

A Search for Warm/Hot Gas Filaments Between Pairs of SDSS Luminous Red Galaxies

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The first detection of the imprint of filaments on CMB lensing

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(Dated: September 11, 2017)

Where are the baryons ?



At $z > 2$, all the baryons are expected to be in the Ly α forest ($T_{\text{IGM}} \sim 10^4 - 10^5$ K)



At $z < 2$, observed baryons in stars, Ly α forest, galaxy clusters only account for **50%**

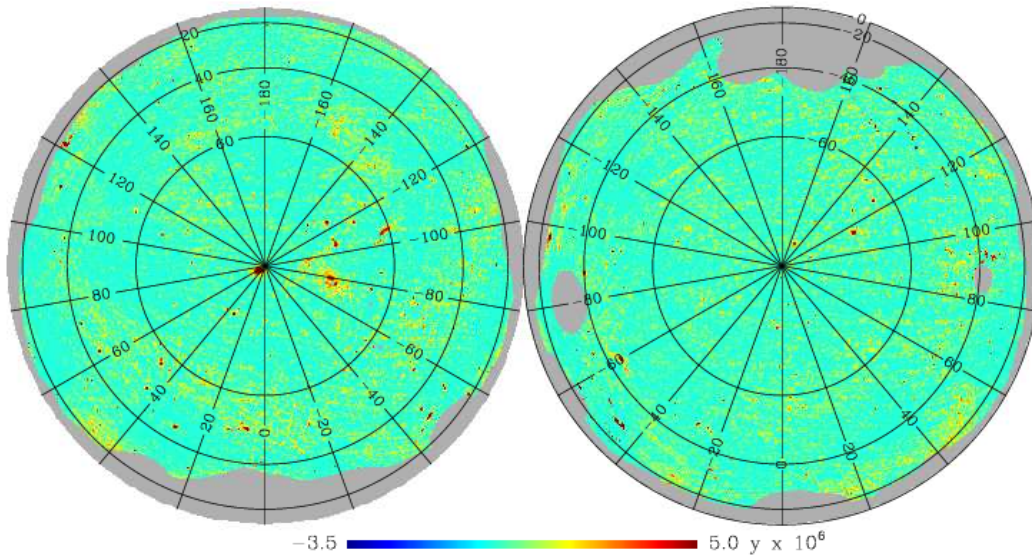


Other 50%?

Warm Hot Intergalactic Medium (WHIM), $T_{\text{WHIM}} \sim 10^5 - 10^7$ K

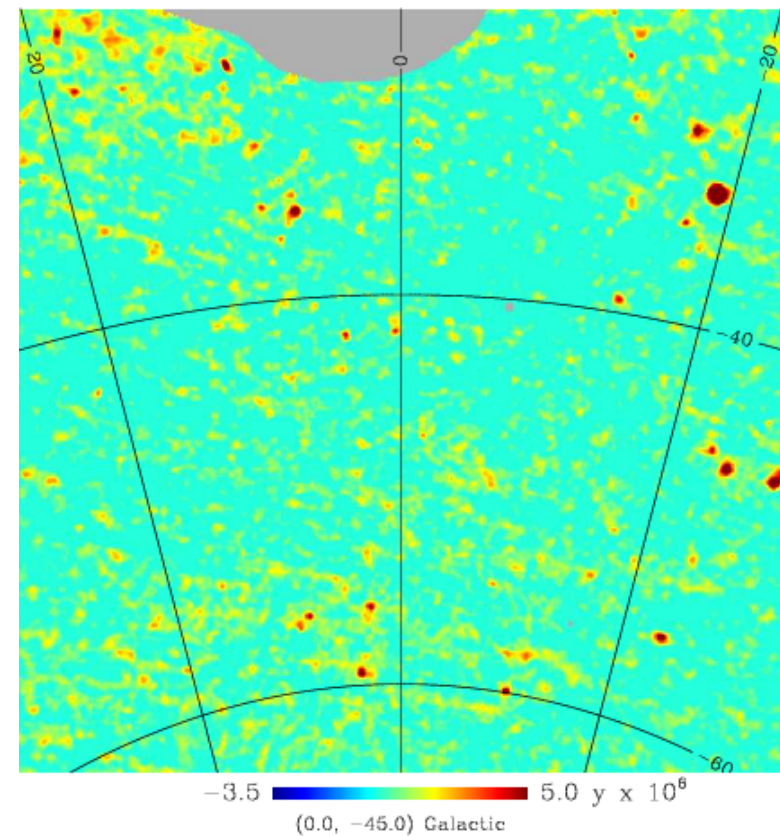
Data (Planck y-map)

MILCA tSZ map



$$y = \frac{\sigma_T k_B}{m_e c^2} \int n_e T_e dl$$

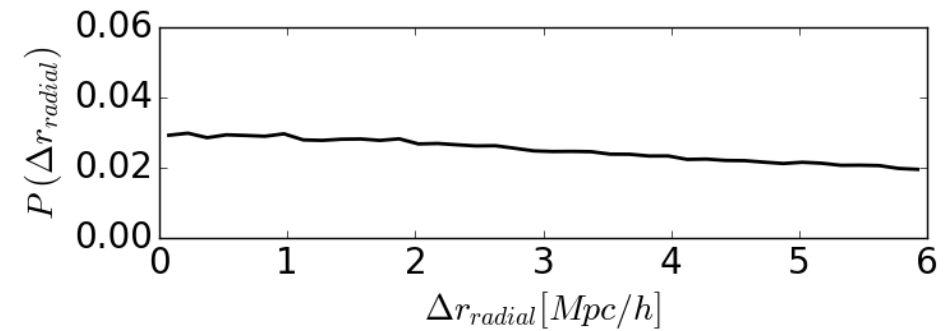
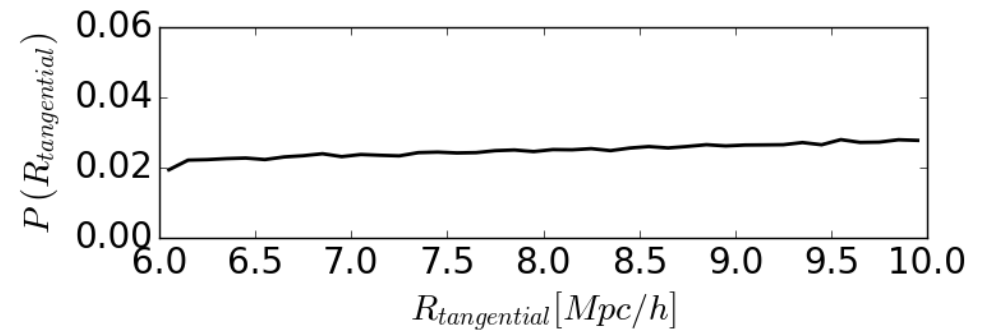
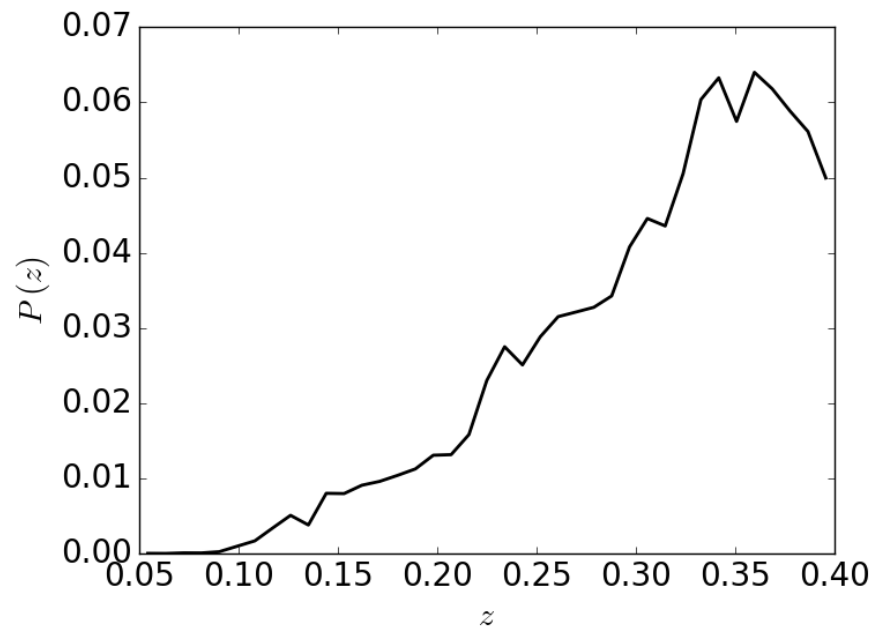
MILCA tSZ map



