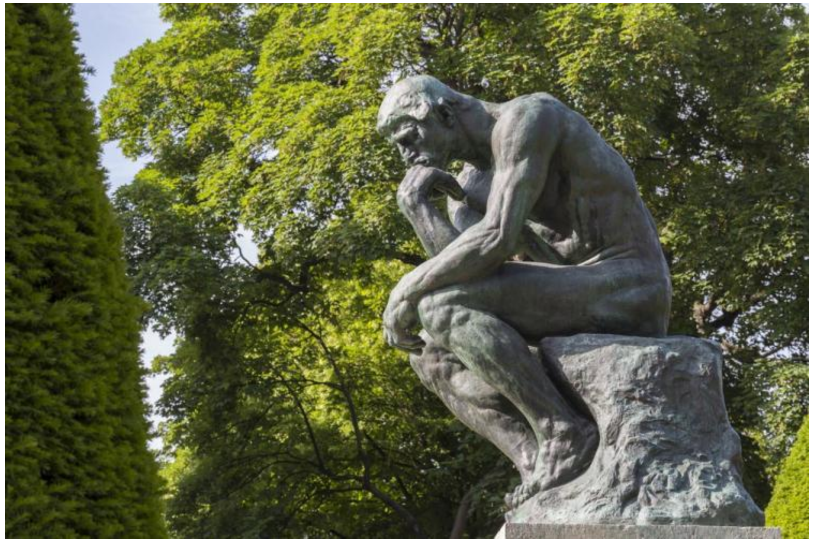
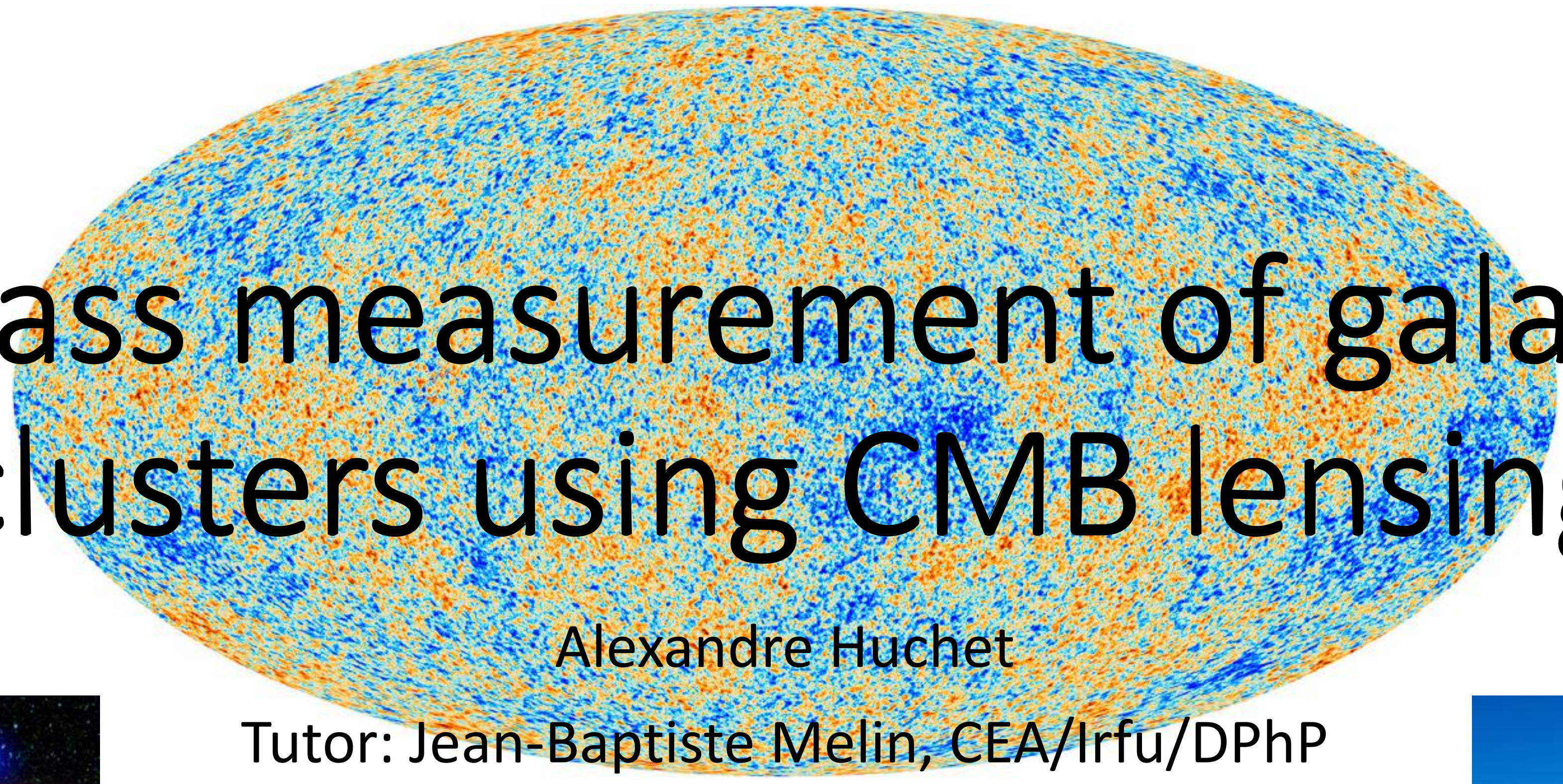
To be determined

Life of a PhD student through hardships

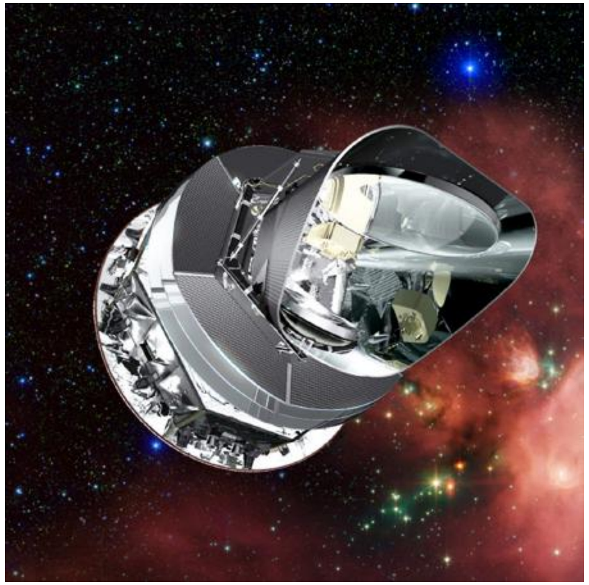


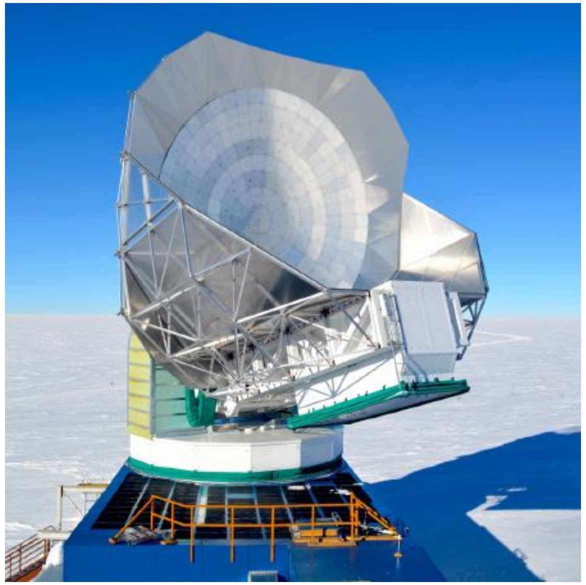


Mass measurement of galaxy clusters using CMB lensing

Alexandre Huchet

Tutor: Jean-Baptiste Melin, CEA/Irfu/DPhP





Mass measurement of galaxy clusters using CMB lensing

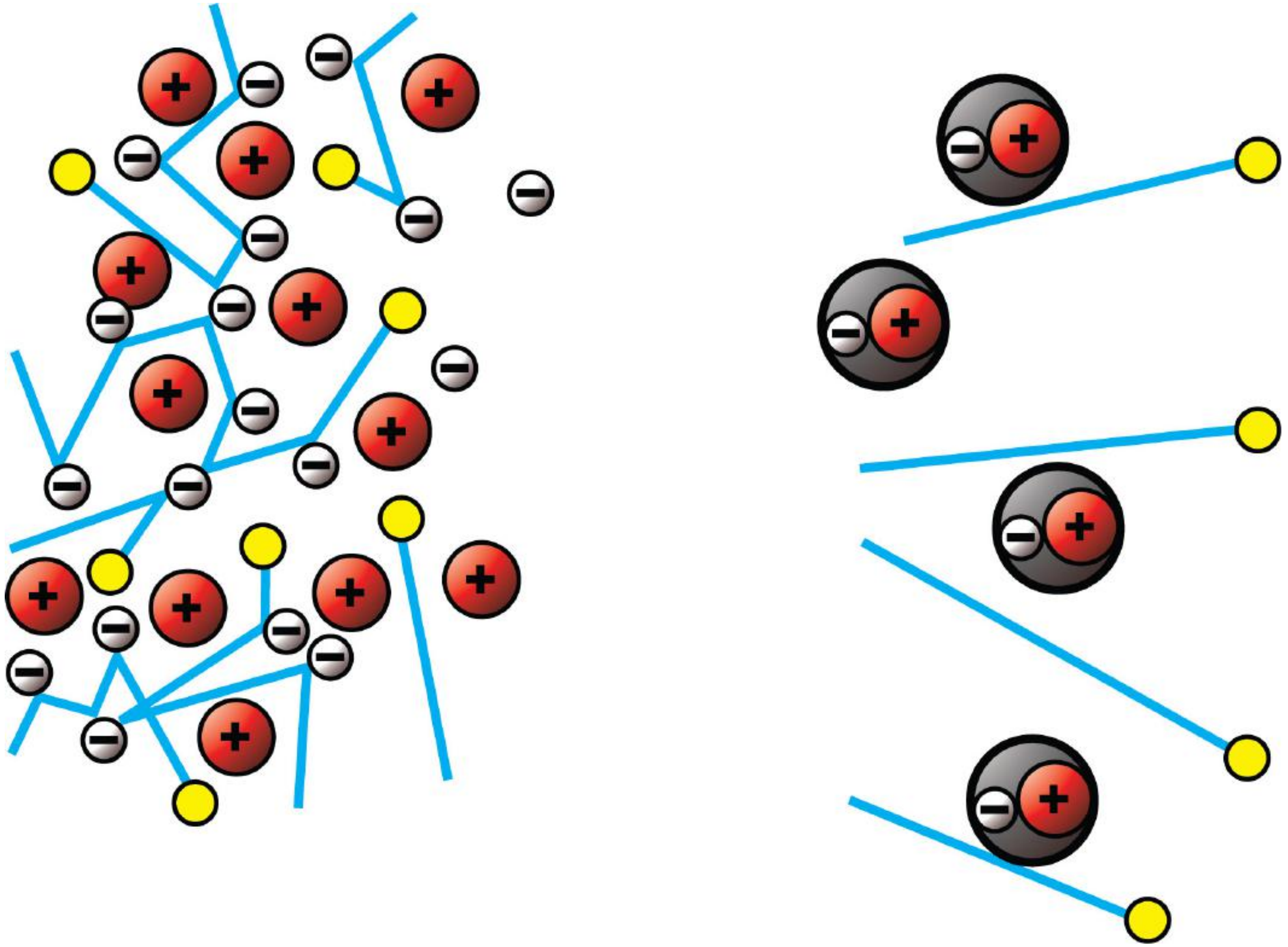
Let’s see what that means

The CMB

- The Cosmic Microwave Background (CMB) was emitted about 13.4 billion years ago
- It got cooler because of the expansion of the Universe:

3000 K --> 2.7 K

Credit: Write Science



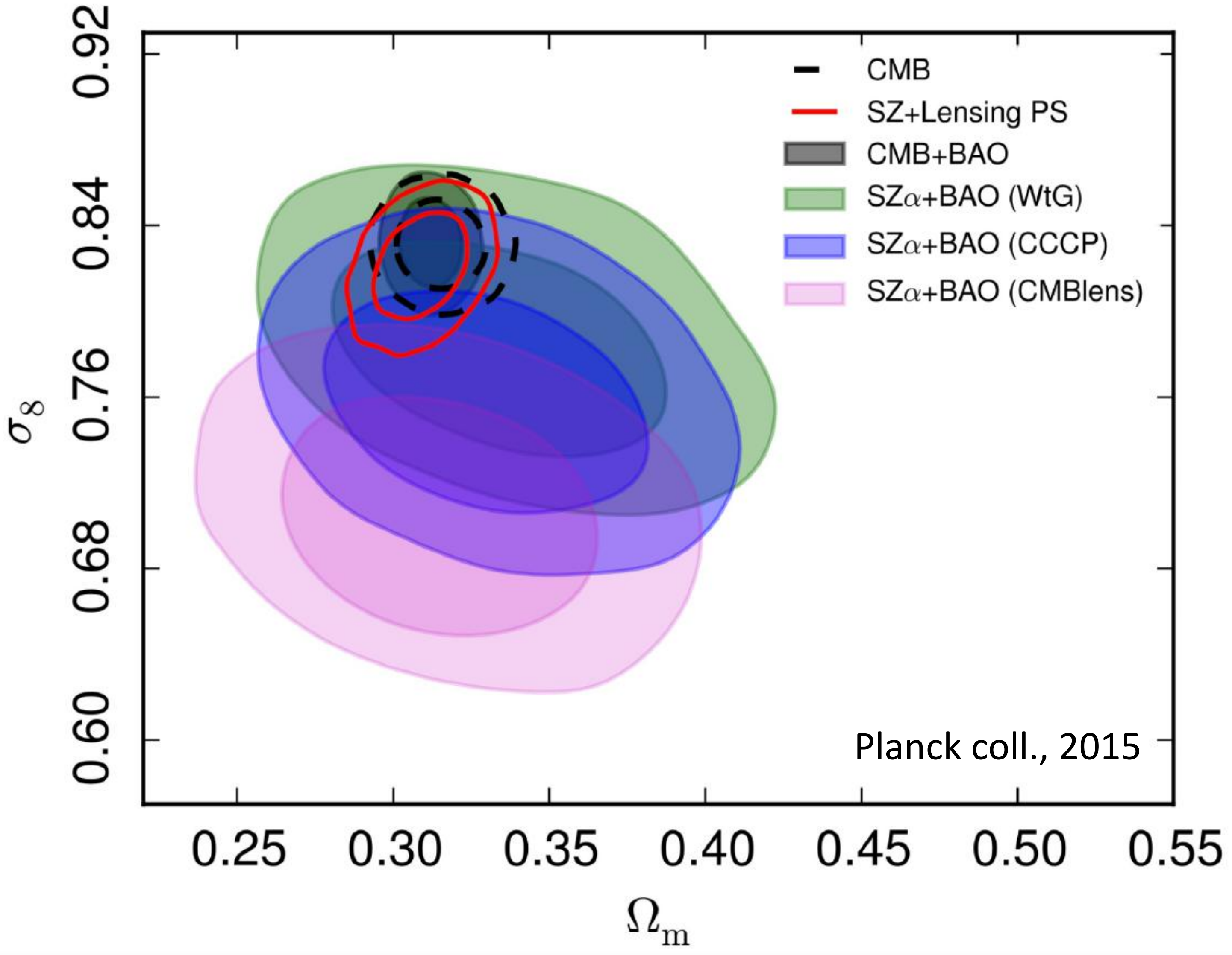
Before (re)combination, the photons are scattered by free electrons. After, they travel freely.

Cosmology with clusters

Mass function:

z, M <---> cosmo

- Redshift from optical survey
- Mass from?



