Probing Galactic sub-structure with Lensed CMB?

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What is being lensed?

Expand

$$T(\vec{\theta}) = T_0 + \nabla T \cdot \vec{\theta} + \frac{1}{2}\frac{\partial^2 T}{\partial\theta_i \partial\theta_j}\theta_i\theta_j + \ldots$$

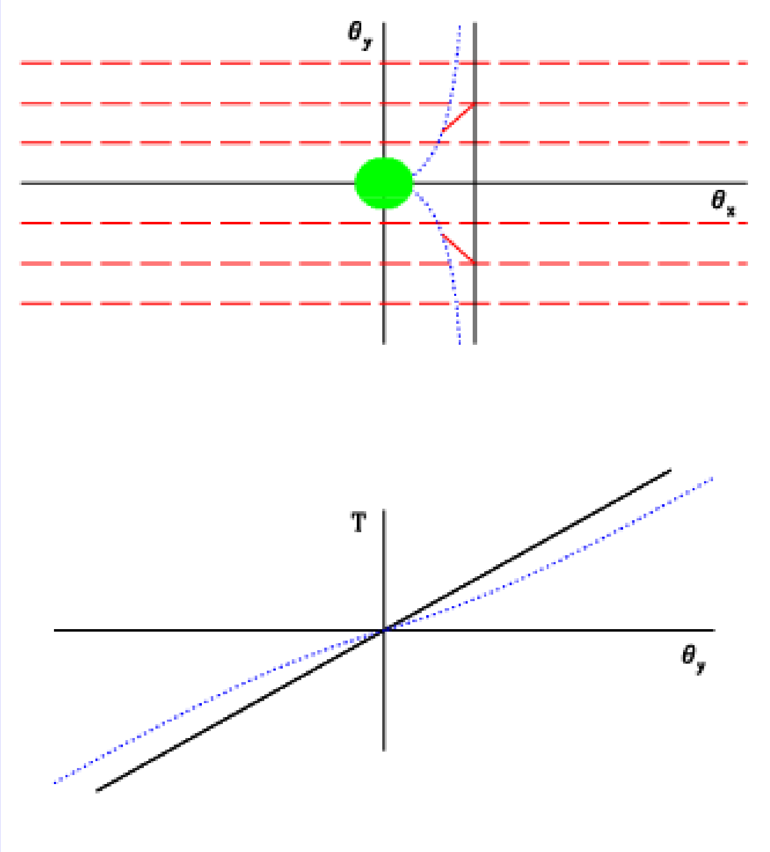
Constant piece does not get lensed. Gradient has rms:

$$\begin{aligned}
\langle|\nabla T|^2\rangle^{1/2}\theta &= \left[\sum_l \frac{l^2 C_l}{2\pi} l^2\right]^{1/2} \theta \\
&\sim (100\mu K) l_{\text{peaks}} \theta \sim (100\mu K) 500 \left(\frac{\theta}{210,000''}\right). \\
&\sim 0.22\mu K \left(\frac{\theta}{1''}\right)
\end{aligned}$$

Quadrupole is smaller by a factor of $l_{\text{peaks}}\theta \sim (\theta/5')$.

The source is a gradient.

Lensed dipole produces asymmetric signal



Seljak & Zaldarriaga 1999

The observed temperature $T(\vec{\theta})$ is equal to unlensed temperature at distorted positions: $\tilde{T}(\vec{\theta}+\delta\vec{\theta})$. Expand

