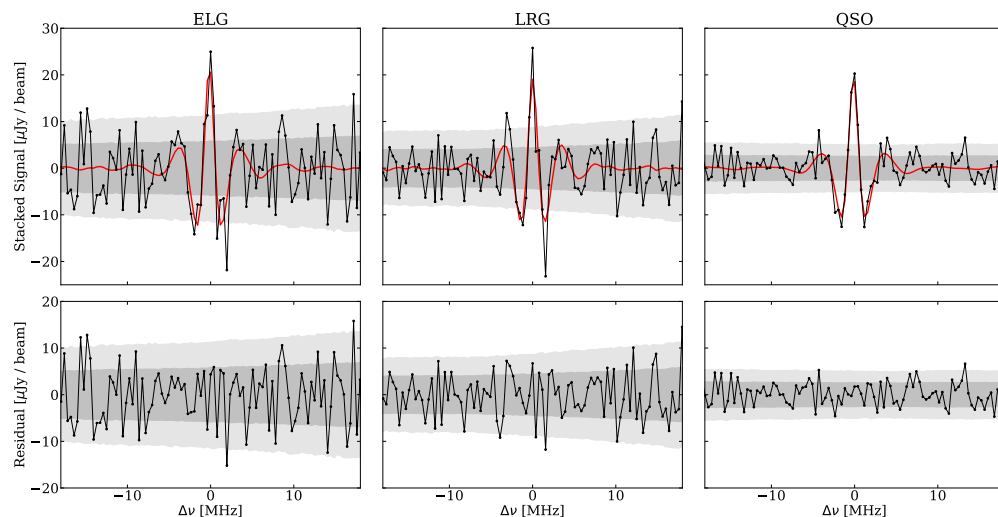


CMB lensing x CHIME²: Current Limits and Forecasts

Tristan Pinsonneault-Marotte
2 June 2025

21 cm cross-correlations from CHIME

SDSS galaxy stacking



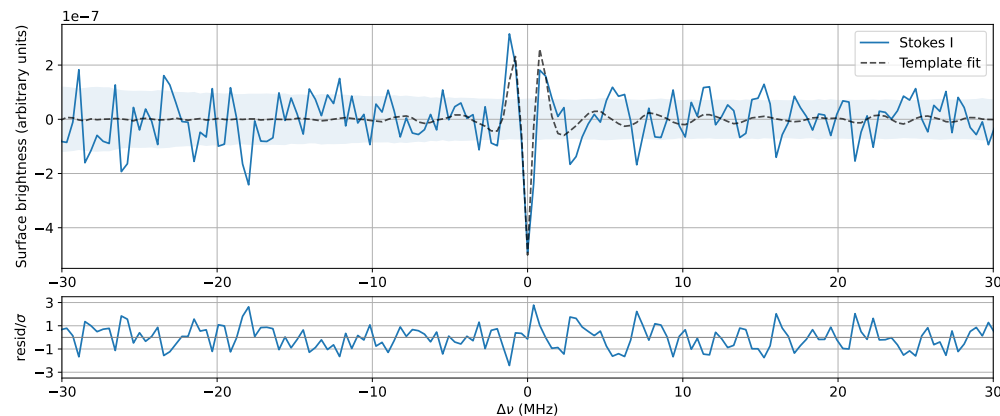
$z = 0.96$

$z = 0.84$

$z = 1.20$

arXiv:2202.01242

SDSS Lyman- α forest



$z = 2.3$

arXiv:2309.04404
(also in my PhD thesis)

21 cm x CMB lensing

- At high redshift, few possibilities for cross-correlation
 - Lensing of the CMB captures structures from all redshifts to last scattering
- Connection of HI to matter involves theoretical uncertainty
 - Lensing is a direct probe of matter density
 - Could help break bias degeneracies

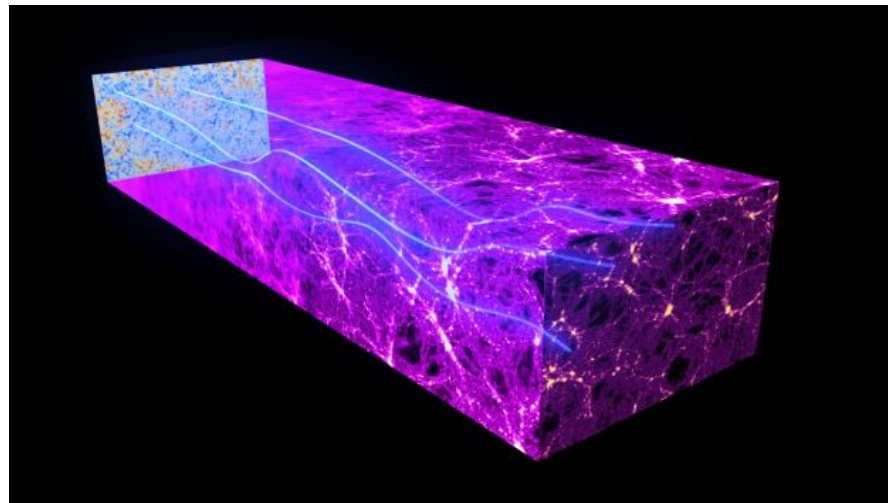
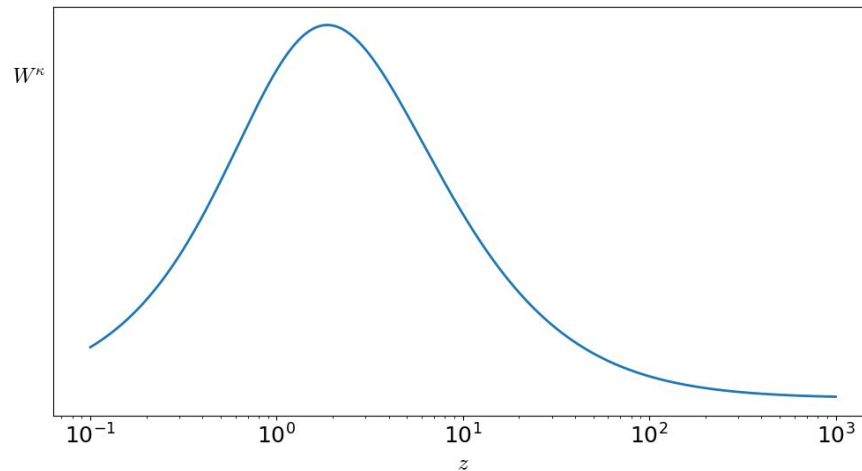
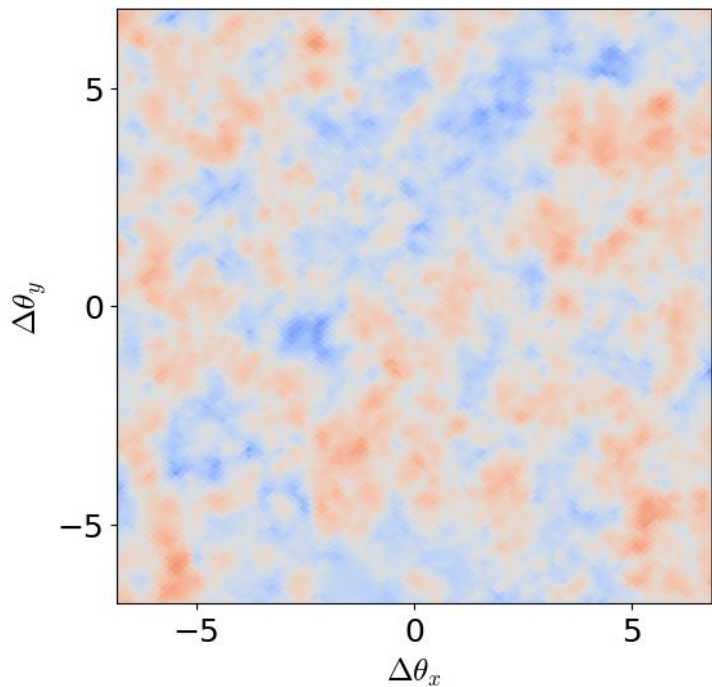


