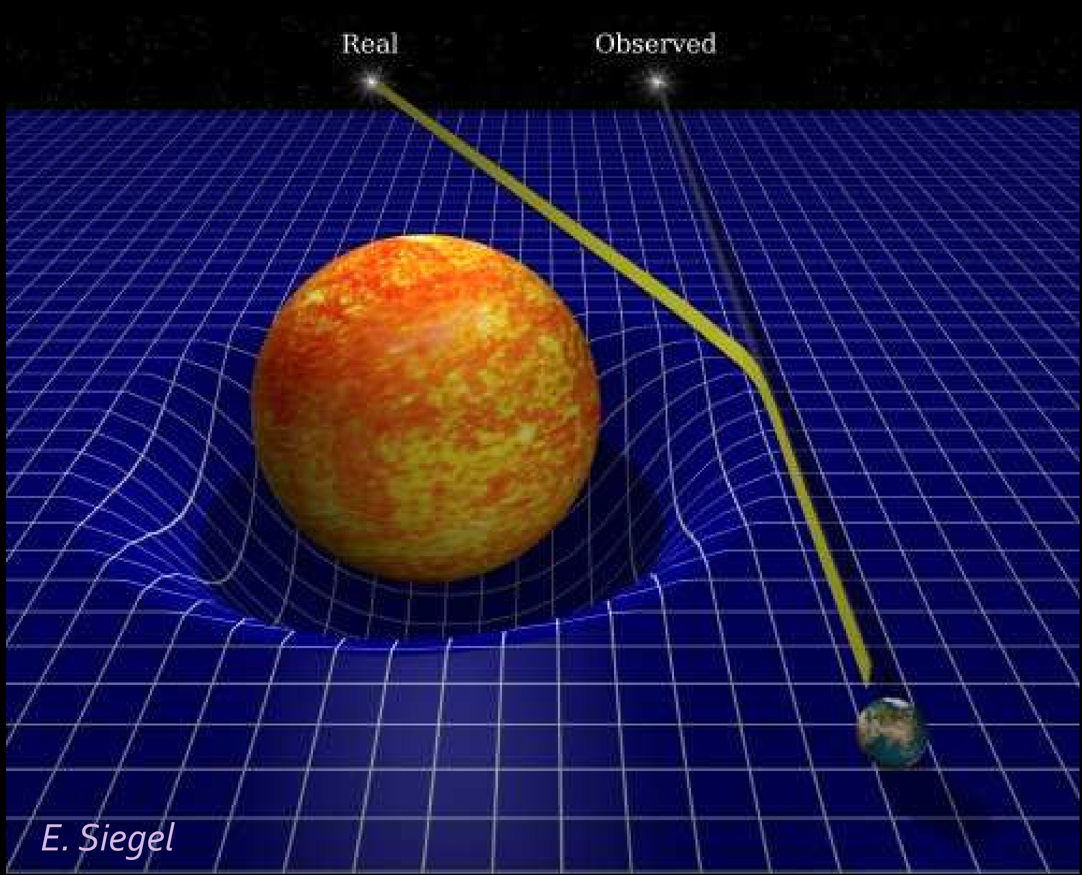
How Sensitive is the CMB to a Single Lens?



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Anastasia Fialkov

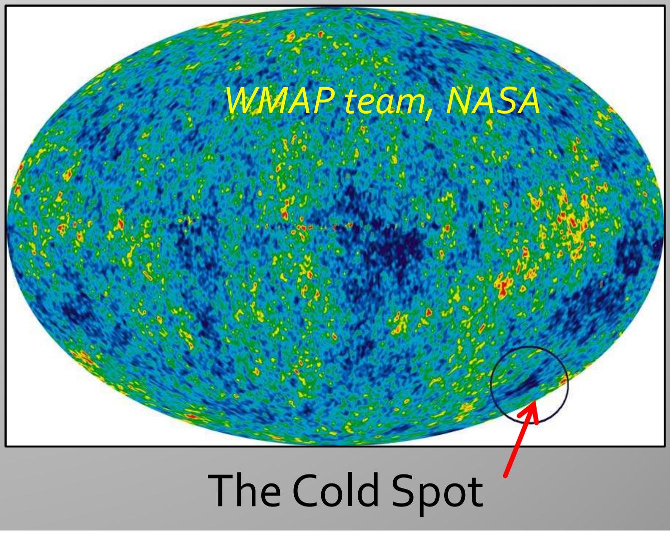
Based on: B. Rathaus, A. Fialkov, N.Itzhaki (JCAP 2011)

Introduction

- We study weak lensing of the CMB by a single lens that breaks statistical isotropy.