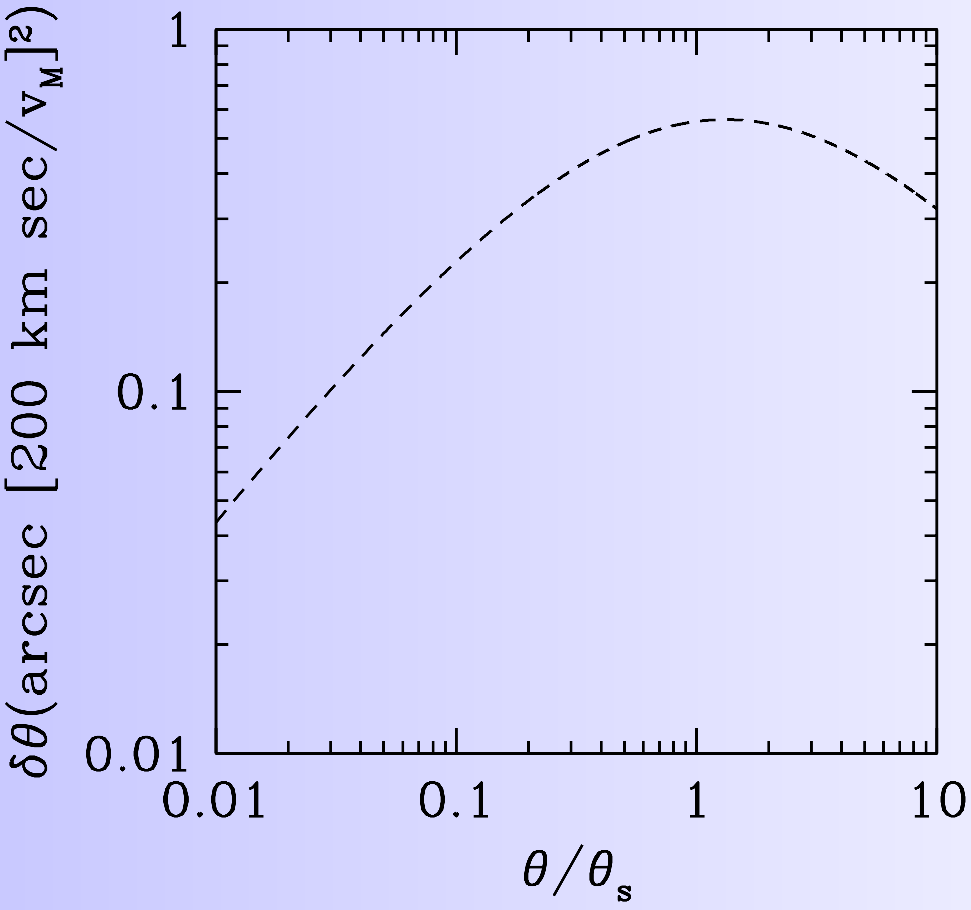
$$T(\vec{\theta}) = \tilde{T}(\vec{\theta}) + \frac{d\tilde{T}}{d\vec{\theta}} \cdot \delta\vec{\theta} = \frac{d\tilde{T}}{d\vec{\theta}} \cdot \left[\vec{\theta} + \delta\vec{\theta}\right]$$

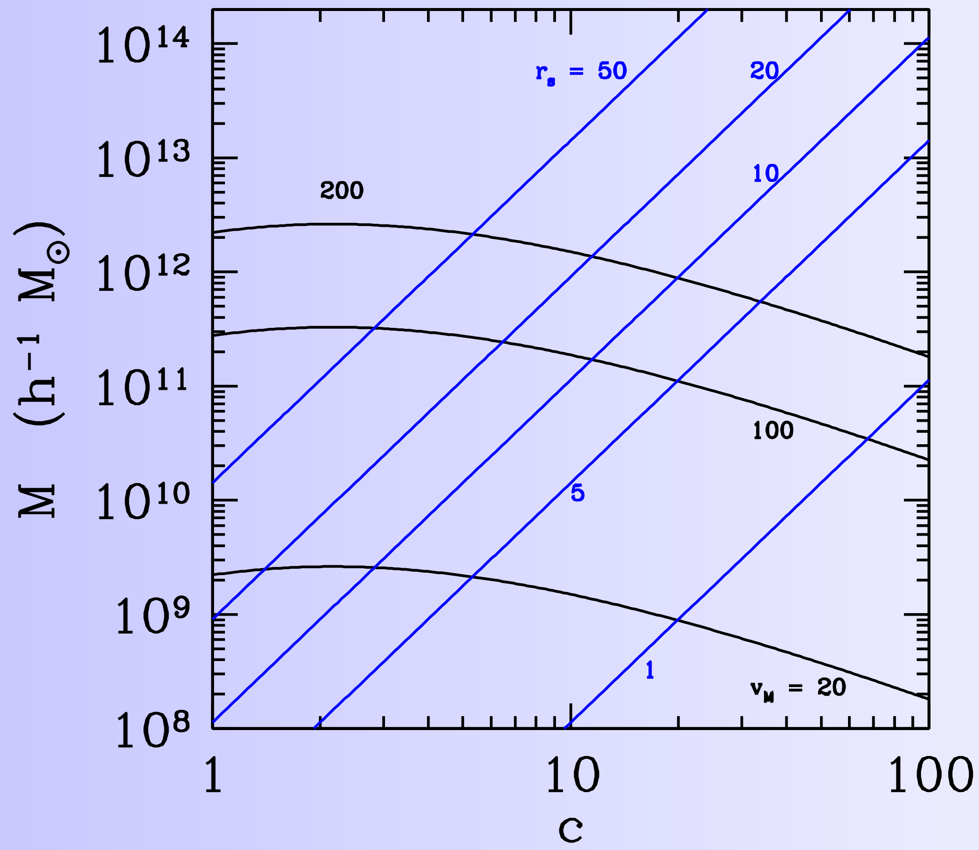
Another unique feature: correlated with large gradient