Illustration from ESA

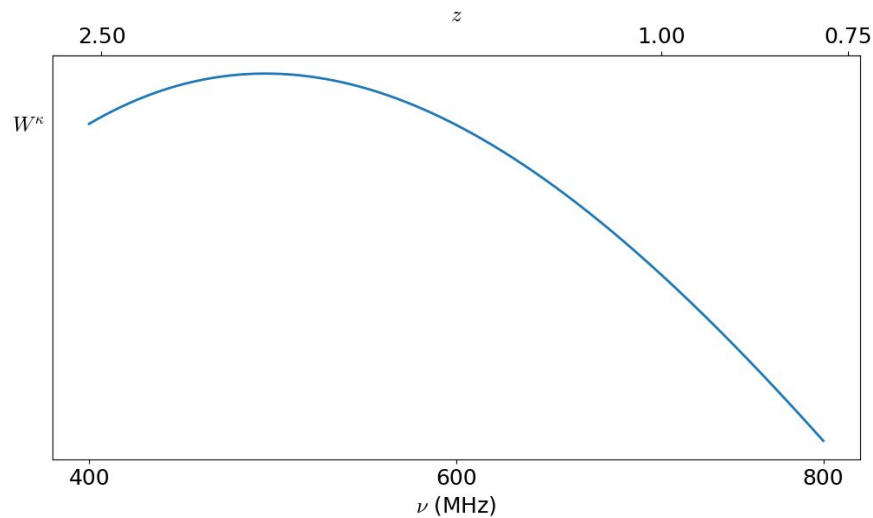
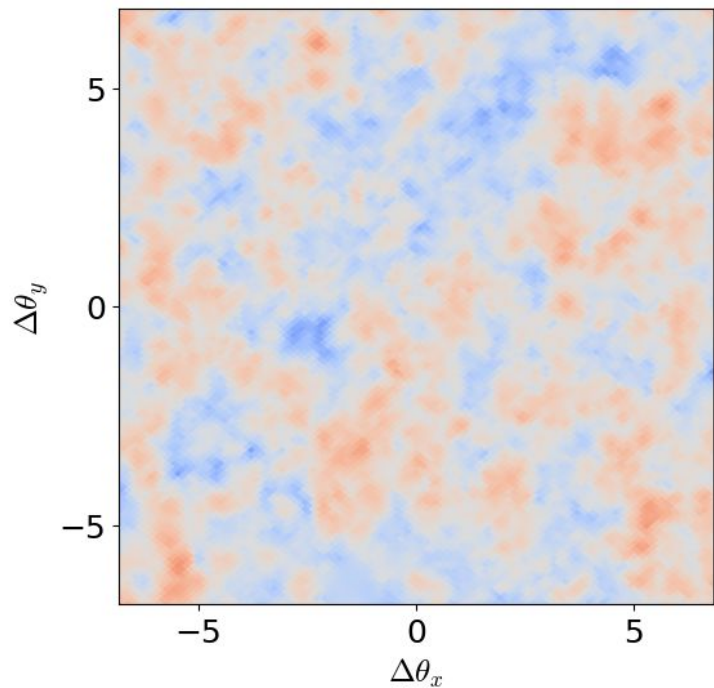
21 cm x CMB lensing



$$\kappa(\hat{\mathbf{n}}) = \int_0^\infty dz W^\kappa(z) \delta_{\text{m}}(\chi(z)\hat{\mathbf{n}}, z).$$

Lensing convergence is an integral of density fluctuations along the LoS, weighted by the kernel W .

