Cosmological studies with cosmic microwave background and radio observations

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University of Science and Technology of China

The 6th BRICS-AGAC Symposium
2026/11/07

Outline

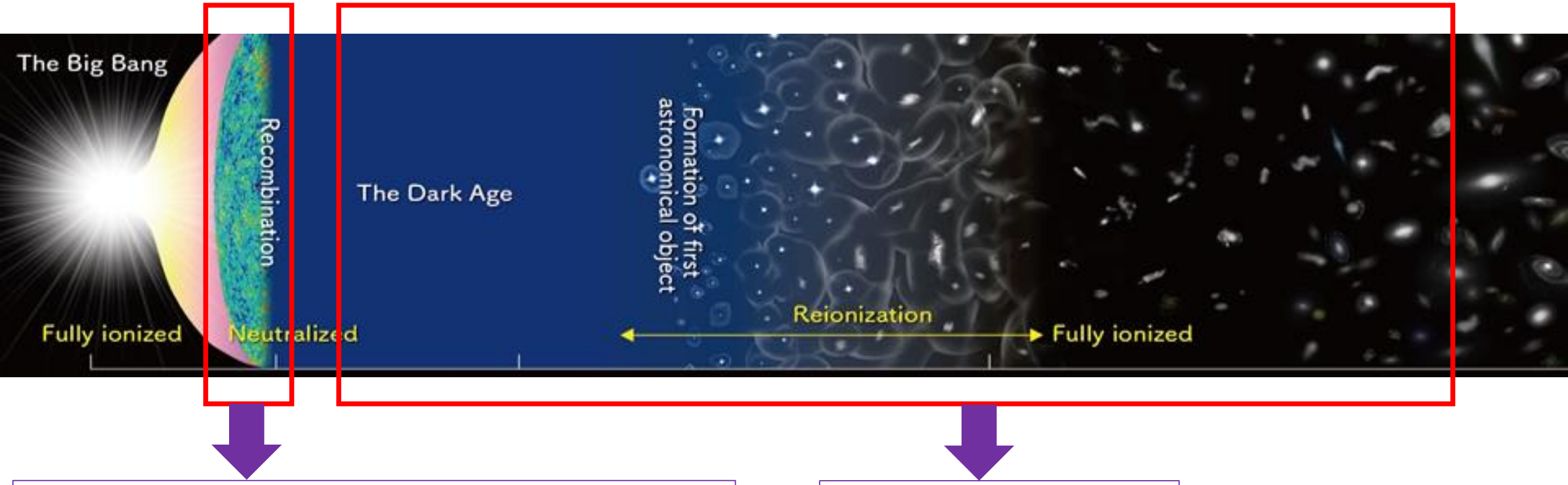
- **The Cosmic Microwave Background polarization**
  - **Polarization signals from large-scale structure and Galactic foreground**
  - **New physics——inflation, primordial magnetic fields, axion-like particles**

- **21 cm intensity mapping**
  - **Detection techniques for neutral hydrogen signals**
  - **New physics ——dynamical dark energy, ultralight axions. neutrinos**

- **Conclusions**

Observations at microwave and radio wavelengths

CMB+21cm probes the largest fluctuation modes crucial for fundamental physics

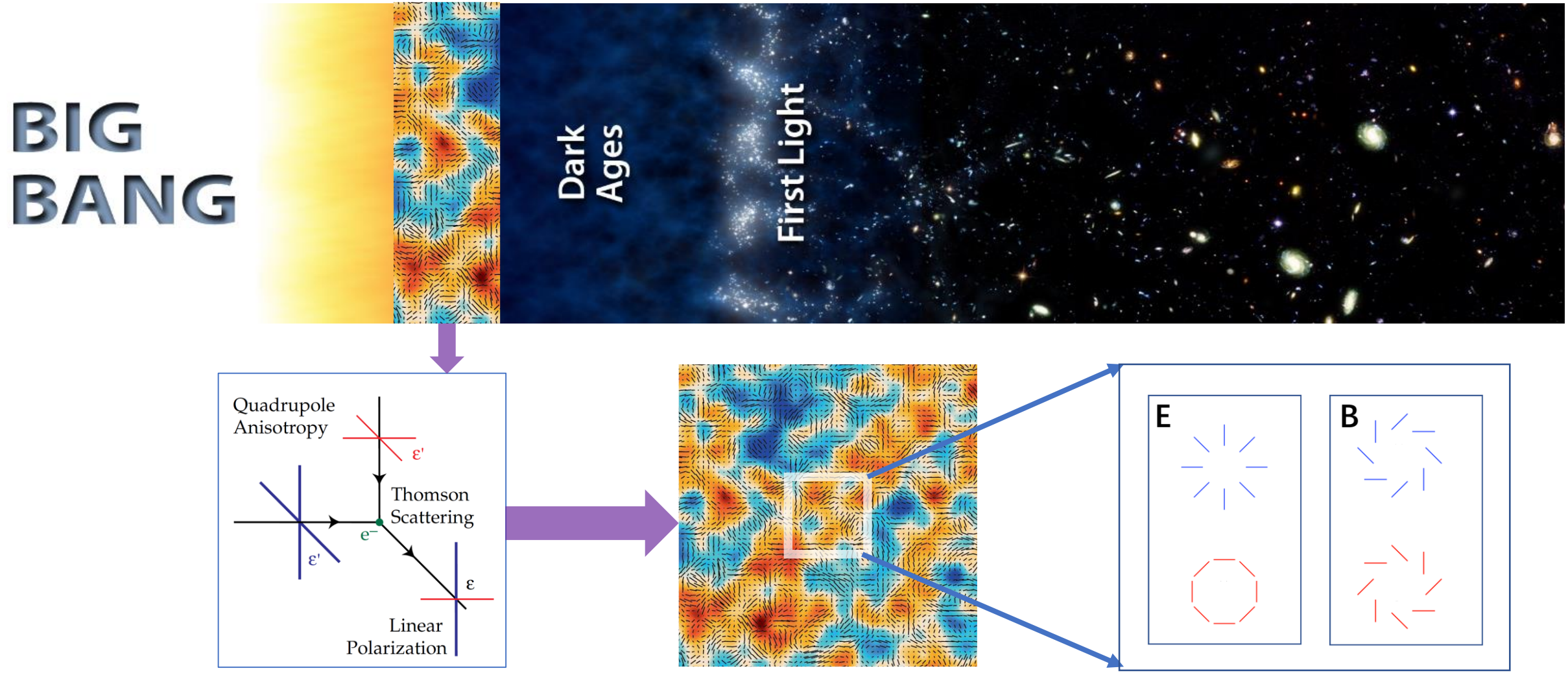


Cosmic Microwave Background (CMB)

Radio wavelengths

Cosmic Microwave Background polarization

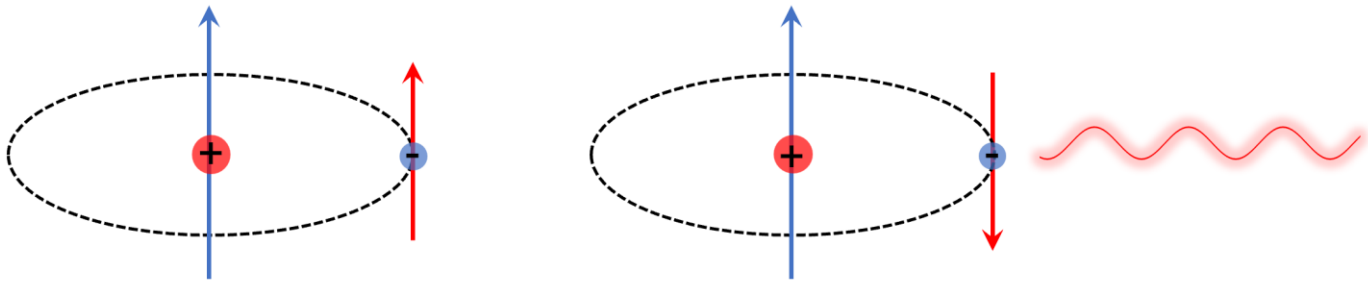
Thomson scattering of temperature anisotropies generates a linear polarization pattern



W. Hu et al. New Astron.2:323,1997

21 cm lines and radio observations

- Tracing the spatial and temporal information of our Universe at radio wavelengths



21 cm line of neutral hydrogen

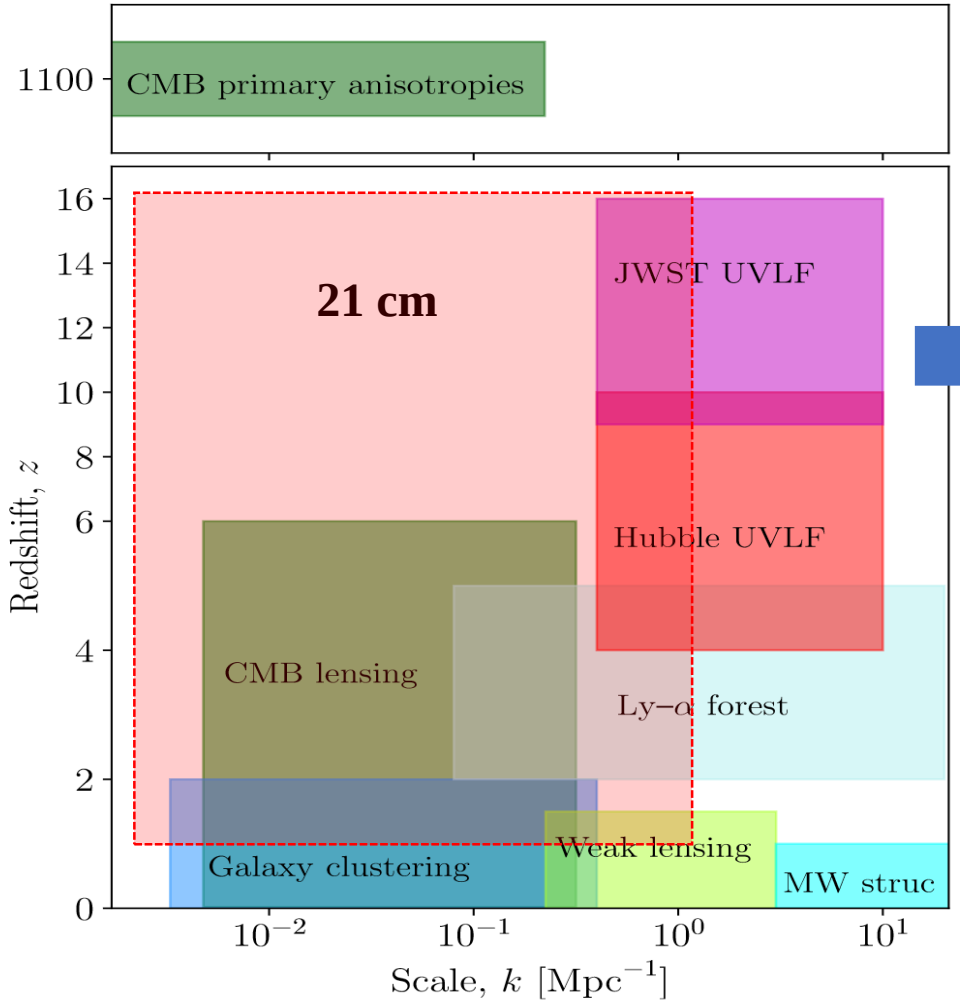


Redshifted 21 cm signals as the Universe is expanding



Studying the dark sectors with CMB+21 cm signals

☐ A broad spatial and temporal coverage

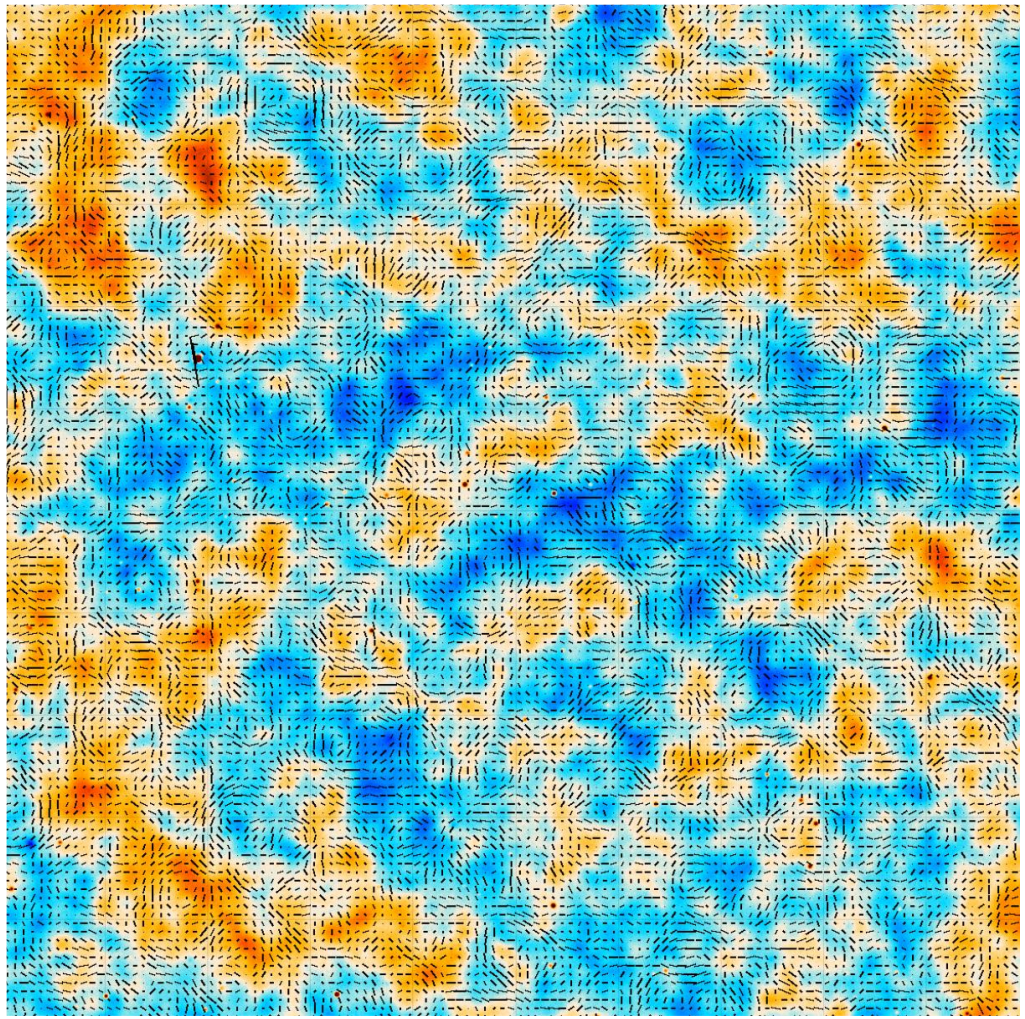


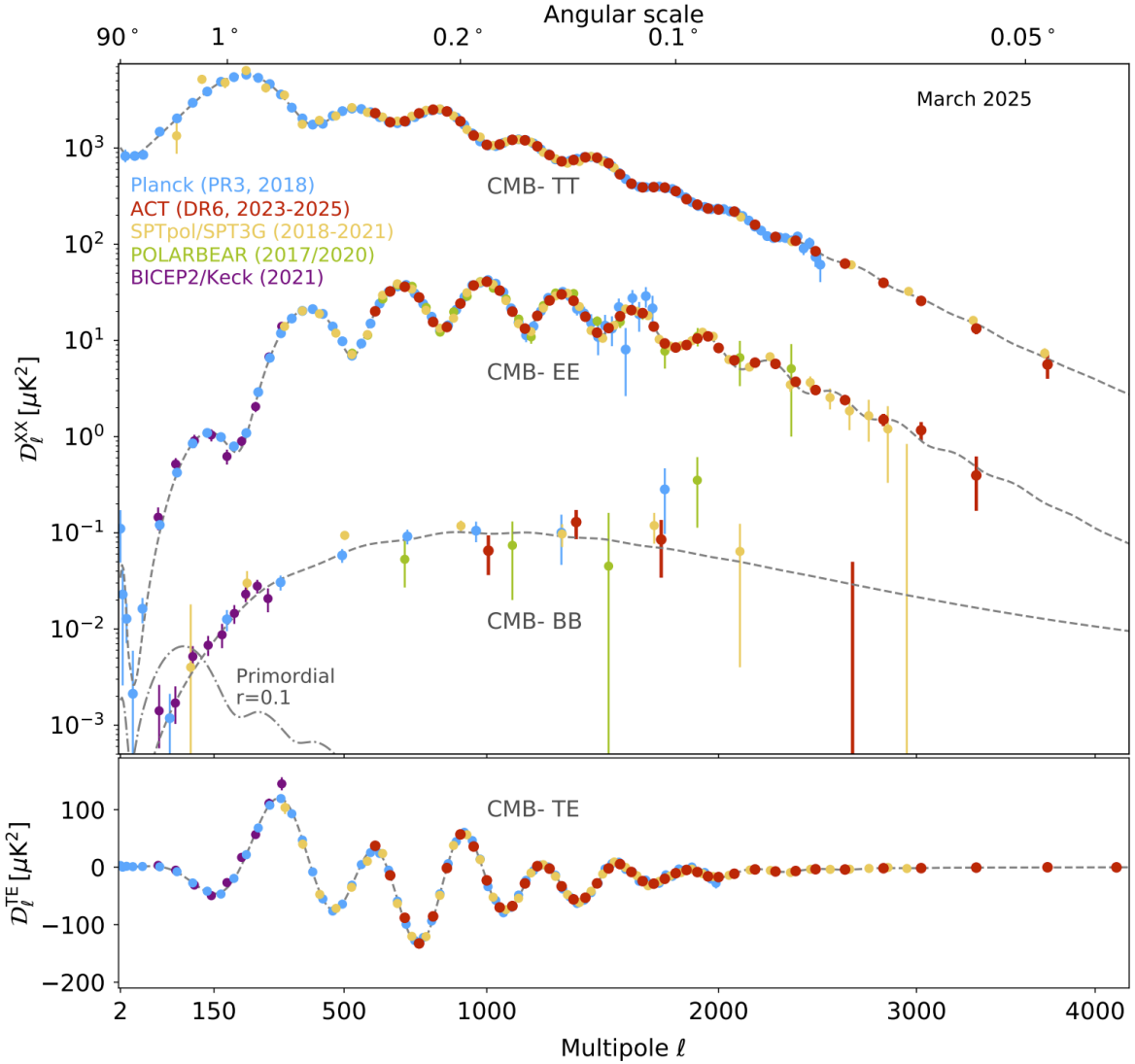
☐ A joint cosmological probe with CMB+21 cm

