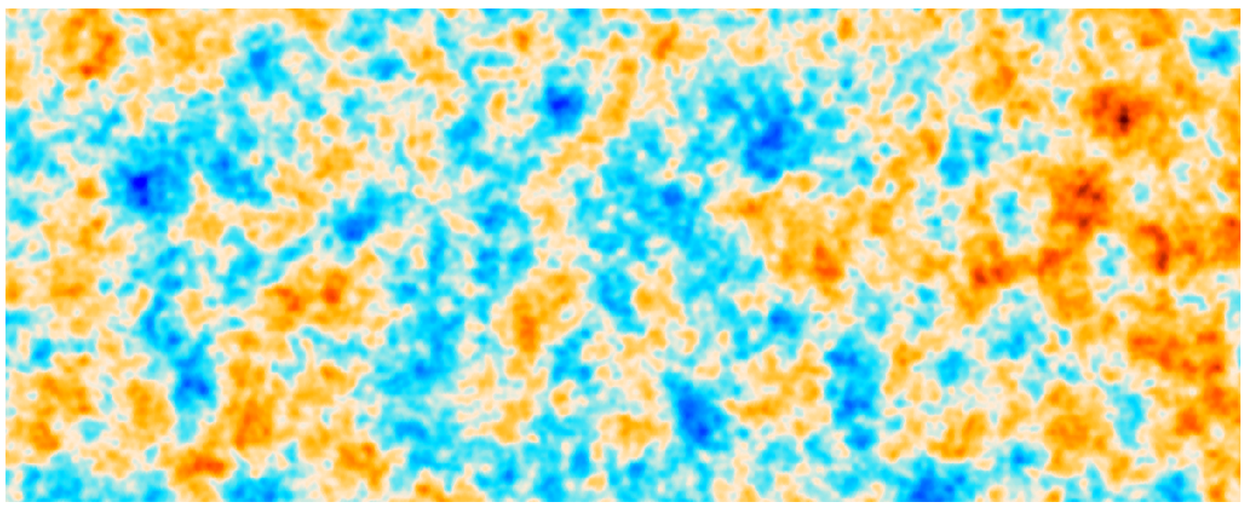
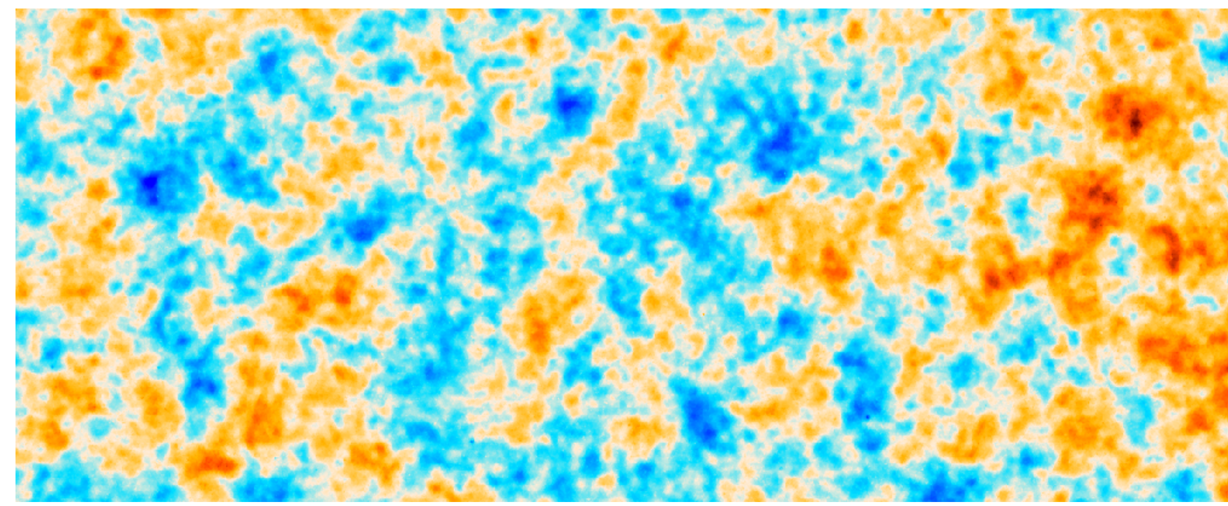
The Websky Extragalactic Simulations

@ mocks.cita.utoronto.ca

George Stein, Marcelo Alvarez, Dick Bond, Alex van Engelen, Nick Battaglia





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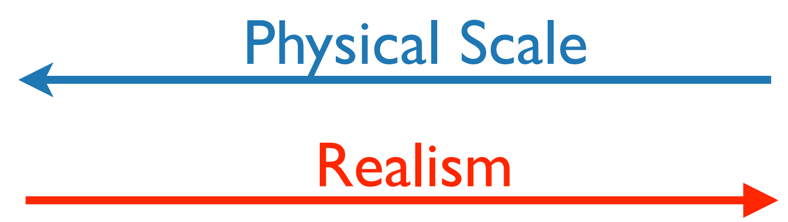
BERKELEY CENTER *for* COSMOLOGICAL PHYSICS

Modern Cosmological Simulations

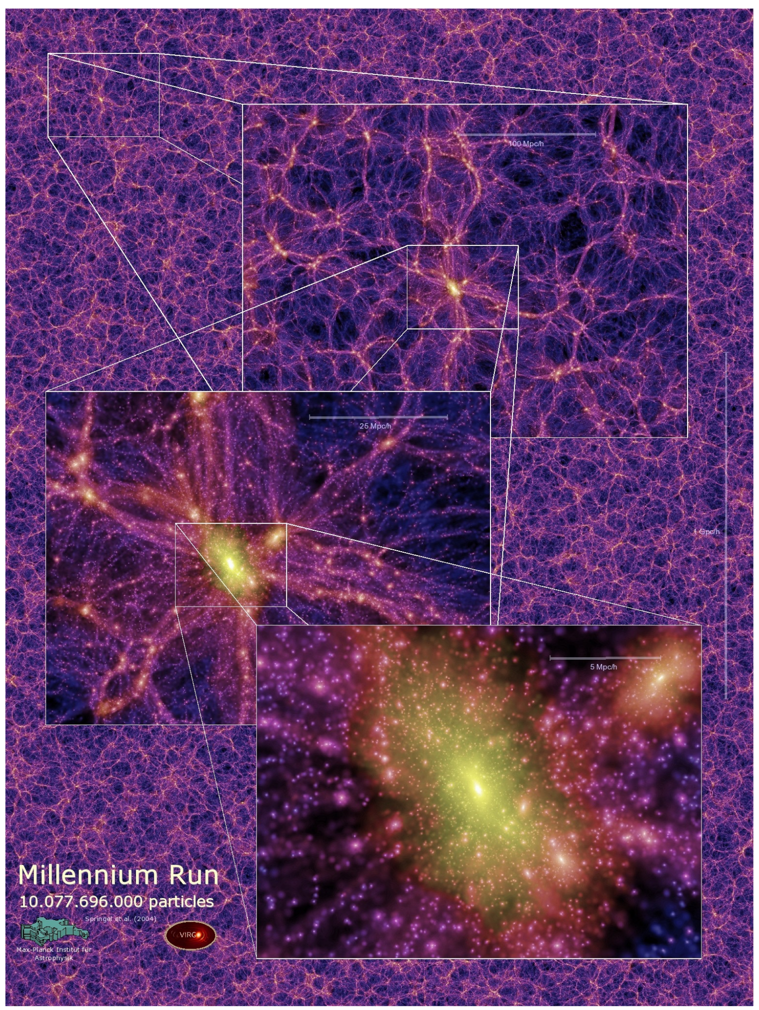


Modern Cosmological Simulations

Physical Scale

Realism

ultra large box, gravity only
Cosmic Web



N-body or 'approximate methods'

Modern Cosmological Simulations

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Realism →

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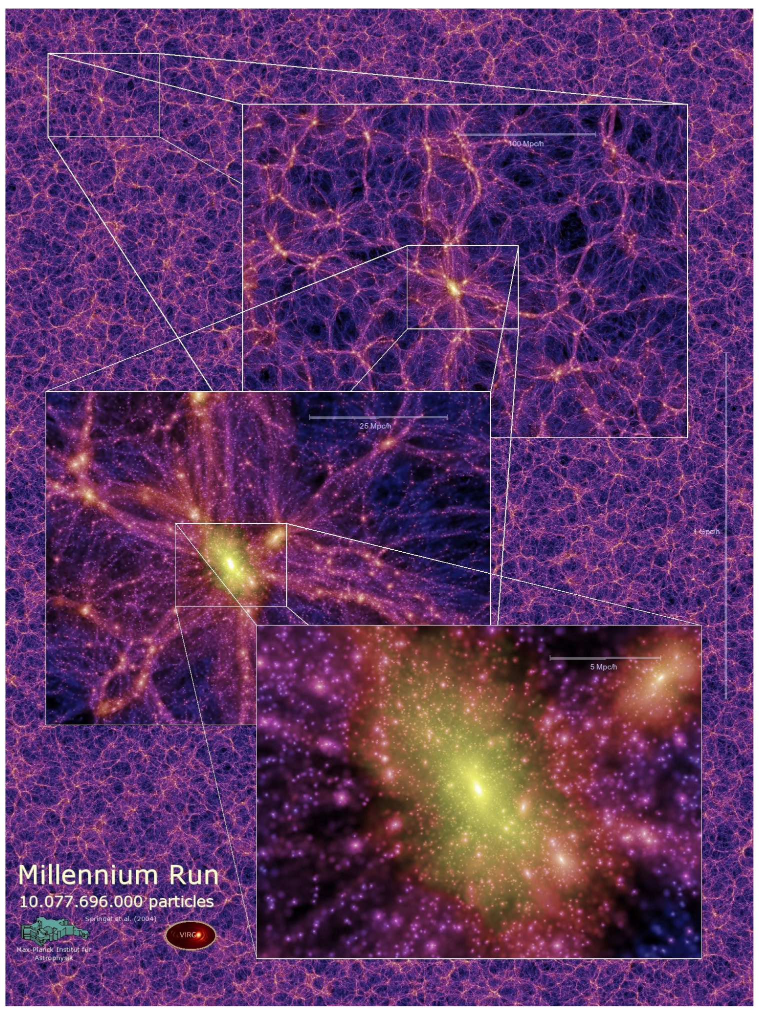
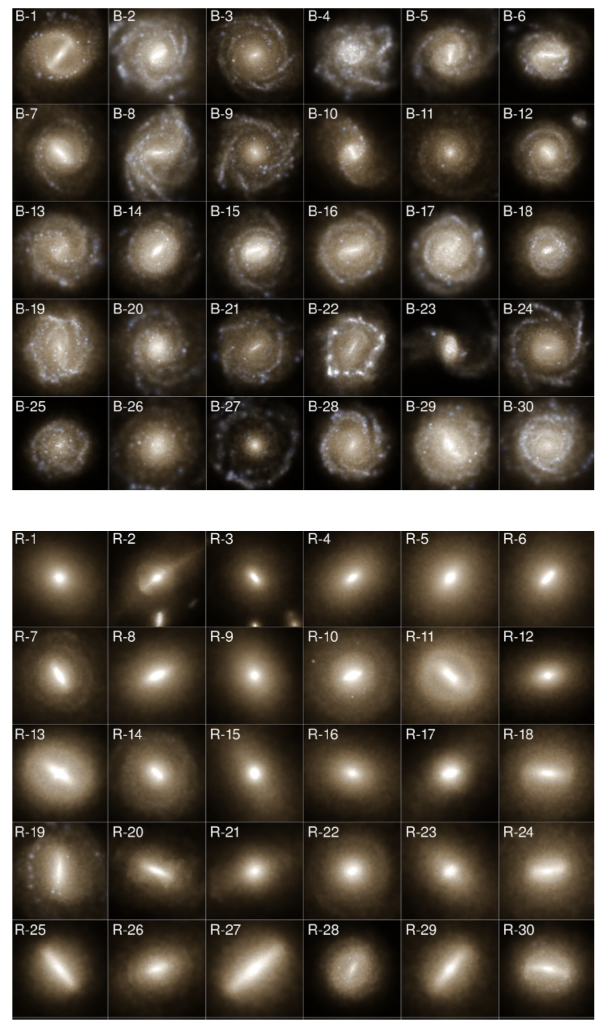


N-body or 'approximate methods'

full physics, medium sized box
The properties of dark matter halos



e.g. *Illustris*

Modern Cosmological Simulations

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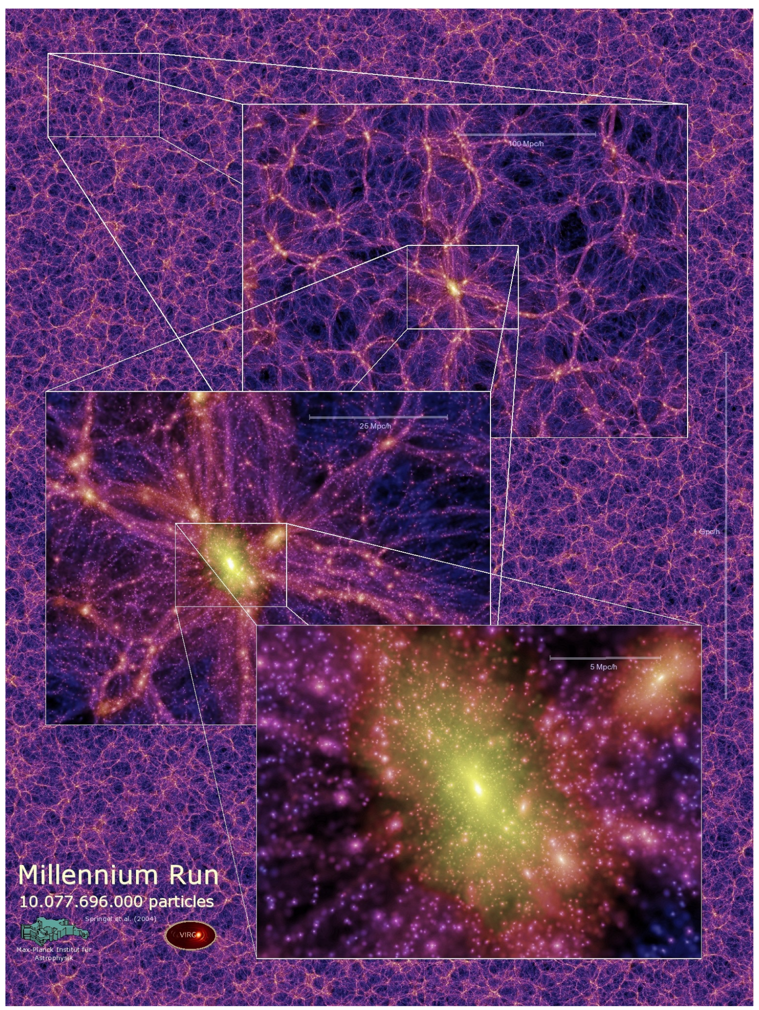