21 cm x CMB lensing

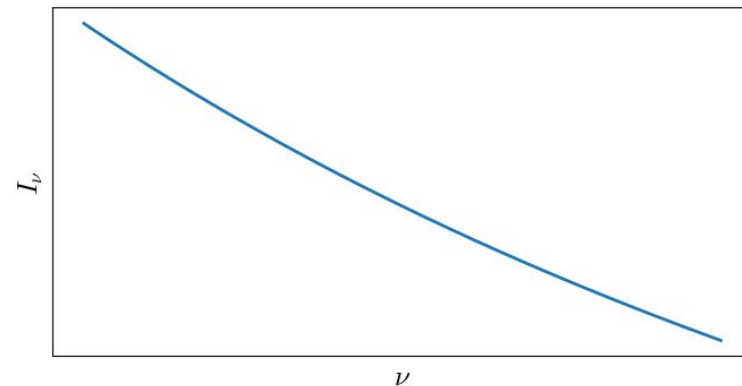
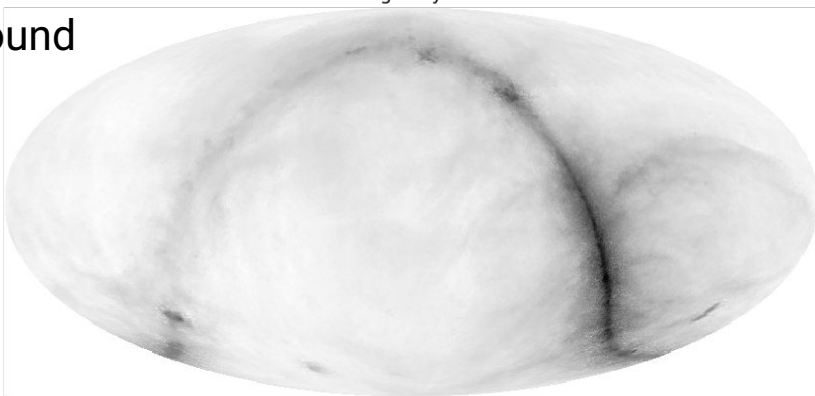


$\kappa(\hat{\mathbf{n}}) \sim \text{long wavelength mode}$

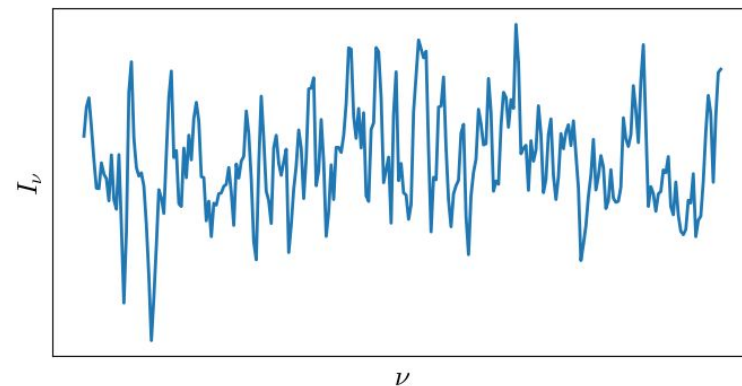
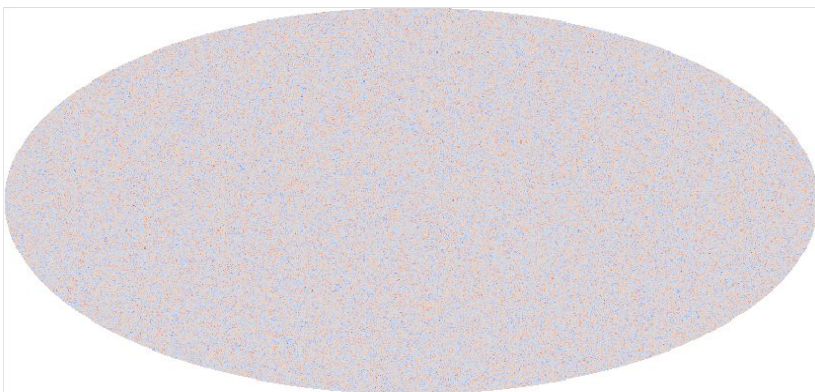
The kernel is a smooth function of redshift, shown here projected onto the CHIME observing band.

21 cm x CMB lensing

Foreground



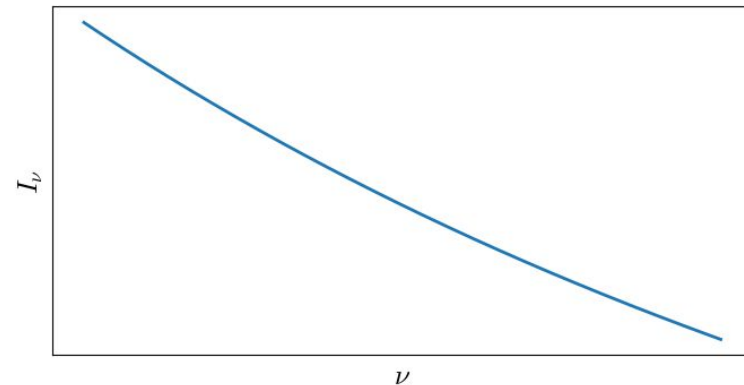
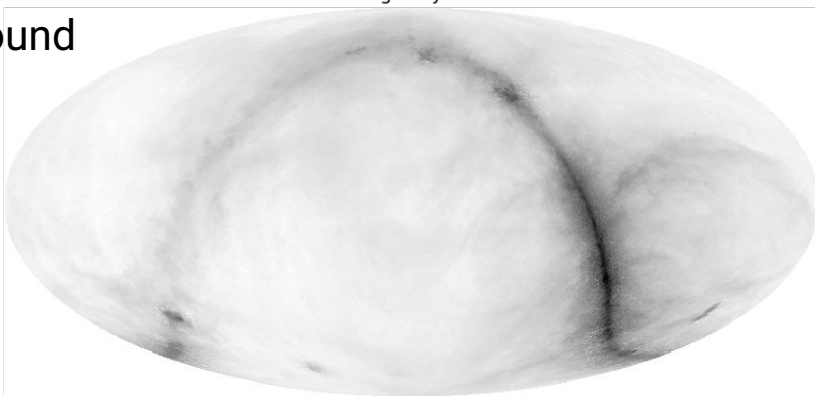
HI