- ✓ **Large-scale structure**
- ✓ **Parity violating physics**
- ✓ **Dark matter (warm, fuzzy, …)**
- ✓ **Dark energy (dynamical…)**
- ✓ **Modified gravity**
- ✓ **…**

Latest measurements of CMB polarization

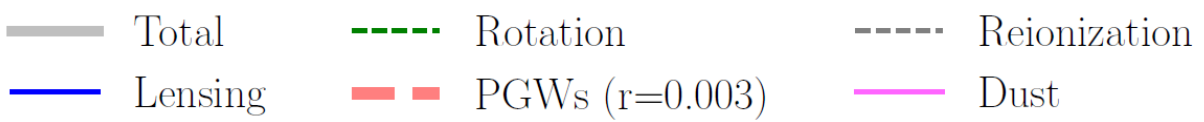
ACT DR6 Data Release. arXiv:2503.14451, arXiv:2503.14452



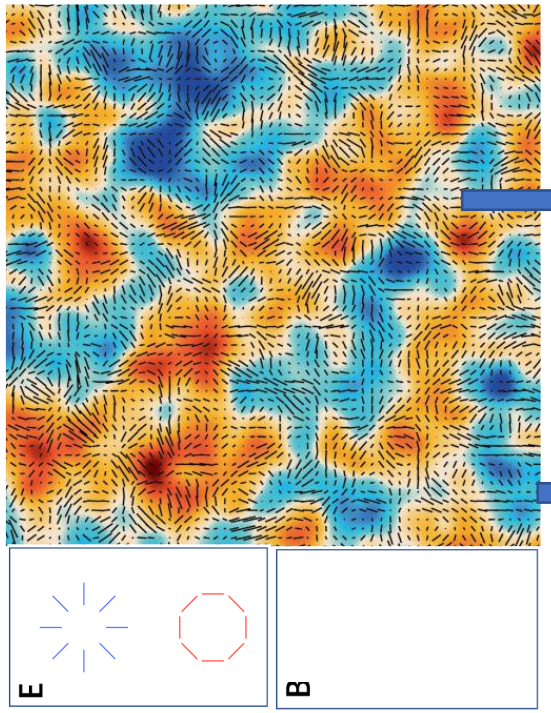


Polarization signals from Galactic dust & gravitational lensing

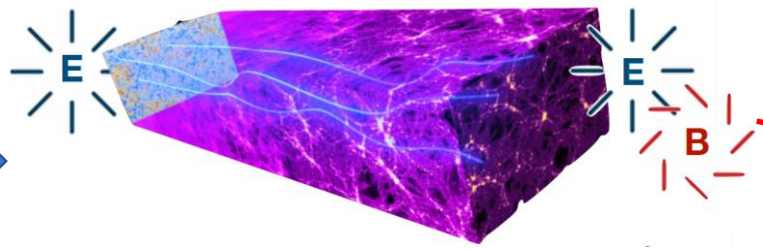
Different B-mode polarization!



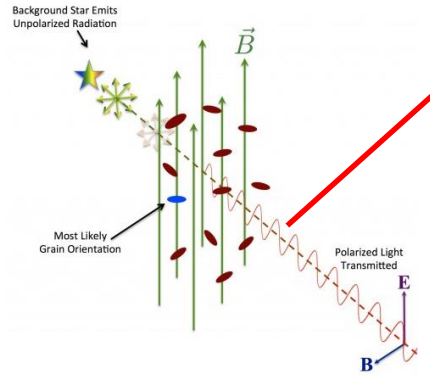
Primordial polarization



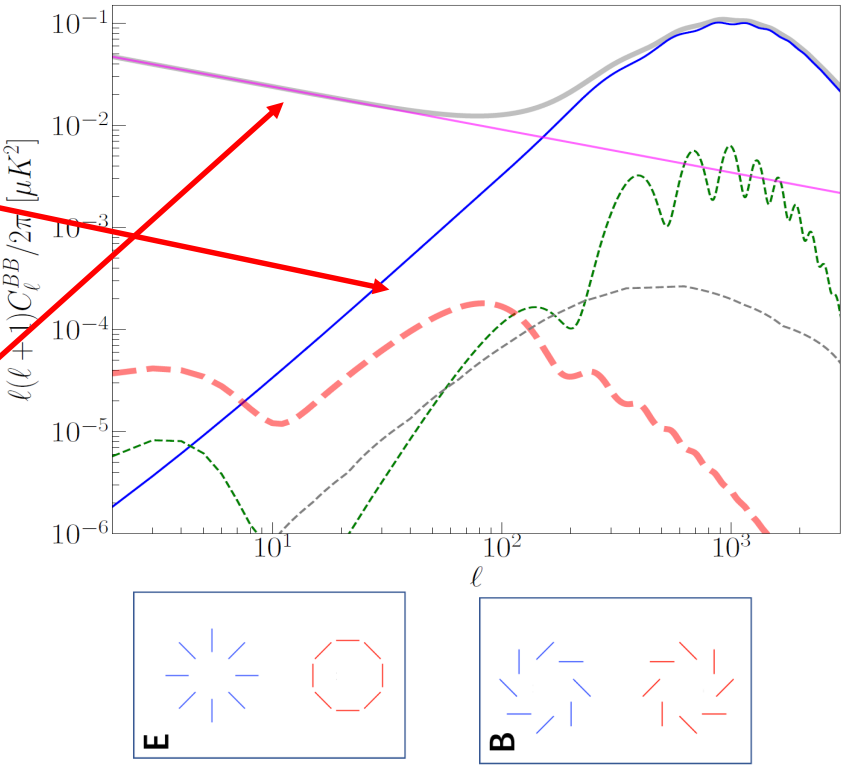
Gravitational lensing



Galactic dust

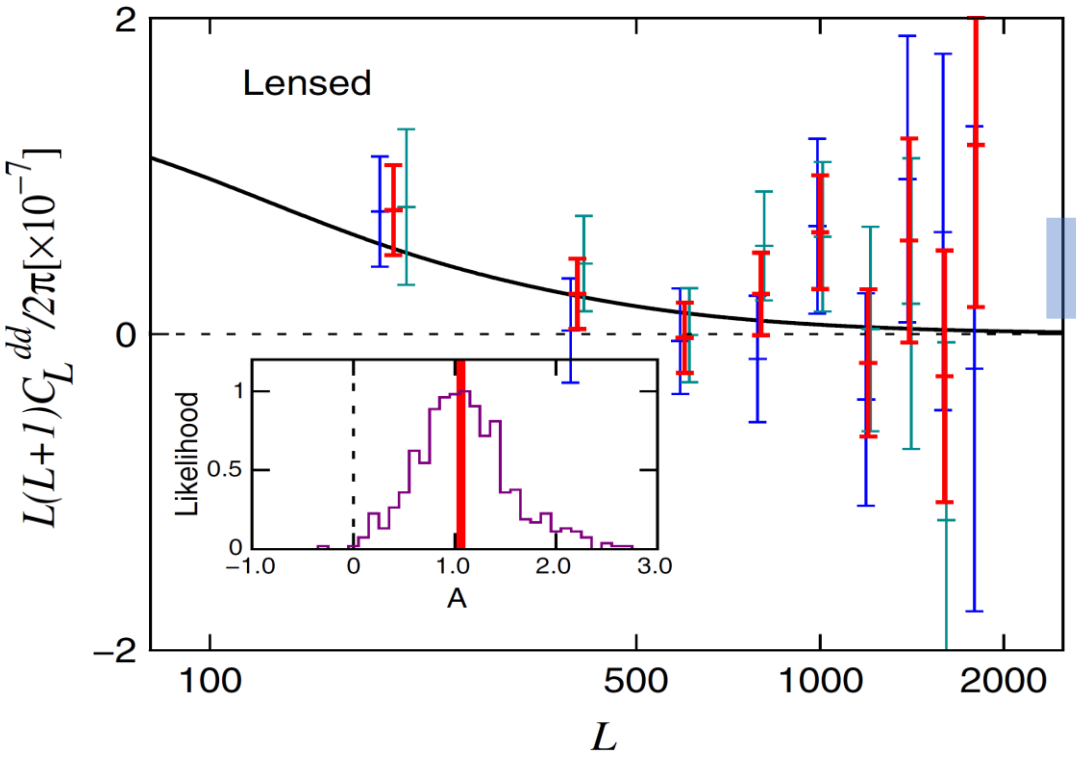


B-mode power spectra



Polarization lensing measurements

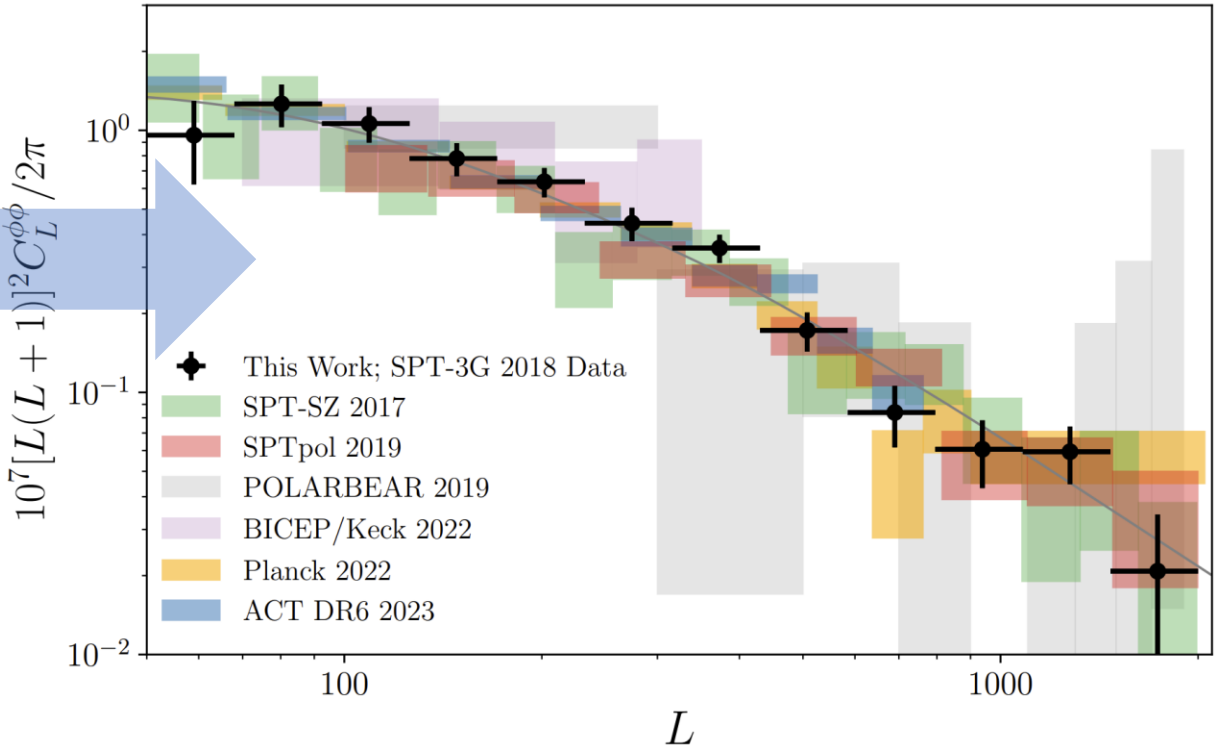
First internal detection of CMB polarization lensing



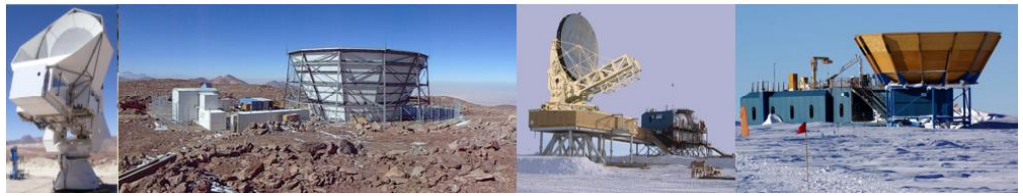
The POLARBEAR Collaboration (C. Feng*).
Phys. Rev. Lett. 113 (2014) 021301. Editors' Suggestion.
Citation 166.

The POLARBEAR Collaboration (+C. Feng).
Phys. Rev. Lett. 112, 131302 (2014). Editors' Suggestion.

Latest CMB lensing measurements



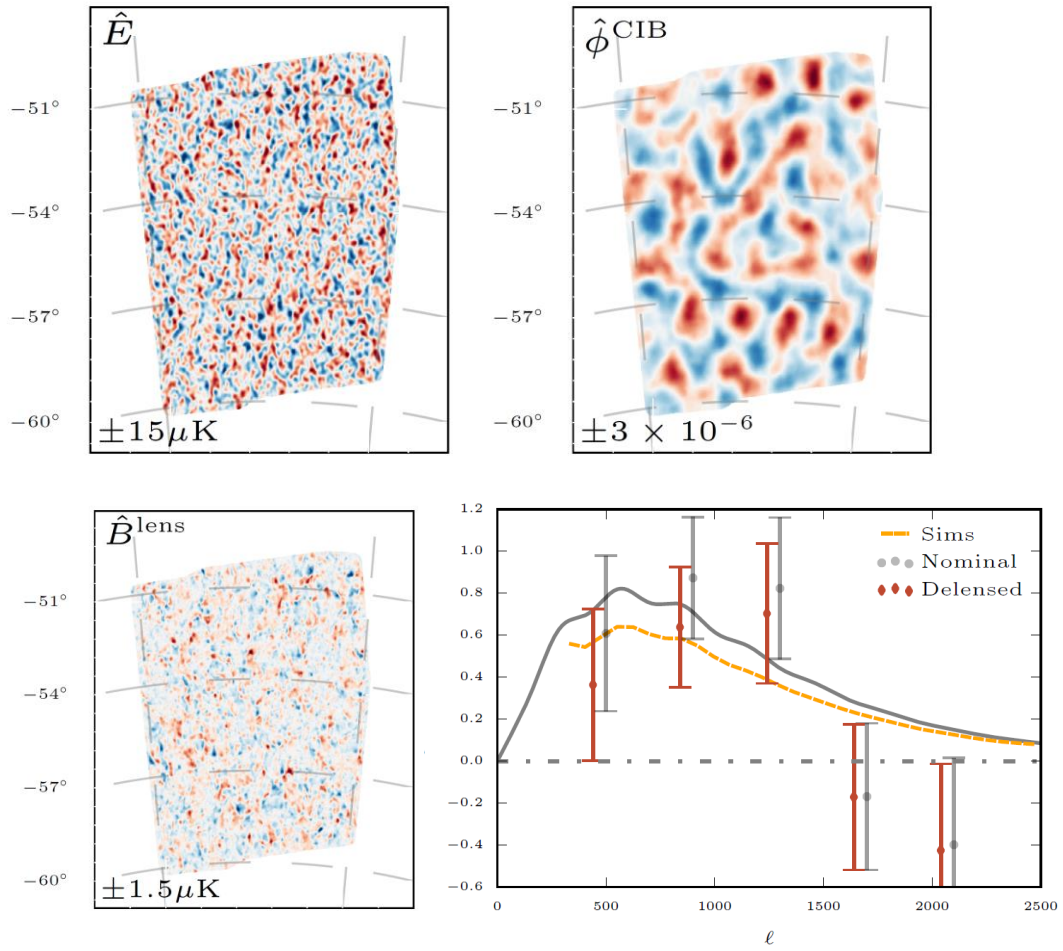
Z. Pan et al. Physical Review D, 108, 122005 (2023)



