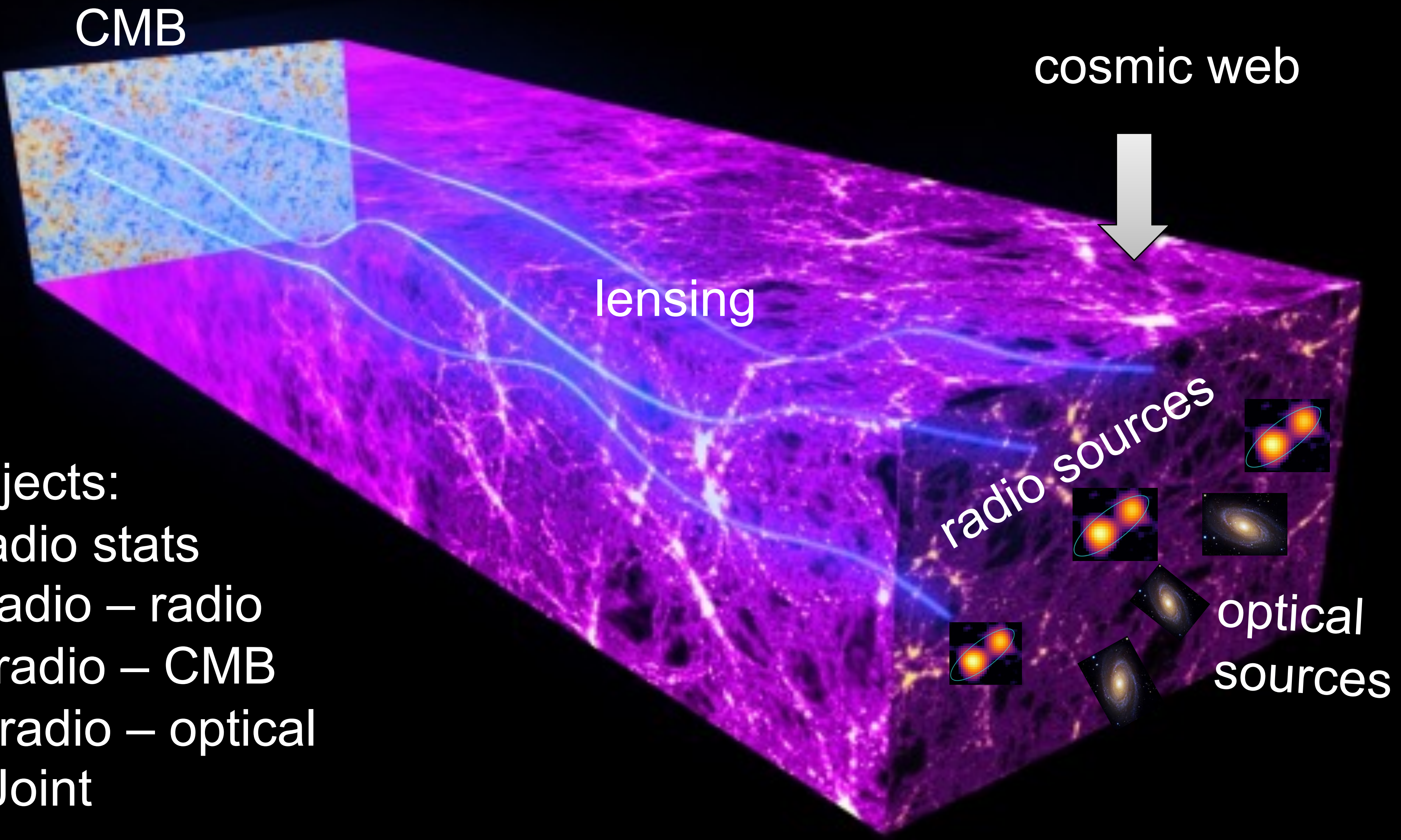
ESA and the Planck Collaboration



ESA and the Planck Collaboration



ESA and the Planck Collaboration



Projects:

I. radio stats

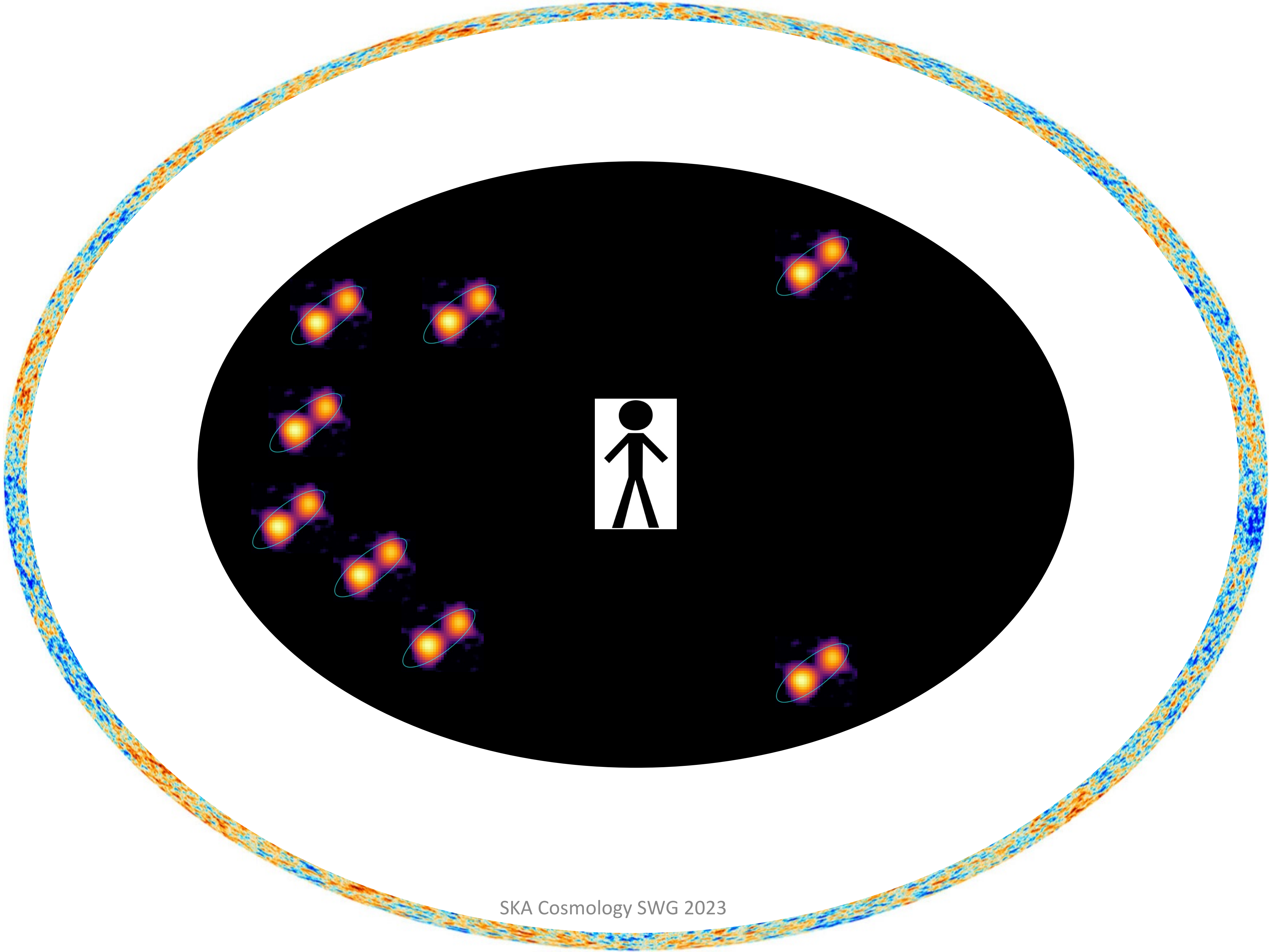
II. radio – radio

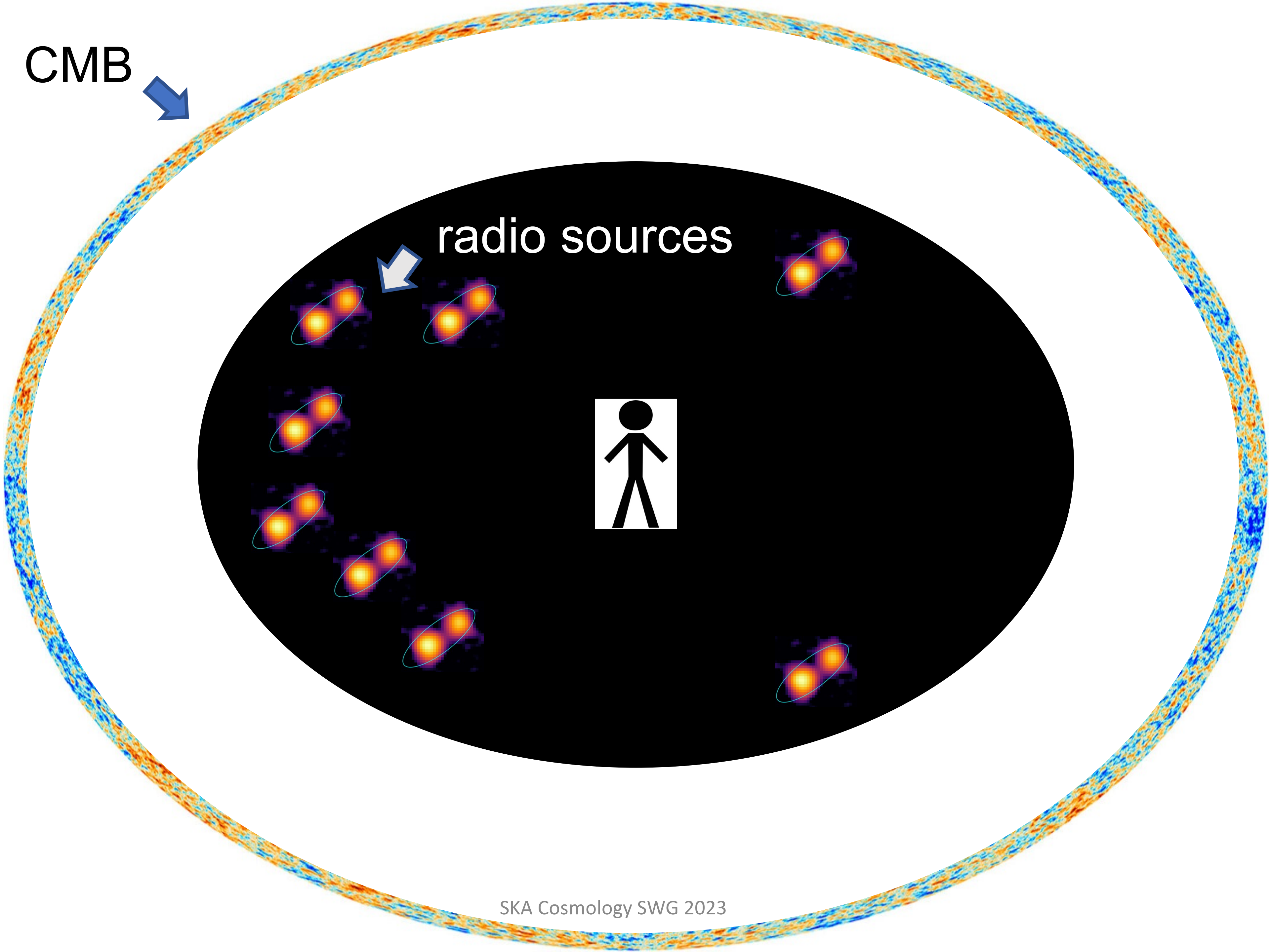
III. radio – CMB

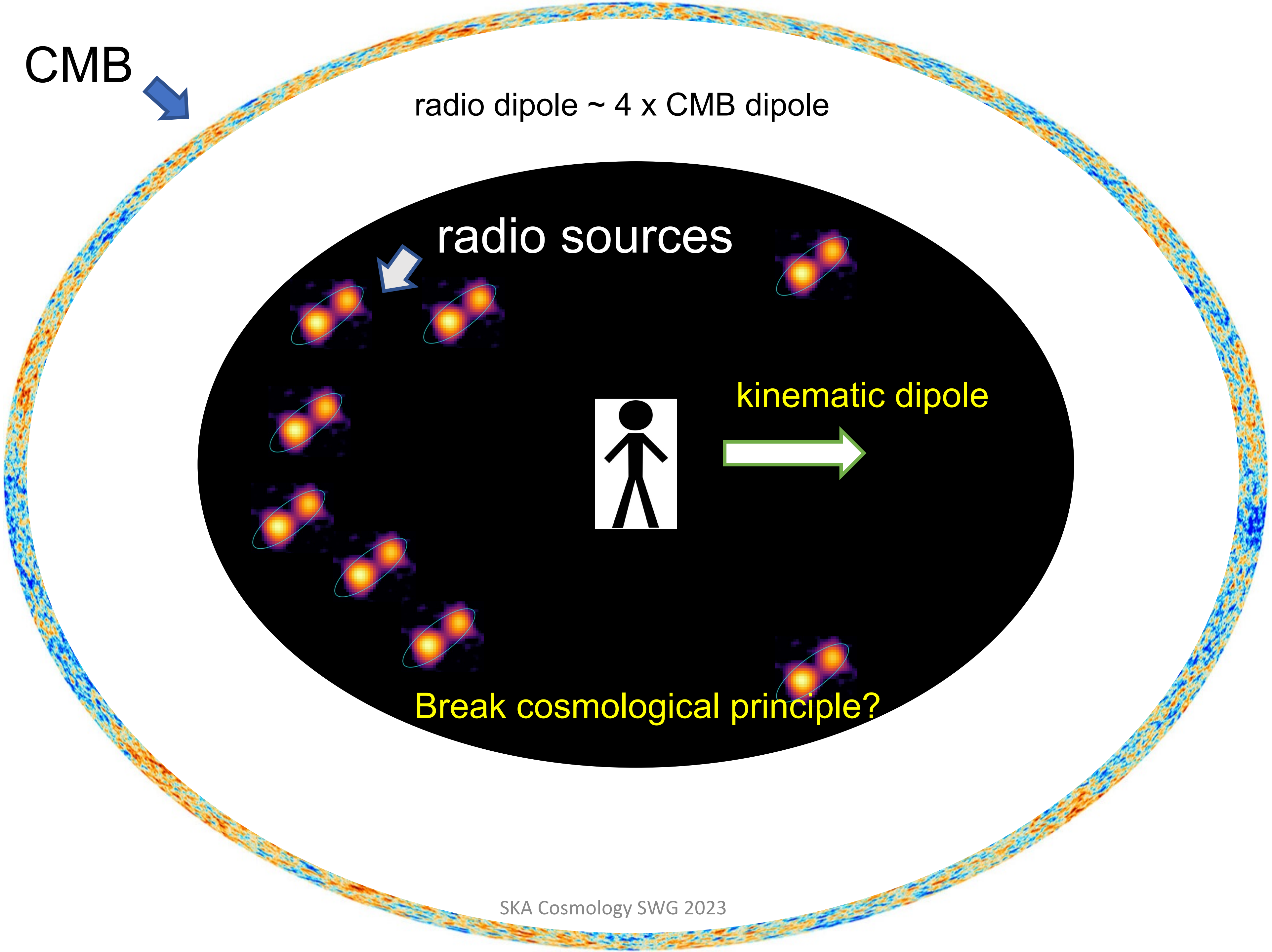
IV. radio – optical

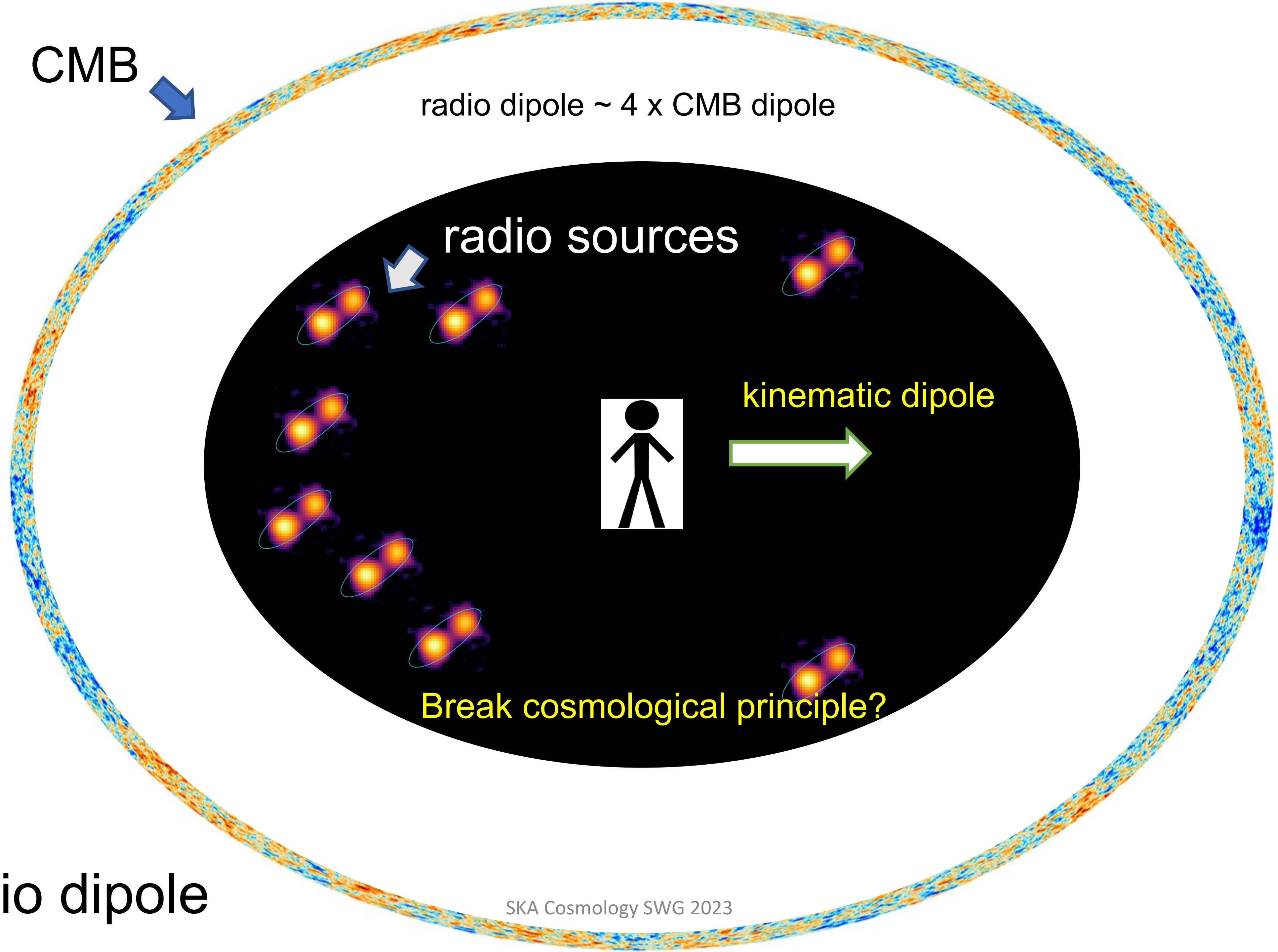
V. Joint

ESA and the Planck Collaboration




CMB
radio sources


CMB
radio dipole ~ 4 x CMB dipole
radio sources
kinematic dipole
Break cosmological principle?



VI. radio dipole

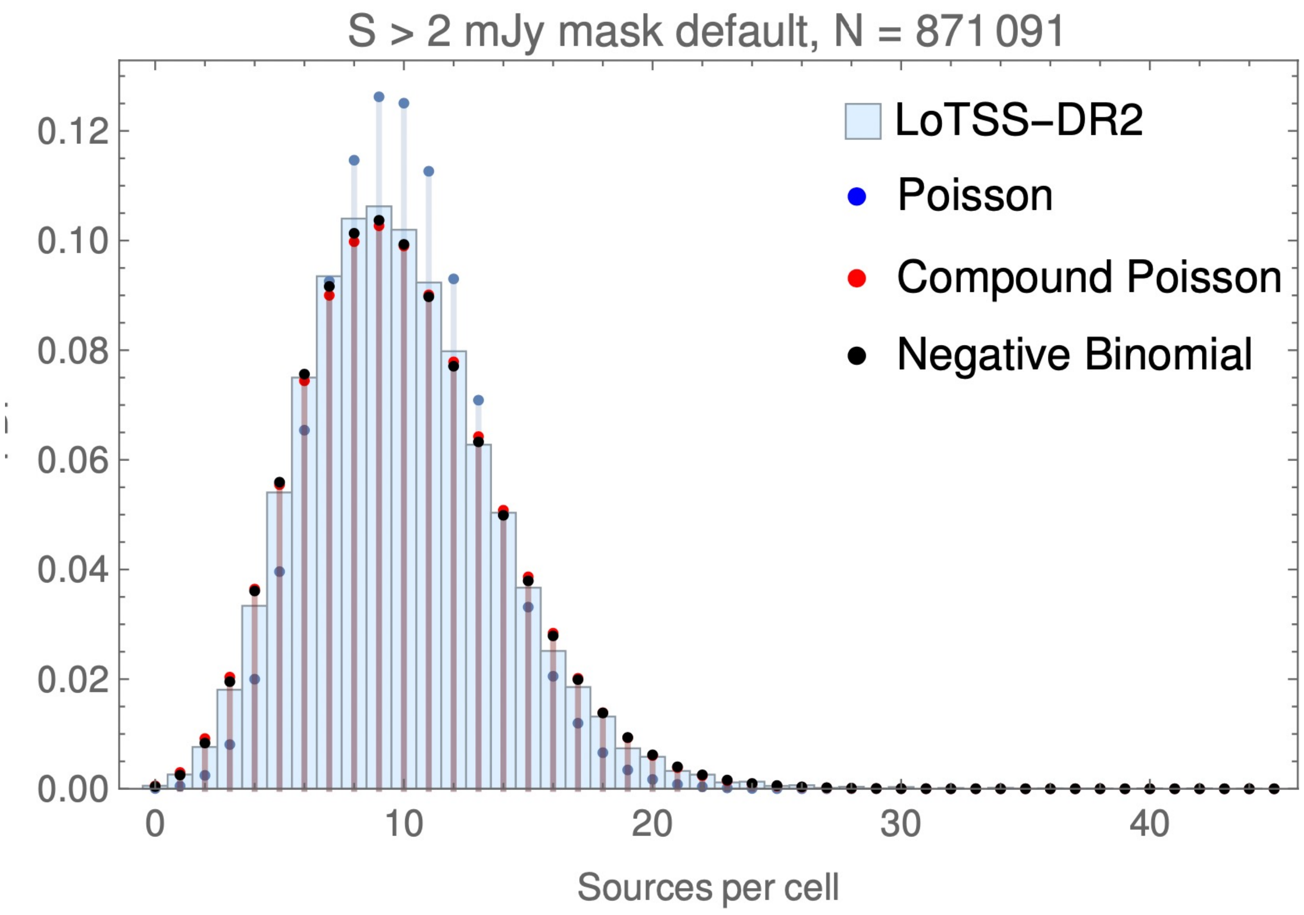
I. Count-in-cell statistics (Pashapouramadabadi, Siewert et al.)

- Cosmological principle: **isotropic sky**
- Naïve expectation: **Poisson distribution** of radio sources
- But: **noise fluctuations**, **multi-component sources, artifacts**, …

- Prepare homogeneous sample from **LoTSS-DR2 source catalogue**
  1. identify survey region
  2. mask incomplete and/or noisy regions
  3. apply flux density threshold
- Several **masking strategies** our default: stay away from survey borders and galactic plane
- Look at **counts-in-cell statistics:** about 100.000 Healpix cells with Nside = 256