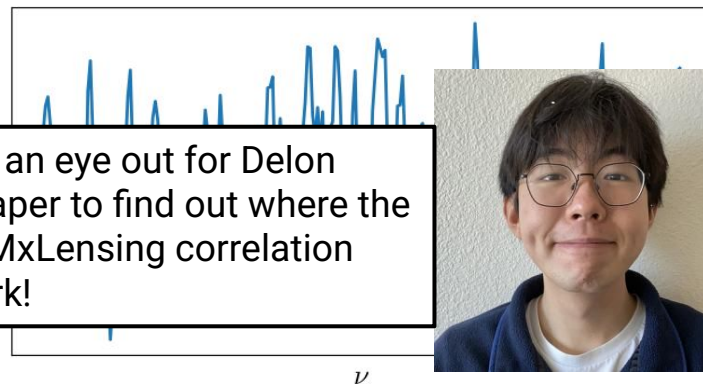
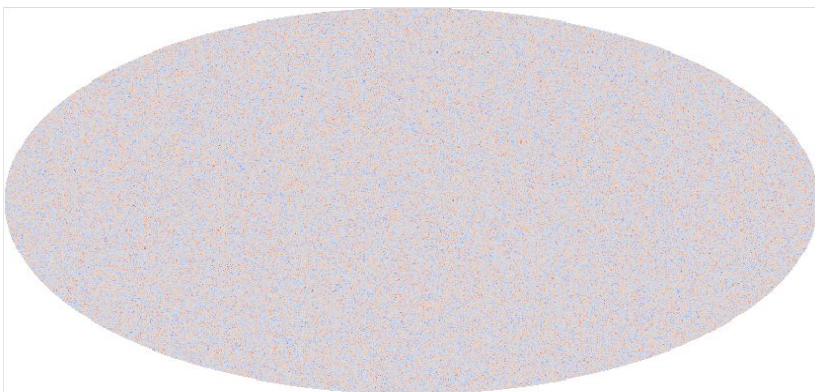
Smooth modes are degenerate with 21cm foregrounds, signal is measured in fast modes.

21 cm x CMB lensing

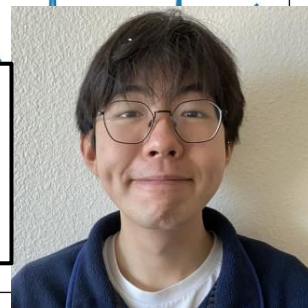
Foreground



HI



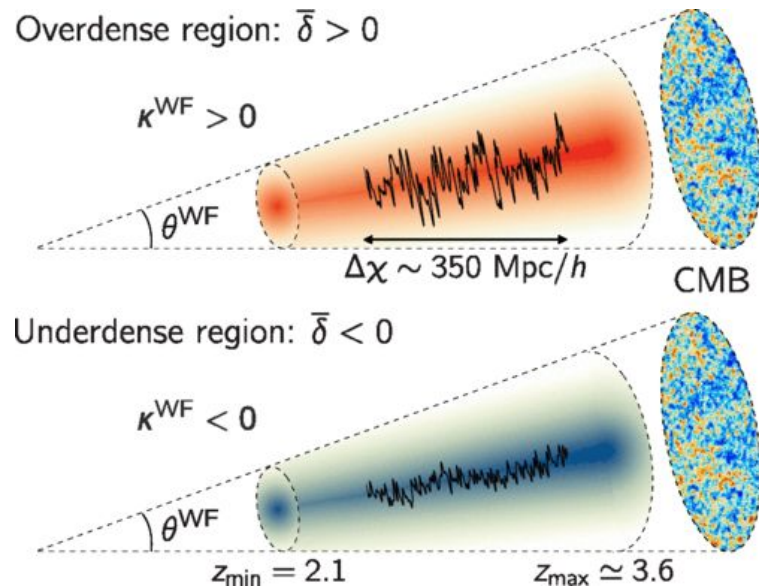
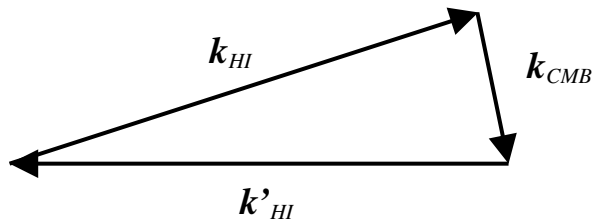
But keep an eye out for Delon Shen's paper to find out where the direct LIMxLensing correlation does work!



Smooth modes are degenerate with 21cm foregrounds, signal is measured in fast modes.