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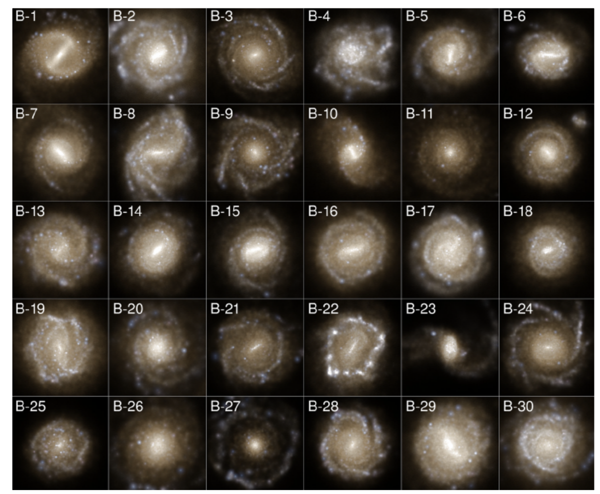
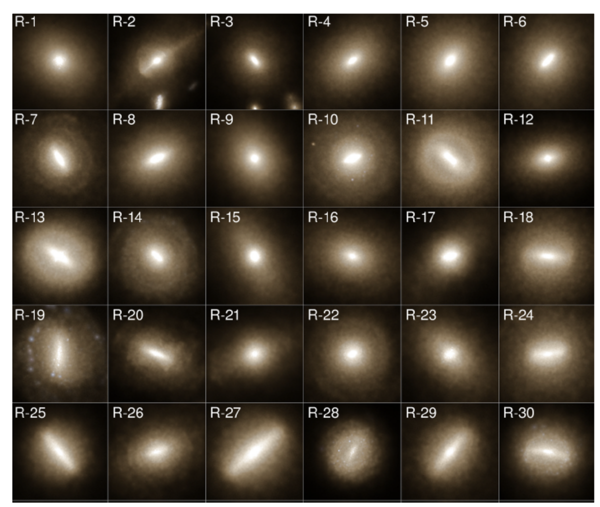
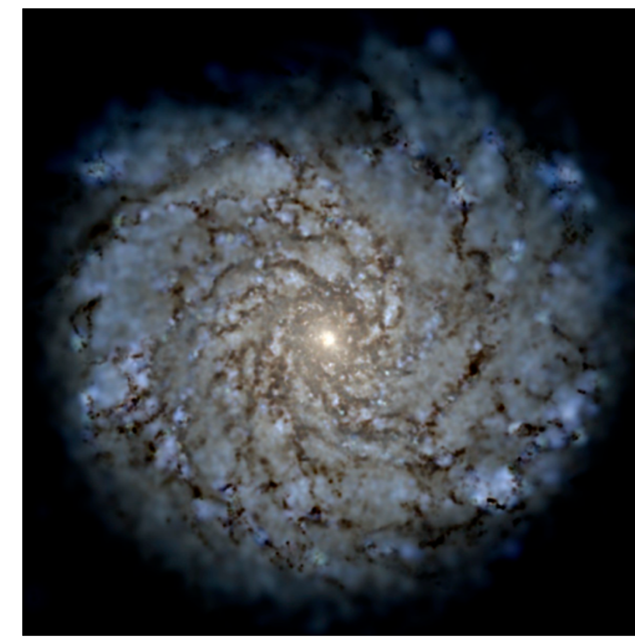




e.g. *Illustris*

full physics, small sized box
Detailed substructures of halos & galaxies



e.g. *FIRE*

Constructing the Microwave Sky

Desired CMB Mock:

Fullsky out to z~5

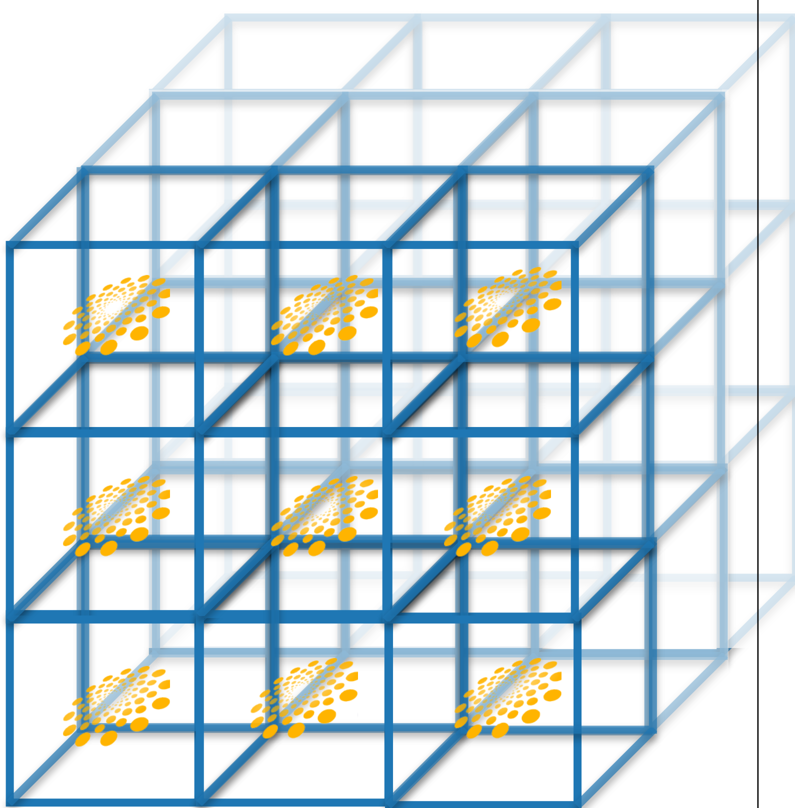
capable of resolving halos above $\sim 1\times 10^{12}\,M_\odot$

Requires:

$\sim 13{,}000^3$ particle simulation in a box size of ~16 Gpc.

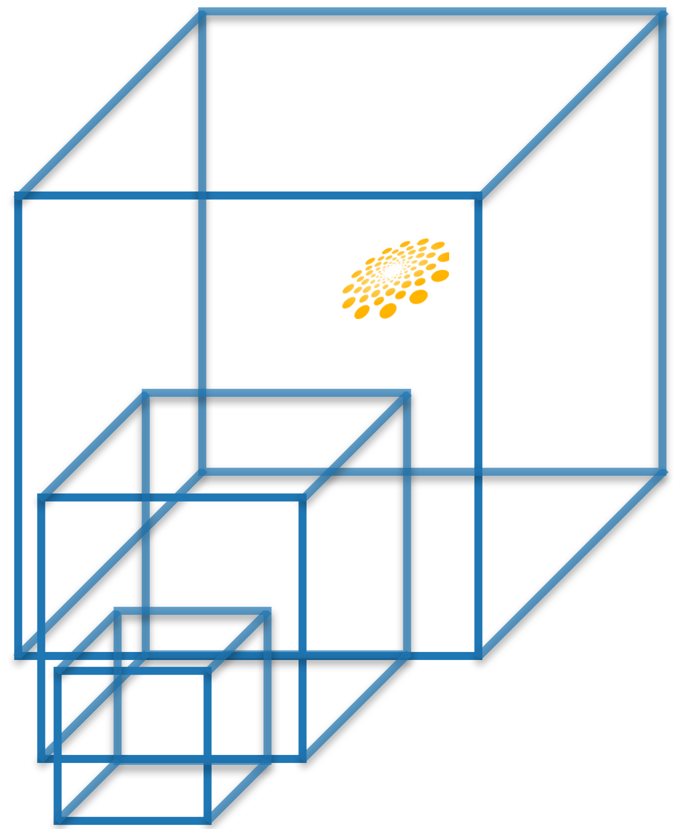
~1 billion halos

Computational Approaches



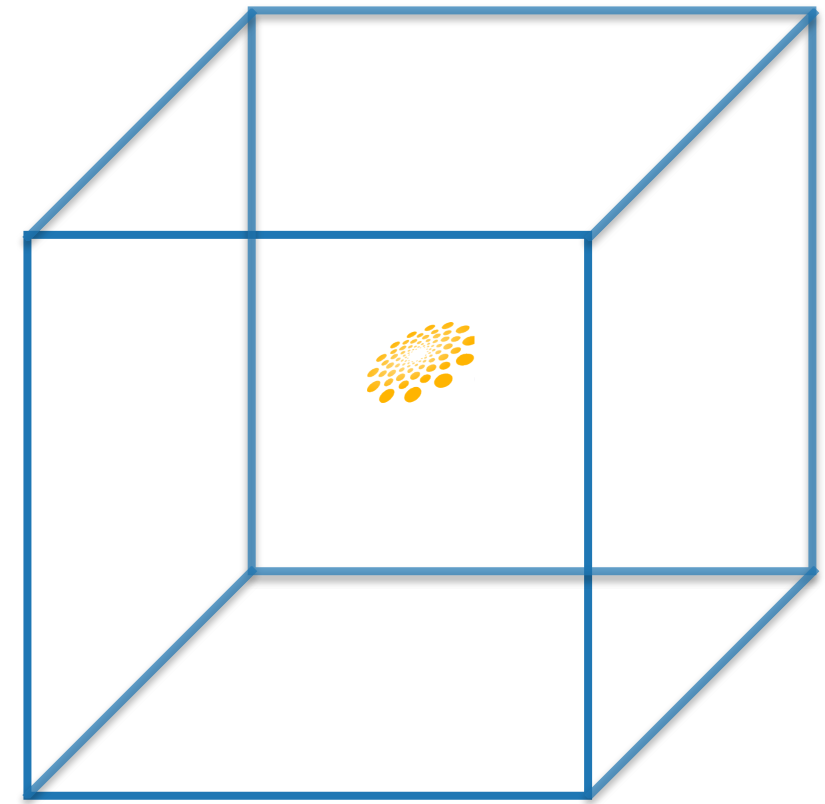
Small Box & Repeat

- Repeats structures
- Miss large scale density and velocity fluctuations & rare objects in the universe



Multi-Scale boxes

- Includes most large scale density and velocity fluctuations
- Introduces discontinuities across boxes



Large Box

- Includes large scale density and velocity fluctuations & rare objects in the universe

Computation Power →

Dark Matter Lightcone

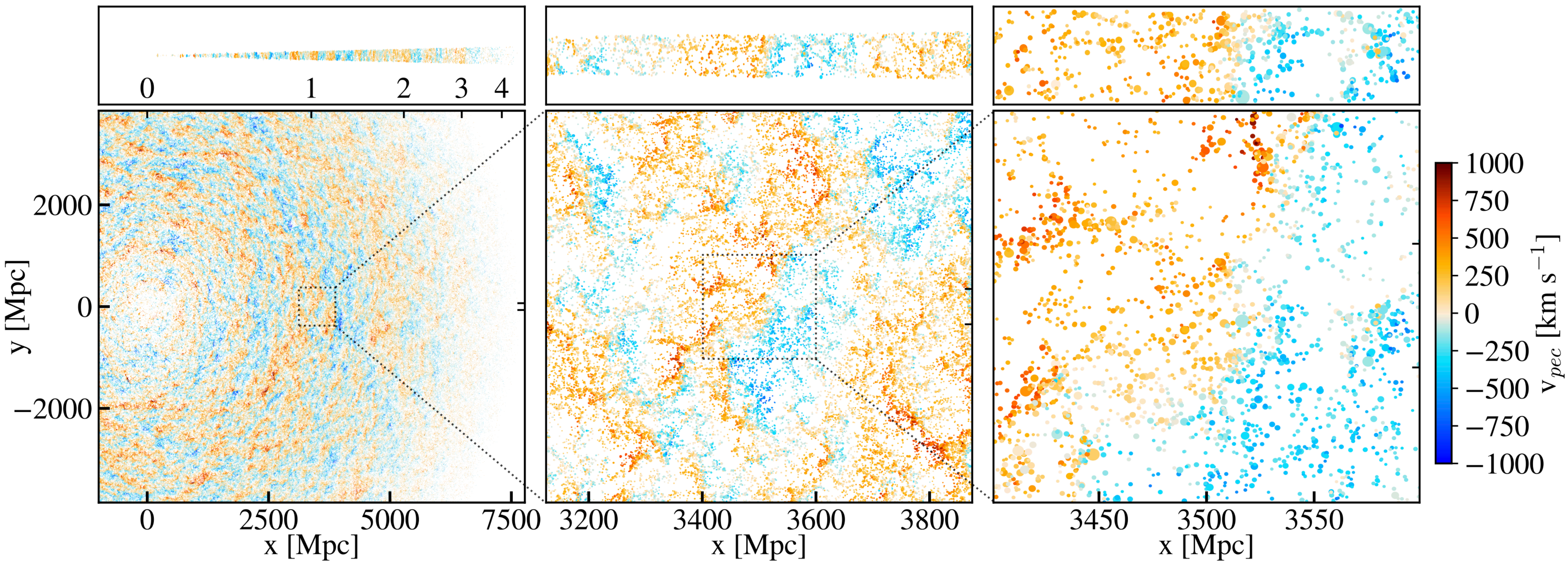
Simulation details:

