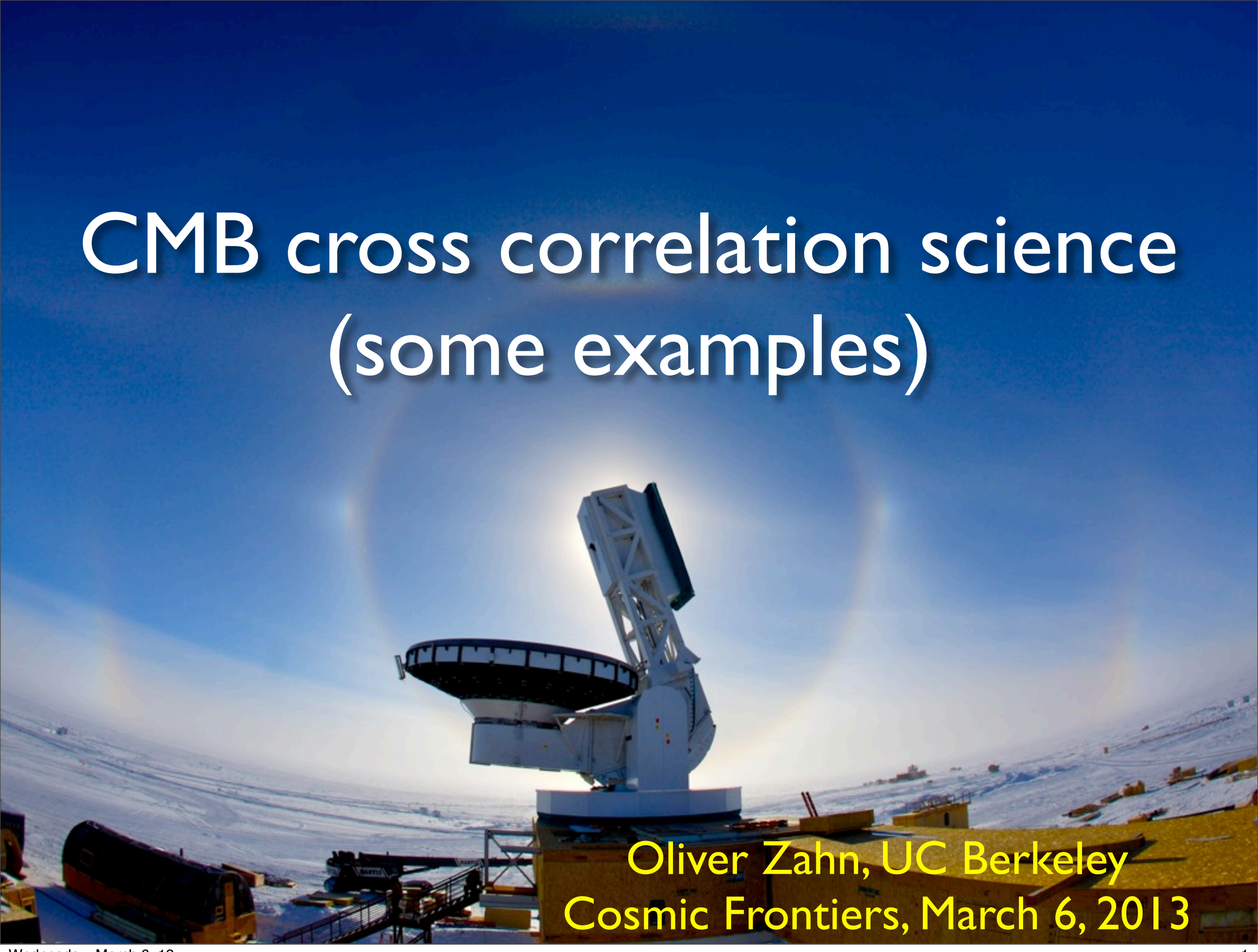
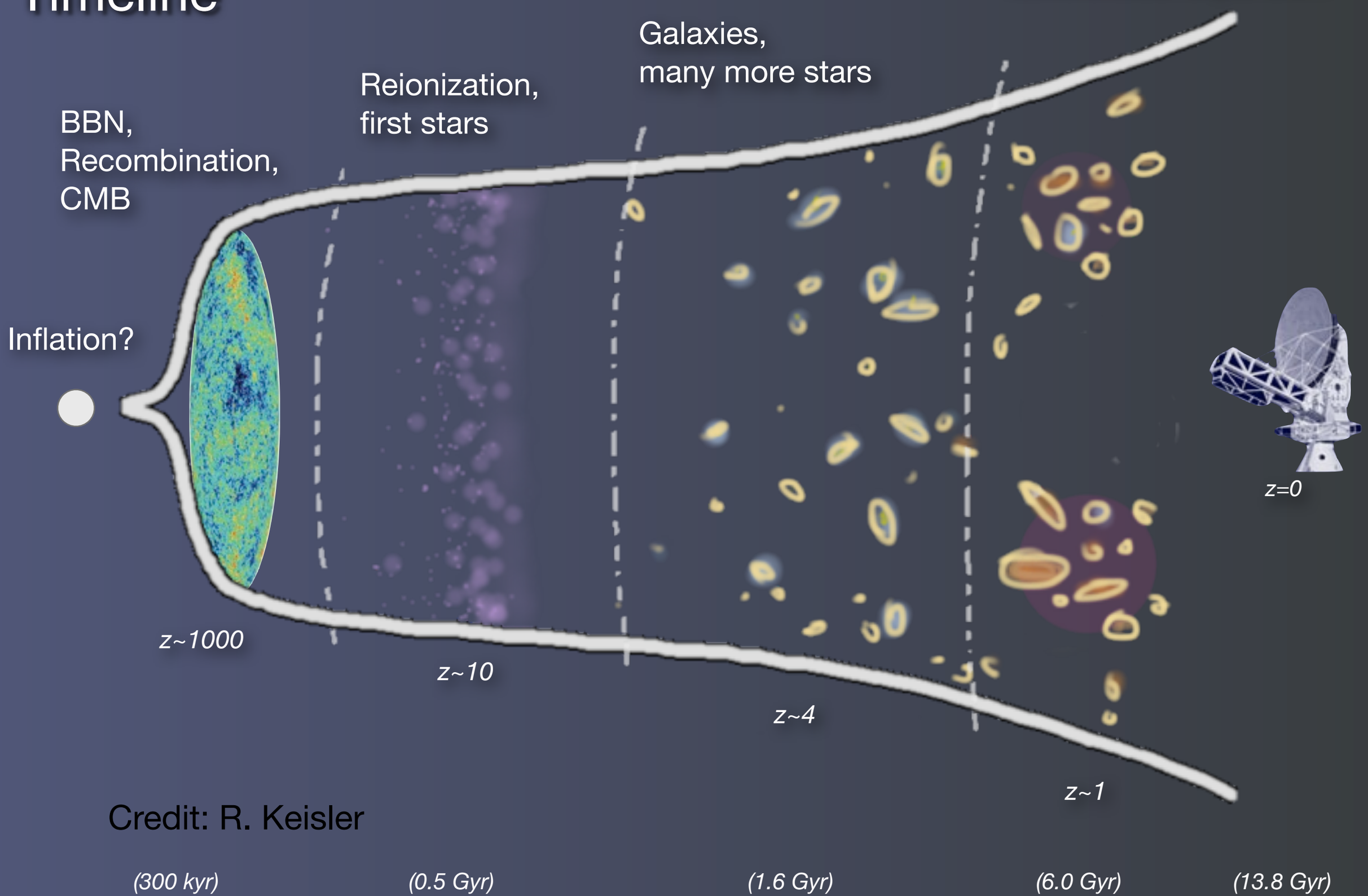
CMB cross correlation science (some examples)



Oliver Zahn, UC Berkeley

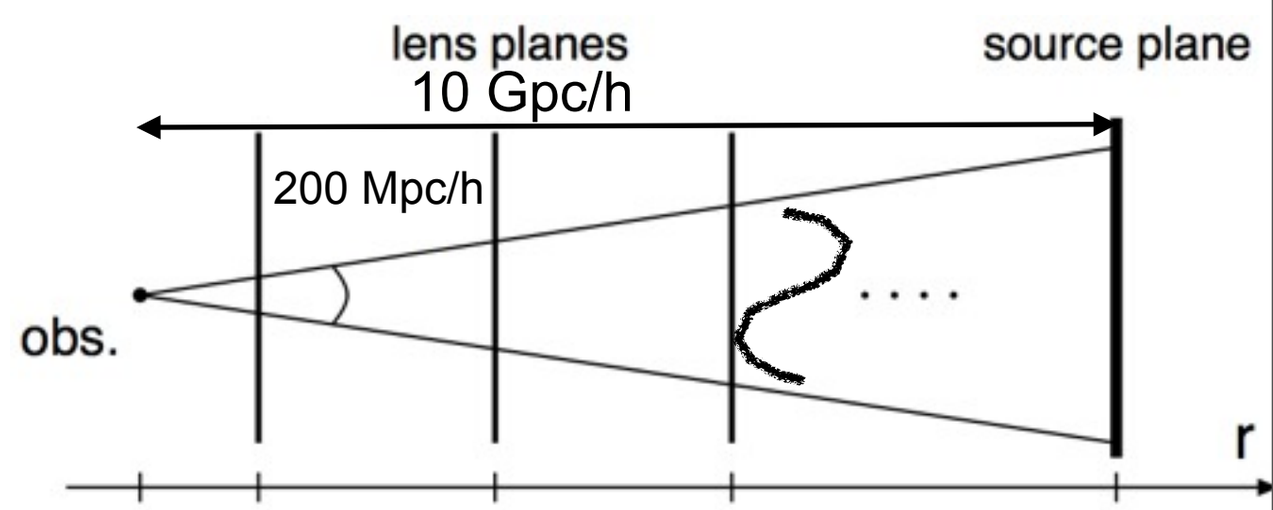
Cosmic Frontiers, March 6, 2013

Cosmic Timeline



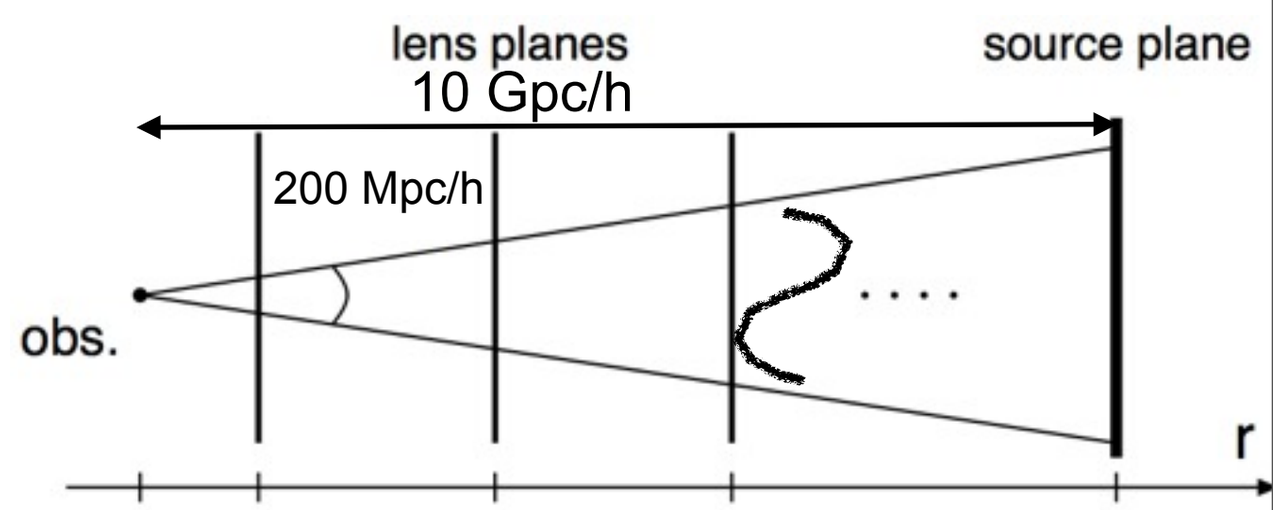
Credit: R. Keisler

CMB lensing order of magnitude



CMB lensing order of magnitude

- Last scattering surface 10,000 Mpc/h away, peak of matter power spectrum at ~200 Mpc/h



CMB lensing order of magnitude

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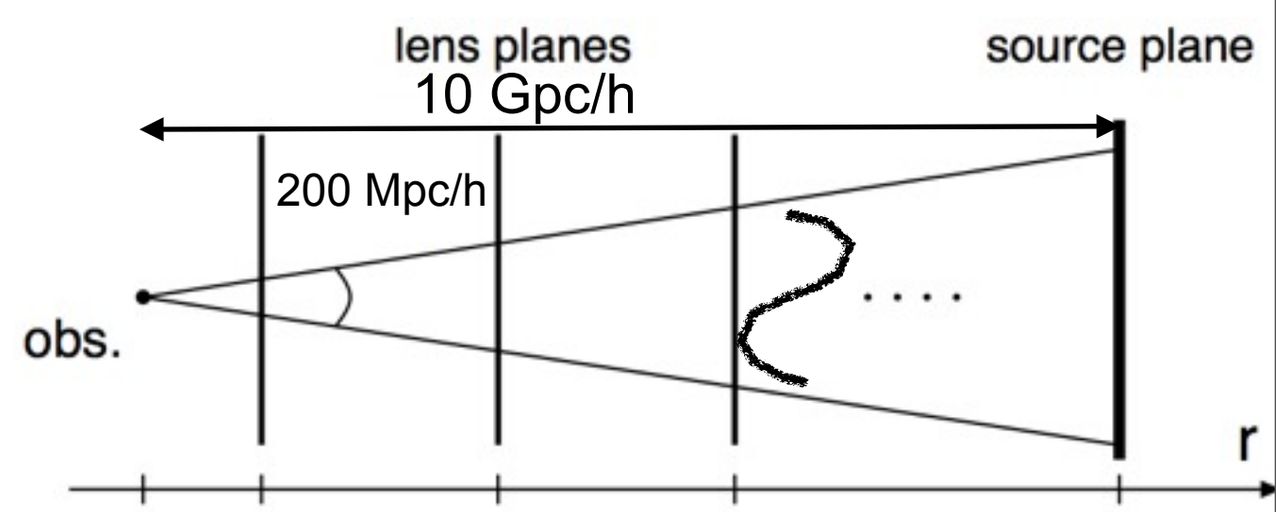
- For potential fluctuations on that scale deflection is ~20 arc seconds



CMB lensing order of magnitude

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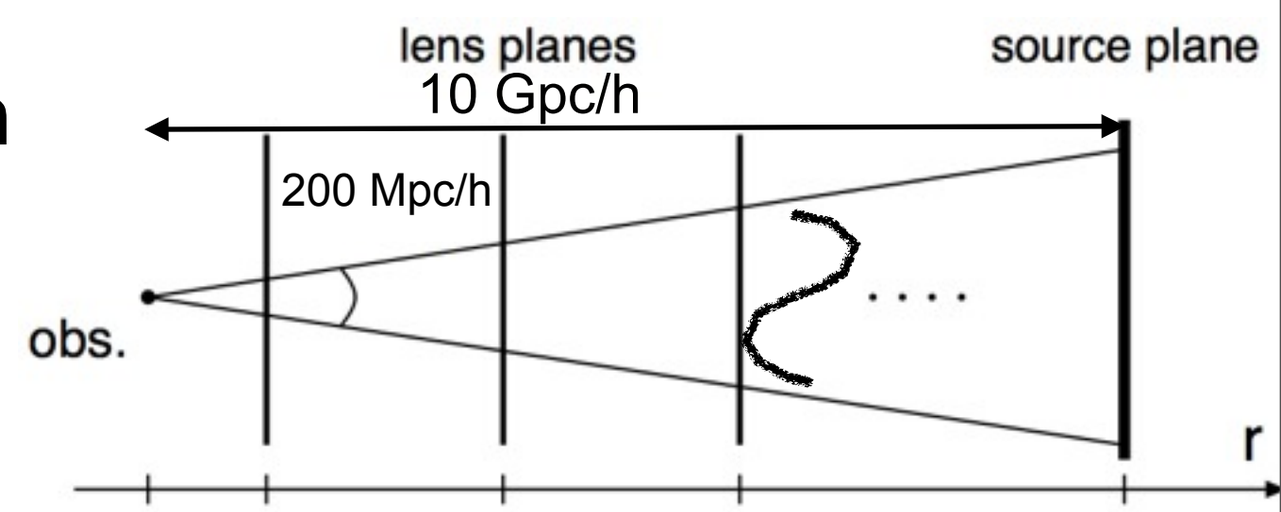
- Imagine random walk through



CMB lensing order of magnitude

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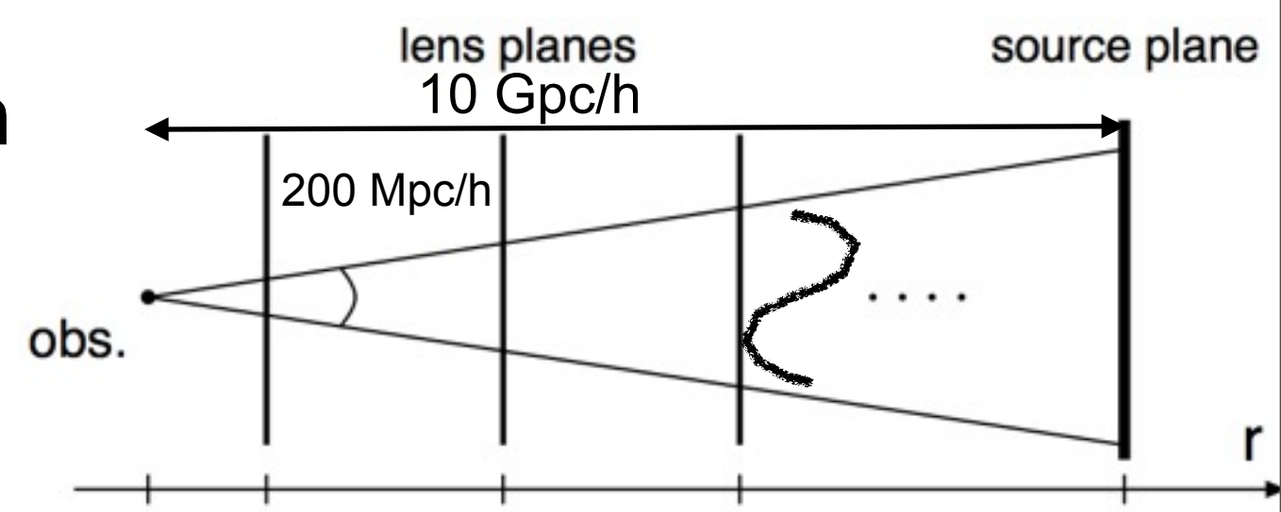
- Imagine random walk through 10,000/200=50 lens planes