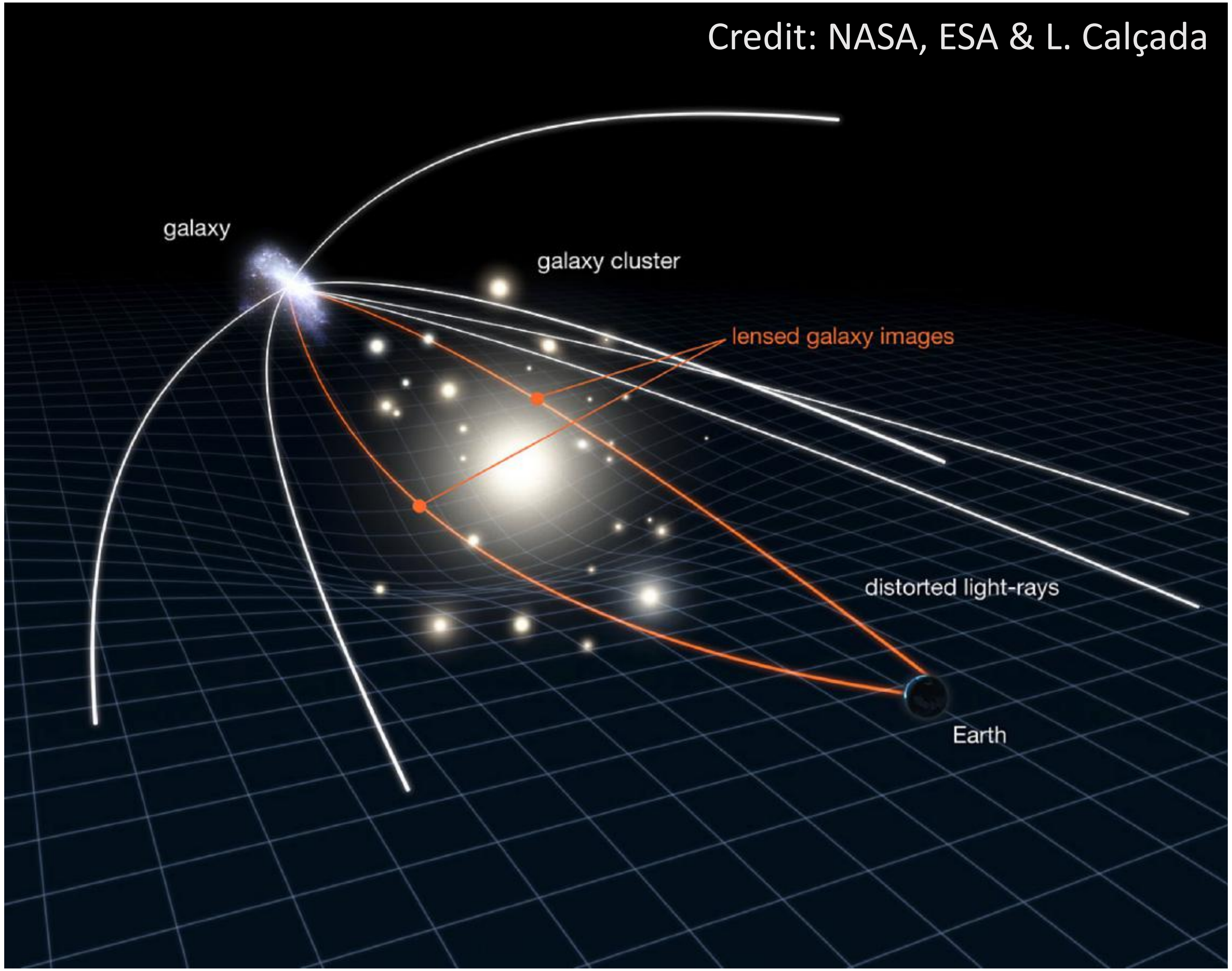
Constraints on σ_8 and Ωm from Planck cluster count, based on different mass calibrations

Gravitational lensing

- Visible light: galaxies, 3% of total mass
- X-rays: hot intracluster gas, 12% of total mass

- Gravitational lensing: the above + dark matter (85%)

= 100% of total mass

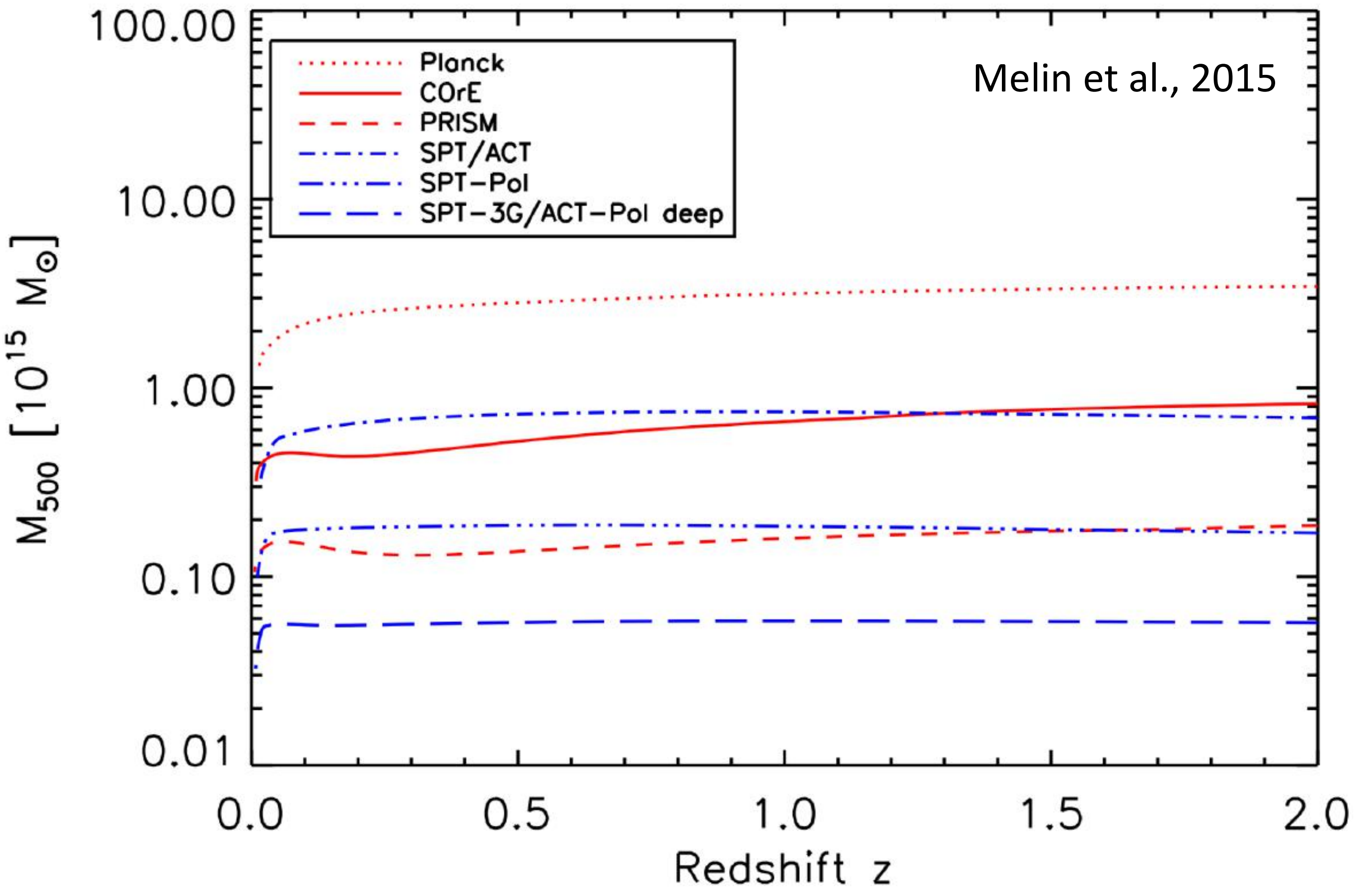


Lensing induced by a cluster on a background galaxy

Clusters as lenses

Two different types of sources:

- Background galaxies: need to find background galaxies, i.e. up to z~1
- CMB: the CMB is the source, i.e. up to z~1100



Mass measured with a signal to noise ratio of 1 as a function of redshift for CMB lensing

What to do then?

- We use Planck et SPT-SZ, two complementary data sets

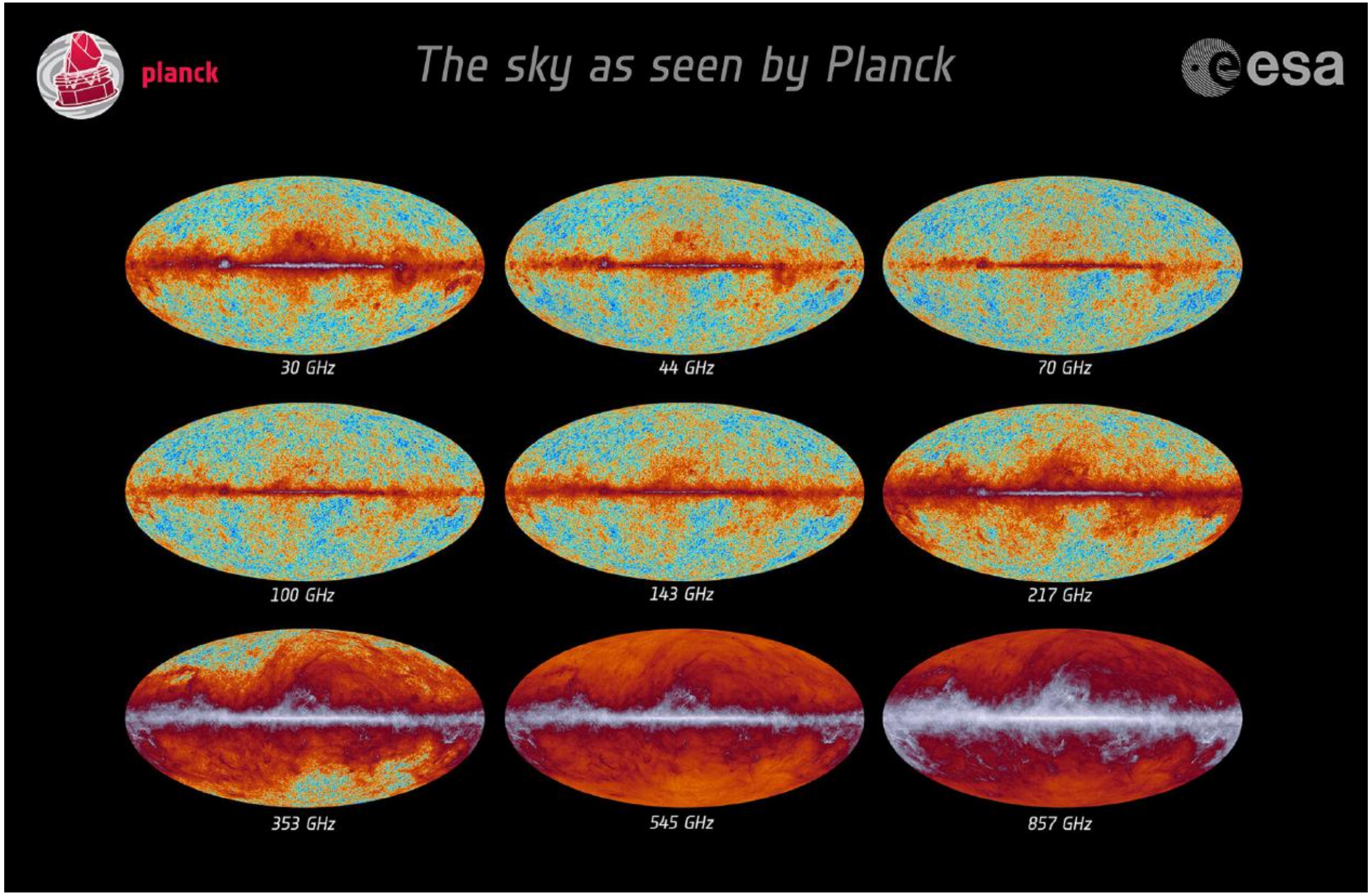
- First steps: one analysis for each data set
  - Analysis on simulated maps
  - Apply the method to real data

- We then combine the Planck and SPT-SZ data sets
  - First simulation
  - Then real data

Two surveys

- Planck survey:
  - All-sky (42000 deg^2)
  - 5 arcmin beam
  - 6 frequencies used
  - In space

- SPT-SZ survey:
  - 2500 deg^2
  - 1.75 arcmin beam
  - 3 frequencies (95, 150, 220 GHz)
  - Ground based

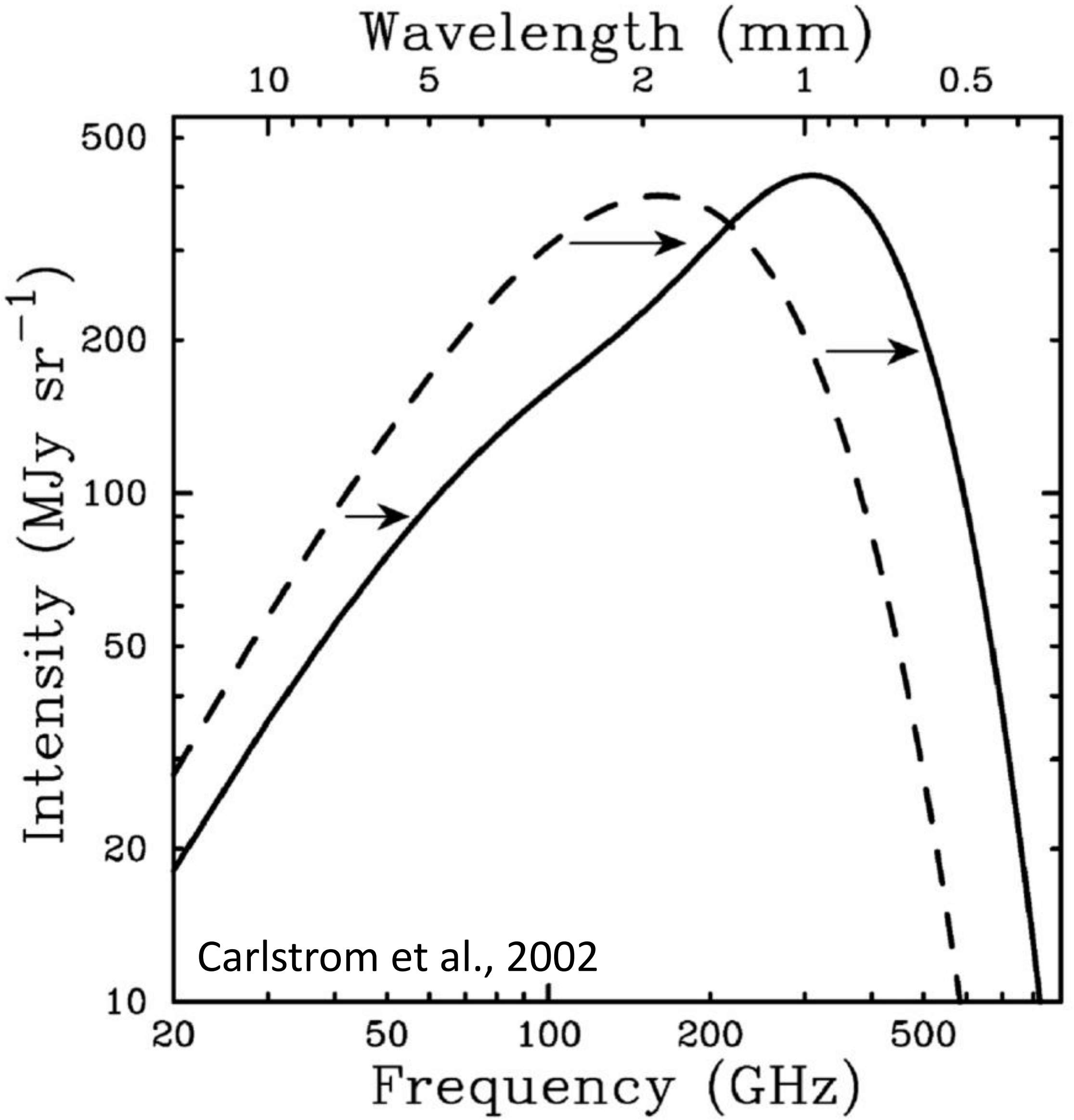


Planck maps of the sky for its 9 frequencies

SZ effect

Sunyaev Zel'dovich effect:

- Inverse Compton scattering of CMB photons by hot intracluster gas electrons
- The CMB blackbody spectrum is shifted
- The detection of this shift is a hint to the presence of a cluster