Impact on delensing

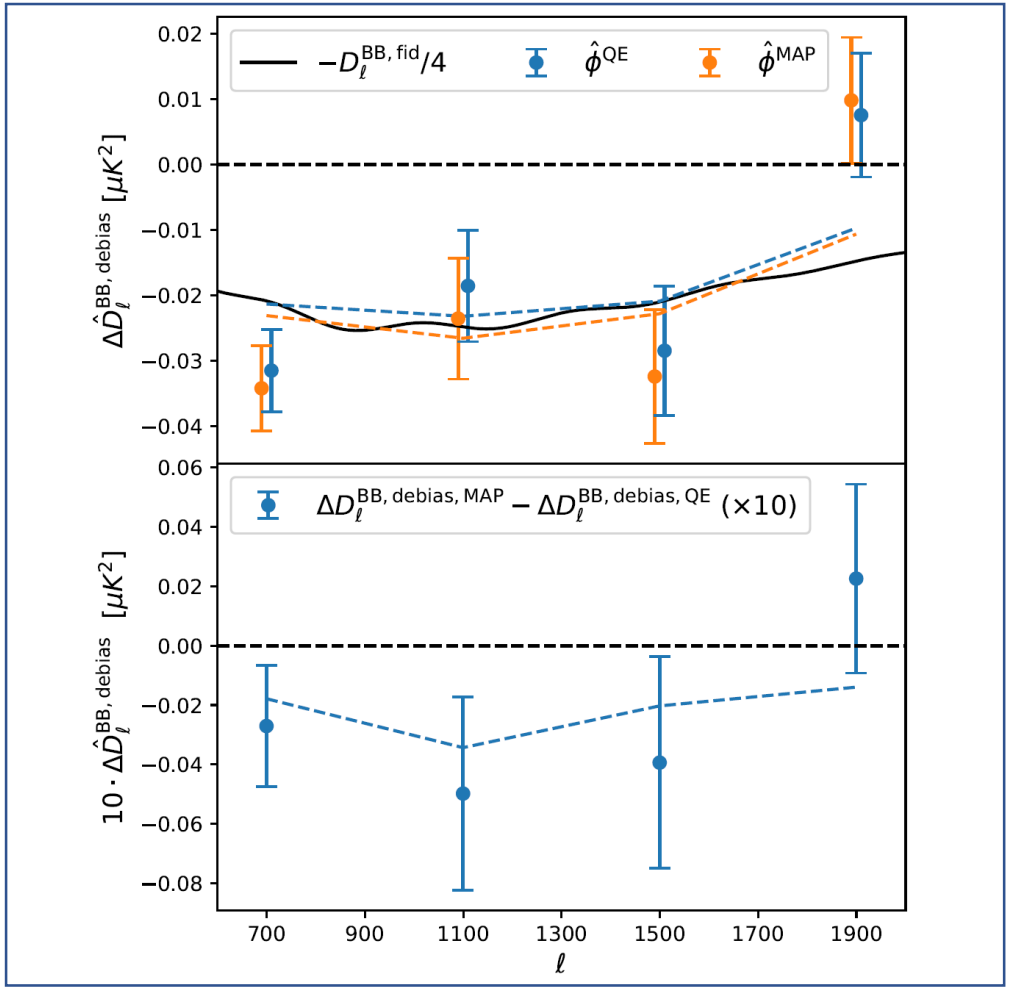
- Construct a B-mode template for lensing

LSS-based



A. Manzotti et al. ApJ 846 1 (2017)

CMB-based

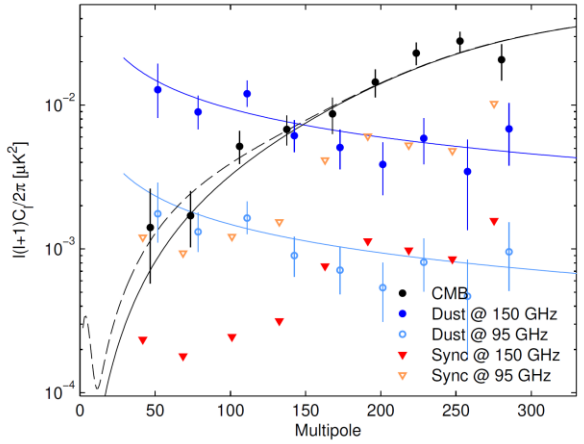


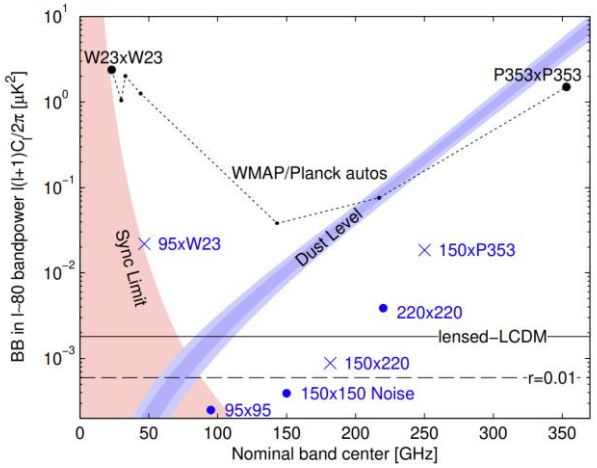
S. Adachi et al (+C. Feng). *Phys. Rev. Lett.* 124, 131301 (2020)

S. Li, C. Feng*, F. B. Abdalla. *In preparation* (2026)

Polarization signals from Galactic dust & gravitational lensing

- **Joint detection of foreground and lensing B-modes** (very challenging for large aperture telescope)

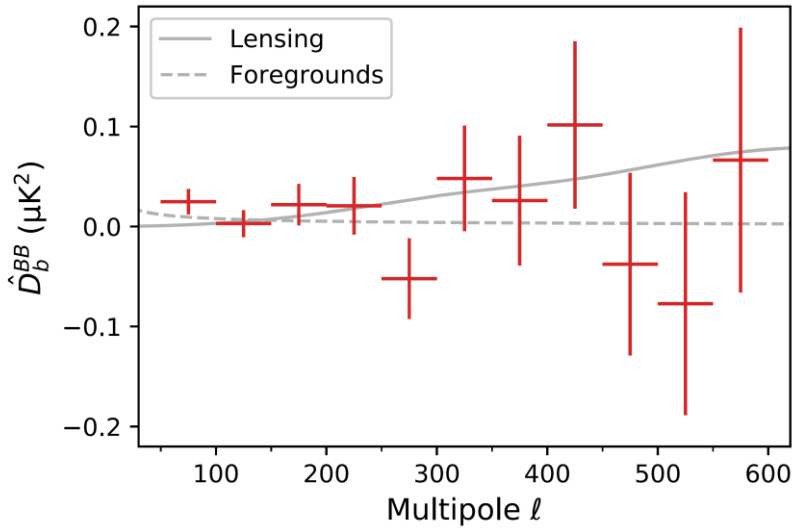




BICEP/Keck Collaboration.
Phys. Rev. Lett. 127, 151301 (2021)

A continuously rotating half-wave plate to modulate polarization/to suppress low-frequency noise

Simons Array/POLARBEAR

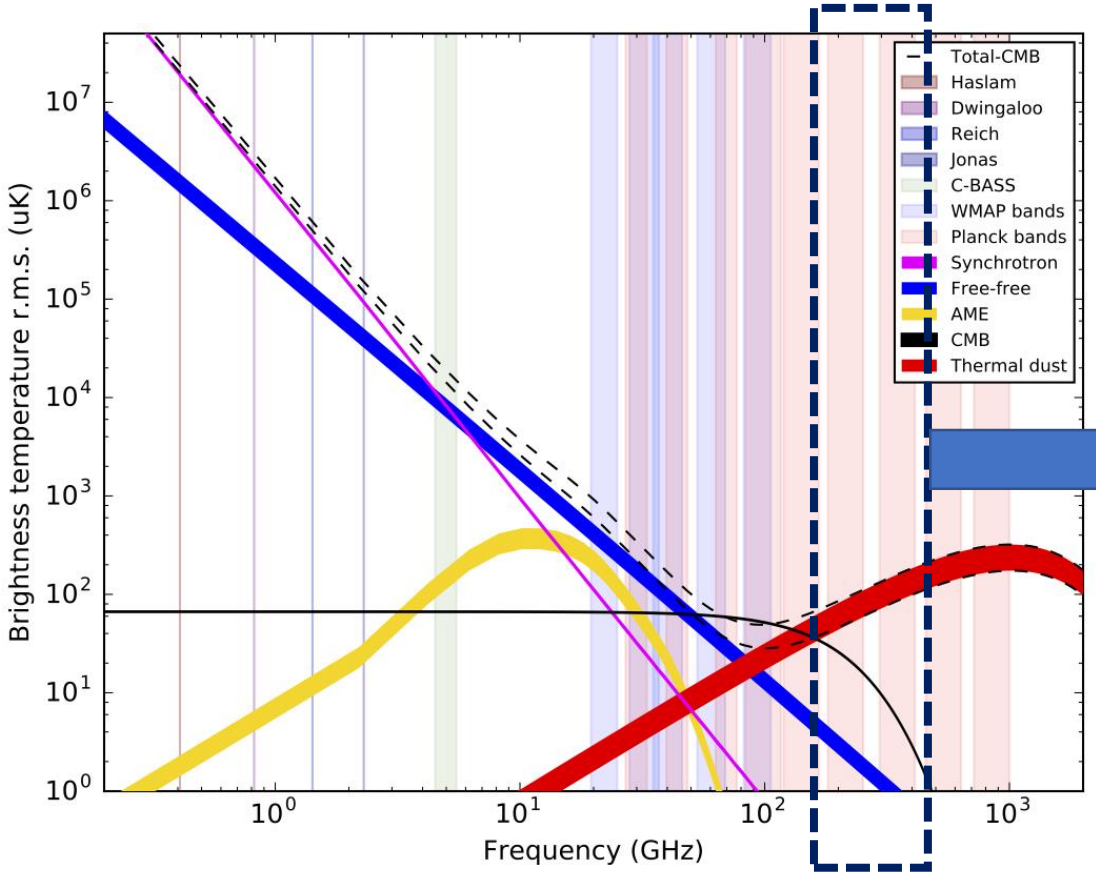




S. Adachi et al (+ C. Feng). *ApJ*, 931, 101 (2022)

Polarized foreground removal

- **Mitigating the Galactic dust polarization is key to detecting large-scale B modes**



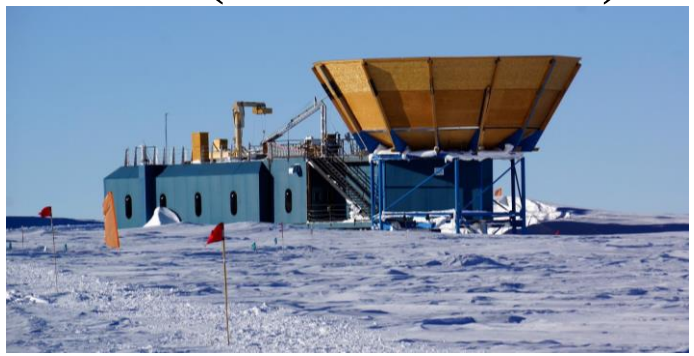
Simons Observatory (225，280GHz)



SPT(+>200GHz)



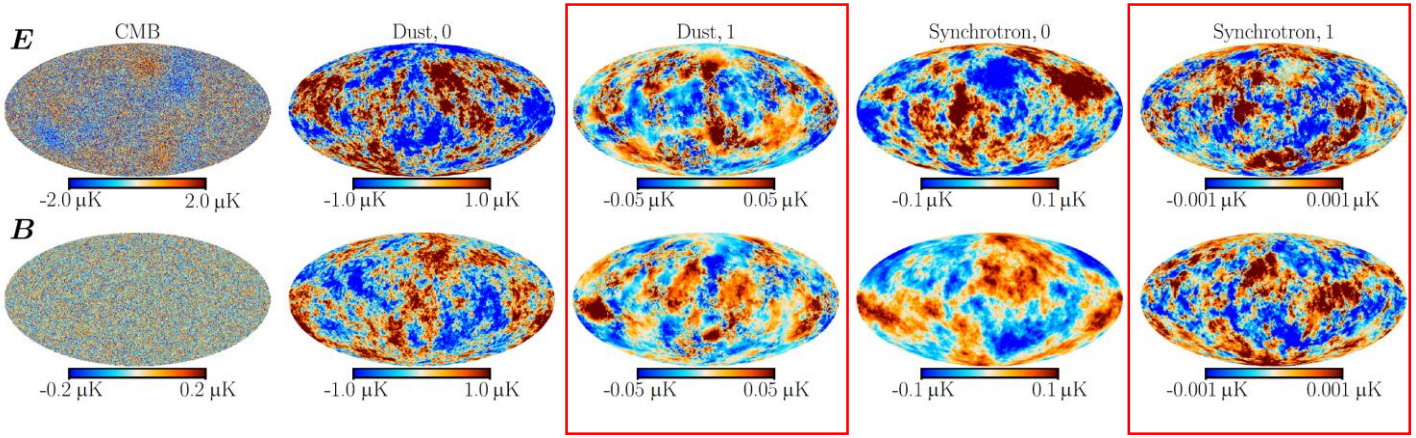
BICEP3(220 and 270 GHz)

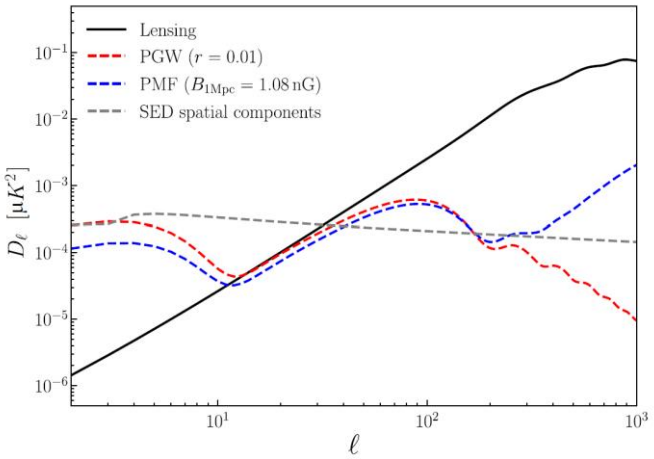


There will be more in the future

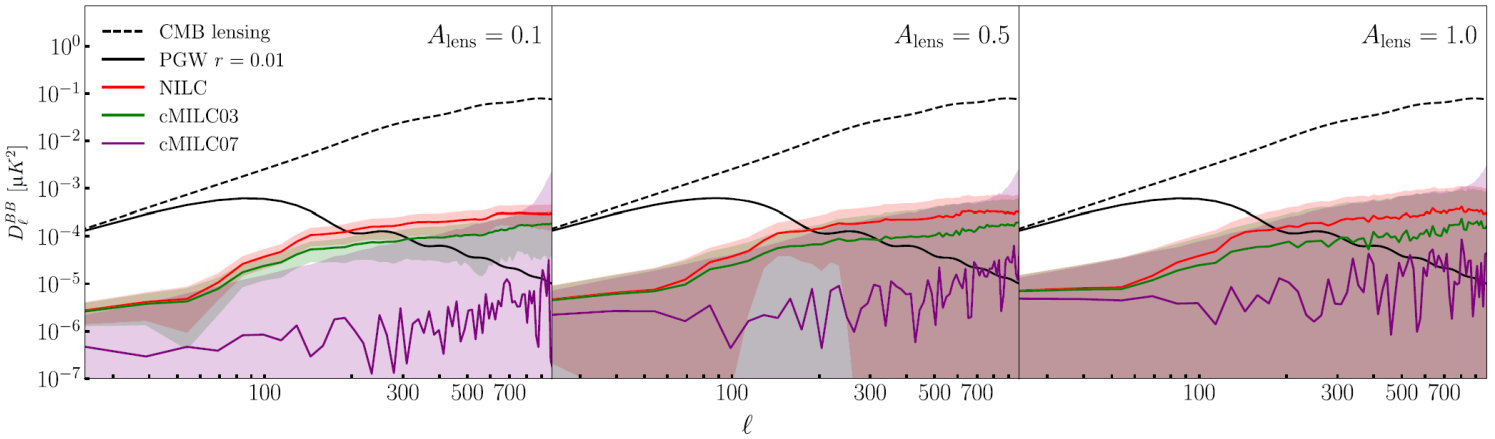
Spatial non-Gaussianity of polarized foreground

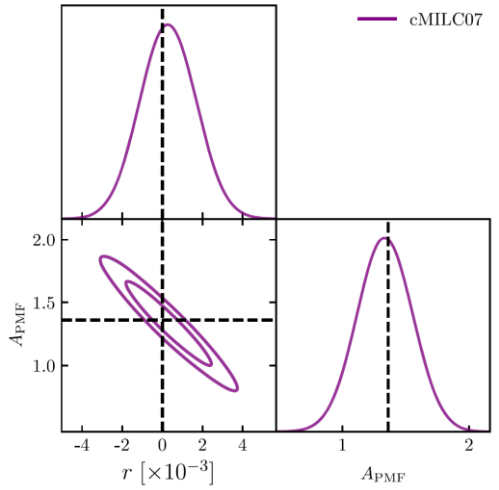
- Polarized foregrounds are highly non-Gaussian: higher-order components may further contaminate the CMB polarization signals





- The cMILC can yield minimum polarized foreground residuals which do not bias the inference of the B-mode signals

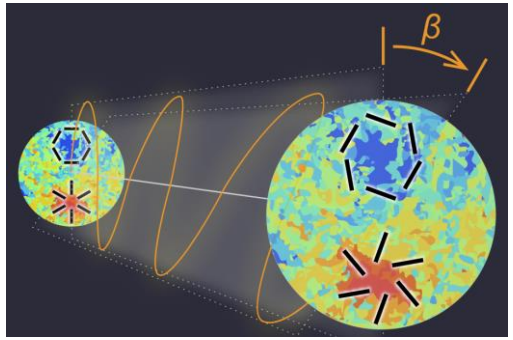




S. Li, C. Feng*, F. B. Abdalla. *Phys. Rev. D* 114, 023544 (2026)

Signatures of axion-like particles

- Cosmic birefringence can be induced by interactions between CMB photons and axion-like particles (ALPs)