- Examples:
  - Texture (Turok & Spergel 1990)
  - Giant Void (Inoue & Silk 2007)
  - Traces of a Pre-Inflationary Point particle (Itzhaki 2008, Fialkov *et al* 2010)

- Previous works in this field study lensing by a giant void and a texture. Motivated by the WMAP cold spot.
  (Masina & Notari 2009, 2010; Das & Spergel 2009)

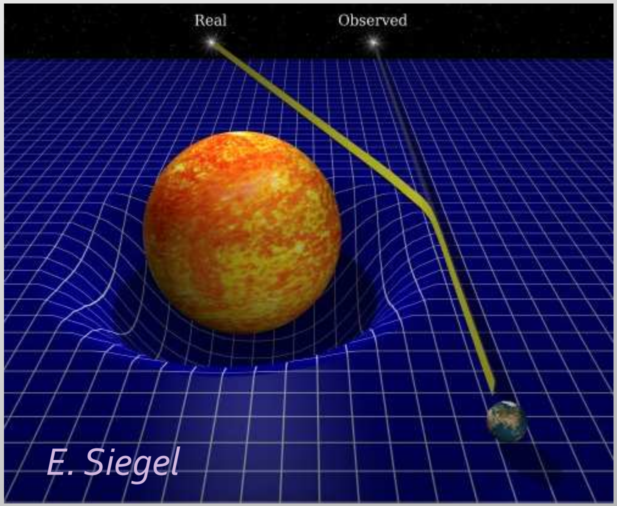


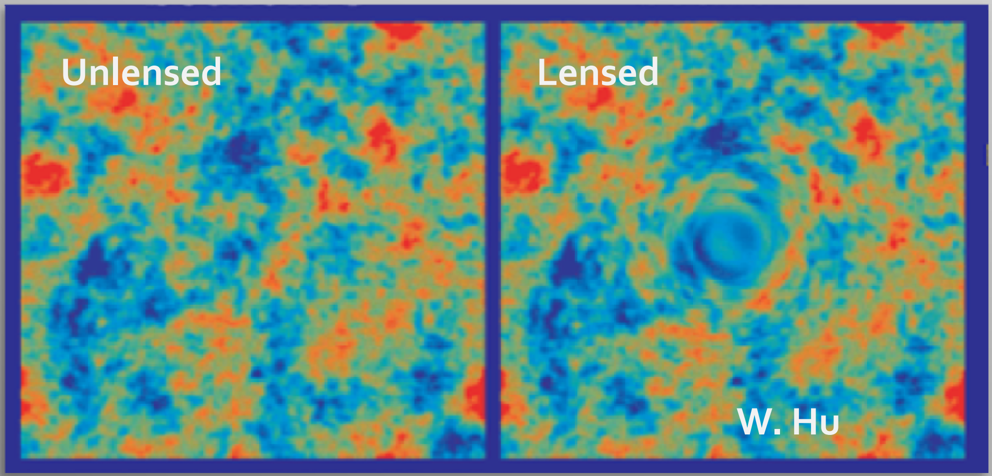
Gravitational Lensing by a Single Lens

- Gravitational lensing is deflection of light by mass

All we need to know is the deflection potential

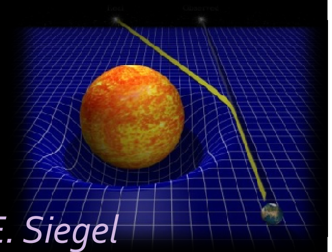
$$\delta\psi = -2\int_0^{r_{lss}} dr \, \frac{r_{lss} - r}{r_{lss} r} \delta\Phi$$





- What is the signal to noise of a single lens in a CMB experiment (e.g. Planck, ACT, SPT)?