The deflection angle is determined by the projected mass density:

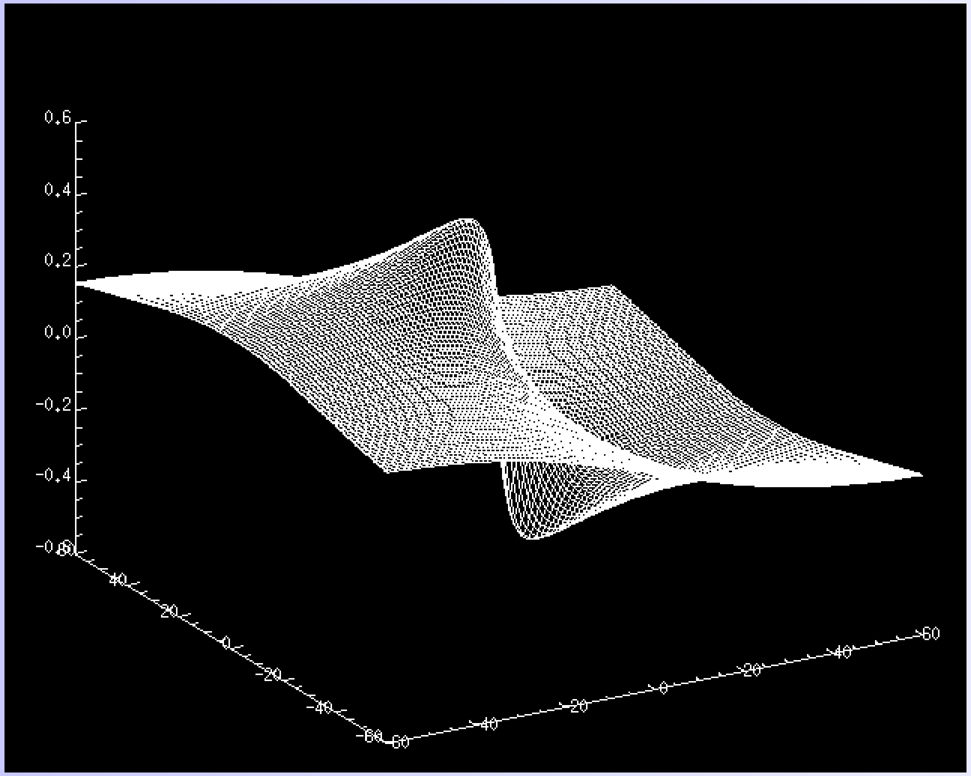
$$\delta\vec{\theta} = -8\pi G \frac{\vec{\theta}}{\theta^2} \frac{(\chi_S - \chi_L)}{\chi_L \chi_S} \int_0^{\chi_L \theta} dR\, R\, \Sigma(R)$$