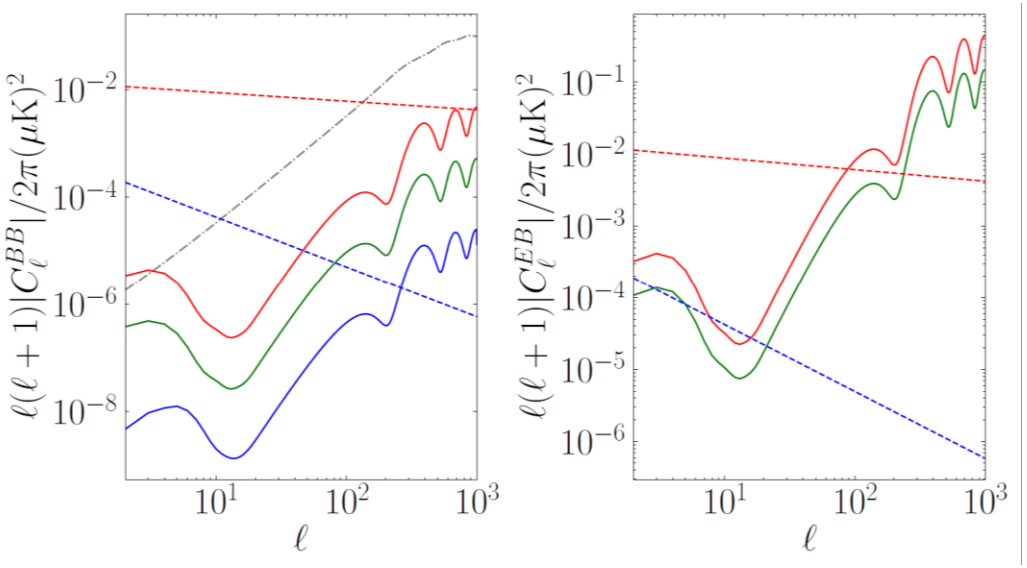


lensing effects

instrumental effects

isotropic rotation

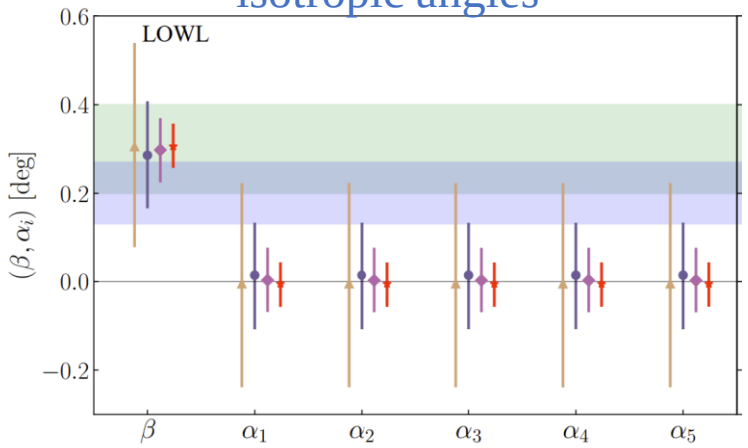
anisotropic rotation



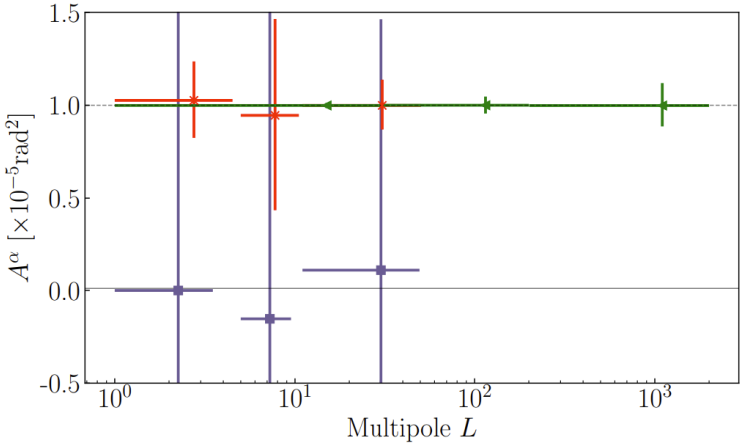
Y. Zhang, C. Feng* et al. arXiv:2607.17500. Under review

- Both the isotropic & anisotropic rotation angles can be decoupled from the polarization power spectra

isotropic angles



anisotropic angles



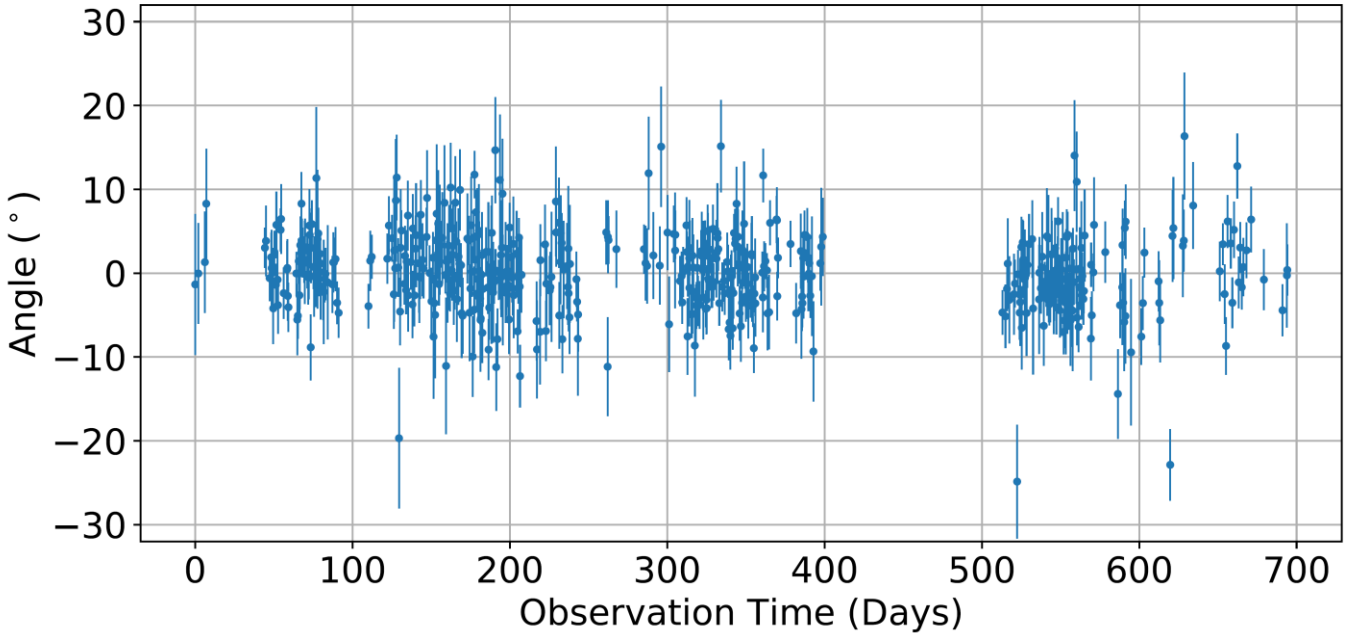
New polarization signals (parity violating physics)

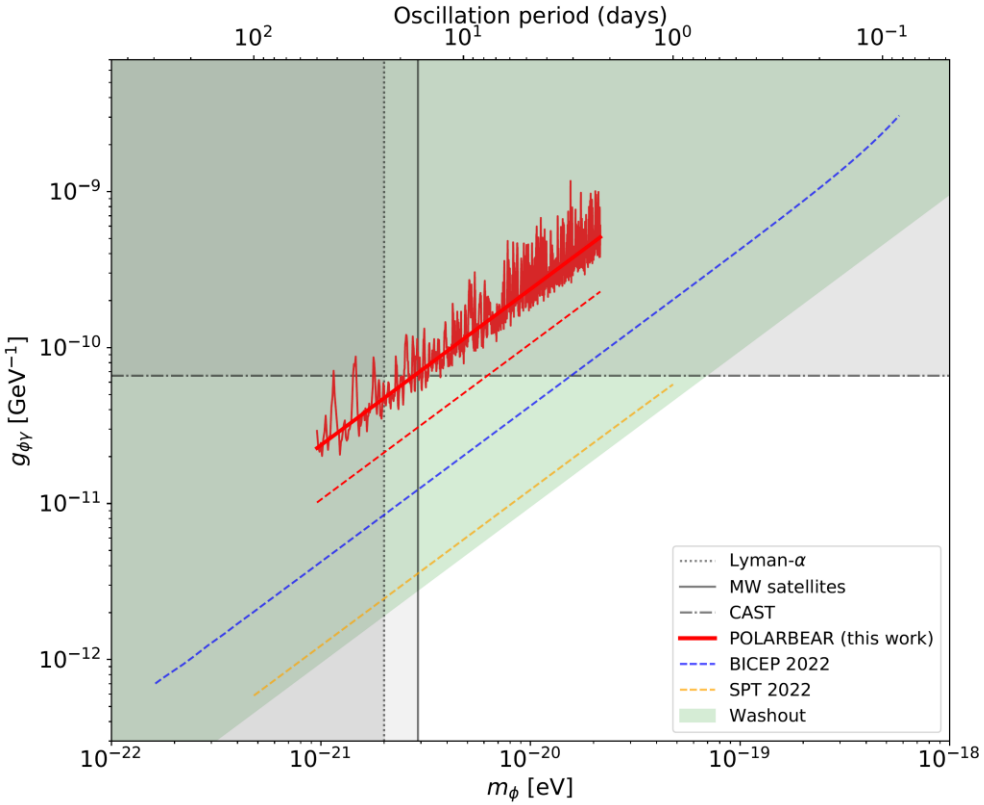


Image from Wikipedia

The polarization angles could be time-dependent

$$\rho_{\mathrm{m}}(t) = A\sin(2\pi f t + \delta) = g_{\phi\gamma}\phi_0 \sin(m_\phi t + \delta)$$



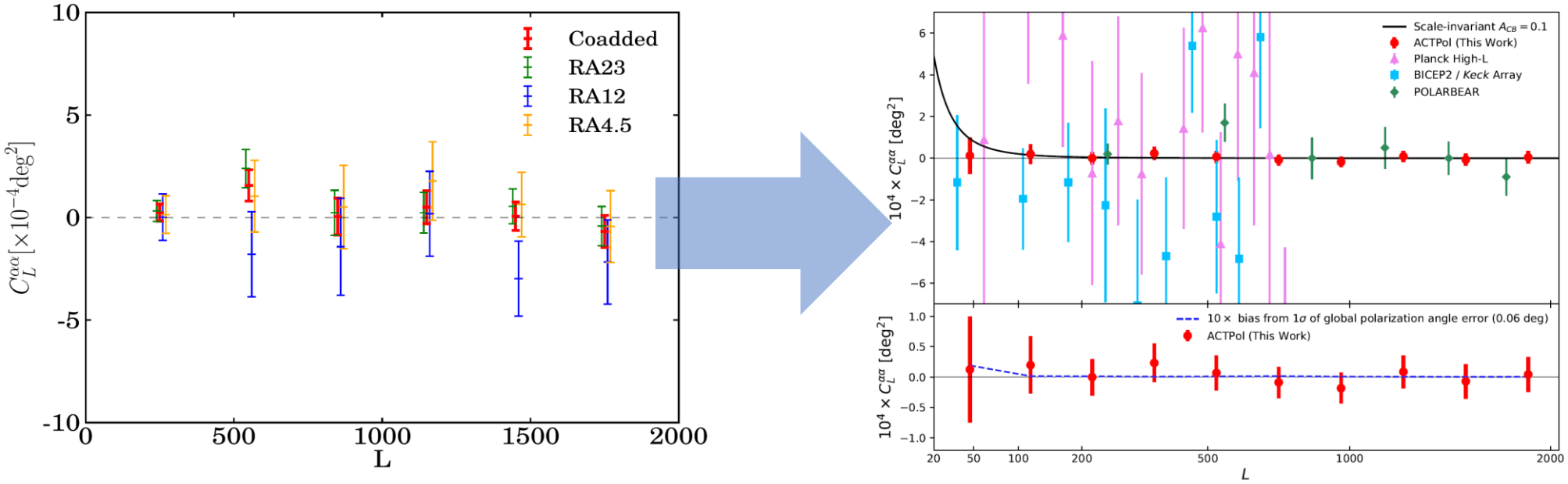


The POLARBEAR Collaboration (+C. Feng). *Phys. Rev. D* 108, 043017 (2023)

New polarization signals (parity violating physics)

Anisotropic cosmic rotation effects of CMB polarization

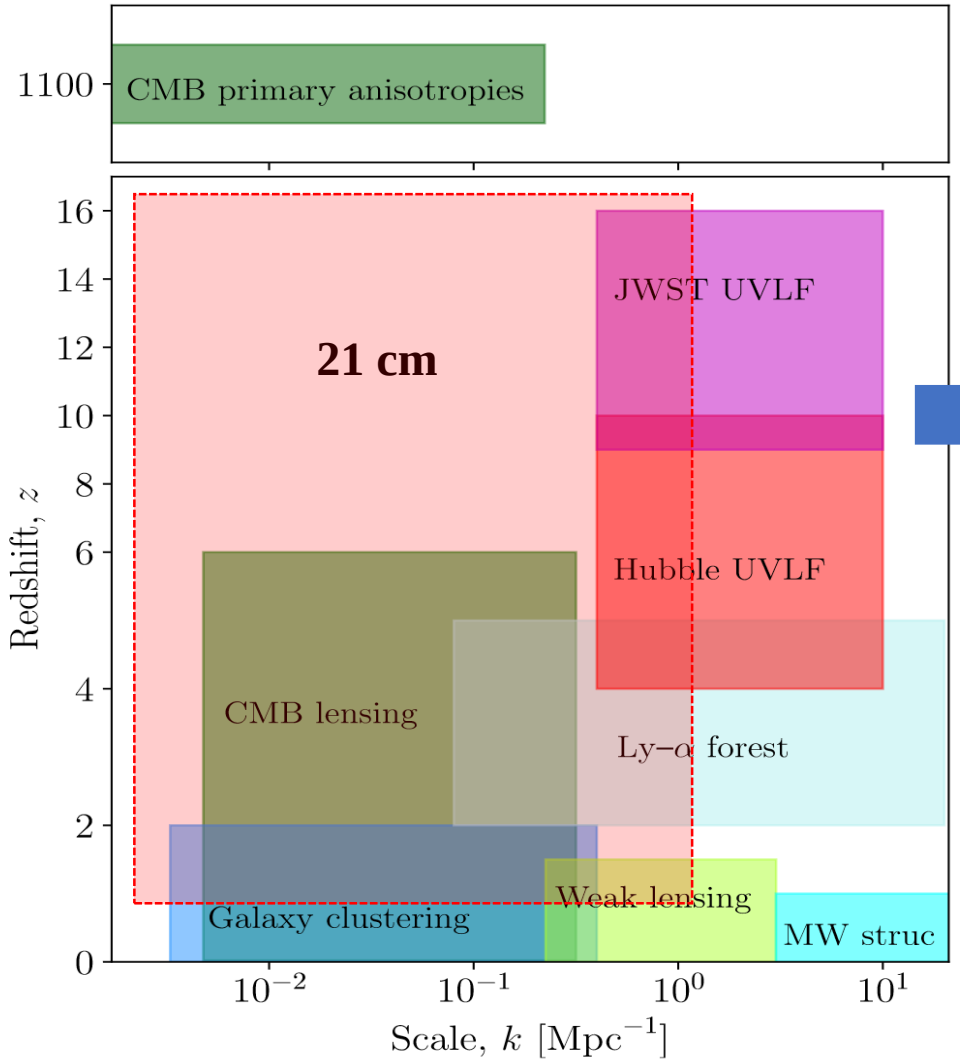
First constraints on anisotropic cosmic birefringence or primordial magnetic fields from the ground at subdegree scales



The POLARBEAR Collaboration (C. Feng*). *Phys. Rev. D* 92 (2015) 123509. Editors' Suggestion. Front-page highlight. Citation 101.