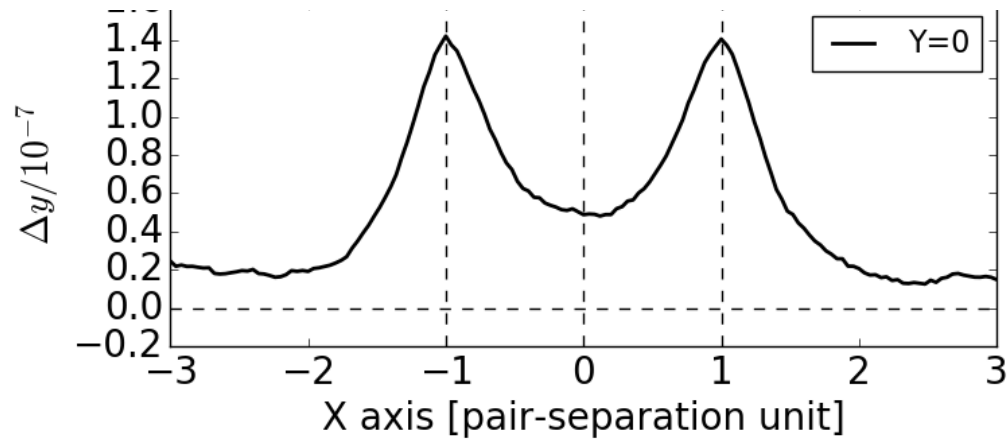
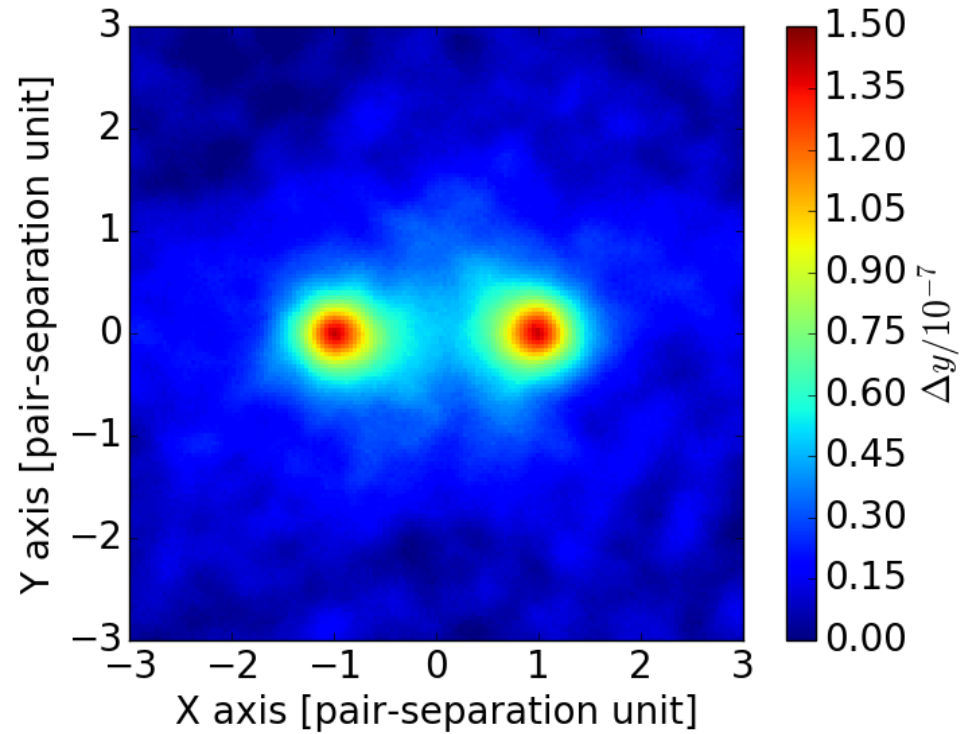
obtained thanks to the Sunyaev-Zel'dovich effect

Data (LRG)

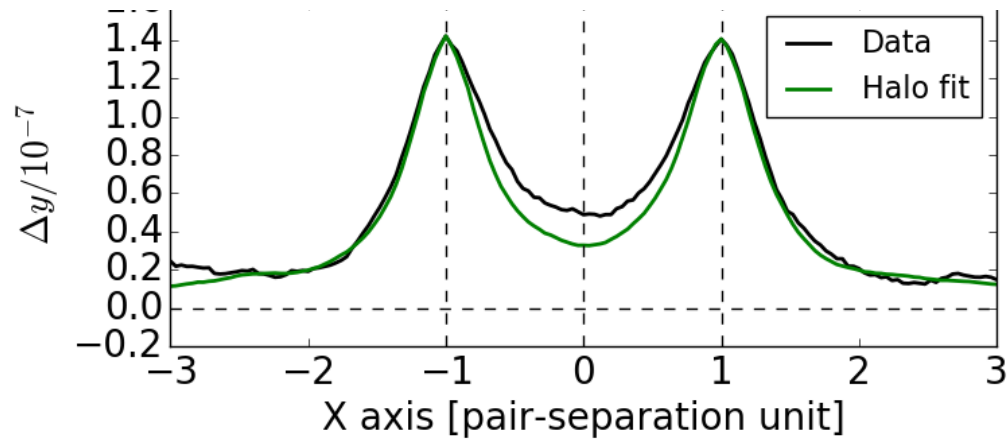
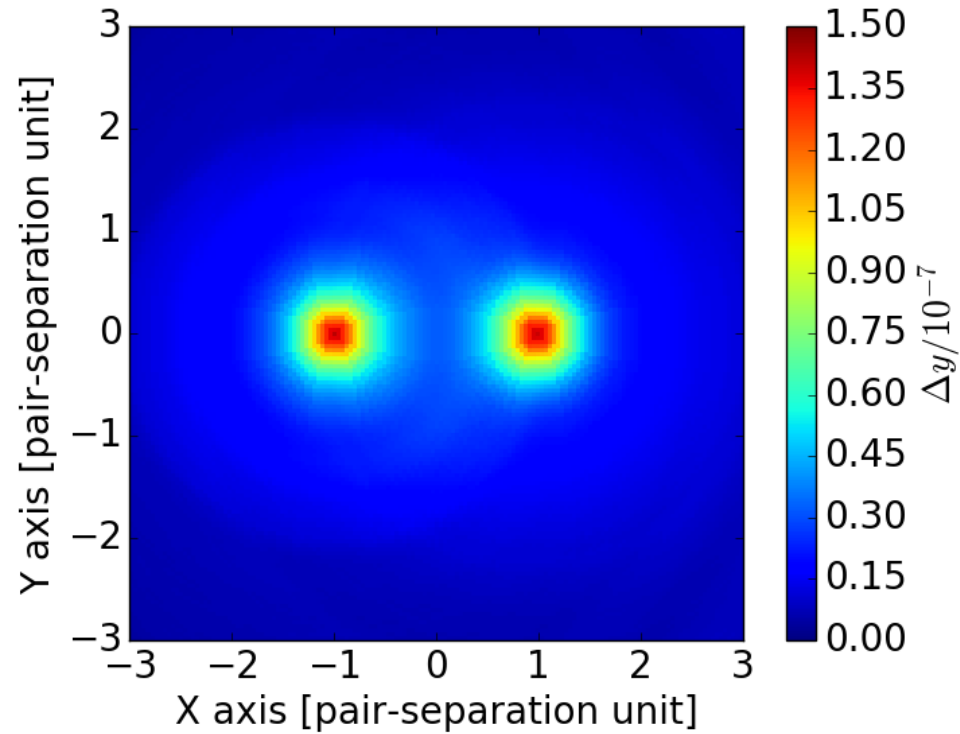
262,864 LRG pairs
from SDSS III (DR 12) locally most-massive LRG