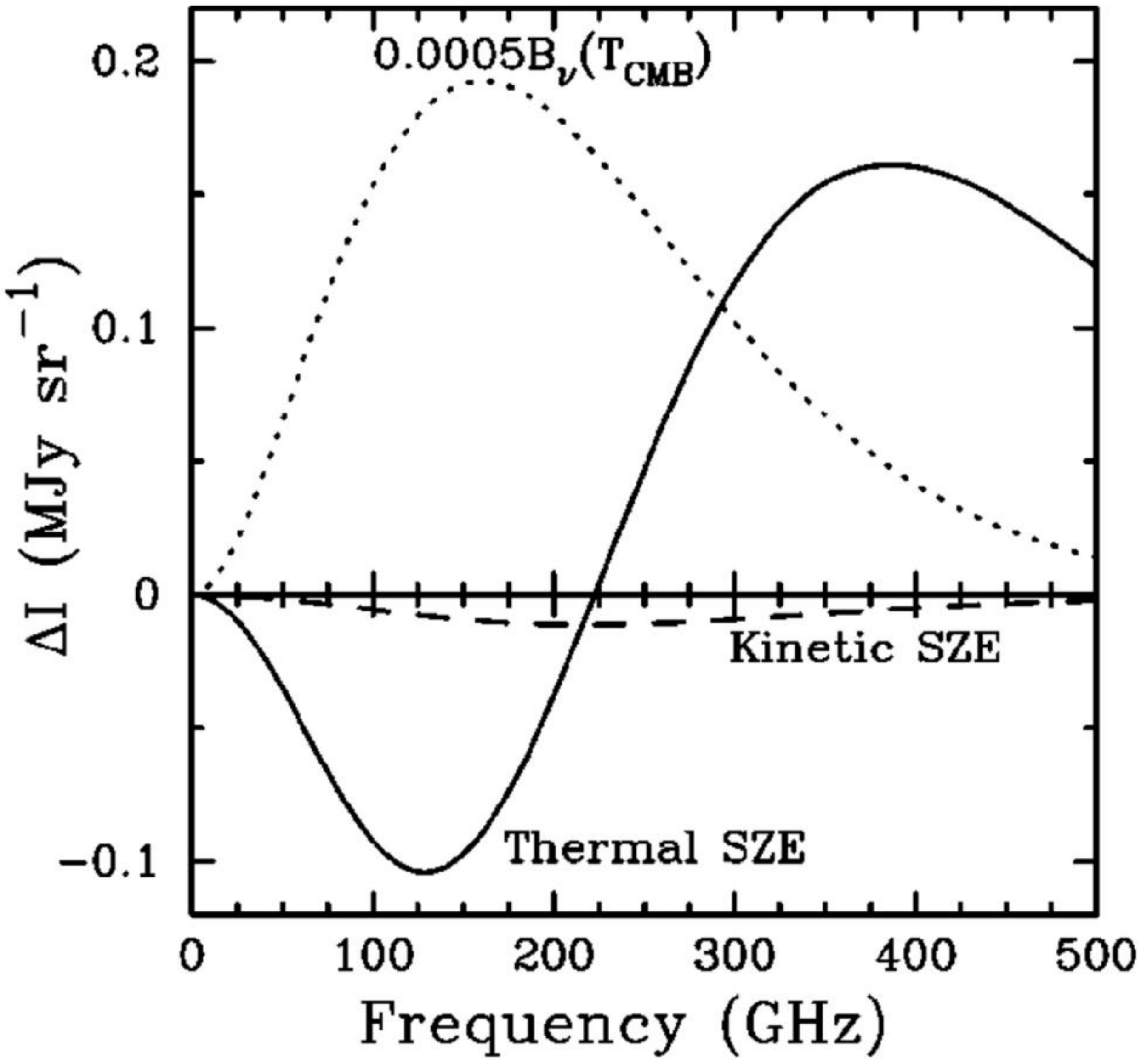


Intensity of the CMB with respect to frequency before and after the scattering

Map simulation

- CMB: built from Planck CMB power spectrum
- Cluster lens: Navarro-Frenk-White (NFW) density profile
- SZ effect: generalized NFW (GNFW) profile
- Instrumental point spread function (PSF)
- Instrumental noise

