Non-Gaussianities with next generation CMB experiments: challenges and new observables

Daan Meerburg

VENI
VIDI
VICI

rijksuniversiteit
groningen

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BUT:

Still pursue this since we have good theoretical understanding of CMB bispectrum *and* space between fnl = 1 and current bounds is populated with many early universe models and a detection would be monumental.

Background on NGs

Bispectrum basics

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- 3pt function uniquely sensitive to dynamics in the early Universe. Schematically:

$$\langle\zeta(\mathbf{k}_1)\zeta(\mathbf{k}_2)\zeta(\mathbf{k}_3)\rangle \propto f_{\rm NL}^X \delta(\mathbf{k}_1+\mathbf{k}_2+\mathbf{k}_3) f^X(k_1,k_2,k_3)\,.$$

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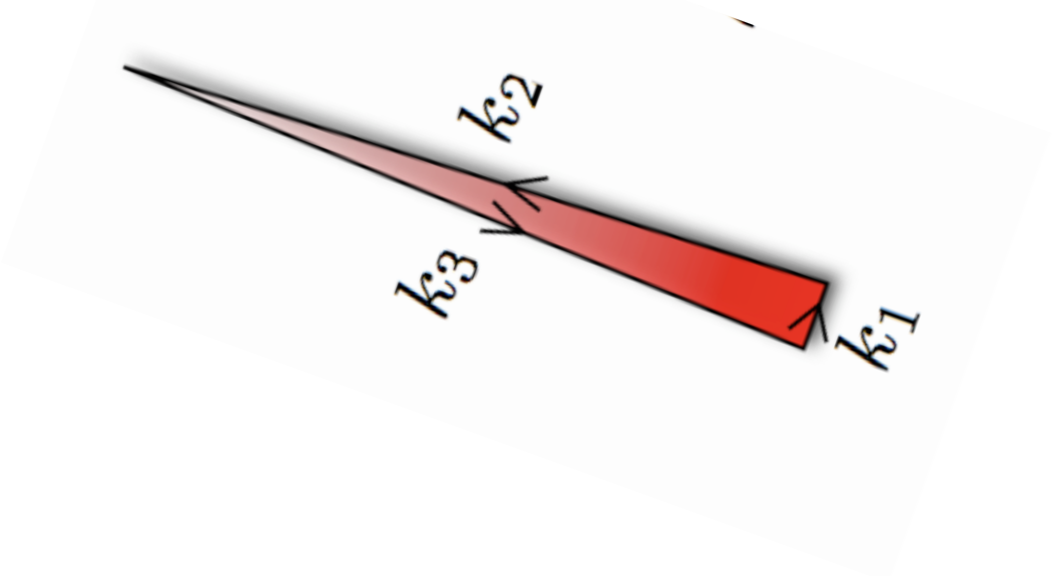
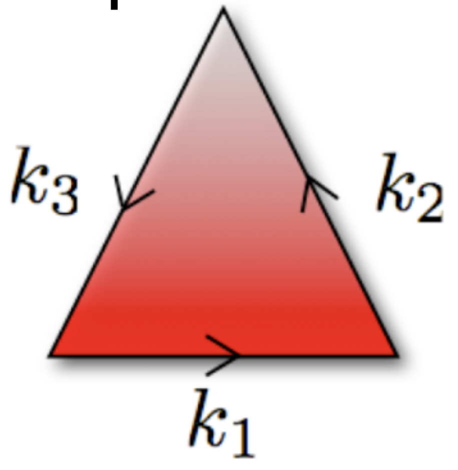
- Shape: $f^{X}(k_1,k_2,k_3)$

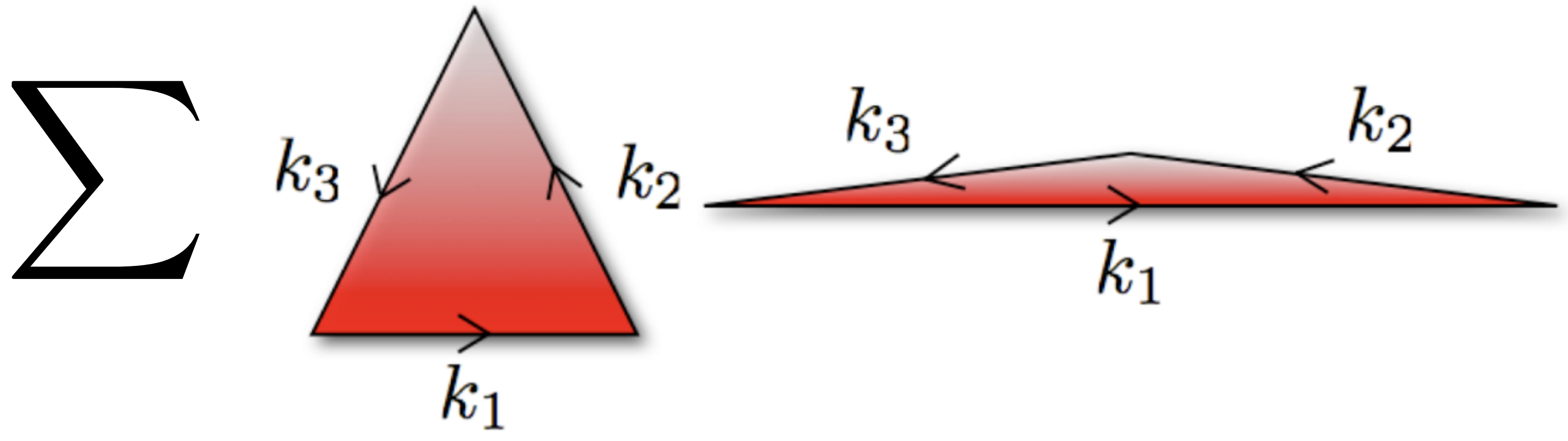
'Local'



'Equilateral'



'Orthogonal'



Alvarez et al 1412.4671

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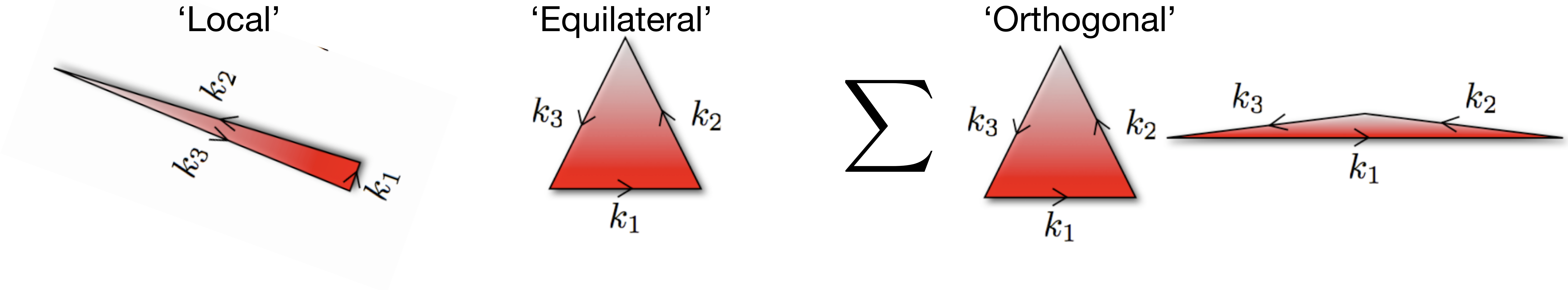

- Amplitude: $f_{\rm NL}^X$

Alvarez et al 1412.4671

	$f_{\rm NL}^{\rm loc} \lesssim 1$	$f_{\rm NL}^{\rm loc} \gtrsim 1$
$f_{\rm NL}^{\rm eq,\,orth} \lesssim 1$	Single-field slow-roll	Multi-field
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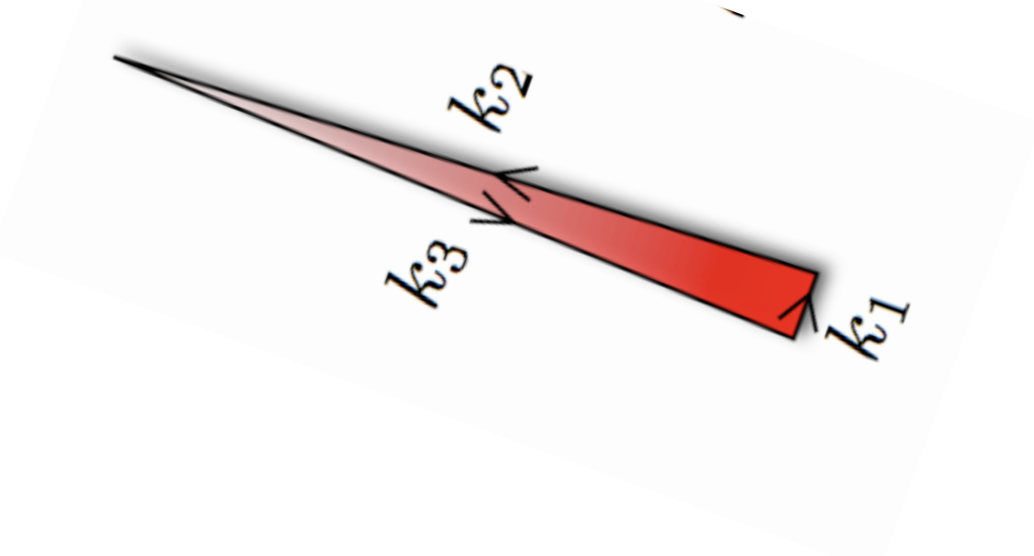

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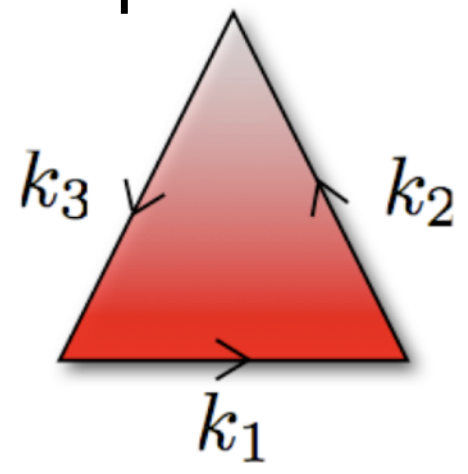