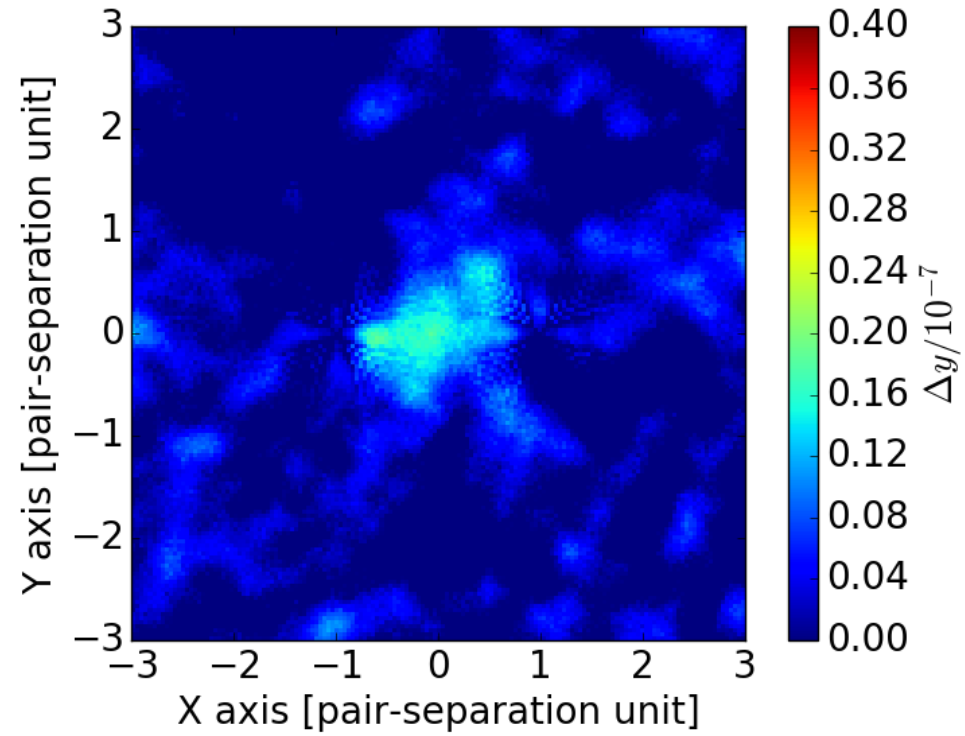
Stack (on LRG pairs)



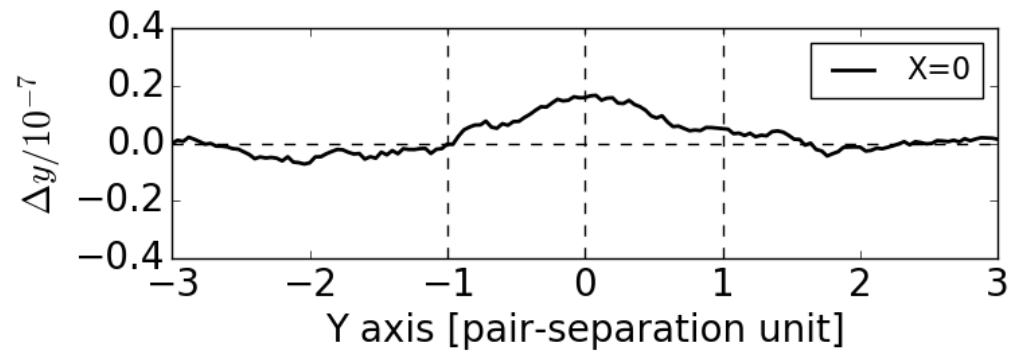
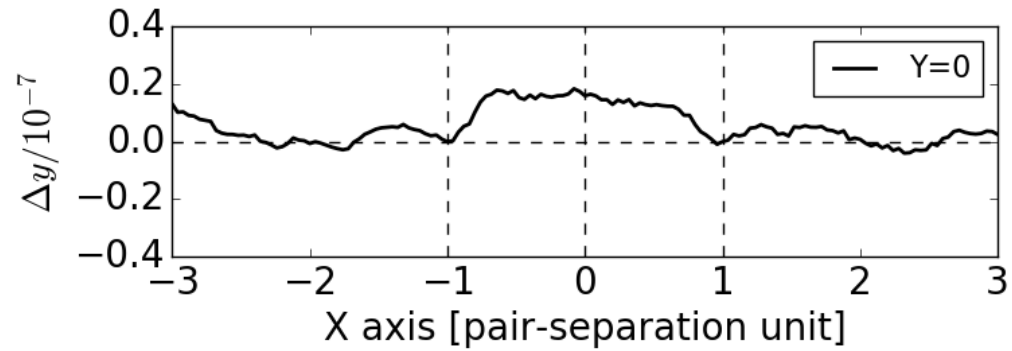
Stack (halo fit)



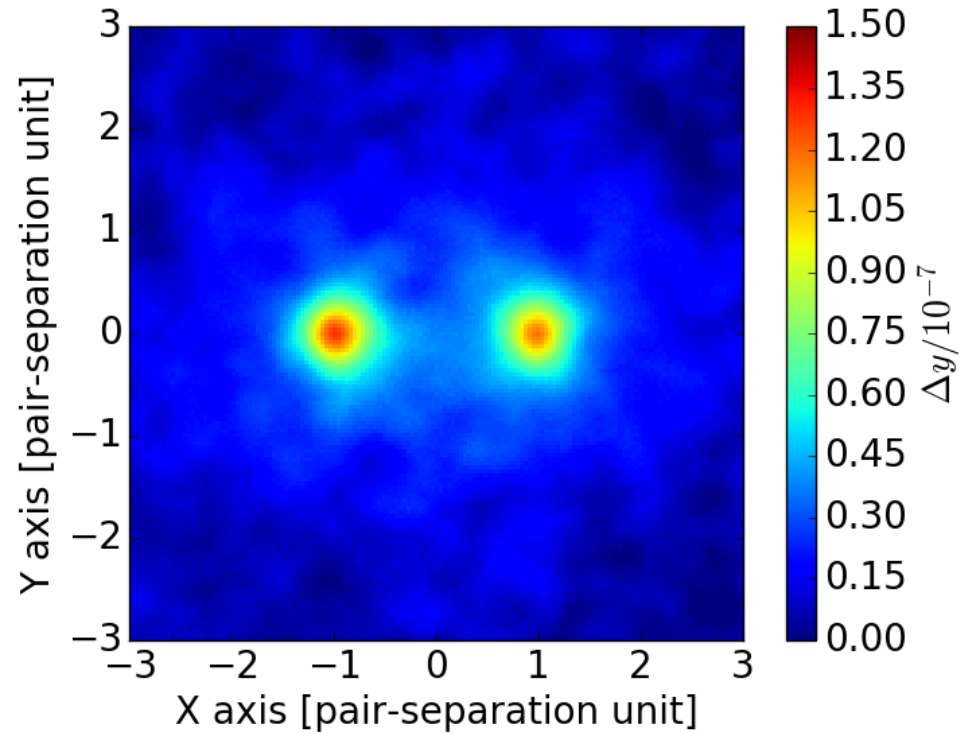
Stack (residual)