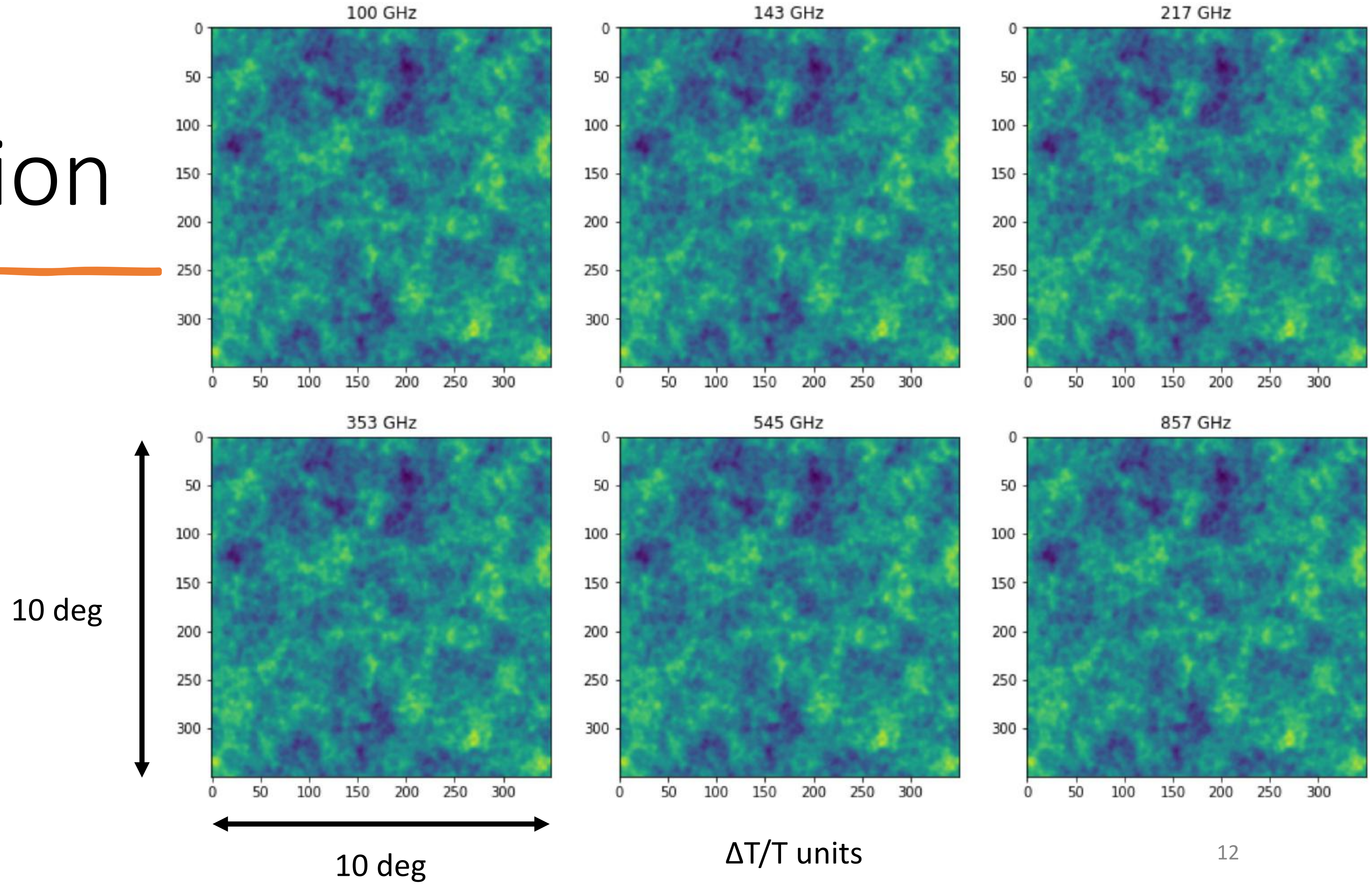
Carlstrom et al., 2002



Sunyaev-Zel'dovich intensity shift with respect to frequency

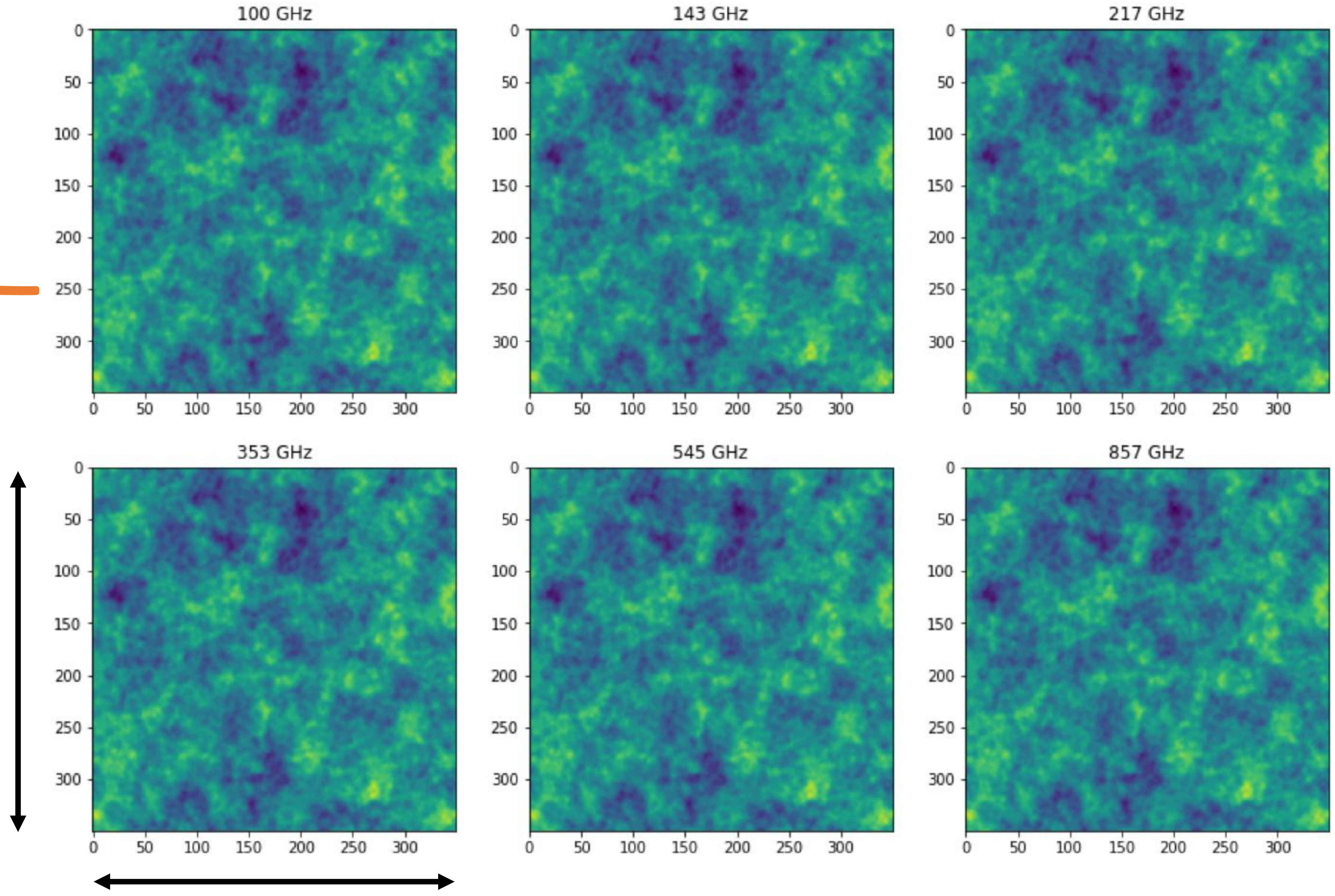
Planck simulation

- CMB



Planck simulation

- CMB
- Cluster lens



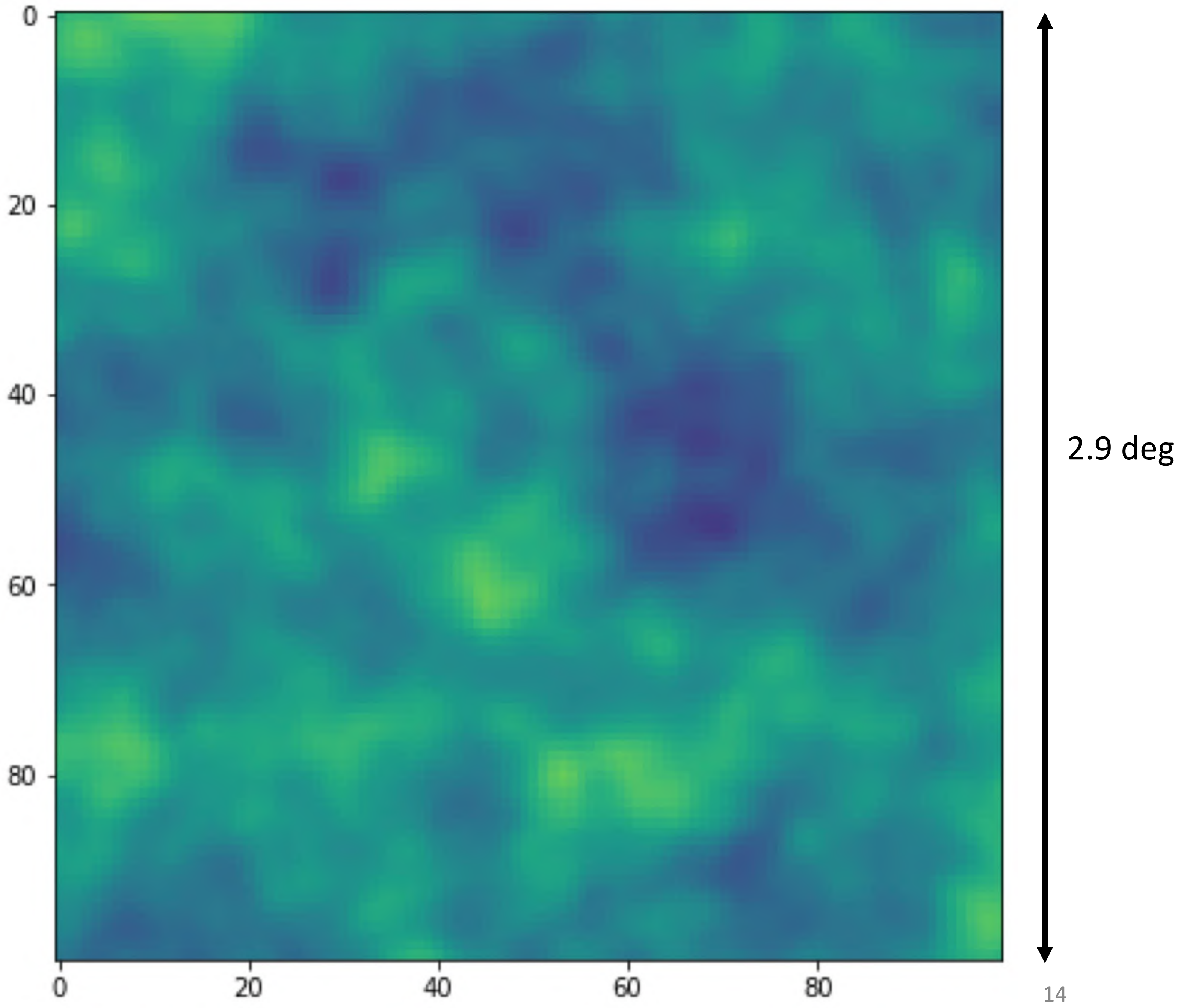
10 deg

10 deg

ΔT/T units

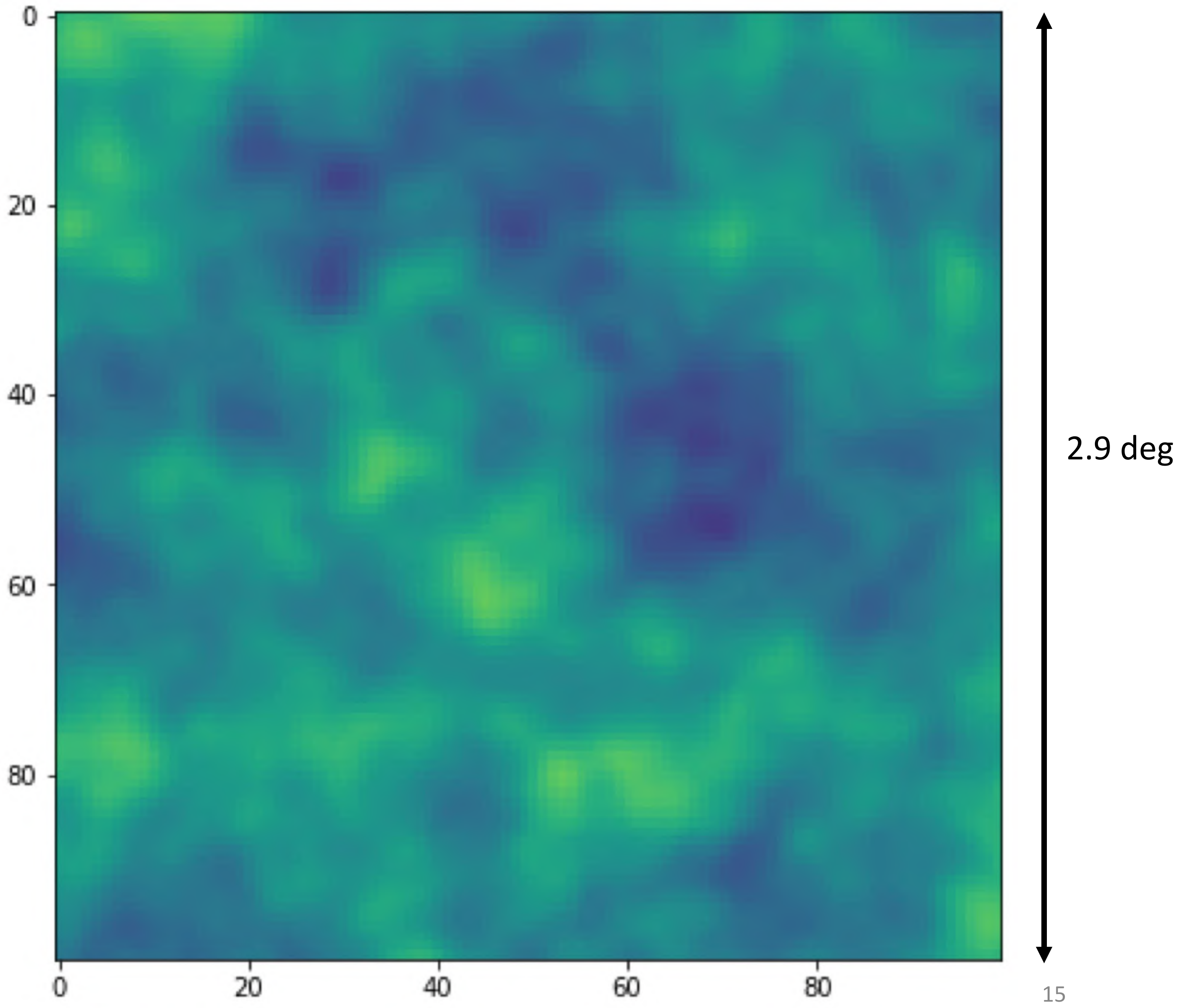
Planck simulation

- CMB



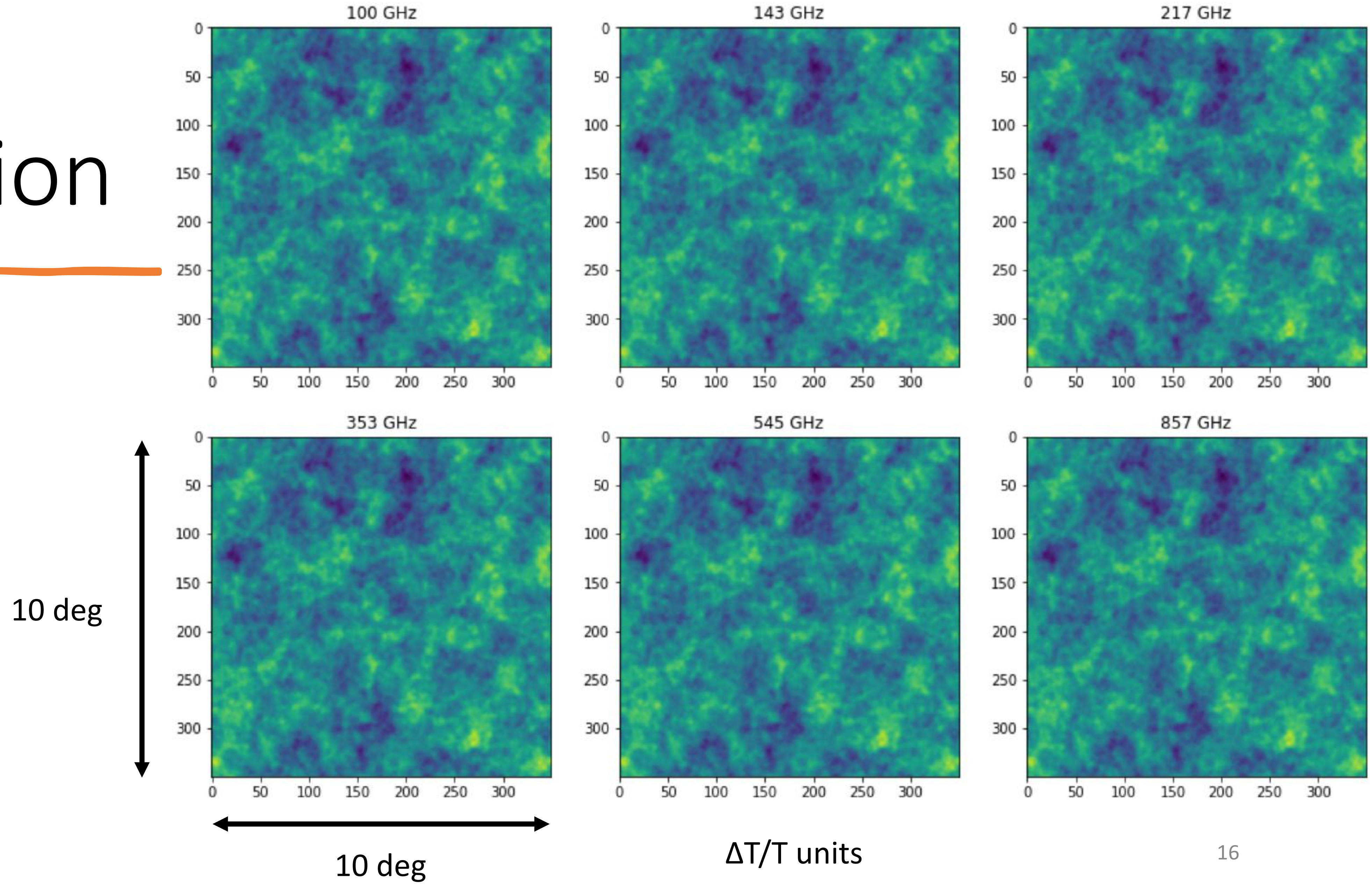
Planck simulation

- CMB
- Cluster lens



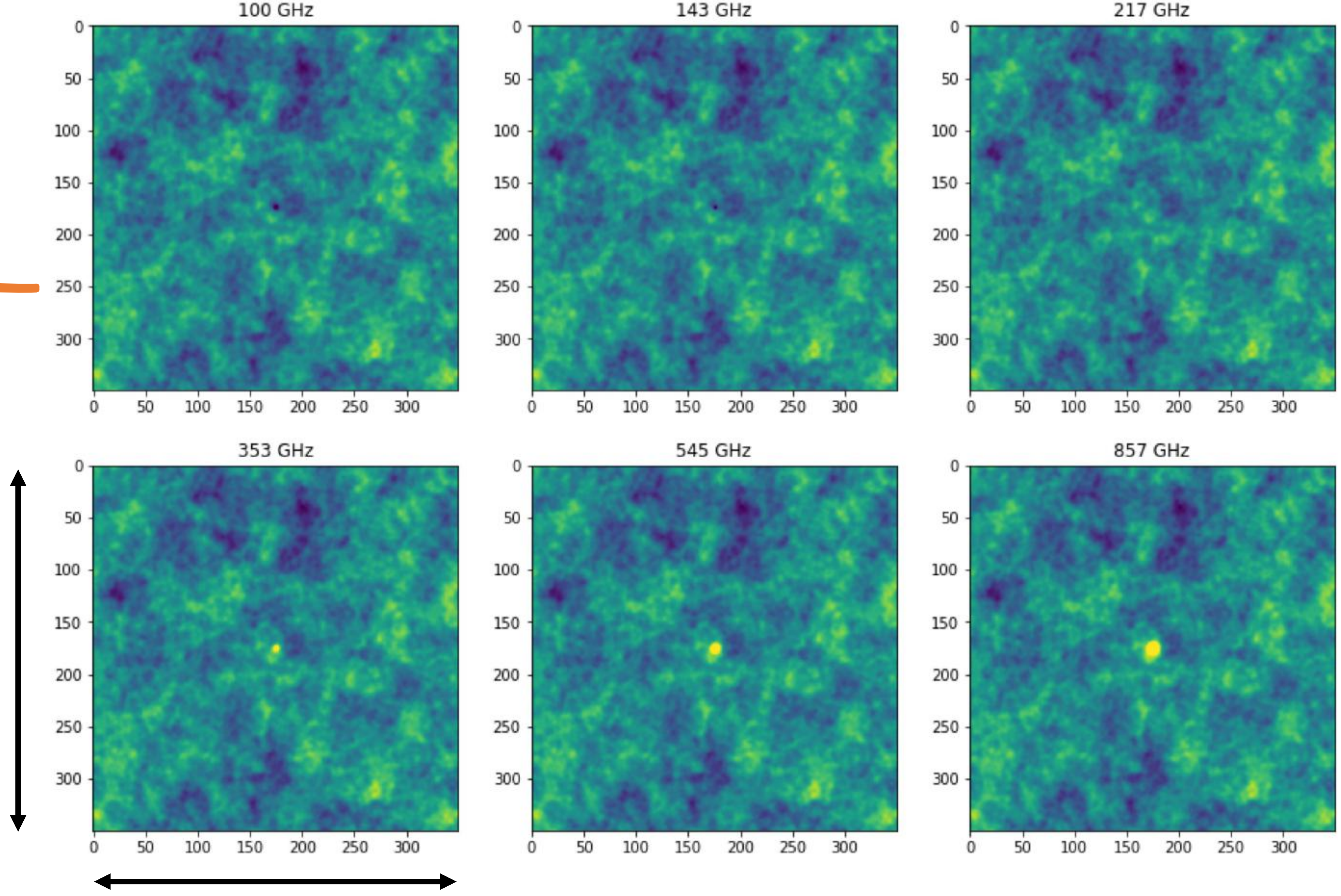
Planck simulation

- CMB
- Cluster lens



Planck simulation

- CMB
- Cluster lens
- SZ effect



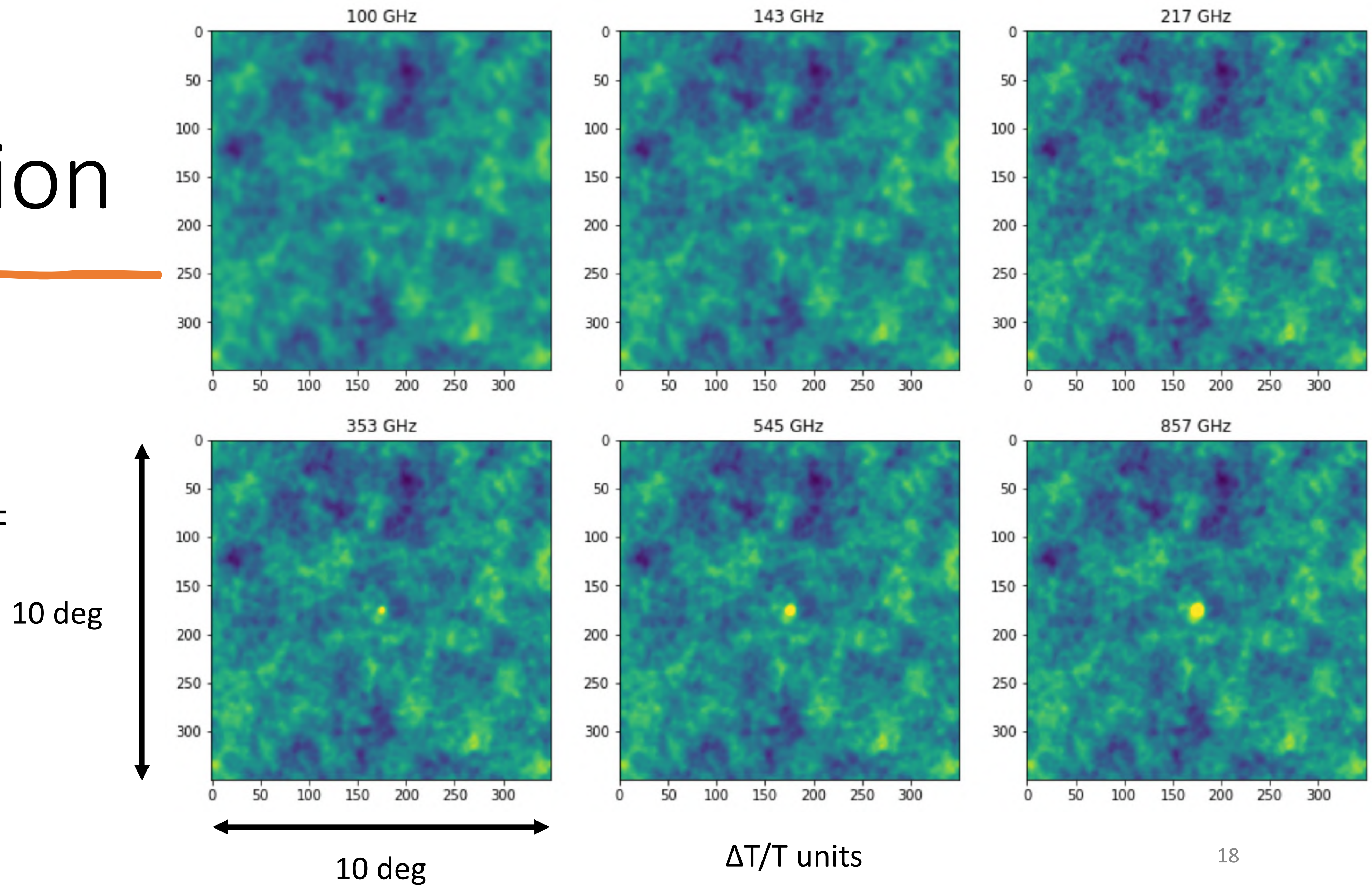
10 deg

10 deg

ΔT/T units

Planck simulation

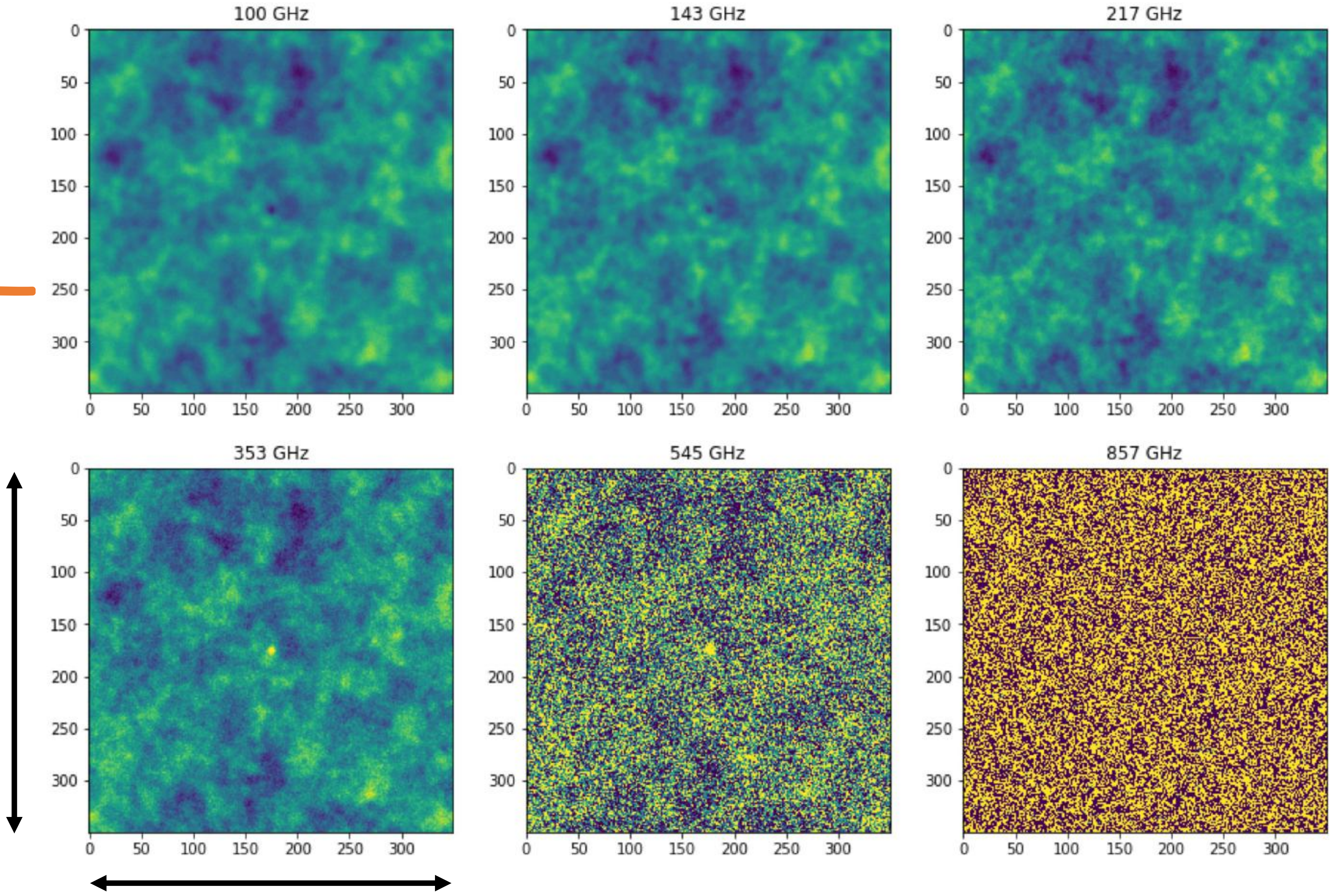