Created using the mass-Peak Patch method *Stein, Alvarez, Bond - 1810.07727*

fullsky $z<4.6$, 9×10^8 halos,

effective 12,288 particles, 1900 Gpc^3 volume, from octants

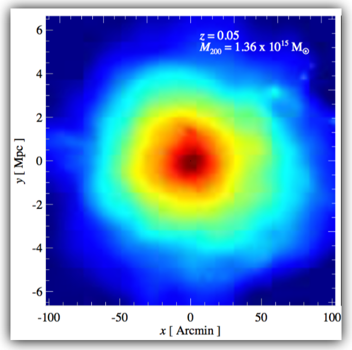
4336 CPU hours, 7.67 TB



Dark Matter to Baryonic Observables

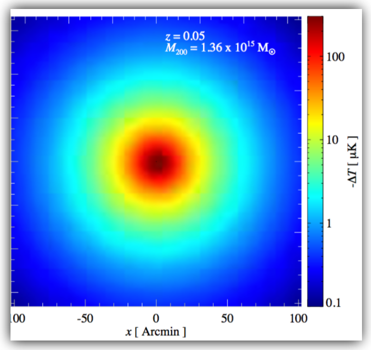
- Use spherical halo profiles fit to small box hydrodynamical simulations

Full Simulation

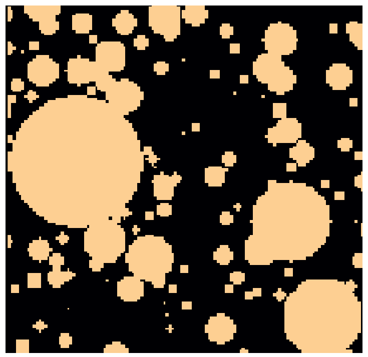


Hydro

Measure Fitting Functions

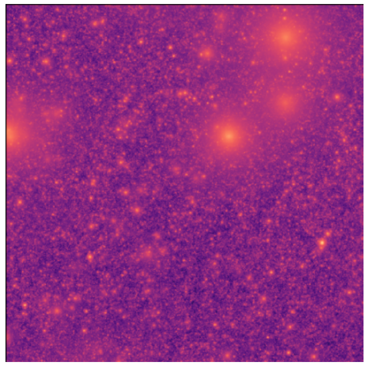


Fast Simulation



mass-Peak Patch

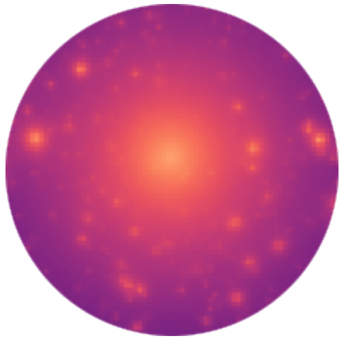
Mock Observation



Painting the Extragalactic Sky

thermal Sunyaev-Zel'dovich (tSZ)

$$\propto \frac{k_B \sigma_T}{m_e c^2} \int d\chi (1+z)^{-1} P_{th}(\chi \hat{n})$$



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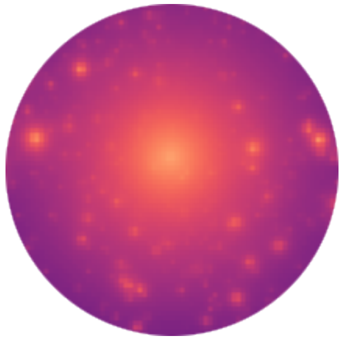
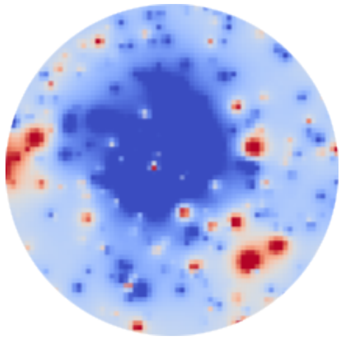


kinetic Sunyaev-Zel'dovich (kSZ)

$$\propto \frac{\rho_{b,0} \sigma_T}{\mu_e m_p} \int d\chi (1+z)^2 \Delta_g(\chi \hat{n}) \mathbf{v}(\chi \hat{n}) \cdot \hat{n}$$



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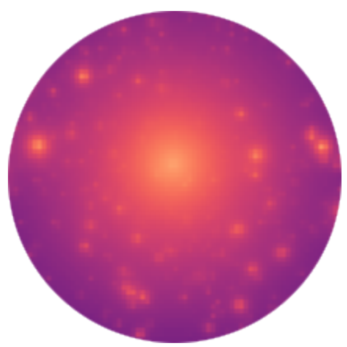

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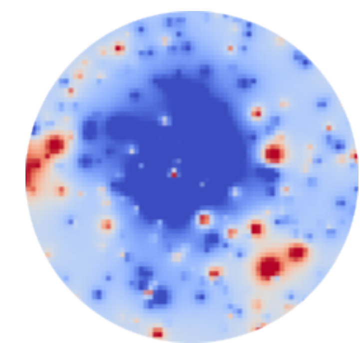

using gNFW profiles from *Battaglia, Bond, Pfrommer, Sievers (2012)*

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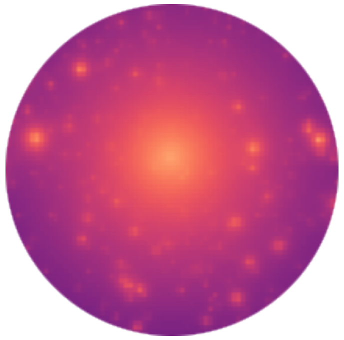

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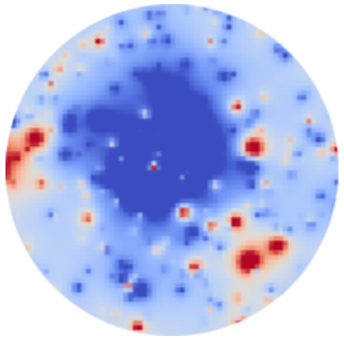

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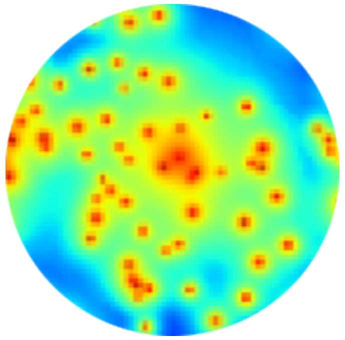
Weak Lensing

$$= \int d\chi W_\kappa(\chi) \delta(\chi \hat{n})$$



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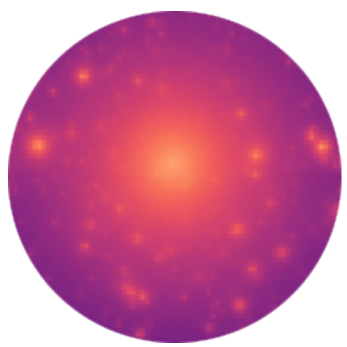

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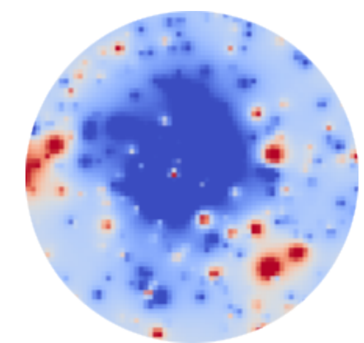

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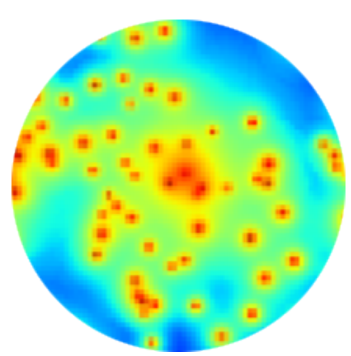
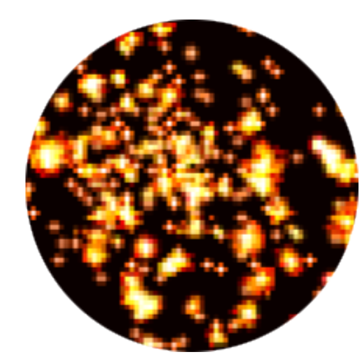


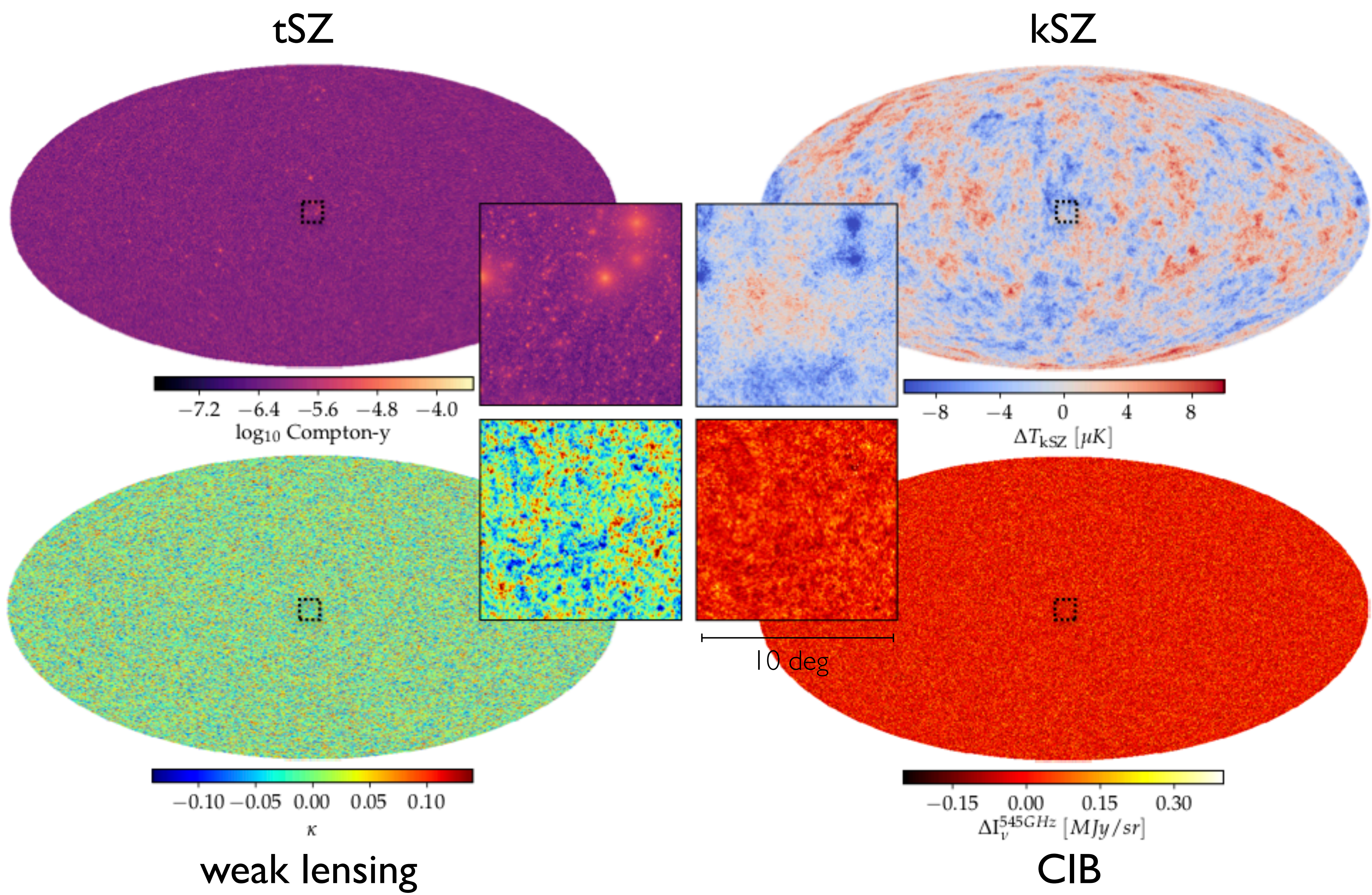
Cosmic Infrared Background (CIB)