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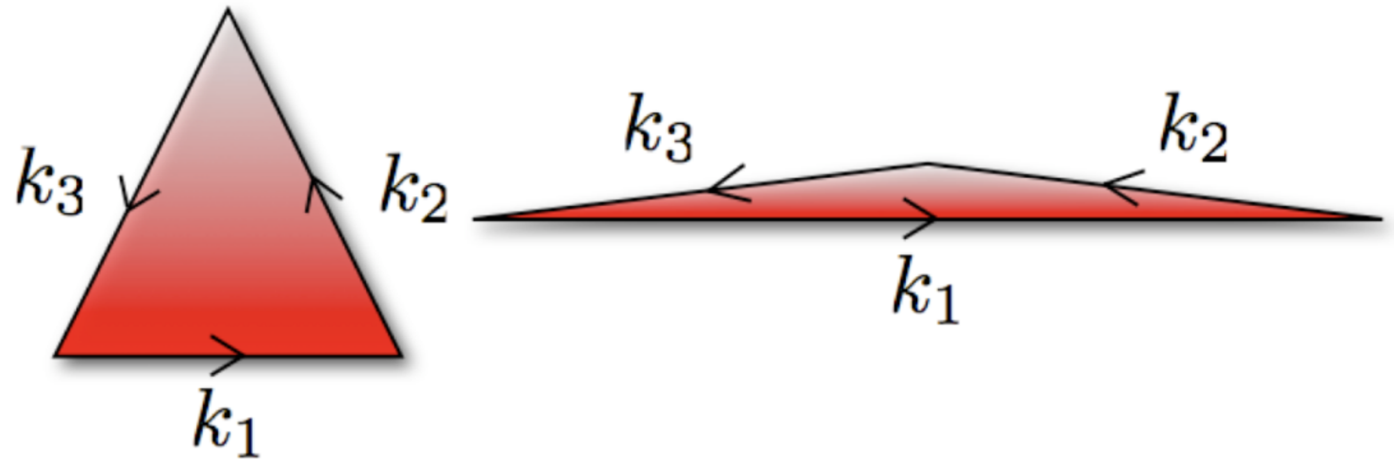
$\sum$



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- Main take-away $f_{\rm NL} \sim \mathcal{O}(1)$ typically presents theoretically compelling threshold

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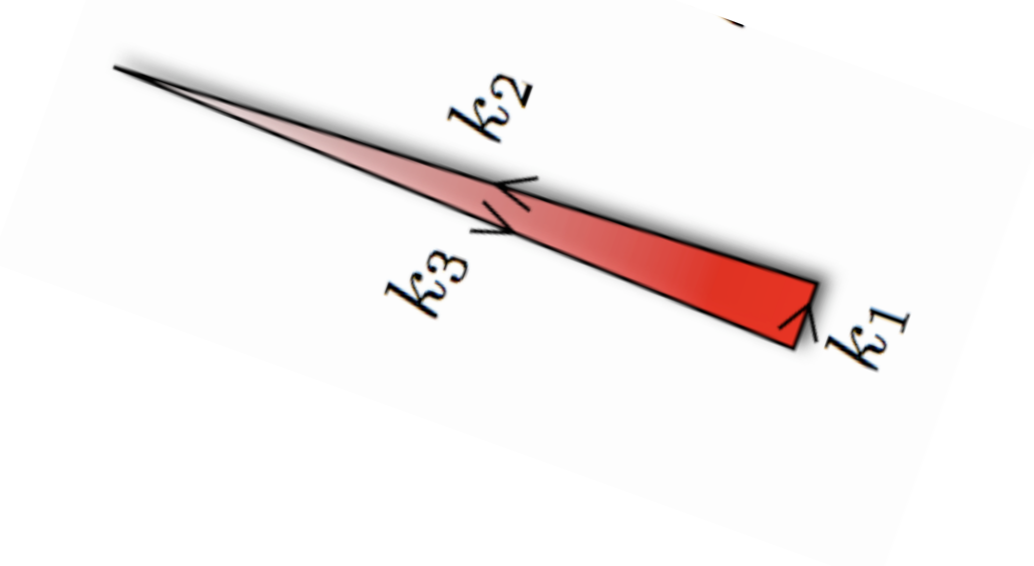

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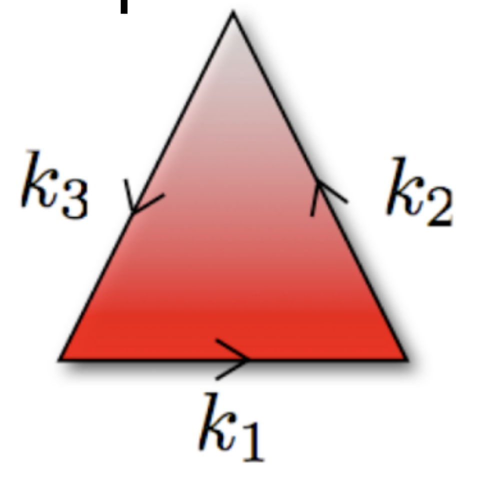

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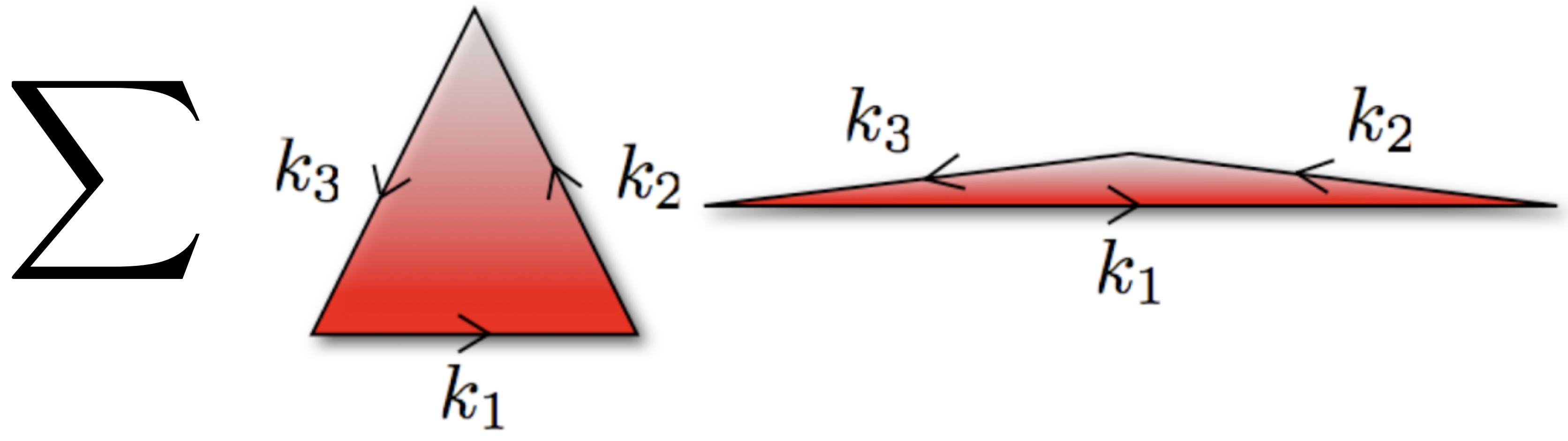

- What are these shapes:

$$f^{\rm loc} = (k_1 k_2)^{-3} + 2 \text{ perm.}$$

$$f^{\rm equil} = -f_{\rm loc} - 2(k_1k_2k_3)^{-2} + k_1^{-1}k_2^{-2}k_3^{-3} + 5 \text{ perm}$$

$$f^{\rm ortho} = -3f_{\rm loc} + 8(k_1k_2k_3)^{-2} + 3k_1^{-1}k_2^{-2}k_3^{-3} + 5 \text{ perm.}$$

CMB: theoretical limitations

Mode counting

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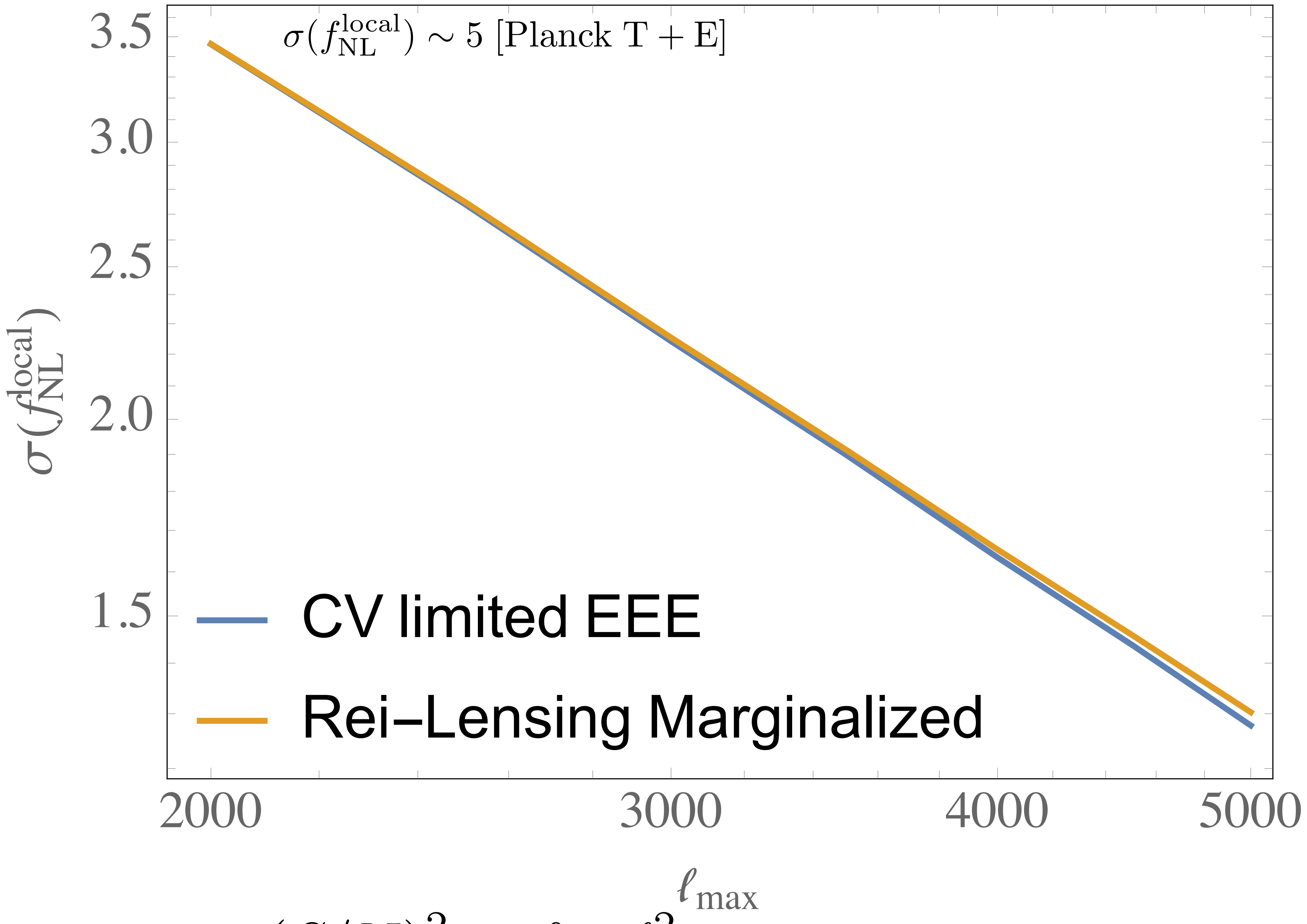
- Similarly, in a full 3D experiment, e.g. large scale structure (see next talk by Olivier) we count as $k_{\rm max}^3$ and signal to noise going as the square root
- Hypothetically then, a theoretical limitation for constraints on the amplitude of the bispectrum $f_{\rm NL}$ is determined by this scaling