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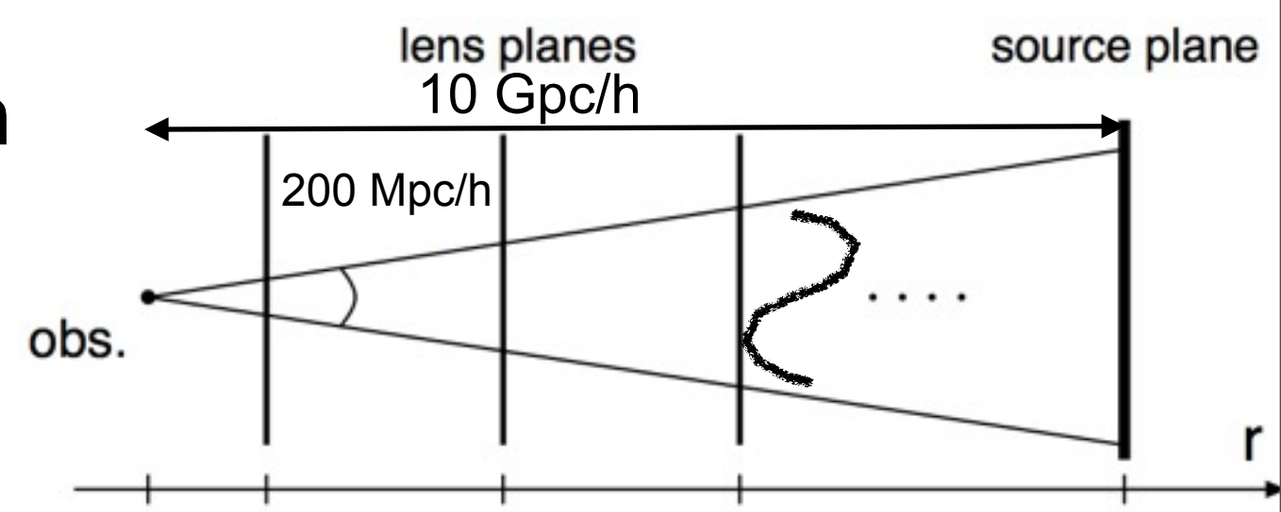
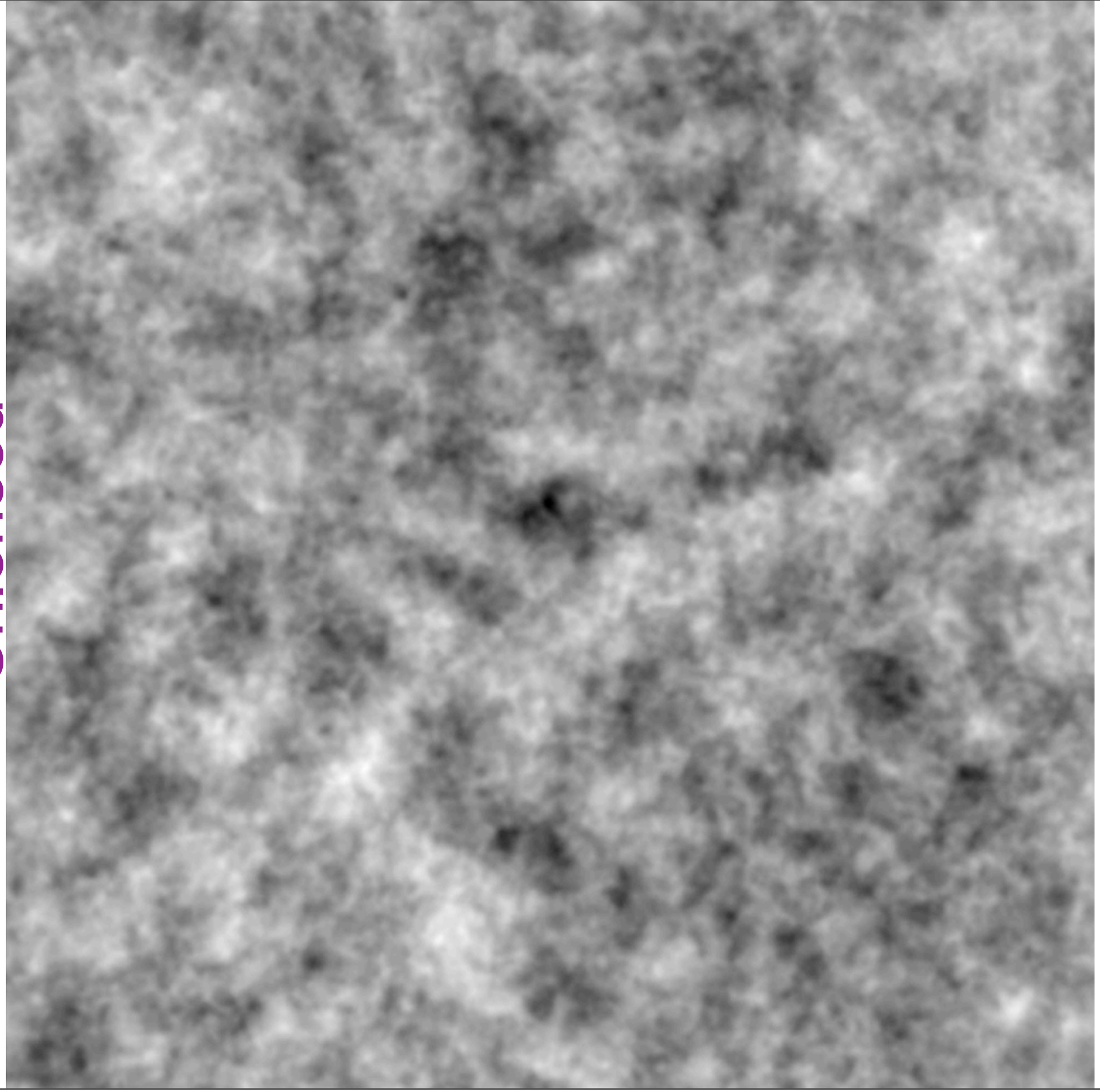
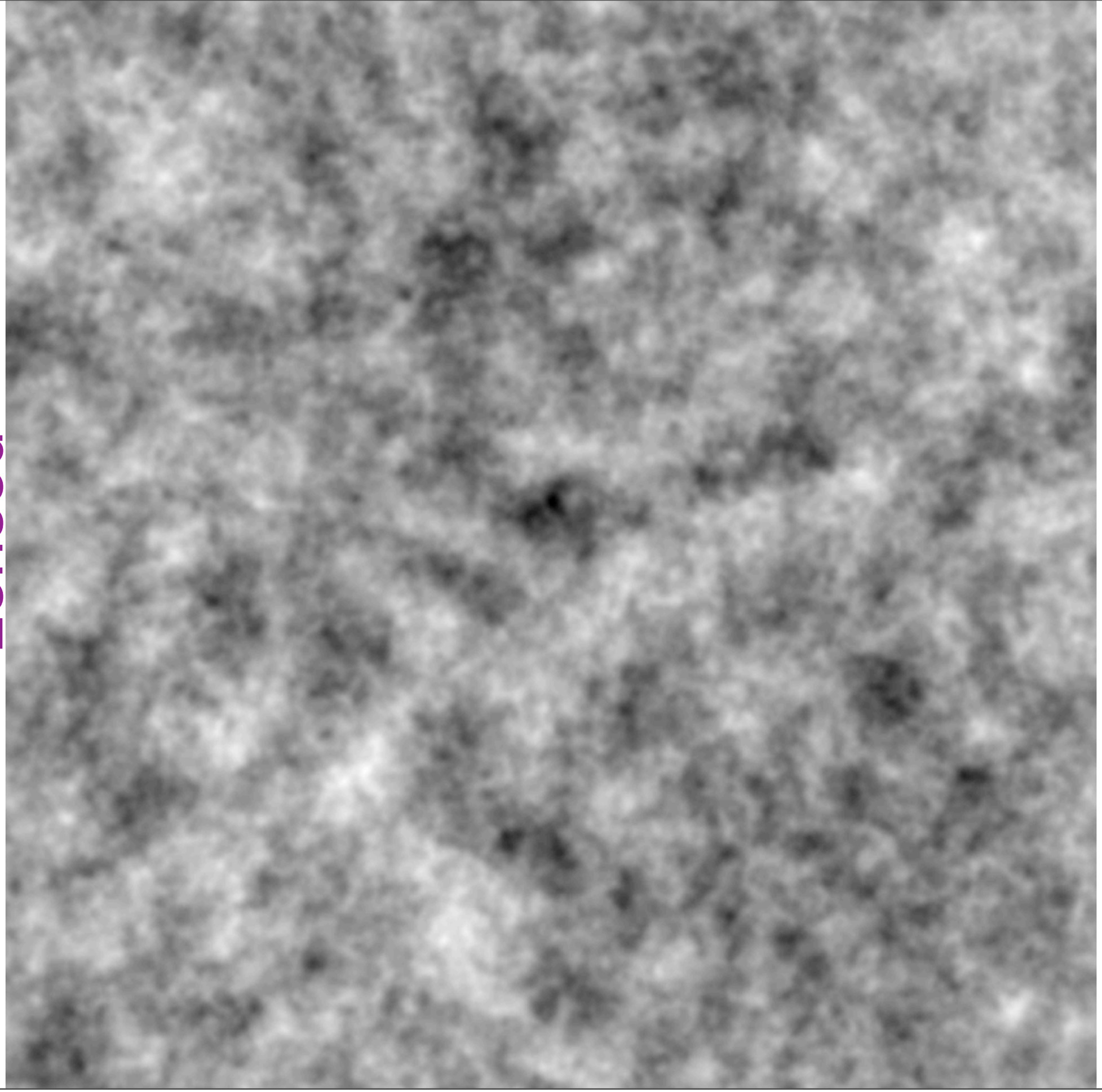


- => get total typical deflection of ~2.5 arcminutes

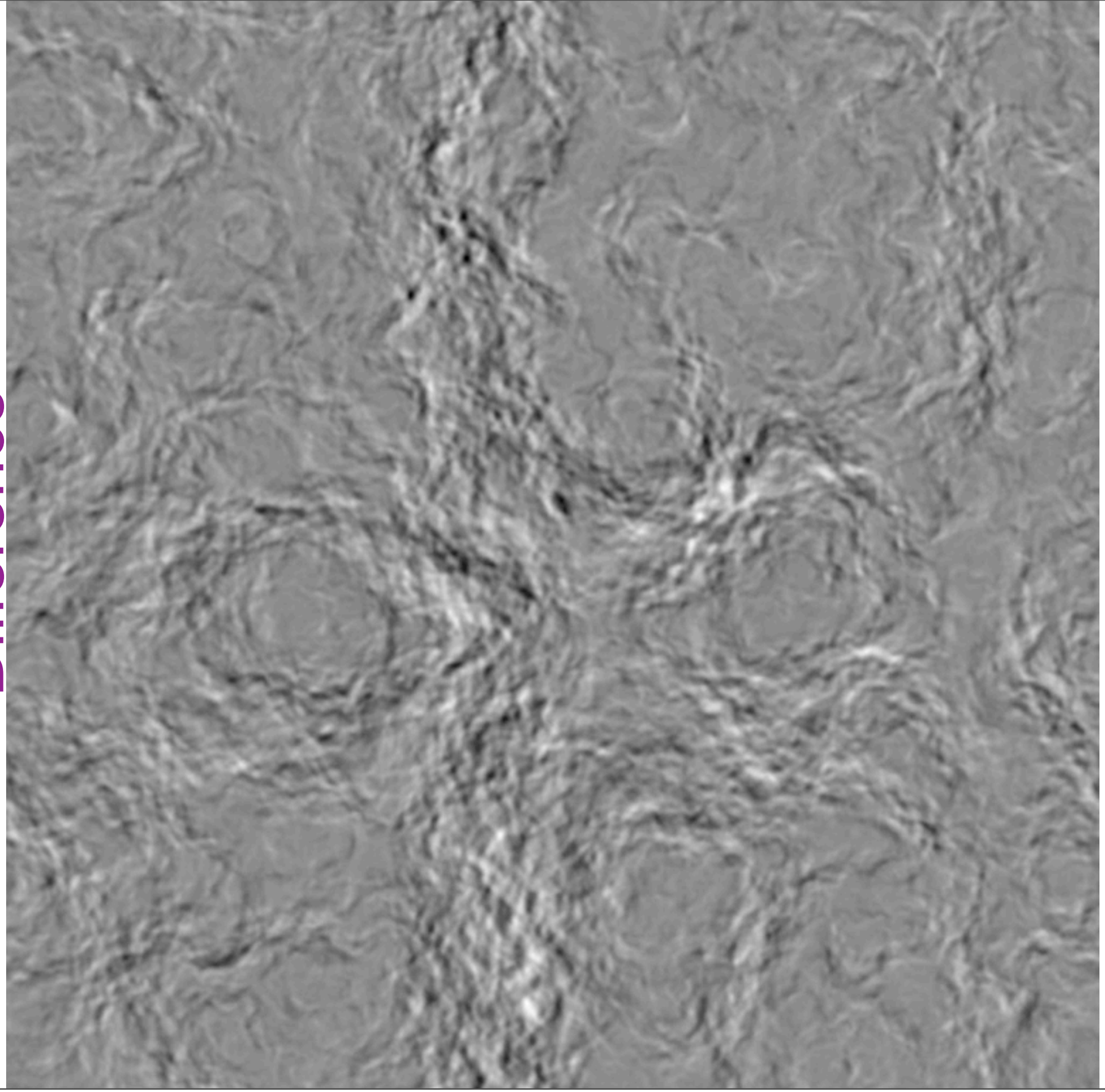
Unlensed



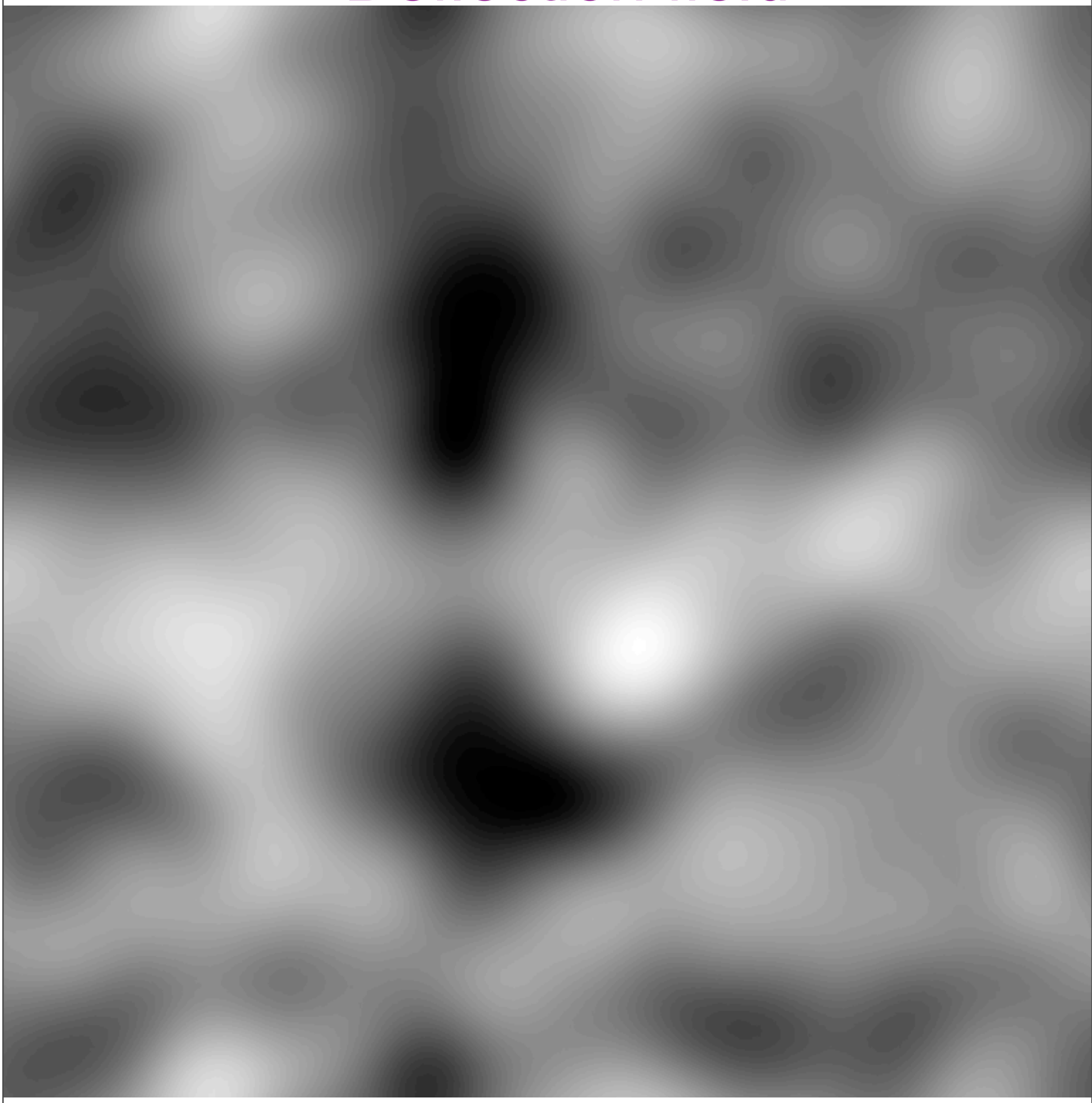
Lensed



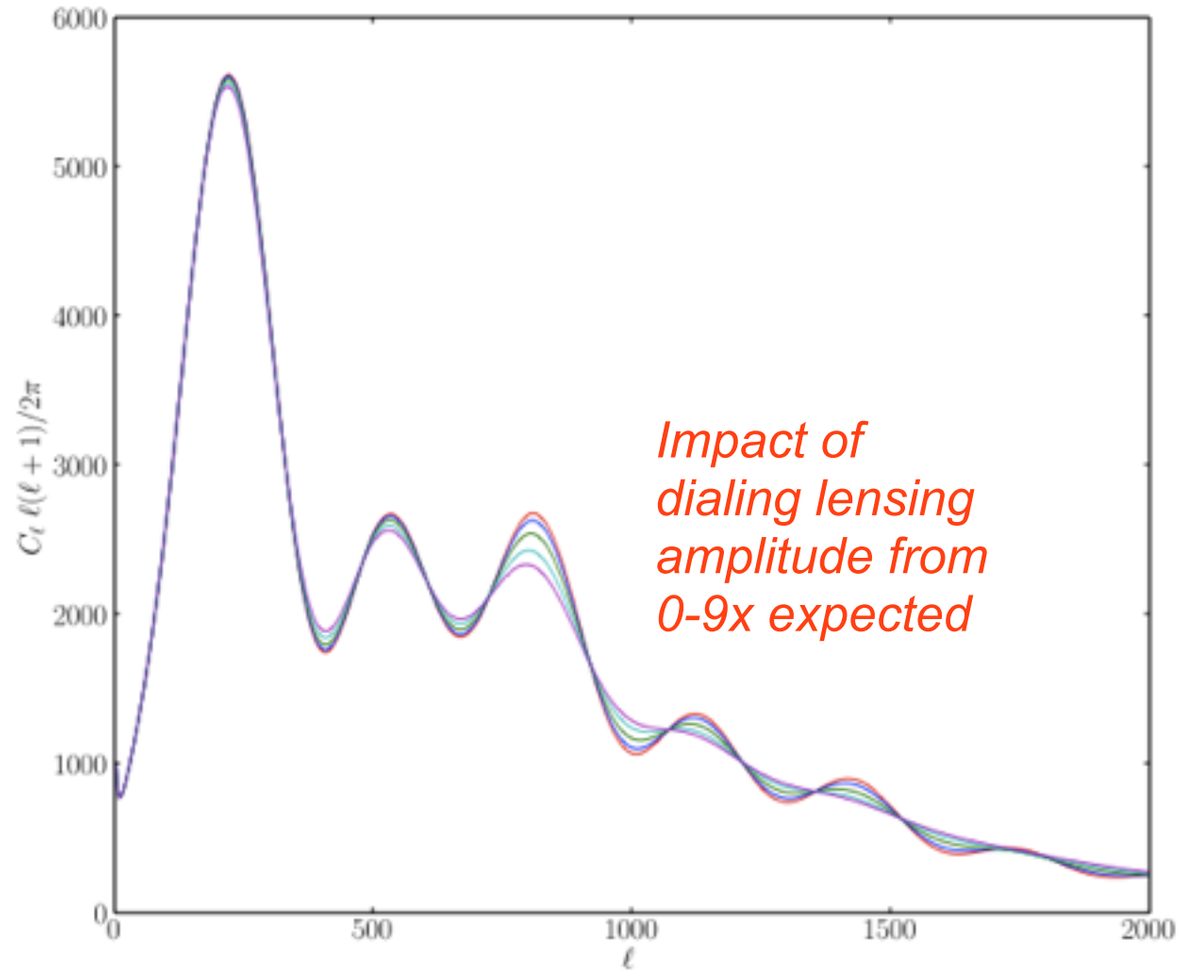
Difference

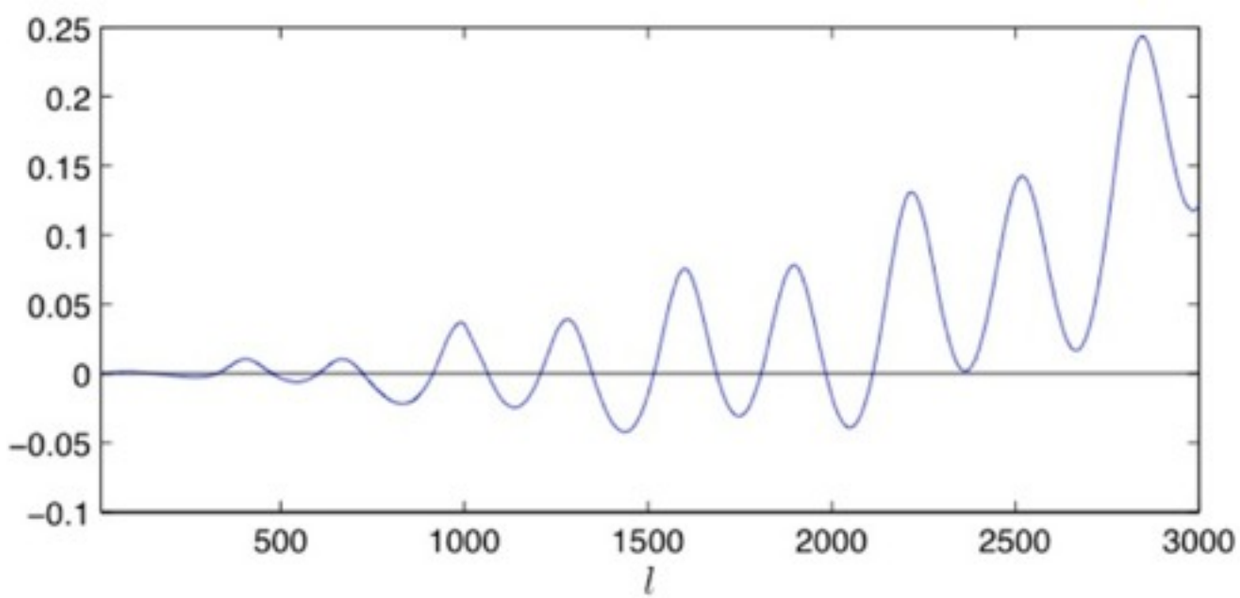


Deflection field



Effect 1: Peak smearing





Calabrese et al. (2008)