Single Lens in an Ideal CMB Experiment

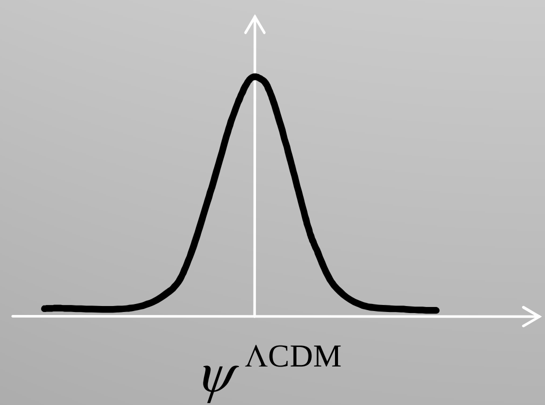


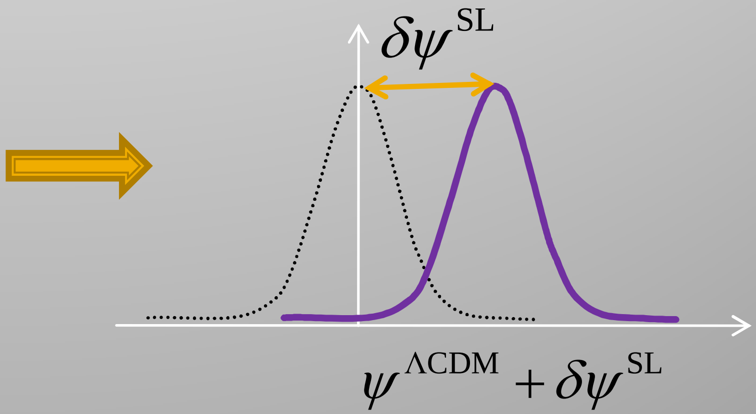
- Complete reconstruction of the deflection potential

Observed: $$\psi^{\Lambda\text{CDM}} + \delta\psi^{\text{SL}}$$

random *non-random*

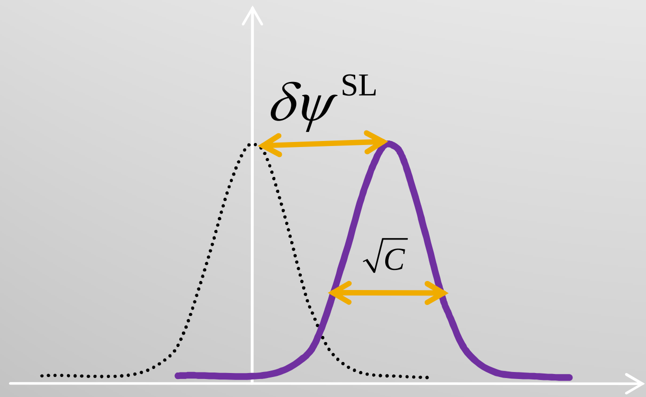
- The single lens adds a 1-point function to the deflection field





Signal to Noise in an Ideal CMB Experiment

- Assuming gaussian distribution

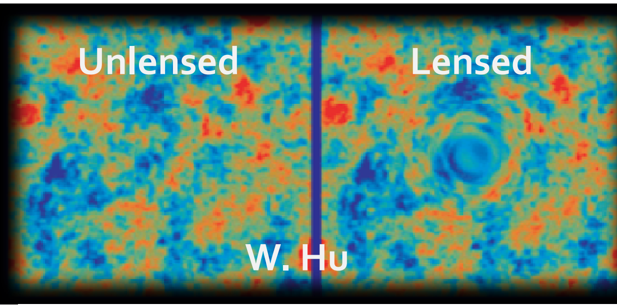


$$\left(\frac{S}{N}\right)^2_{\mathrm{IDEAL}} = \sum_{lm} \frac{\left|\delta\psi^{SL}_{lm}\right|^2}{C_l^{\psi}}$$

This is the upper limit of the signal to noise. Any observable signature should be smaller!

$$\left(\frac{S}{N}\right)^2_{\mathrm{OTHER}} < \left(\frac{S}{N}\right)^2_{\mathrm{IDEAL}}$$

Observed Temperature Anisotropy.