I. Count-in-cell statistics (Pashapouramadabadi, Siewert et al.)

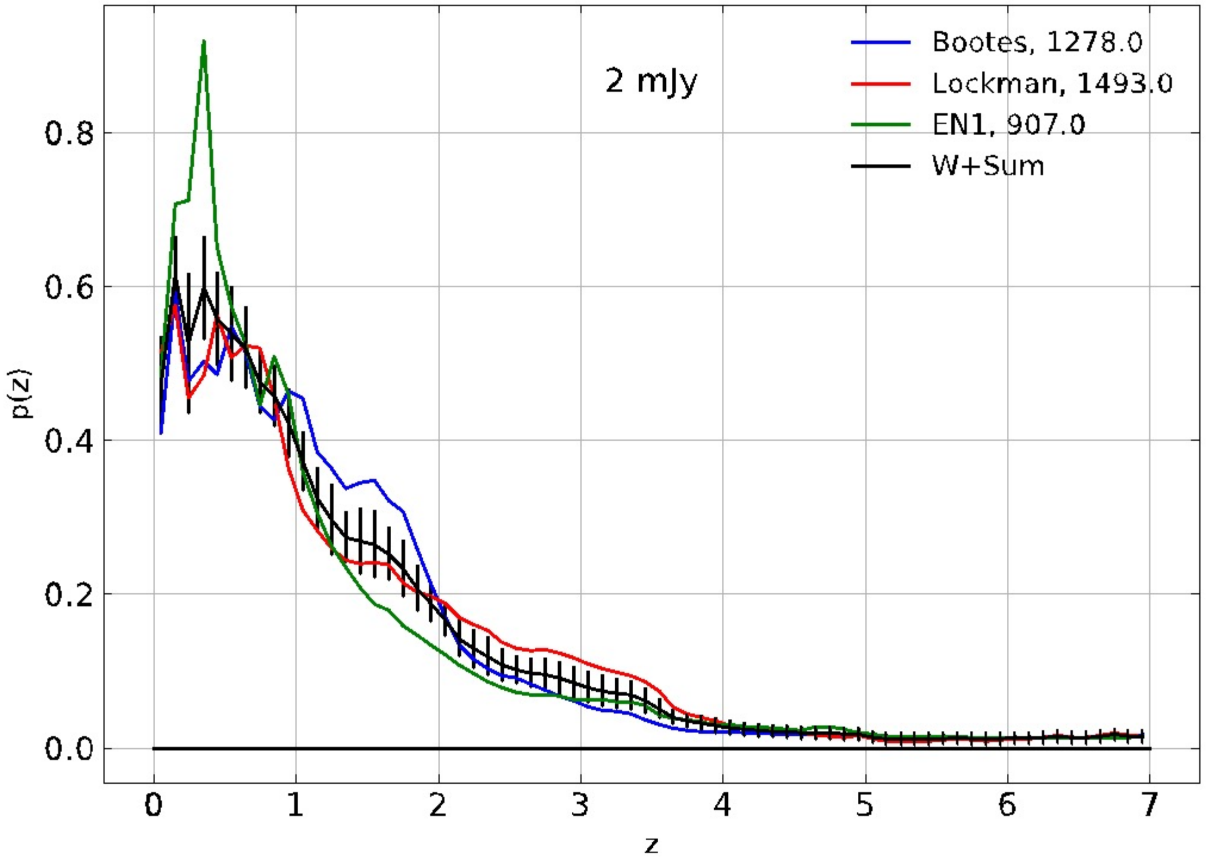
- Compare **LoTSS-DR2 count-in-cell** distribution with **Poisson**, **compound Poisson**, and **negative binomial** distributions:
  Cox processes, i.e. multiple components, fit better than Poisson process
- confirms LoTSS-DR1 analysis (Siewert et al. 2019)



I. Redshift distribution from LoTSS Deep-DR1 (Bhardwaj et al.)

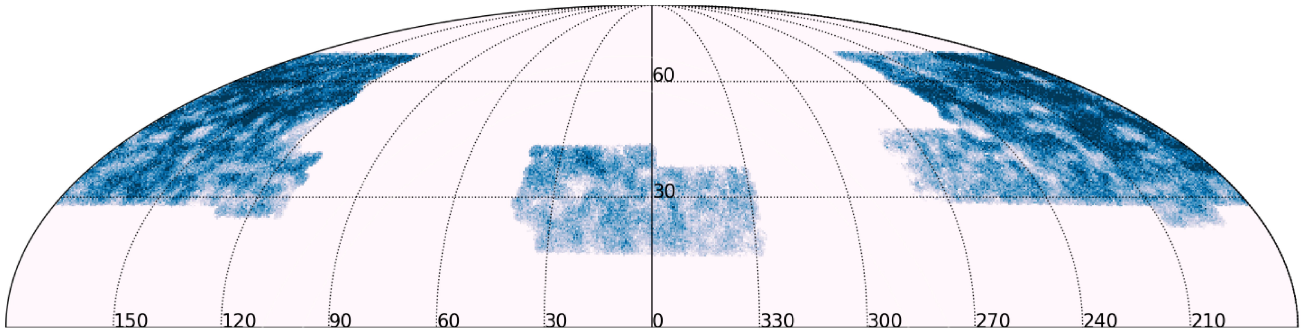
To compare cosmological models:
estimate redshift of radio sources

Models or measurements from photo-z posteriors in LoTSS Deep-DR1

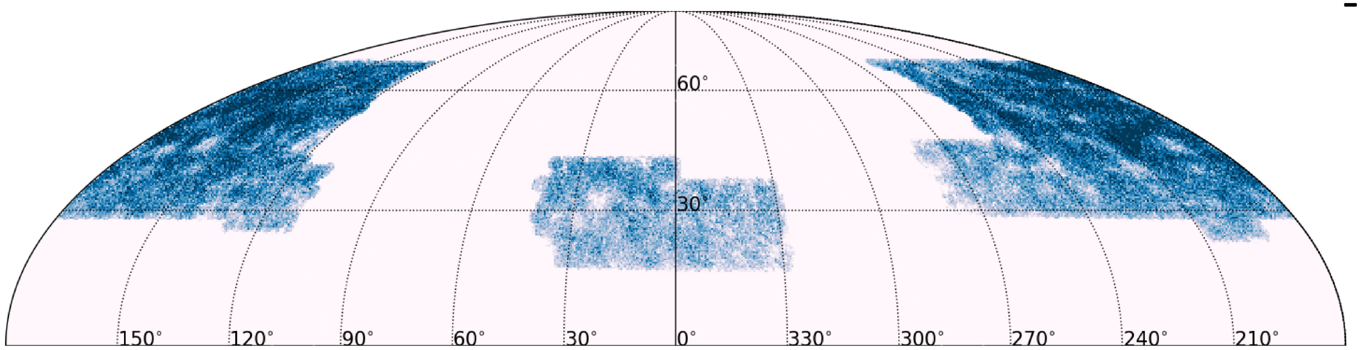


II. Auto-correlation (Hale et al.)

Data



Randoms



Generate Mock Random Sources across the field, taking into account:

- <u>Expected flux density distribution</u>

  Using simulated catalogues from Wilman+ 2008

- <u>Completeness</u> due to sensitivity variation and source finder detection

  Using simulations for each pointing from Shimwell+ 2022

- Differences between <u>measured</u> and <u>intrinsic</u> fluxes to account for Eddington and source finder bias

  Using simulations for each pointing from Shimwell+ 2022

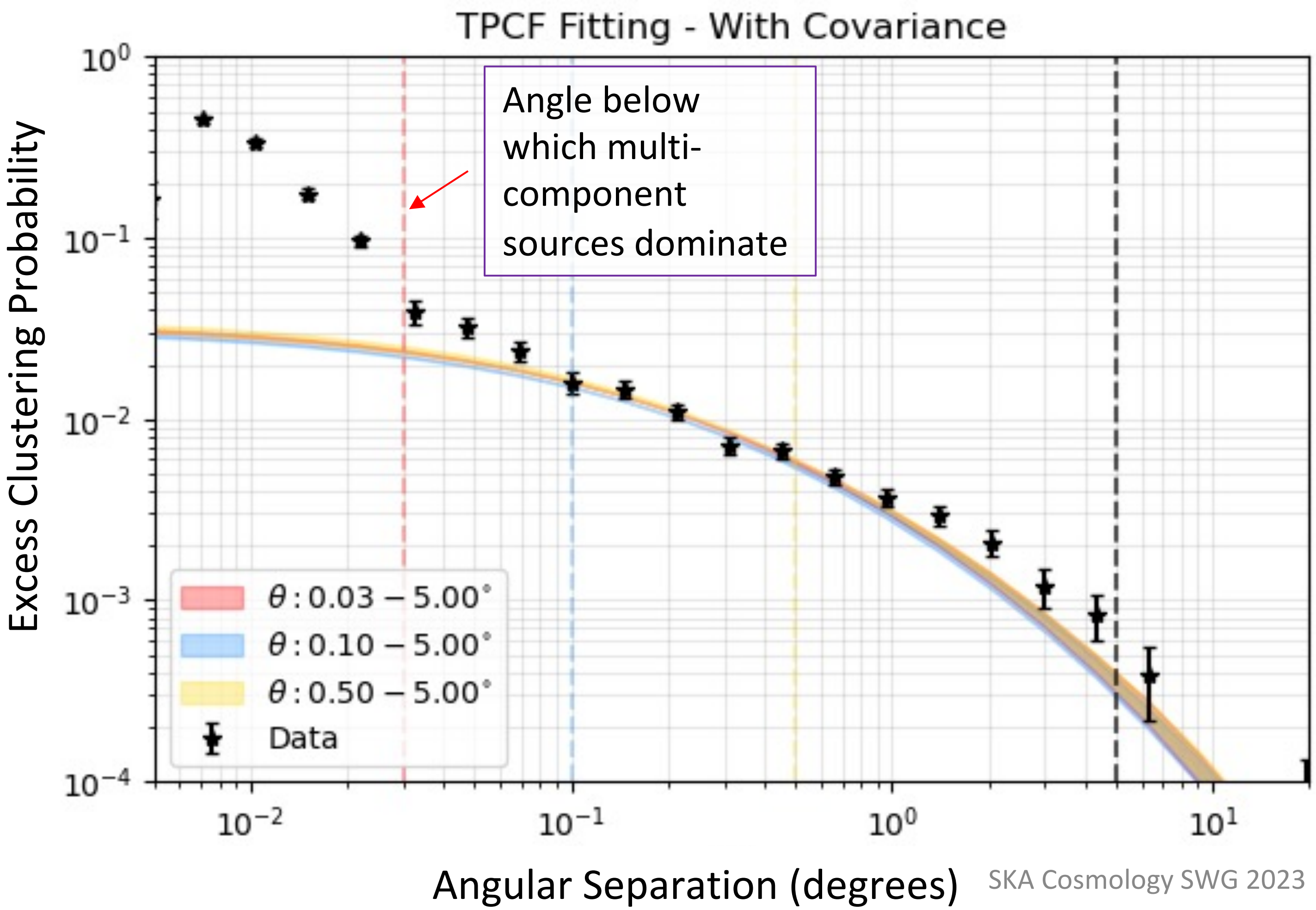
- <u>Source size distribution</u> to account for resolution bias