Local non-Gaussianity

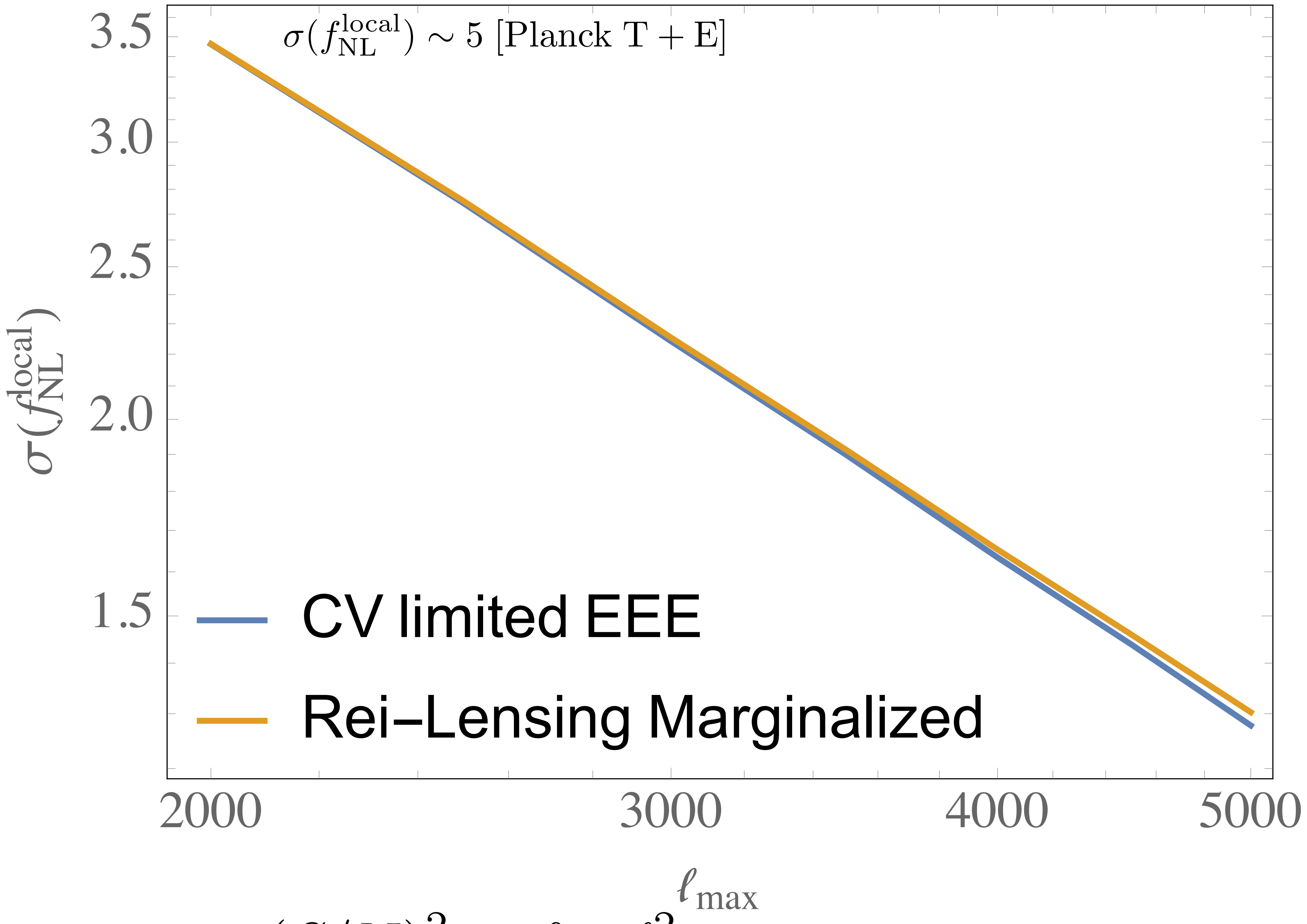


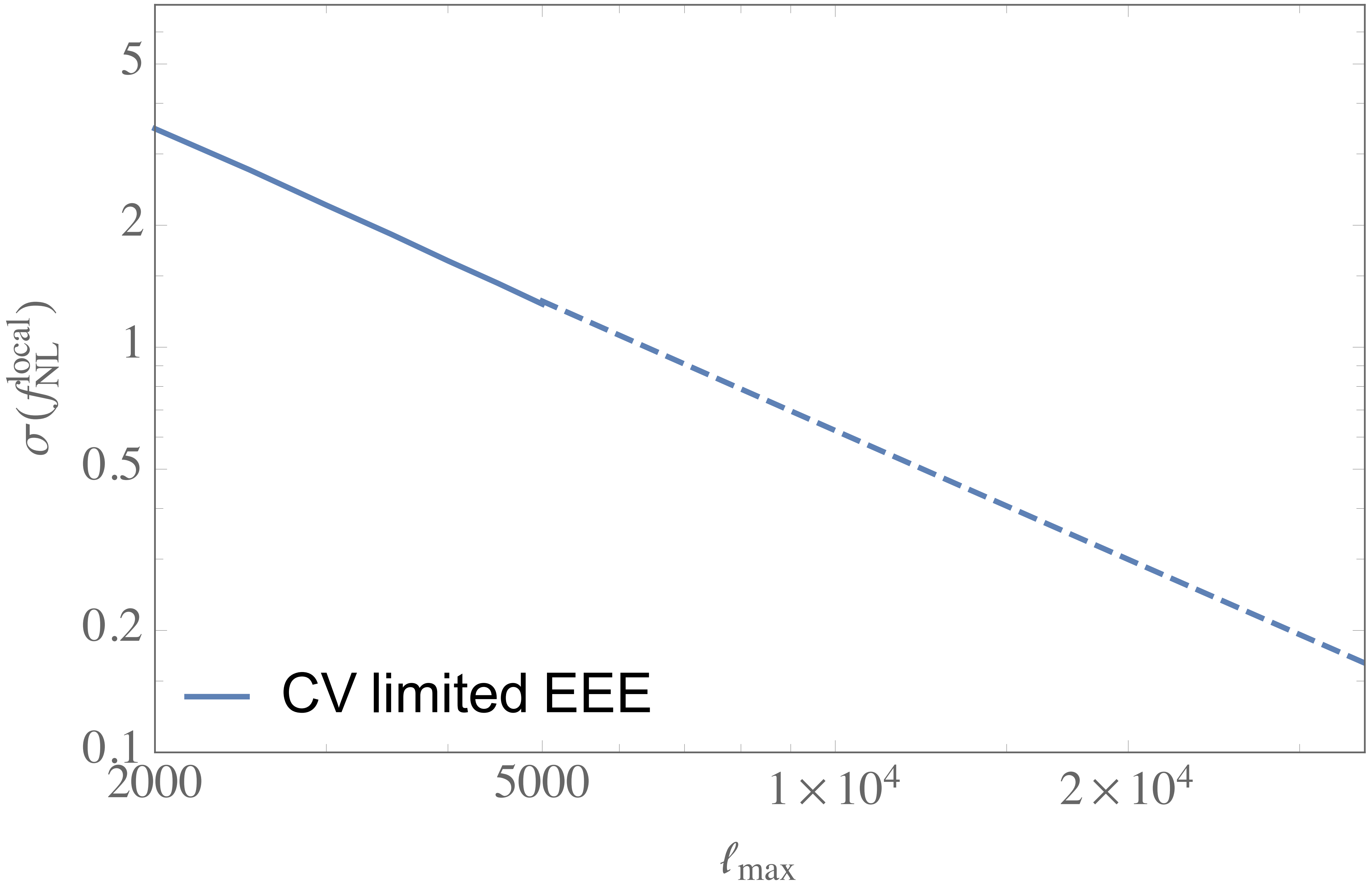
$$(S/N)^2 \propto f_{\rm sky} \ell_{\rm max}^2$$ [Mode counting]

$$(S/N)^2 \propto f_{\rm sky} \ell_{\rm max}^2 \log[\frac{\ell_{\rm max}}{\ell_{\rm min}}]$$ [Actual]

Local non-Gaussianity

CMB in HD workshop 2018





$(S/N)^2 \propto f_{sky}\ell_{max}^2$ [Mode counting]

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$$\sigma(f_{NL}^{local}) = 0.17/\sqrt{f_{sky}}$$

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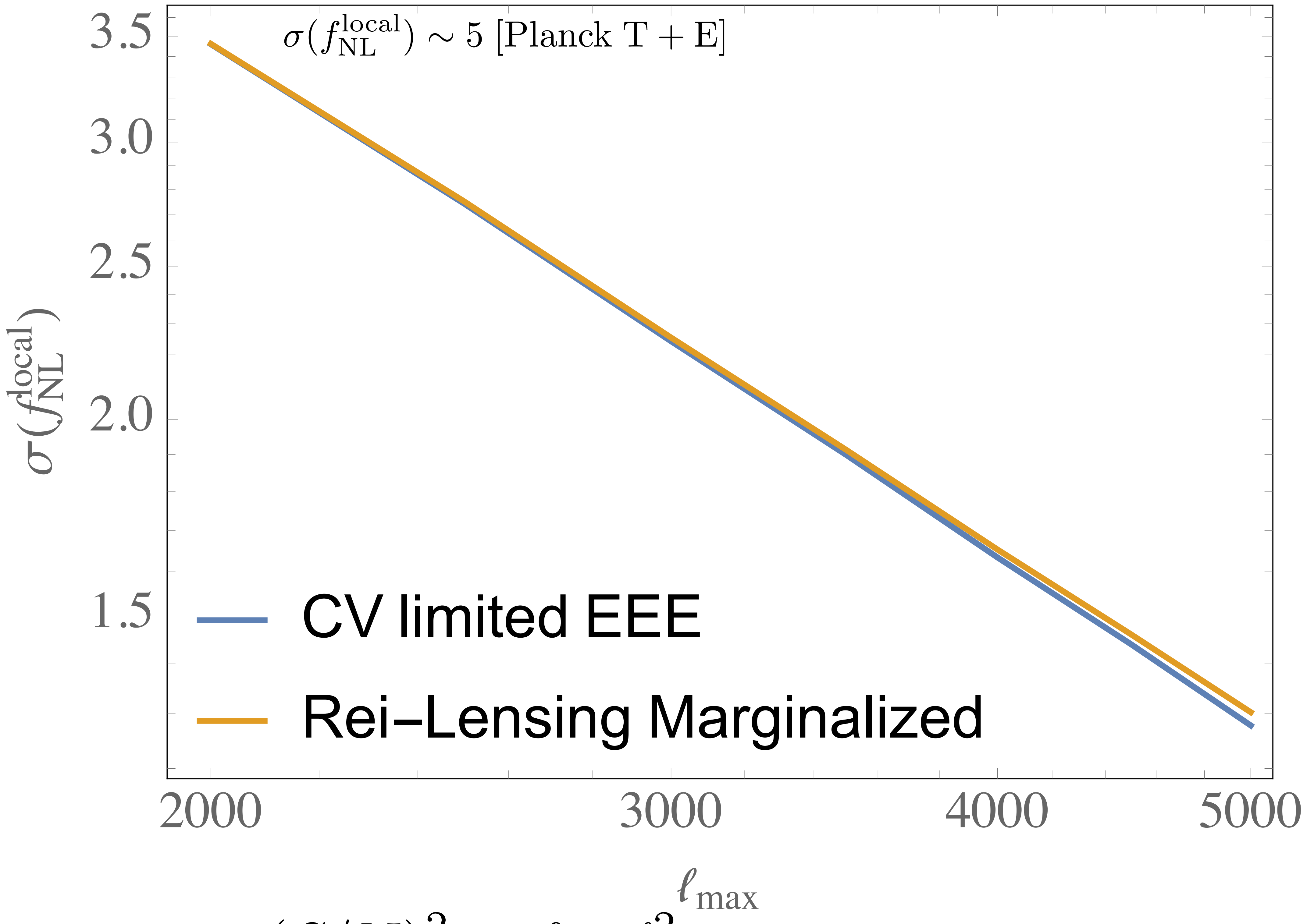