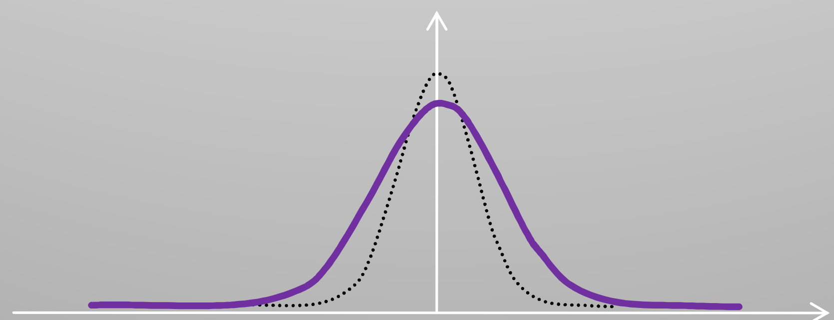


- Effect of lensing is to re-map the CMB sky

$$\tilde{T}(\theta)=T\left(\theta+\nabla\delta\psi^{\mathrm{SL}}\right) \xrightarrow[\textit{Weak lensing}]{} \tilde{T}(\theta)=T(\theta)+\underbrace{\nabla\delta\psi^{\mathrm{SL}}\,\nabla T(\theta)}_{\delta T}$$

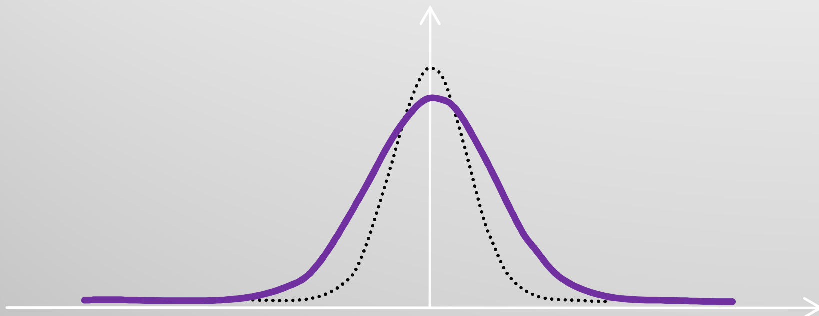
Random

- The single lens changes the 2-point function



Signal to Noise in a Realistic CMB Experiment

- Assuming gaussian distribution



$$\left(\frac{S}{N}\right)^2_{\mathrm{TEMP}} = \frac{1}{2}\sum_{ll'}\frac{\left|\Delta C_{l,l'}\right|^2}{C_l^T C_{l'}^T}$$