  Using simulated catalogues from Wilman+ 2008

- <u>Smearing</u> across the field of view

II. Auto-correlation (Hale et al.)

Angular Clustering of LoTSS Sources with SNR>7.5 and Flux density > 1.5 mJy



Compute angular two-point correlation function (TPCF):

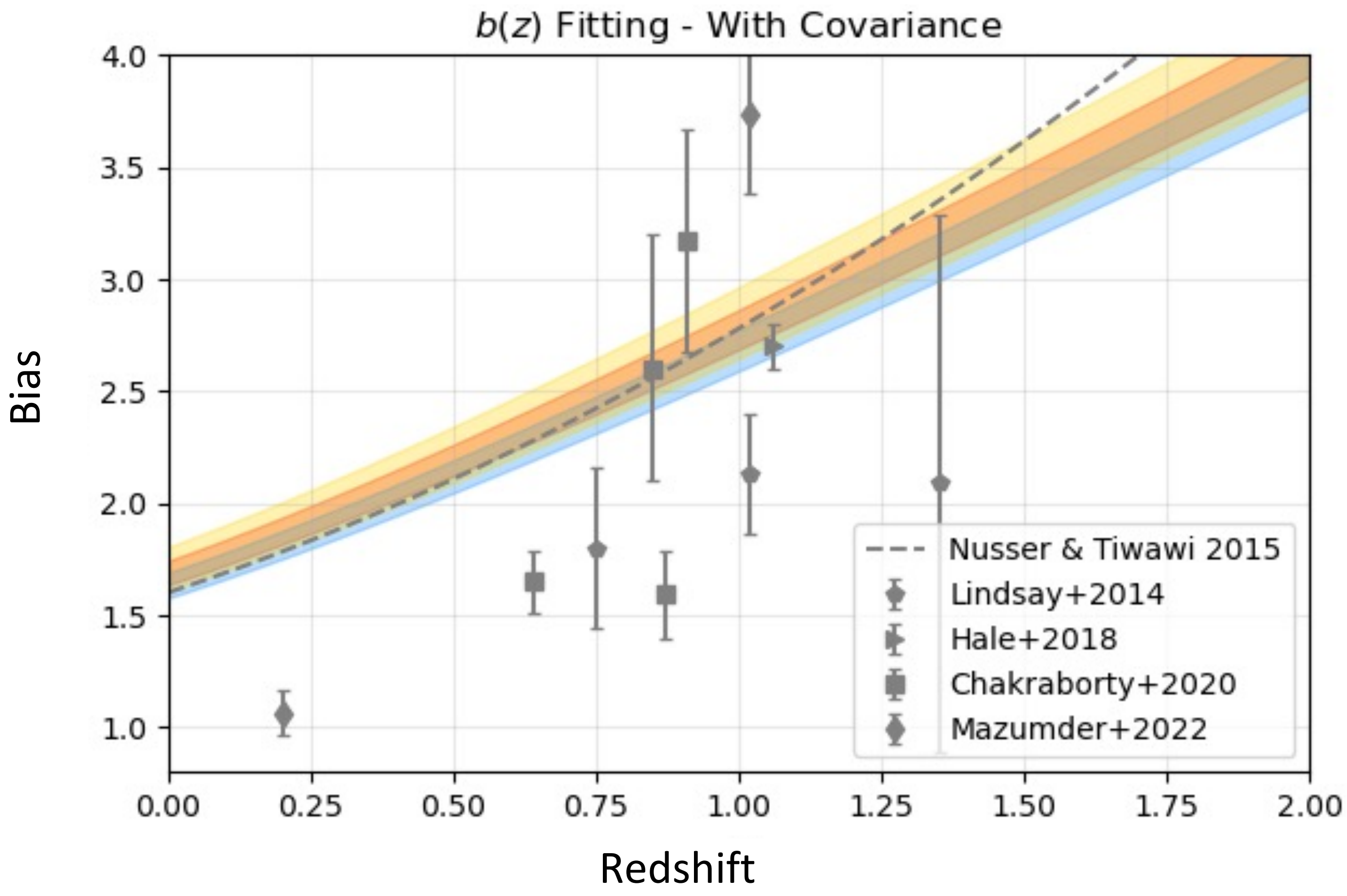
- Excess probability to detect galaxies in given angular separations compared to randomly distributed sources*
- Allows us to understand large scale structure
- Combine with redshift information to understand bias
- Bias describes clustering compared to dark matter and can infer dark matter halo mass

* Using randoms described earlier

Work makes use of PyCCL: Chisari+2019

II. Auto-correlation (Hale et al.)

Evolution of Bias of LoTSS Sources with SNR>7.5 and Flux density > 1.5 mJy



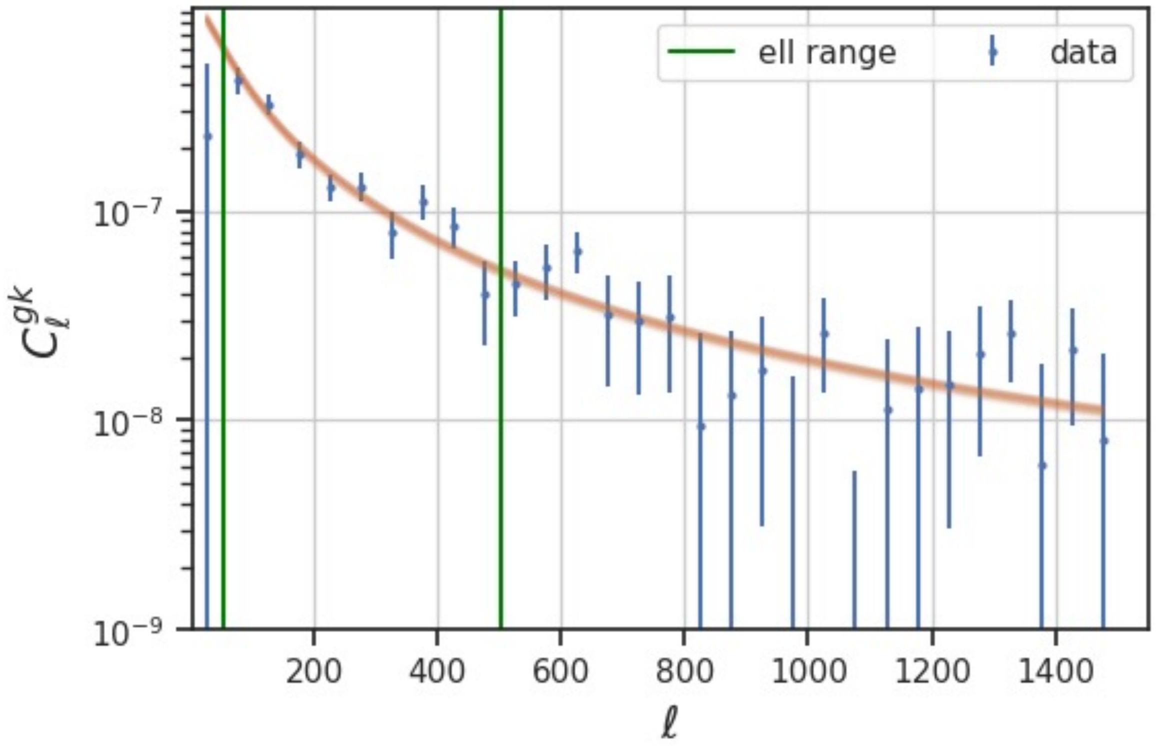
Different colours = Using different θ_{Min} in the fitting