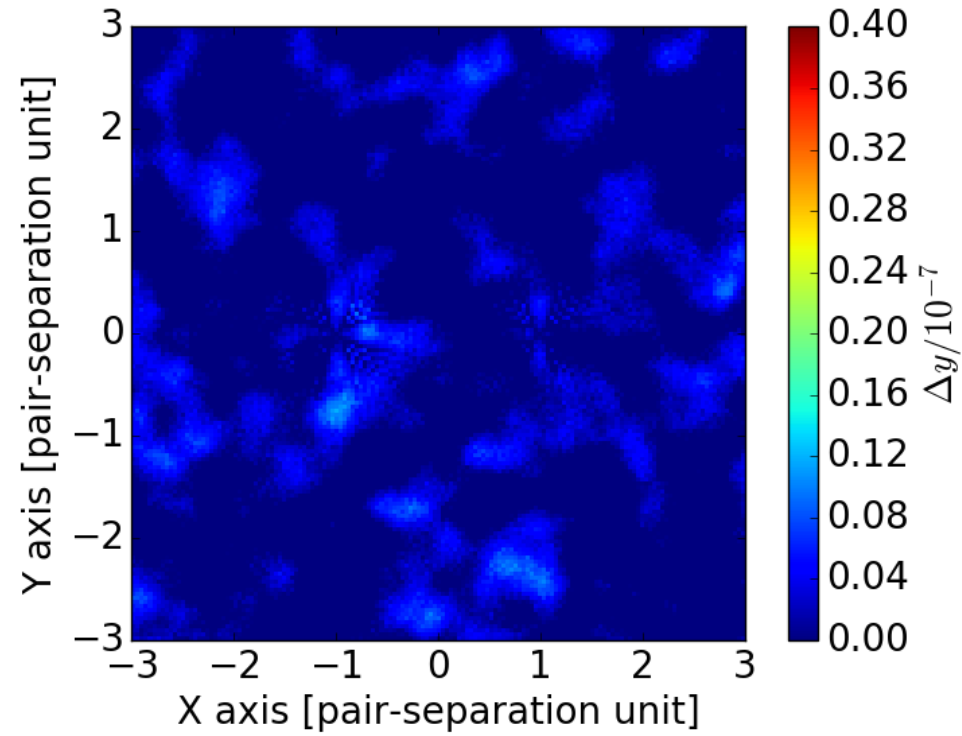
Stack (residual)



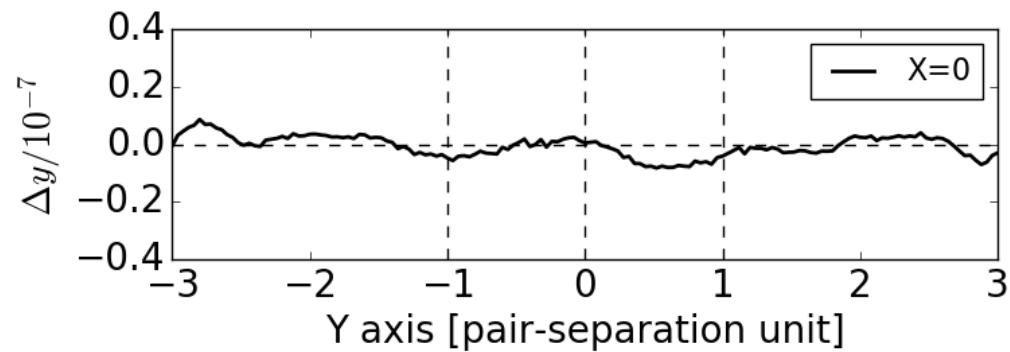
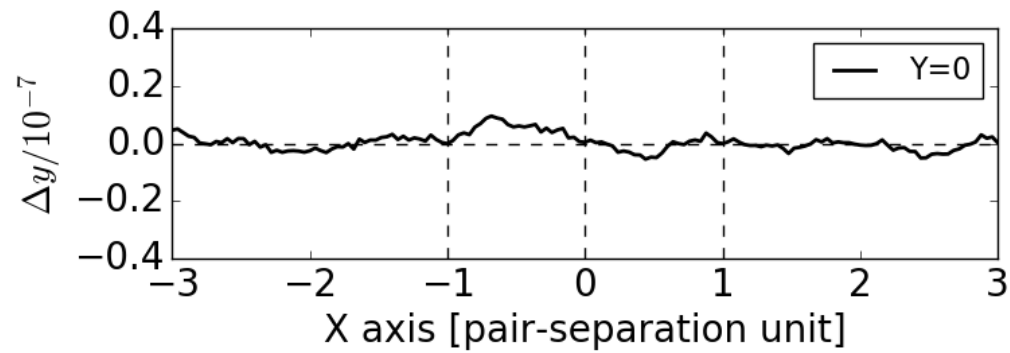
Stack (on LRG pseudo-pairs)



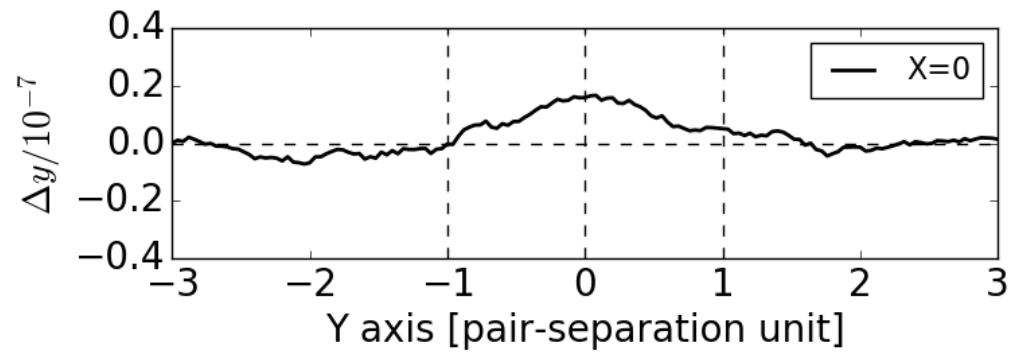
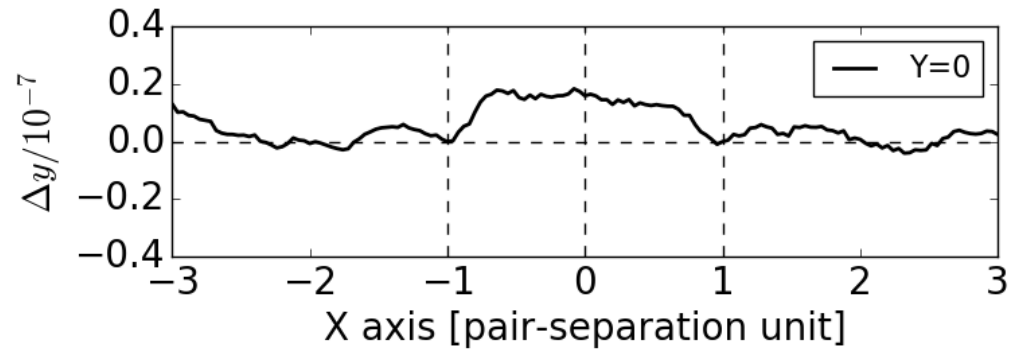
Stack (pseudo-pairs residual)