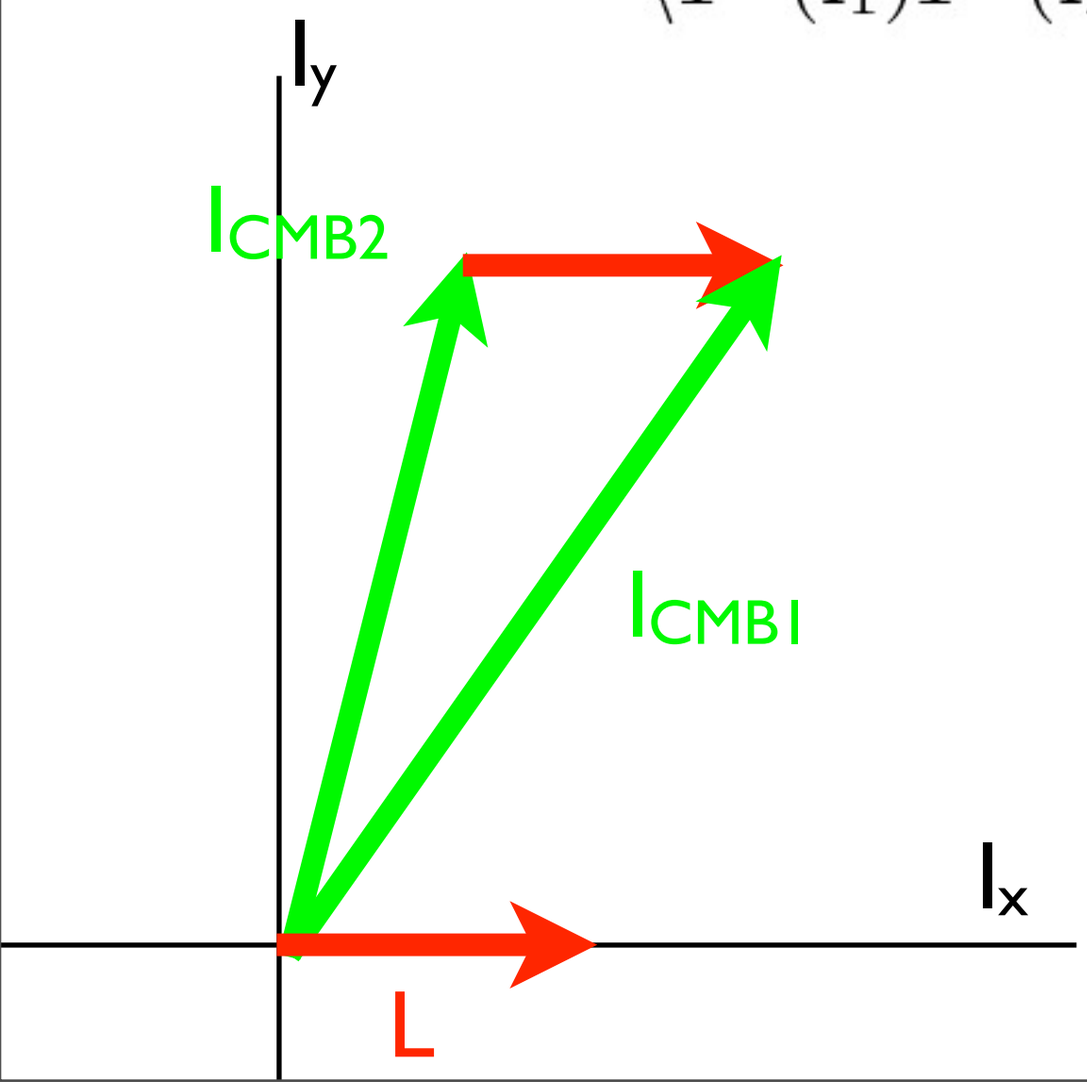
Effect 2: Mode coupling

$$T^L(\hat{\mathbf{n}}) = T^U(\hat{\mathbf{n}} + \nabla\phi(\hat{\mathbf{n}}))$$
$$= T^U(\hat{\mathbf{n}}) + \nabla T^U(\hat{\mathbf{n}}) \cdot \nabla\phi(\hat{\mathbf{n}}) + O(\phi^2),$$

- Non-gaussian mode coupling for $\mathbf{l_1} \neq -\mathbf{l_2}$:

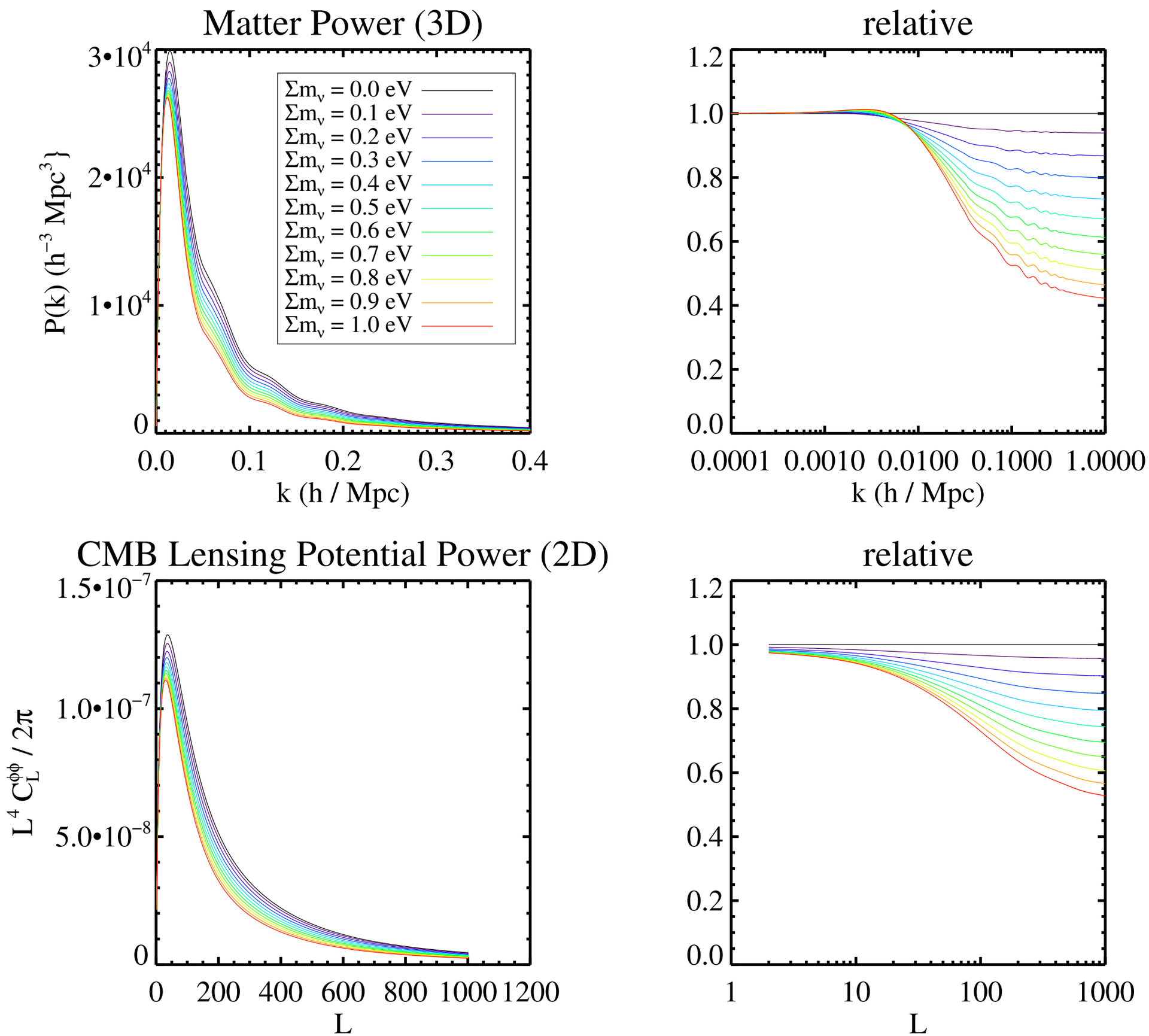
$$\langle T^L(\mathbf{l}_1) T^L(\mathbf{l}_2)\rangle = \mathbf{L} \cdot (\mathbf{l}_1 C^T_{l_1} + \mathbf{l}_2 C^T_{l_2})\phi(\mathbf{L}) + O(\phi^2)$$

$$\mathbf{L} = \mathbf{l}_1 + \mathbf{l}_2$$

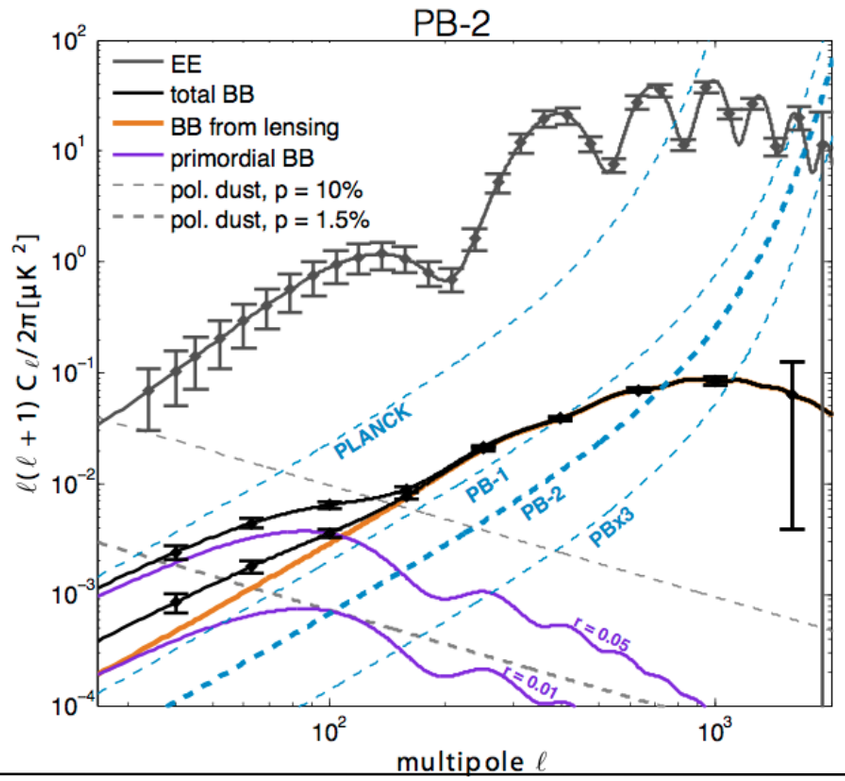


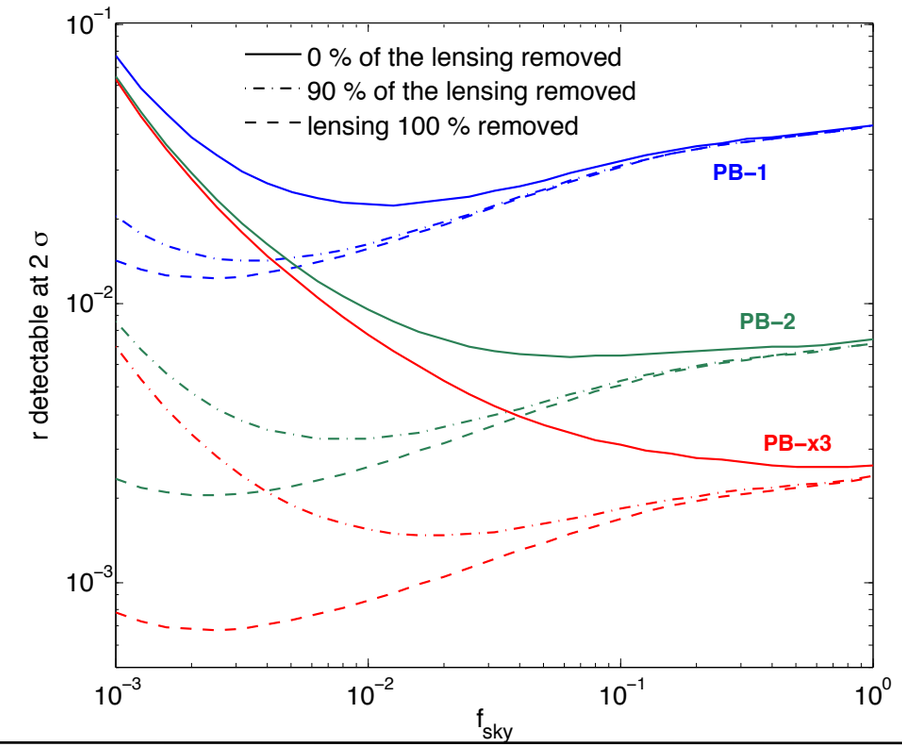
- We ***image*** ϕ by taking a suitable average over CMB multipoles separated by a distance L
- Effect is best measurable as perturbation of a large scale gradient

Uses of CMB lensing: 1. Neutrino masses

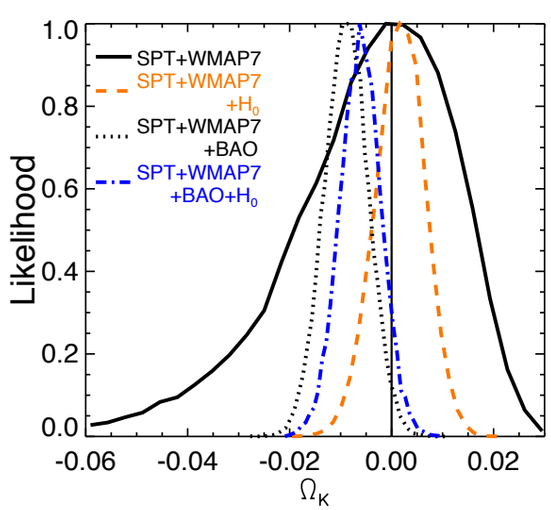


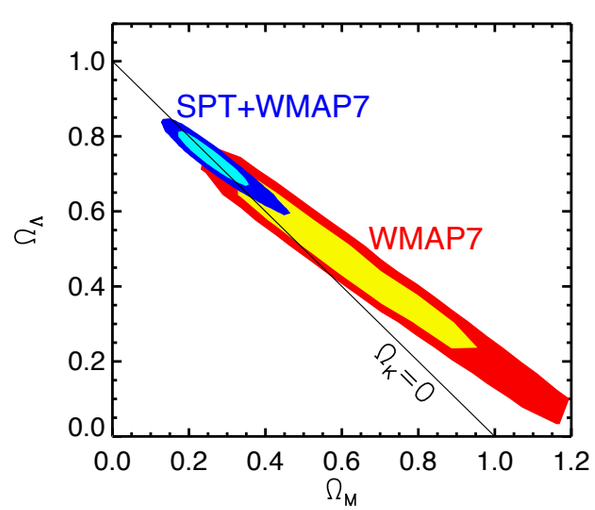
2) Inflationary science: Will become one of the main systematics at T/S levels below 1%

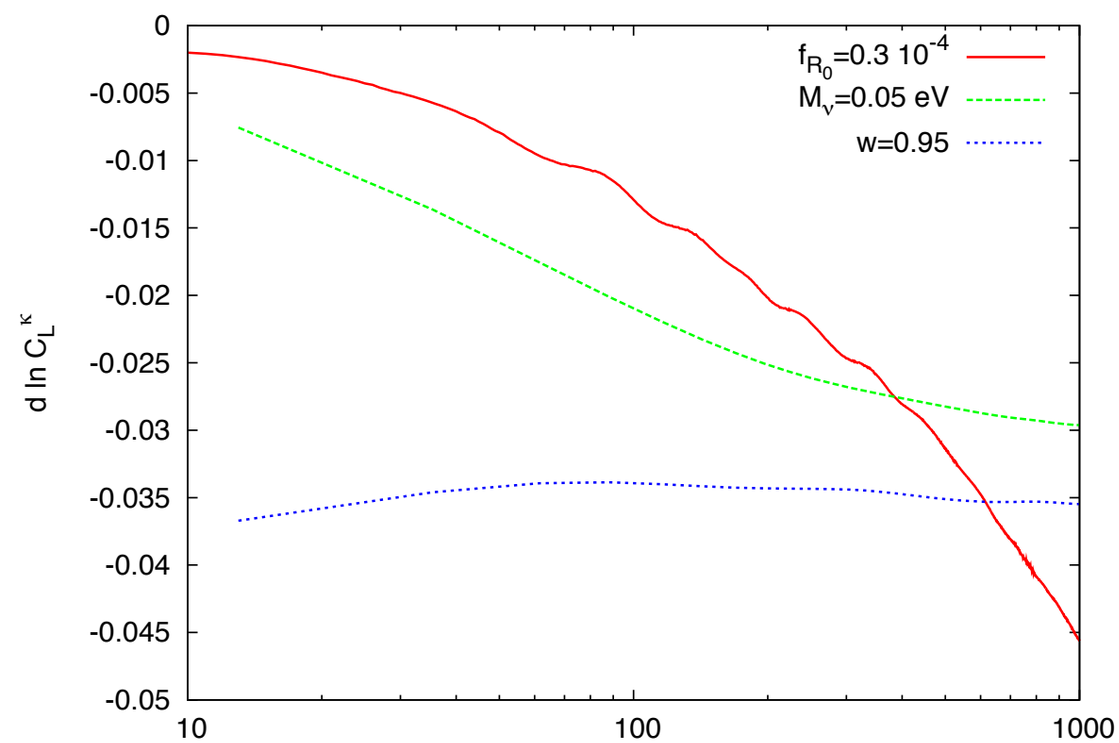




3) Dark energy, f(R) gravity (compare Sherwin&Das et al 2012)



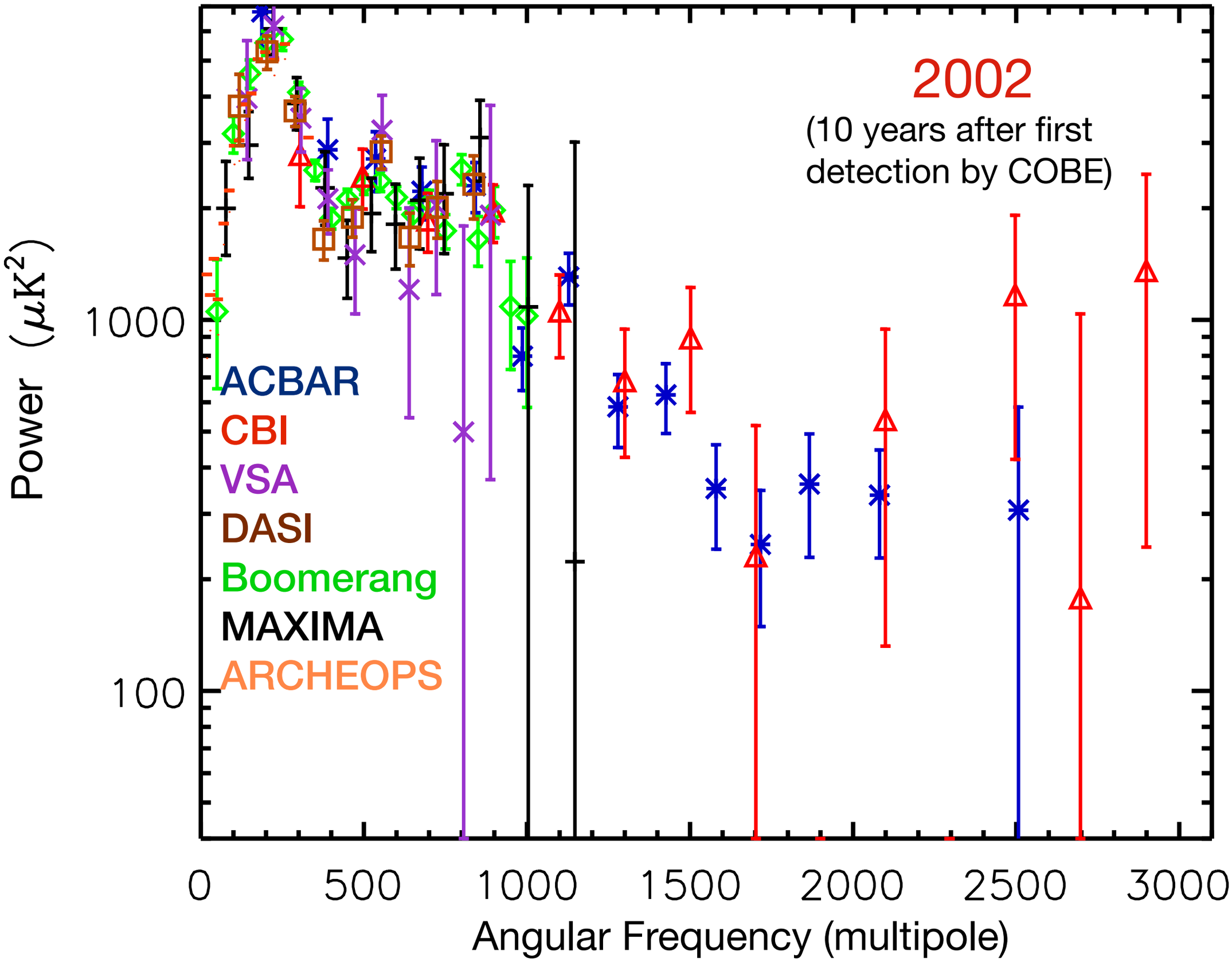




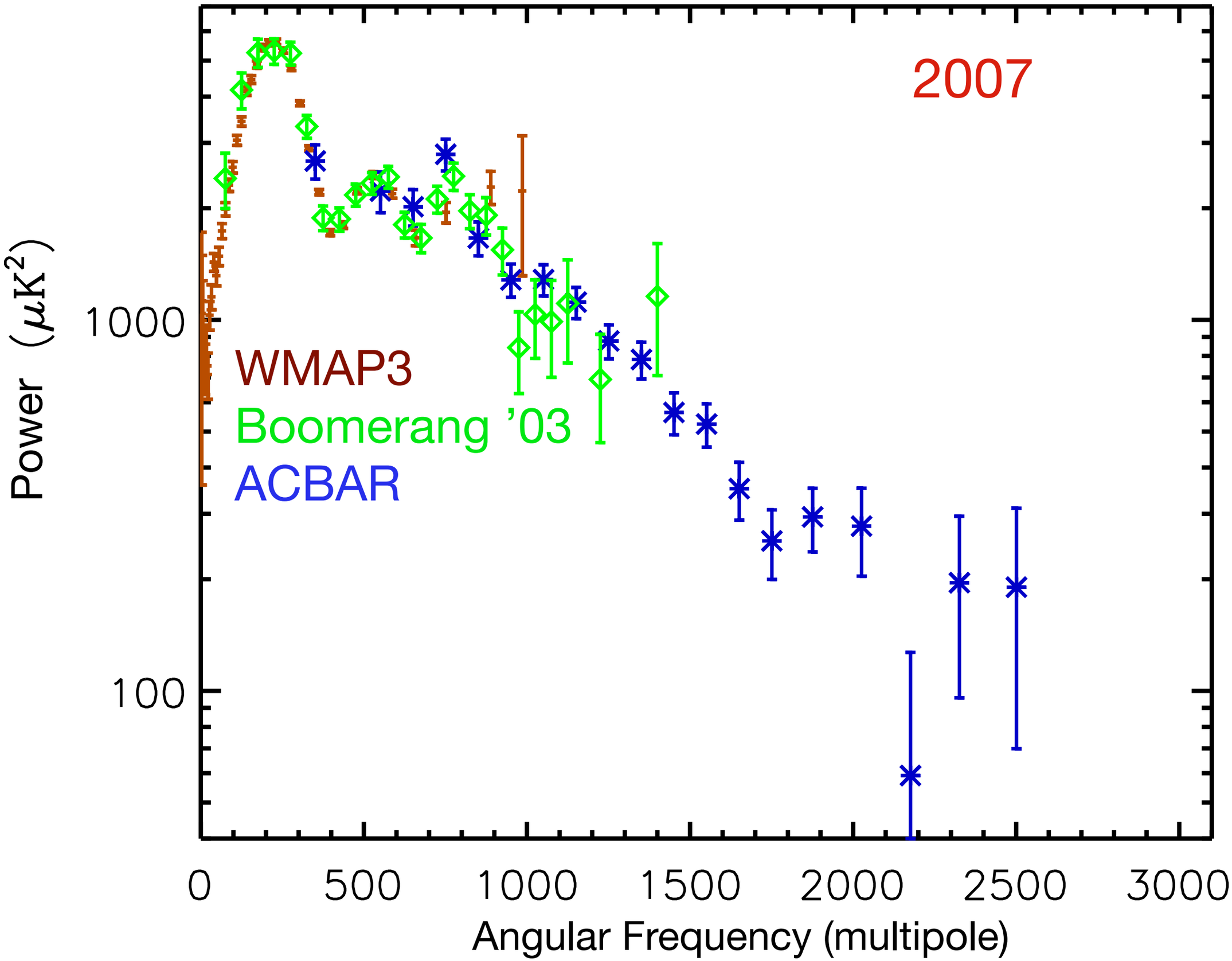
credit: F. Schmidt

4) Cross correlation science (improvements in cosmological parameters and galaxy formation information -- see also later)