- CMB
- Cluster lens
- SZ effect
- Instrumental PSF



Planck simulation

- CMB
- Cluster lens
- SZ effect
- Instrumental PSF
- Instrumental noise

10 deg

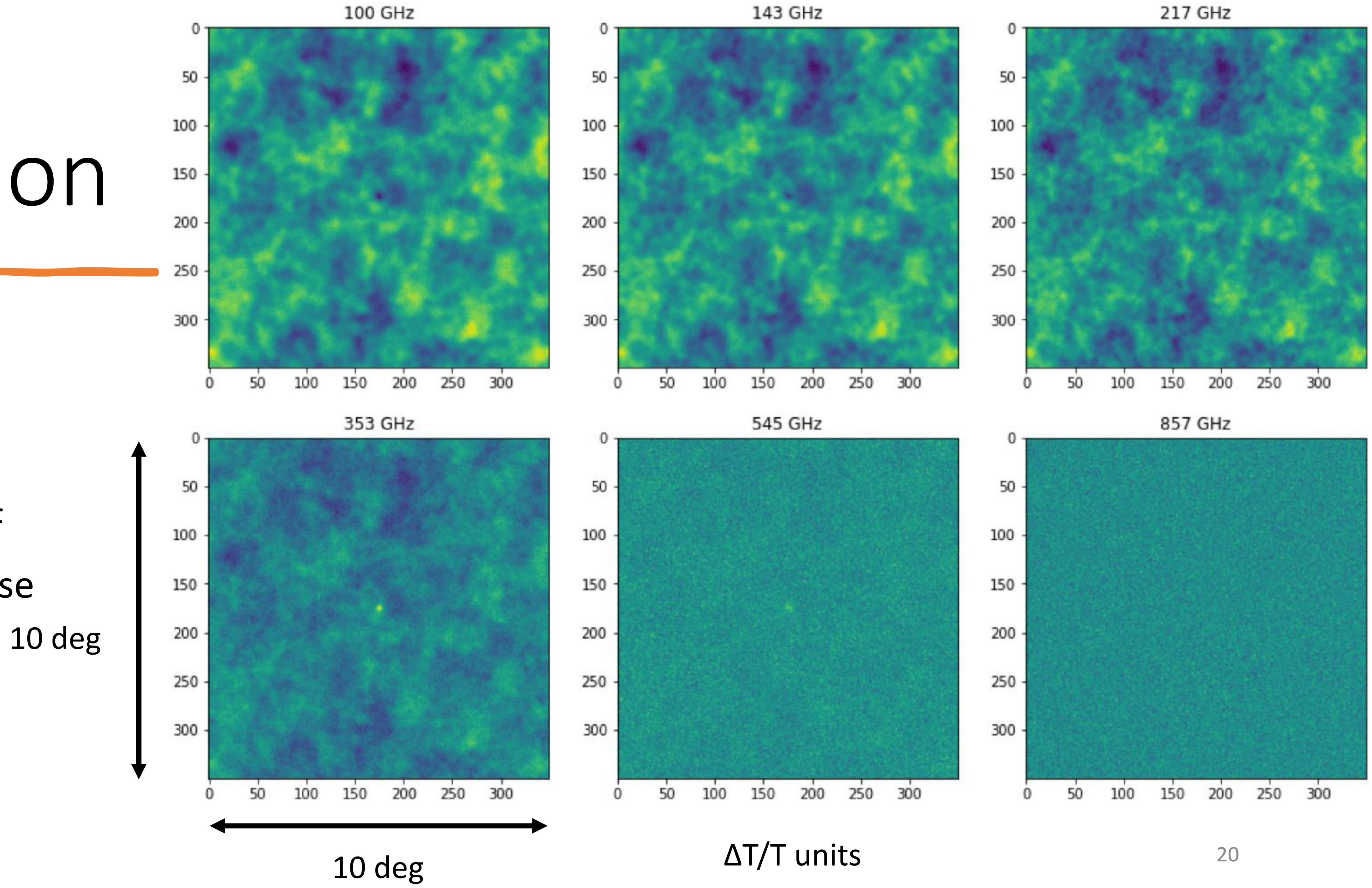


10 deg

ΔT/T units

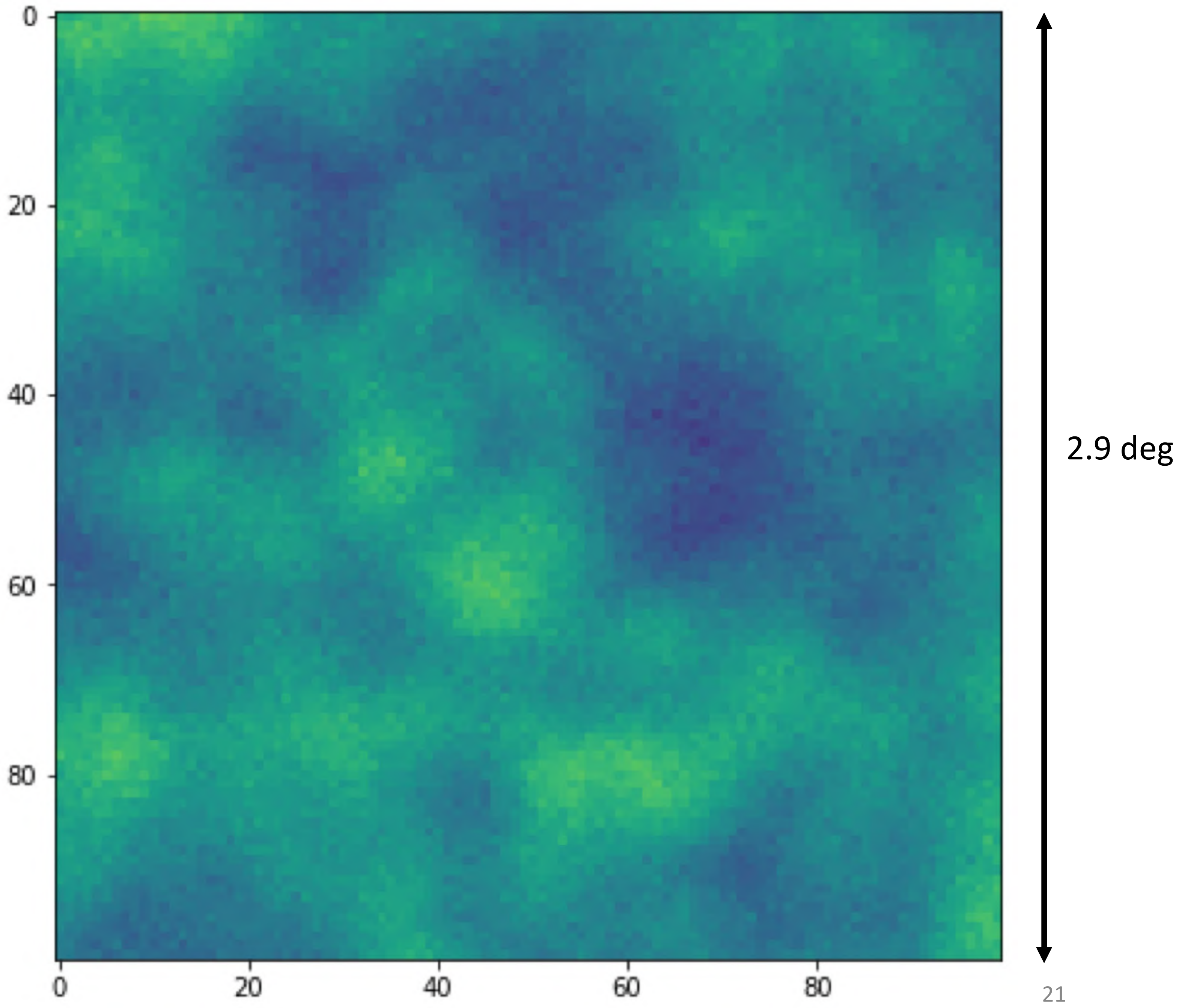
Planck simulation

- CMB
- Cluster lens
- SZ effect
- Instrumental PSF
- Instrumental noise



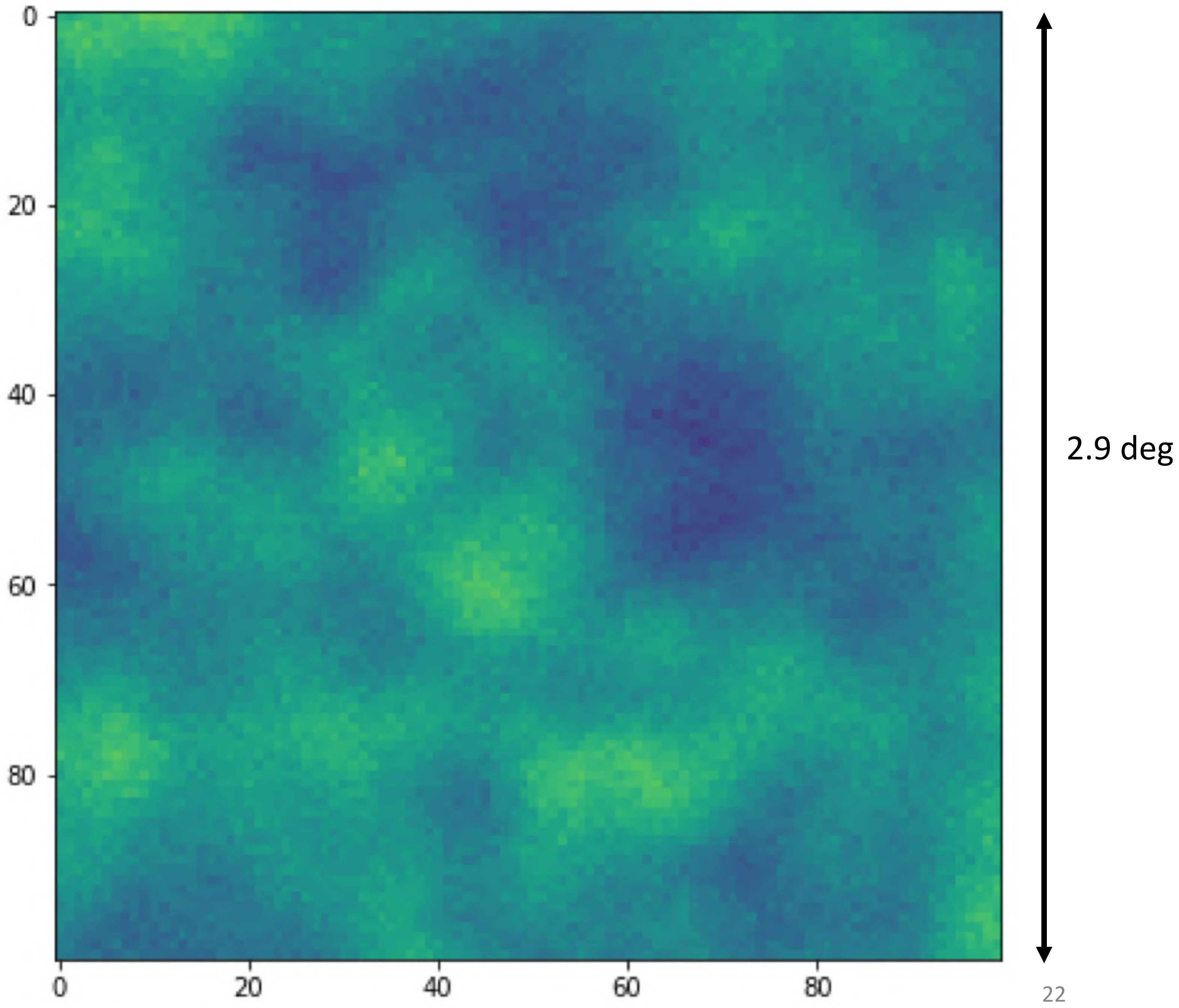
Planck simulation

- 100 GHz map
- No SZ
- No lens



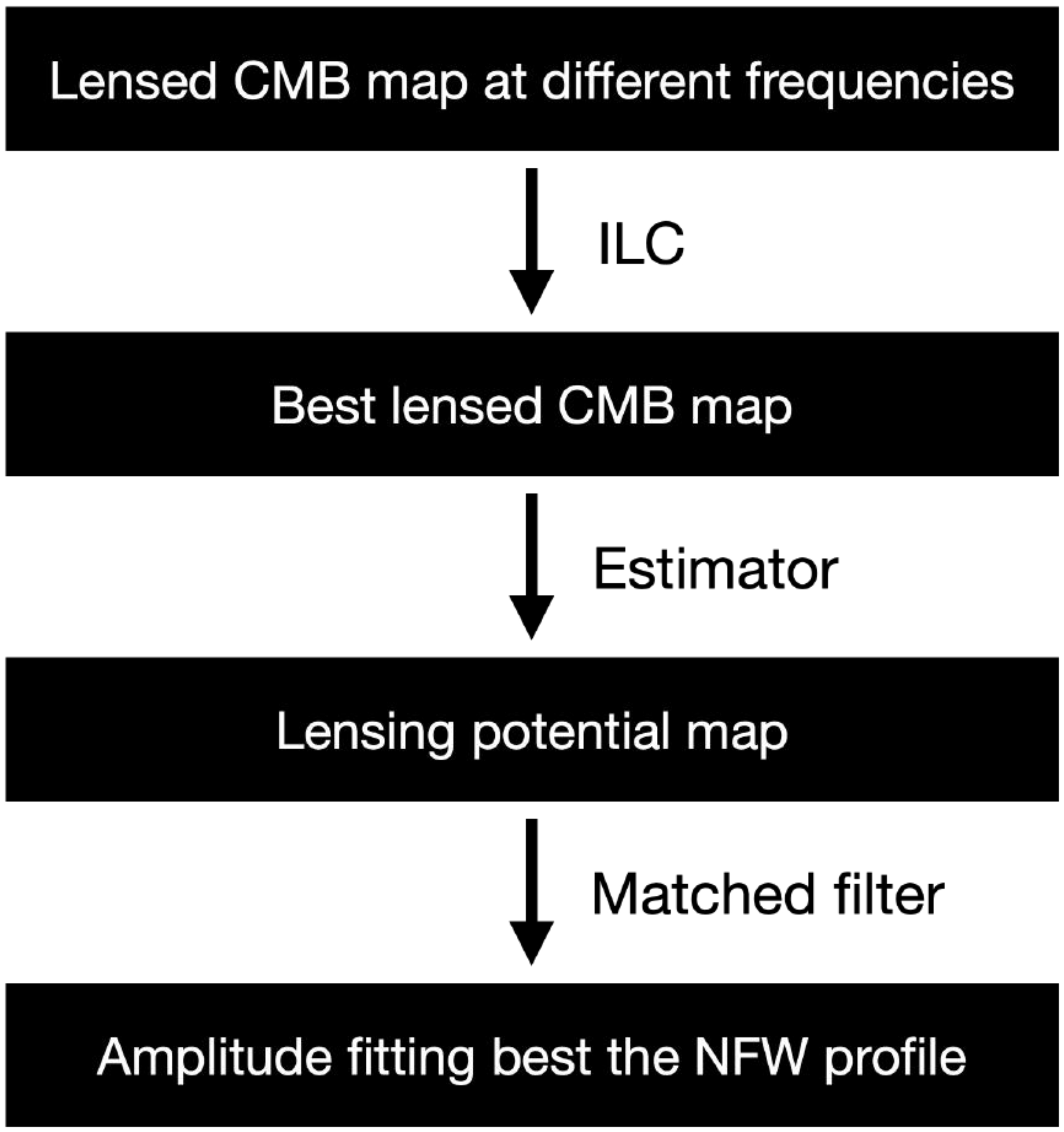
Planck simulation

- 100 GHz map
- No SZ
- Cluster lens



Data analysis

- Internal Linear Combinations (ILC), Remazeilles et al., 2011
- Lensing estimator, Hu & Okamoto, 2002
- Matched filter, Melin et al., 2015



