# Constraints on the thermal Sunyaev-Zeldovich effect and $\mu$-type distortion fluctuations and primordial non-Gaussianity from Planck data

Rishi Khatri

$$\bar{y} = 10^{-6} \pm ?$$
$$\bar{y} < 2.2 \times 10^{-6}, \text{ COBE-FIRAS: } < 15 \times 10^{-6}$$
$$\mu_{\rm rms}^{10'} < 6.4 \times 10^{-6}, \text{ COBE-FIRAS: } \bar{\mu} < 90 \times 10^{-6}$$
$$D_\ell^{\mu T}|_{\ell=2-26} = 2.6 \pm 2.6 \times 10^{-12}\ \text{K}$$
$$f_{\rm NL} < 10^5, k_{\rm S}/k_{\rm L} = 10^6$$

with Rashid Sunyaev

arXiv:1505.00781
arXiv:1507.05615

Max-Planck-Institut
für Astrophysik

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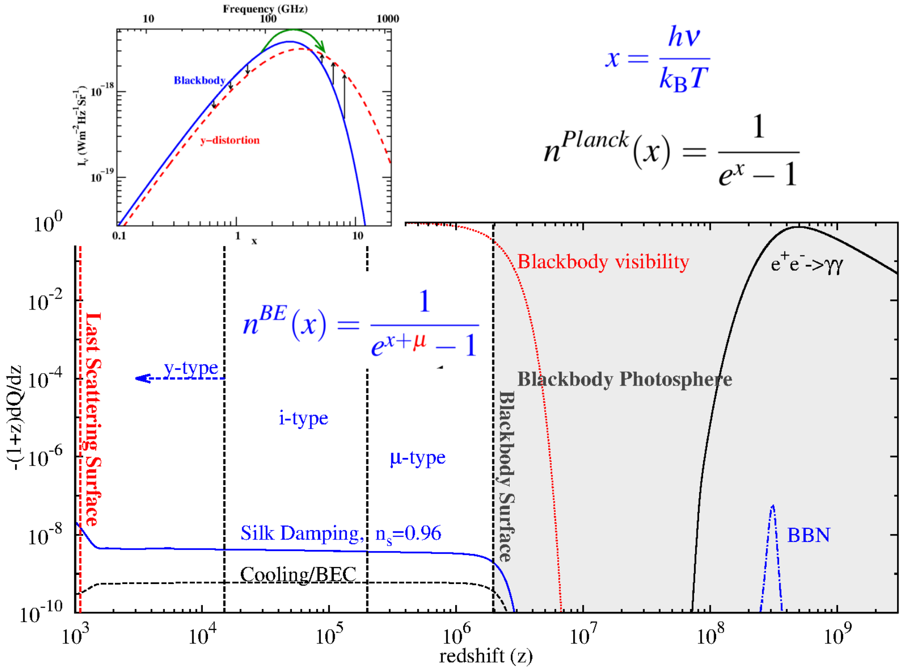
# CO mask, annotations to second Planck cluster catalog, $\mu$-map and masks publicly available

http://www.mpa-garching.mpg.de/~khatri/szresults/
http://www.mpa-garching.mpg.de/~khatri/muresults/



Frequency (GHz)
10
100
1000
Blackbody
y–distortion
$I_\nu$ (Wm$^{-2}$Hz$^{-1}$Sr$^{-1}$)
$10^{-18}$
$10^{-19}$
0.1
1
x
10
$x = \frac{h\nu}{k_B T}$
$n^{Planck}(x) = \frac{1}{e^x - 1}$
$n^{BE}(x) = \frac{1}{e^{x+\mu} - 1}$
Blackbody visibility
$e^+e^- \to \gamma\gamma$
Last Scattering Surface
y-type
i-type
μ-type
Blackbody Photosphere
Blackbody Surface
BBN
Silk Damping, $n_s$=0.96
Cooling/BEC
-(1+z)dQ/dz
$10^0$
$10^{-2}$
$10^{-4}$
$10^{-6}$
$10^{-8}$
$10^{-10}$
$10^3$
$10^4$
$10^5$
$10^6$
$10^7$
$10^8$
$10^9$
redshift (z)