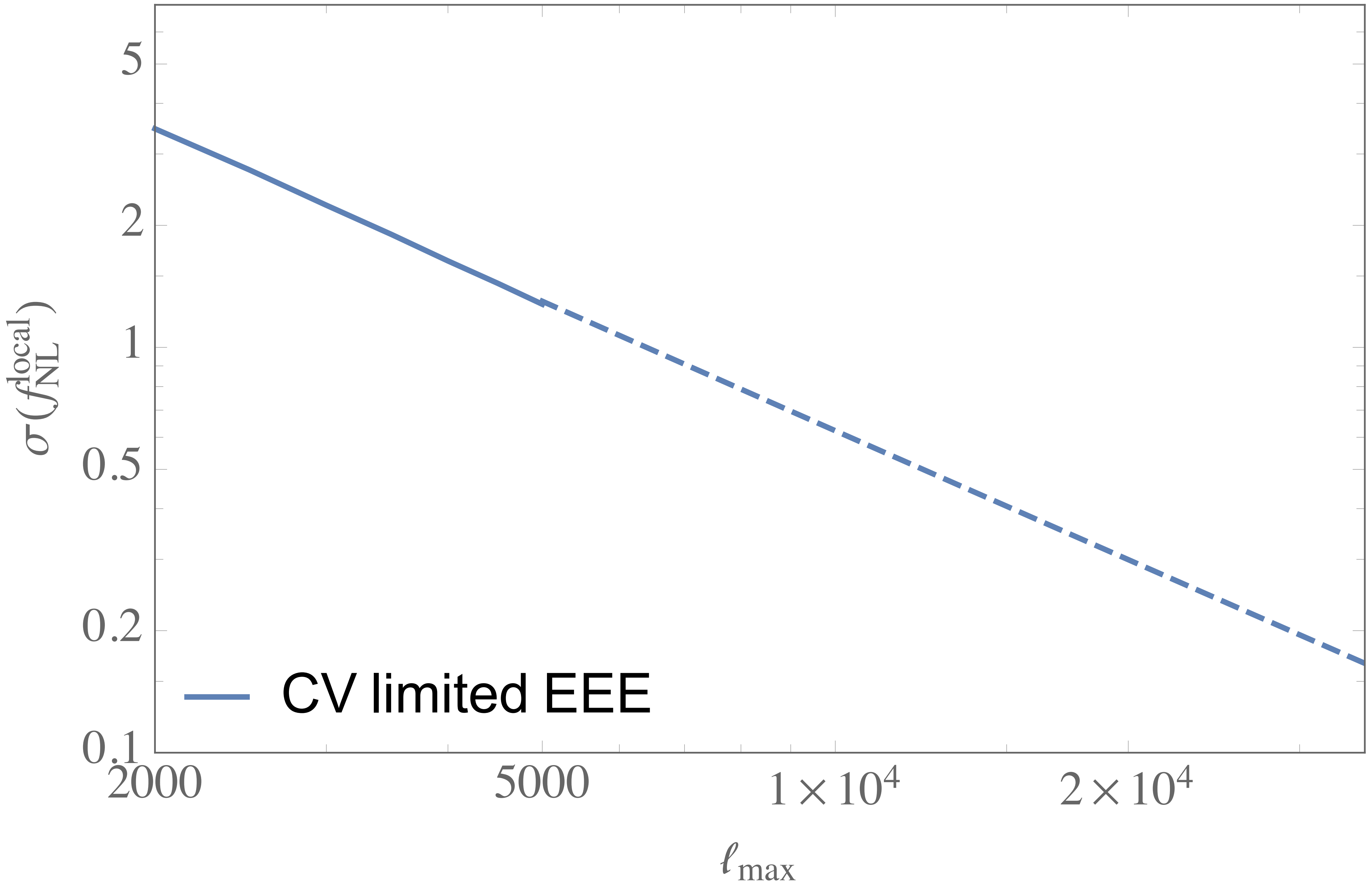

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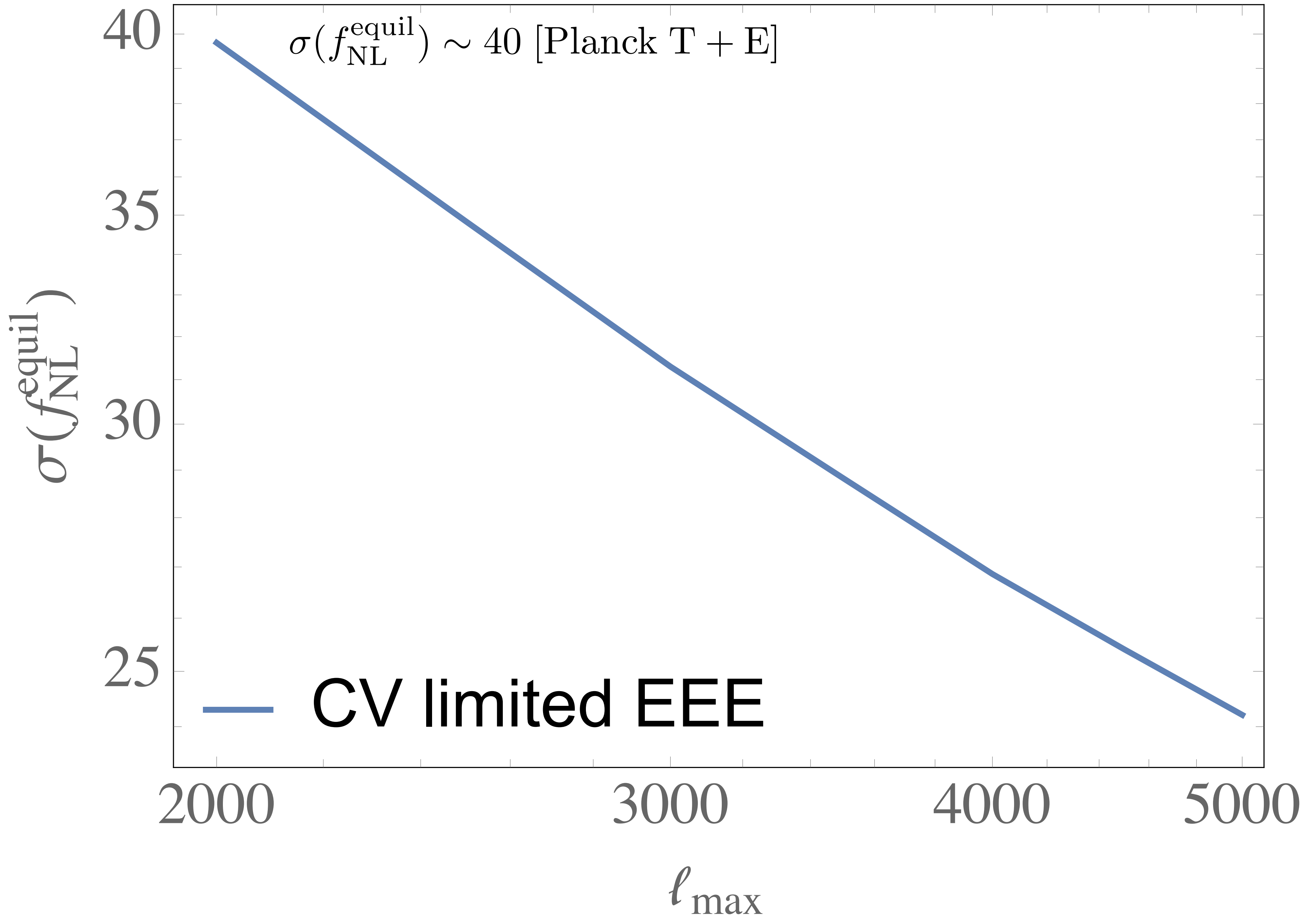
- So, in principle could reach compelling threshold. (For very high ell back to mode counting (Babich & Zaldariagga 2004))