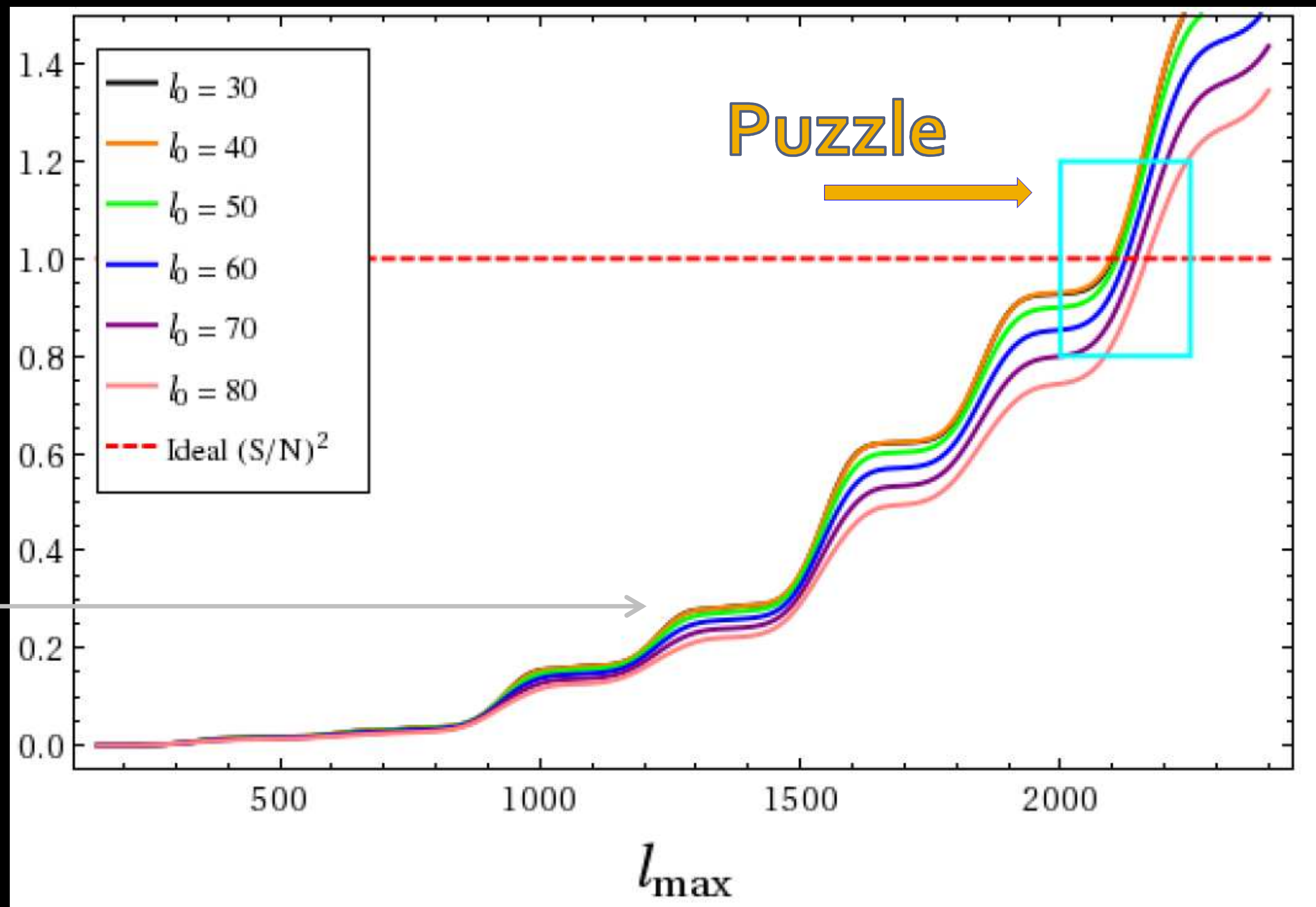
$$\Delta C_{l,l'} = \left\langle \tilde{T}_l \tilde{T}_{l'} \right\rangle - \left\langle T_l T_{l'} \right\rangle = \left\langle T_l^* \times \left(\nabla \delta\psi^{\mathrm{SL}}\, \nabla T\right)_{l'} \right\rangle + \mathrm{cc} \quad \left\{ \begin{array}{l} \textit{leading term} \\ \propto \delta\psi^{\mathrm{SL}} \end{array} \right.$$

The leading contribution to the signal to noise comes from the off-diagonal terms of $\Delta C_{l,l'}$

*** This signal to noise should be smaller than the Ideal**

Accumulated SN² vs. the resolution of a CMB experiment

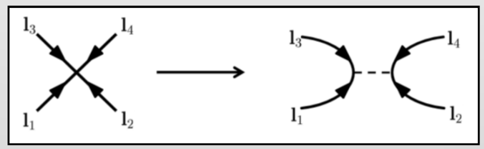
$$\left(\frac{S}{N}\right)^2_{\mathrm{TEMP}} \Big/ \left(\frac{S}{N}\right)^2_{\mathrm{IDEAL}}$$



- Wrong behavior at l > 2000.
- Universal behavior. Does not depend on the deflecting potential *(plotted: single-mode deflection)* and/or parameters of the model.