# *y*-type (Sunyaev-Zeldovich effect) from cluster Abell 2319 seen by Planck

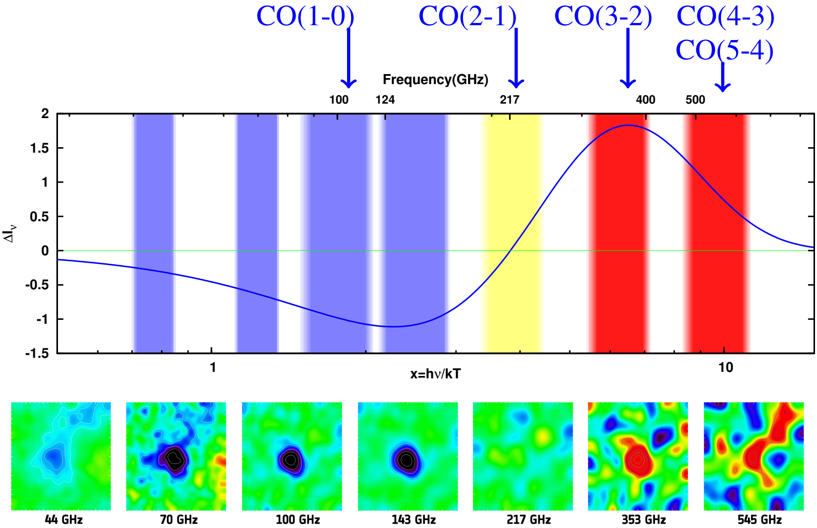
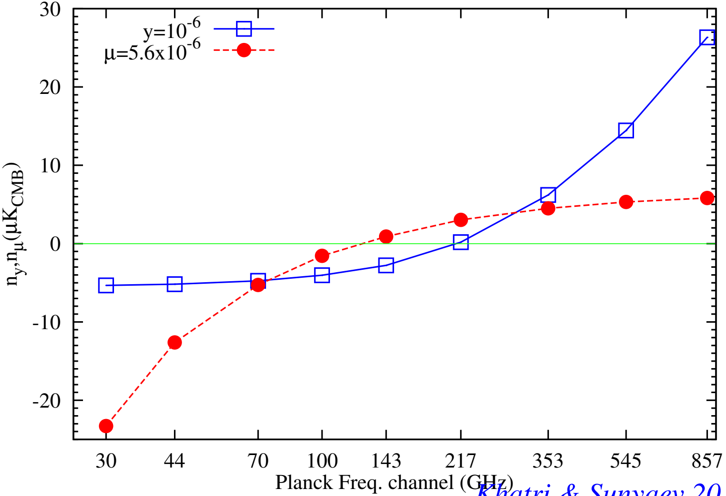



*Image credit: ESA / HFI & LFI Consortia*

# Each Planck frequency channel contains contribution from many components

Sunyaev-Zeldovich or $y$-distortion signal is a weak signal $\lesssim 100\ \mu$K except in the central part of strong nearby clusters




*Khatri & Sunyaev 2015*

# Component separation methods: Internal linear combination

y map = linear combination of channel maps

$$y(p) = \sum_i w_i T_i(p)$$

Weights are given by minimizing the variance of $y$ preserving the $y$ signal.

In principle can be done in any space:
pixel, harmonic, needlet, ....

# Alternative: parameter fitting (LIL)

- Fit a (non-linear) parametric model
- CMB + y + dust or CMB + CO + dust or CMB + $\mu$ + dust
- dust: grey body with spectral index as free parameter, temperature fixed to 18 K : 2 parameters
- CO: fixed line ratios : 1 parameter