Studying the dark sectors with CMB+21 cm signals

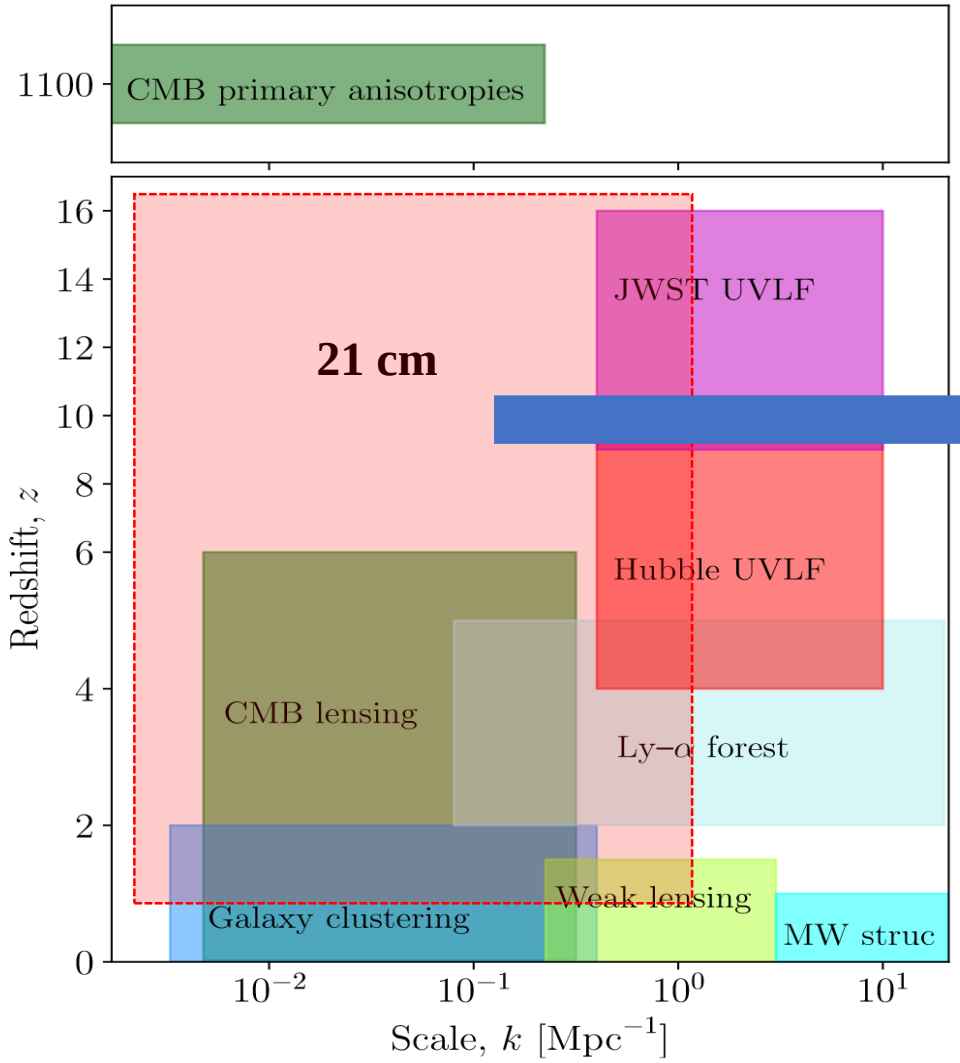
☐ A broad spatial and temporal coverage



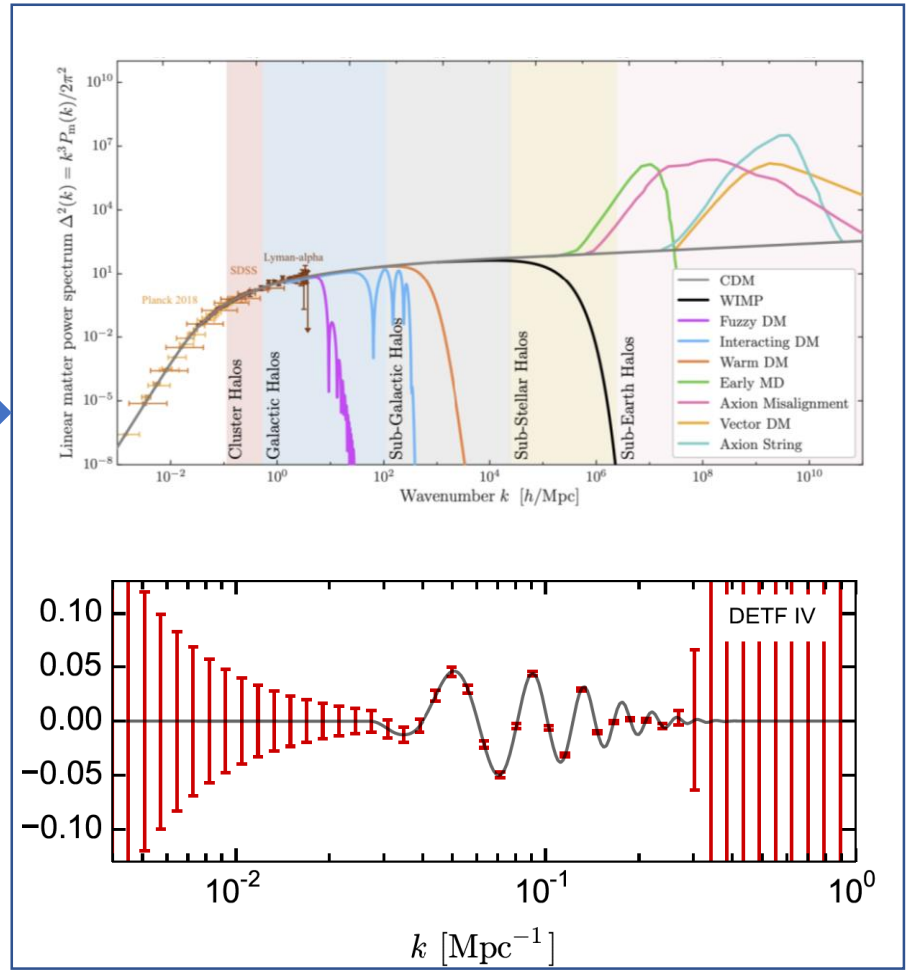
- ✓ **Large-scale structure**
- ✓ **Parity violating physics**
- ✓ **Dark matter (warm, fuzzy, …)**
- ✓ **Dark energy (dynamical…)**
- ✓ **Modified gravity**
- ✓ **…**

Studying the dark sectors with 21 cm signals

☐ A broad spatial and temporal coverage



☐ Dark matter/dark energy



Indirect Detection of neutral hydrogen signals

Green Bank telescope



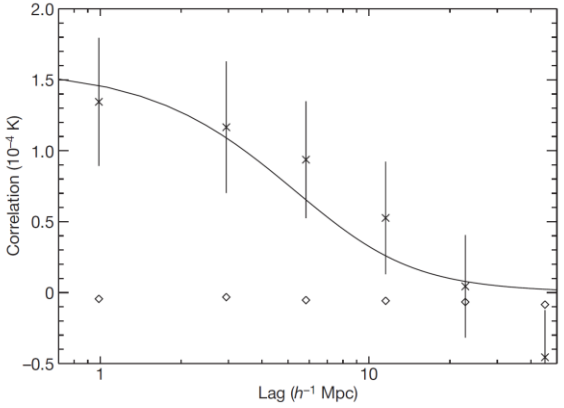
MeerKAT telescope



CHIME telescope

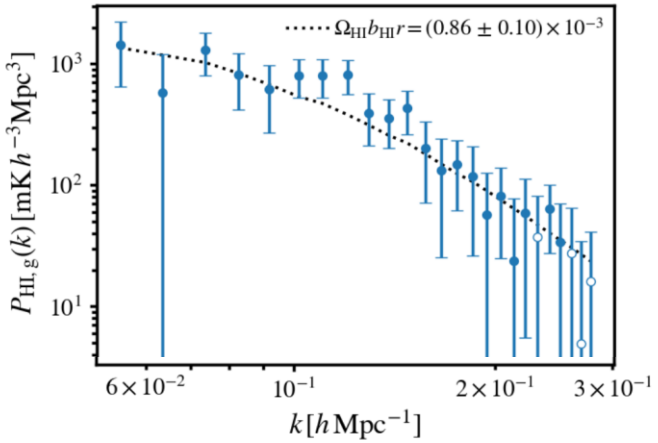


GBT×DEEP2 density field



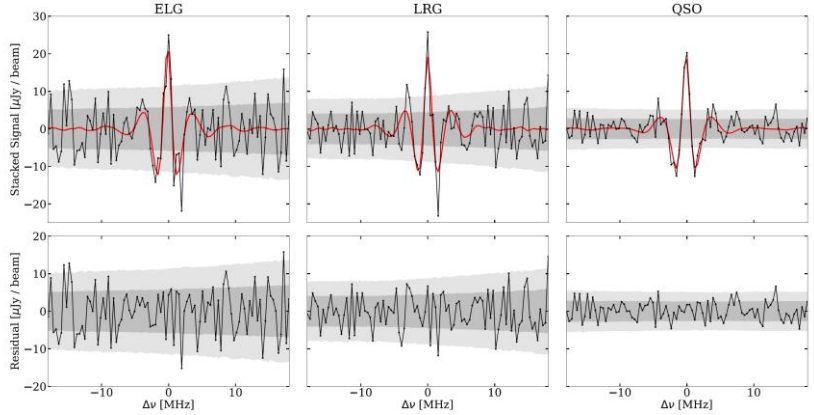
T. Chang et al. Nature 466, 463-465 (2010)

MeerKAT × WiggleZ DES



S. Cunnington et al. MNRAS, 518 (2023) 6262

CHIME × eBOSS catalogs

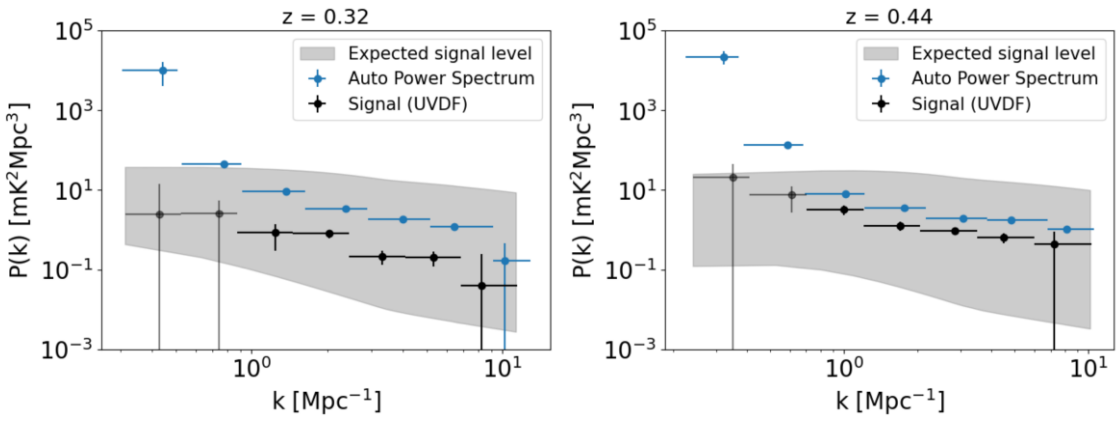


M. Amiri et al. ApJ, 947 (2023) 16

Direct Detection of neutral hydrogen signals

MeerKAT telescope

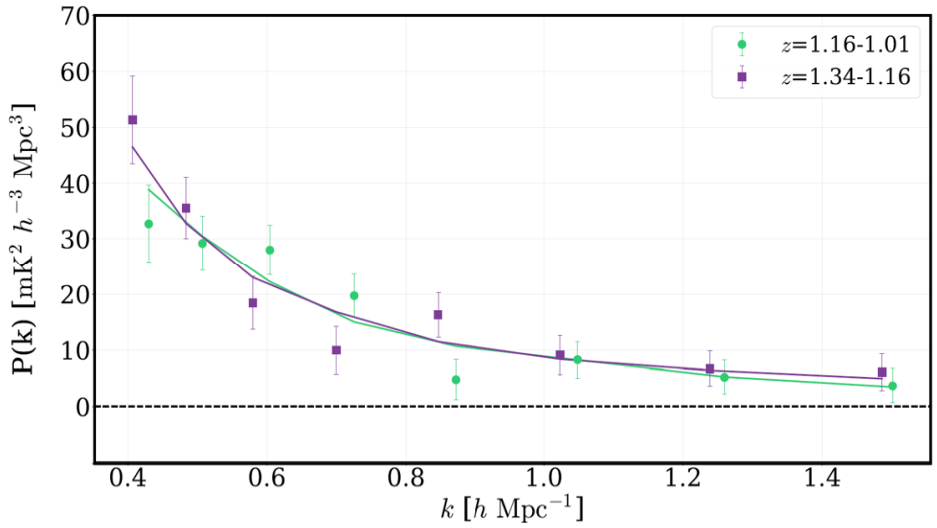




S. Paul et al. ApJL 1005 (2026) L56

CHIME telescope

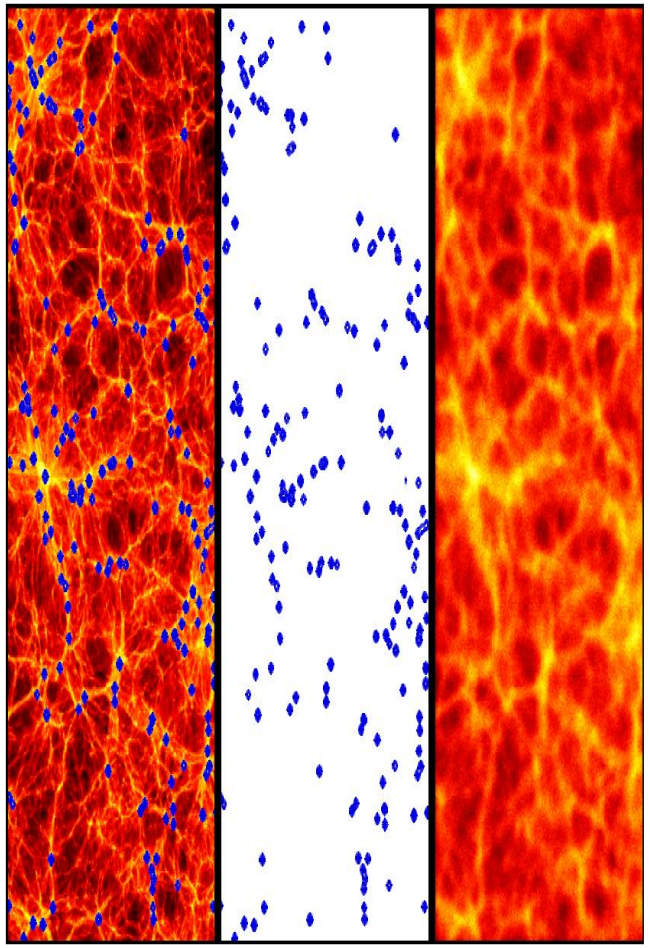




CHIME Collaboration. arXiv:2511.19620

Main radio telescopes over the world

Intensity Mapping



Intensity Mapping radio telescopes



Foreground contaminants on 21 cm signal

The foregrounds are orders of magnitude brighter than the 21-cm

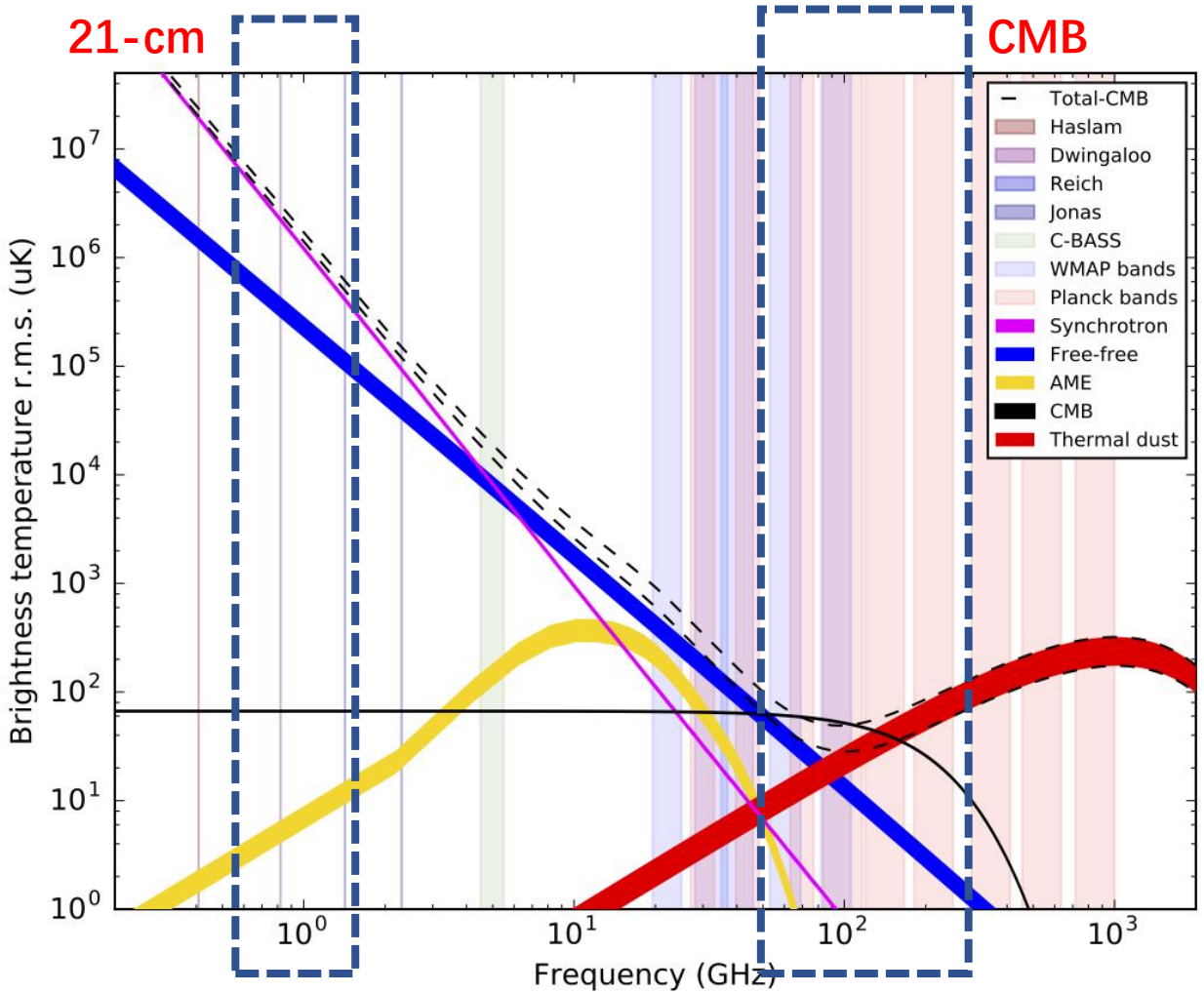
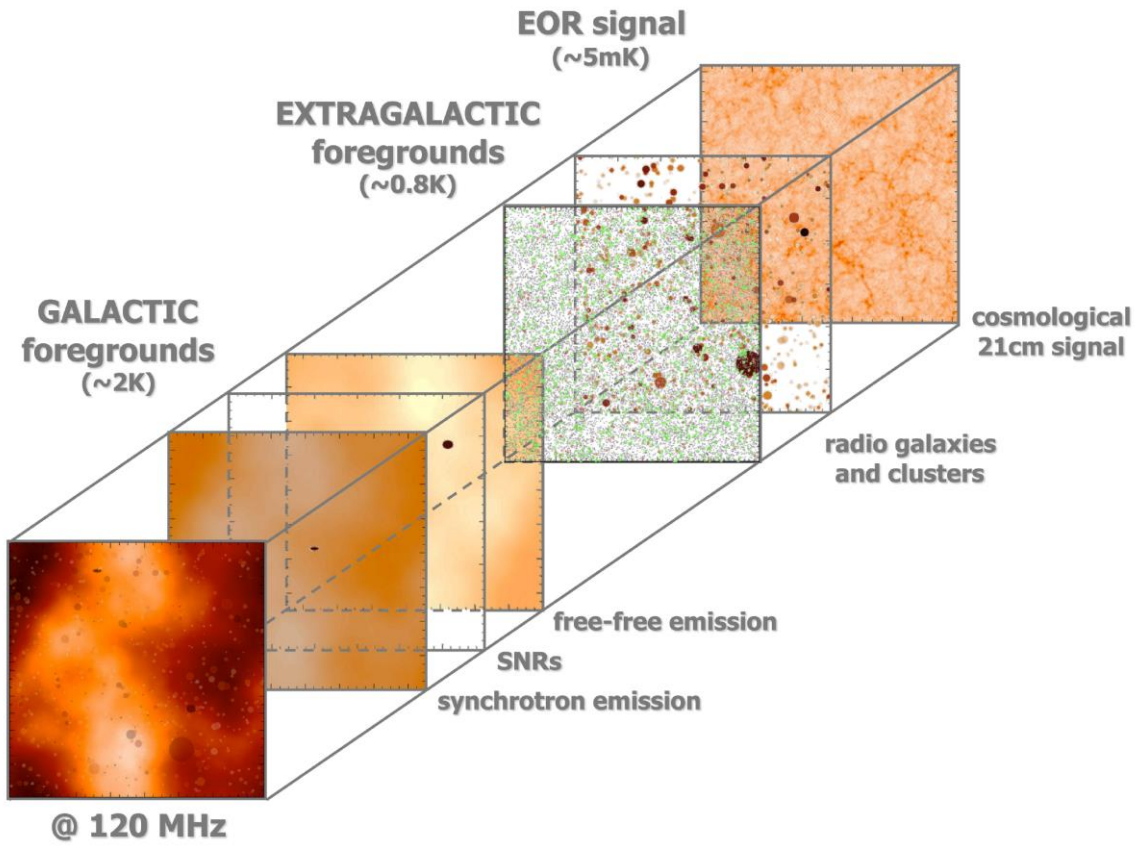