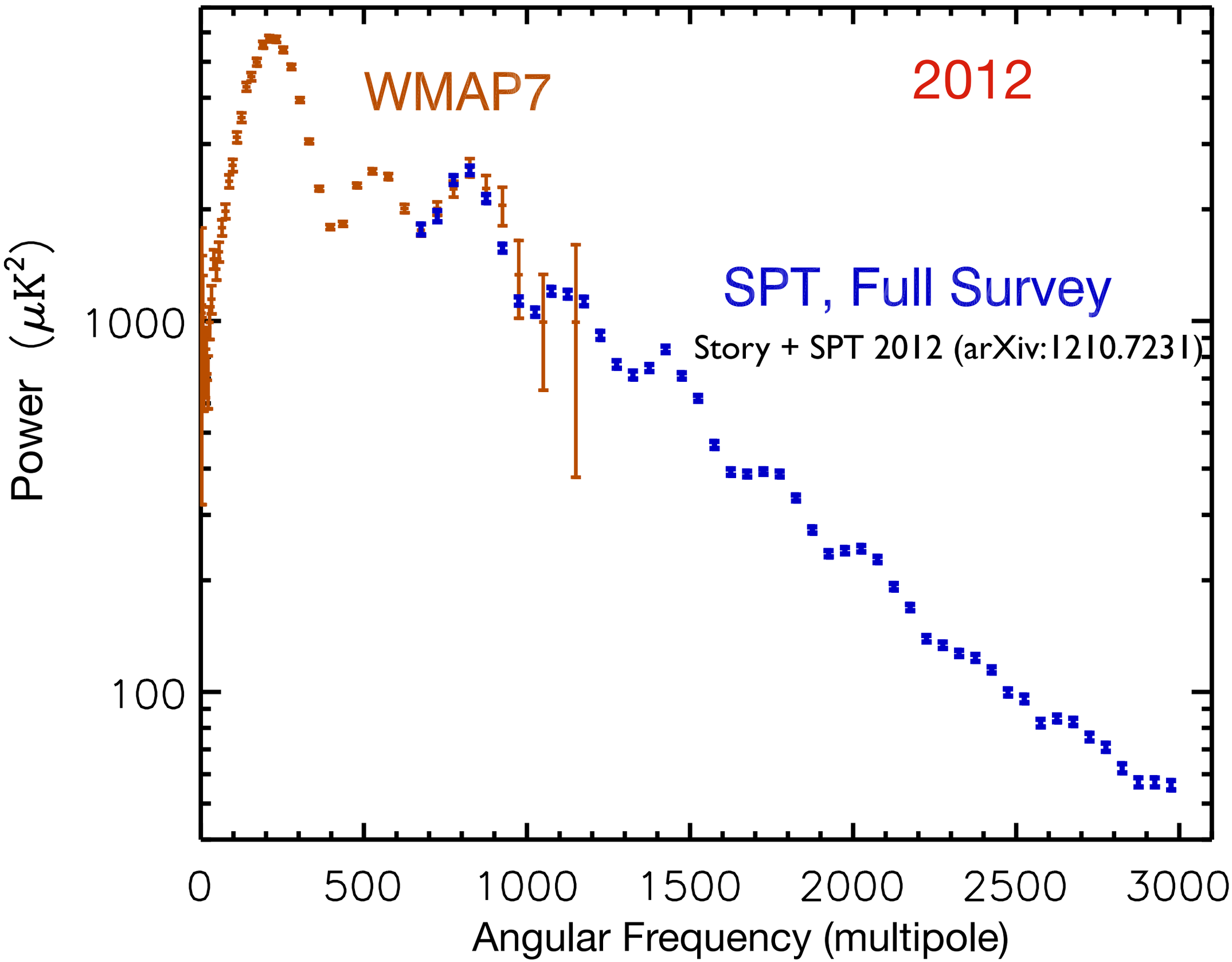
2-point experimental progress



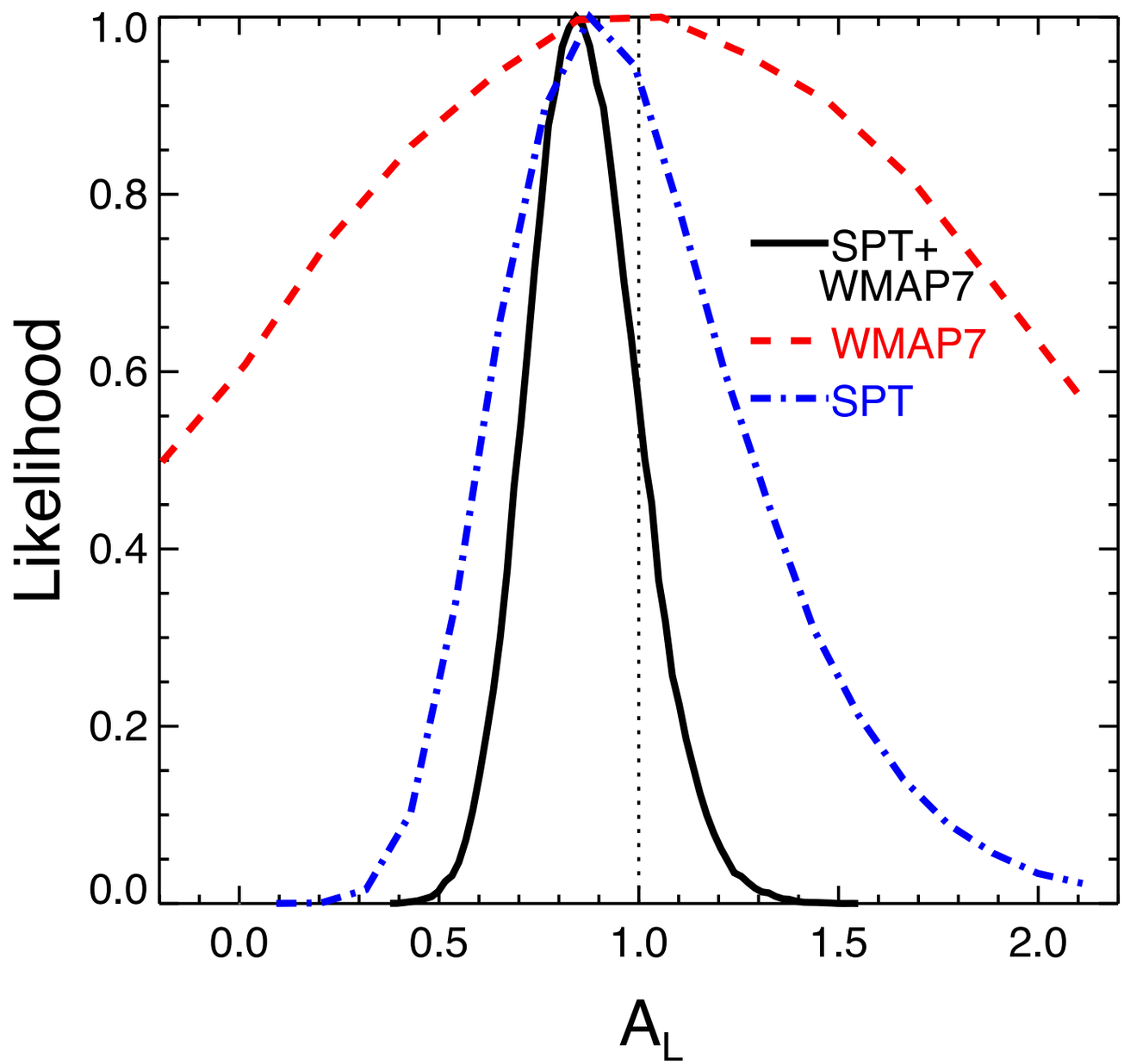
2-point experimental progress



2-point experimental progress



8.1 sigma measurement of lensing...

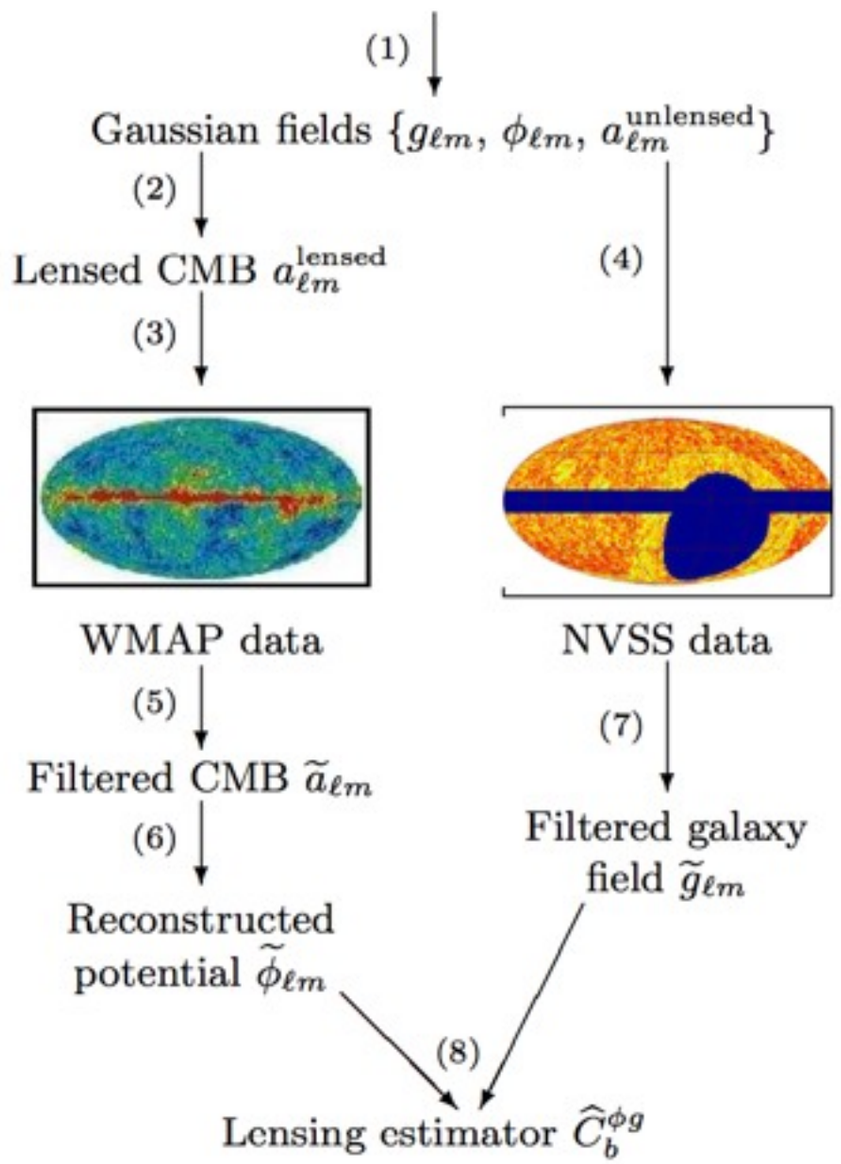


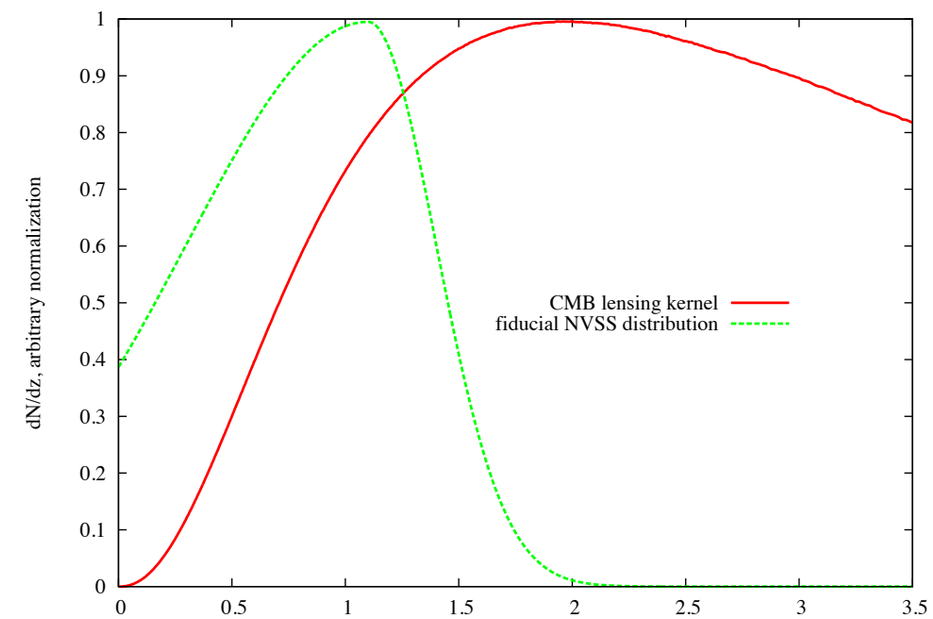
Story et al. 2012

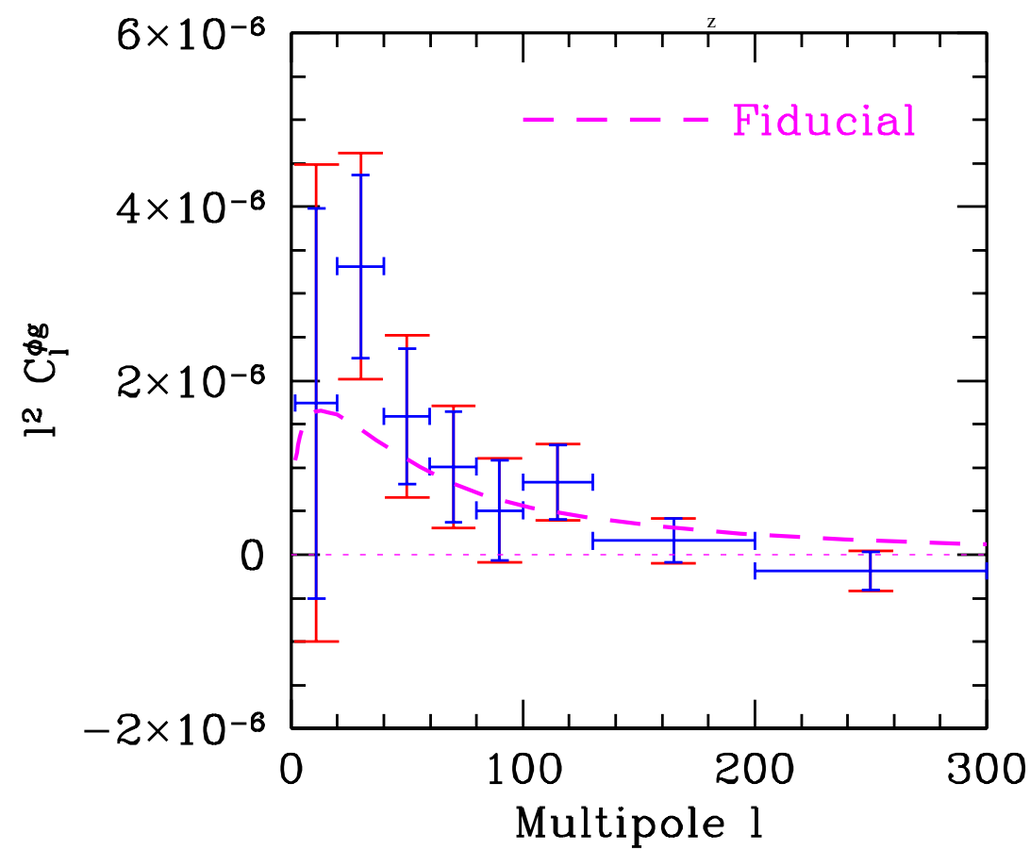
3-point measurements (CMBlens X LSS)

(Smith, OZ, Dore 2007, also Hirata et al. 2007 using SDSS&NVSS data)

Idea to use the NVSS: 1.8 Million 1.4 GHz radio sources, fsky=0.77, overlap with WMAP after masking is 0.58, ~4 sources per WMAP beam.



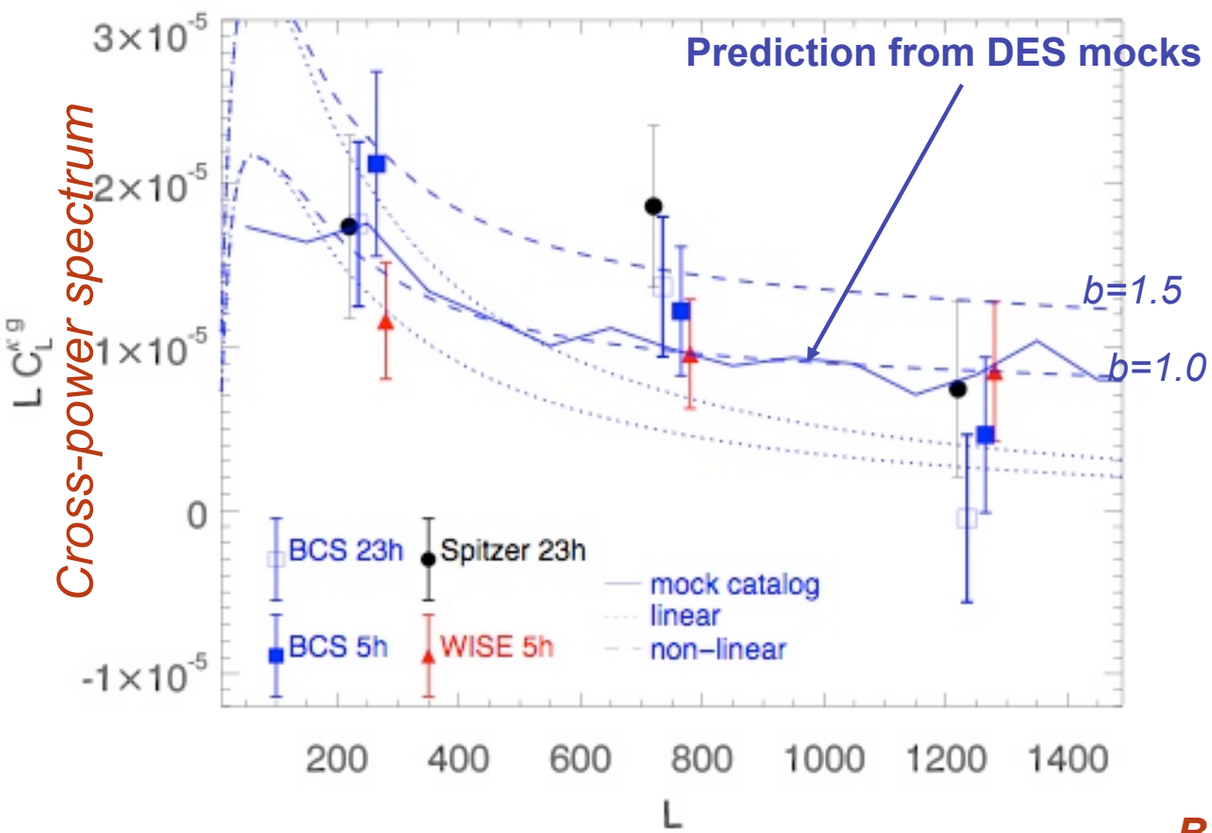




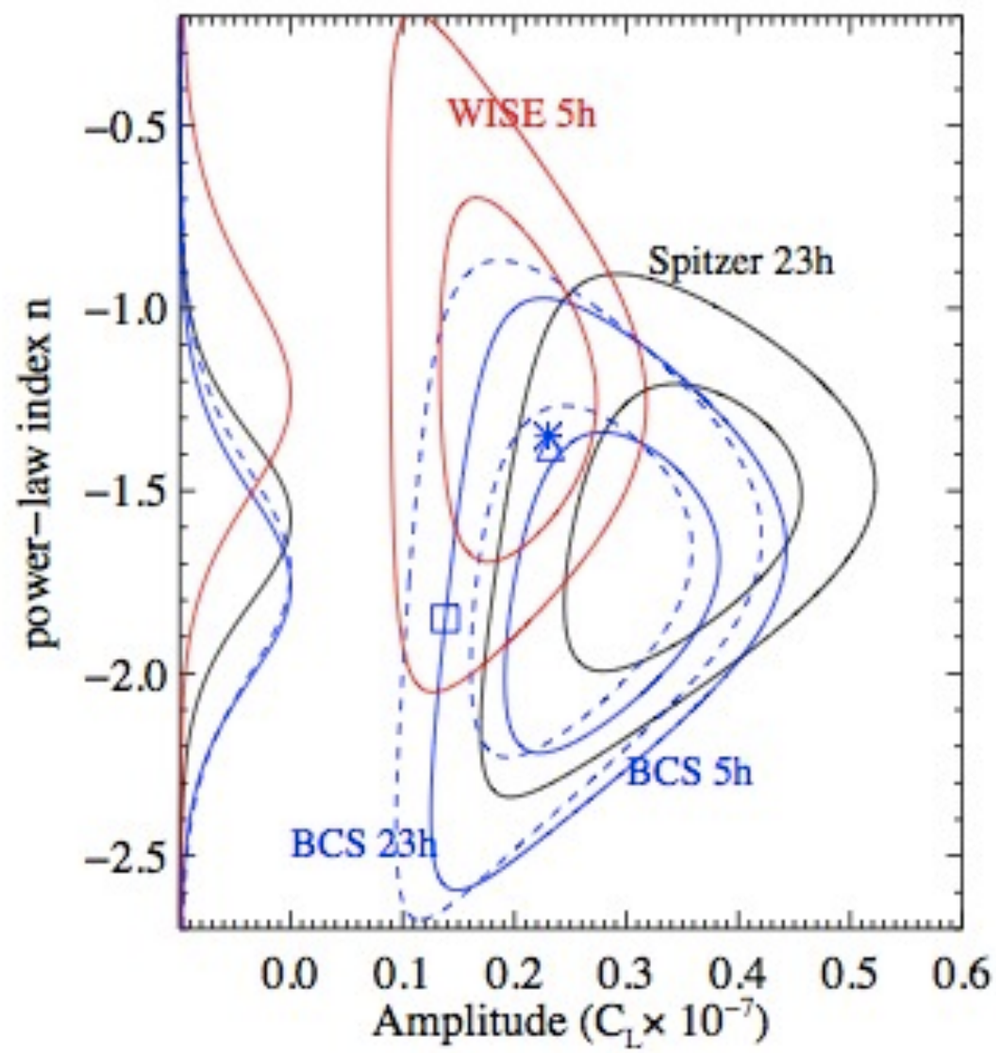
3.4 sigma (stat.+sys.)!