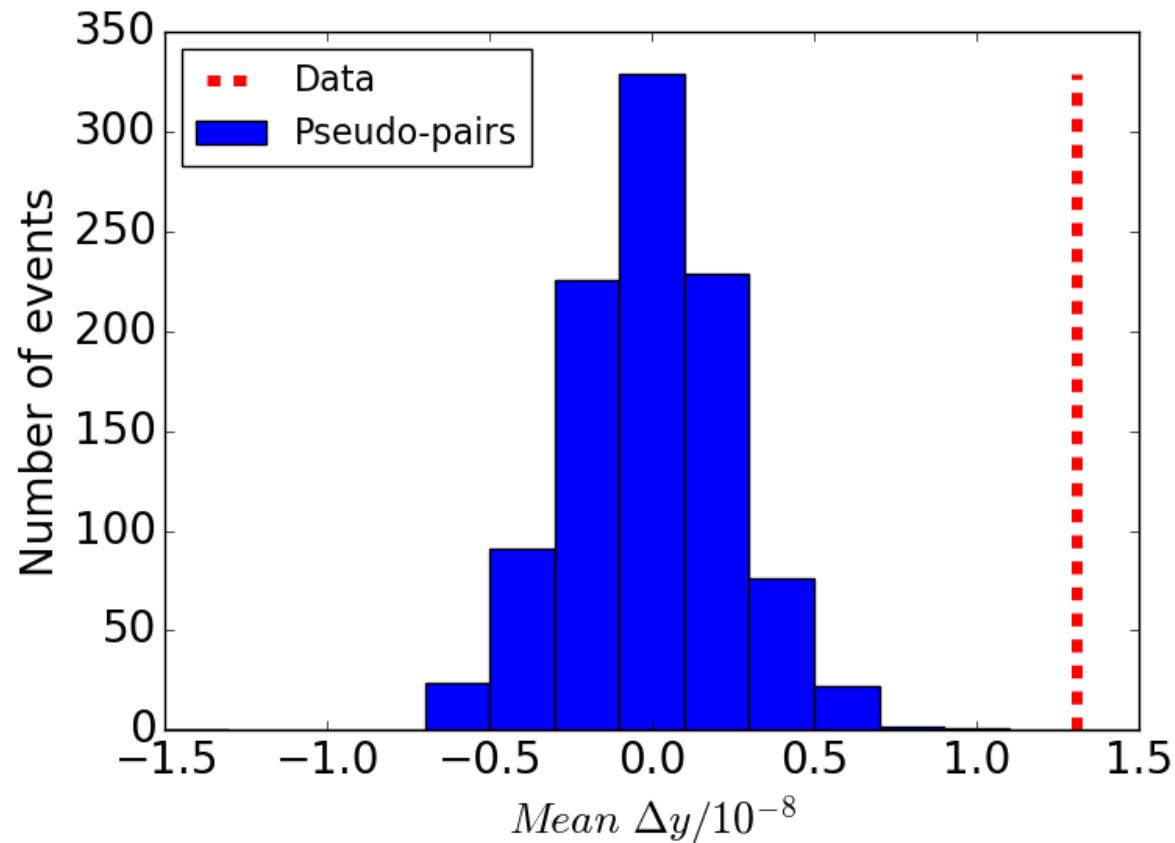
Stack (pseudo-pairs residual)



Stack (residual)

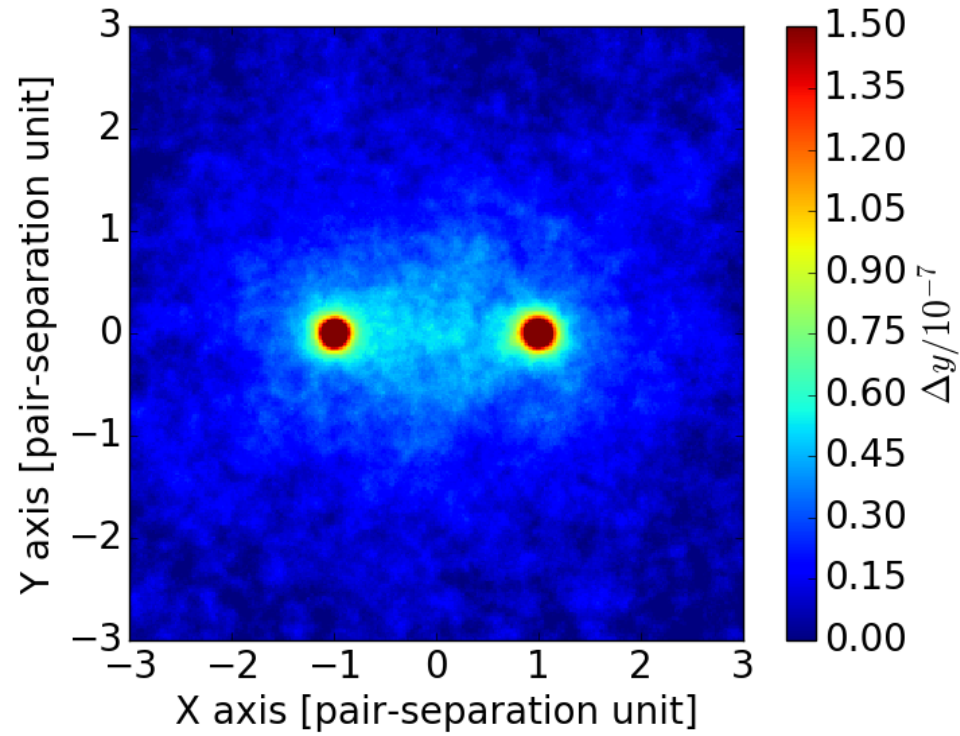


Stack (1000 pseudo-pairs residual)

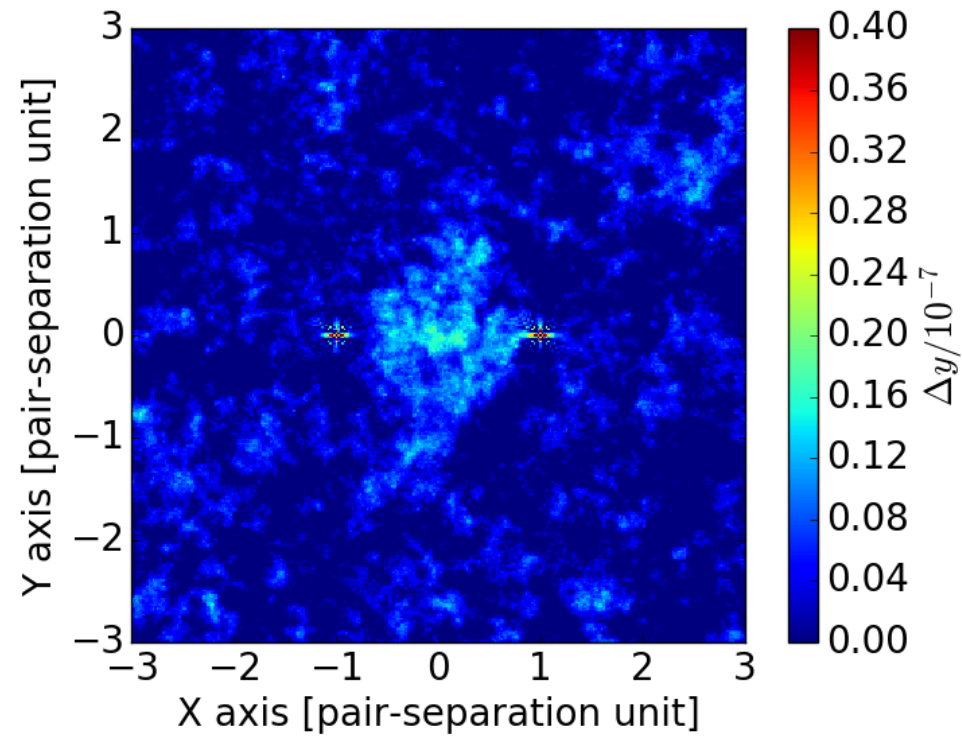


$$\Delta y = (1.31 \pm 0.25) \times 10^{-8}$$

Stack (on simulations)