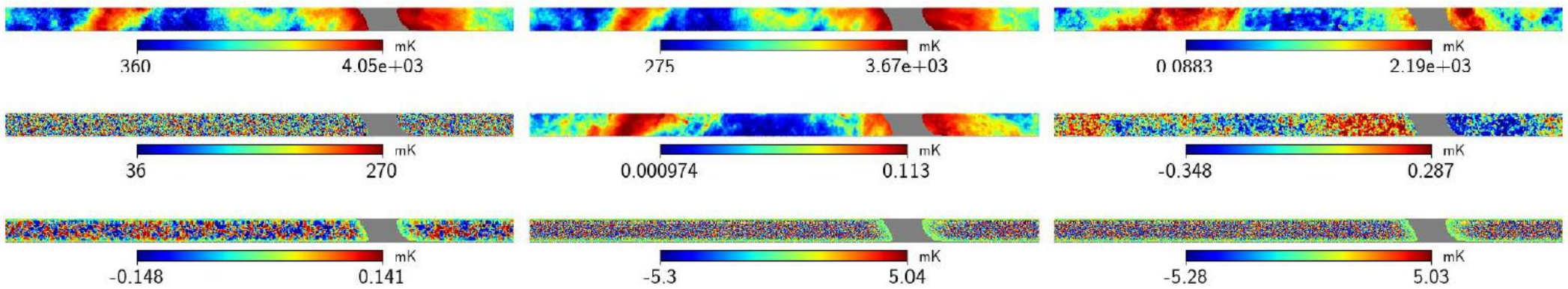
Image credit: CBASS



V. Jelic. PoS(ISKAF2010)028

Measuring the HI fluctuations in map space

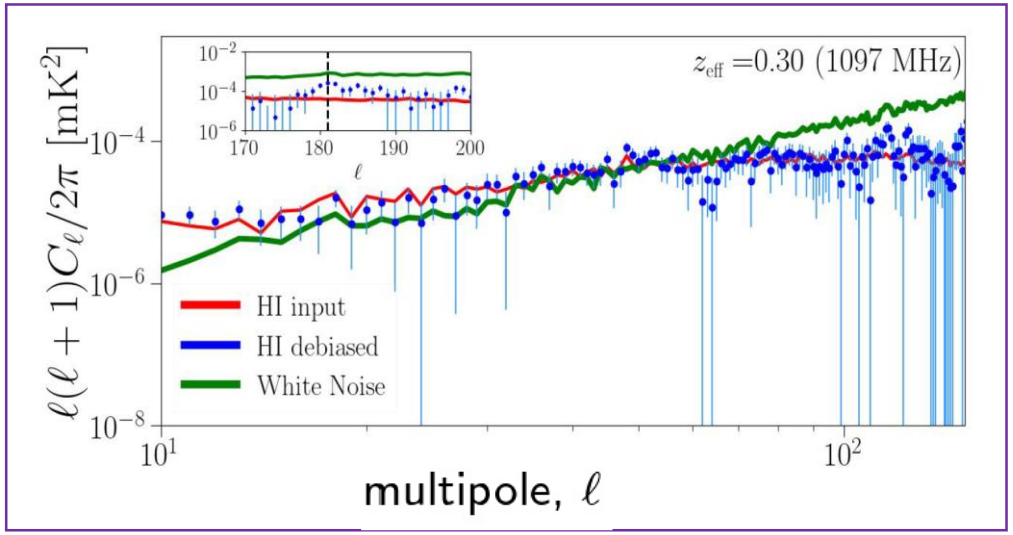
Map-level radio foreground removal



GNILC
—Generalized Needlet Internal Linear Combination

GMCA
—Generalized Morphological Component Analysis

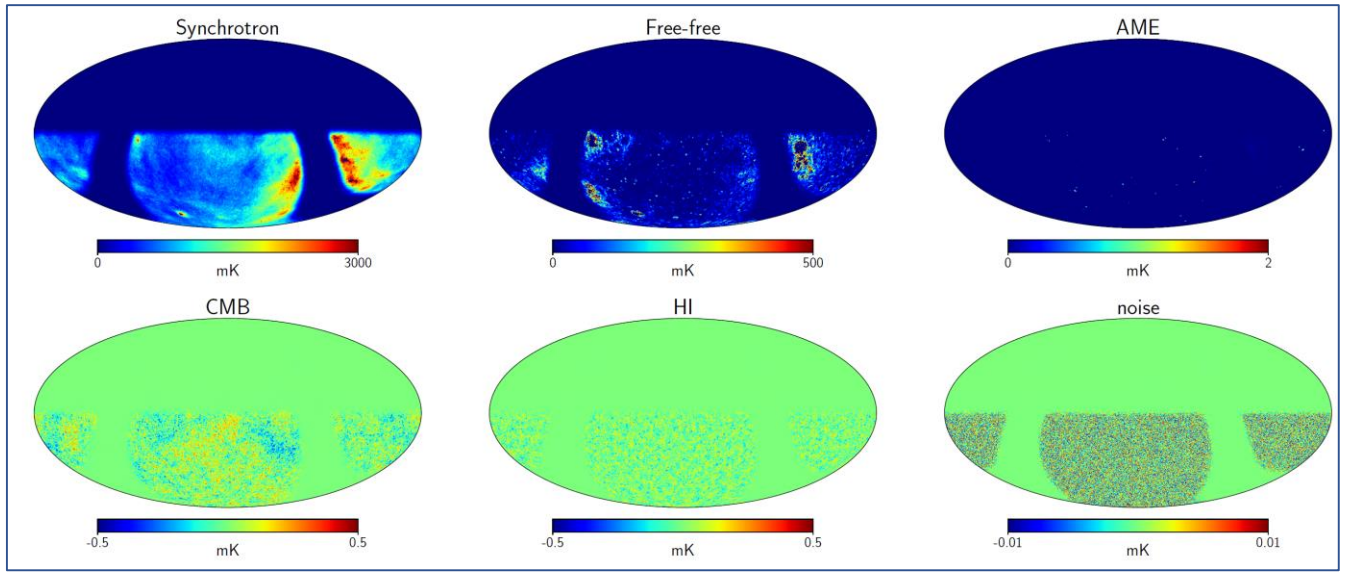
FastICA
—Fast Independent Component Analysis

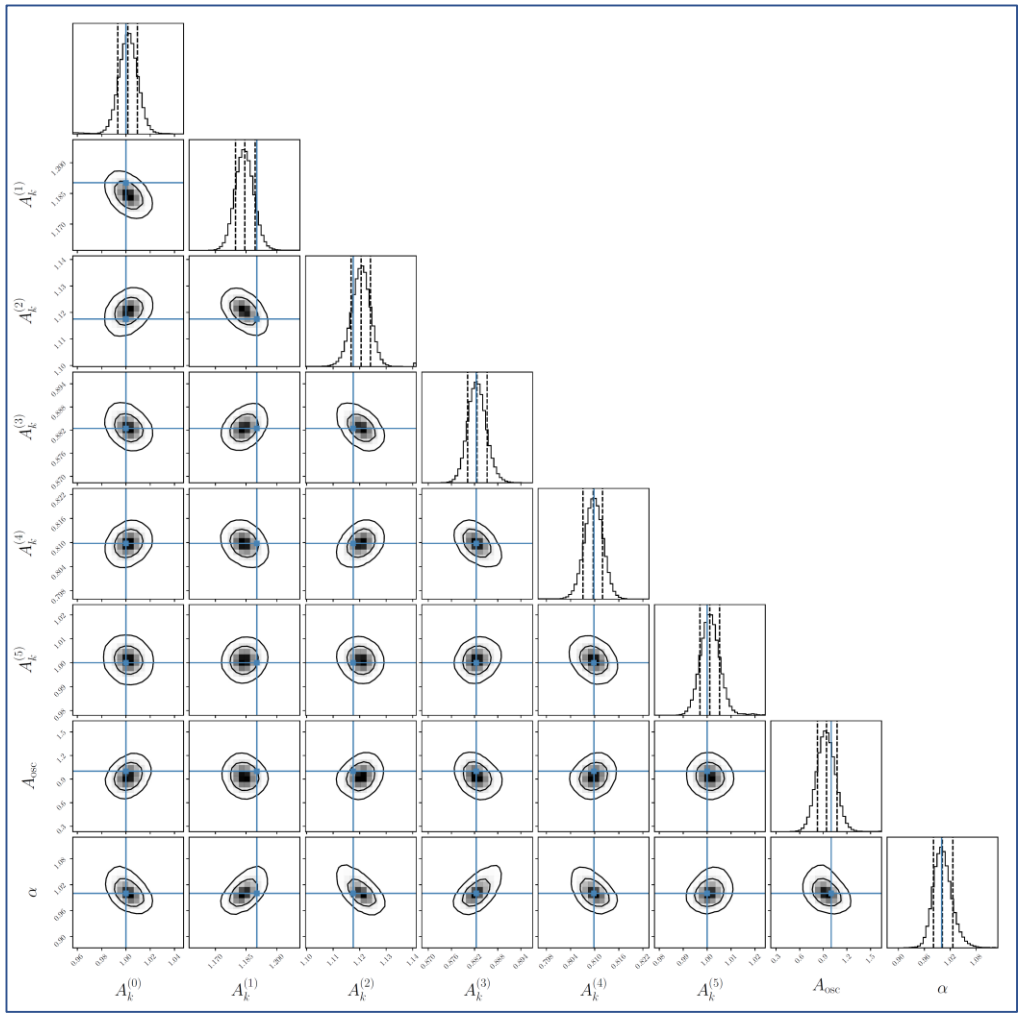


A. Marins (+ C. Feng*) et al. *JCAP* 08, 028 (2026)

Power-spectrum space decomposition of frequency tomographic data (PSDFT)

A non-image based solution for multifrequency data analyses in a reduced Fourier domain