$(21\text{ cm})^2 \times \text{CMB}$ lensing

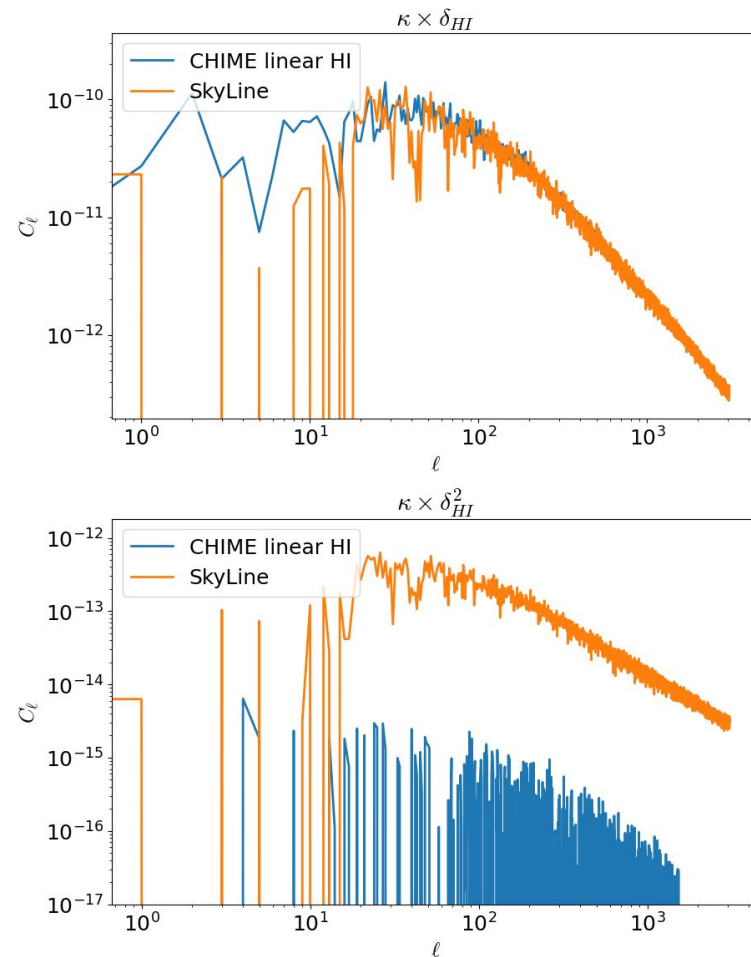
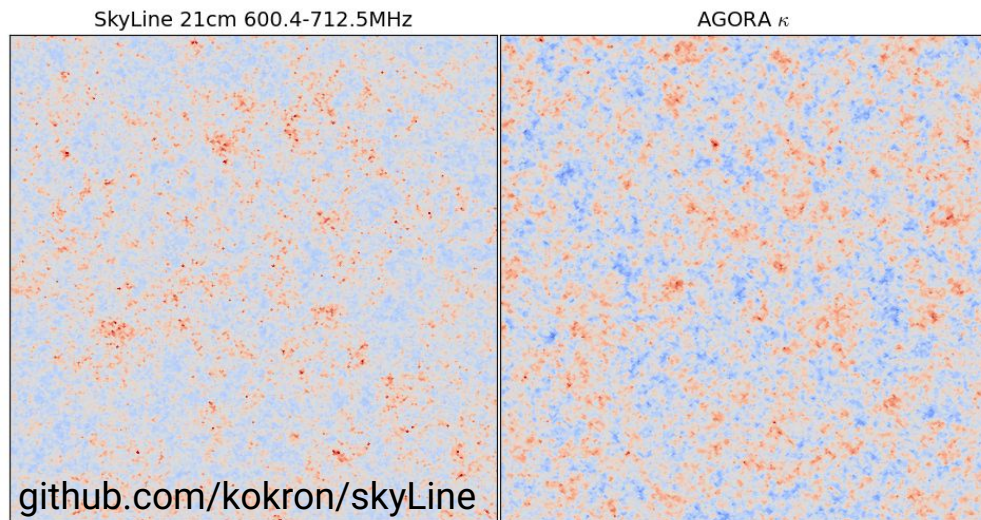
- Coupling of small and large scales from non-linear evolution
- Correlating the LoS power spectrum of 21cm with CMB lensing maps
 - “position-dependent power spectrum”
 - corresponds to squeezed modes of the bispectrum
- Analog measurement with Lyman- α forest by Doux et al.



Doux et al. (arXiv:1607.03625)

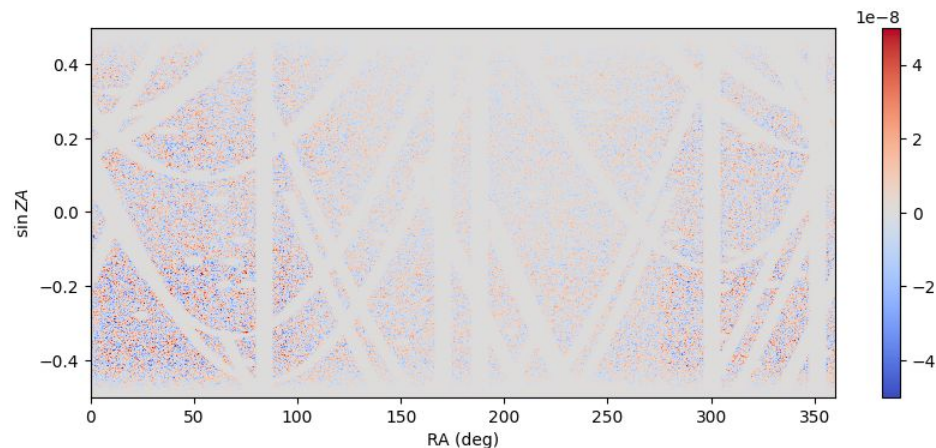
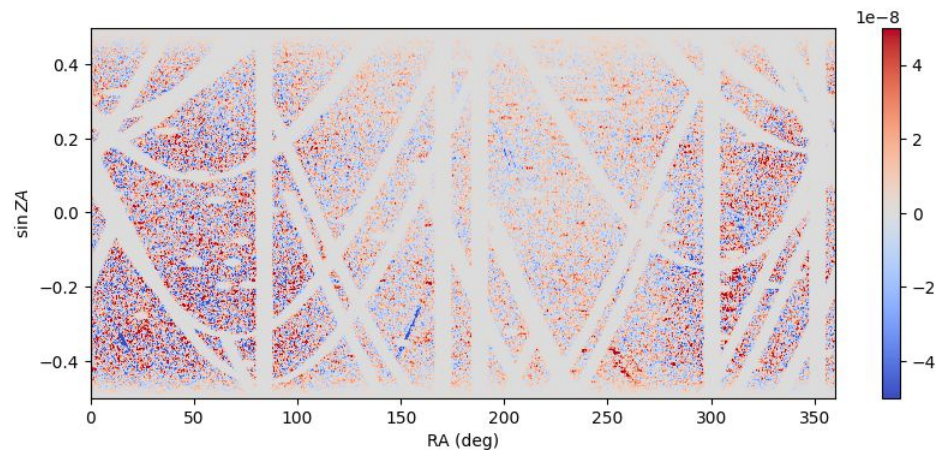
$(21\text{ cm})^2 \times \text{CMB}$ lensing – in simulation

- SkyLine (Sato-Polito, Kokron et al.; arXiv:2212.08056)
 - paints LIM onto N-body sim MultiDark Planck 2
 - captures higher-order correlations
 - correlated with the AGORA suite of CMB observables