NFW profile leads to “gentle” deflection



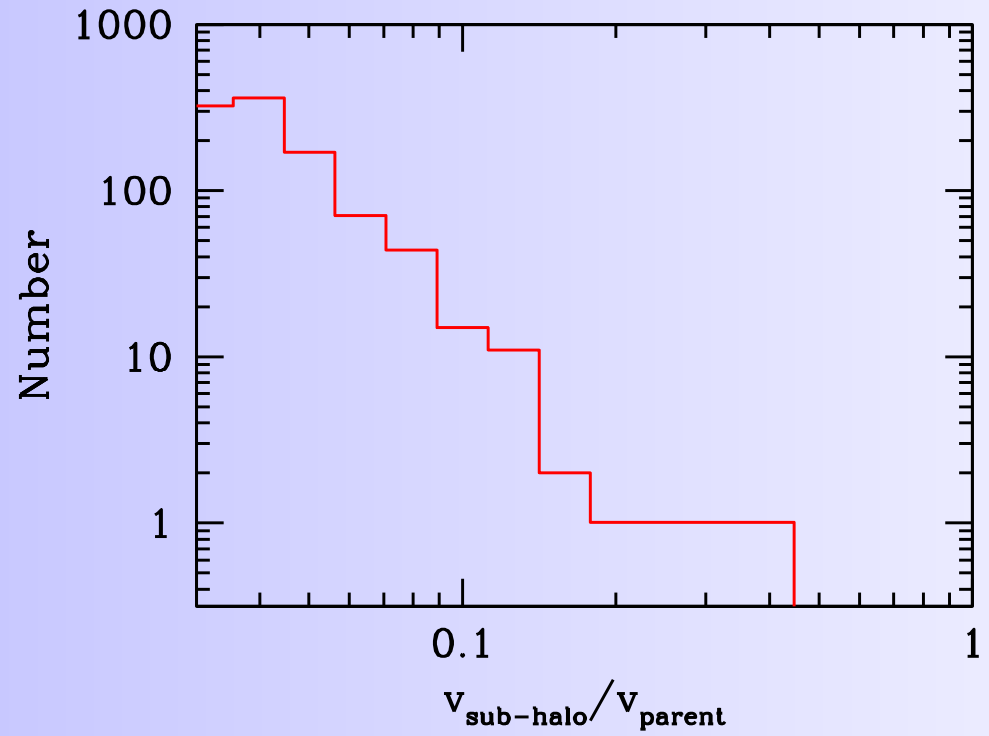


Scale radius is tens of kpc $\leftrightarrow \sim 5''$ at $z = 1$