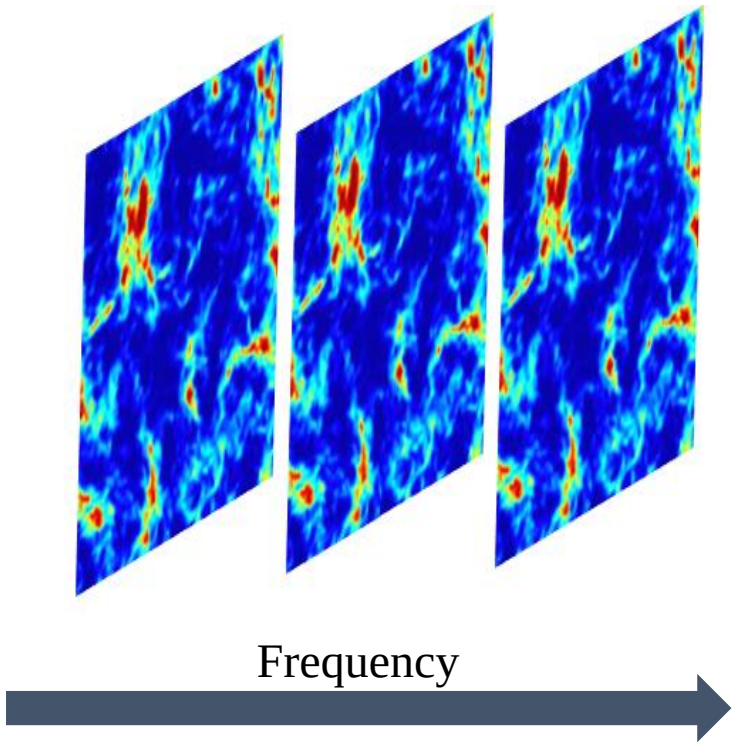


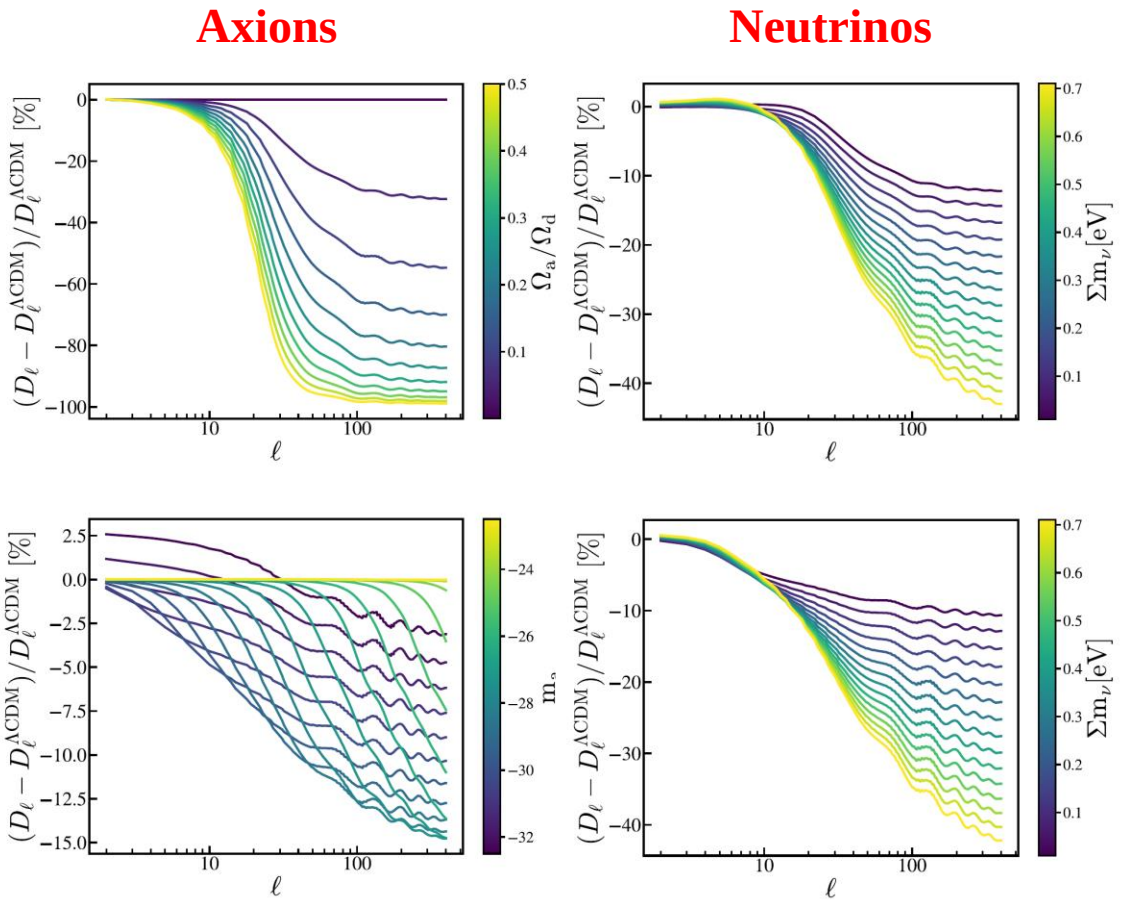


C. Feng*, F. Abdalla. *ApJS* 278, 3 (2025)

Constraints on axion-like particles using intensity mapping

- Distinct structure suppression by axions and neutrinos

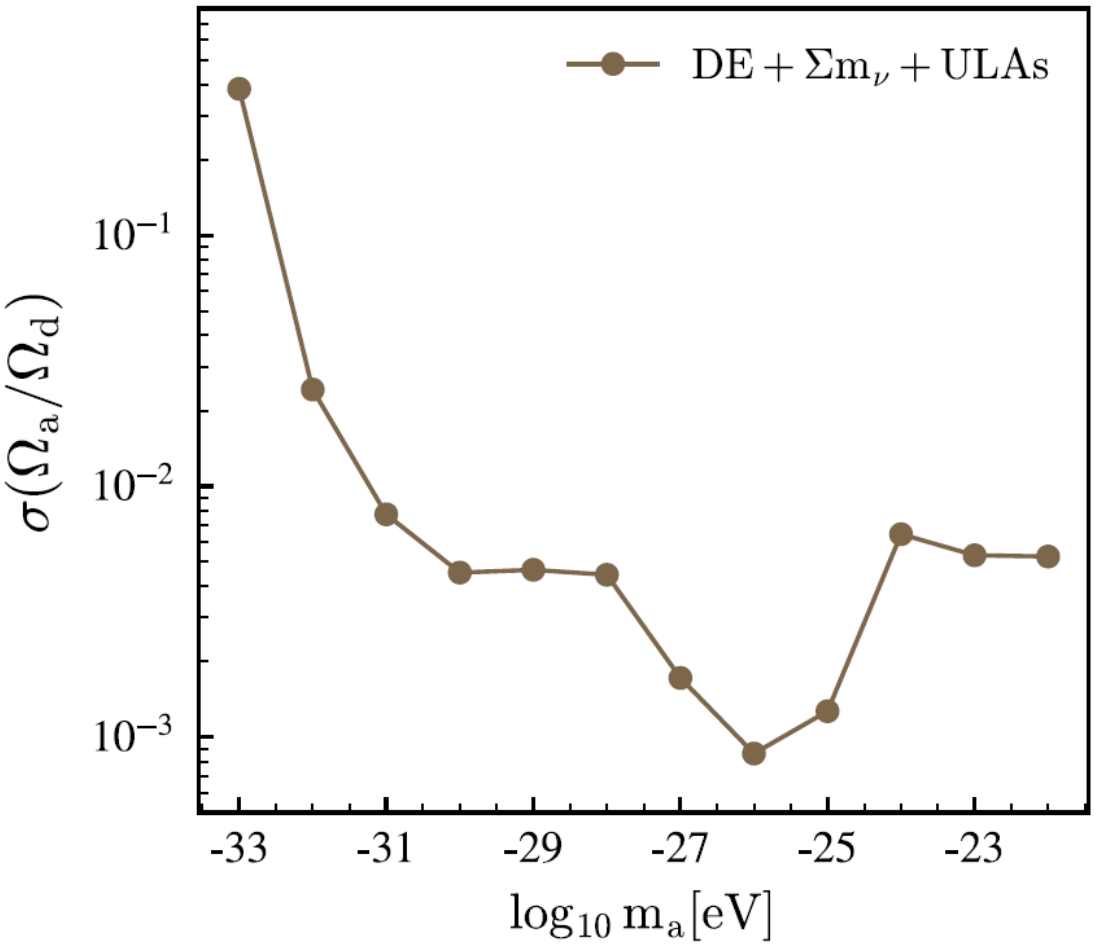




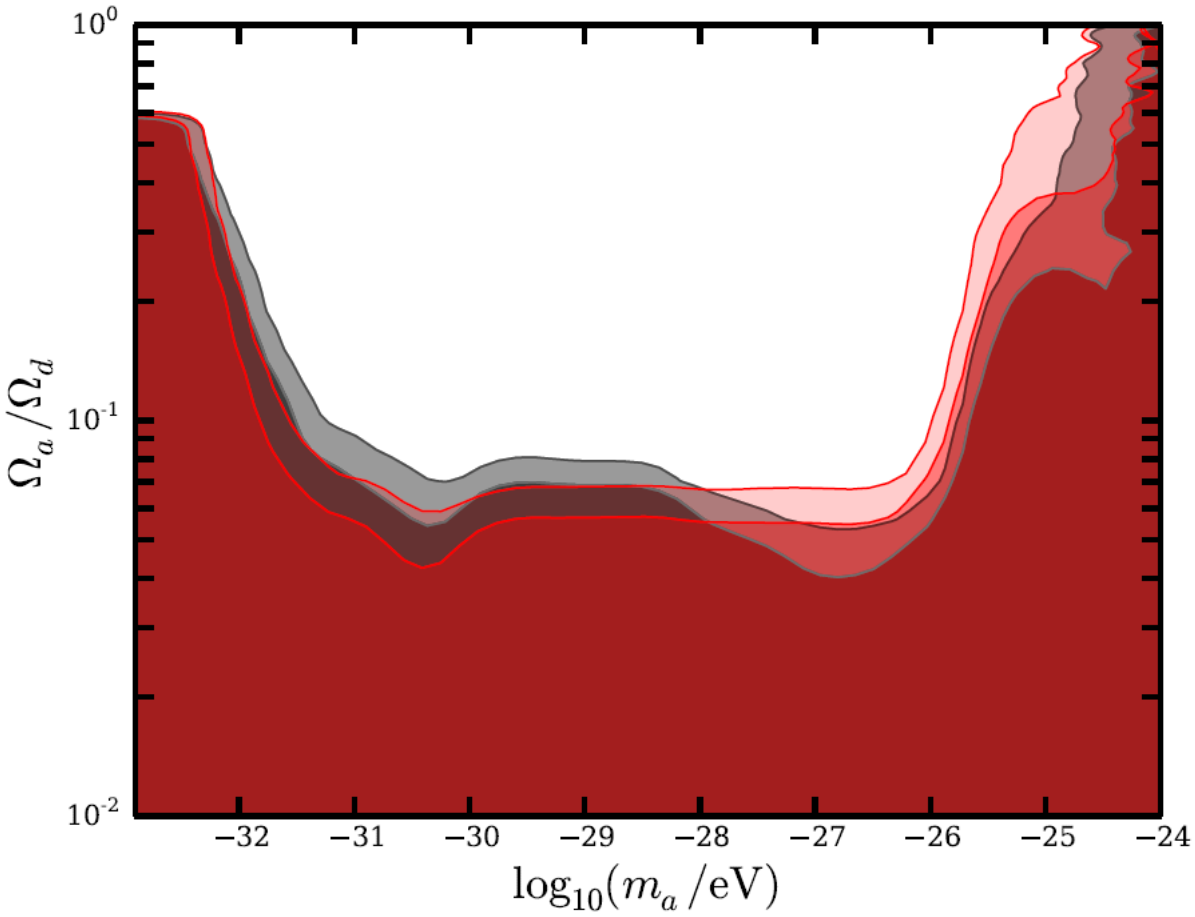
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Constraints on axion-like particles using intensity mapping

Future 21 cm experiments



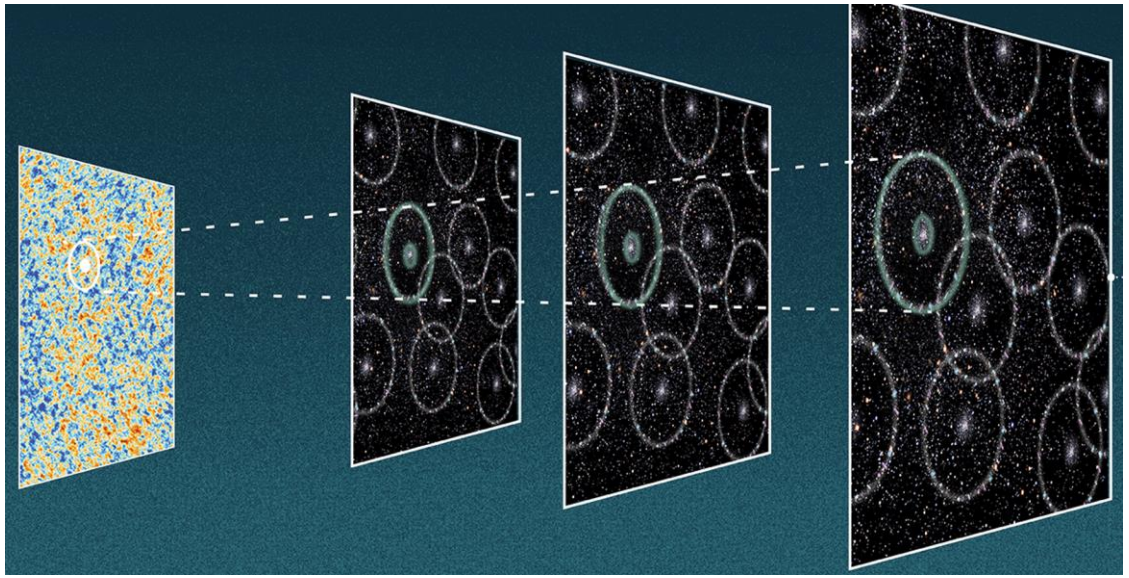
The CMB-only (red) and CMB+WiggleZ (black) combinations of data sets

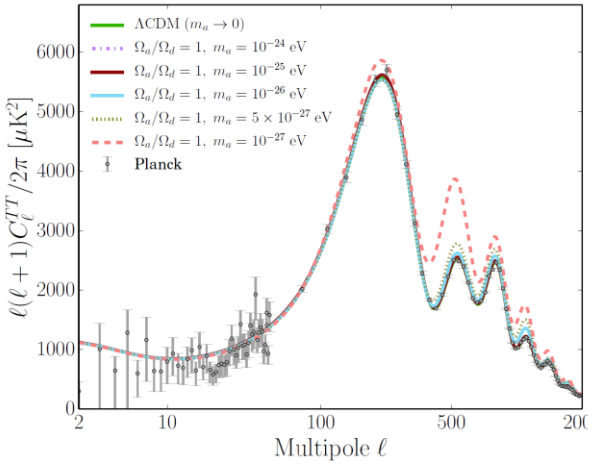


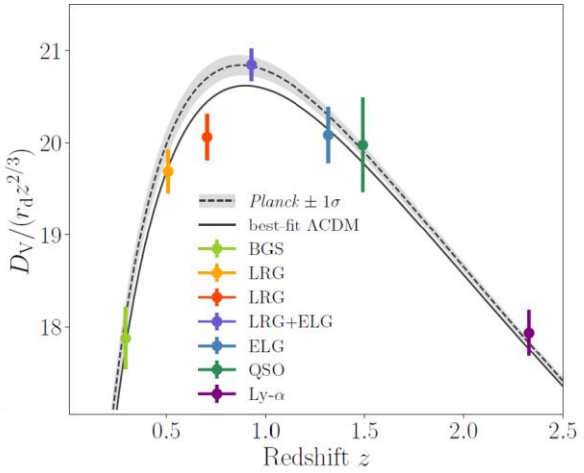
Q. Liu, C. Feng*, F. B. Abdalla. *Phys. Rev. D* 111, 023030 (2025)

Constraints on axion-like particles using CMB+BAO

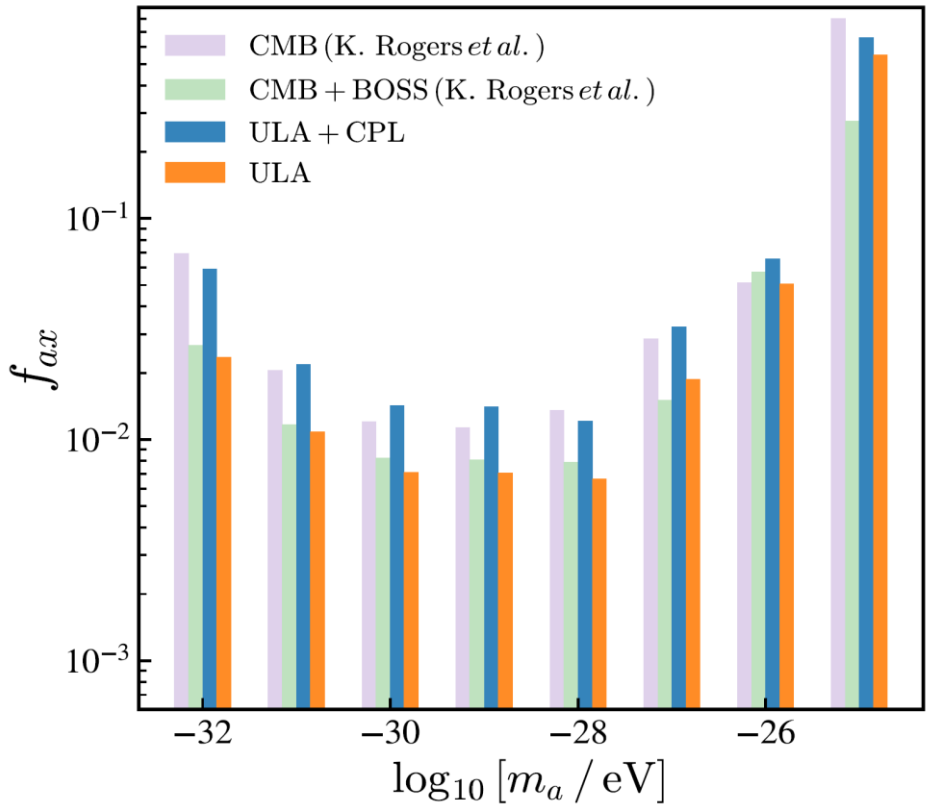
CMB + Distance measurements





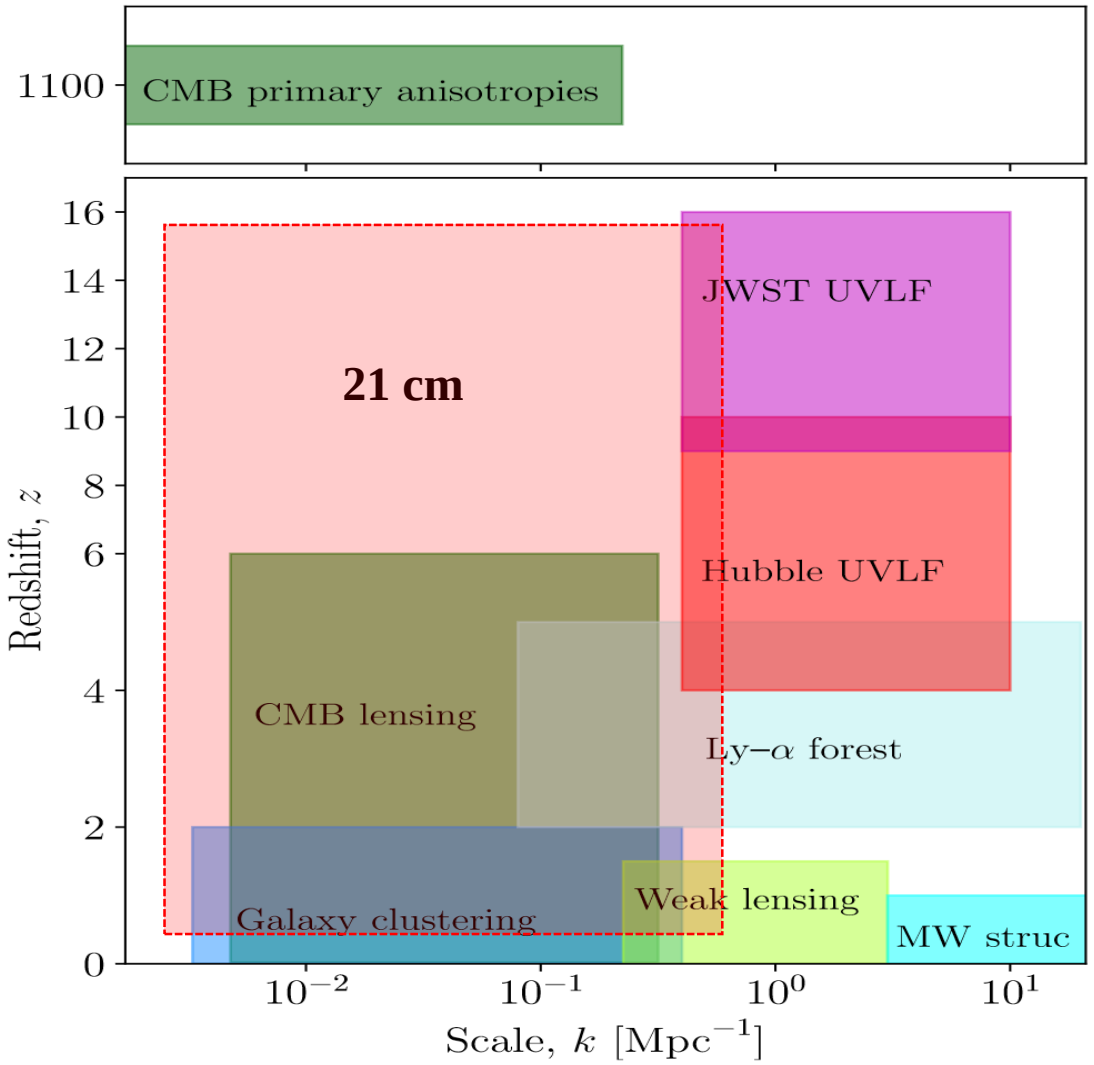


- The most stringent constraint of ULA so far f_{ax}<0.007



Q. Liu, C. Feng*, F. B. Abdalla. *Phys. Rev. D* 113, 043526 (2026)

Studying the dark sectors with 21 cm signals

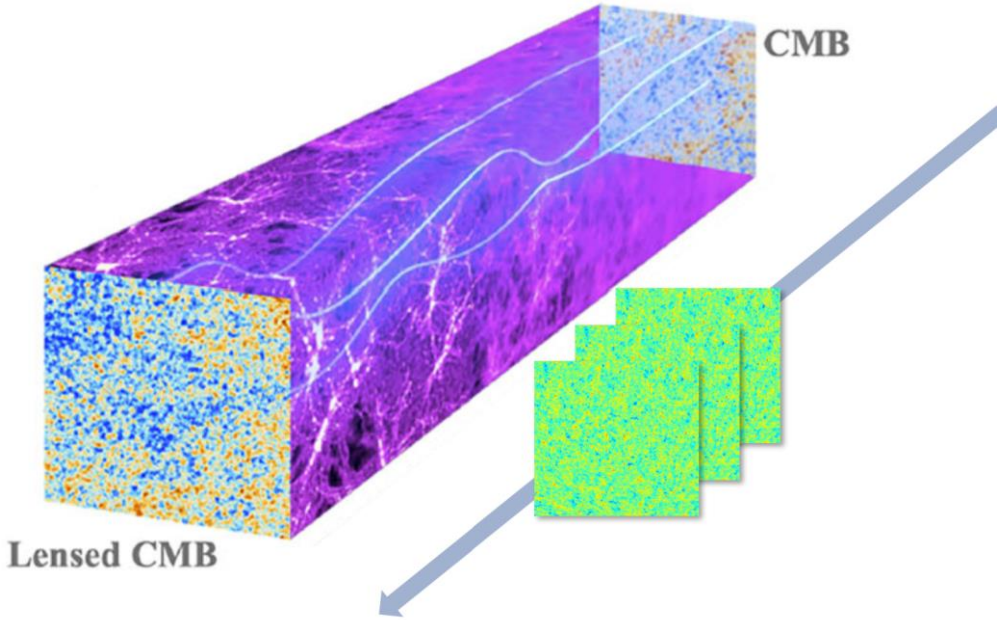


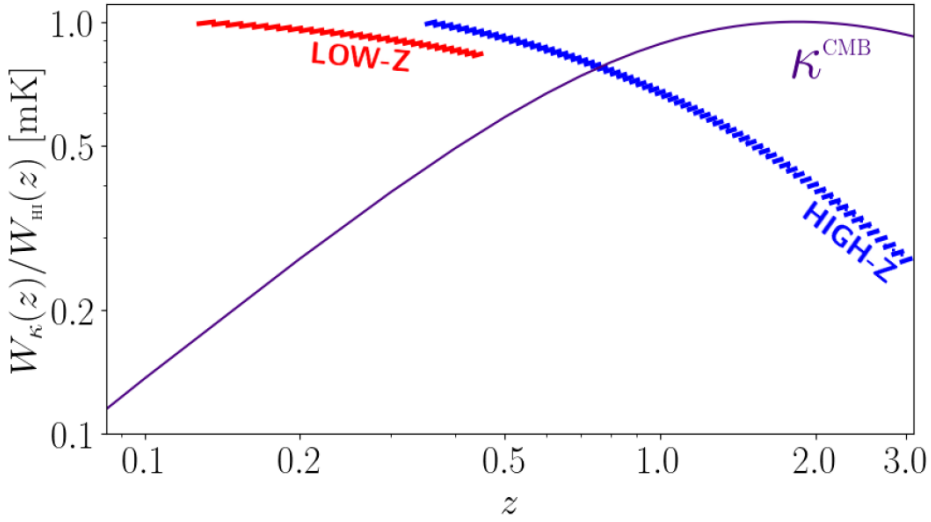
- **Auto-power spectra may suffer from unknown/complicated systematic effects**
- **Cross correlations can be a complementary probe to new physics**