Stack (on simulations, residuals)



$$\Delta y = (0.84 \pm 0.24) \times 10^{-8}$$

Conclusion

- **Statistically significant residual** between LRG pairs

$$\Delta y = (1.31 \pm 0.25) \times 10^{-8}$$

- **Low over-density δ**

$$\delta_c \left(\frac{T_e}{10^7 \text{ K}} \right) \left(\frac{r_c}{0.5 h^{-1} \text{ Mpc}} \right) = 2.7 \pm 0.5$$

- Marginally consistent with hydro simulations BAHAMAS

$$\Delta y = (0.84 \pm 0.24) \times 10^{-8}$$

- Consistent with Epps & Hudson 2017: weak lensing studies of filaments between LRG pairs ($\delta \sim 4$)

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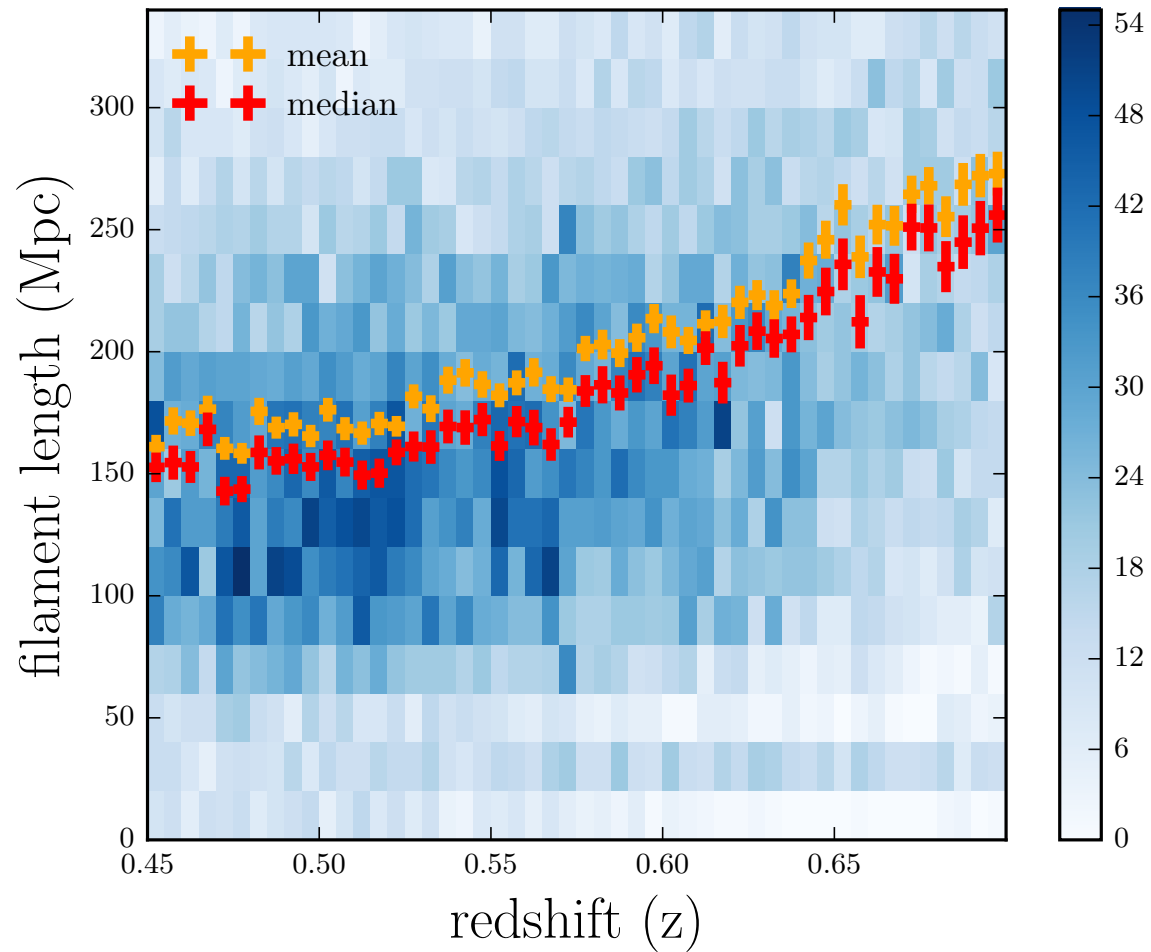
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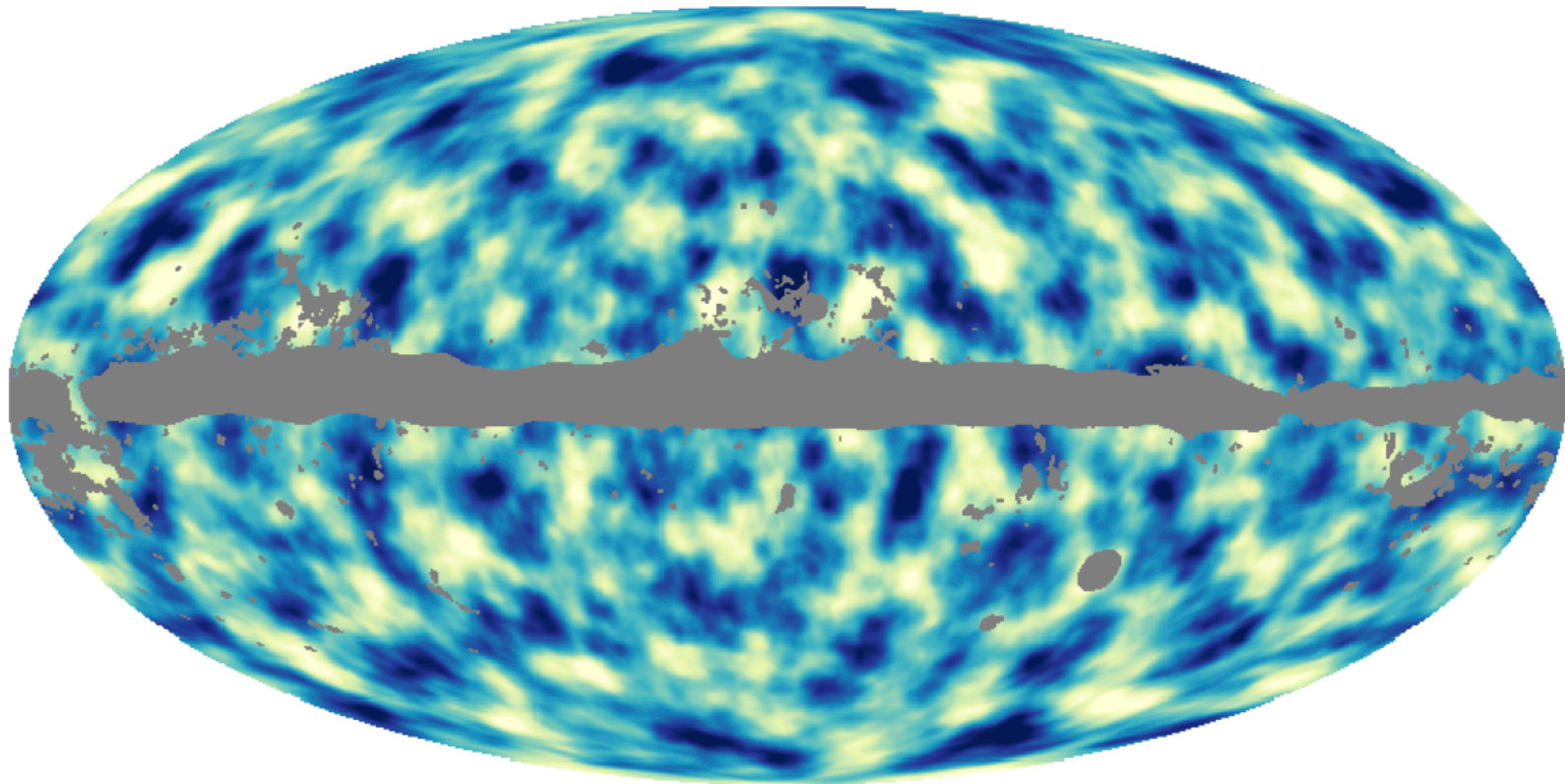
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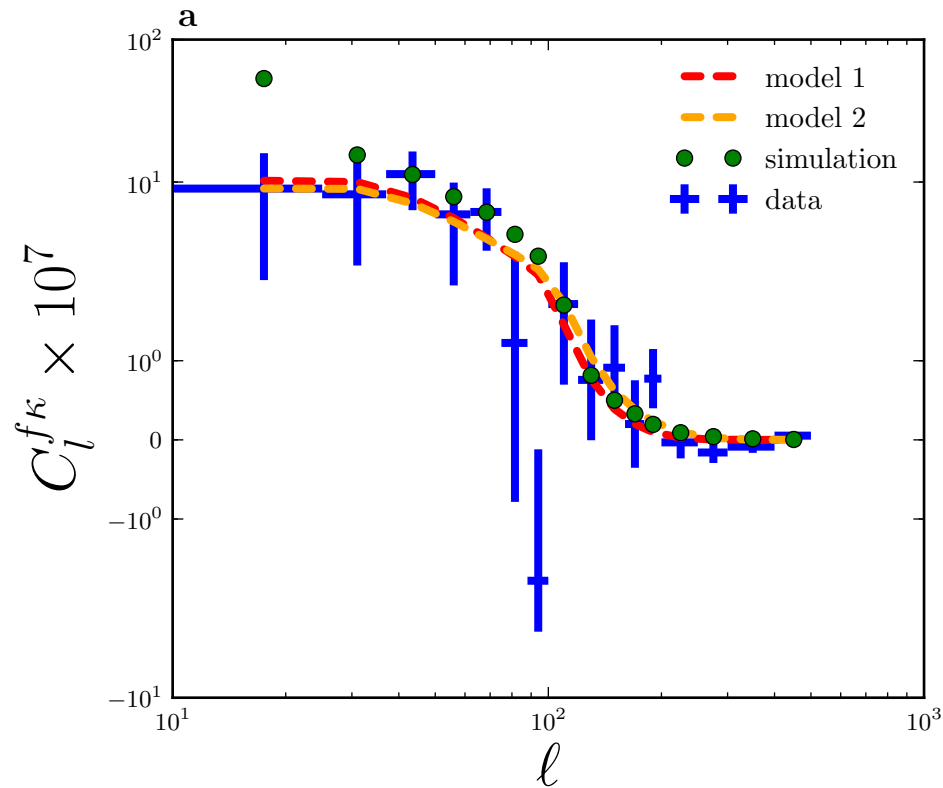
SDSS DR12 filaments