Equilateral non-Gaussianity



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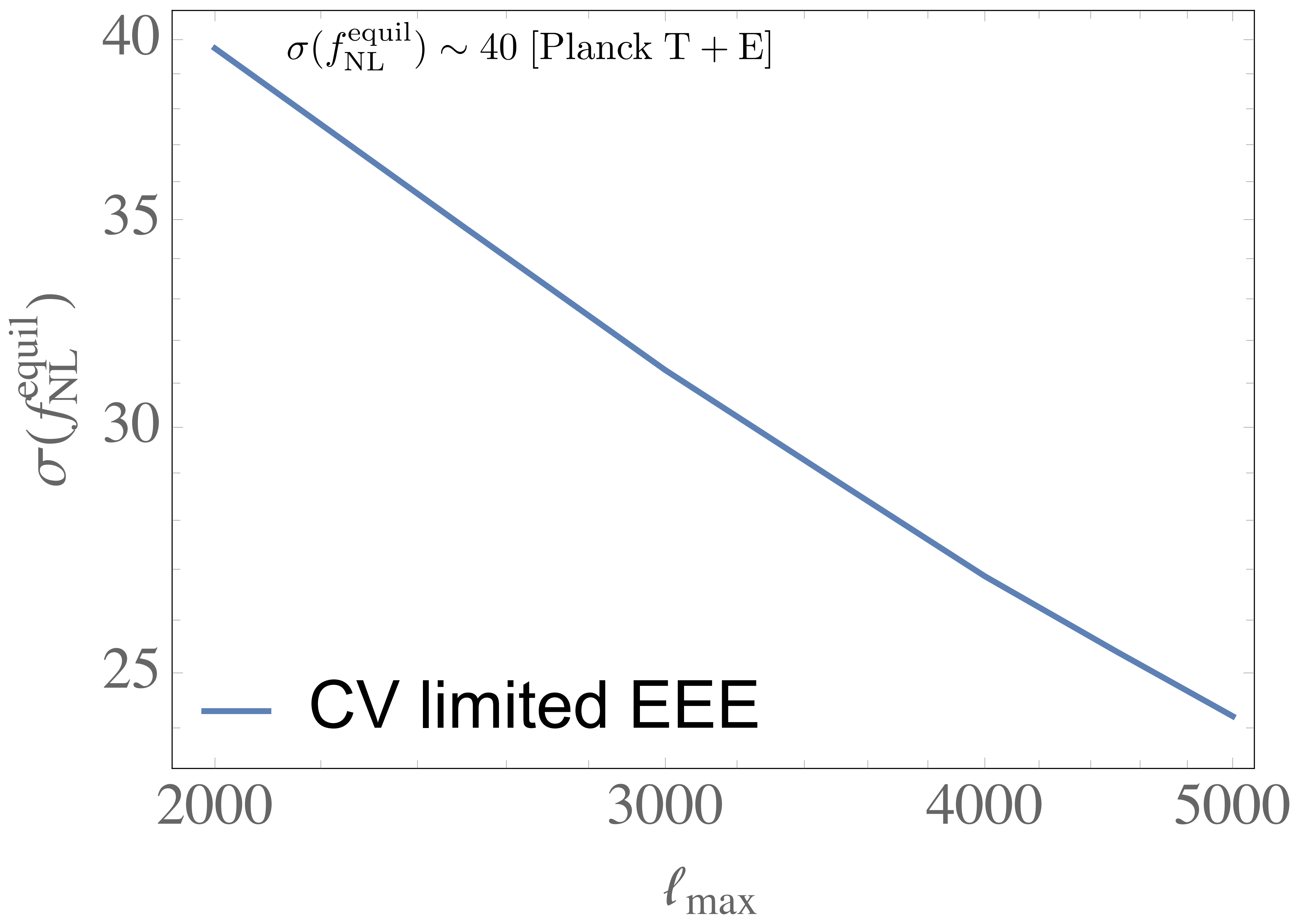

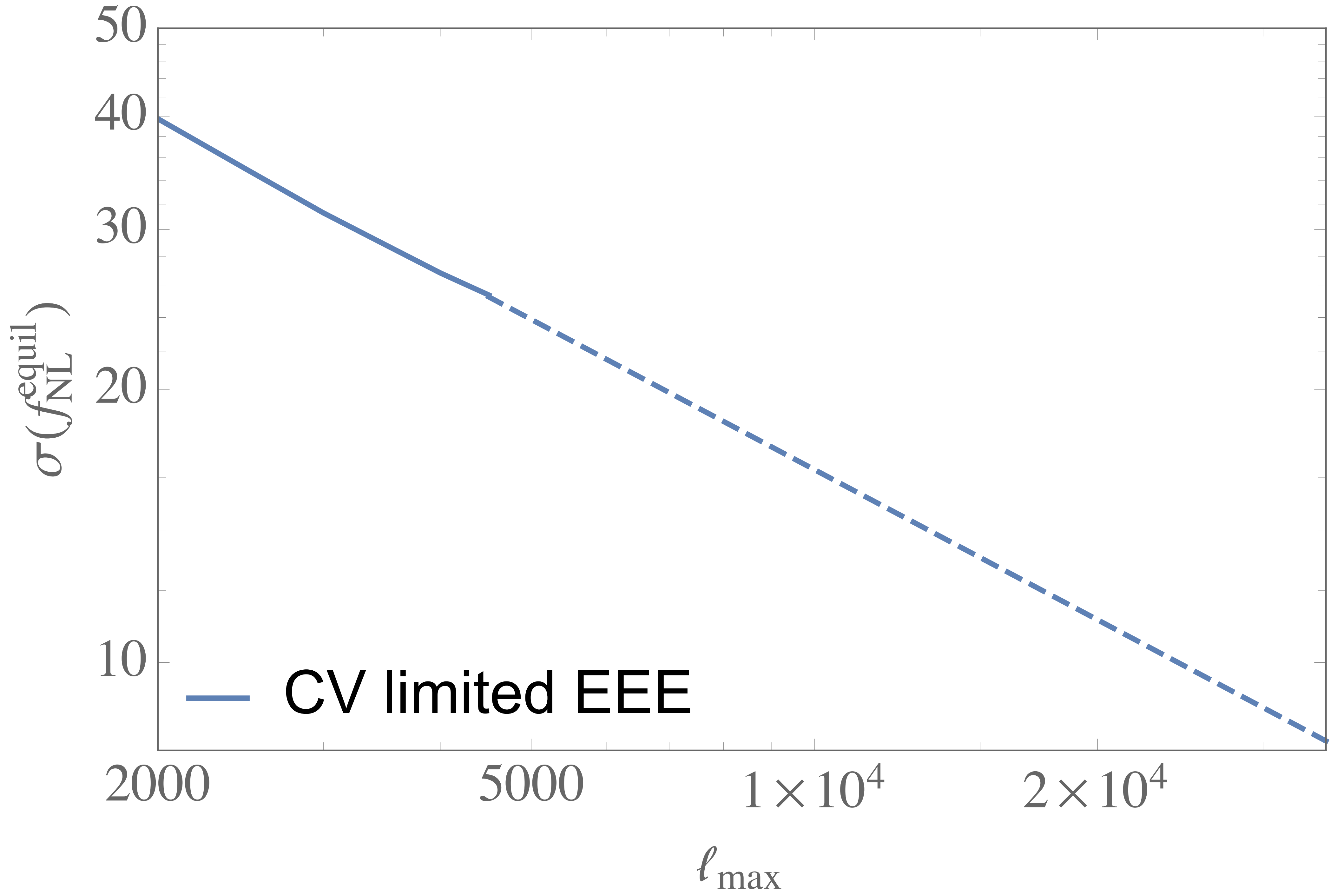

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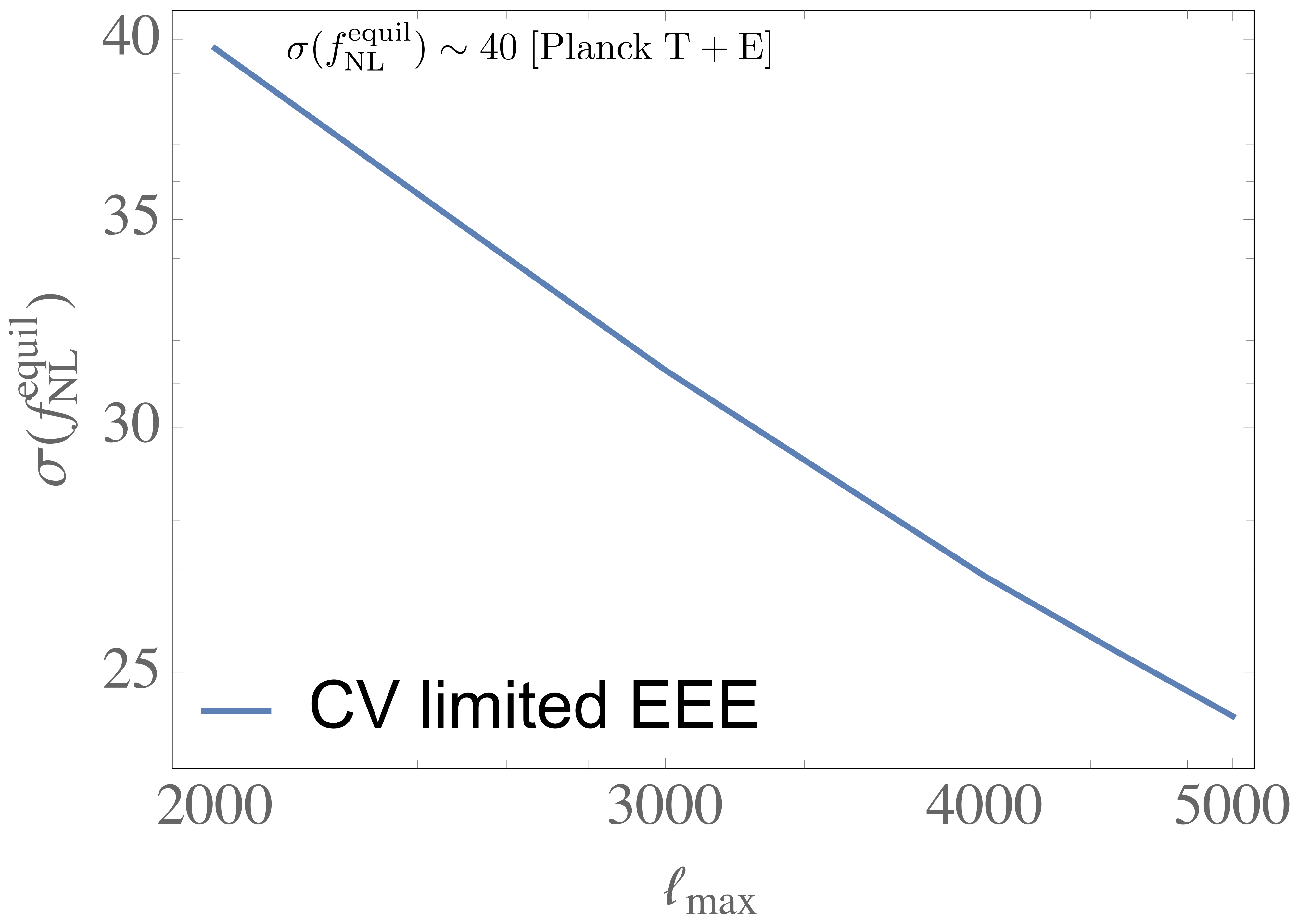