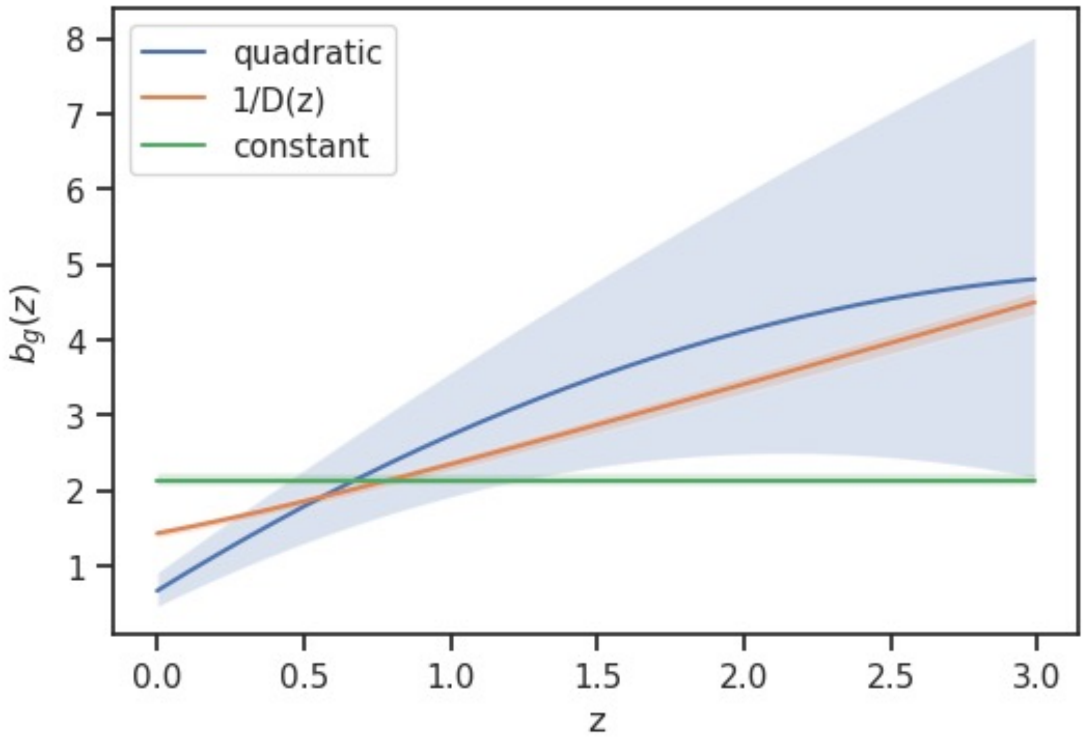
Fit using pyCCL assuming a linear model.

Redshift distribution from LOFAR deep fields

Work in Progress

III. Cross-correlation with CMB lensing and temperature (Nakoneczny et al. see also next talk)

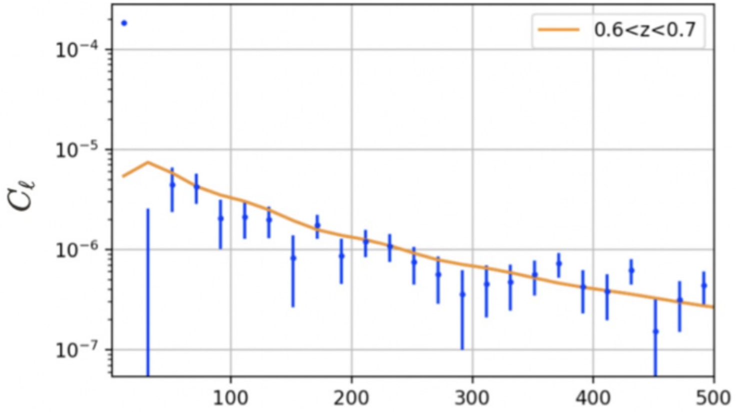


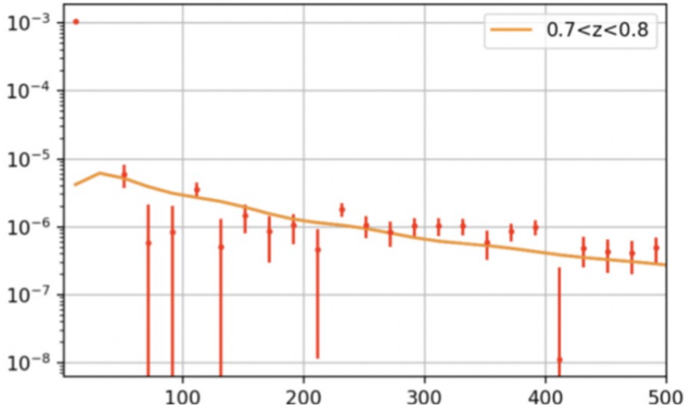


- cross-correlation with CMB lensing: 1.5 mJy, 7.5 SNR, 22 sigma detection
- **Right**: bias constraints: fit to C_gg + C_gk + deep fields + tomographer (tomographer.org)

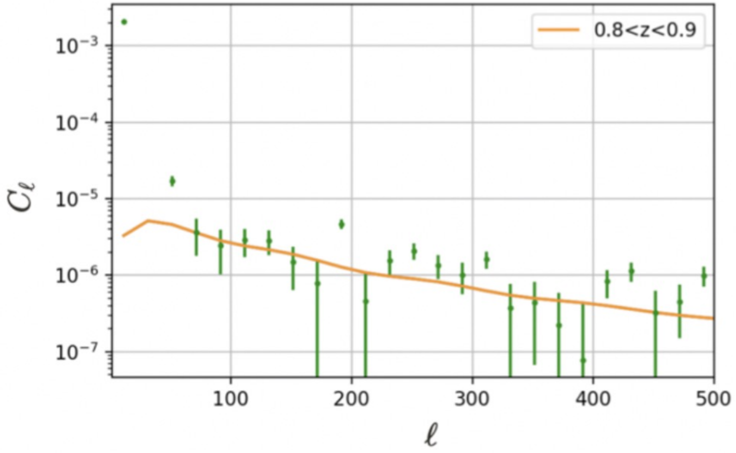
Work in Progress

IV. Cross-correlating with eBOSS(Zheng et al.)

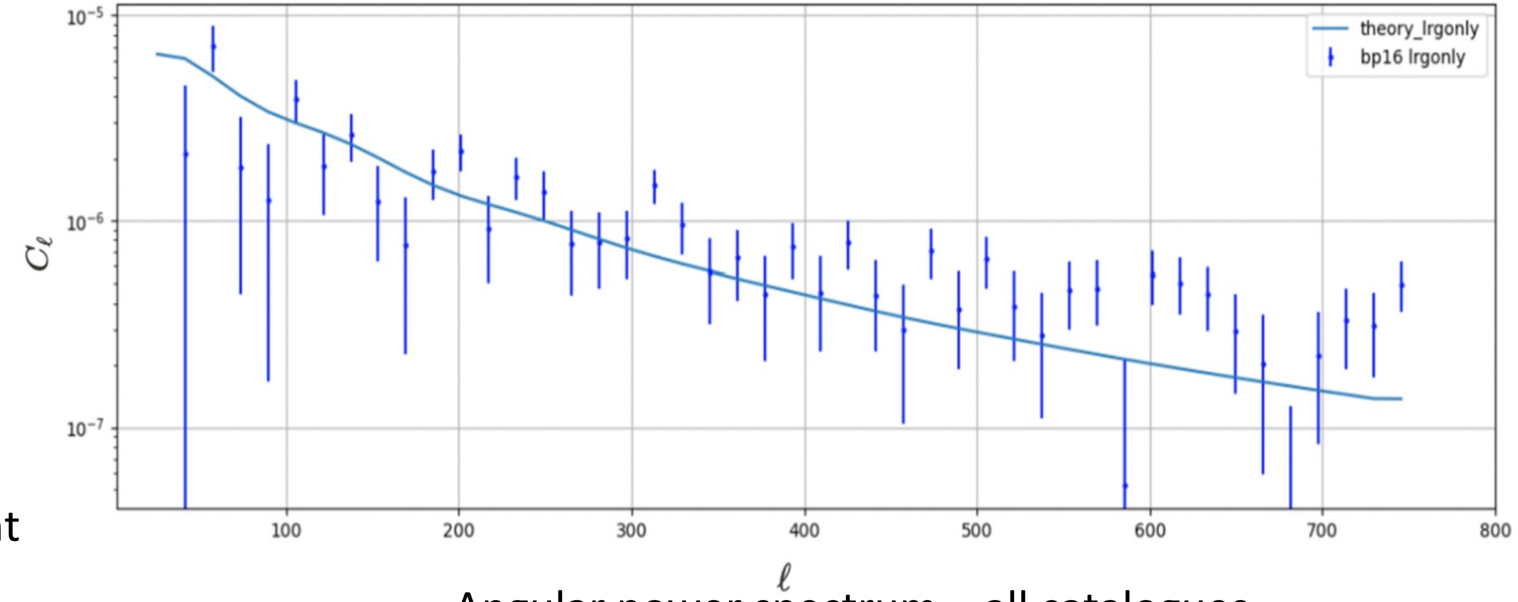




b(z) eBOSS: EZmock
n(z) eBOSS: catalogue
b(z) LoTSS: DR1(Tiwari et al. ApJ 2022)
n(z) LoTSS: T-RECS(Bonaldi et al.)