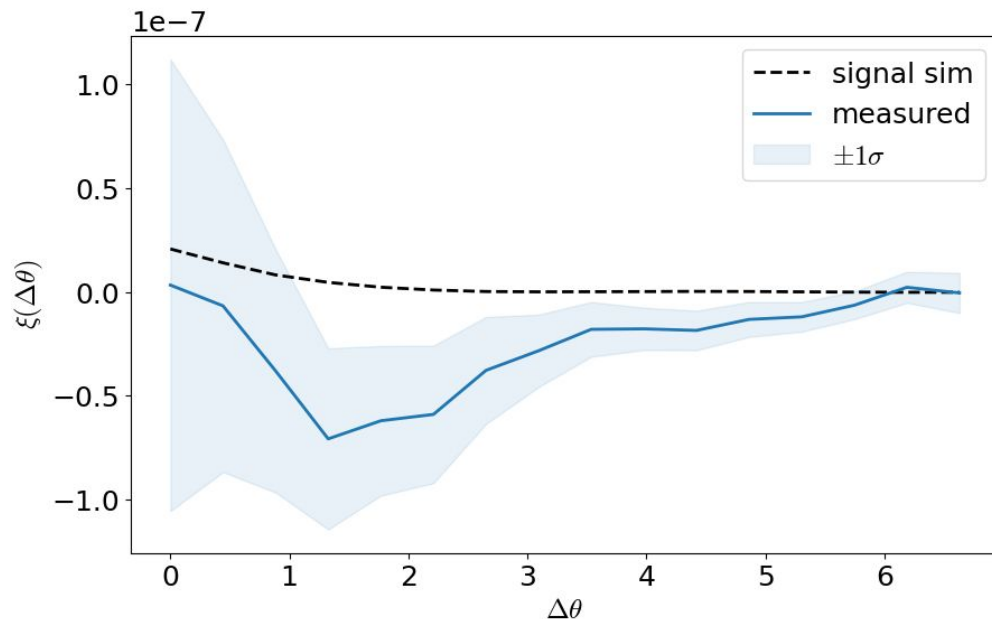
Line-of-sight variance maps

- Same 94 nights and processing as CHIME PS analysis
- Estimate variance along LoS using product of maps from distinct polarisations
- Corresponding simulated maps from Skyline
- +gaussian noise realisation at expected level for CHIME map
- (no foreground residuals)



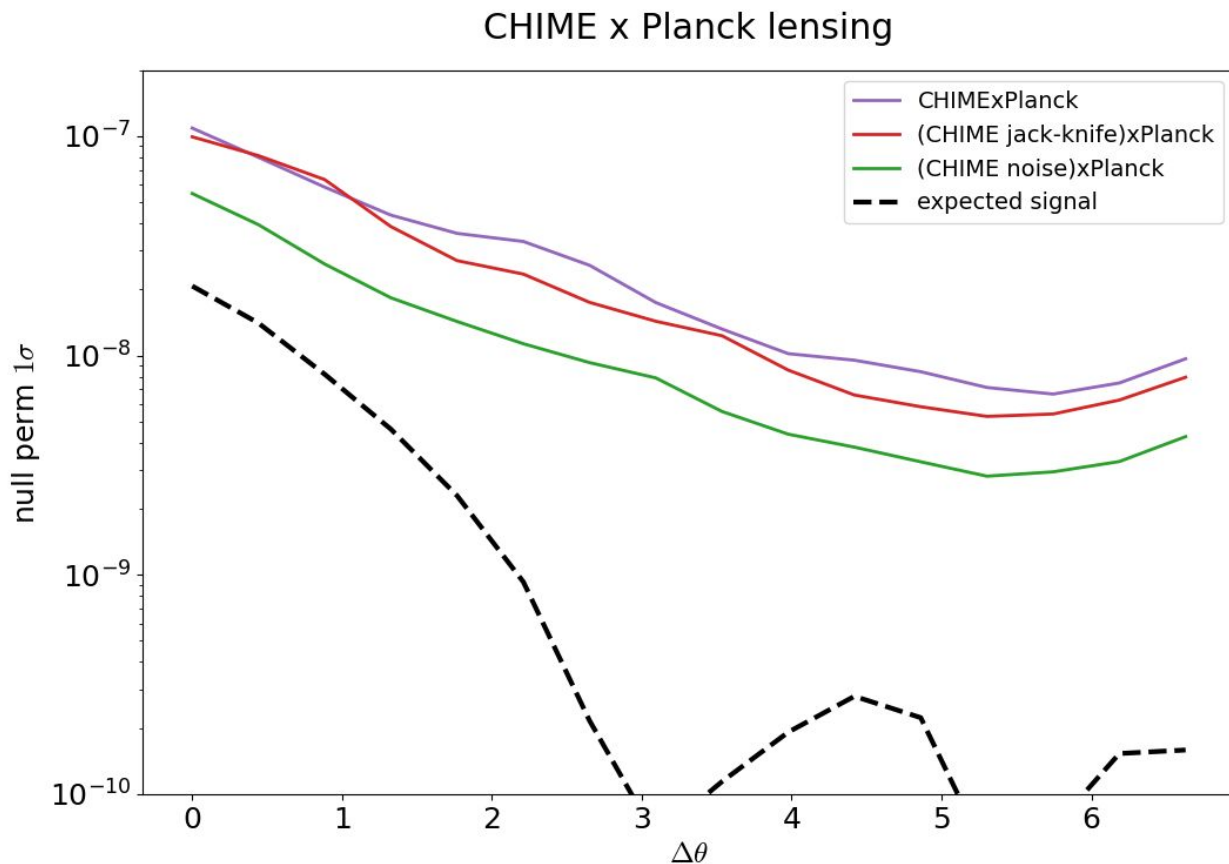
CHIME²xPlanck

- Angular cross-correlation
- Fit signal-only template for single parameter amplitude
 - uncertainty from the fit is ~ 5 times the expected signal amplitude
 - reduced $\chi^2 = 1.0$, PTE 0.45
 - NB correlated samples – this is accounted for in χ^2
- **Conclude: Signal is not an OOM greater than expected!**