SPTlens X LSS 1.0 (Bleem et al. 2012)

Galaxy-Mass Cross-Correlation Detected

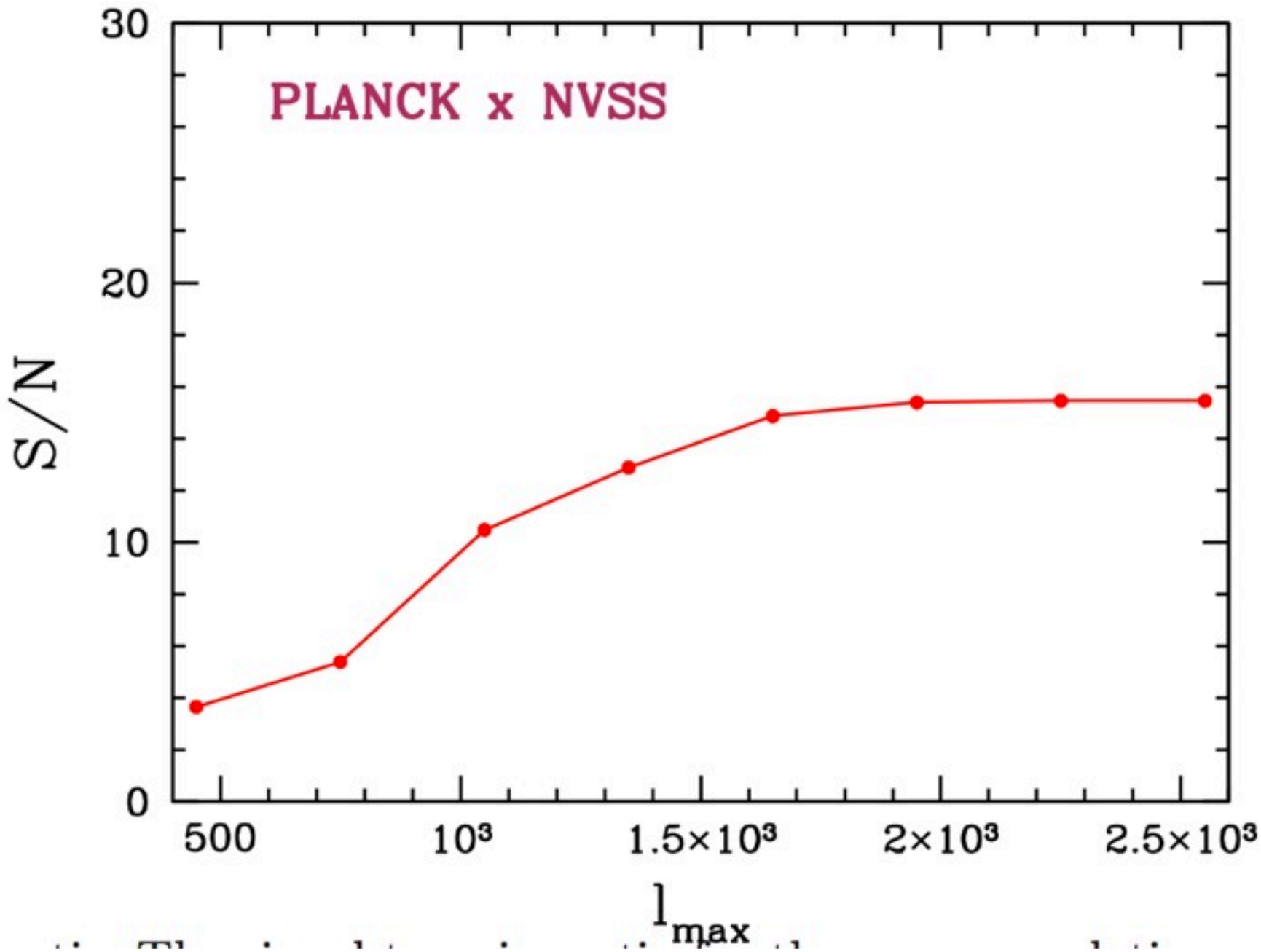


Galaxy bias ~0.9-1.7

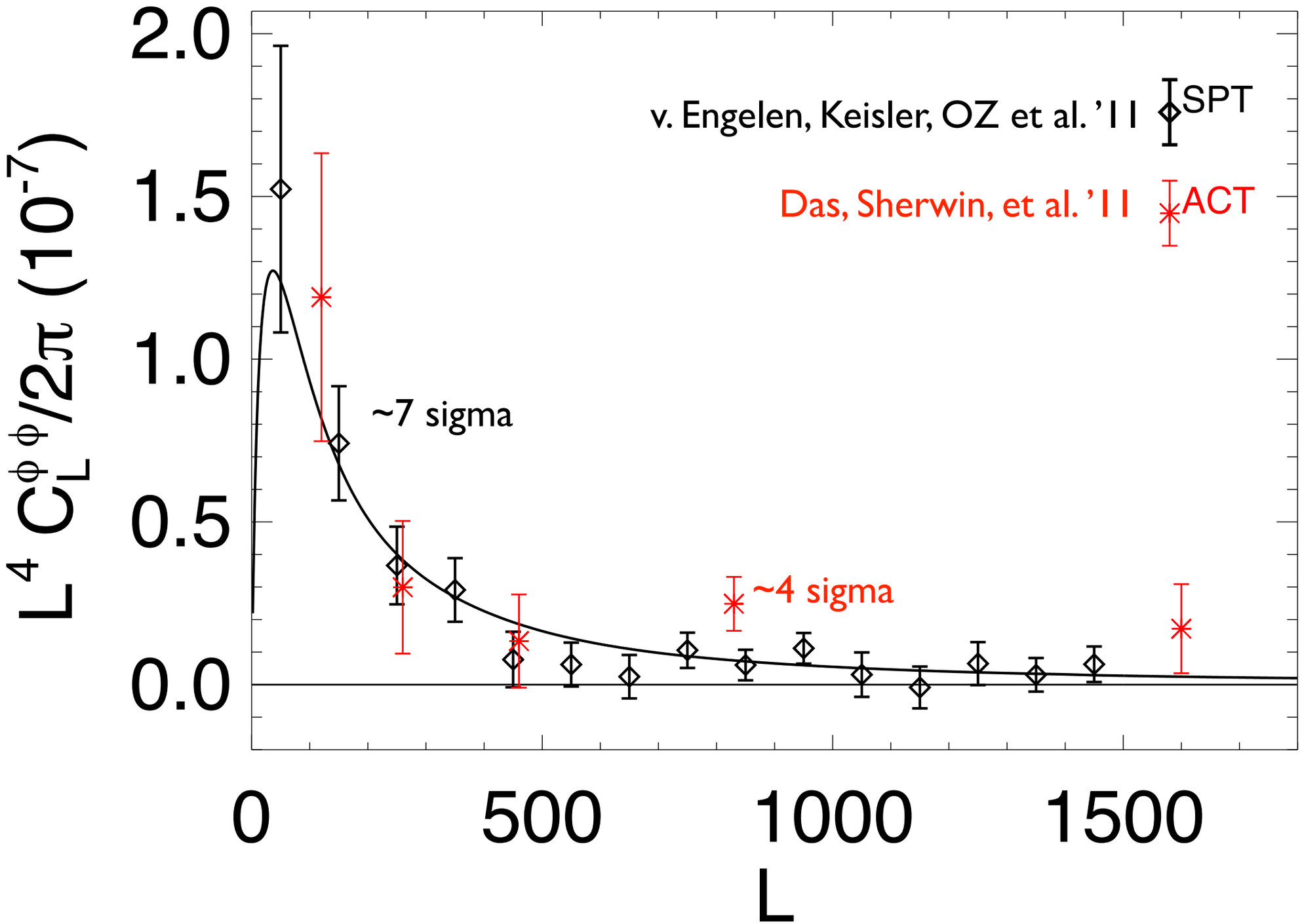


Bleem et al

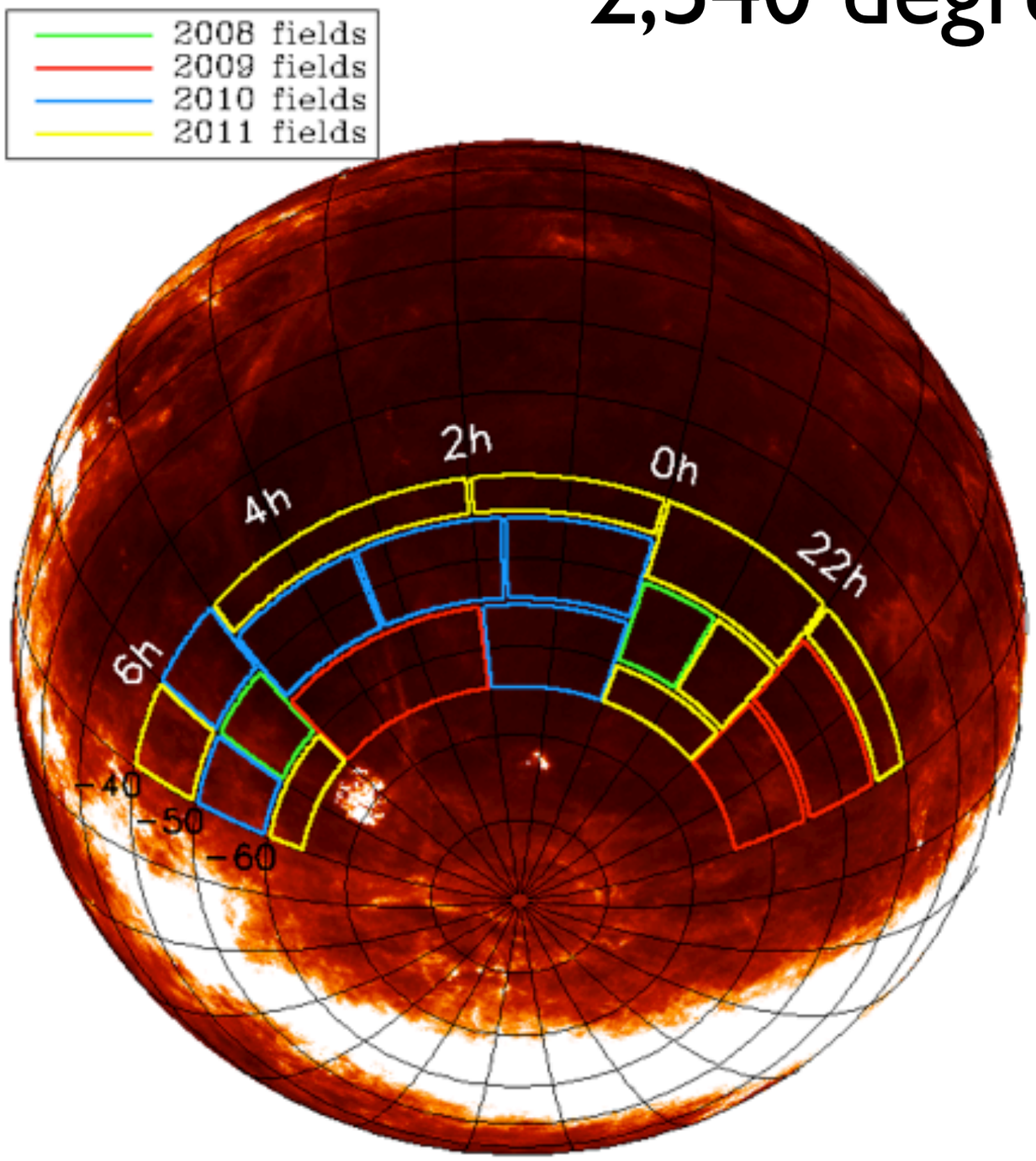
Planck Forecast (credit: C. Feng)

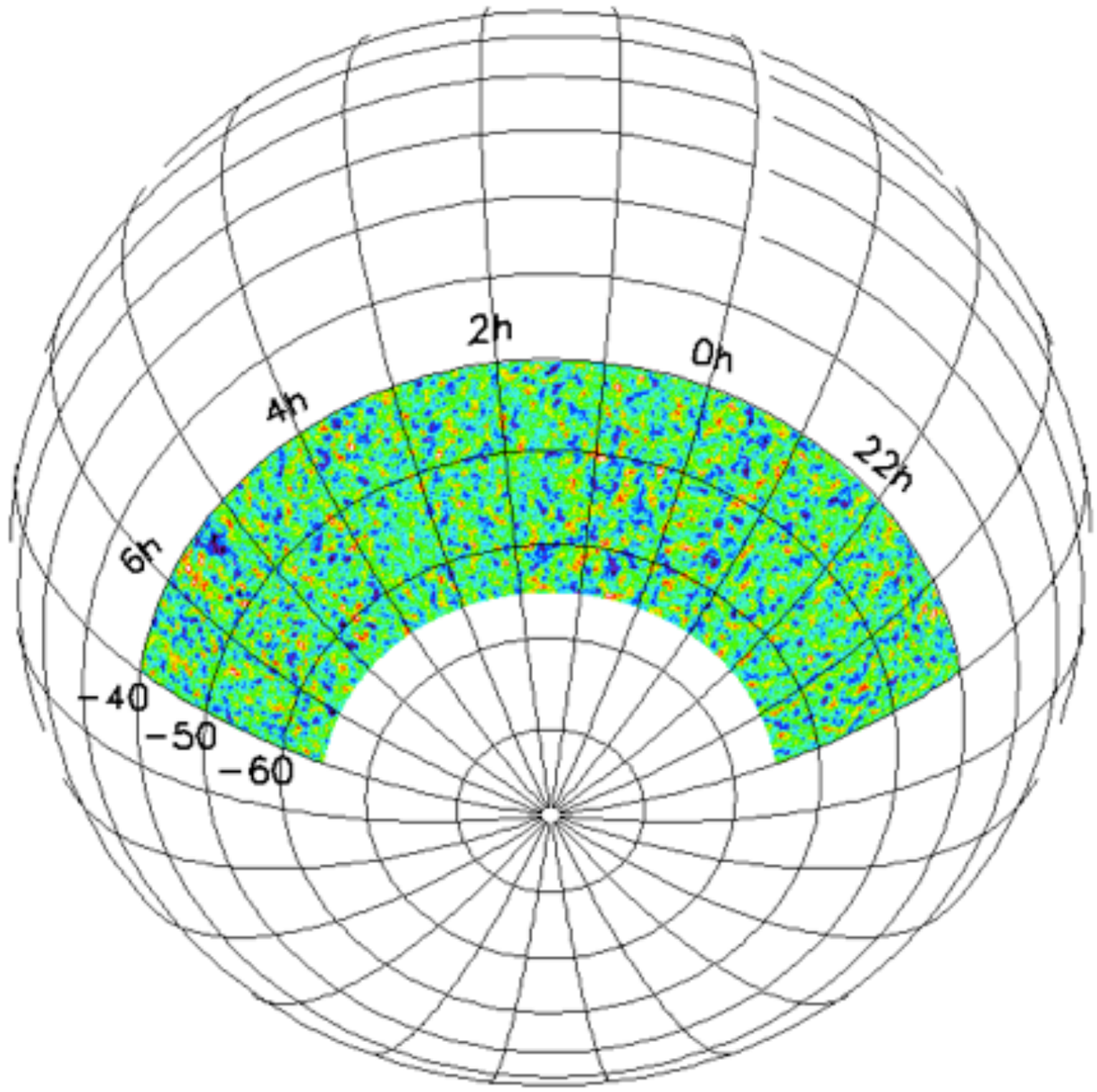


Trispectrum Detections



Lensing reconstruction from entire 2,540 degree SPT survey...



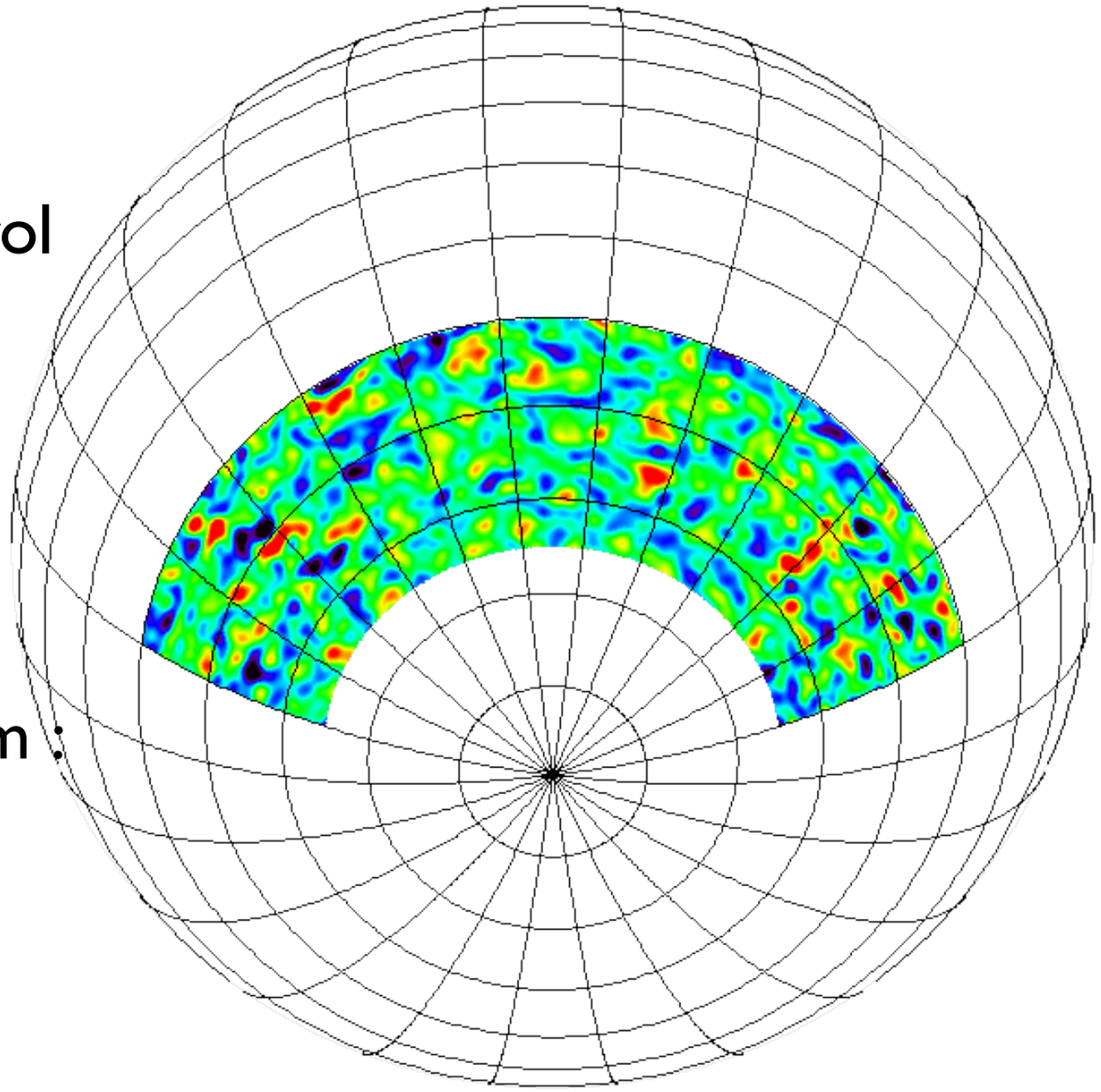


Hocus Pocus Fidibus...

Weighing the Hubble volume!!