$$L_{(1+z)\nu}(M,z) = L_0 \Phi(z) \Sigma(M,z) \Theta[(1+z)\nu, T_d(z)]$$



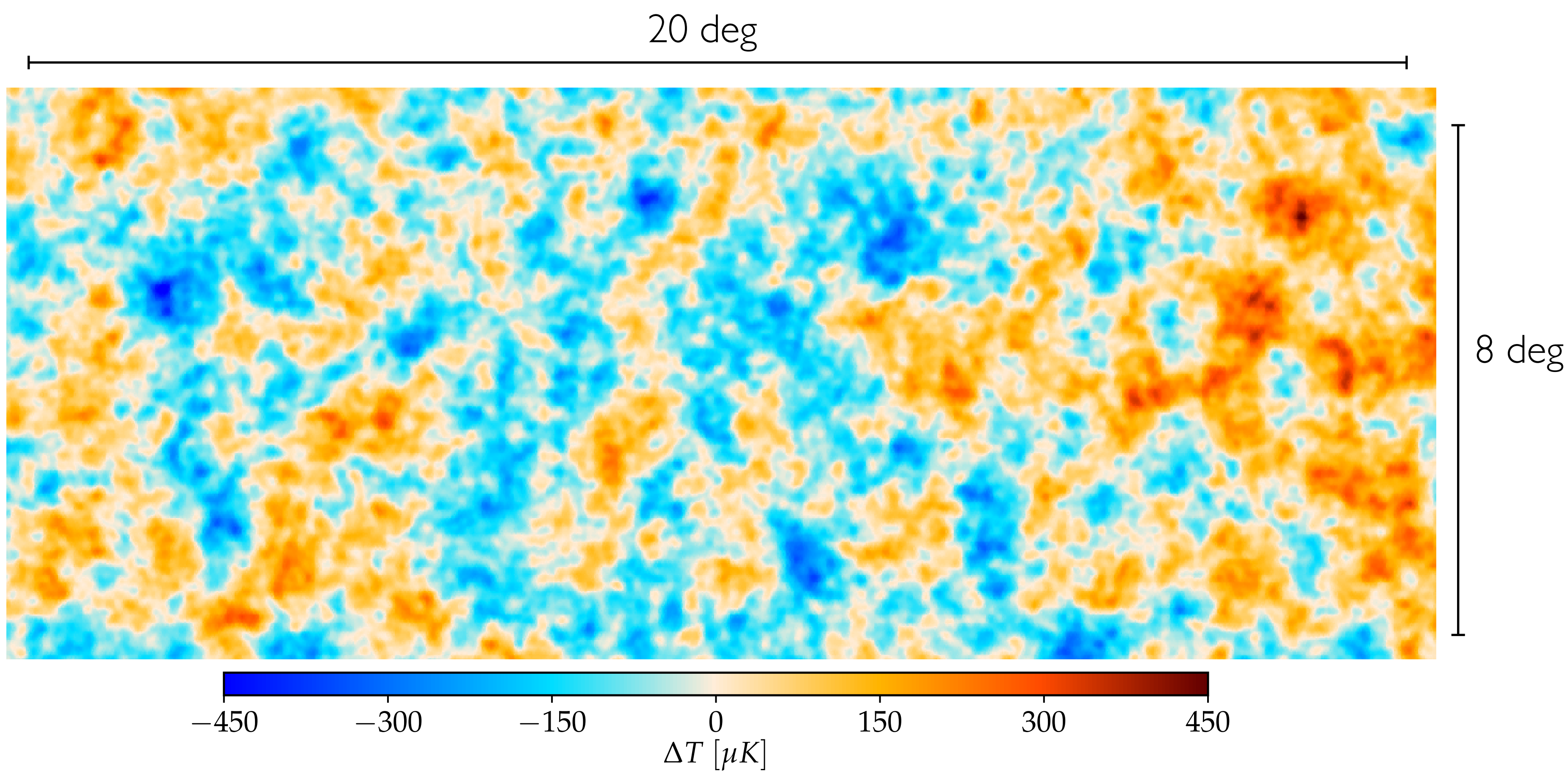
$\Phi(z)$: normalization of the L-M relation
$\Sigma(M,z)$: dependence of the luminosity on halo mass
$\Theta[(1+z)\nu, T_d(z)]$: spectral energy distribution