Non-Gaussianity of Lensed Temperature

- We know that: weak lensing introduces non-gaussianity via connected 4-point function

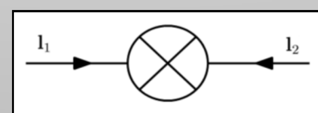


(e.g. Lewis & Challinor 2006)

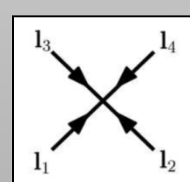
- "Field theory for lensing". Feynmann rules:

Propagator: lensed LCDM temperature power spectrum

Vertices:



Single lens

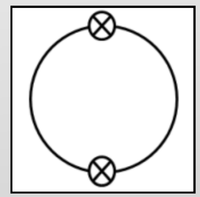


LCDM 4pf (connected)

Correction to the Realistic Signal to Noise

- An alternative way to calculate the realistic signal to noise

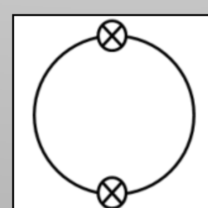
$$\left(\frac{S}{N}\right)^2_{\mathrm{TEMP}} = \frac{1}{2}\sum_{ll'}\frac{\left|\Delta C_{l,l'}\right|^2}{C_l^T C_{l'}^T} =$$



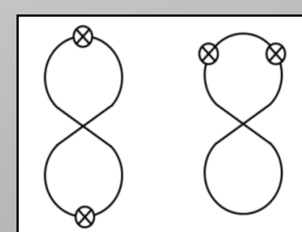
$$\propto \left(\delta\psi^{\mathrm{SL}}\right)^2$$

- The 2-loop correction to the signal to noise (contributed by the non-gaussianity)