Estimator improvements:

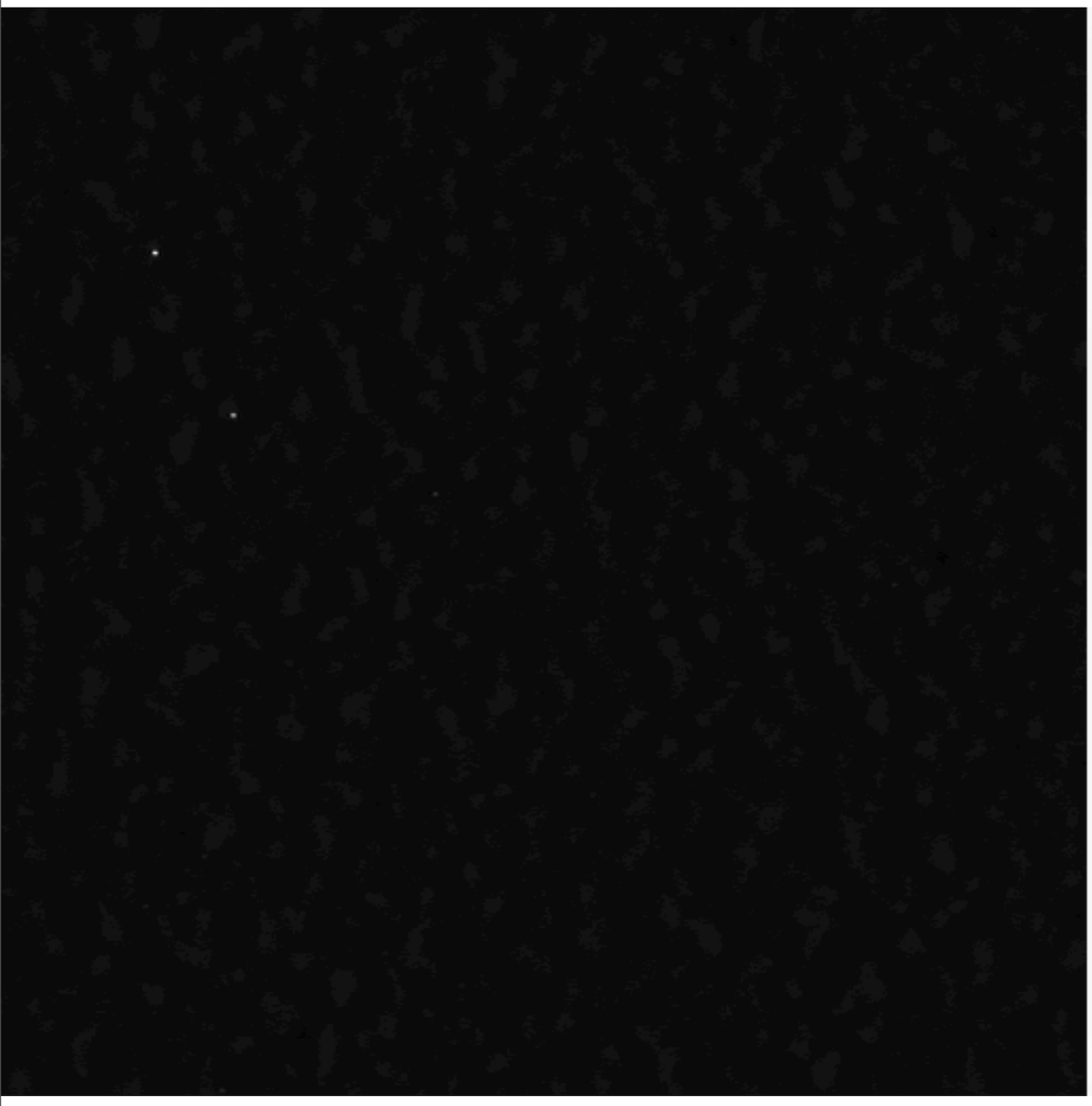
- ~4X more sky area: ~2X
- Expanded l-range (improved control of SPT transfer function and foreground biases): 1.5 X
- Realization-dependent bias subtraction: 1.1 X
- Combination with power spectrum : 1.15 X
- =>~20 sigma, mnu error ~0.12 eV
- Complementary to Planck!

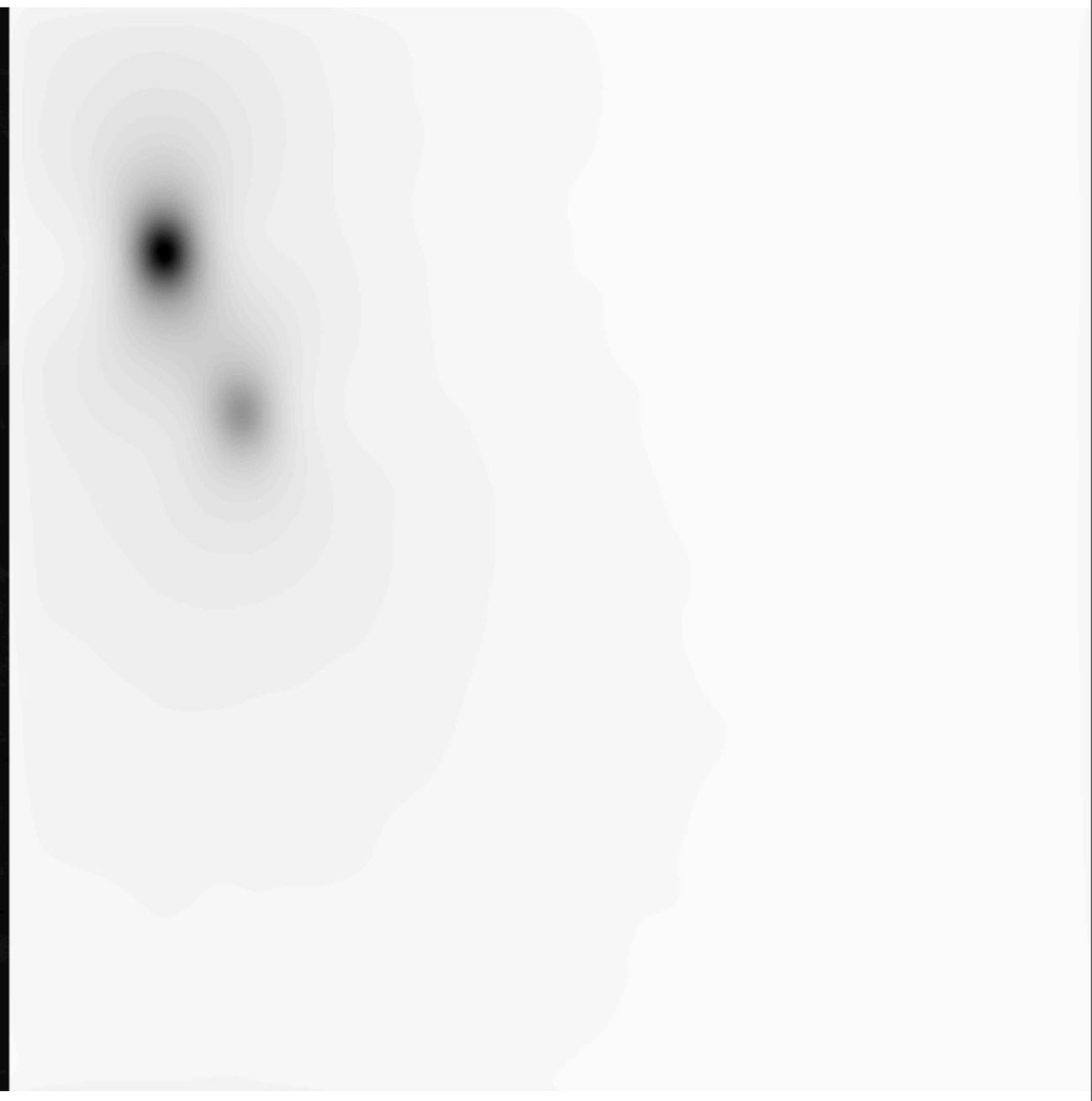


Map of 6% of matter in observable Universe

Point sources and clusters...

Point sources and clusters...





5.2% constraint on Alens

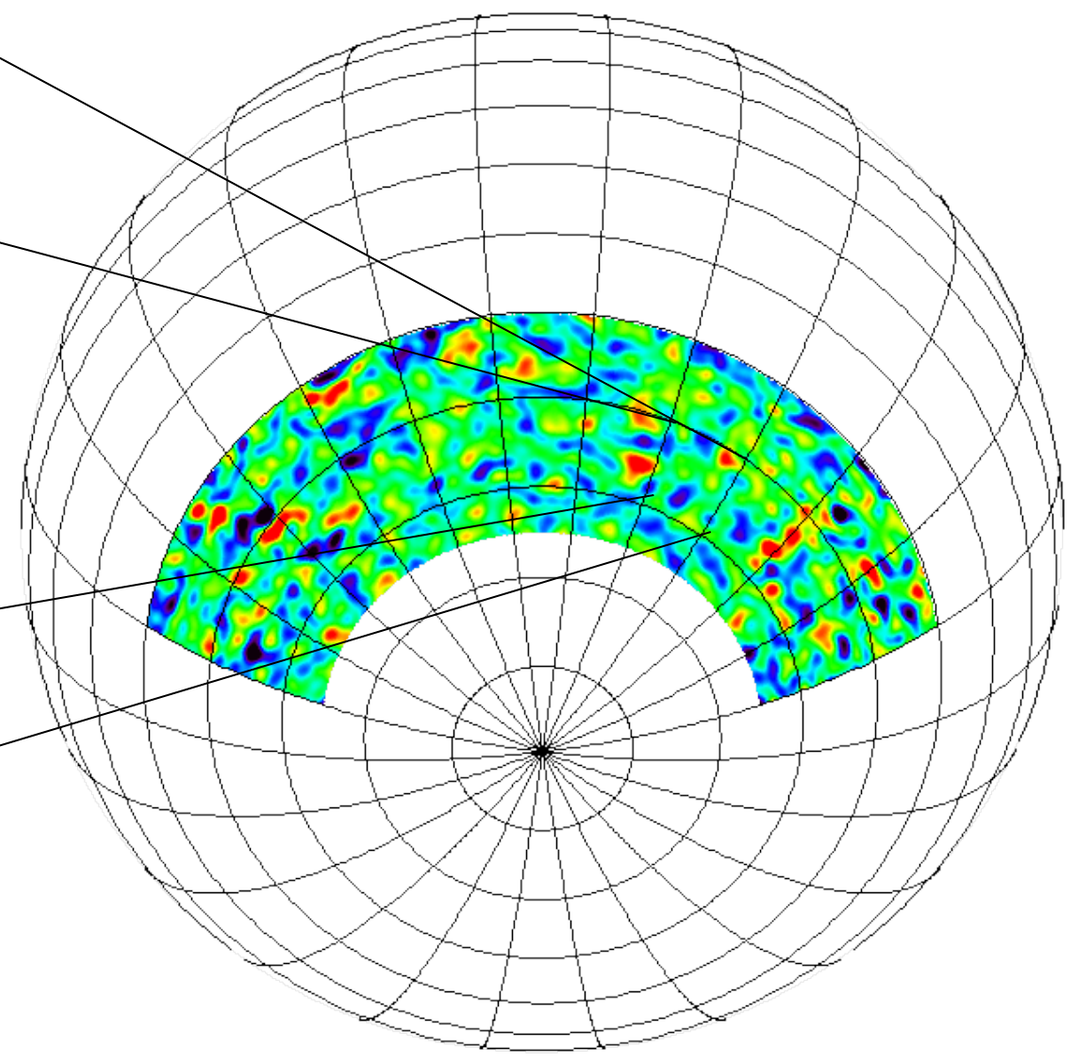
nary!!

Would enable a solid detection of 0.3 eV of massive neutrinos

Additionally use SPT bispectrum, clusters, Planck priors...

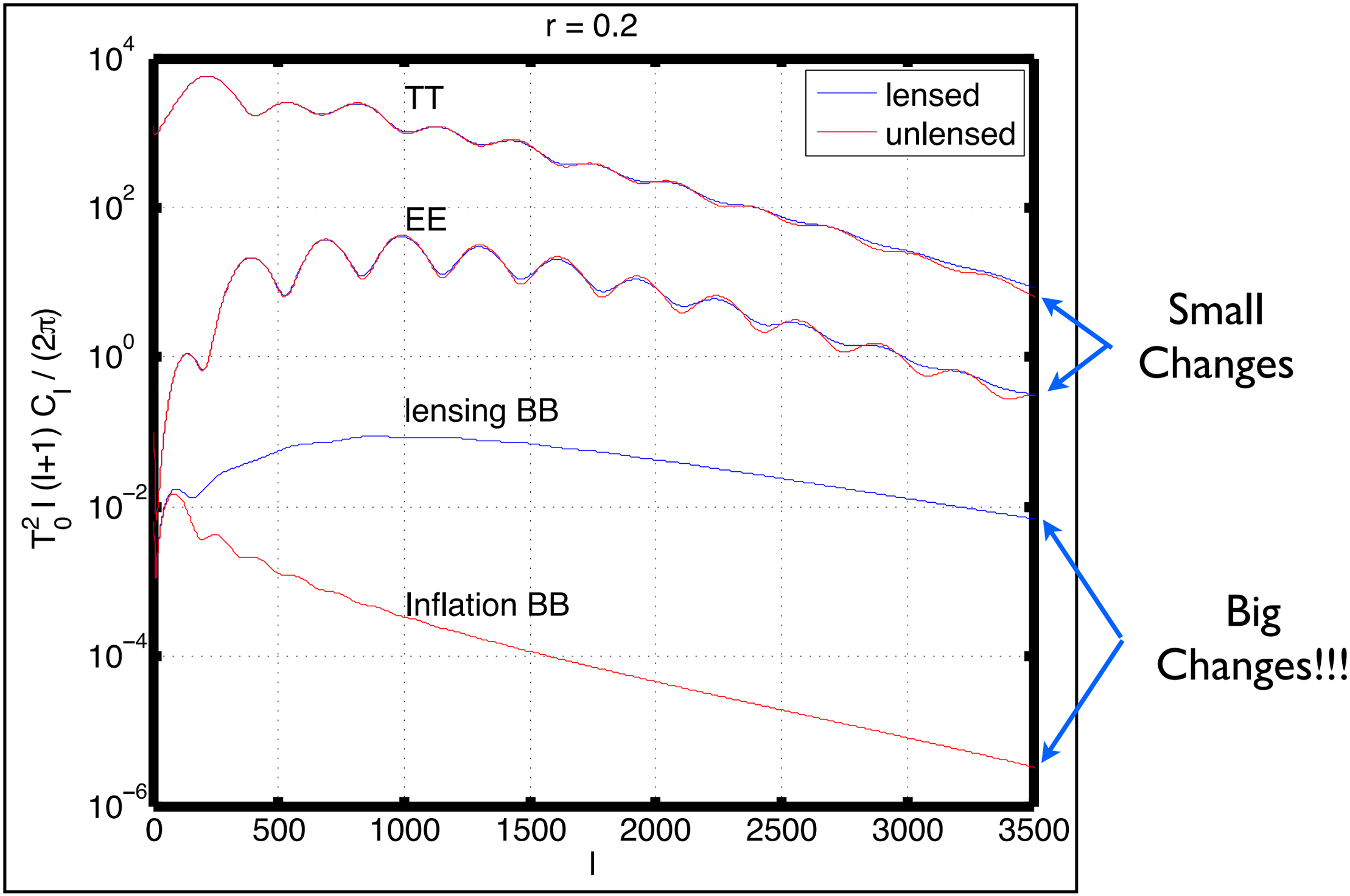
Back to cross correlations for another minute

Sorry, can't post



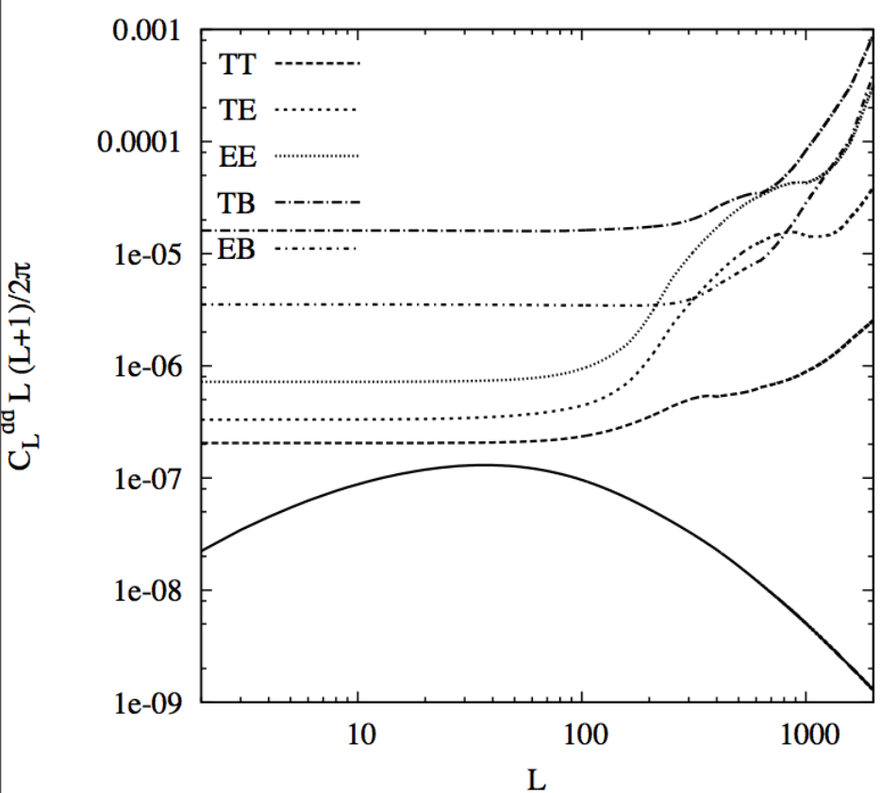
with G. Holder + SPT

B-modes from Lensing

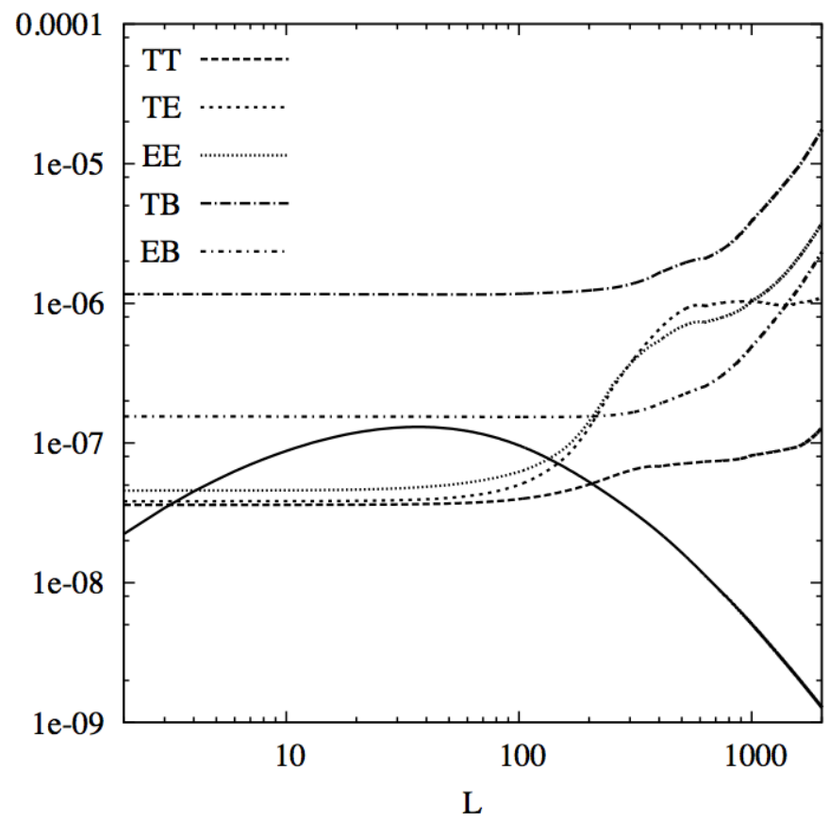


Dramatic improvements from polarization possible

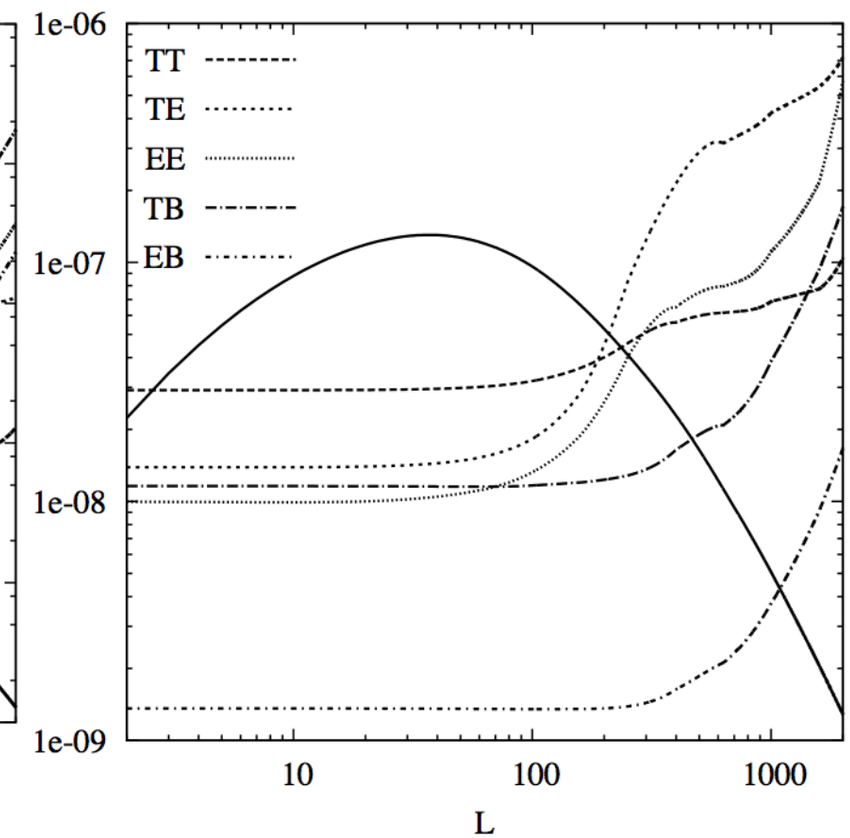
Planck



SPT



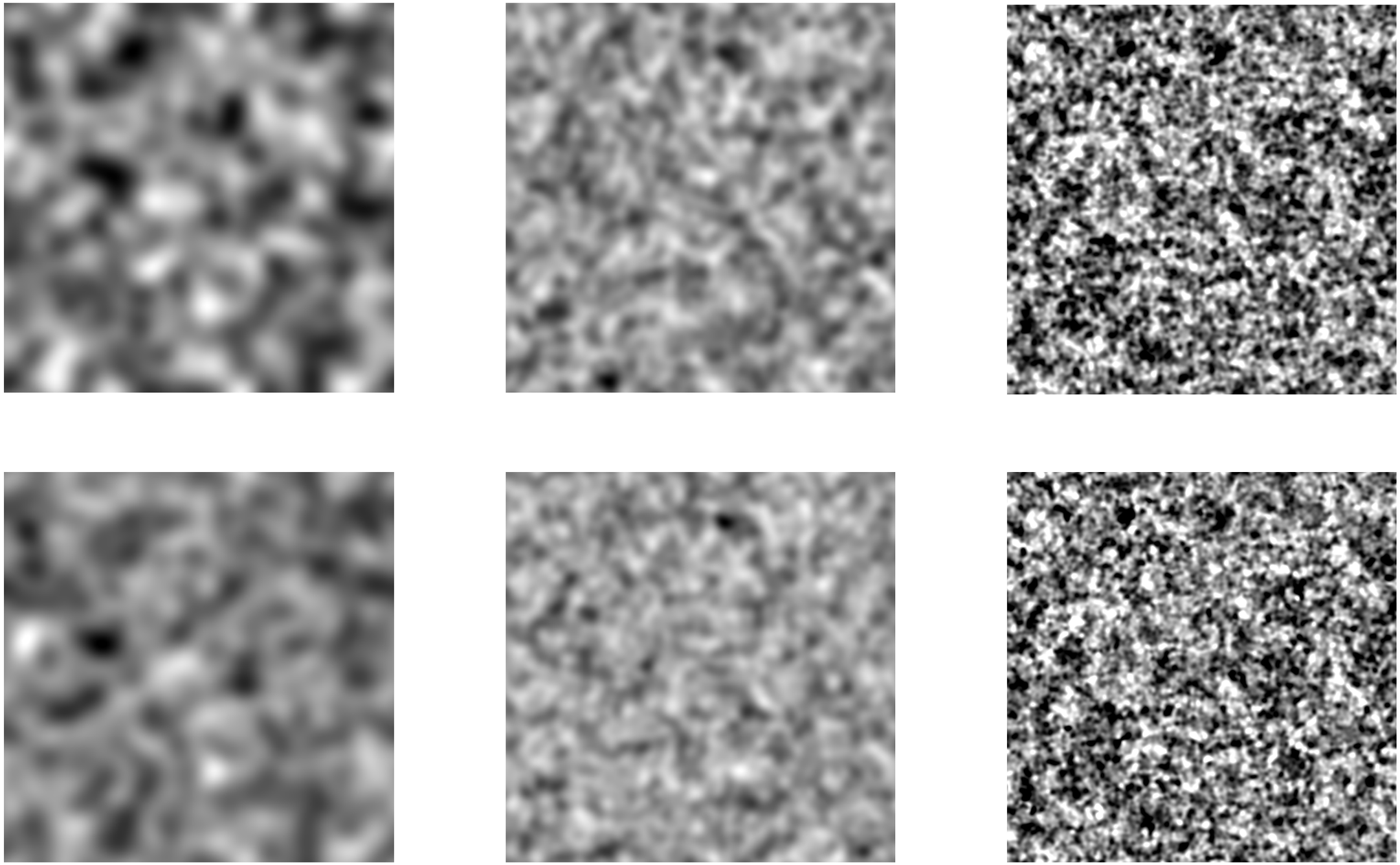
CMBpol or PBext



(simulated reconstructions)