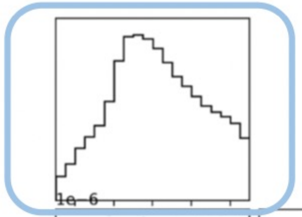
Angular power spectrum from different eBOSS redshift bins



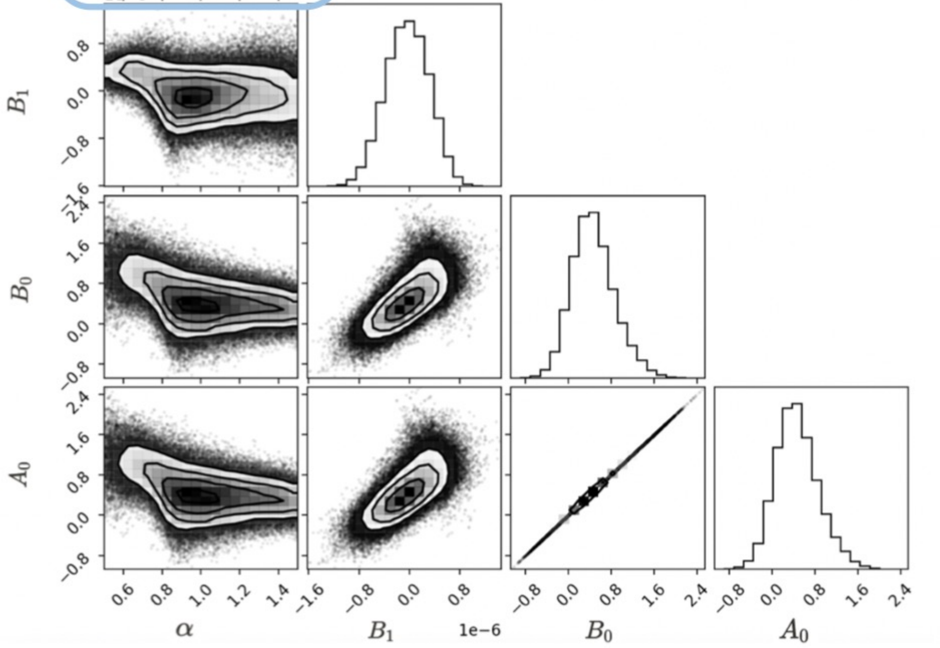
Angular power spectrum – all catalogues

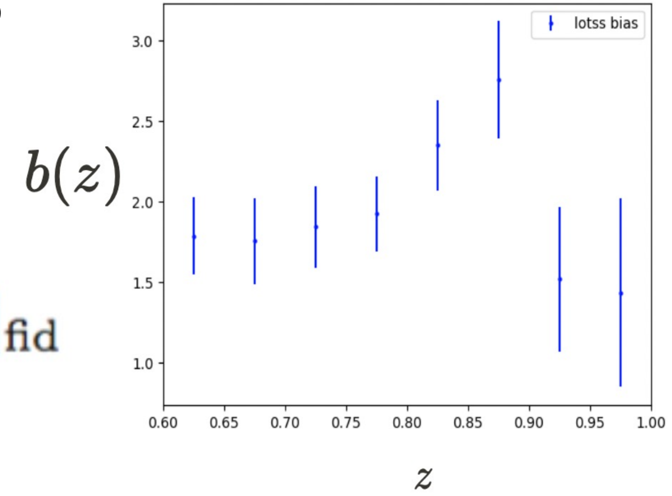
Measurements: BAO and bias

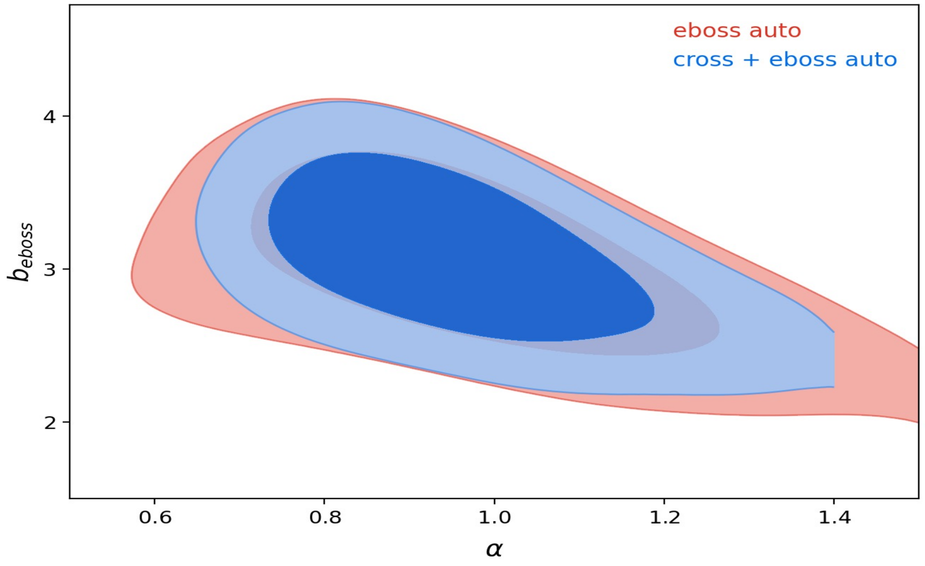
Baryon Acoustic Oscillations : the ‘shift’ parameter of wiggles, indicates **the first BAO detection of radio continuum surveys**



$$\alpha = \ell_{\rm obs}/\ell_{\rm fid} = [D_A(z)/r_s]_{\rm obs}/[D_A(z)/r_s]_{\rm fid}$$







V. Joint constraints (Heneka et al.)

We combine:

- Angular galaxy clustering 'TPCF'
  Redshift distribution pz
- Cross-correlation with CMB lensing 'gk'
- Cross-correlation with eBOSS 'xeBOSS'

Sensitive to:

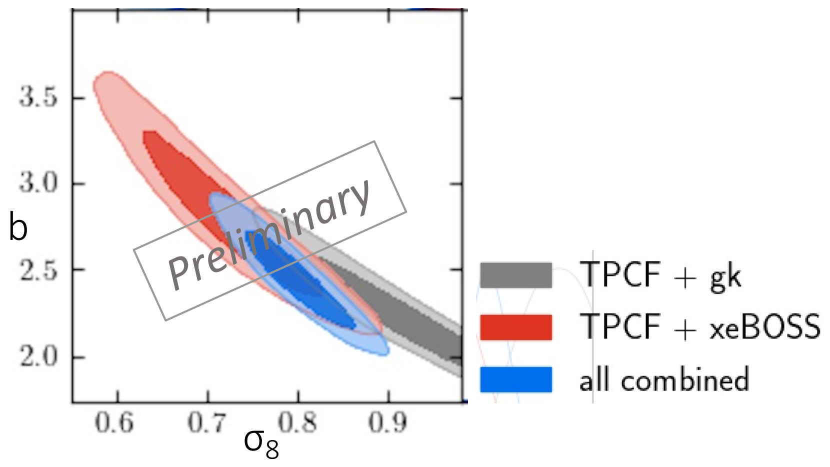
- b, pz
- Ω_m
- σ_8
- Dark energy EOS w

→ We find:

w consistent with LCDM (constrained at about 10% level)