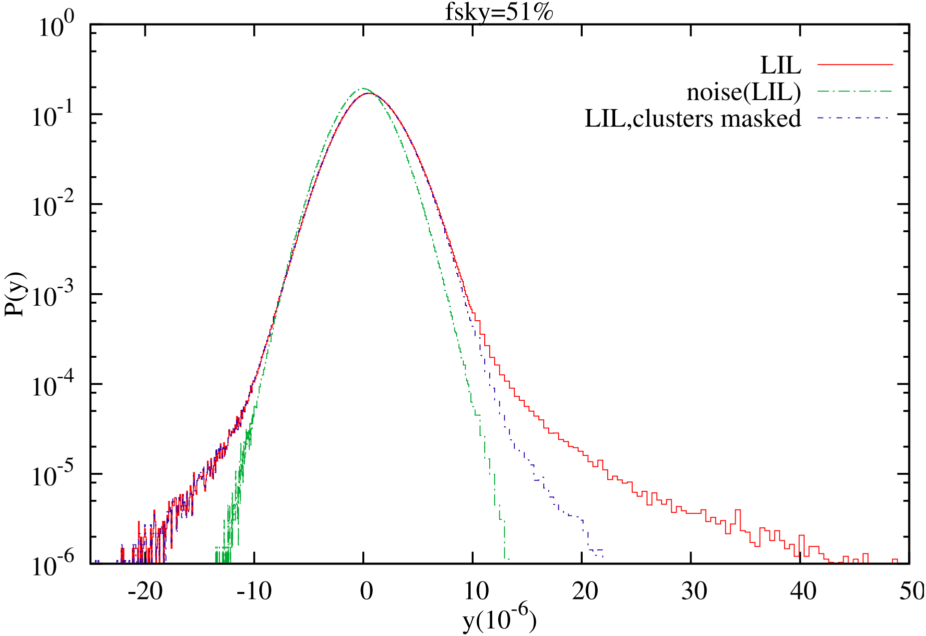
Advantages: Can use $\chi^2$ for CO vs y to decide which is the dominant component in a given part of the sky $\Rightarrow$ CO mask, alternative validation of Planck cluster catalog *(see arXiv:1505.00778 for details)*
Map, validation annotation to second Planck cluster catalog publicly available
`http://www.mpa-garching.mpg.de/~khatri/szresults/`

Disdvantage: Have to assume a model

# SZ/$y$-distortion

# Map pdfs *(Khatri & Sunyaev 2015)*

skewness even at small *y* as predicted (*Rubino-Martin & Sunyaev 2003*)



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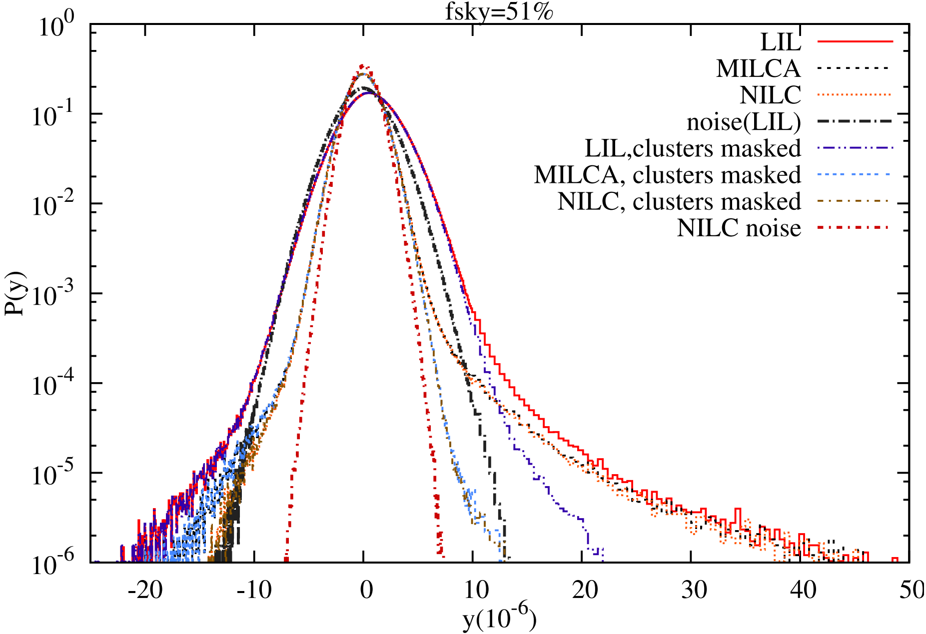
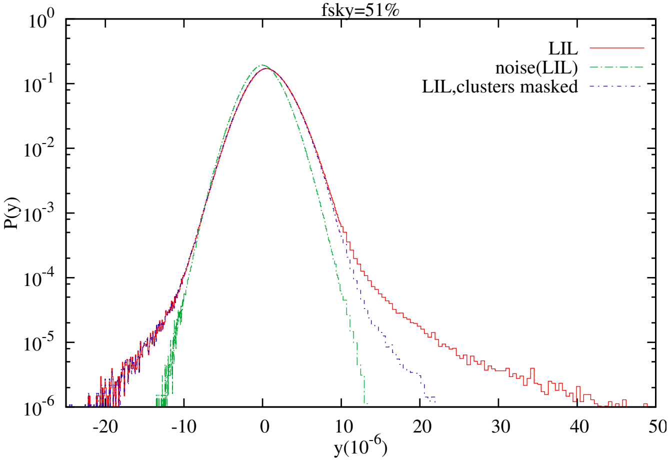