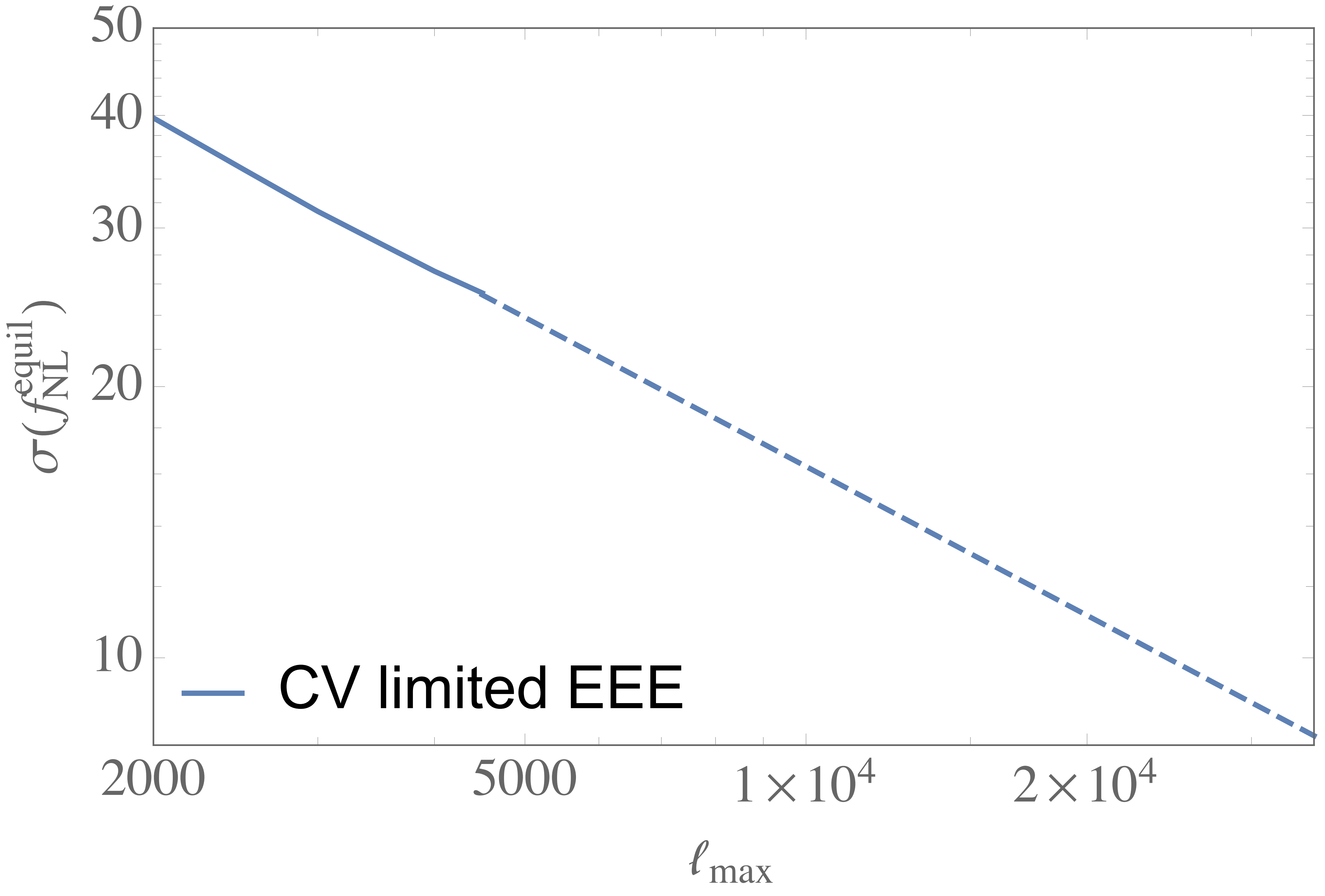

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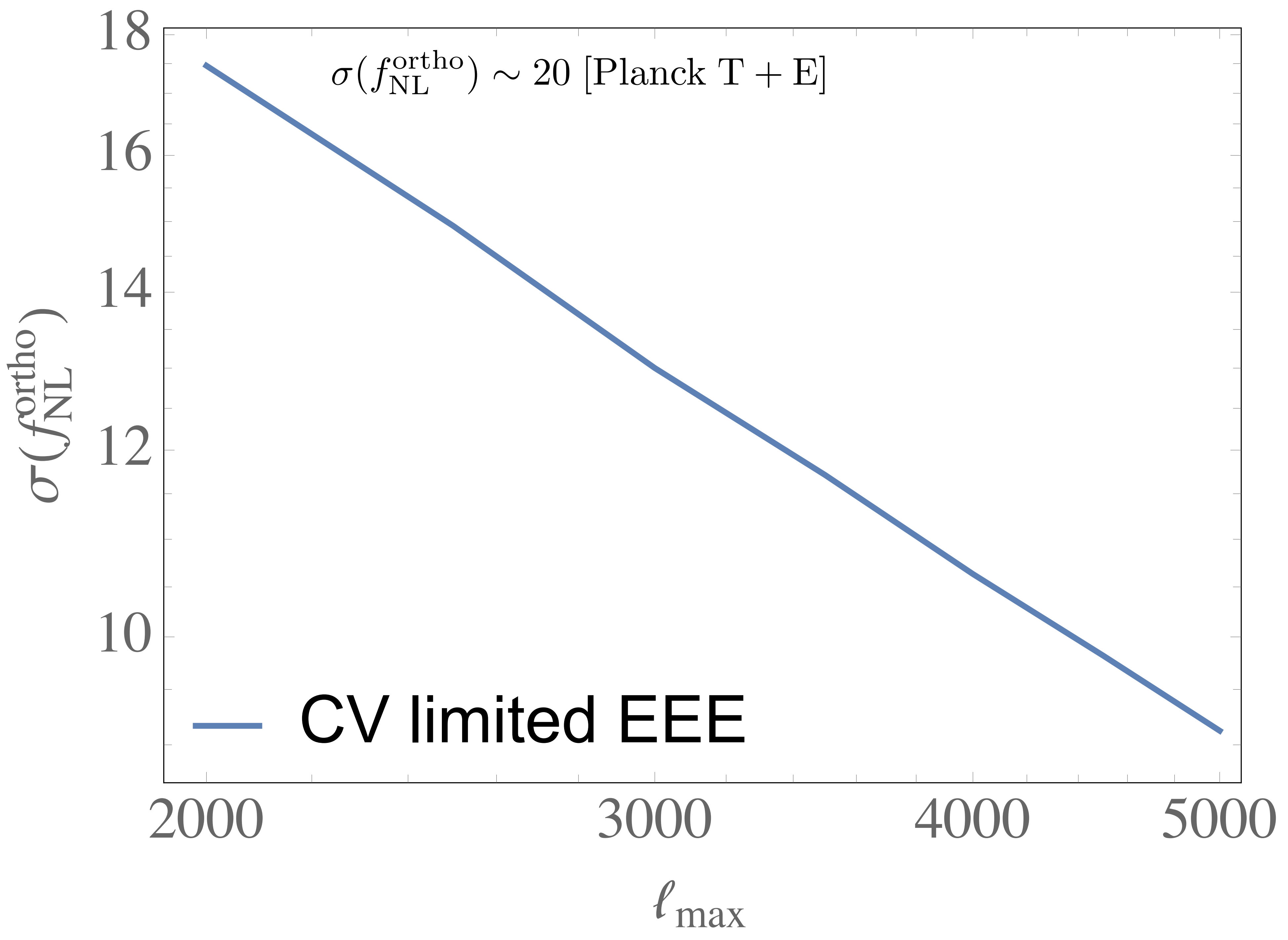
- Very poor scaling; pretty much impossible to reach threshold w CMB even in crazy limit

Orthogonal non-Gaussianity



$(S/N)^2 \propto f_{sky}\ell_{max}^2$ [Mode counting]

$(S/N)^2 \propto f_{sky}\ell_{max}^{3/2}$ [Actual, Kalaja et al in prep]

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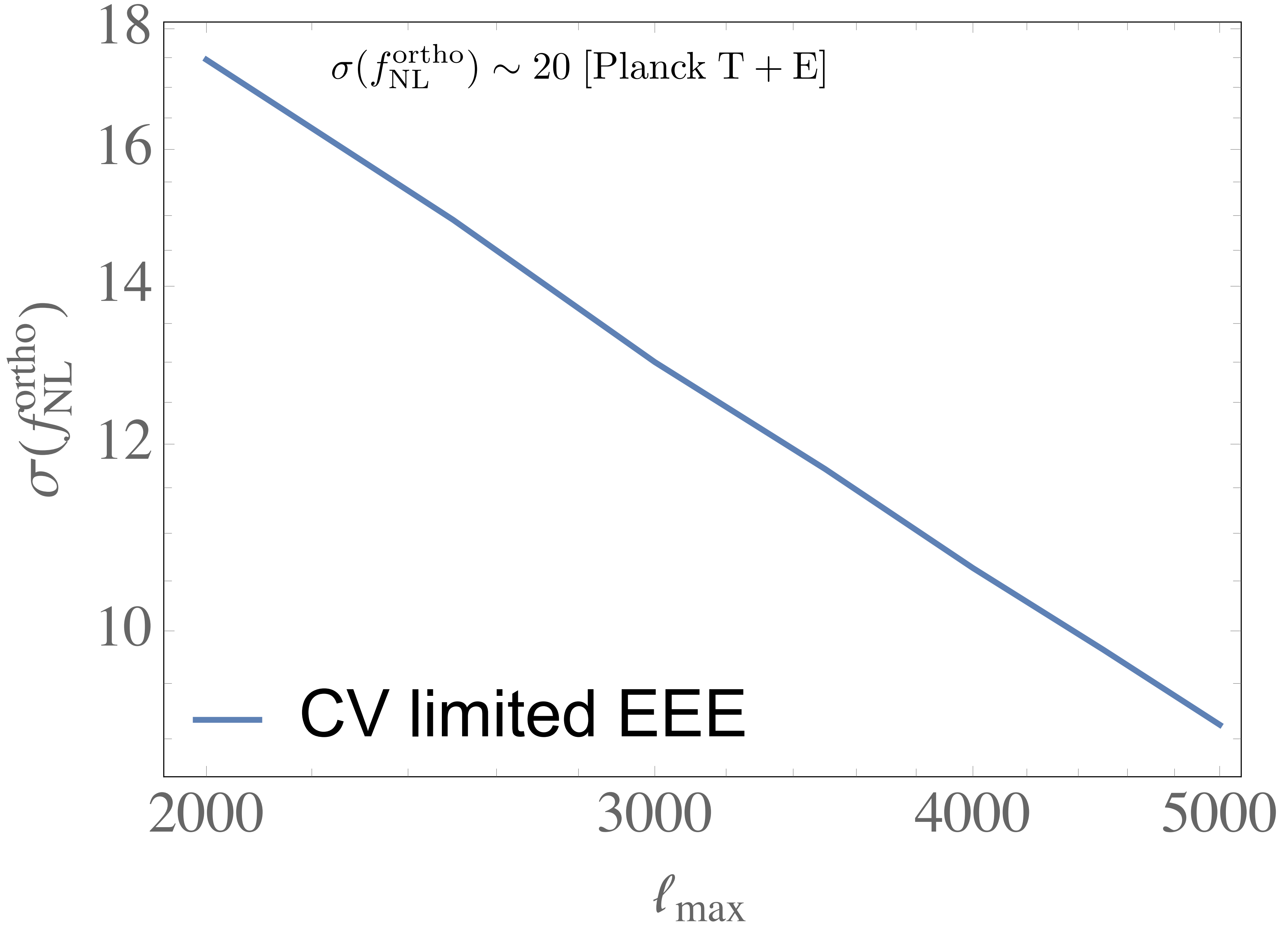