The Websky Extragalactic Maps



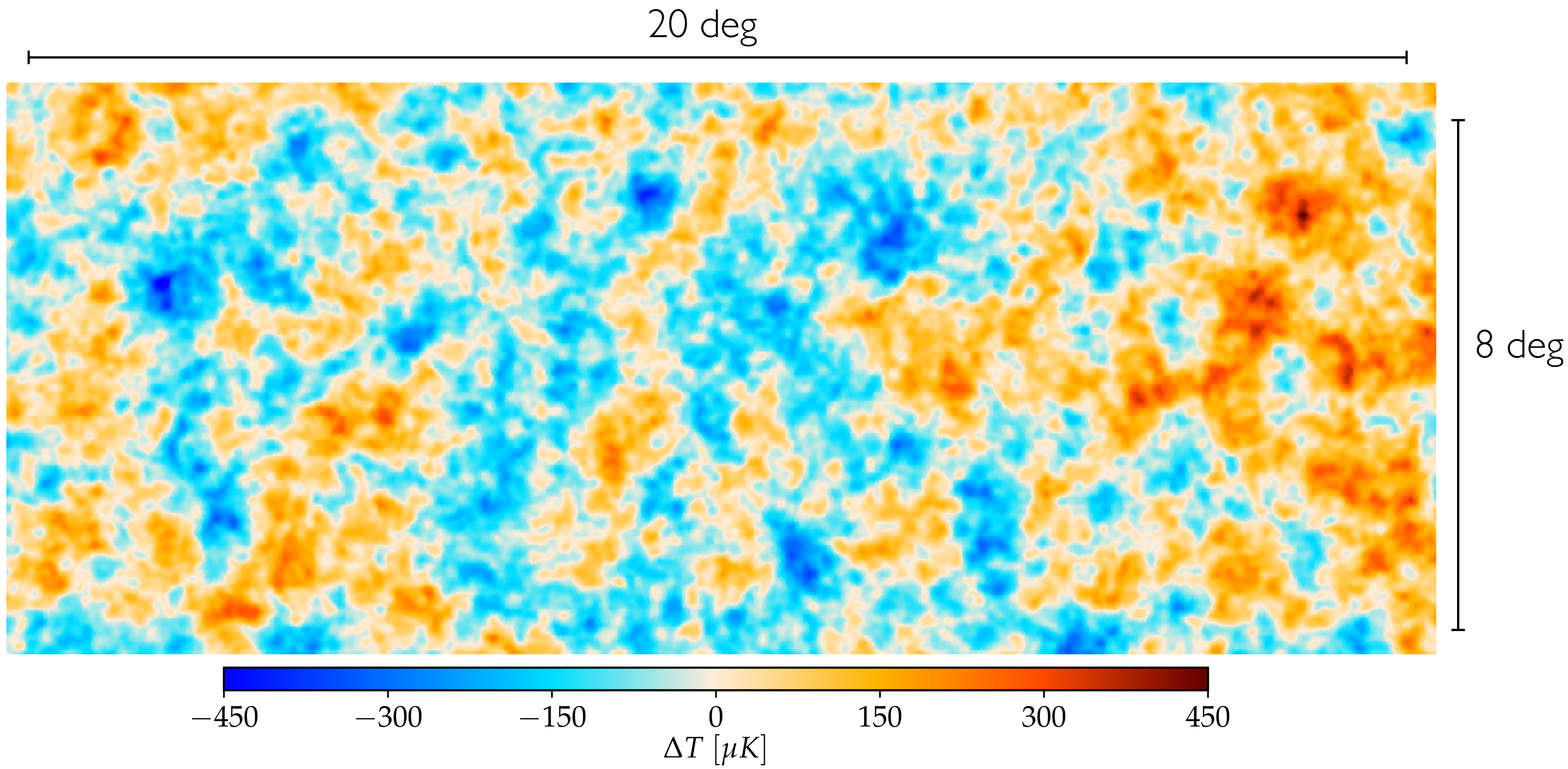
Extragalactic Foregrounds

CMB

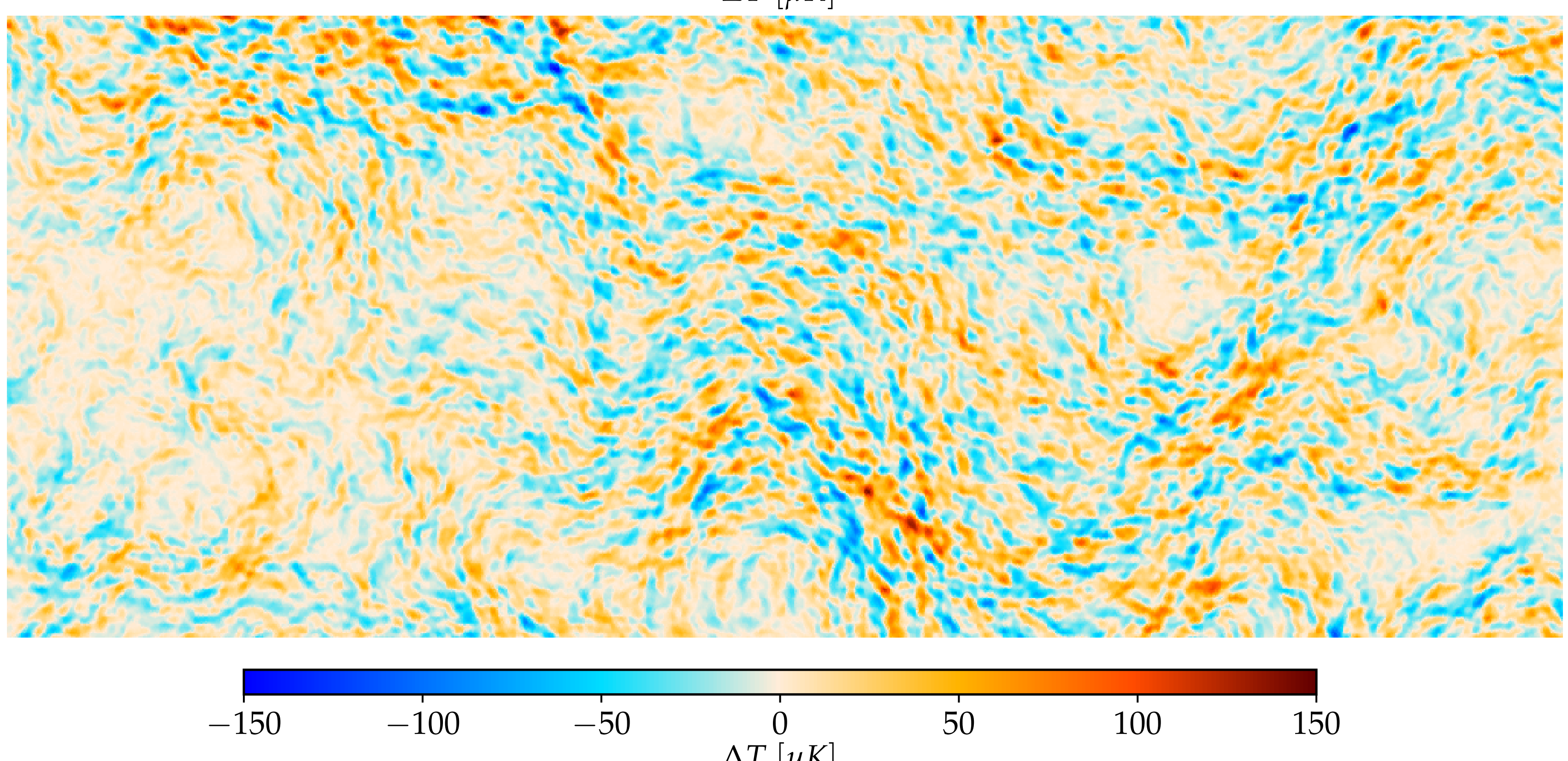


Extragalactic Foregrounds

Observed CMB



Lensing



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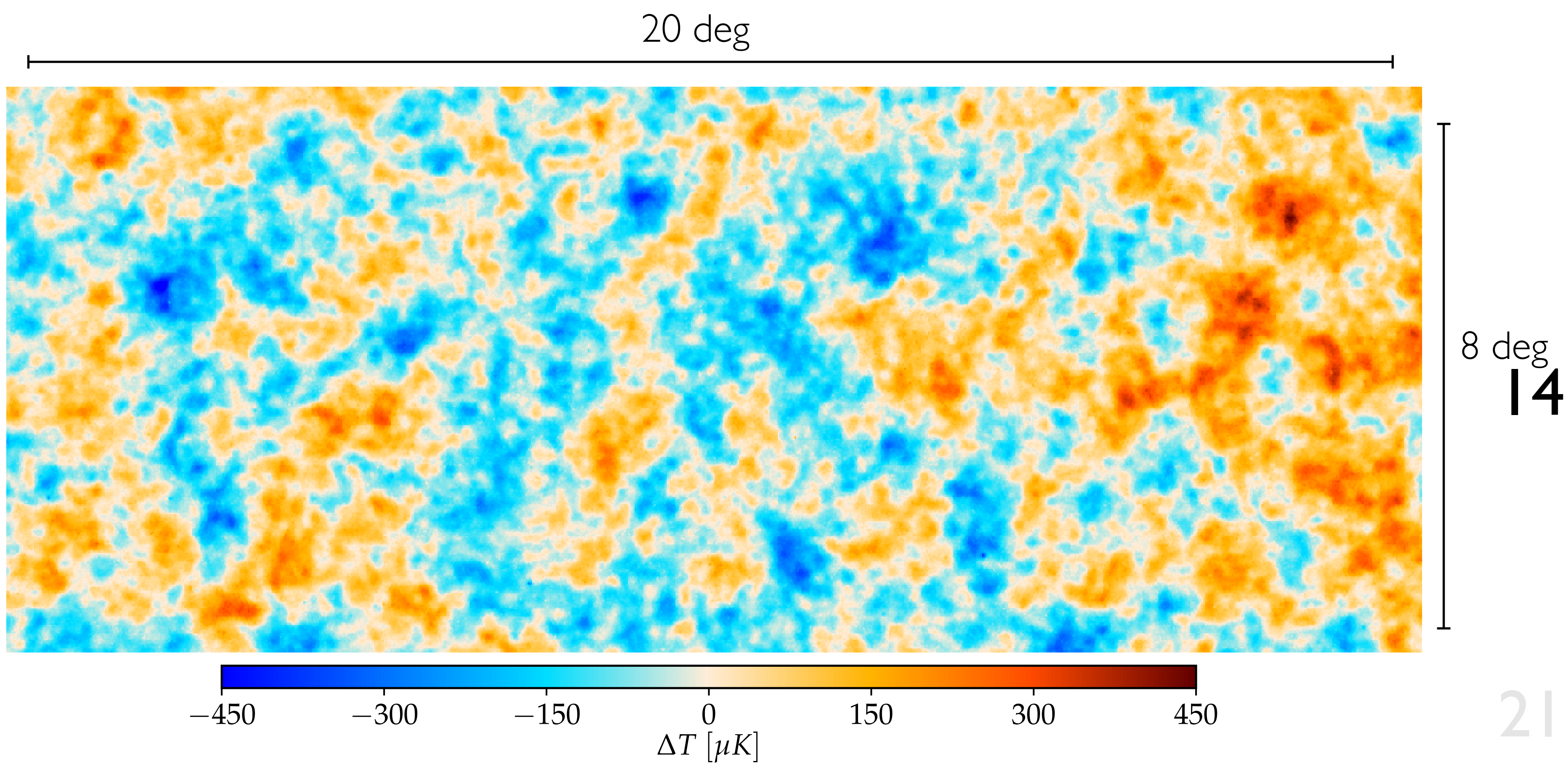
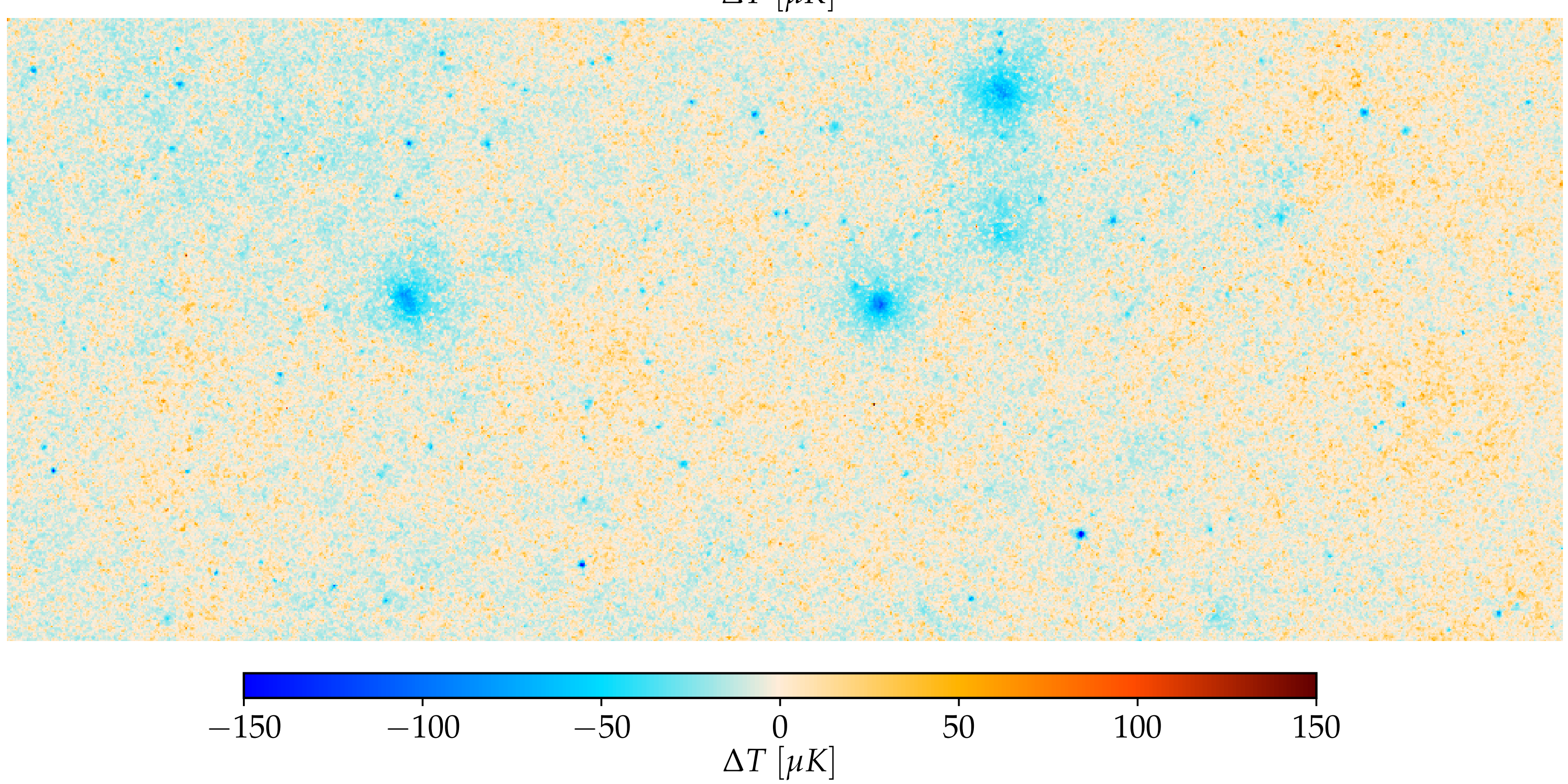


143 GHz

217 GHz

353 GHz

tSZ + kSZ + CIB



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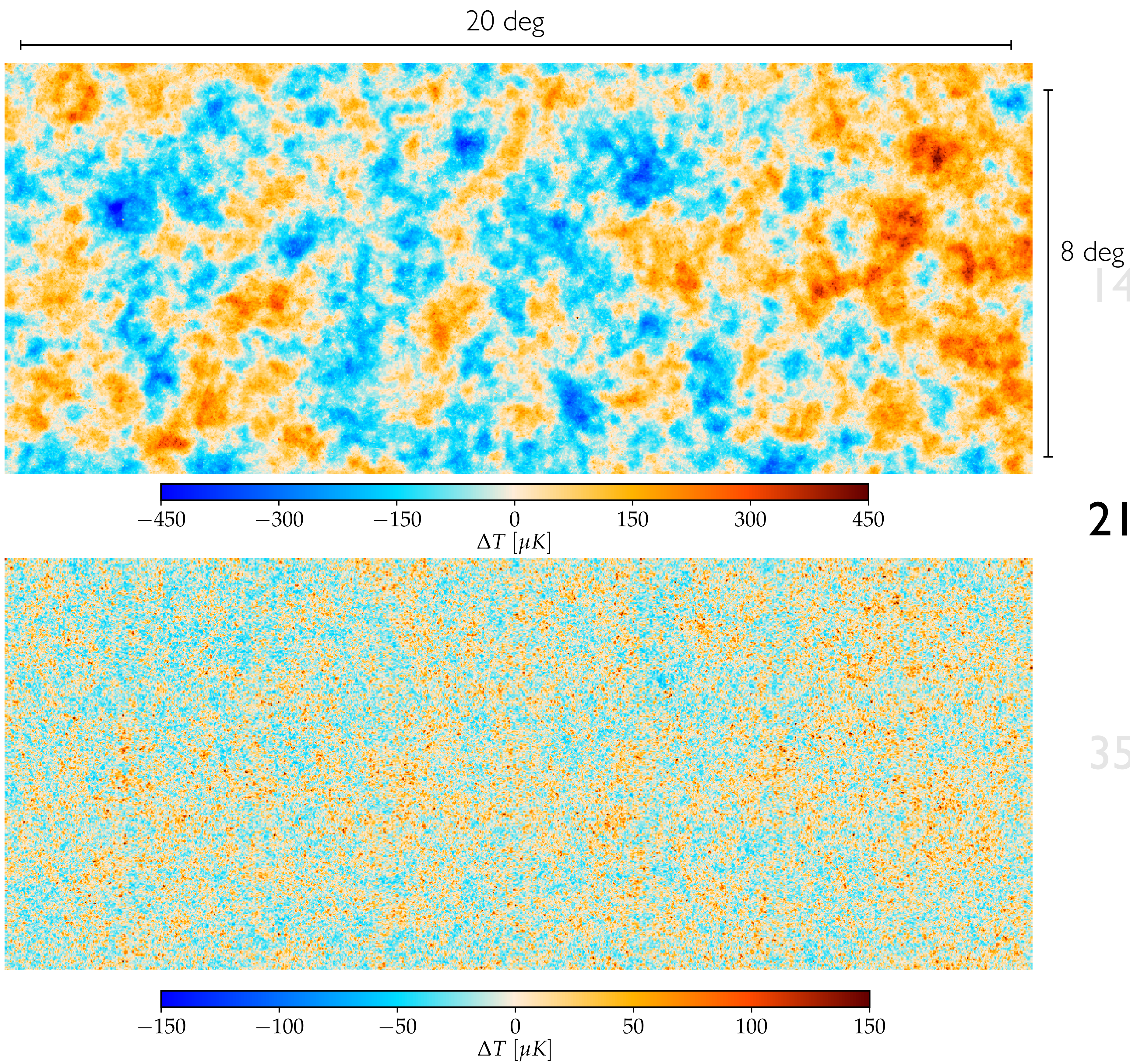

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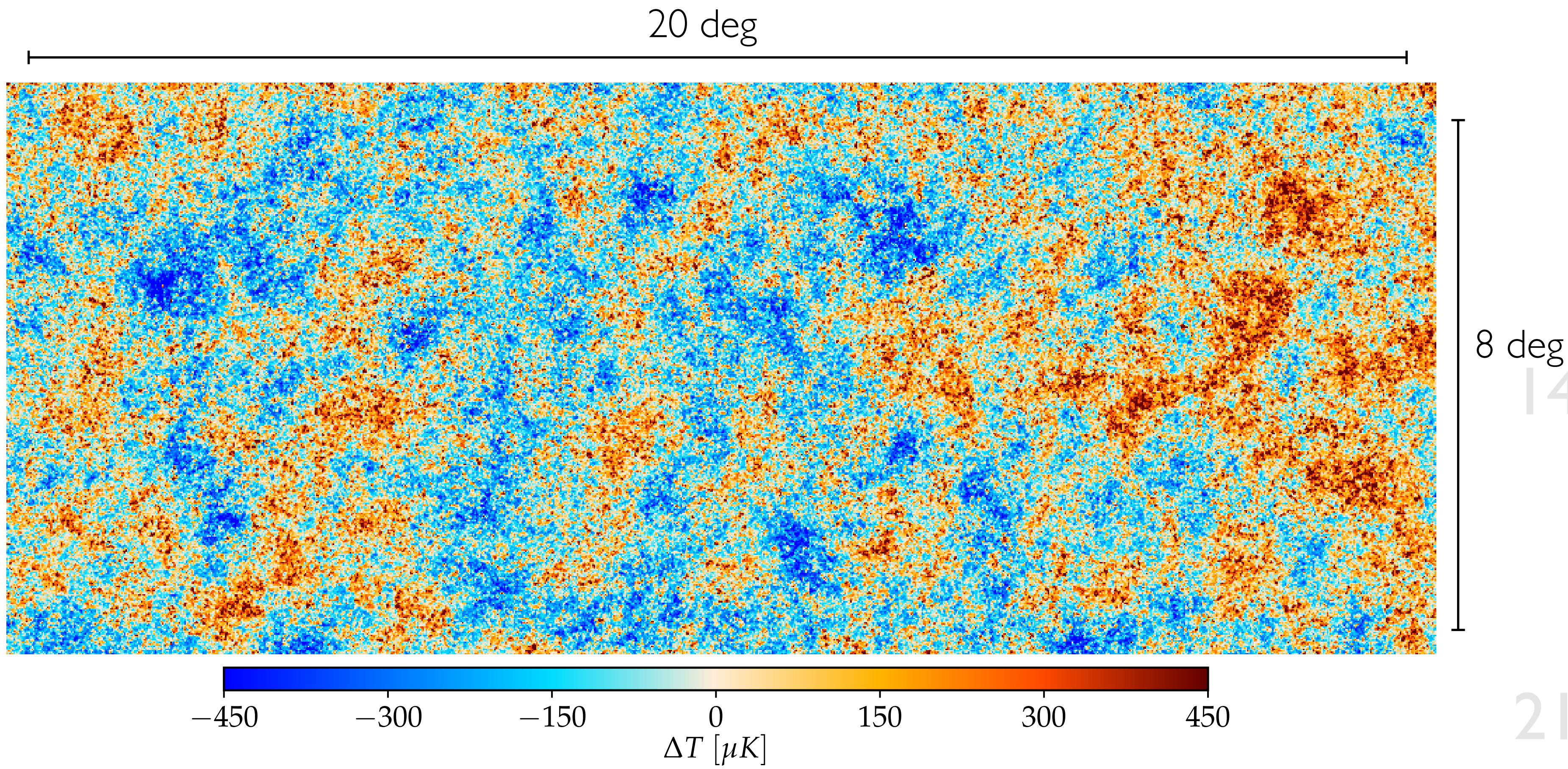