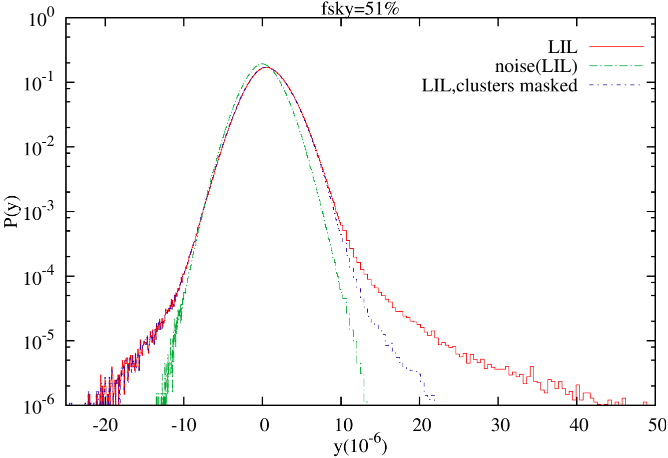
# New upper limit on $\langle y \rangle$ from $y$-map created by combining Planck HFI channels

*(Khatri & Sunyaev 2015)*



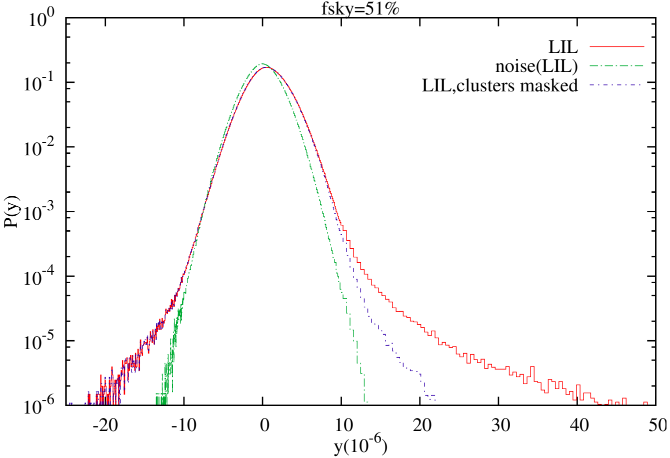
# New upper limit on $\langle y \rangle$ from $y$-map created by combining Planck HFI channels

average the full pdf: $\langle y \rangle \approx 1.0 \times 10^{-6}$ *(Khatri & Sunyaev 2015)*



# New upper limit on $\langle y \rangle$ from $y$-map created by combining Planck HFI channels

average the positive tail: $\langle y \rangle < 2.2 \times 10^{-6}$ *(Khatri & Sunyaev 2015)*



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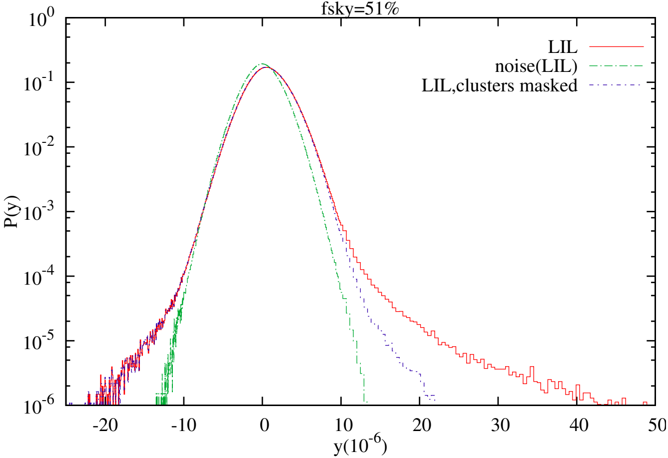
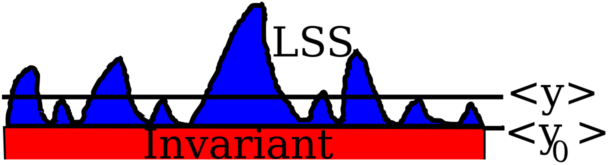