Planck CMB lensing map



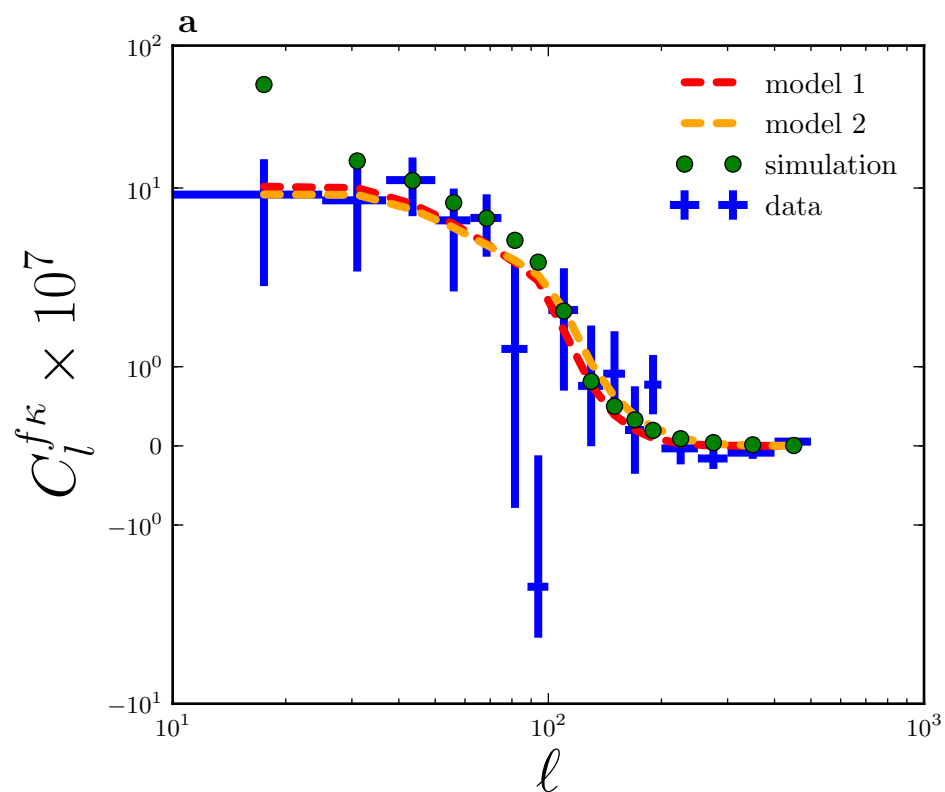
Result



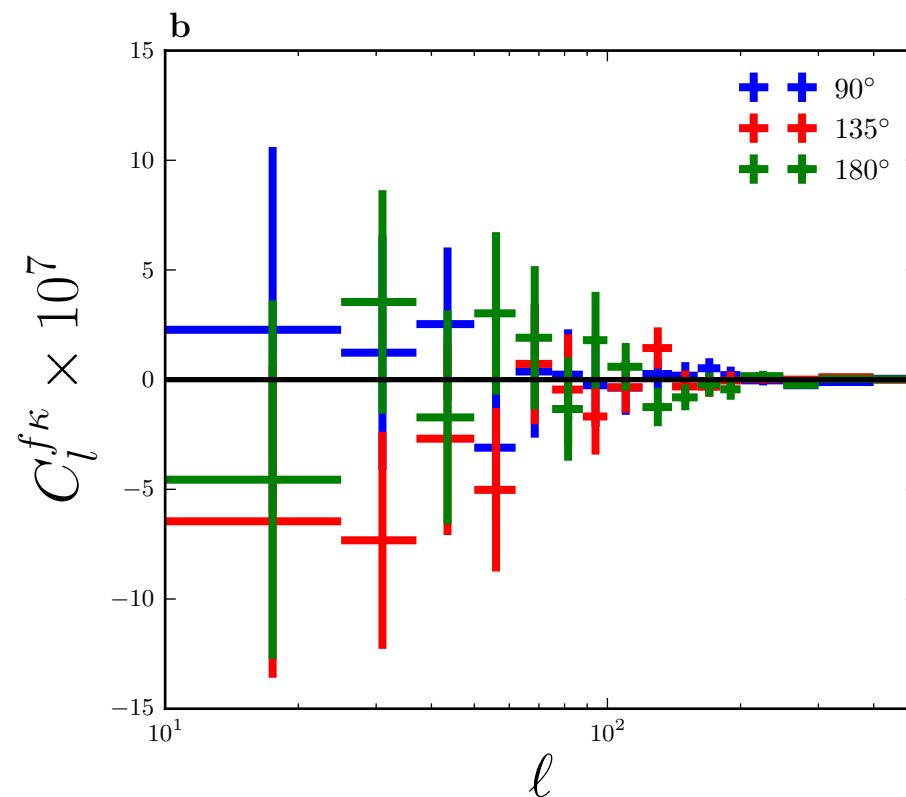
$$C_l^{\kappa f} = \frac{3H_0^2 \Omega_{m,0}}{2c^2} \int_{z_1}^{z_2} dz W(z) f(z) \chi^{-2}(z) (1+z) \times P_{mf} \left(\frac{l}{\chi(z)}, z \right)$$

$$P_{mf}(k, z) = \frac{1}{2\pi} \int d\phi b_f P_{mm}(k, z) \times e^{-(k \cos(\phi)/k_{\perp}(z))^2 - (k \sin(\phi)/k_{\parallel}(z))^2}$$