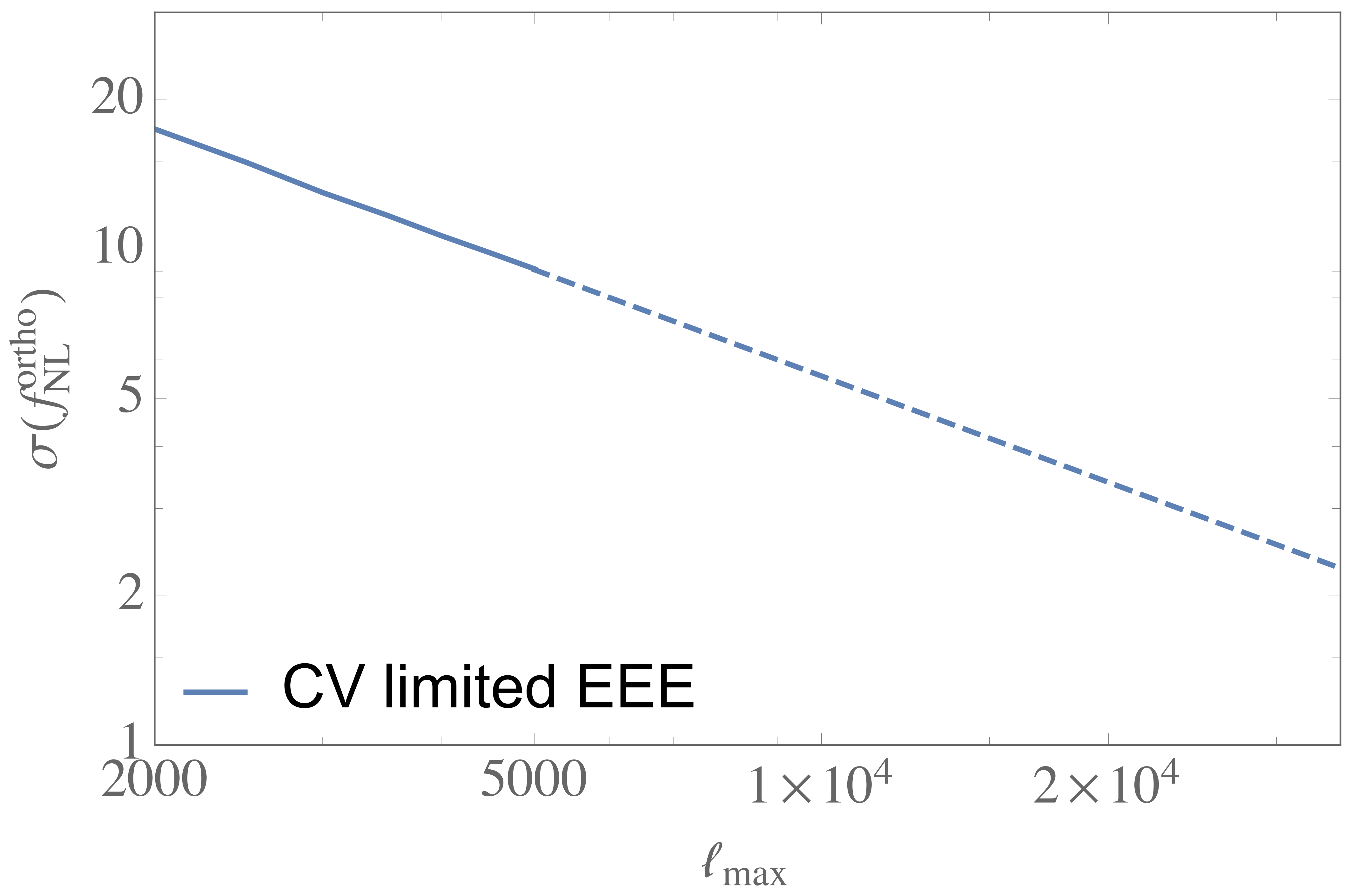

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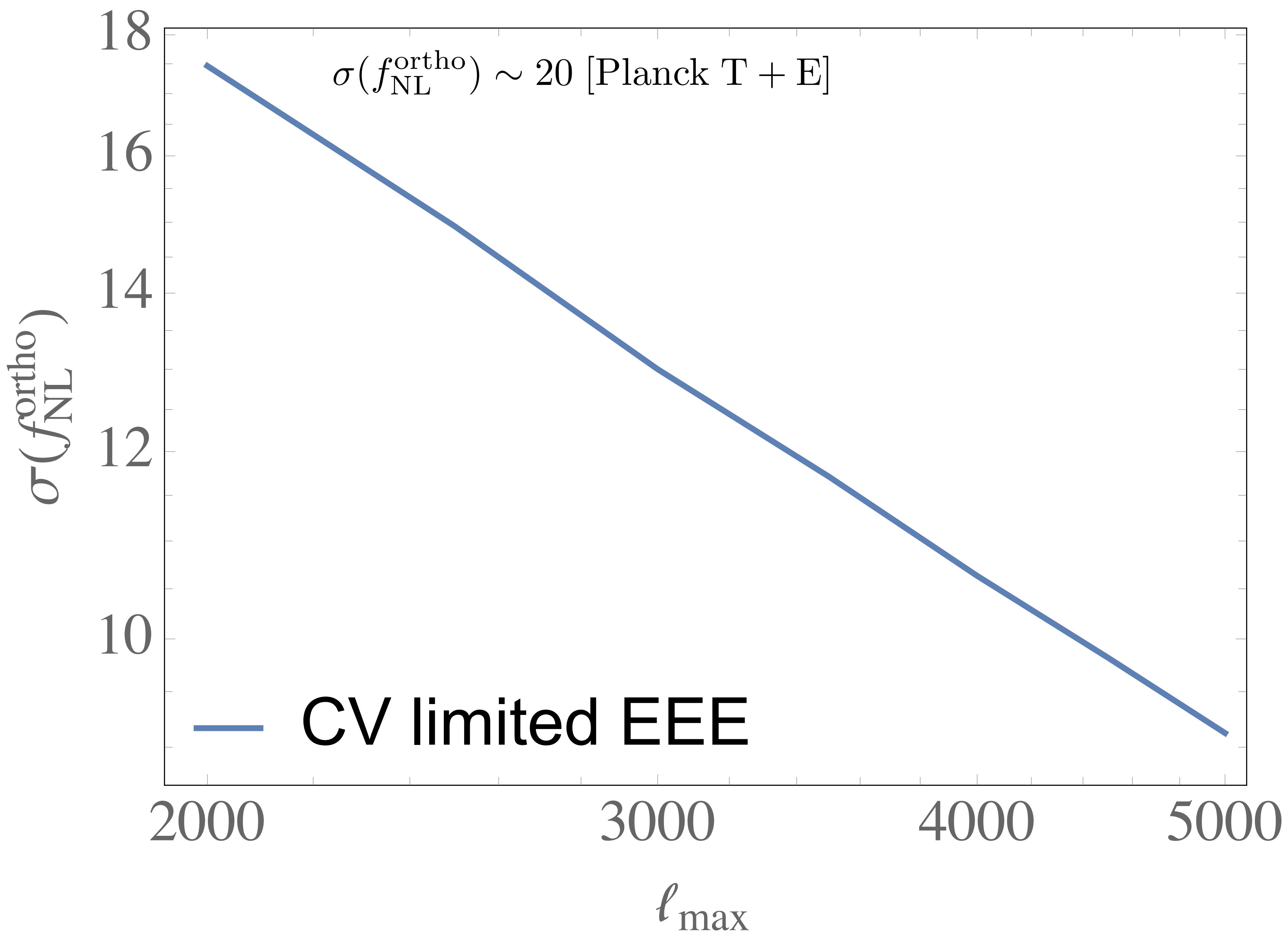

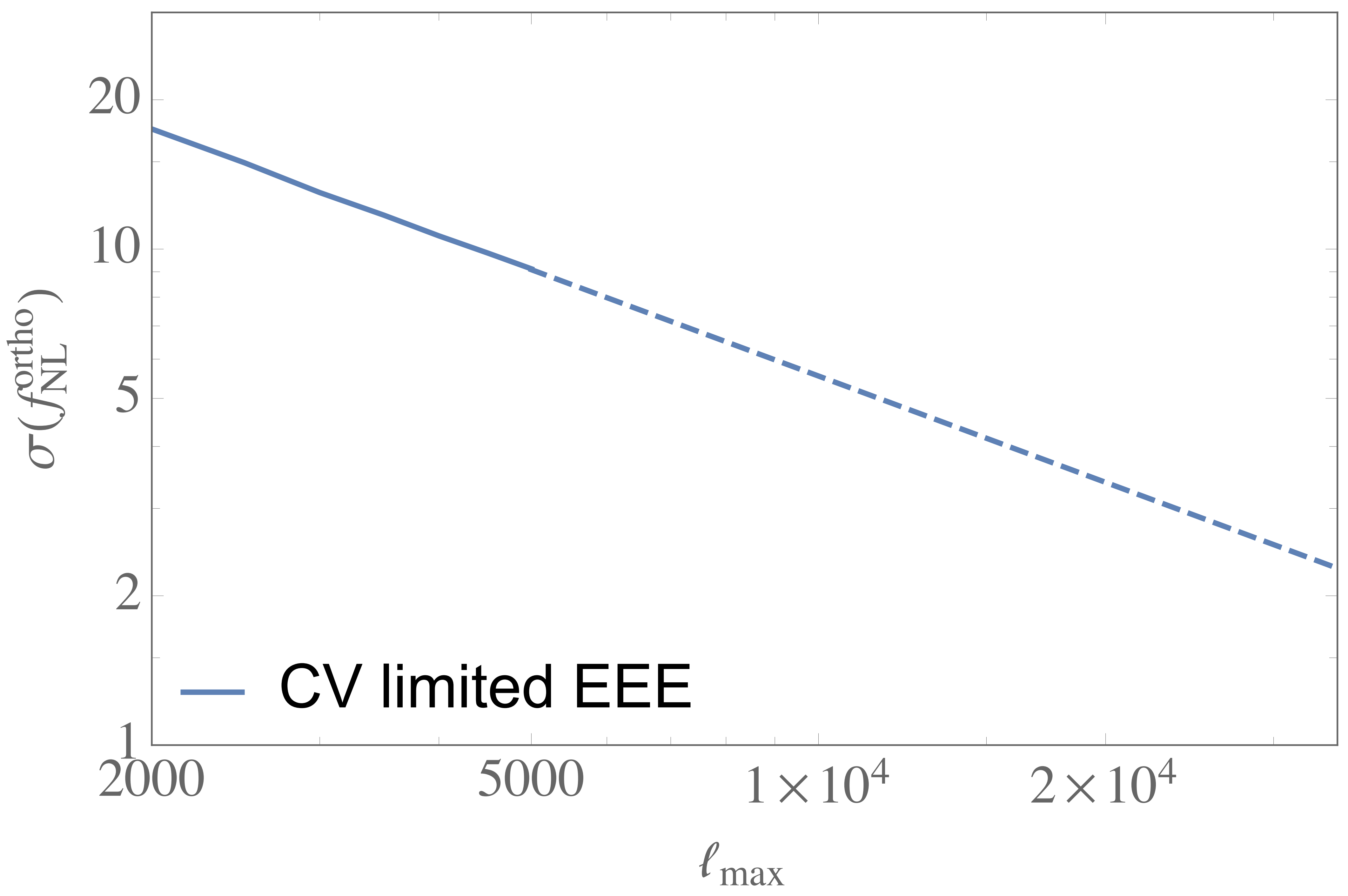

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- Somewhere in between; Take away, not good/great. *Worse then mode-counting for all shapes other than local*

So what about this scaling?