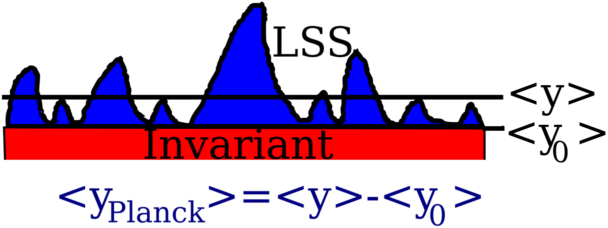

6.8 times stronger compared to the COBE-FIRAS upper limit:
$\langle y \rangle < 15 \times 10^{-6}$ *(Fixsen et al. 1996)*

# Planck is sensitive to only the fluctuations in *y*




$$\langle y_{Planck} \rangle = \langle y \rangle - \langle y_0 \rangle$$

# Planck is sensitive to only the fluctuations in $y$



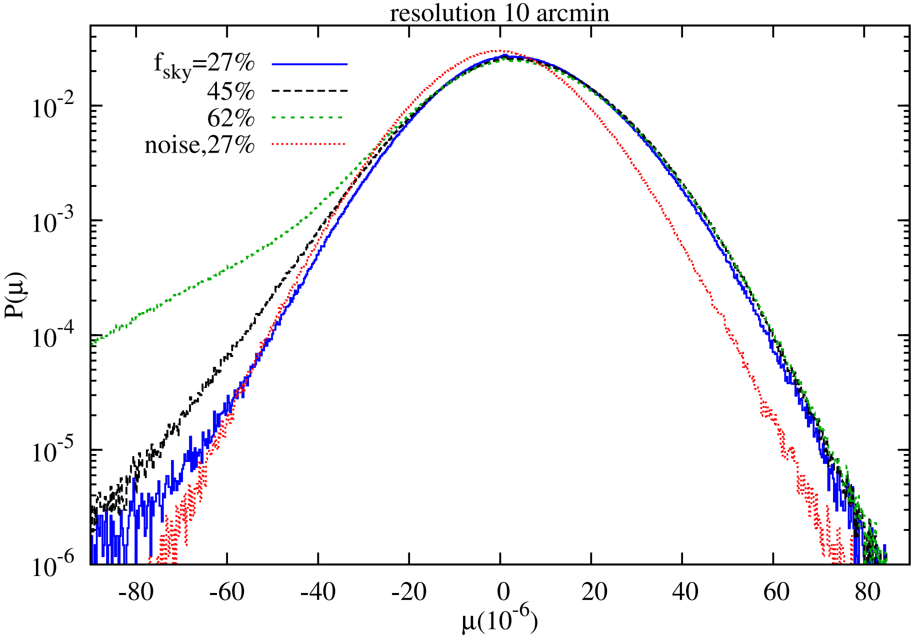

- In the standard model of cosmology the invariant component is smaller, $\langle y_0 \rangle \ll \langle y \rangle$
- This upper limits rules out models involving preheating of the IGM

  *Springel et al. 2001,Munshi et al. 2012*
- Most simulations predict $\langle y \rangle \ll\sim 10^{-6} - 3 \times 10^{-6}$

  *Refregier et al. 2000, Nath & Silk 2001, White et al. 2002,Schaefer et al. 2006*
- Indications from our analysis of Planck that true value may be closer to $\approx 10^{-6}$ (*Khatri & Sunyaev 2015*).