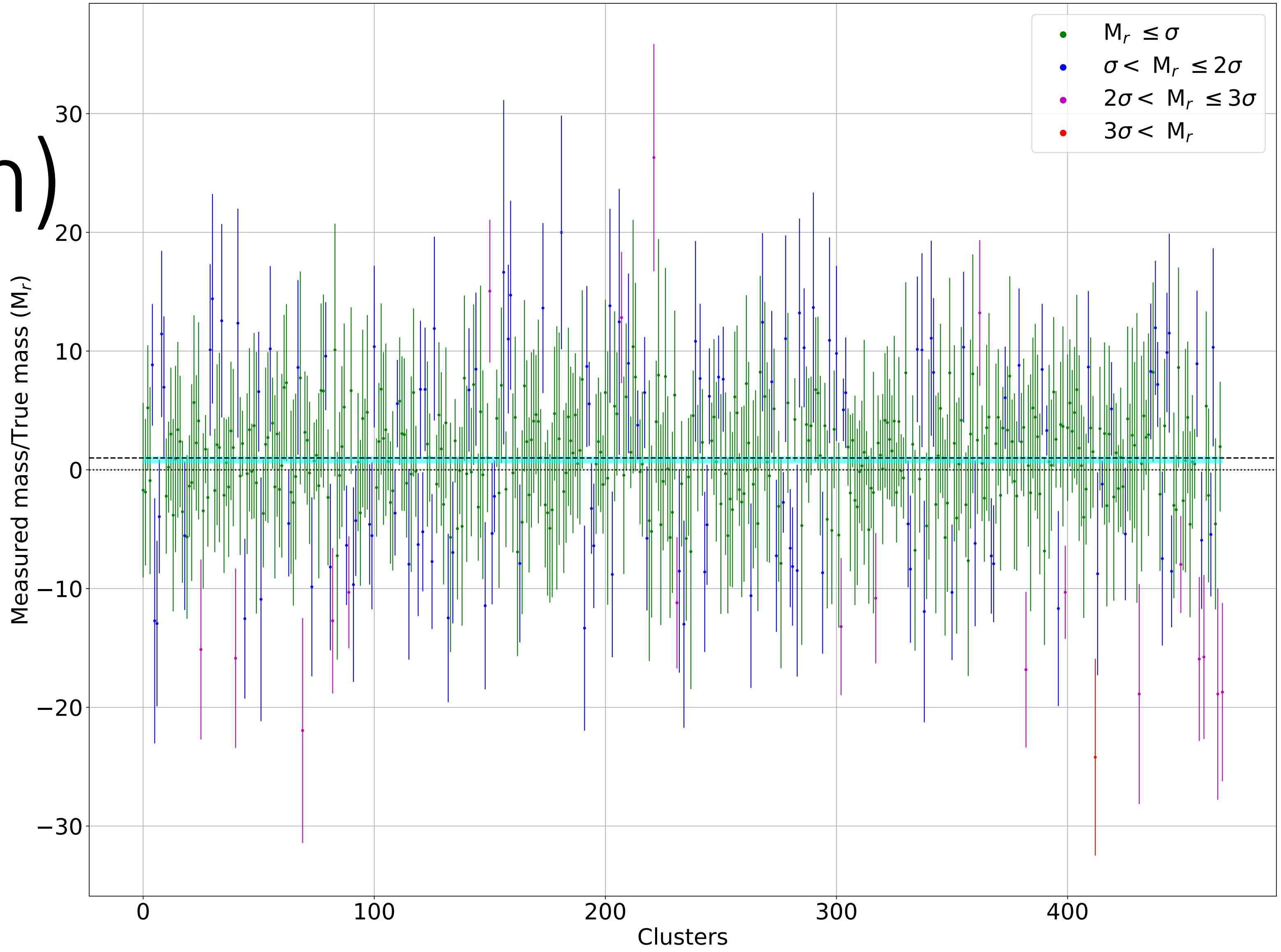
Planck results (one realization)

Each point and associated error bar correspond to an individual cluster mass measurement, for a total of 468.

Averaging these measurements provides

<Mr> = 0.84 ± 0.25,

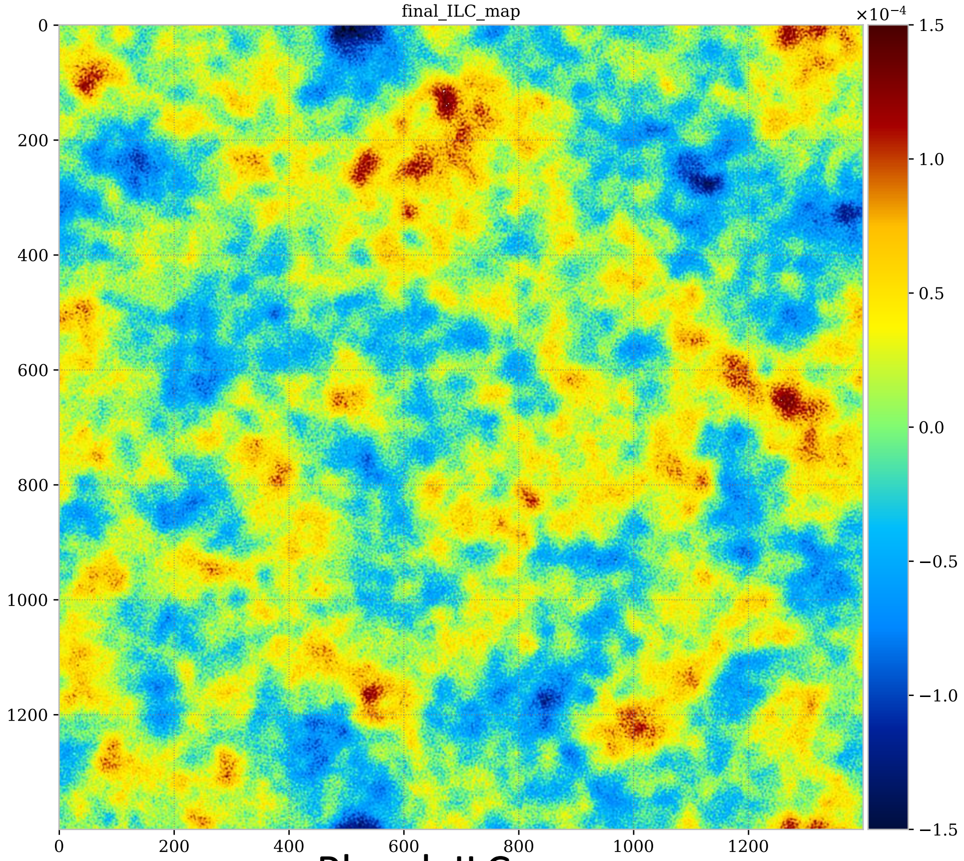
compatible with one



Comparison between Planck and SPT results…

Planck ILC maps: large scales

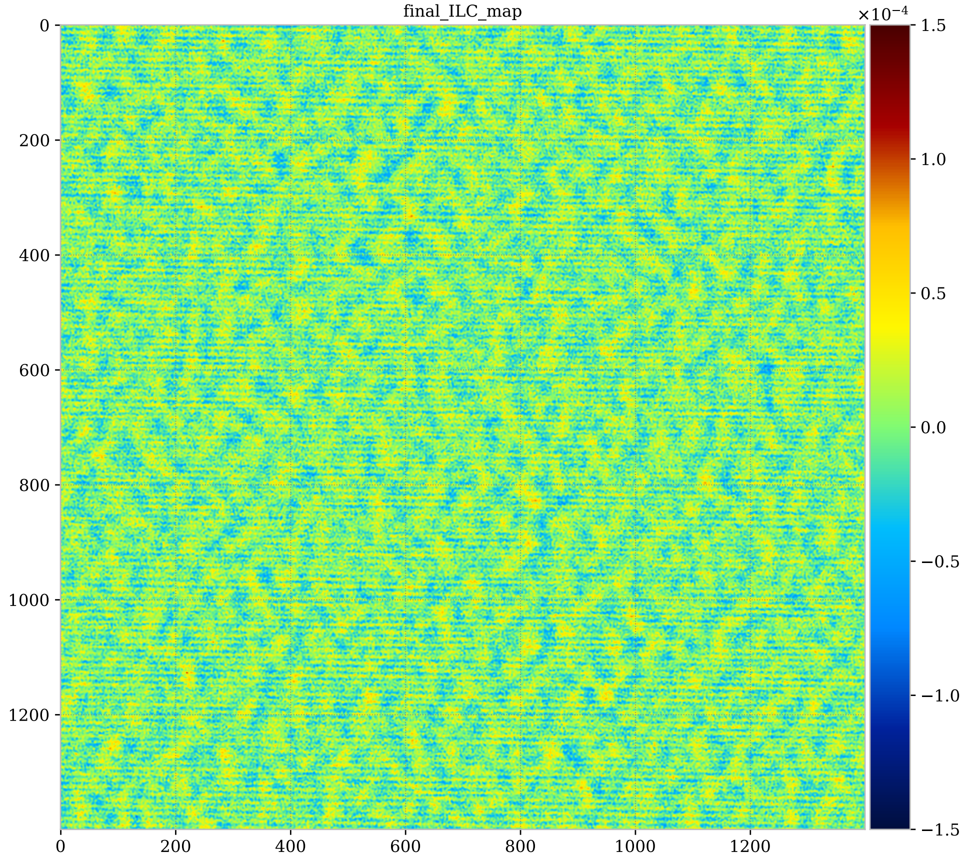
<Mr> = 0.84 ± 0.25 (one realization)



Planck ILC map

SPT ILC maps: small scales

<Mr> = 0.91 ± 0.22 (one realization)



SPT ILC map

Final ILC maps for the same location

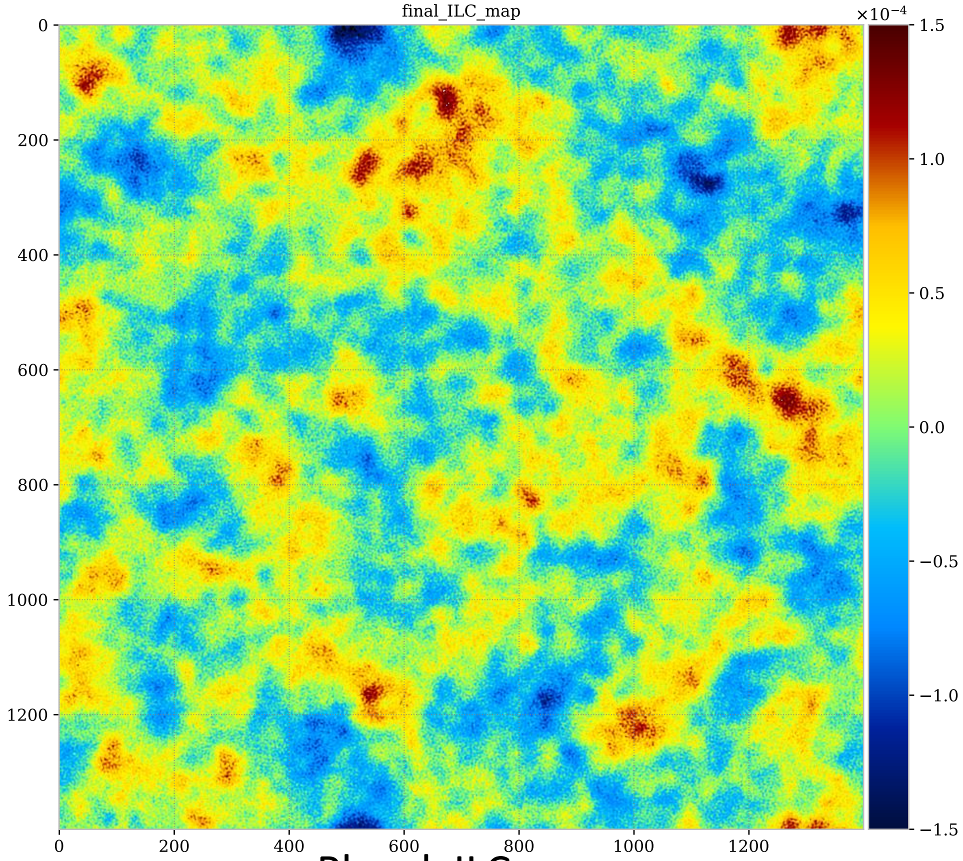
… and the combination of both

Planck: <Mr> = 0.84 ± 0.25 (one realization)

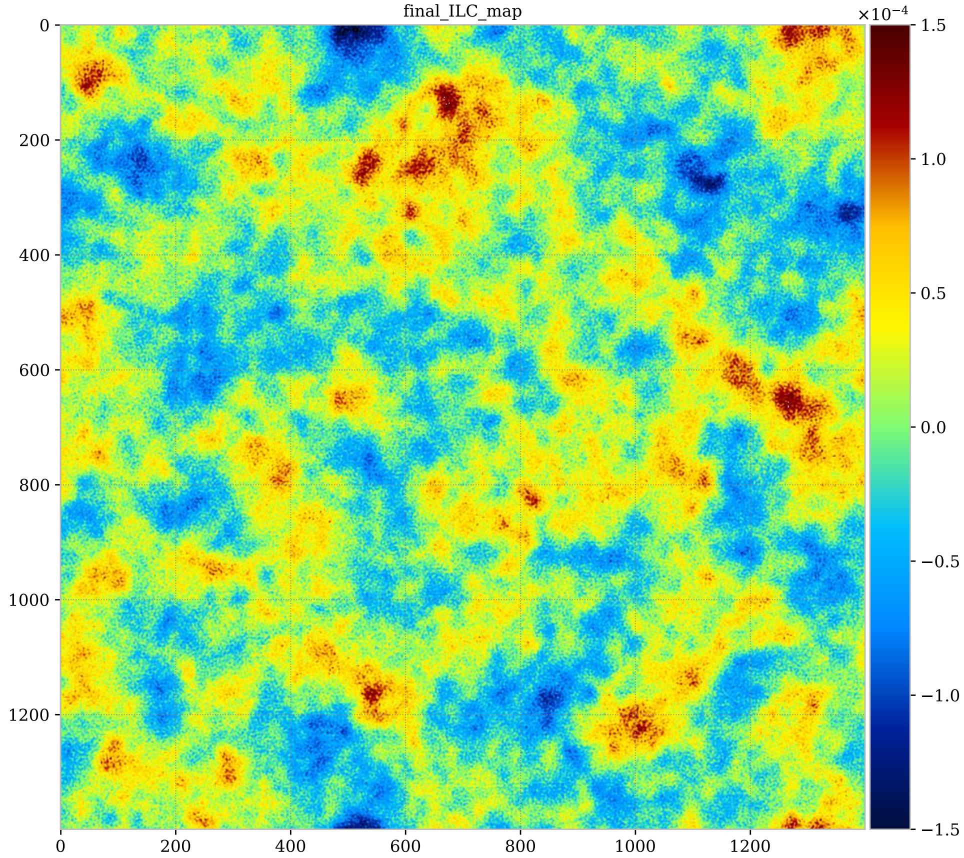
SPT: <Mr> = 0.91 ± 0.22

Combination:

<Mr> = 0.88 ± 0.17



Planck ILC map

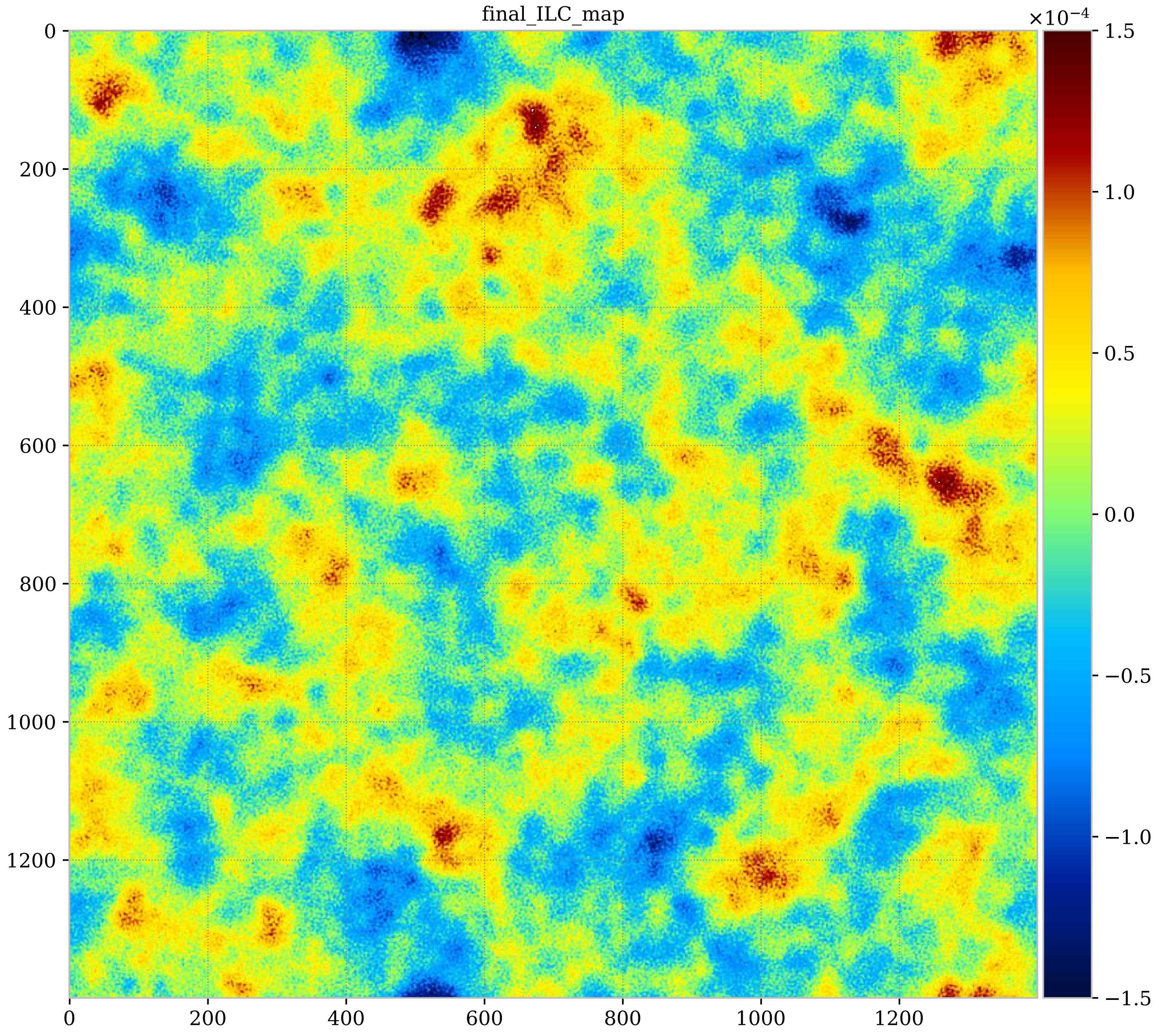


Combi ILC map

Final ILC maps for the same location

Planck ILC map

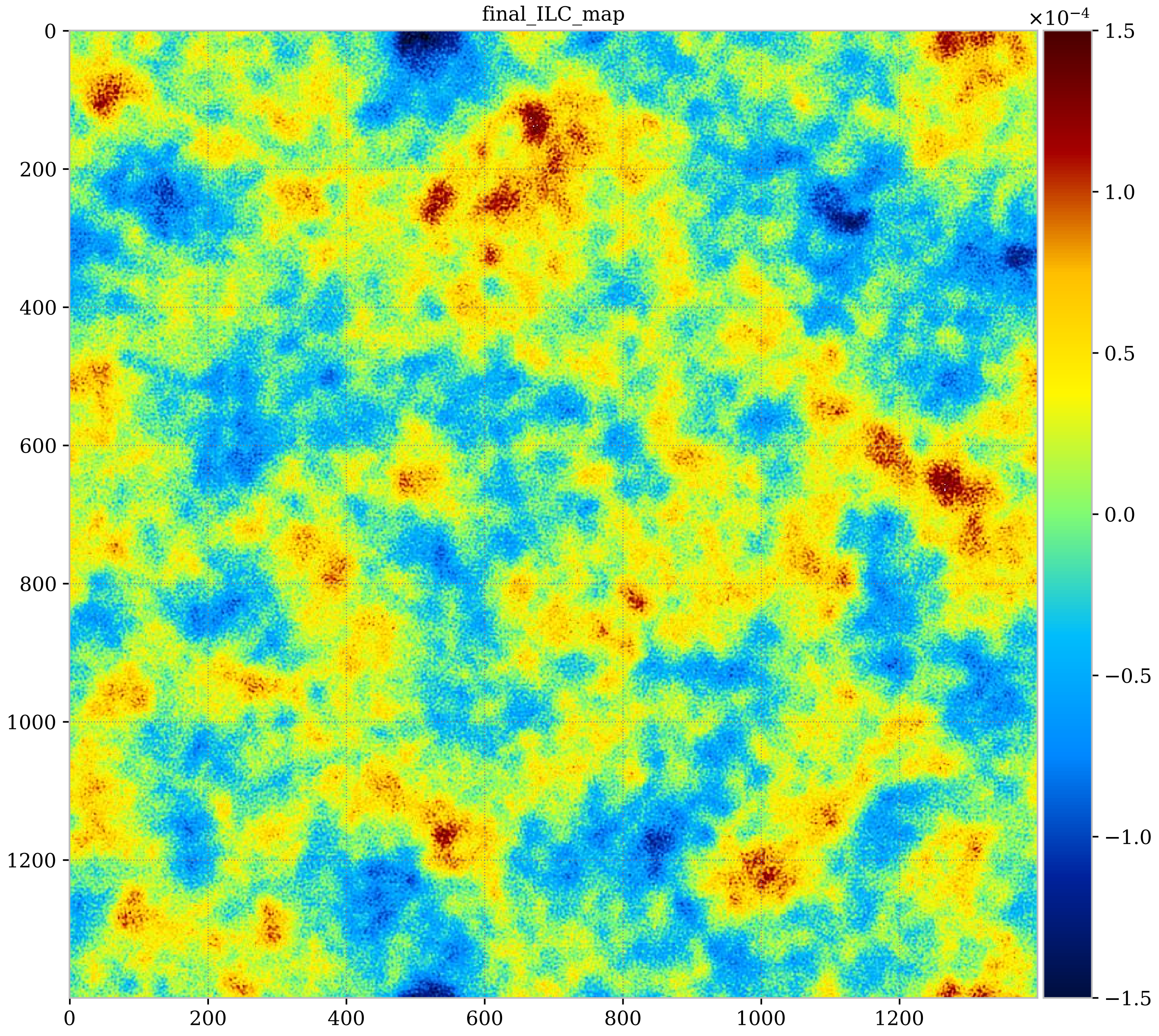
- For one simulated cluster
- No foreground simulated
- The map is periodic



Combined ILC map

- Better small scales than Planck only
- The surveys really are complementary

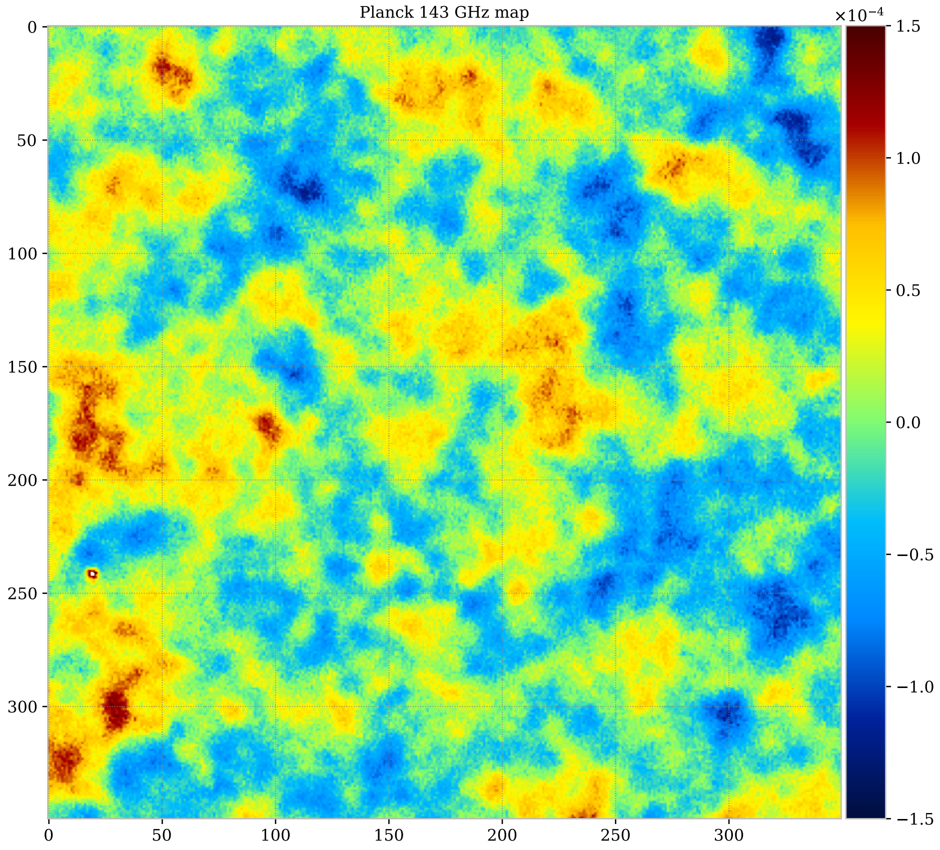
$$\frac{1}{\sigma^2_{combi}} = \frac{1}{\sigma^2_{planck}} + \frac{1}{\sigma^2_{SPT}}$$

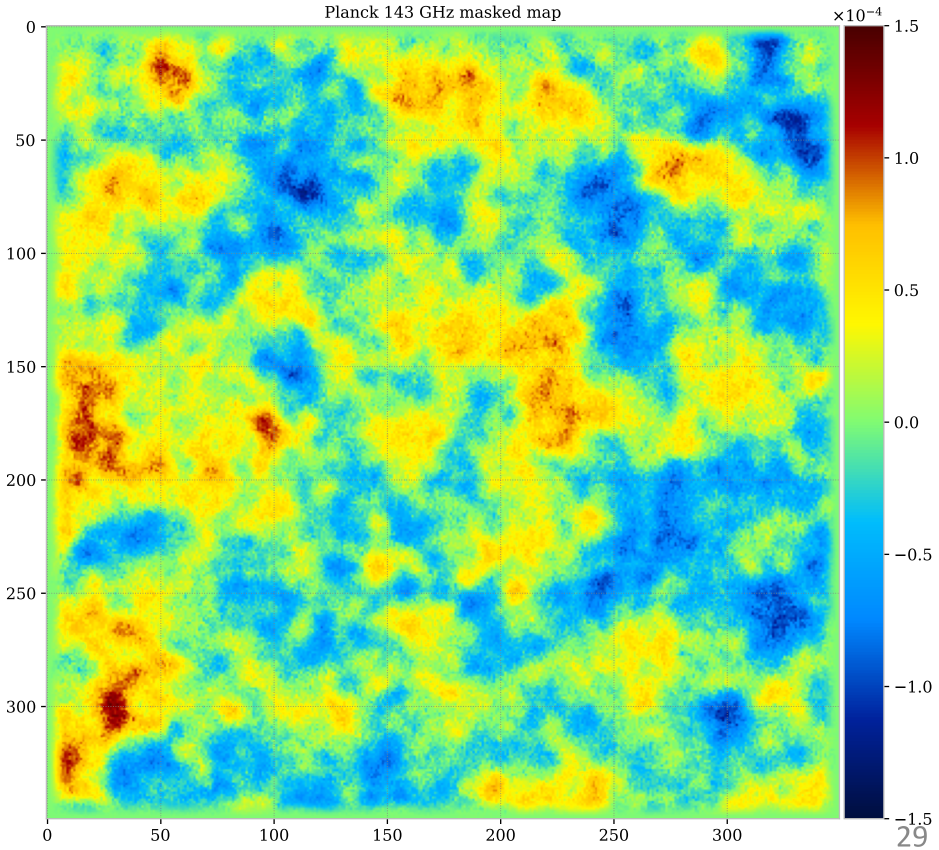


Real maps need to be cleaned

Points sources: replaced by gaussian field with CMB properties, continuity with vicinity