In

Out



Planck SPT PolarBear/SPTpol

Timeline of CMB Lensing Measurements

- 2007: 3s (WMAP+) *Smith, OZ, Dore '07* *(TT) x (LSS)*
- 2011: 2s (WMAP) *Smidt et al, Feng+OZ et al.* *(TTTT)*
- 2011: 4s (ACT+WMAP) *Das et al* *(TTTT)*
- 2011: 5s (SPT+WMAP) *Keisler et al* *(TT)*
- 2012: 7s (SPT) *van Engelen, Keisler, OZ et al.* *(TTTT)*
- 2012: 6-9s (SPT+) *Bleem et al., Story et al.* *(TT) x (LSS), (TT)*

- 2012: ~20-25s (SPT) *OZ et al.*
- 2013: ~30s (PLANCK) [all-sky]
- 2013: >50 s (SPTpol; PolarBEAR) [500+ sq deg]
  +ACTpol

(rapidly evolving field: **20-30s** measurements imminent!)

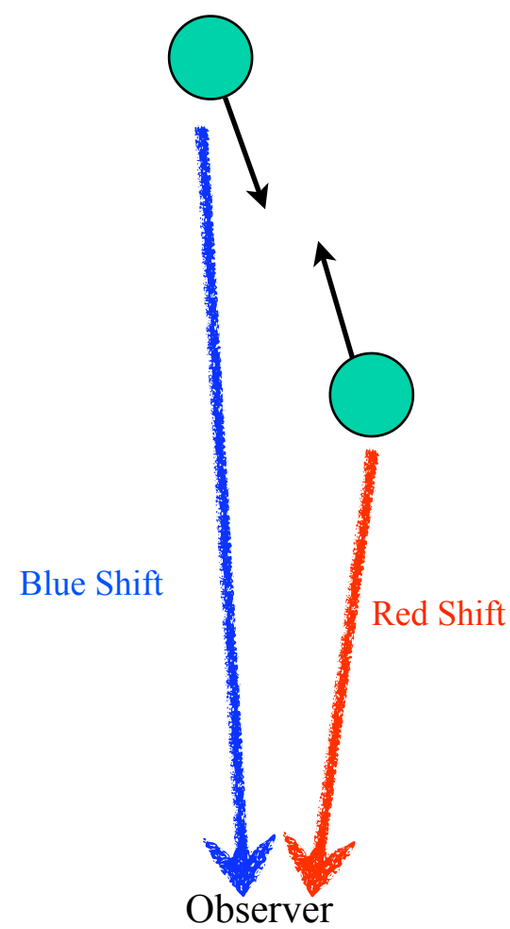
Testing Gravity on Large-scales

kSZ Pairwise Velocity Signal

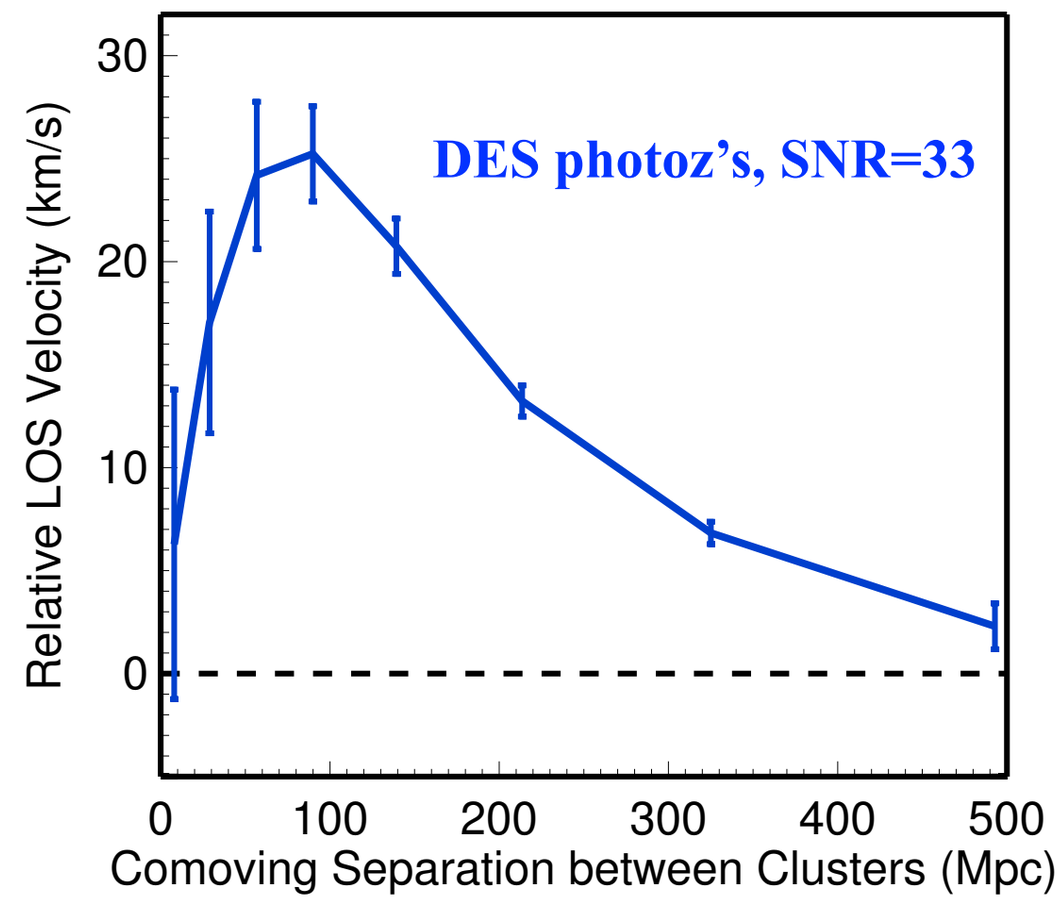
(Hand et al., ACT Collaboration, 1203.4219)

Galaxy clusters tend to fall towards each other (w.r.t. Hubble flow).

For a given pair, the high-z (low-z) cluster tends to move towards (away from) us
=>
differential CMB signal from kSZ effect.



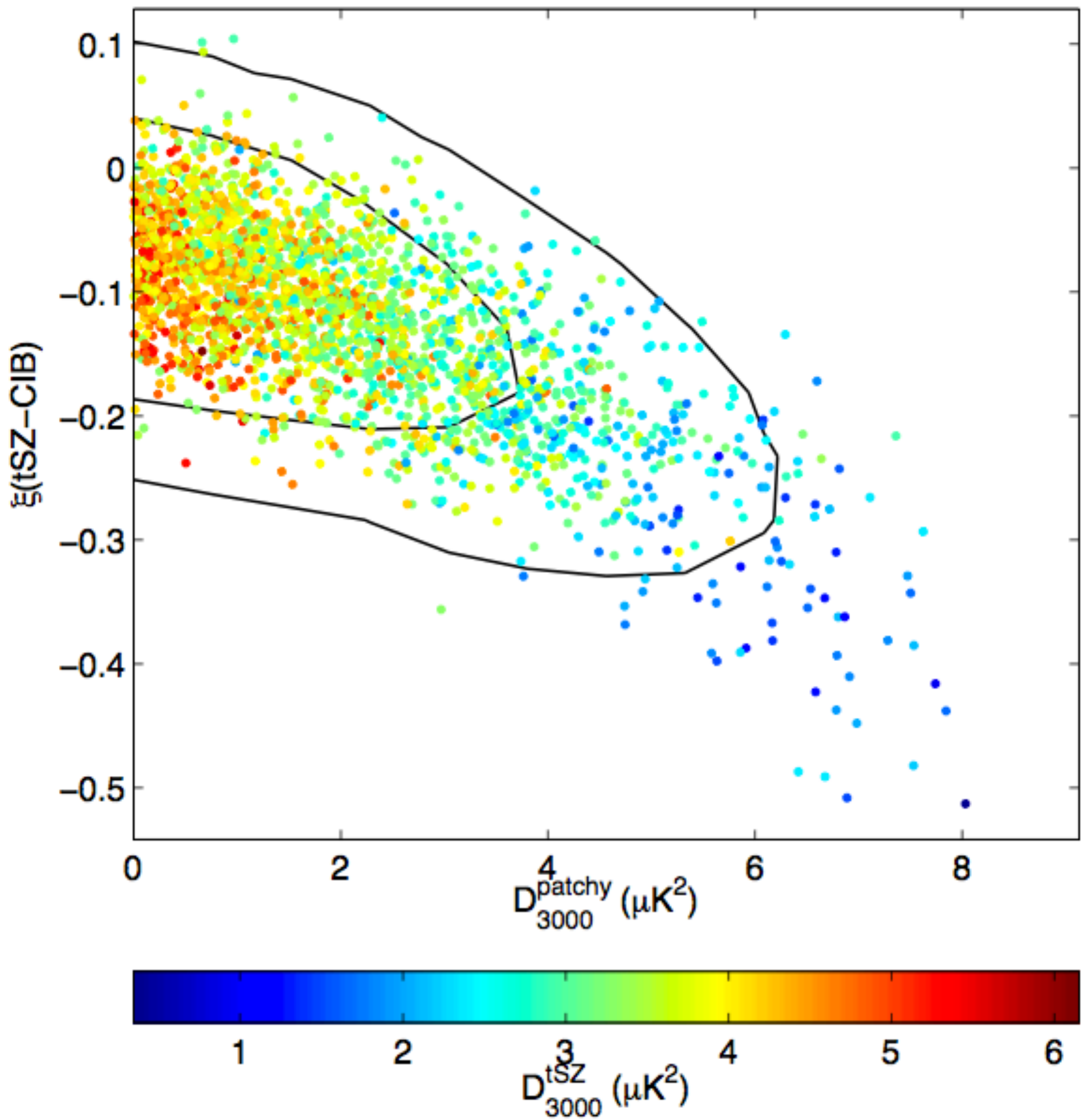
Project a **33-sigma** detection of the pairwise kSZ signal for SPT-3G and a DES-like cluster sample with photoz errors.



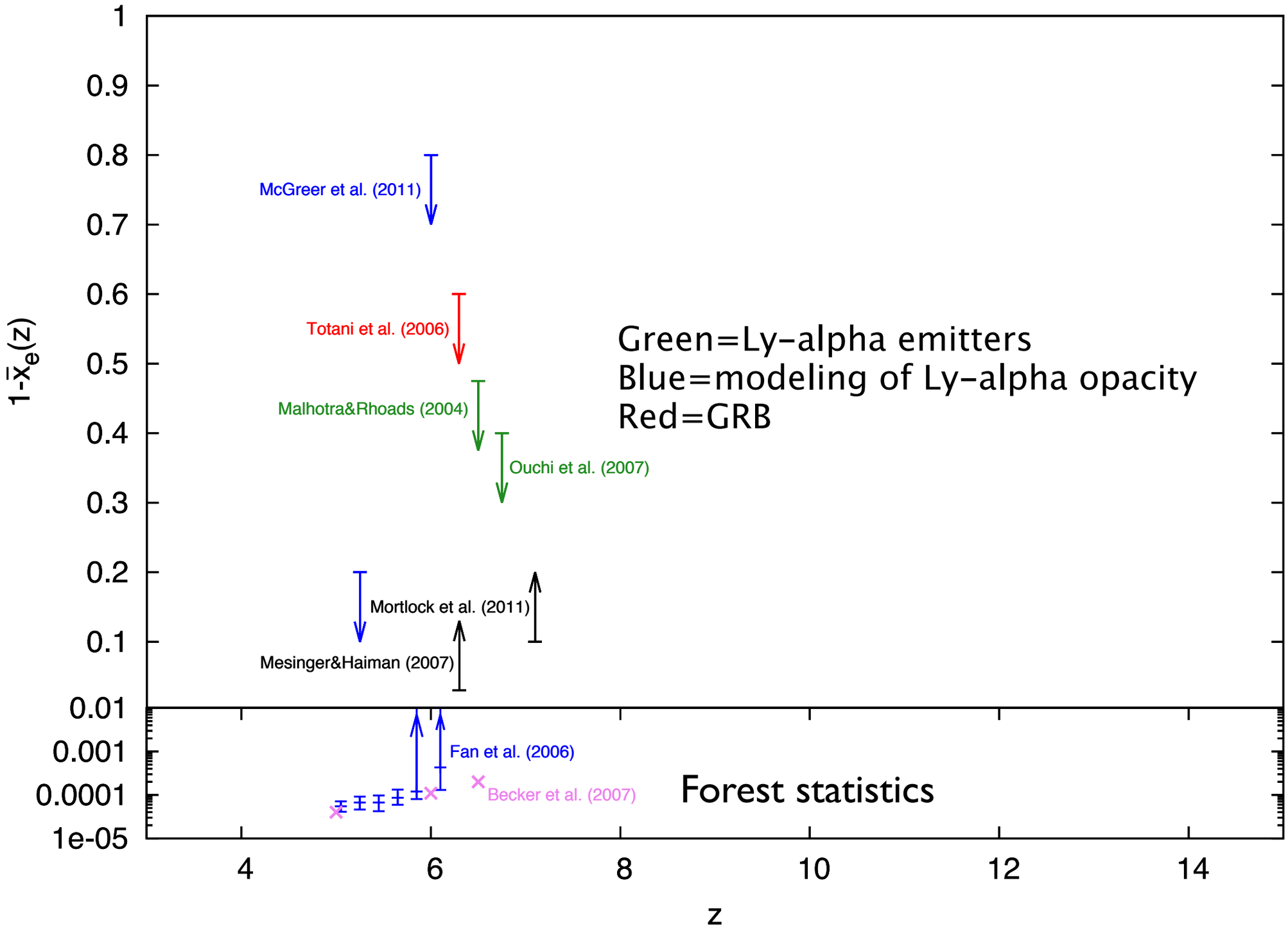
This provides a novel probe of gravity on **~50-200 Mpc** scales and competitively constrains modified theories of gravity (f(R)/ chameleon and DGP) on very large length scales.