## $\mu$-distortion

*(Khatri & Sunyaev 2015)*



# Upper limit on the $\mu$-distortion fluctuations

- Variance: $\sigma^2_{\text{map}} = \mu^2_{\text{rms}} + \sigma^2_{\text{noise}}$
- Remove the noise contribution from map variance using half-ring half difference maps from Planck
- Remove mean $\langle\mu\rangle$ to get the central variance, $\mu^{\text{central}}_{\text{rms}} \equiv (\mu^2_{\text{rms}} - \langle\mu\rangle^2)^{1/2}$

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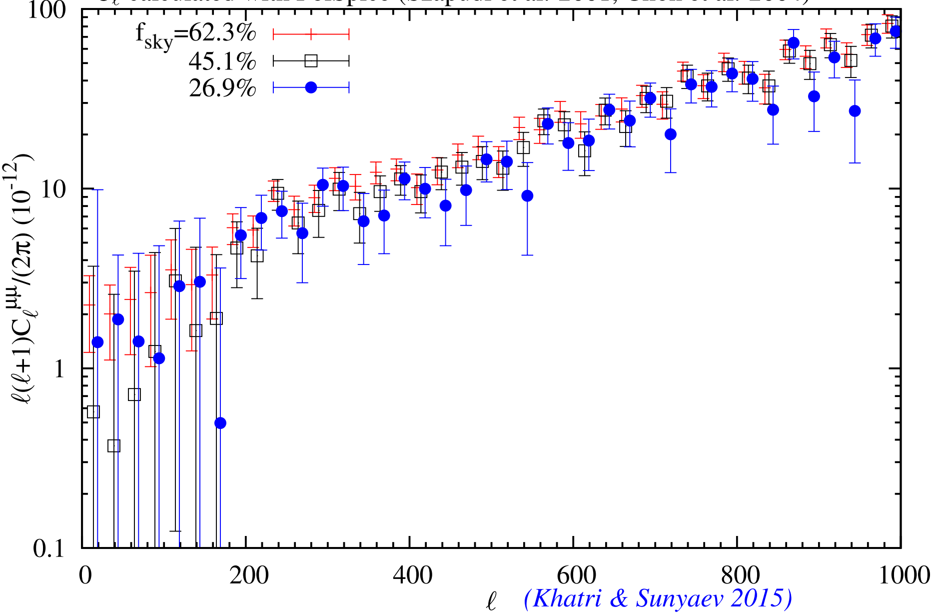
- COBE limit: $\langle\mu\rangle < 90 \times 10^{-6}$ *(Fixsen et al. 1996)*

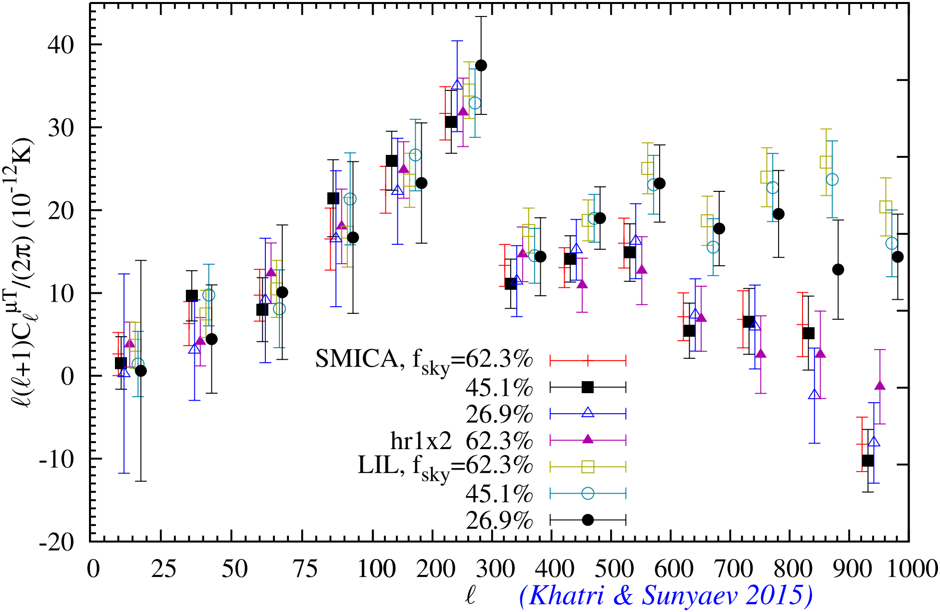
## Power spectrum: $C_\ell^{\mu\mu}|_{\ell=2-26} = (2.3 \pm 1.0) \times 10^{-12}$