CHIME²xPlanck sensitivity

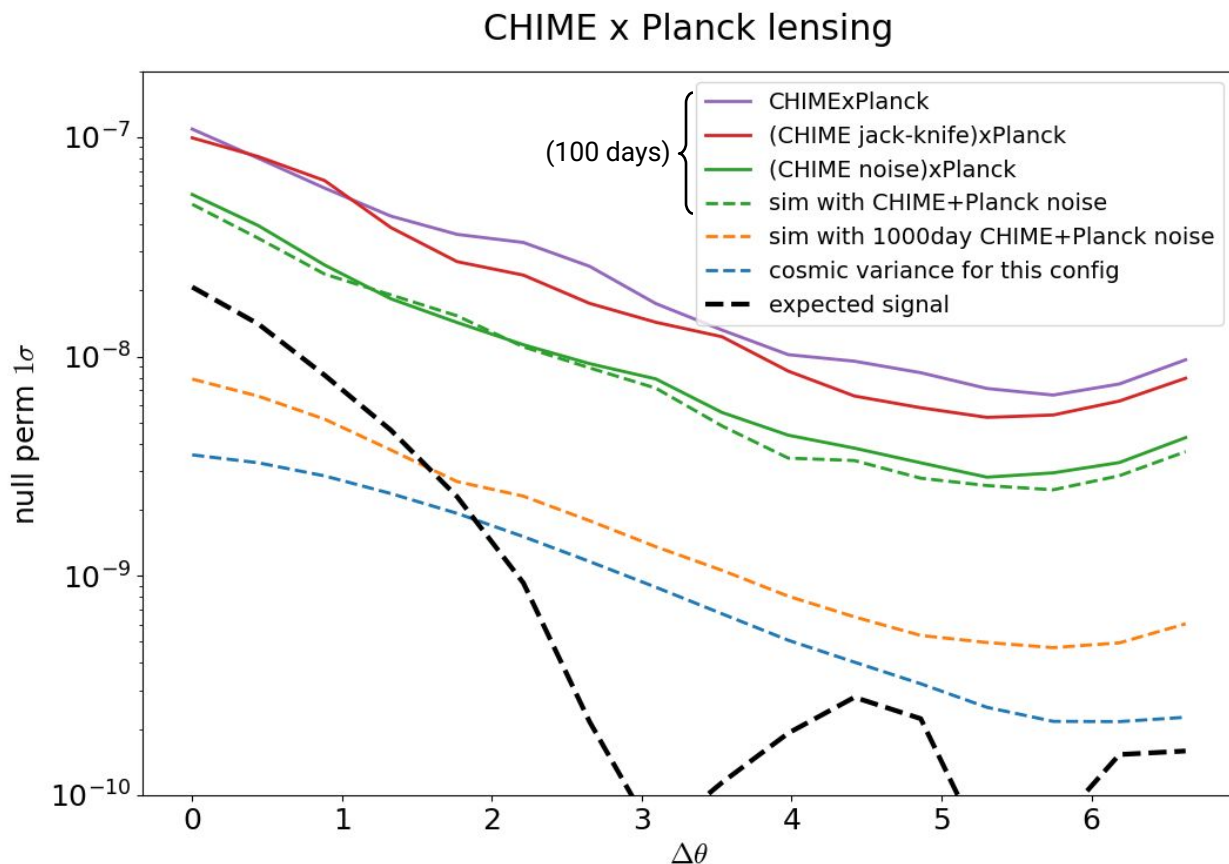
- jack-knife difference of even and odd days of CHIME data
 - removes sky signals – both HI and foreground
 - what is left: RFI, thermal noise, calibration errors
- measurement is consistent with jack-knife: not foreground dominated
- residuals remain $\sim 2\times$ above thermal noise



CHIME²xPlanck sensitivity

- simulation is noise-dominated, matches (CHIME noise)xPlanck
- extending to 1000days of CHIME brings detection within reach
 - but excess residuals could be an issue
- blue curve is intrinsic variance due to limited number of modes is the chosen data volume

	S/N
CHIME 100day	0.2
CHIME 1000day	3
cosmic variance	13



Future: more CHIME

With more days of CHIME a detection may be possible, but we can expand the dataset in other directions as well:

- more observations – there is an OOM more CHIME data to analyse
- more frequencies – only used ~half of the useable CHIME band
- more sky area – pushing closer to the horizon would add more modes
- less filtering – relaxing the delay filter

None of these options are low-hanging fruit – **but we have only started tapping the depth of CHIME data.**

Future: ~~more~~beyond CHIME ?

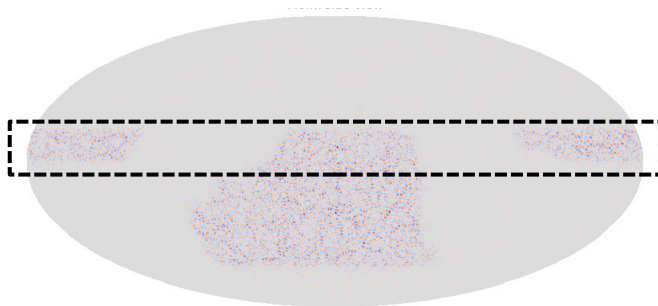
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None of these options are low-hanging fruit – **but we have only started tapping the depth of CHIME data.**

What will upcoming southern radio telescopes together with next-gen CMB lensing enable? Can use the sims presented here to study this question.