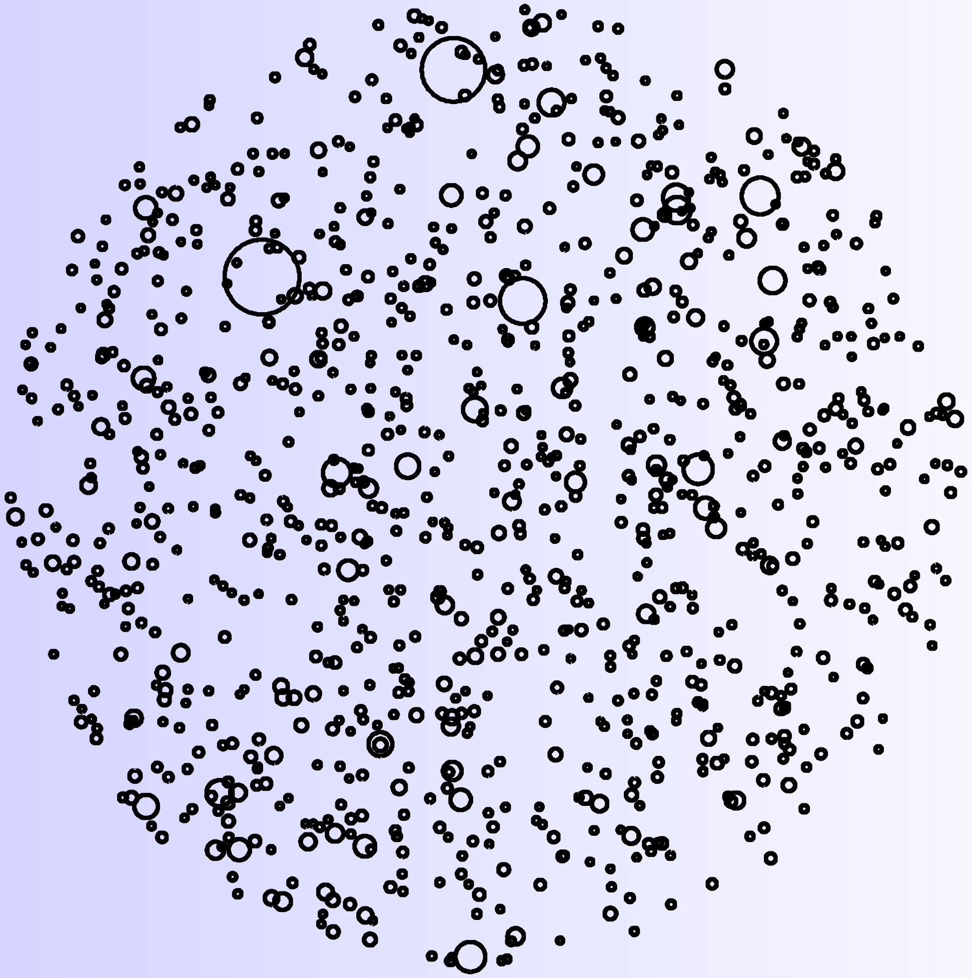


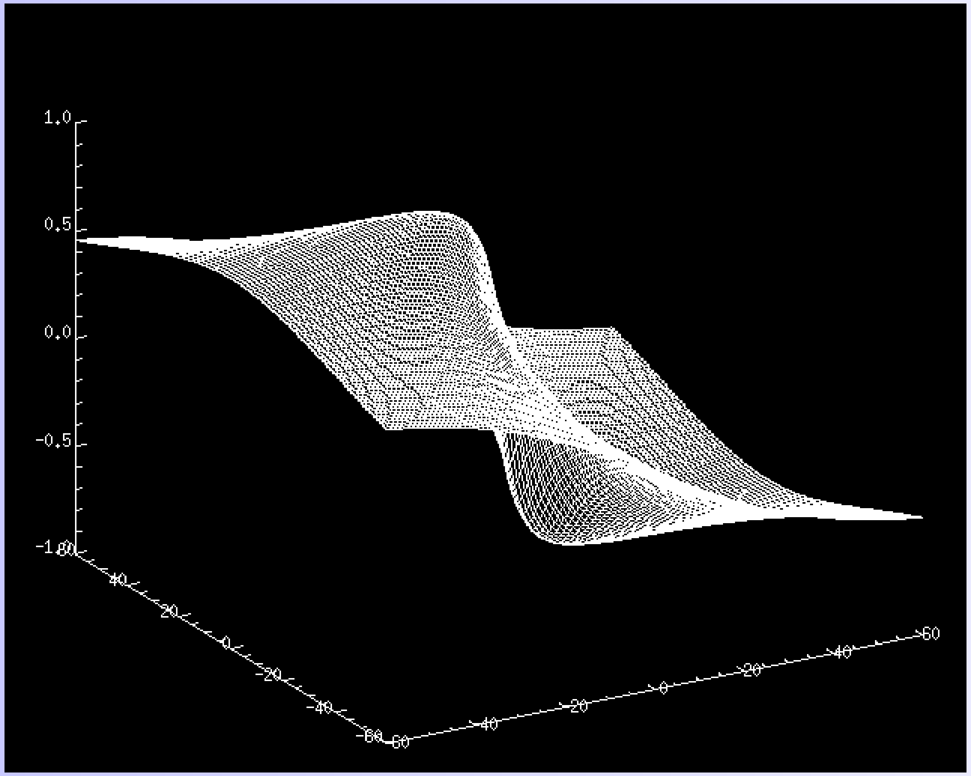
Characteristic signal peaks on either side at $\sim 5''$.

Put in sub-structure a la Moore et al.