$C_\ell$ calculated with PolSpice (Szapudi et al. 2001, Chon et al. 2004)

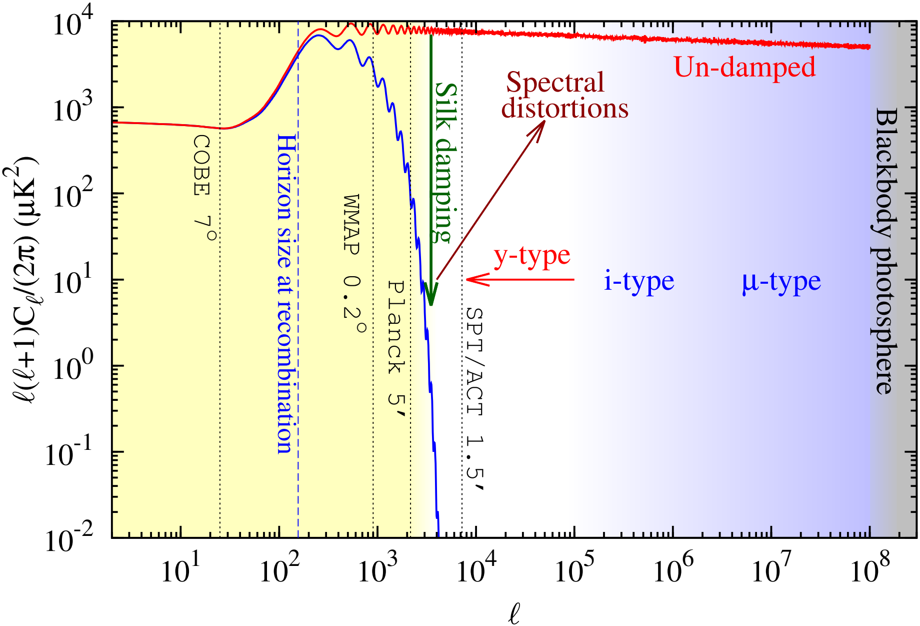



*(Khatri & Sunyaev 2015)*

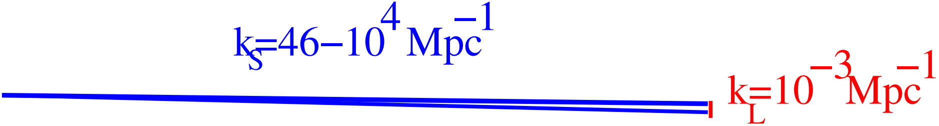
# Power spectrum: $C_\ell^{\mu T}|_{\ell=2-26} = (2.6 \pm 2.6) \times 10^{-12}$ K



# Silk damping: 17 e-folds of inflation!



# Fluctuations in $\mu$ if non-Gaussianity (Pajer & Zaldarriaga 2012)




*Khatri& Sunyaev 2015*

$$\frac{\ell(\ell+1)}{2\pi}C_\ell^{\mu T} \approx 2.4\times 10^{-17} f_{\rm NL}\ \mathrm{K}$$

$$\frac{\ell(\ell+1)}{2\pi}C_\ell^{\mu\mu} \approx 1.7\times 10^{-23} \tau_{\rm NL}$$

$$\tau_{\rm NL} = \frac{9}{25} f_{\rm NL}^2$$

# Fluctuations in $\mu$ if non-Gaussianity (Pajer & Zaldarriaga 2012)

$k_S$=46–$10^4$ $Mpc^{-1}$

$k_L$=$10^{-3}$ $Mpc^{-1}$

*Khatri& Sunyaev 2015*

$$f_{\rm NL} < 10^5$$

$$\tau_{\rm NL} < 10^{11}$$

$$5 \times 10^4 \lesssim \frac{k_S}{k_L} \lesssim 10^7$$

Only other comparable constraints from primordial black holes

*Byrnes, Copeland, & Green 2012*

## We have (re-)entered the era of CMB spectrum cosmology

Future: Many orders of magnitude improvement in next decade
PIXIE (NASA), LiteBIRD (JAXA)

http://www.mpa-garching.mpg.de/~khatri/szresults/
http://www.mpa-garching.mpg.de/~khatri/muresults/