$$\left(\frac{S}{N}\right)^2_{\mathrm{OBS}} =$$

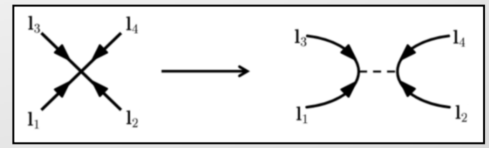


$$+$$



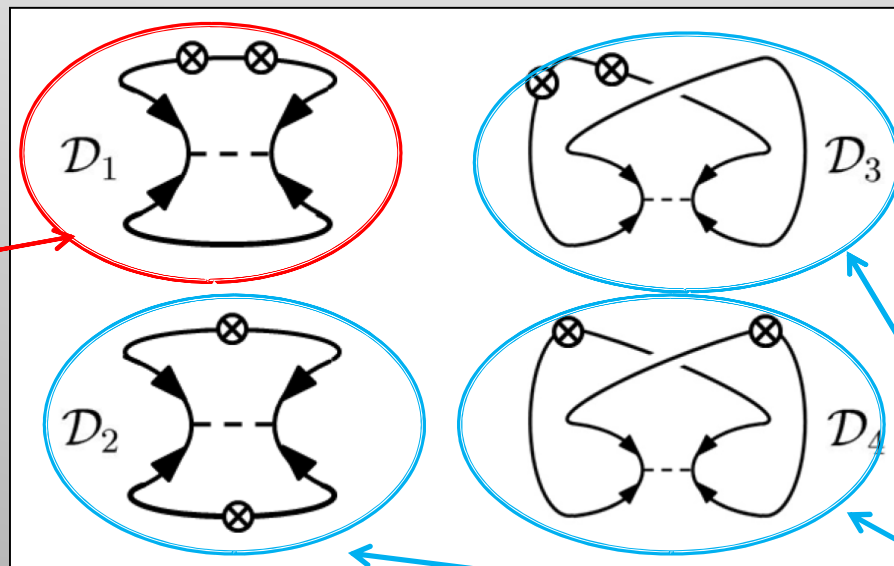
Details of Calculation

- Substructure of the vertex is complicated



- 4 different ways to add the lens and to close loops

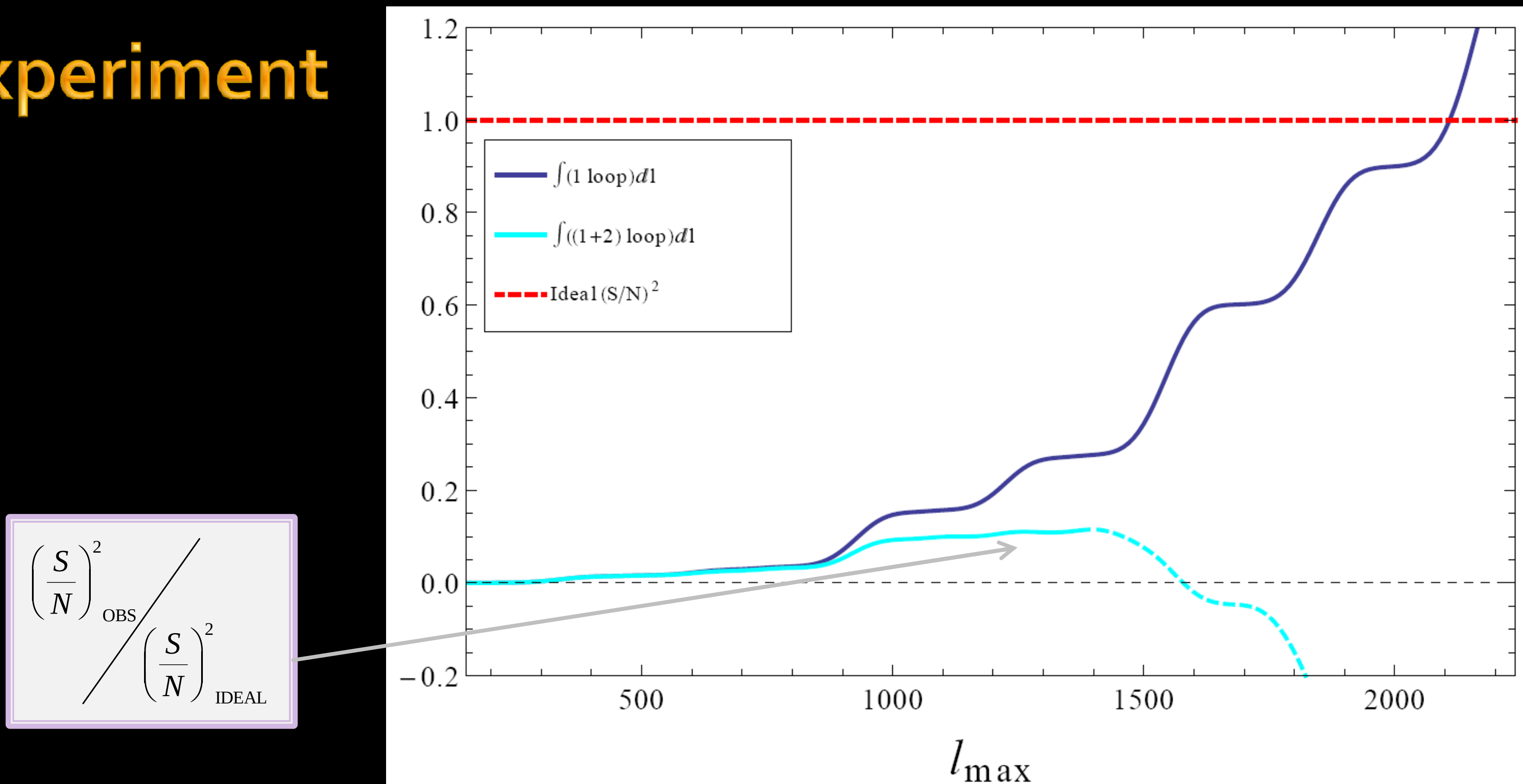
Positive



Negative

*** Overall contribution is negative**

Accumulated SN² vs. the resolution of a CMB experiment



- The correction becomes important at l=900.
- At l = 1400 the accumulated SN^2_{OBS} starts to drop. Higher order terms in loop expansion should be added to fix it.
- Plateau at 1000<l<1400. The true SN from T is: $\left(S/N\right)_{OBS} \sim \frac{1}{3}\left(S/N\right)_{IDEAL}$

Conclusions

- The signal to noise of a single lens (of any kind) is overestimated in literature.
- In particular, a giant void (a texture), that was proposed to explain the cold spot, can barely (cannot) be detected via weak lensing.
- For a void that gives the cold spot:

$$\boxed{\left(S/N\right)_{\mathrm{IDEAL}} = 3.9} \Rightarrow \boxed{\left(S/N\right)_{\mathrm{OBS}} = 1.3}$$

Thank you