Result

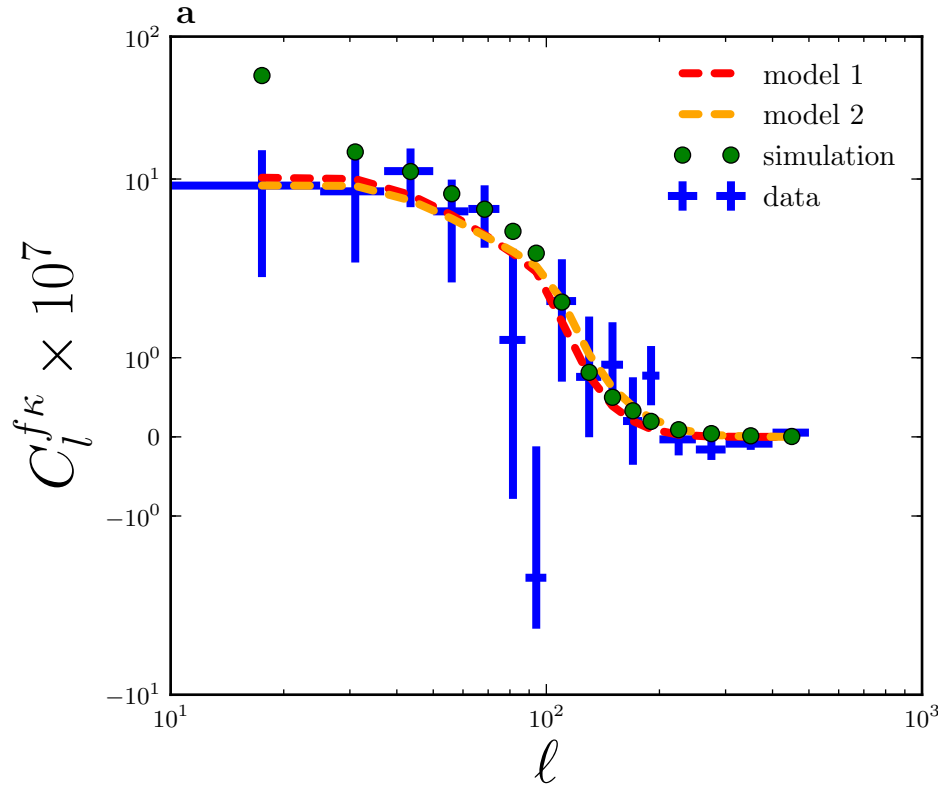


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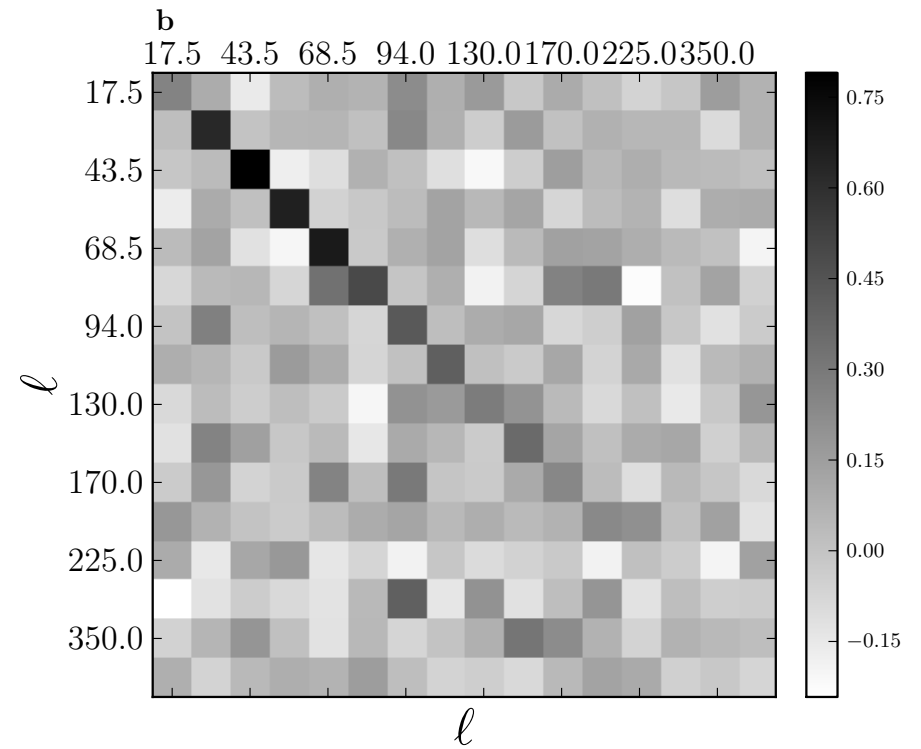
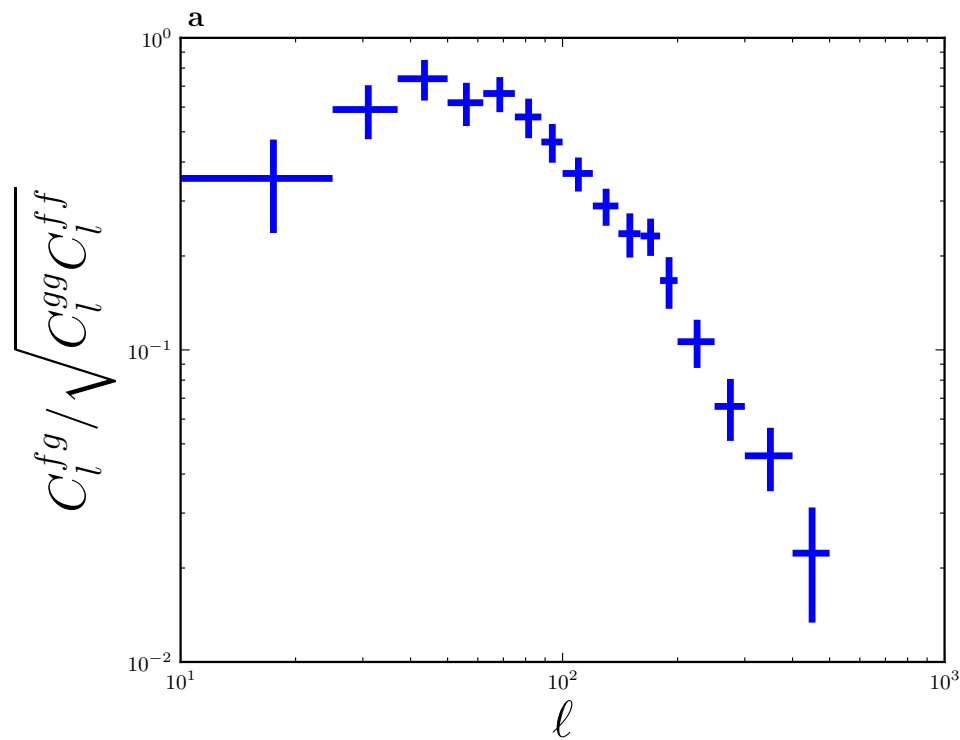


	model 1	model 2
b_f	1.68 ± 0.334	1.47 ± 0.28
S/N	5.0	5.2
χ_{fit}^2	25.77	24.39
$d.o.f.$	15	14

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Filaments or galaxies ?



Conclusion

- **First detection of CMB lensed by filaments (S/N~5)**
- **Bias between filaments and matter rather small ($b_f = 1.64 \pm 0.33$)**
 - low density region
- **Filaments or galaxies ? C_l^{kf} and C_l^{kg} correlated but not on small scale**
 - “Establishing the amount of extra cosmological information present in the filaments field would require a joint analysis with galaxy clustering and lensing measurements”