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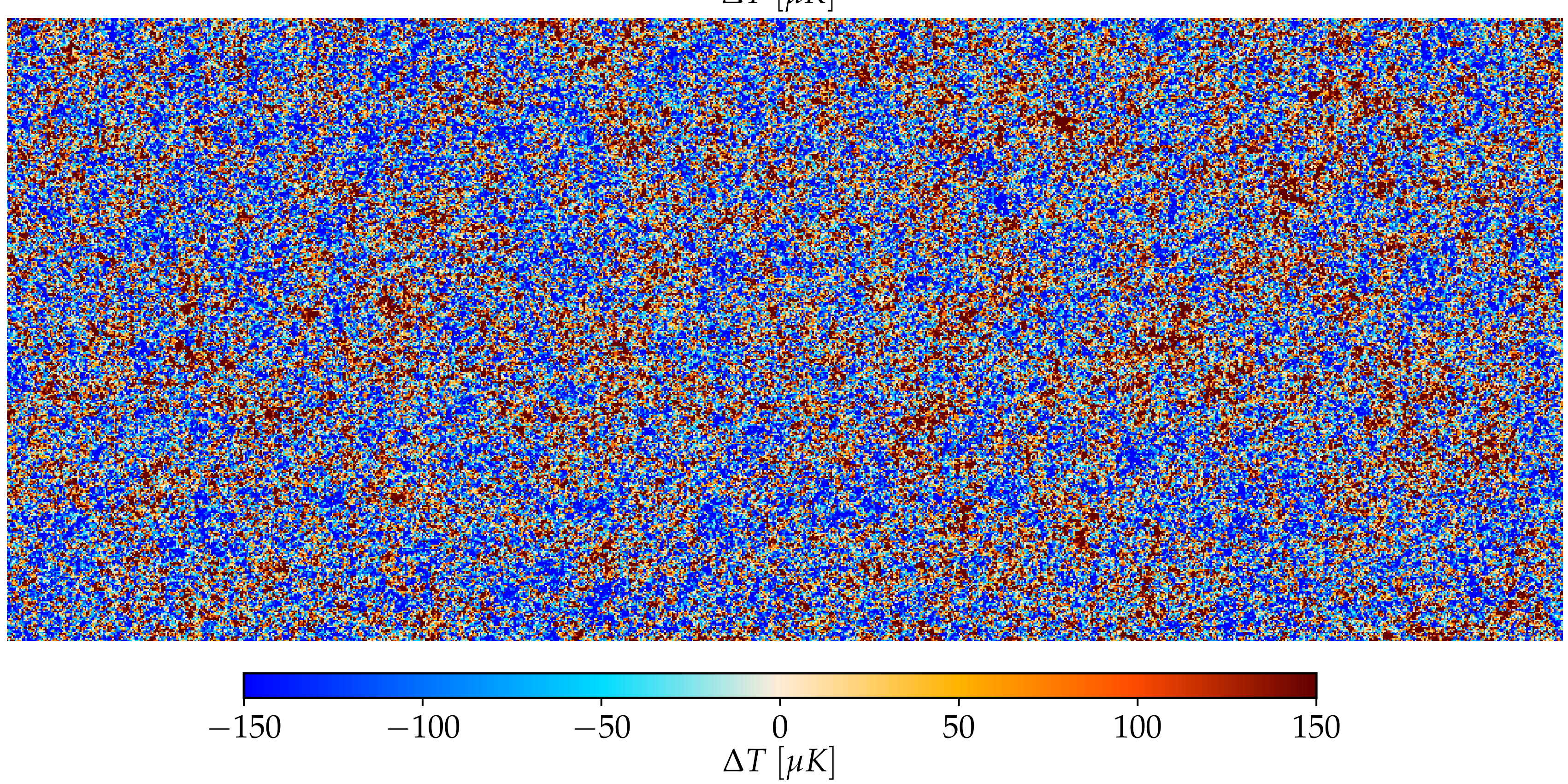
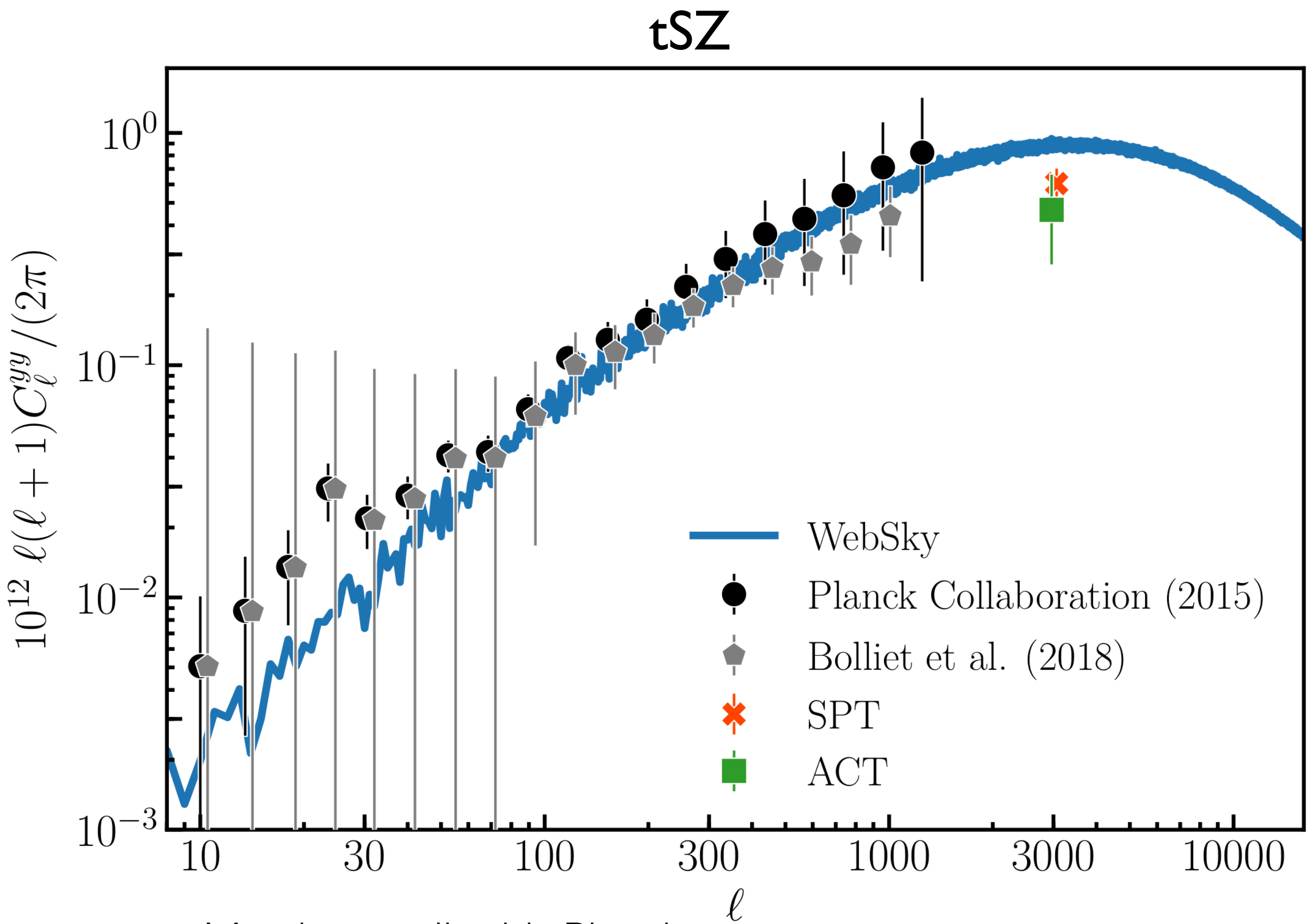


353 GHz

Validations: tSZ

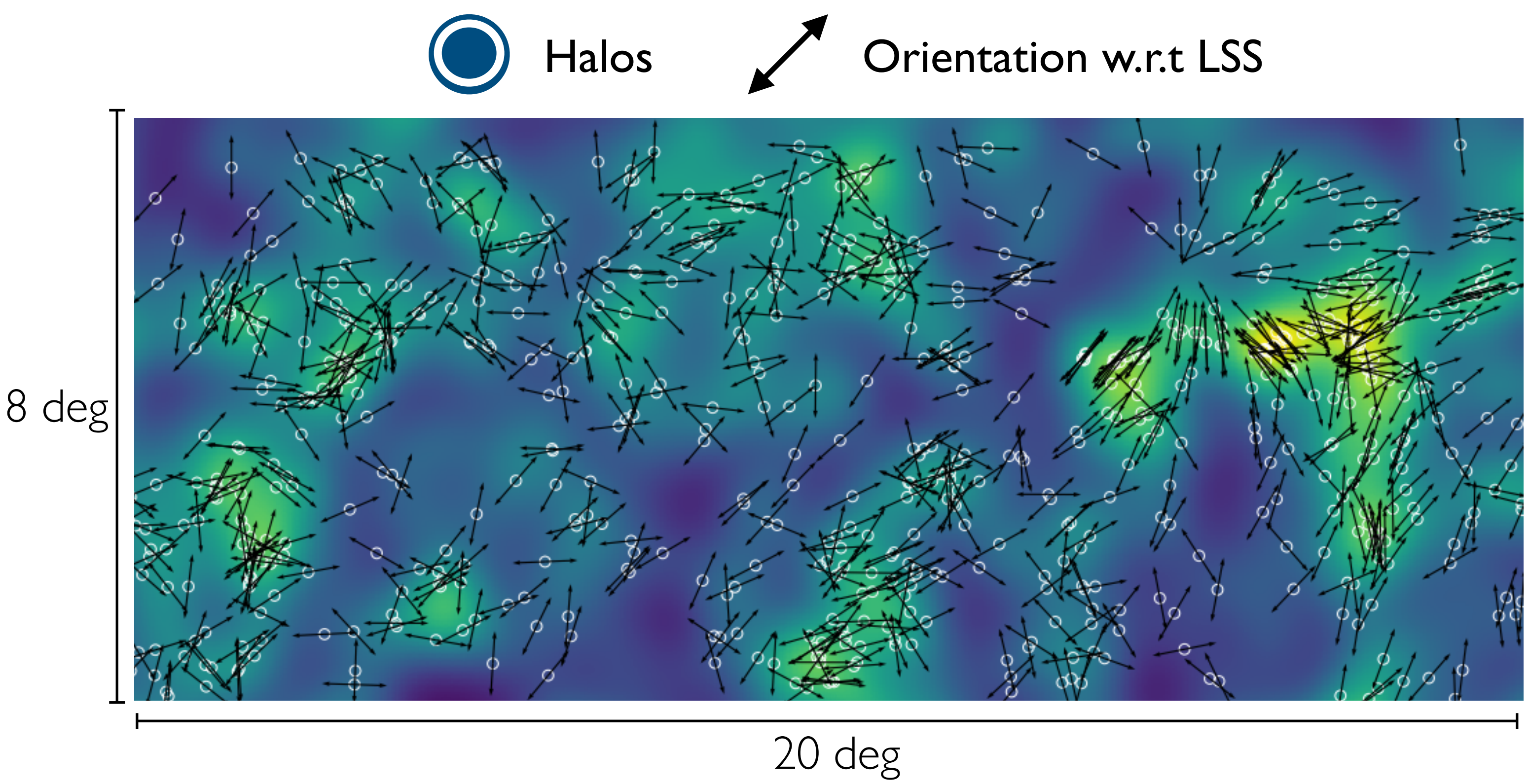


- Matches well with Planck
- ~30% disagreement with ACT and SPT
  - small-scale suppression in the tSZ power?
  - systematic effects in the SPT and ACT measurements?