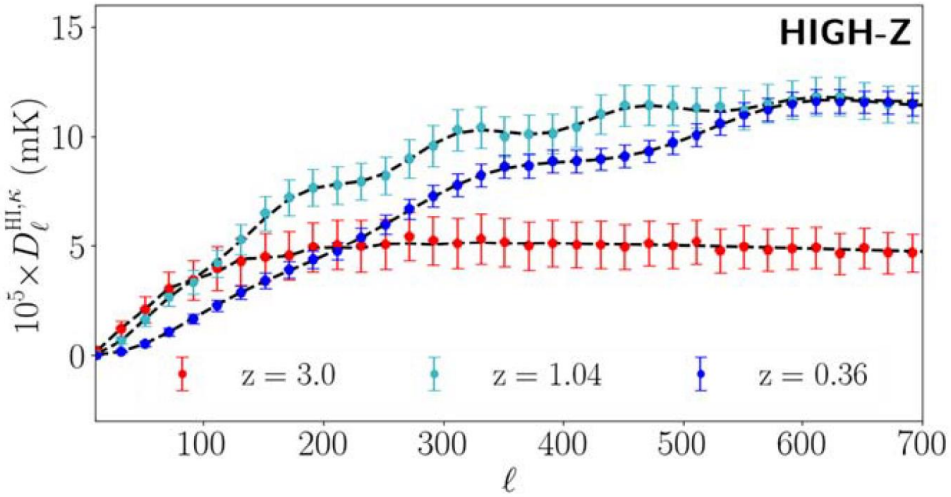
Cross-correlations between CMB lensing and 21 cm intensity mapping

21cm×CMB lensing

- could both confirm the detection of the 21 cm signal
- provide complementary cosmological information





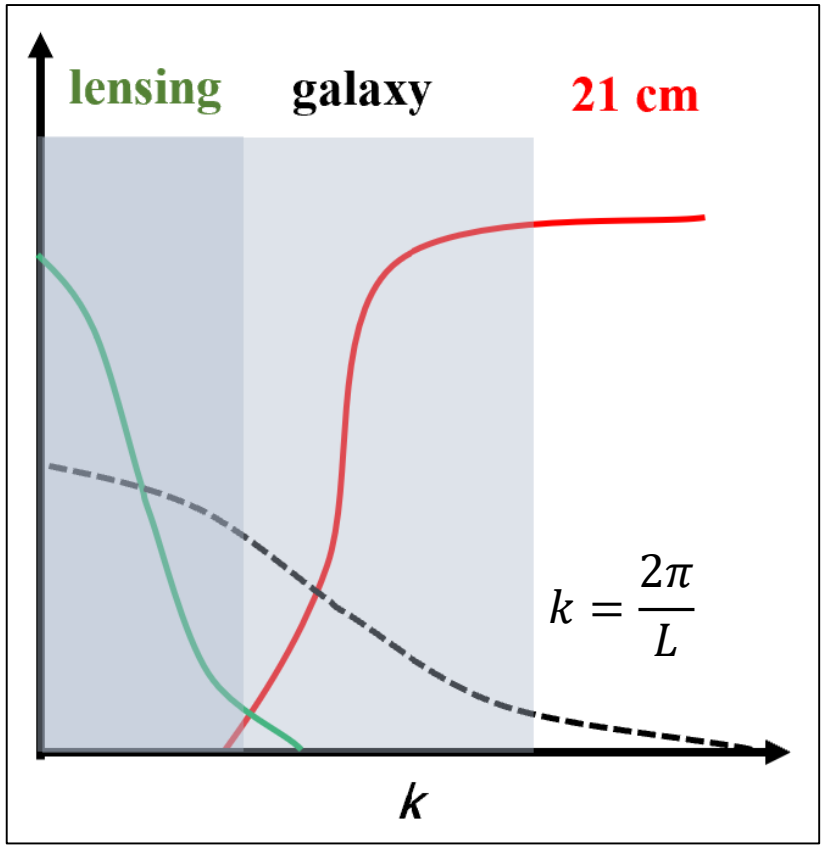


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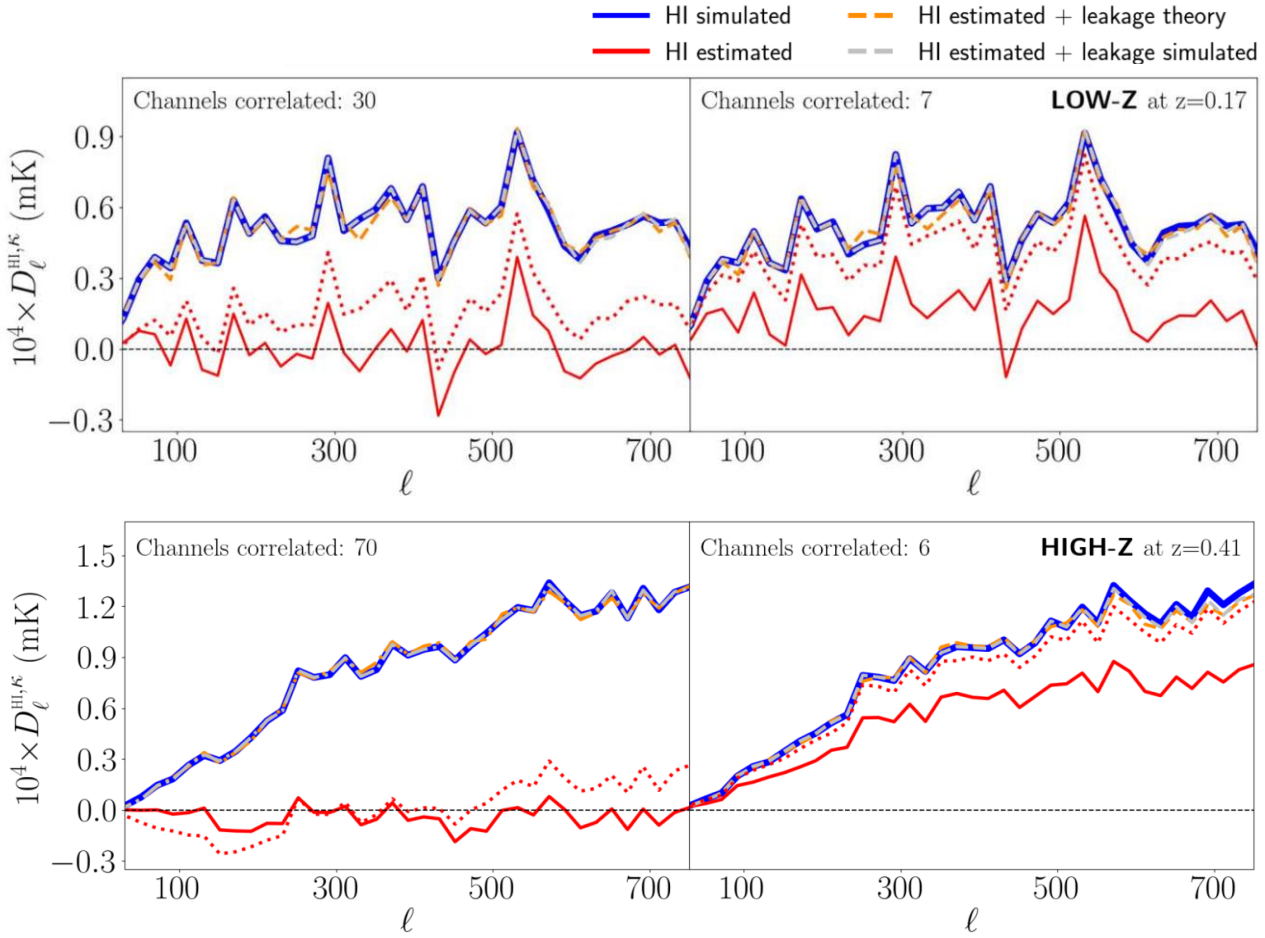
Cross-correlations between 21 cm intensity mapping (IM) & CMB lensing

- **Averaging is equivalent to low-pass filtering**

schematic plot



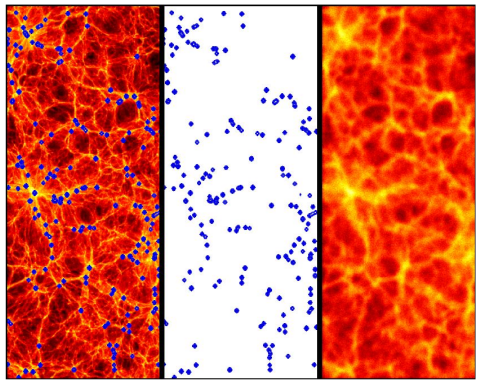
- **Standard foreground removal will suppress the low frequency modes of the 21 cm fluctuations**

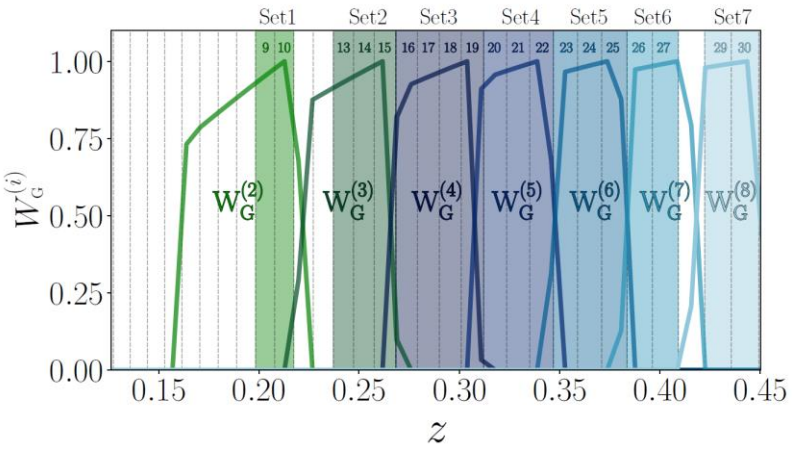


A. Marins, C. Feng*, F. B. Abdalla. *ApJS,* 278, 32 (2025)

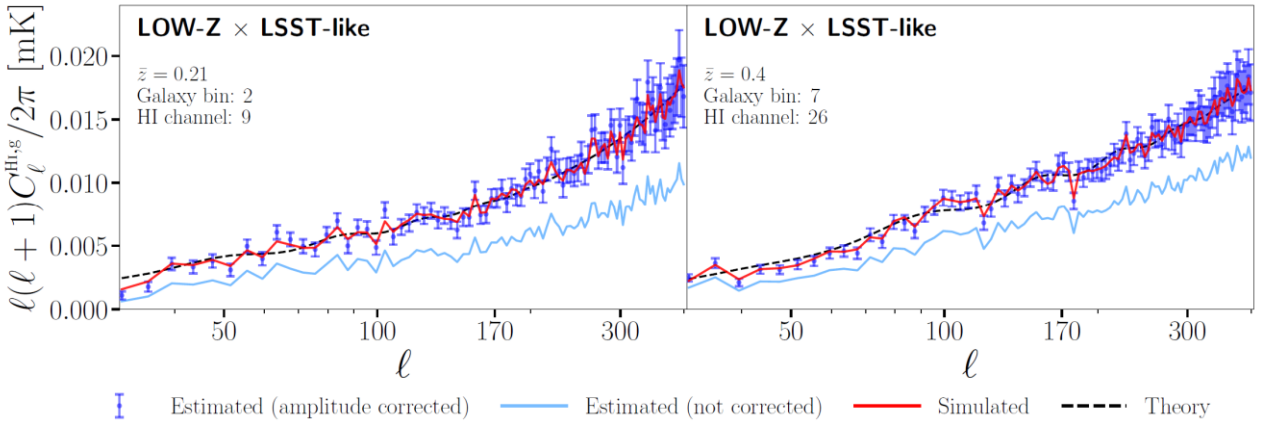
Cross-correlations between 21 cm IM and narrow-band galaxy surveys

Cross correlating narrow-band galaxy surveys with 21 cm IM



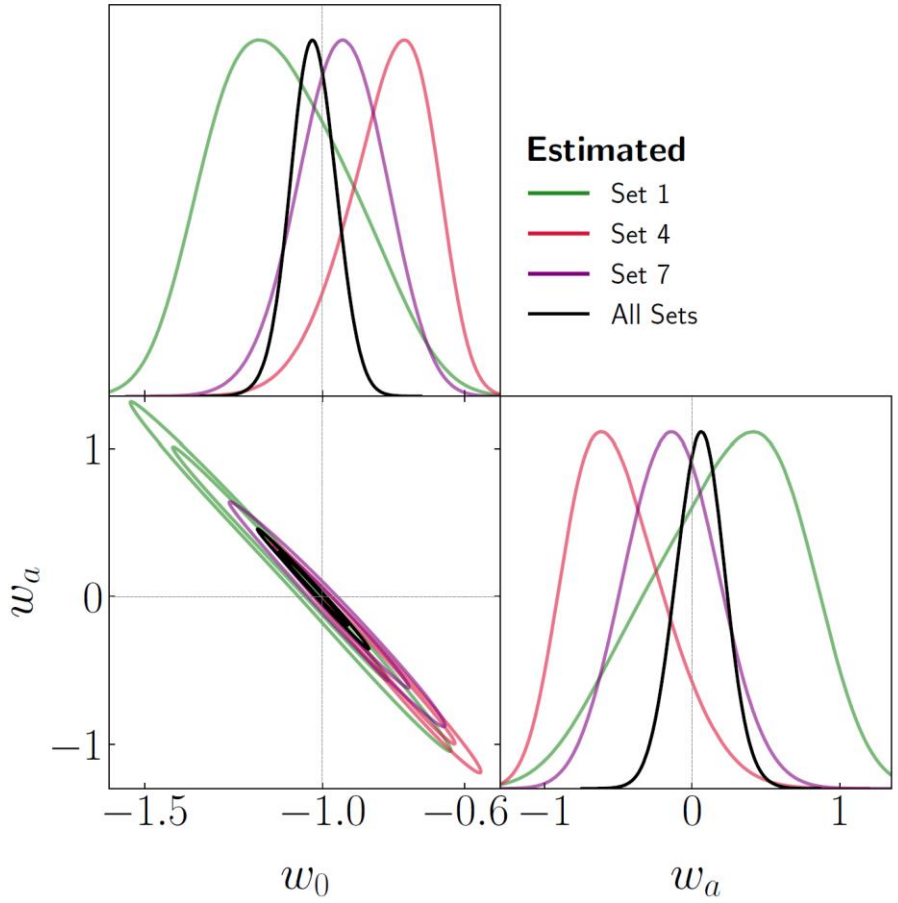


Narrow-band galaxy surveys can significantly reduce the signal loss



A. Marins, C. Feng*, et al. arXiv:2607.17141. Under review

HI IM-g cross correlation is a probe of dark energy



Conclusions

Observations at microwave and radio wavelengths are crucial for fundamental physics ——inflation, dark matter, dark energy…

- **CMB polarization is an early universe probe and is very important for both cosmology and physics**
  - **Known B mode signals consist of both polarized Galactic foreground and gravitational lensing**
  - **New polarization signals can shed light on the inflation, primordial magnetic fields, and axion-like particles**
- **21 cm line of neutral hydrogen is a late universe probe and is also important for new physics**
  - **Efficient detection algorithms are crucial for 21 cm cosmology**
  - **Future 21 cm measurements will be important for dark sector studies**

Thank you!