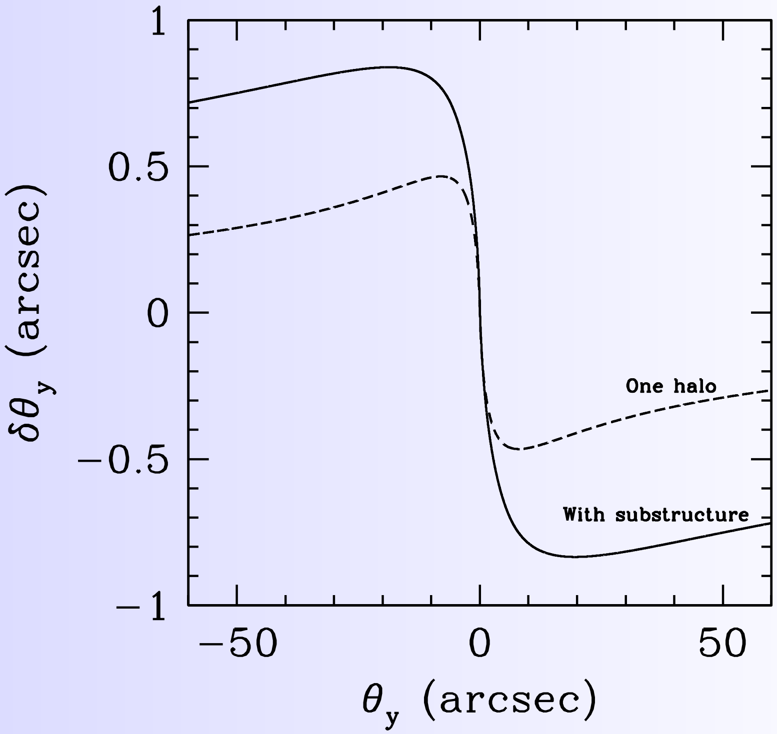
Put them in at random



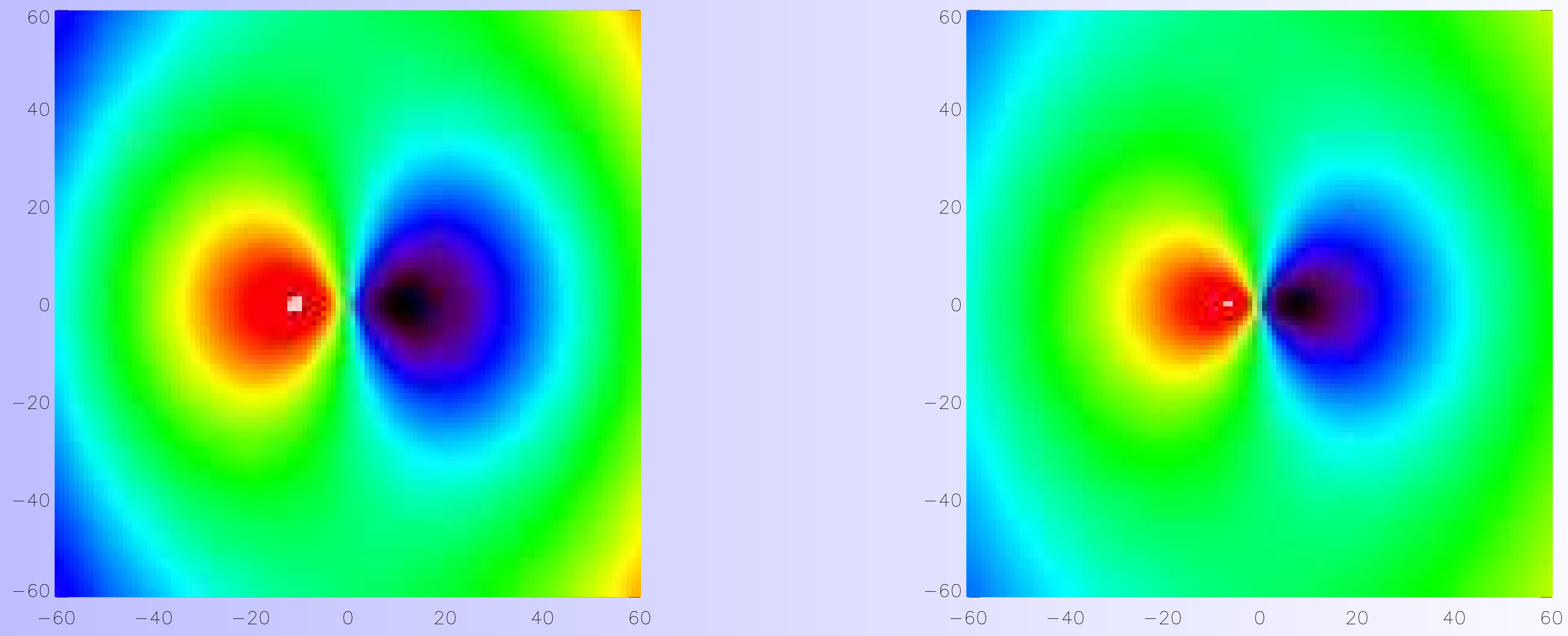


Very similar to no-substructure case

- moves features to larger angles
- lifts amplitude
- probably degenerate with change in one halo parameters



CMB Lensing not sensitive to sub-structure



Amplitude of hot/cold spot (with gradient removed) is $1''$.

Still, there will be unique signature

- Amplitude is of order (background gradient) $\times 1''$. Primary background is $.22\mu K/$arcsec

- Signal to noise for a single galaxy might be $1:10$ or even $1:100\ldots$

- But, there are many galaxies

- Source SZ might lead to (much) larger signal

Conclusions

- Lensed CMB *cannot* probe galactic sub-structure
- Can see effects of galaxies on angular scales $\sim 20 - 40''$
- Could probably average over hundreds of galaxies to learn about average mass