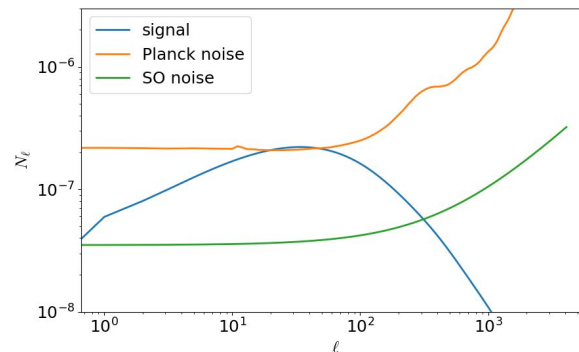
Explore other configurations



CHIME x ACT

- overlap limited to equatorial strip
 - fewer modes
- ACT noise < Planck noise
- near horizon at CHIME, noise is worse

	S/N
CHIME 1000day	0.4
cosmic variance	6



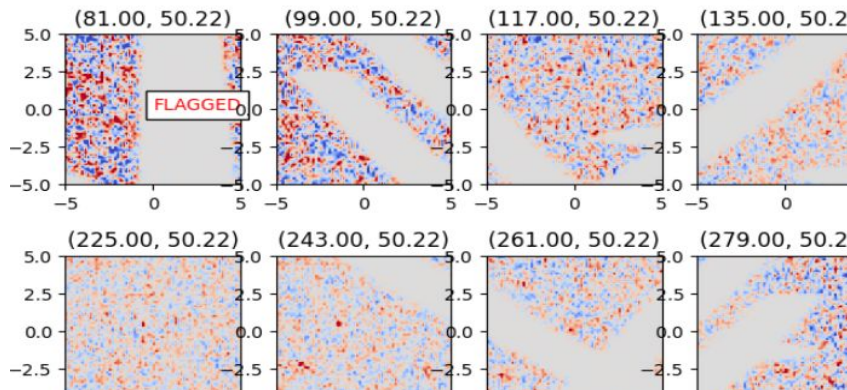
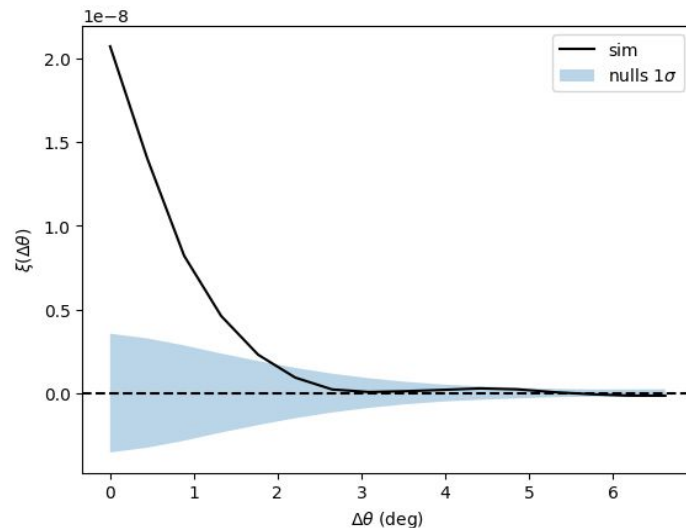
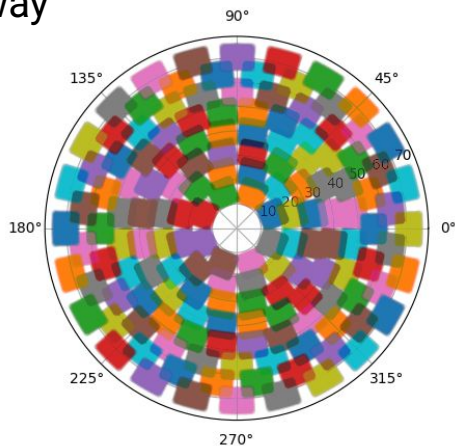
CHIME x SO lensing noise

- **CHIME will have little overlap with SO**
- what is the impact of just setting lensing noise to SO-like level? otherwise unchanged
- S/N is improved by ~ 2

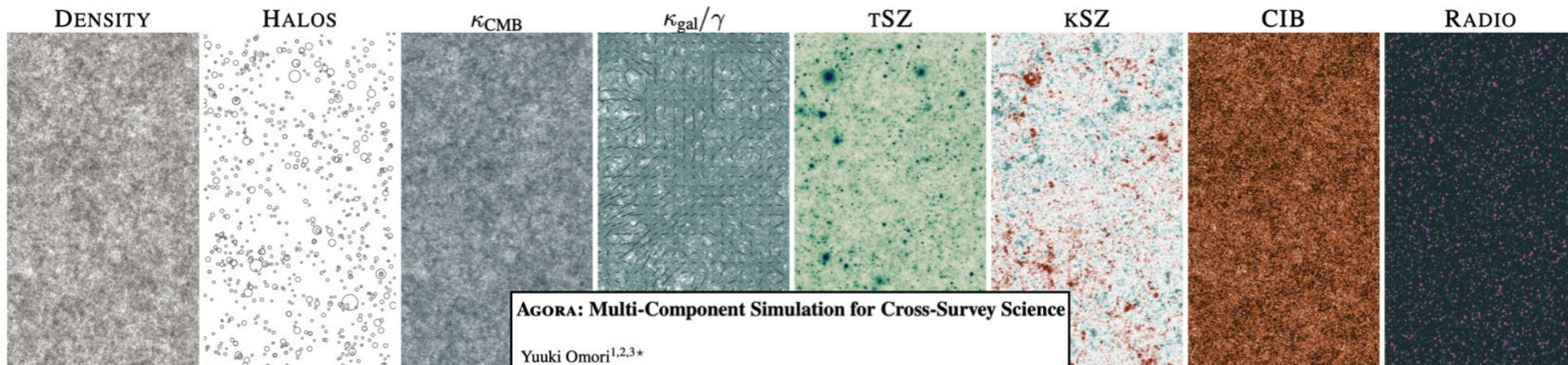
	S/N
CHIME 1000day	5
cosmic variance	14

Angular x-corr: Flat-sky tiling

- Tile CHIME field into 10x10 deg patches
- Measure az-averaged correlation function
- As a null test, take random permutations of the patches
 - eliminates correlation but retains background contributions
 - measure covariance of the correlation function in this way



Coordinated production with the Agora simulation — A coherent high-fidelity multi-tracer sky



+