Maps not periodic: apodisation of the maps





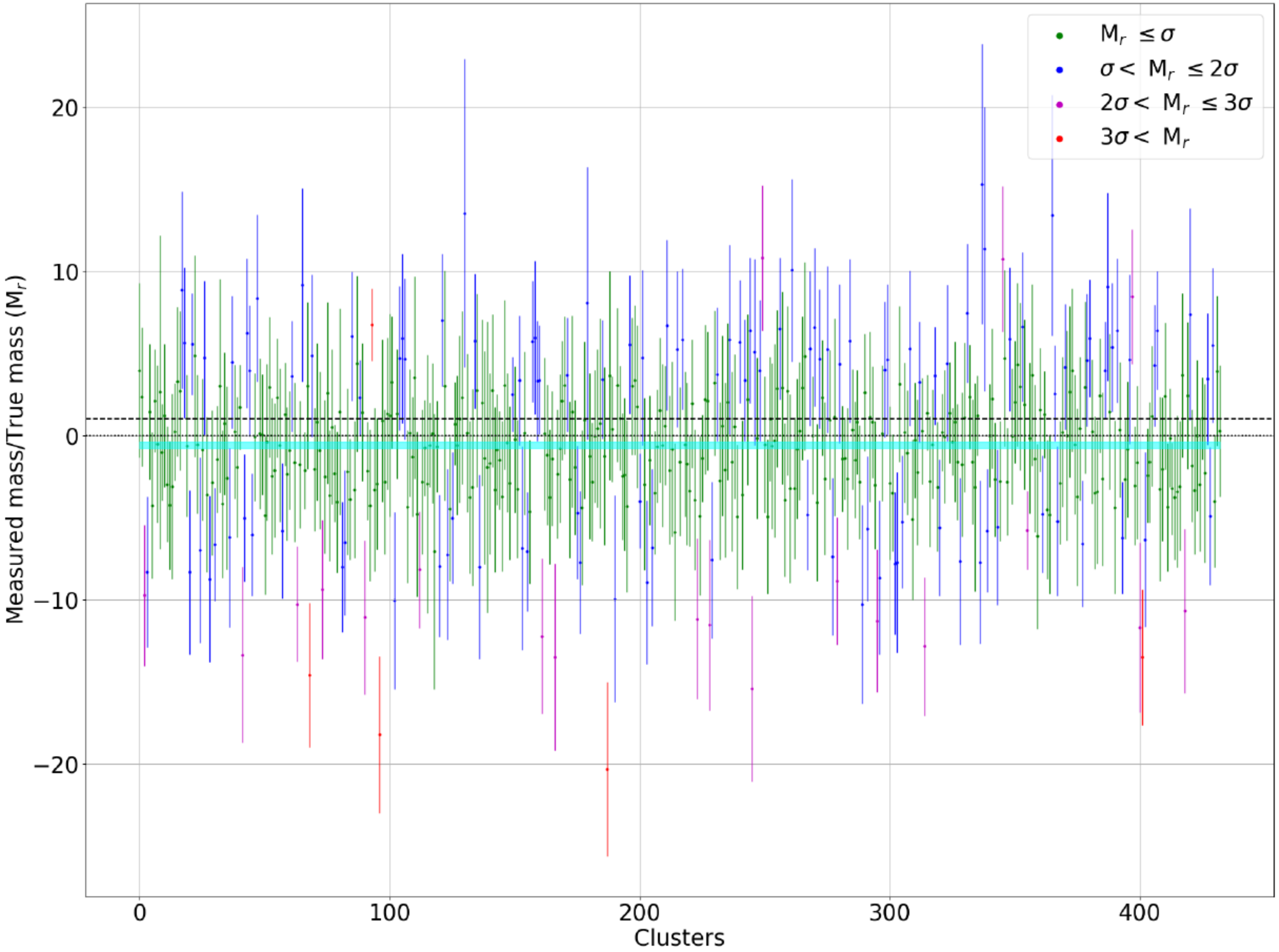
Planck results (real maps)

- The point sources are masked
- The lensing due to foregrounds is subtracted using “off” measurements

Averaging these measurements and subtracting the offs provides

<Mr> = 0.97 ± 0.28,

compatible with one



To be continued

Thank you for your attention

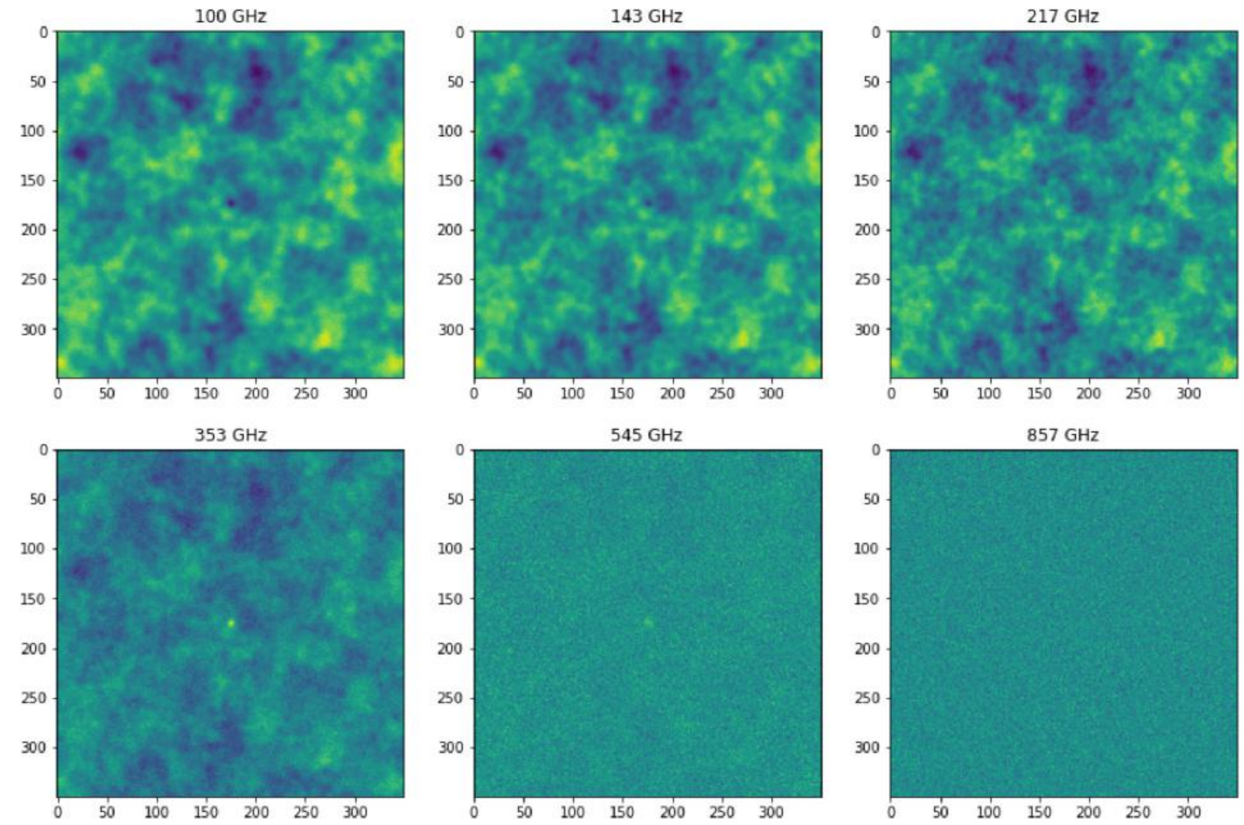
Backup slides

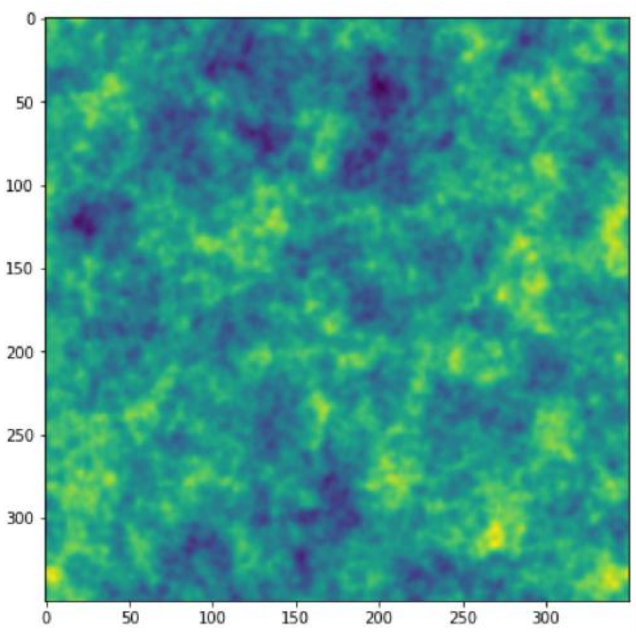
Internal Linear Combinations

- Contaminants: SZ effect, foreground
- Instrumental characteristics: PSF, noise

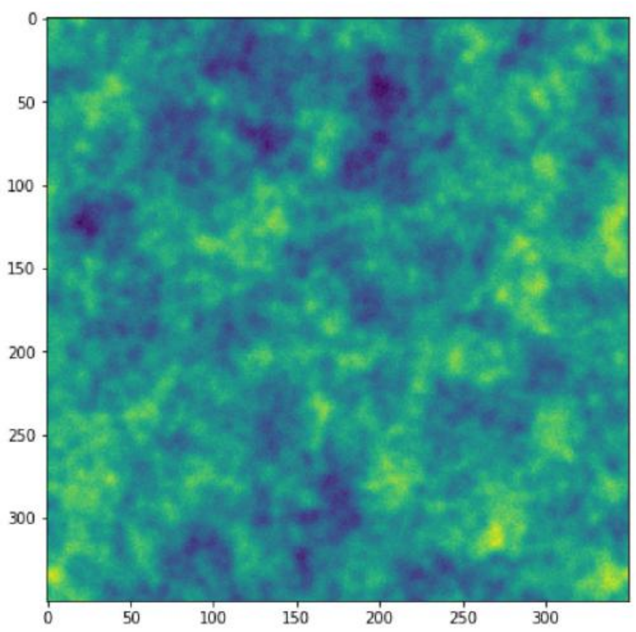
Combine the maps at different frequencies to remove contaminants, easier when we know the recipe

→ Best lensed CMB map





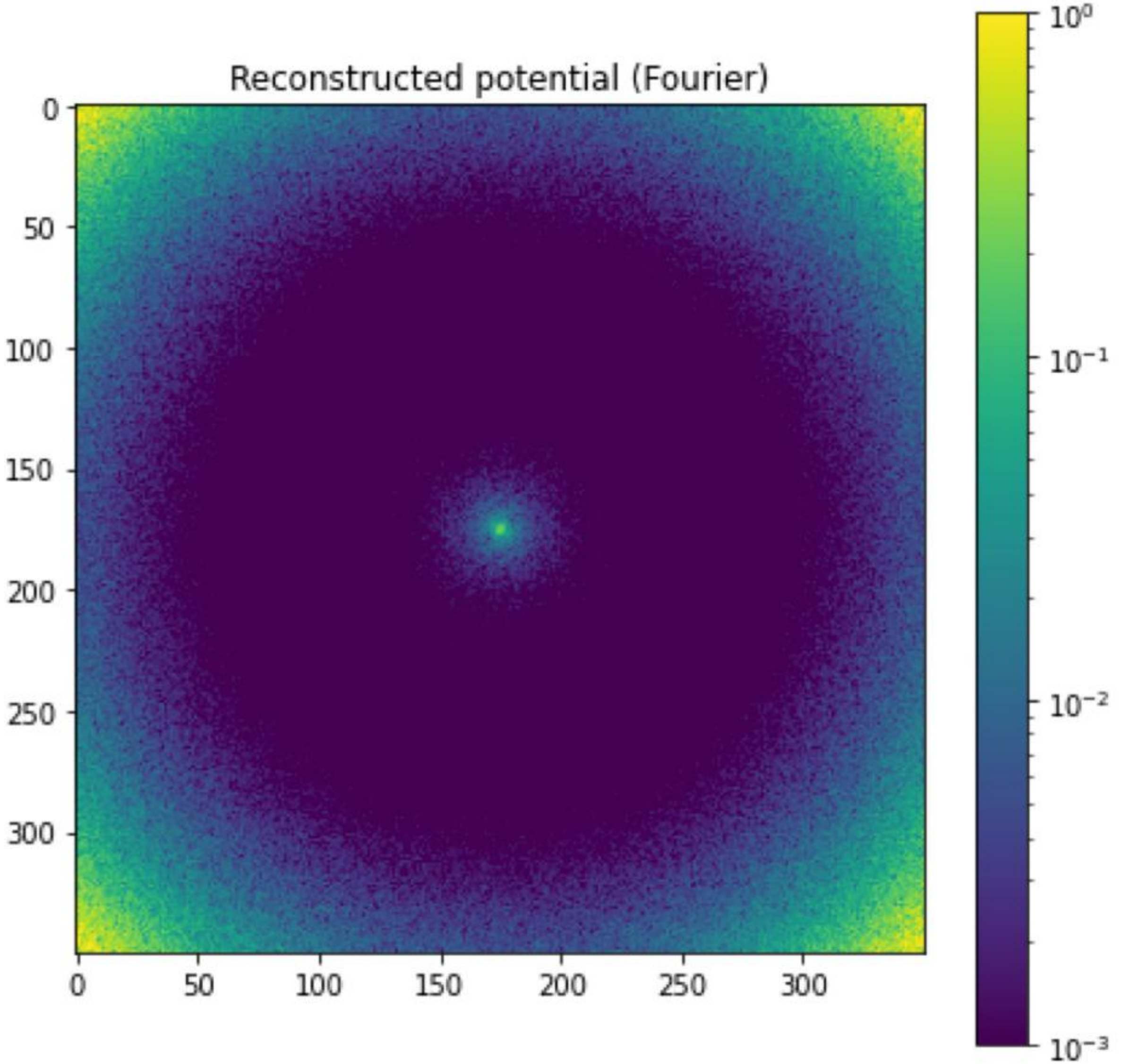
Input lensed CMB



Reconstructed ILC map

Lensing estimator

- The CMB k-modes (spatial frequencies, i.e. the different scales) are uncorrelated
- The CMB on our map is lensed, inducing spatial correlations
- Use these correlations to rebuild the lensing potential



2D-Fourier transform of the reconstructed gravitational potential (small k-modes – large scales in the middle)

Matched filter

- Compares the obtained lensing potential to a NFW profile for a given mass
- We know the NFW profile used in the simulations
- Returns the estimation of the amplitude fitting best the NFW profile. For simulations, we expect to get, in average:

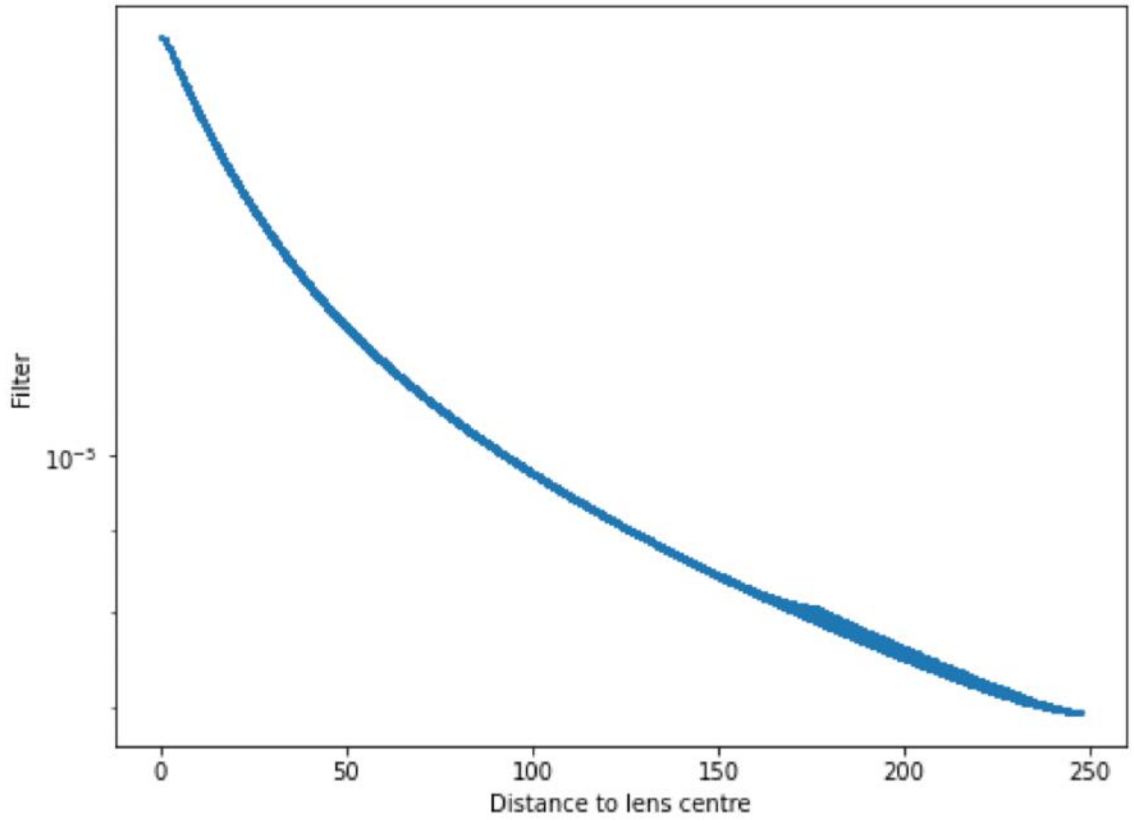
$$\frac{M_{measurement}}{M_{true}} = 1$$

$$\hat{\phi}_0 = \left[\sum_{\boldsymbol{K}} \frac{|\Phi(\boldsymbol{K})|^2}{A(\boldsymbol{K})} \right]^{-1} \sum_{K} \frac{\Phi^*(\boldsymbol{K})}{A(\boldsymbol{K})} \hat{\phi}(\boldsymbol{K})$$

NFW lensing potential

Obtained lensing potential

Variance of measure obtained for **K**



Filter NWF lensing profile