Cluster applications: ACT tSZ stacking on DES Clusters

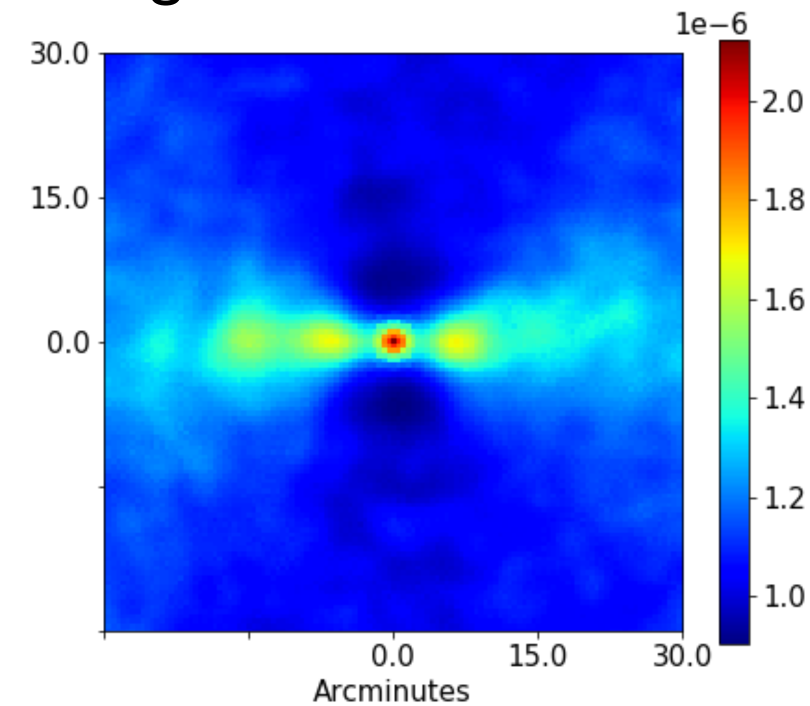
Preliminary

Martine Lokken, Mat Madhavacheril, Renee Hlozek, …

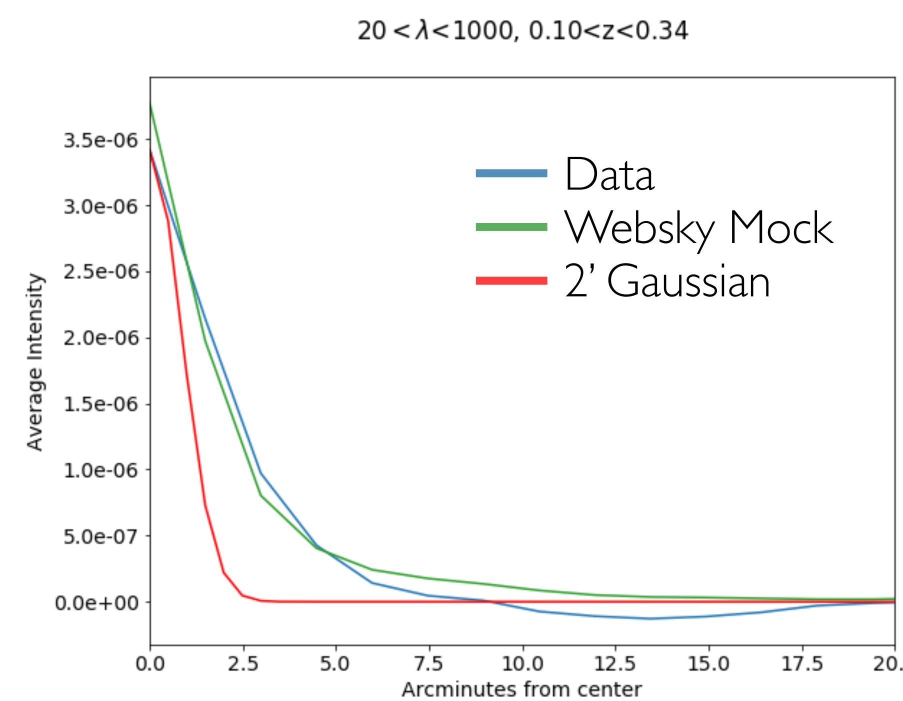


Websky halos

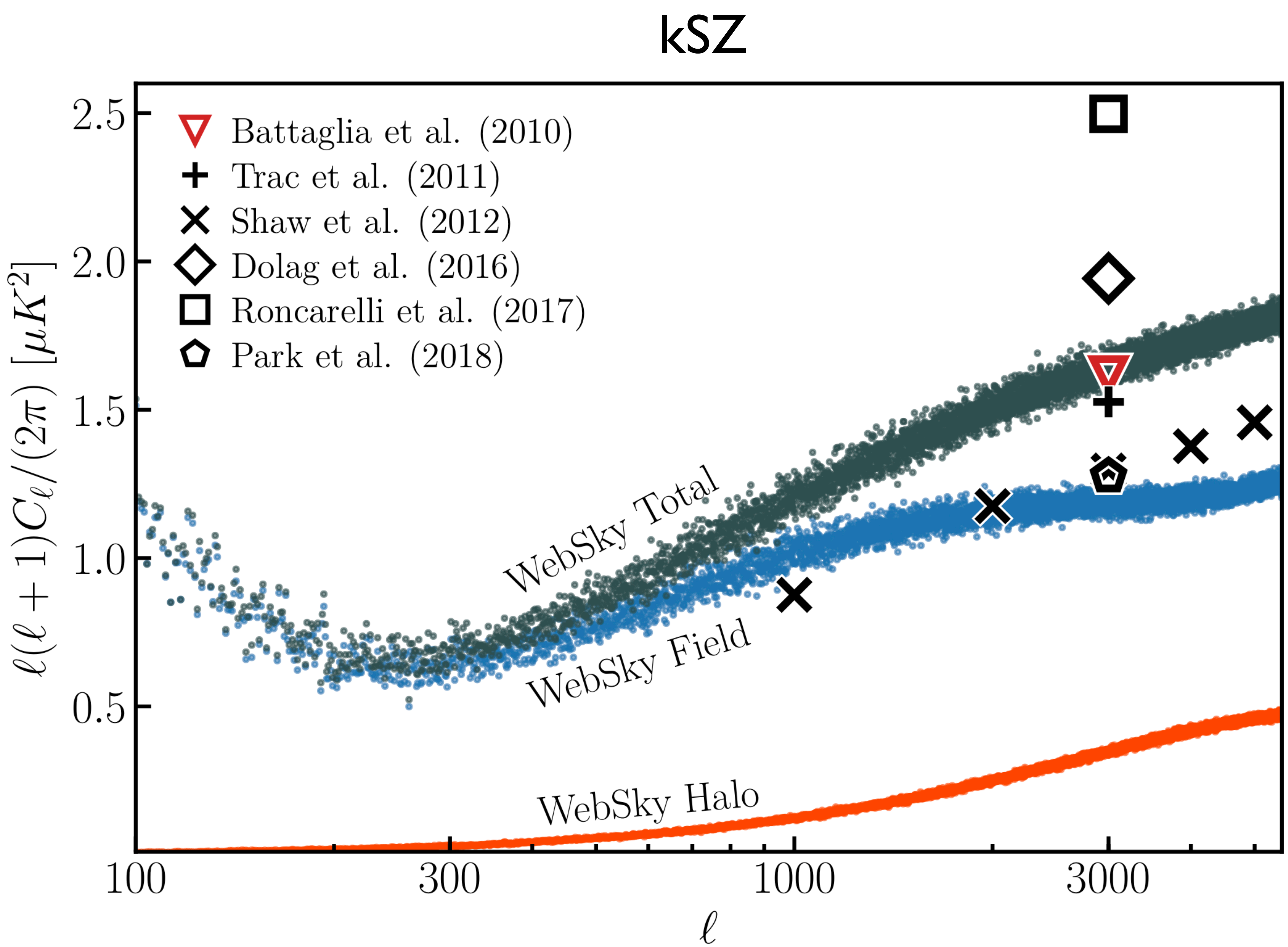
tSZ signal of Oriented Stack



Radial profile compared to data

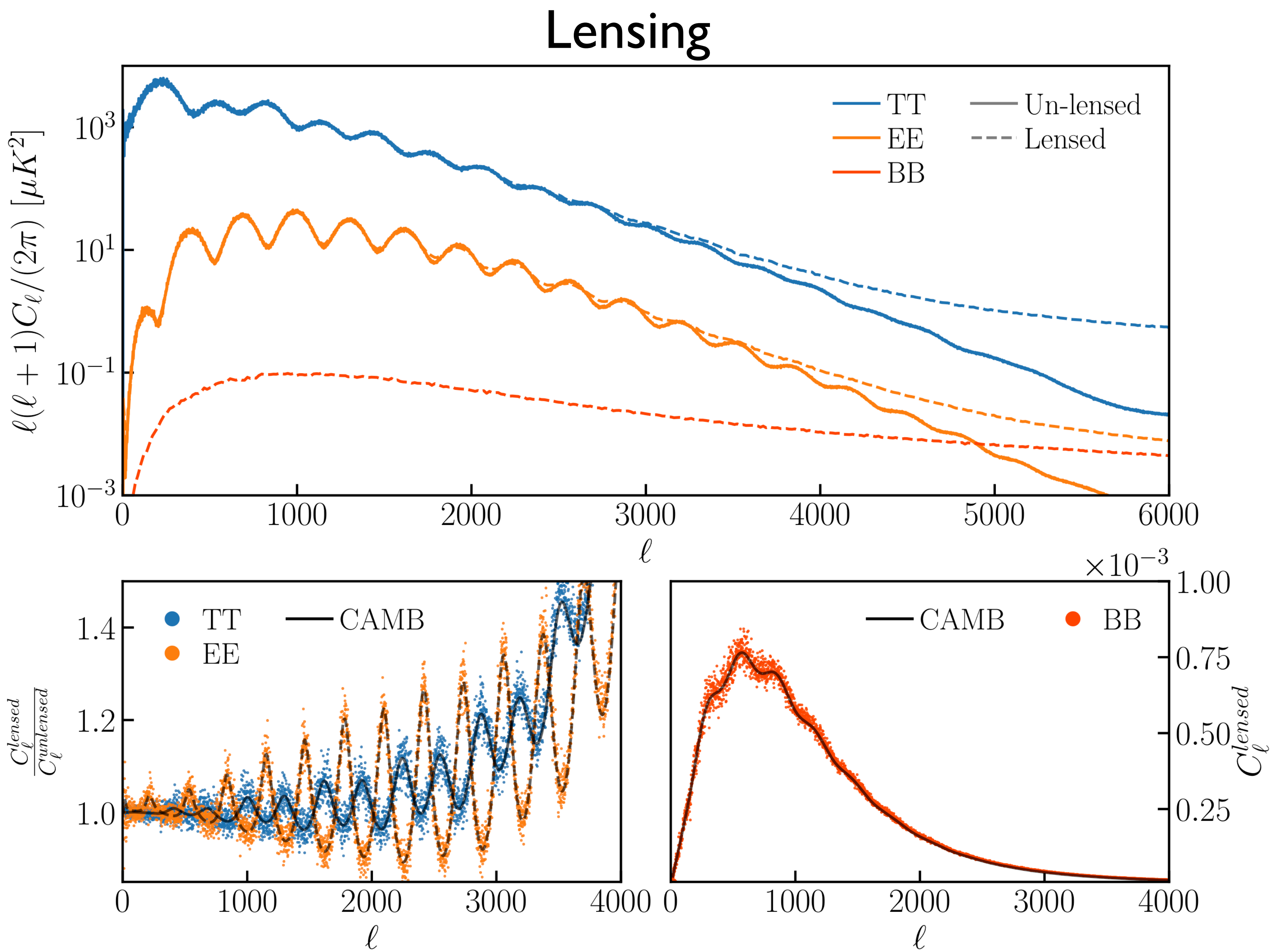


Validations: kSZ



- Agrees with various hydrodynamical studies
- Includes late-time contribution only. Early time kSZ can be added independently

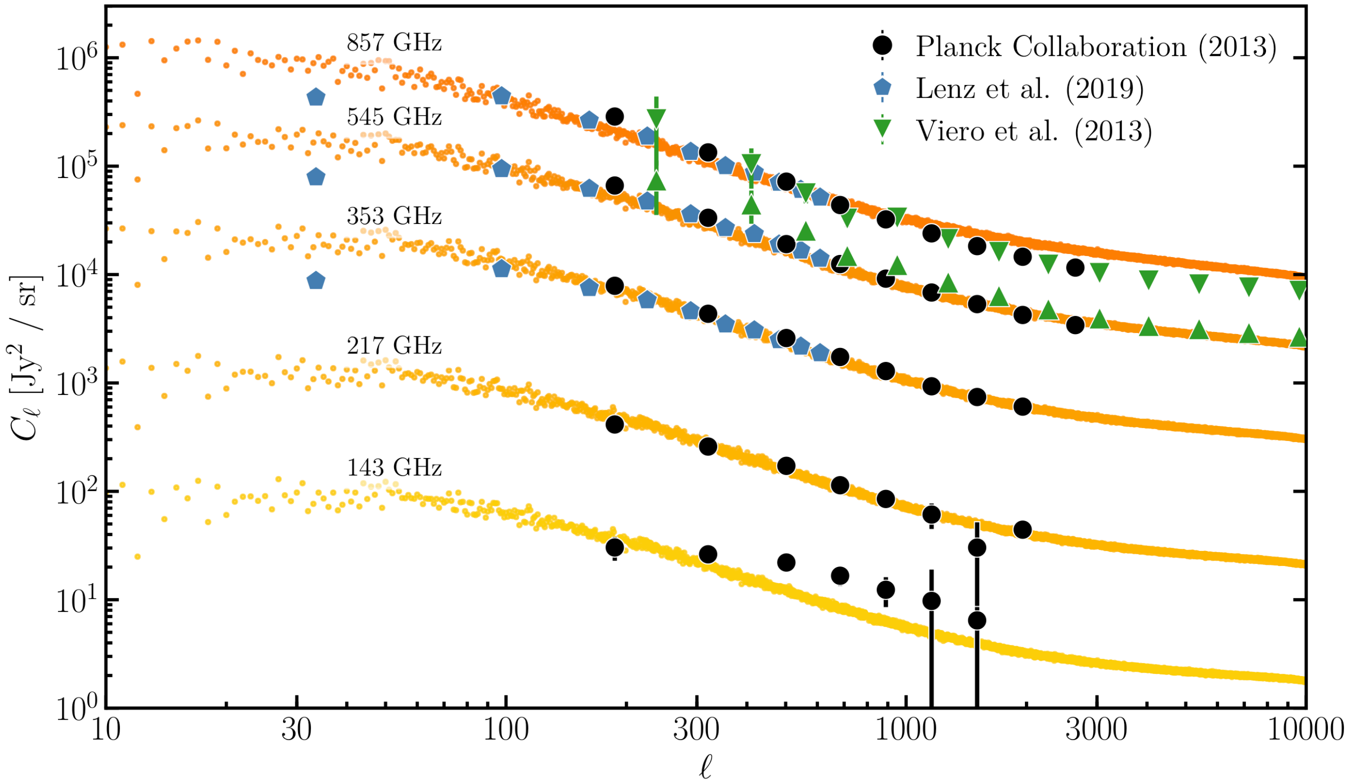
Validations: Weak Lensing



- Peak Smearing well reproduced
- r=0 in input CMB - feel free to lens your own with the convergence map

Validations: CIB

CIB Powerspectra



- Slight excess in small scale power at 857 GHz
  - $M_{h,min} \sim 1 \times 10^{12}\ M_\odot$