Credit: R. Keisler

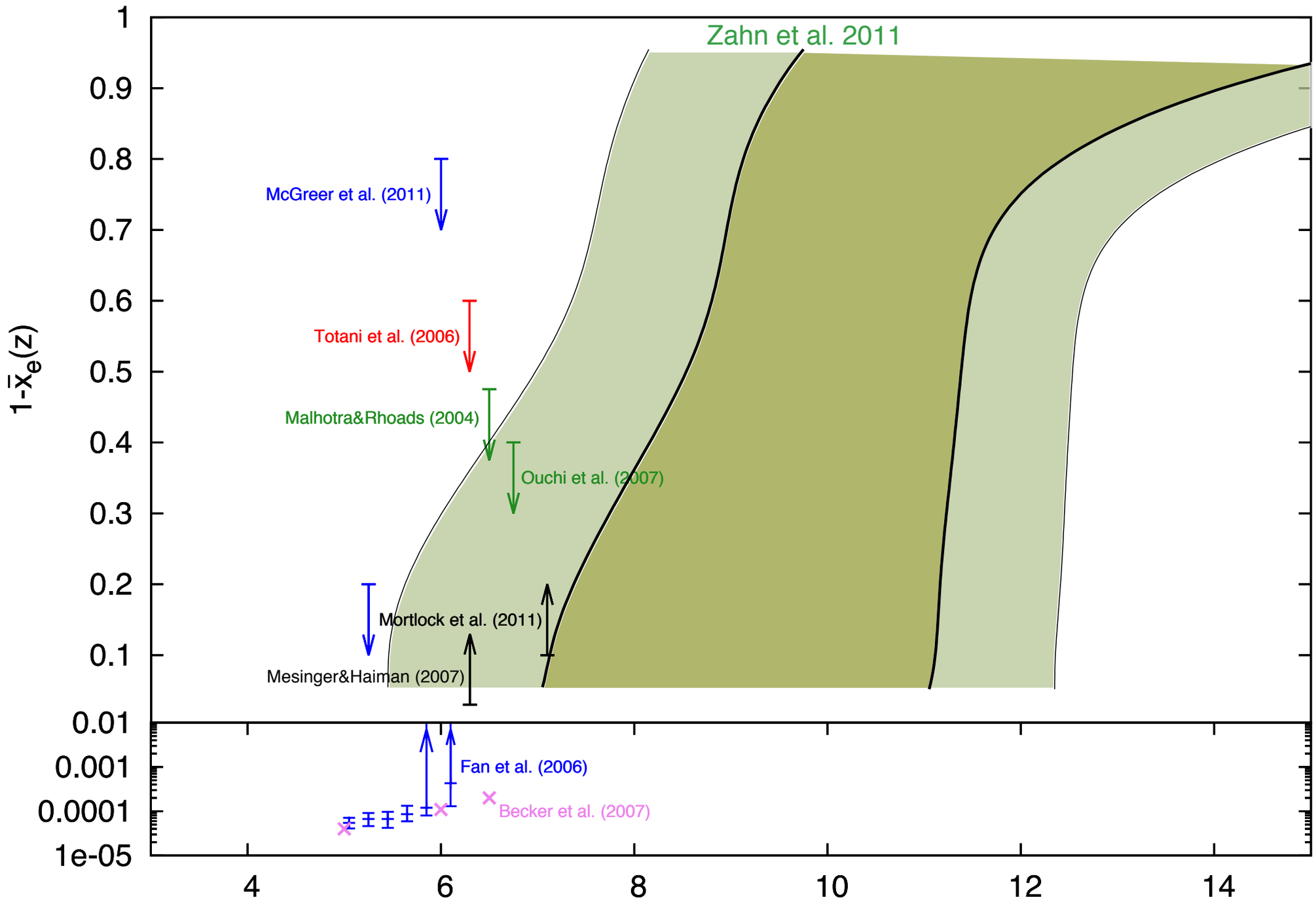
Correlation between kSZ, tSZ and CIB



Reionization constraints Nov 2011

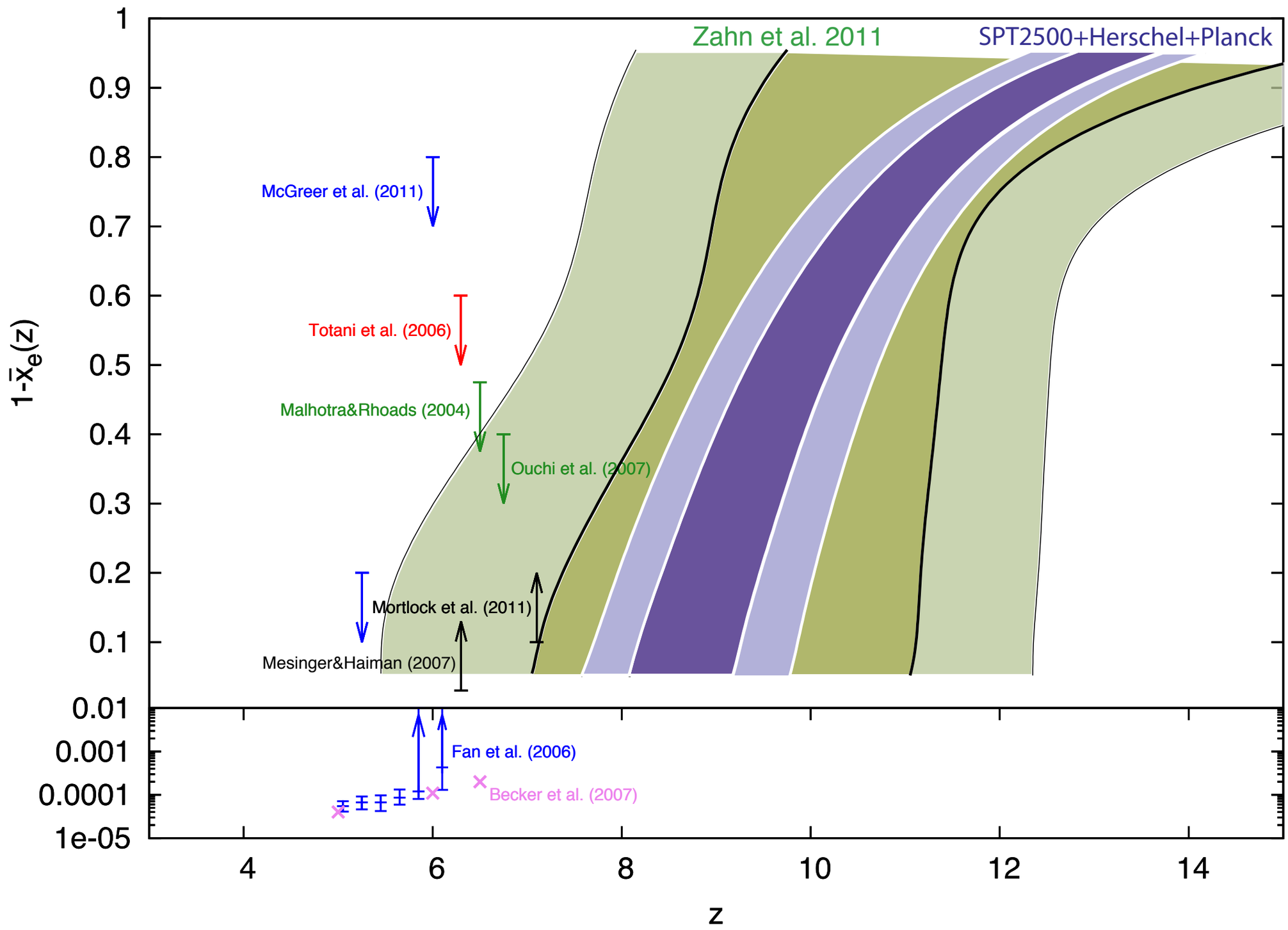


Reionization constraints Dec 2011

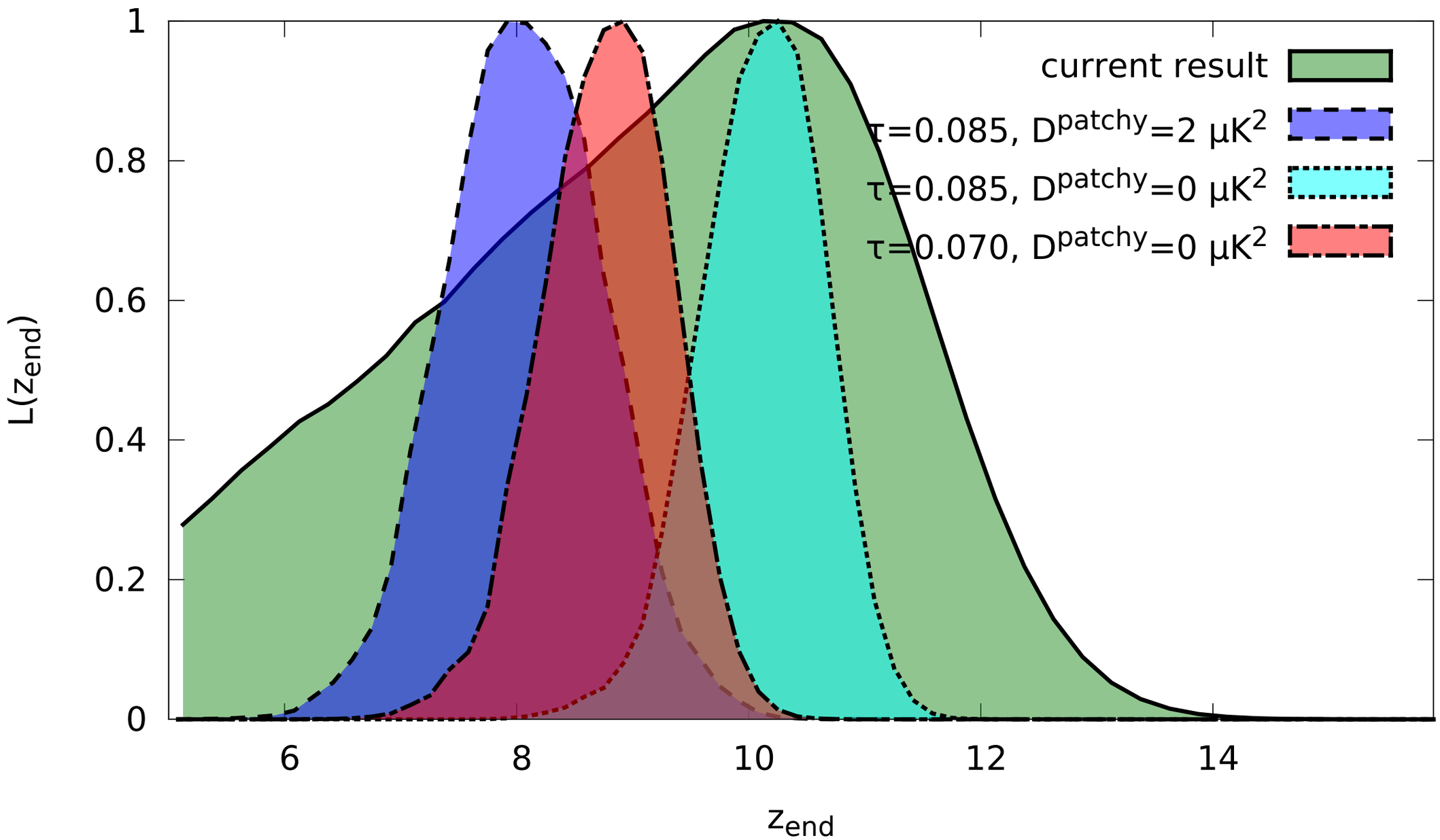


(showing <u>conservative</u> CMB constraint)

Forecast for Planck, Herschel, SPT2500



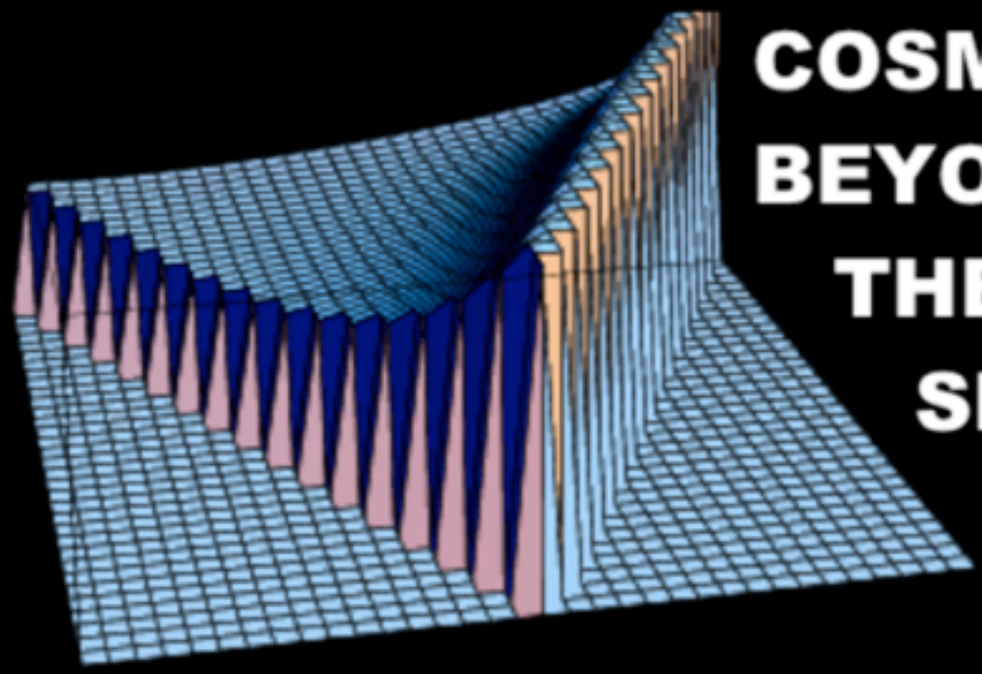
zend scenarios (Planck, Herschel, SPT 2500)



Summary

- CMB lensing reconstruction ("weighing the Hubble volume") is a rapidly growing probe of astroparticle physics and gravity theory with well understood systematics.
- CMBlens X LSS studies will inform galaxy formation studies and cosmology -- will have deeper CMB lensing maps soon, want more LSS to correlate with
- Kinetic SZ and cross correlations are quickly becoming important tools for studying reionization and gravity
- => Many symbiotic science products that will lead to fruitful exchanges between different areas of astrophysics

BERKELEY CENTER *for* COSMOLOGICAL PHYSICS



COSMOLOGY BEYOND THE POWER SPECTRUM

APRIL 17-20, 2013

Home Application Logistics Participants Schedule

Non-Gaussian statistics are rapidly becoming crucial cosmological tools. The main aim of this workshop is s to bring together a broad spectrum of researchers studying various observables, and epochs.

The goal will be to share techniques for optimizing estimators and dealing with systematics associated with searches for primordial and non-primordial sources of non-Gaussianity.

Main topics to be covered include:

General:

- Theory of higher order statistics/estimators
- Astrophysical and instrumental contaminants

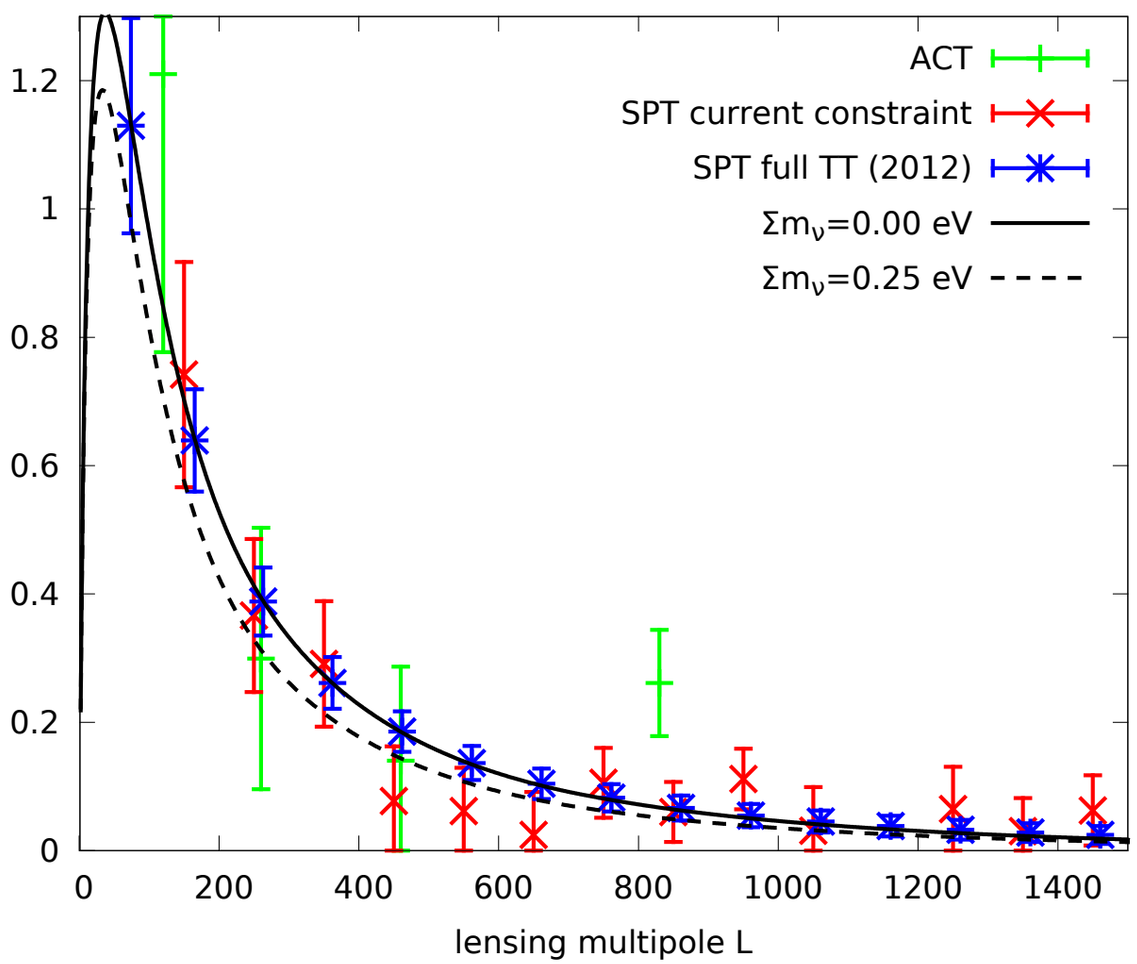
L.O.C.:

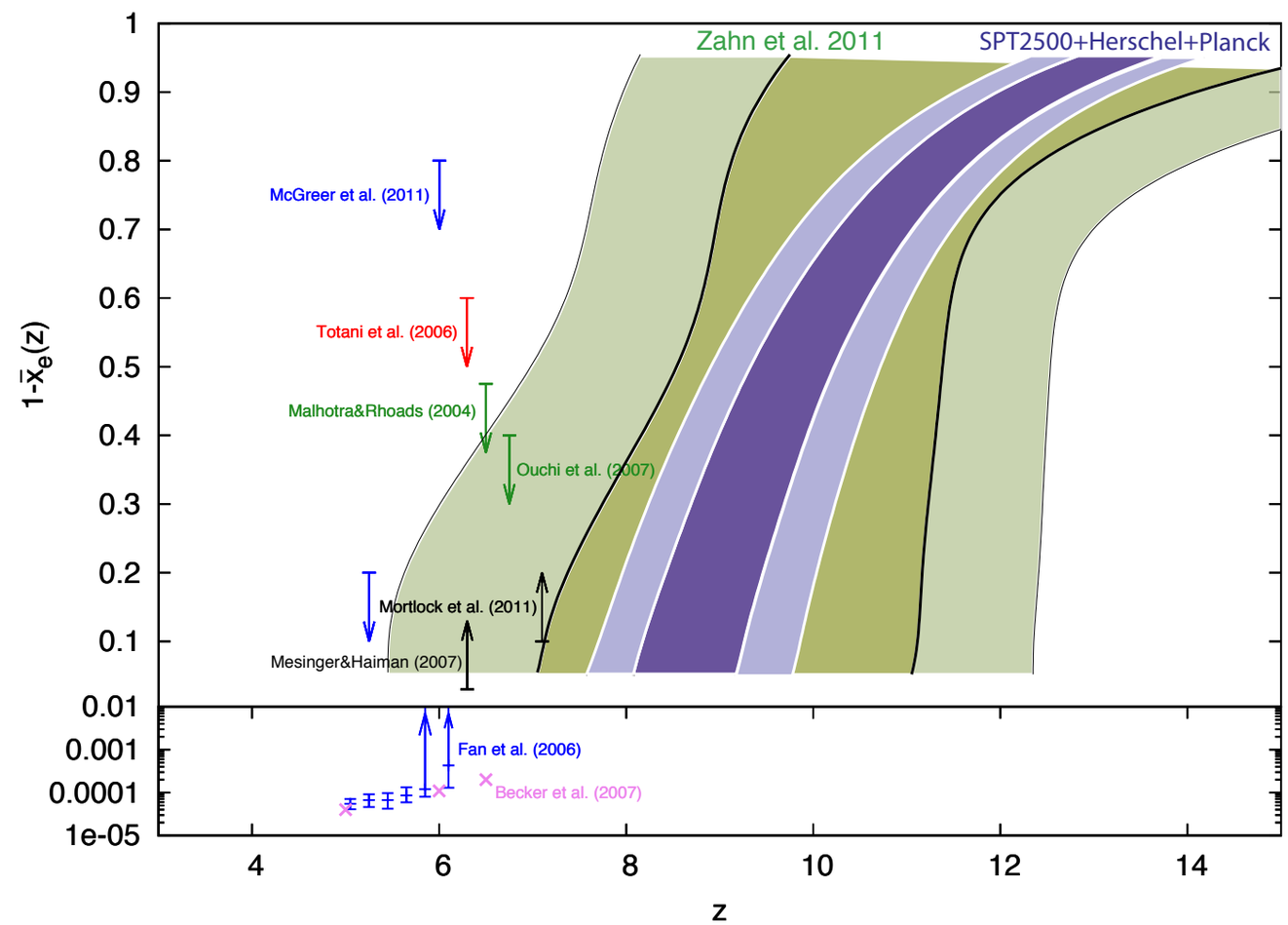
Sudeep Das
Uros Seljak
Oliver Zahn

S.O.C.:

Sudeep Das
Duncan Hanson
Uros Seljak
Kendrick Smith
Oliver Zahn

Thanks!


ACT
SPT current constraint
SPT full TT (2012)
Σm_ν=0.00 eV
Σm_ν=0.25 eV
L² C_L^αα/2 π² [10⁻⁷]
lensing multipole L
0
0.2
0.4
0.6
0.8
1
1.2
0
200
400
600
800
1000
1200
1400

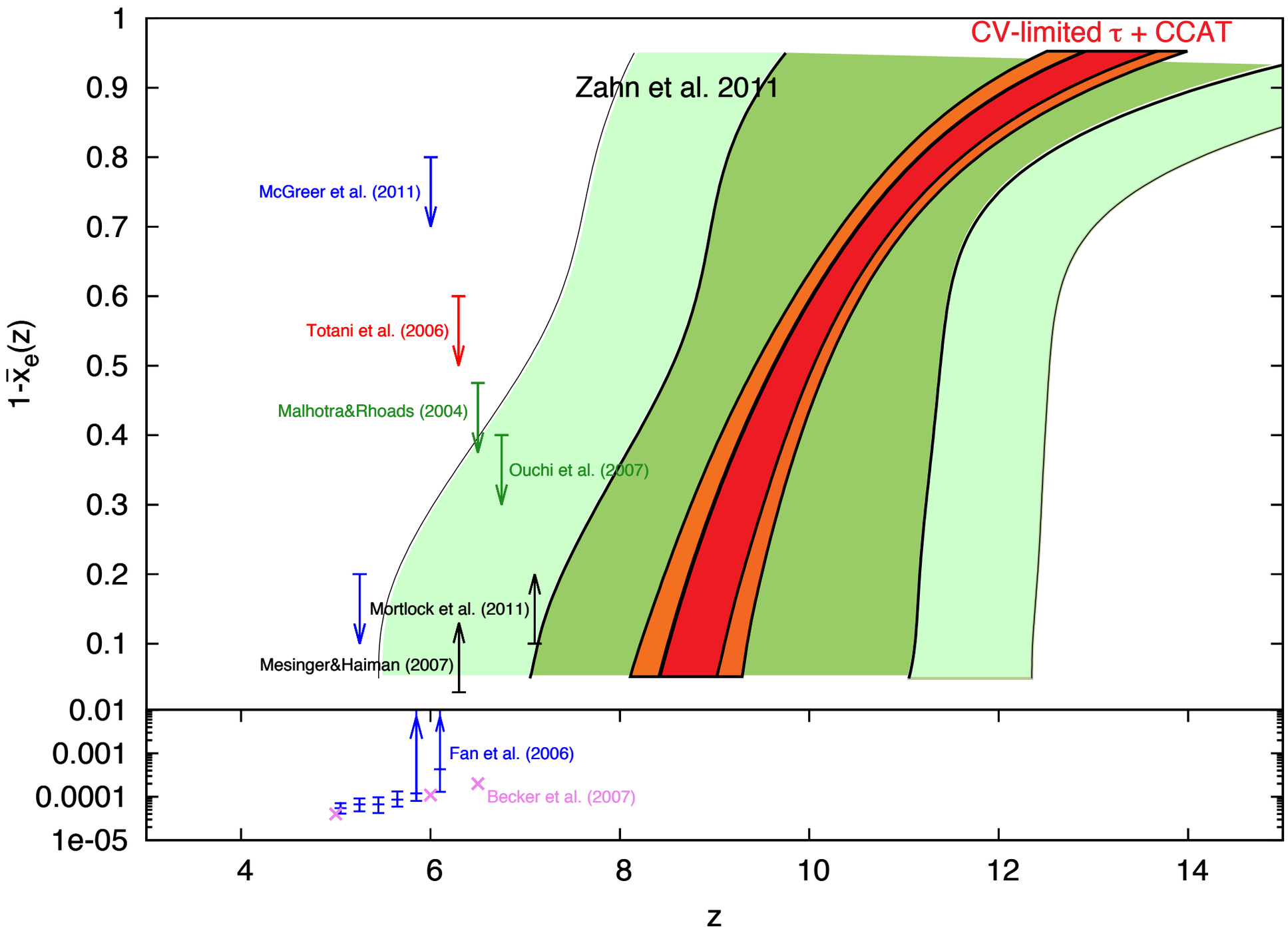

Zahn et al. 2011
SPT2500+Herschel+Planck
McGreer et al. (2011)
Totani et al. (2006)
Malhotra&Rhoads (2004)
Ouchi et al. (2007)
Mortlock et al. (2011)
Mesinger&Haiman (2007)
Fan et al. (2006)
Becker et al. (2007)
1-x̄_e(z)
z
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.01
0.001
0.0001
1e-05
4
6
8
10
12
14

Summary

We now are beginning to make mass maps of the Universe -- "weighing the Hubble volume"

These maps can be correlated with any other tracers of the baryonic or dark matter content

This might allow us to constraint the redshift distribution and bias of the second tracer simultaneously -- specific goals need to be identified

It might also allow us to improve constraints on cosmological parameters -- forecasts need to be done

Reionization science with CCAT/SPT3