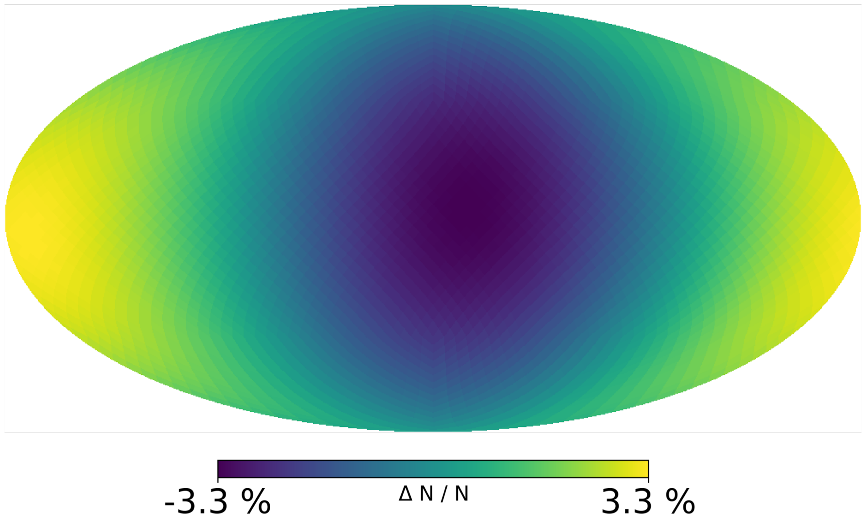
σ_8 (constrained at few % level) consistent with CMB

Bias b (10% level) remains consistent wrt fixed cosmology



Competitive constraints with LOFAR radio survey data for astrophysics & cosmology jointly varied

VI. Cosmic radio dipole (Böhme, Tiwari et al.)



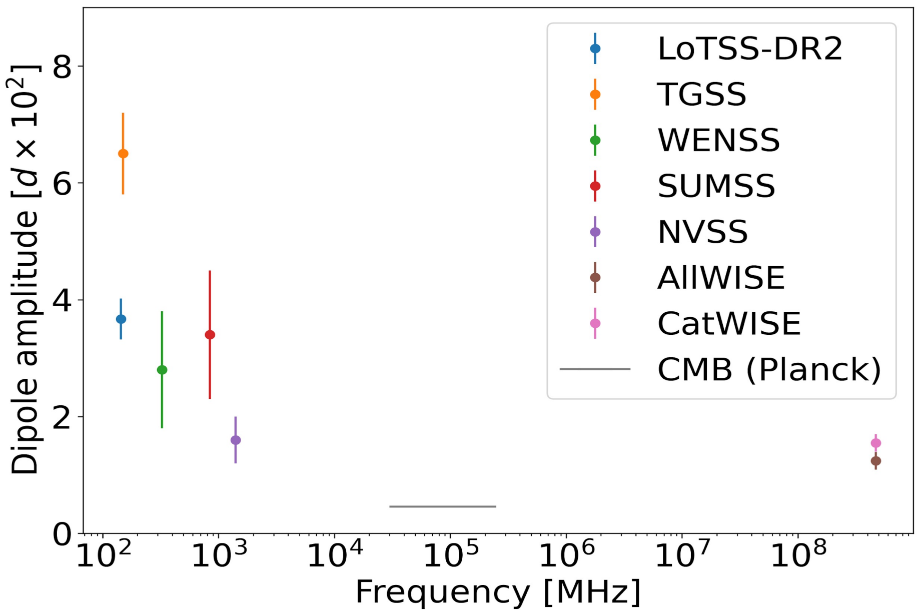
- Proper motion of Solar system
  ⇒ **kinematic dipole** *(Ellis & Baldwin 1984)*

- Compare dipoles at different frequencies:
  test cosmological principle, but

- different, **contradicting** measurements in radio
  (see e.g. Blake & Wall 2002, Singal 2011, Rubart & Schwarz 2013, Nusser & Tiwari 2015, Bengaly et al. 2018, Siewert et al. 2021)

- Simulations: Large signals (d > 0.01) can be detected at high significance from LoTSS-DR2, despite biases due to limited sky coverage

- Now: Test TGSS radio dipole
  Future: Dipole measurement with LoTSS-DR3

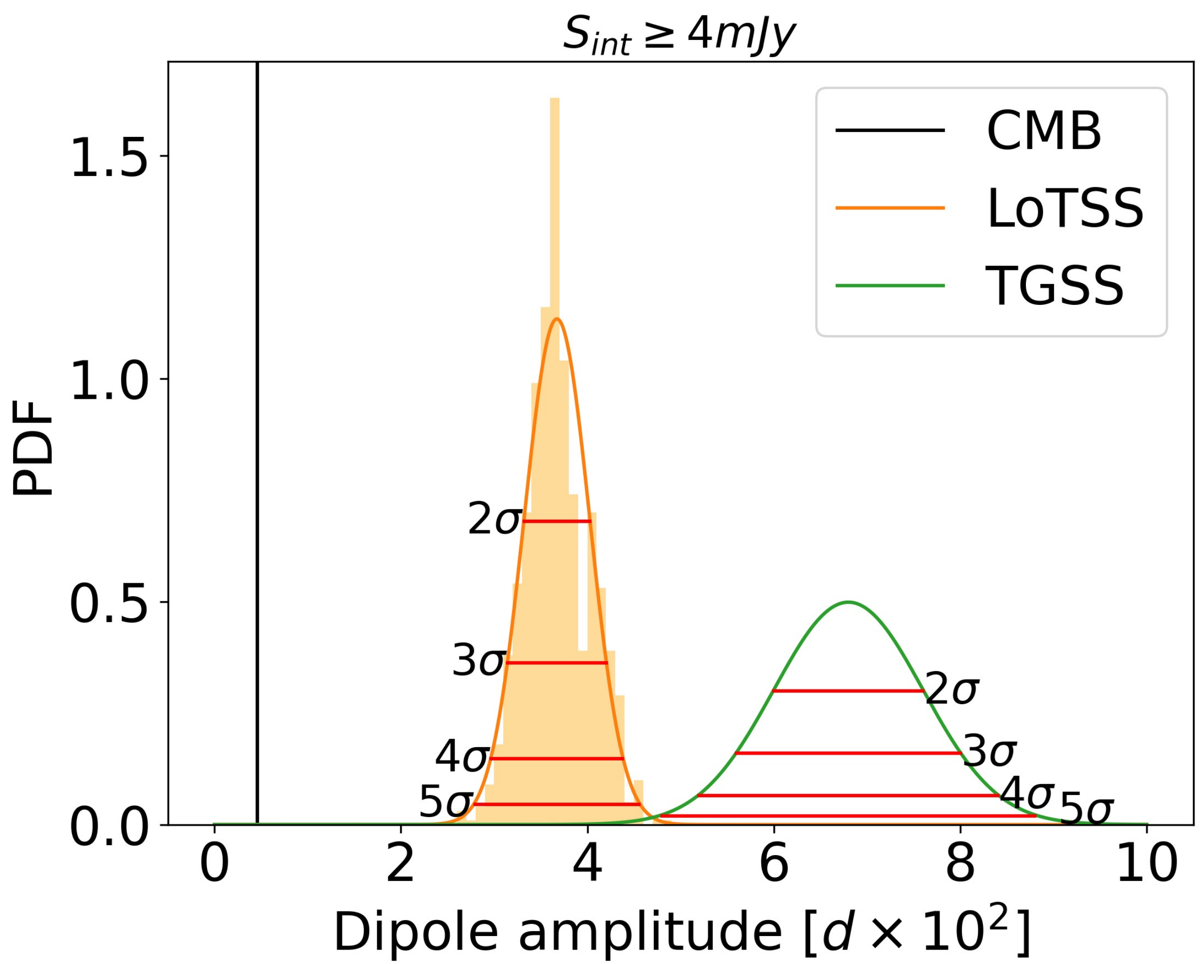


VI. Cosmic radio dipole (Böhme, Tiwari et al.)

- Use LoTSS-DR2 to test TGSS dipole
  (e.g. Bengaly et al. 2018, Siewert et al. 2021)

- **LoTSS-DR2 radio dipole rules out TGSS excess**, but

- **consistent with excess dipoles measured at higher radio frequencies**



Summary

- LoTSS DR2, is indeed capable of measuring cosmological parameters!
- DR1: able to reproduce expectations from cosmology
- DR2: able to present measurements of cosmological parameters; detect physically effects at high statistical significance, e.g. lensing x gal

Outlook

- full data release e.g. DR3
- improve all precisions at least 3 times as much as the statistics for now