Validations: CIB

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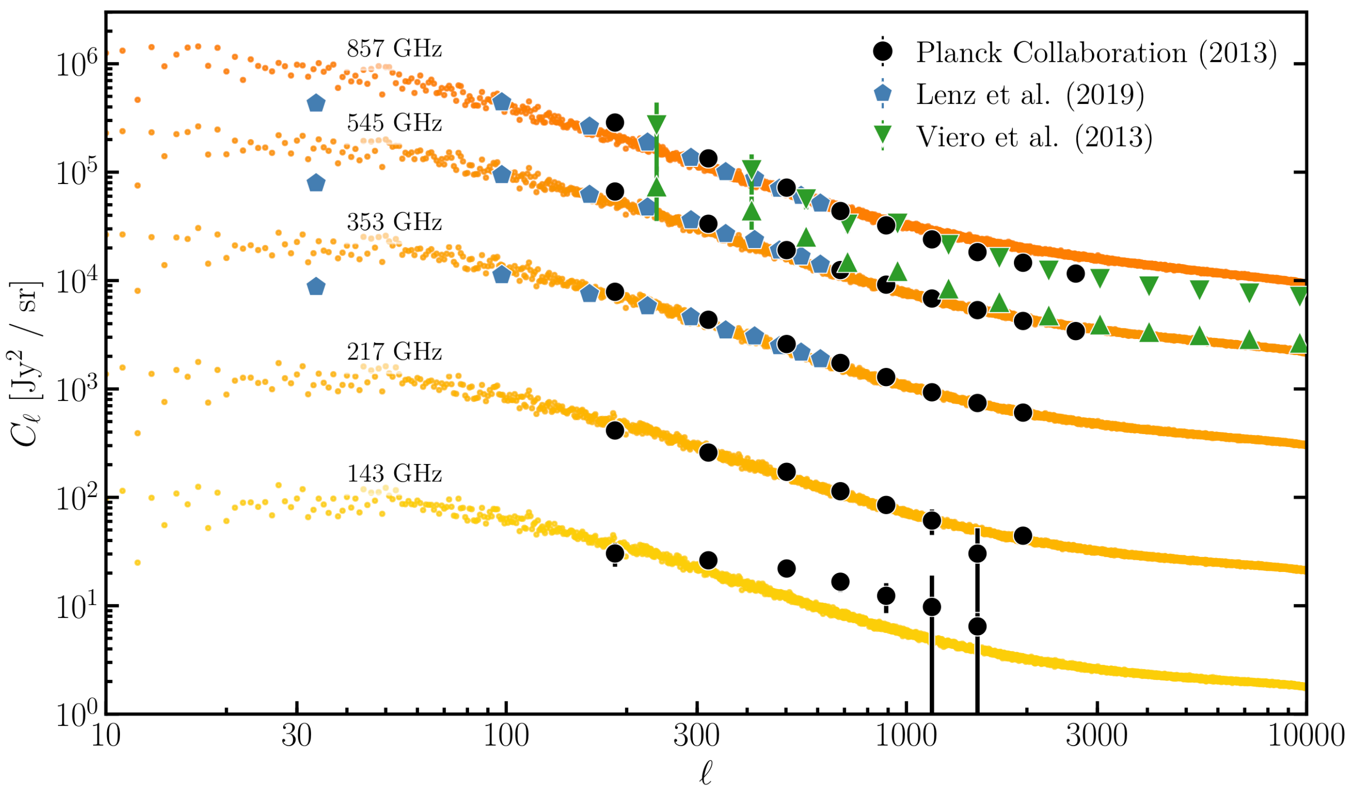

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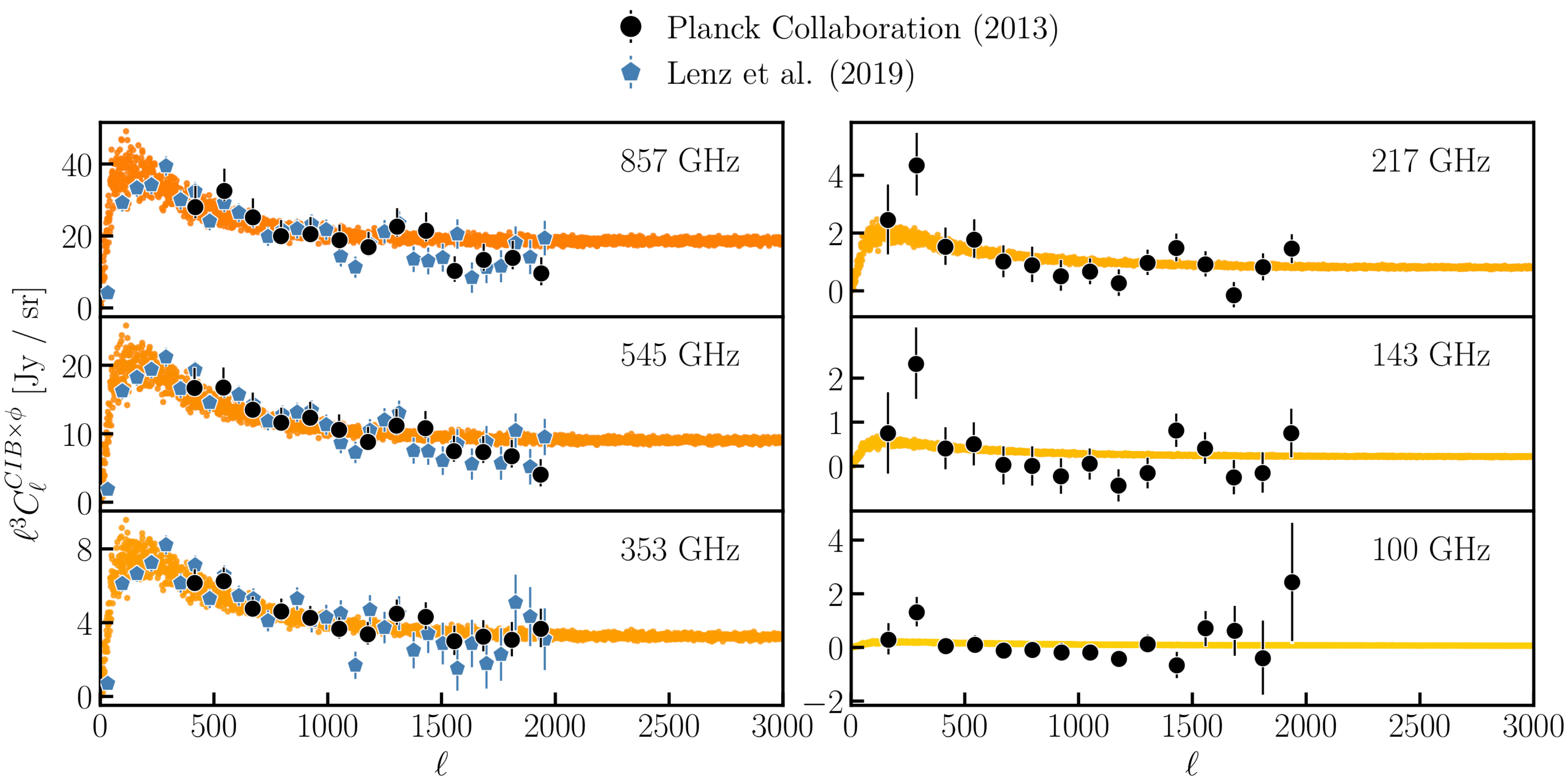
CIB Decoherence

		857	545	353	217
857	*Websky*	1	0.933 ±0.017	0.882 ±0.021	0.838 ±0.026
	Planck	1	0.949 ±0.005	0.911 ±0.003	0.85 ±0.05
	Lenz et al.	1	0.96 ±0.01	0.91 ±0.01	0.85 ±0.05
545	*Websky*	...	1	0.960 ±0.014	0.935 ±0.018
	Planck	...	1	0.983 ±0.007	0.90 ±0.05
	Lenz et al.	...	1	0.98 ±0.01	
353	*Websky*	...	...	1	0.968 ±0.014
	Planck	...	...	1	0.91 ±0.05
	Lenz et al.	...	...	1	

Table 1. Frequency decoherence of the CIB measured by averaging $C_\ell^{\nu\nu'}/(C_\ell^{\nu\nu}C_\ell^{\nu'\nu'})^{1/2}$ over the range $150 < \ell < 1000$. Error bars correspond to the standard deviation in this range. We include the Planck measurements of [16] and the Lenz et al. measurements of [100].

- Frequency dependence not just an amplitude scaling

Validations: CIB x lensing



- Cross correlations to date look good

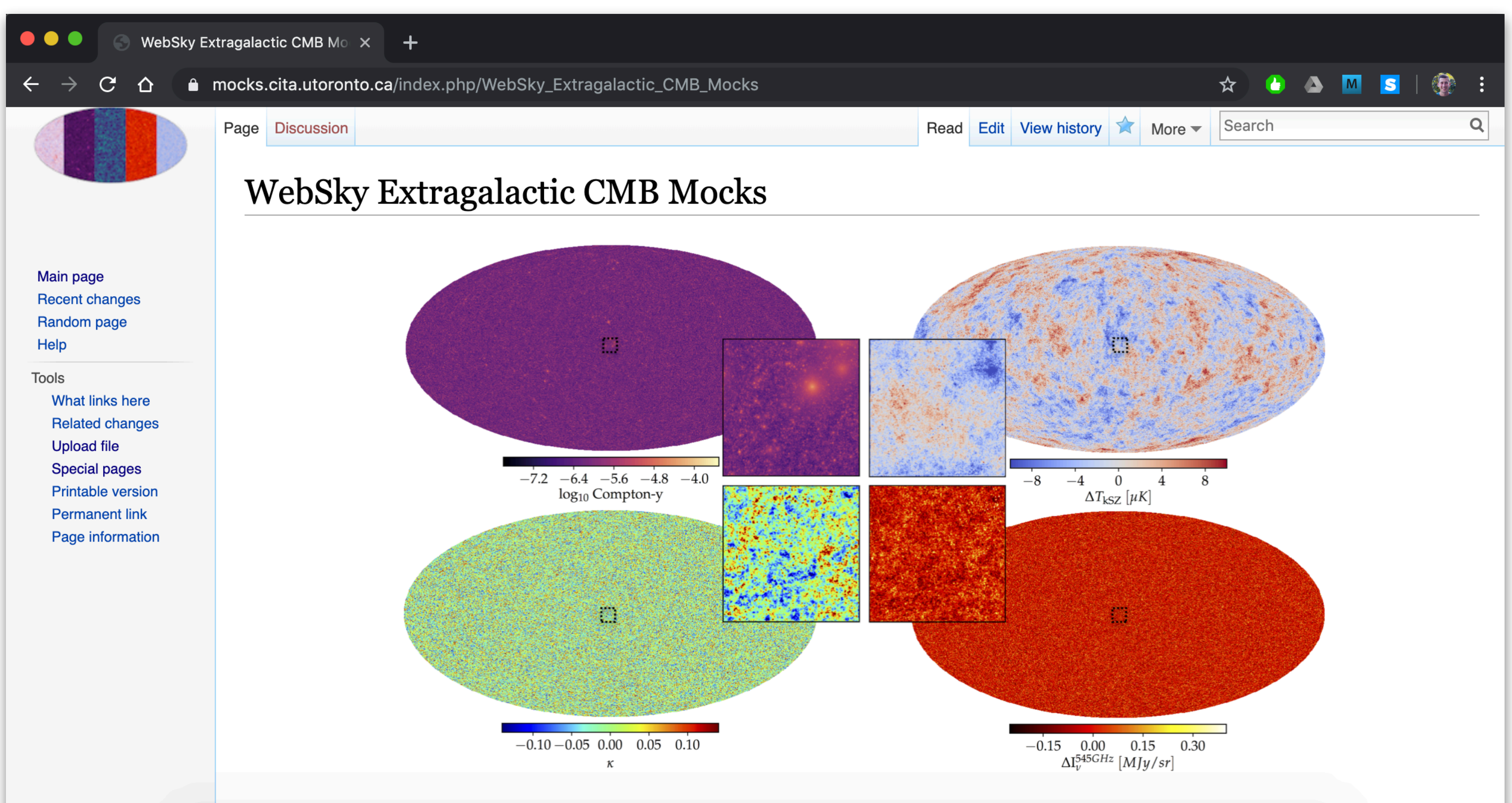
The Current Generation of CMB Extragalactic Simulations

Things to Note for DESI

- Spherical halo profiles used
- Minimum halo mass of $\sim 1 \times 10^{12}\ M_{\odot}$
- 2LPT displacements used for matter outside of halos = lower lensing power on small scales
- Radio sources on the way

All data publicly available @
mocks.cita.utoronto.ca

Ask away @
websky-cmb

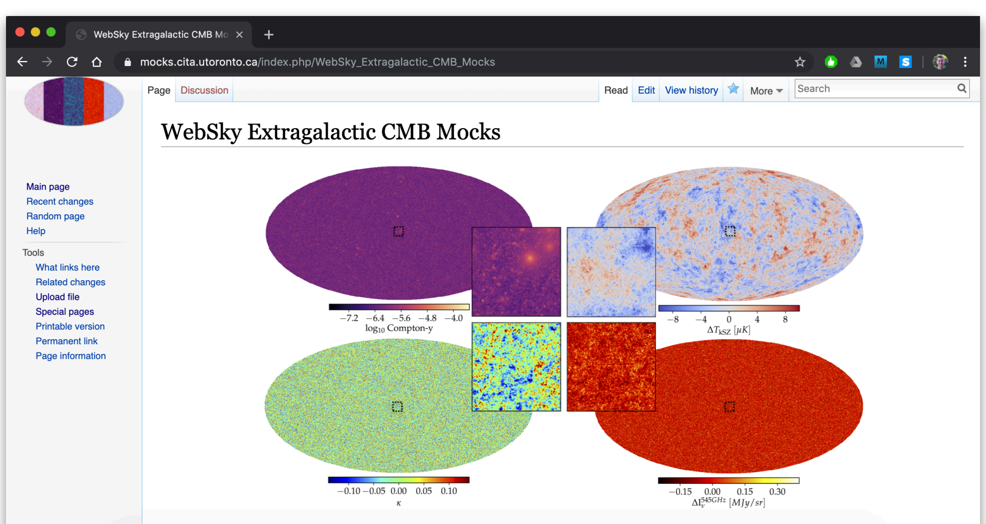


The Next Generation of Galaxy x CMB sims

Desires from DESI?

- Minimum halo mass of ?
- Max redshift of ?
- N body z < 2, mass-Peak Patch 2 < z < 8, Gaussian z>8 ?
- Parameters needed for HOD models (M_h, z_h, ….)
- . . .

All data publicly available @ ***mocks.cita.utoronto.ca***



Ask away @ ***websky-cmb***

slack