Planck 2018 results. X. Constraints on inflation

Planck Collaboration: Y. Akrami[55,57], F. Arroja[59], M. Ashdown[65,5], J. Aumont[94], C. Baccigalupi[78], M. Ballardini[21,39], A. J. Banday[94,8], R. B. Barreiro[60], N. Bartolo[28,61], S. Basak[85], K. Benabed[53,93], J.-P. Bernard[94,8], M. Bersanelli[31,43], P. Bielewicz[77,8,78], J. J. Bock[62,10], J. R. Bond[7], J. Borrill[12,91], F. R. Bouchet[53,88], F. Boulanger[67,52,53], M. Bucher[2,6*], C. Burigana[42,29,45], R. C. Butler[39], E. Calabrese[82], J.-F. Cardoso[53],

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$$\left(\frac{S}{N}\right)^2 \propto \Omega_{sky}\ell_{max}^2 \ln\left(\frac{\ell_{max}}{\ell_{min}}\right). \quad (2)$$

For the local shape, the logarithm enters because most of the signal derives from detecting the modulation of the small-scale power by the large-scale CMB anisotropy, highlighting the importance of full-sky maps for this kind of analysis. For other shapes such as equilateral, one instead has $(S/N)^2 \sim \Omega_{sky}\ell_{max}^2$. *Planck* has significantly sharpened the constraints on

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- Doing this integral for local, equilateral and orthogonal, we find that they all scales as

$$S/N \propto \sqrt{k_{max}^3}\,[\log k_{max}/k_{min}]^{1/2}$$

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- So hurray for LSS

So what about this scaling?

- What about the CMB? Similarly (in flat sky approximation)

$$(S/N)^2 \propto \int \prod_i \left[\frac{d^2\ell}{C_{\ell_i}}\right] \delta(\sum_i \ell_i) B^2(\ell_1, \ell_2, \ell_3)$$

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- We then find

  - Local: $S/N \propto \sqrt{\ell_{\rm max}^2 \log \ell_{\rm max}/\ell_{\rm min}}$

  - Equilateral: $S/N \propto \sqrt{\ell_{\rm max}}$ Found also by Bartolo & Riotto 2009

  - Orthogonal : WIP

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So what about this scaling?

- What about the CMB? Similarly (in flat sky approximation)

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- So this reduction on all other shapes except local, *MUST be a projection effect.* However, it is rather peculiar since remember that both the equilateral and orthogonal shapes are defined containing the local shape.
- Ongoing investigation (Kalaja et al in prep.); it COULD have some consequences also for LSS surveys (e.g. measuring the bispectrum by redshift could significantly reduce your sensitivity to equilateral/orthogonal triangles)

CMB: practical limitations

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- All these in principle could also increase covariance

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- Schematically, the effect of lensing will then be:

$$\langle \hat{B}\hat{B} \rangle \equiv \mathrm{Var}(\widehat{B}) = \mathrm{Var}(\widehat{B})_G + \Delta\mathrm{Var}(\widehat{B}),$$

$$\Delta\mathrm{Var}(\widehat{B}) = \mathrm{Var}(\widehat{B})_{3\times 2p} + \mathrm{Var}(\widehat{B})_{2\times 3p} + \mathrm{Var}(\widehat{B})_{2p\times 4p} + \mathrm{Var}(\widehat{B})_{6p}.$$

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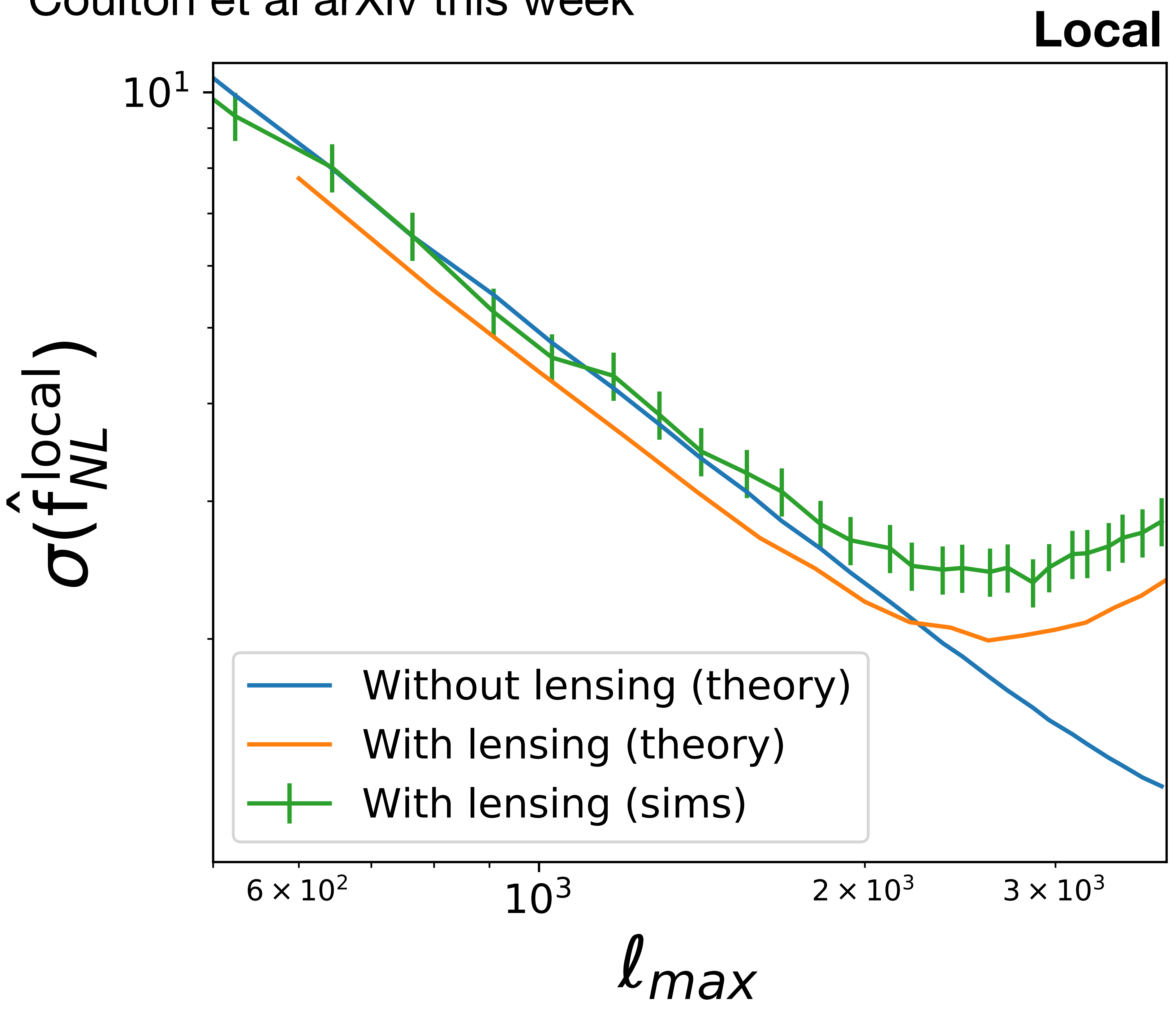
Coulton et al arXiv this week



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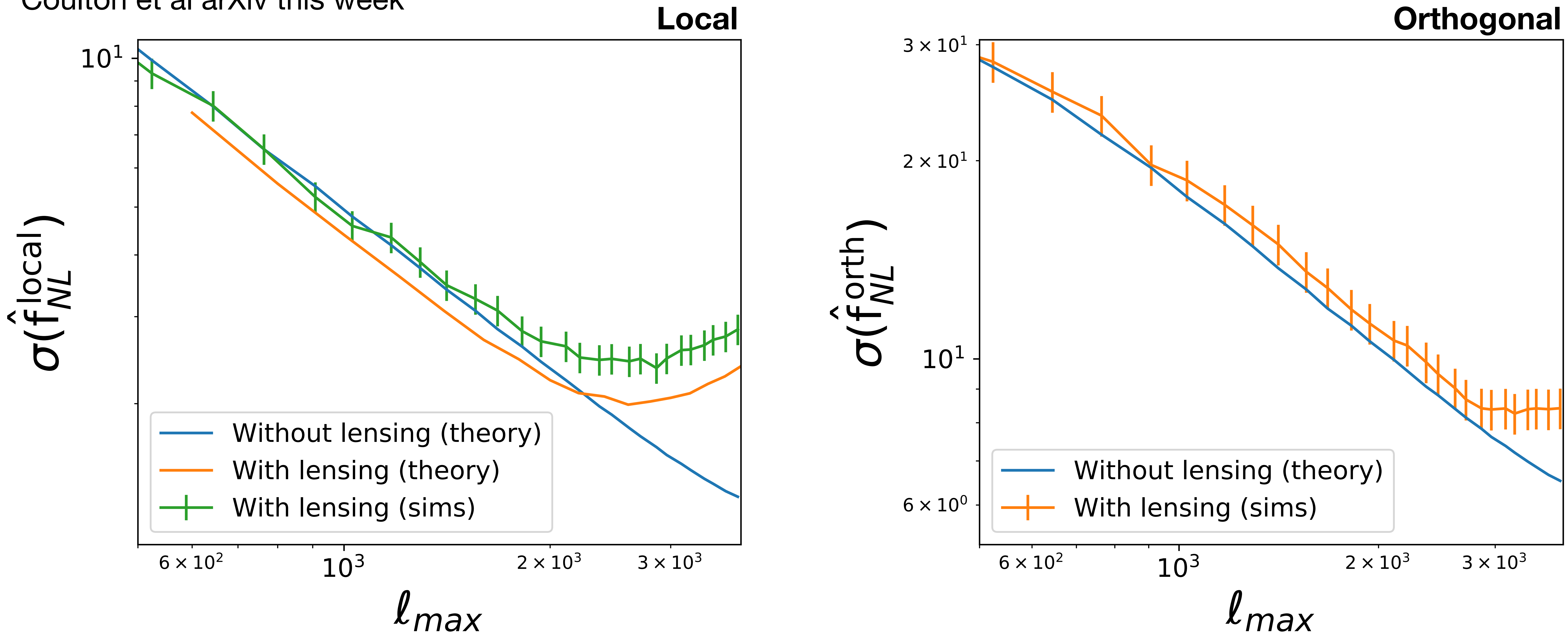

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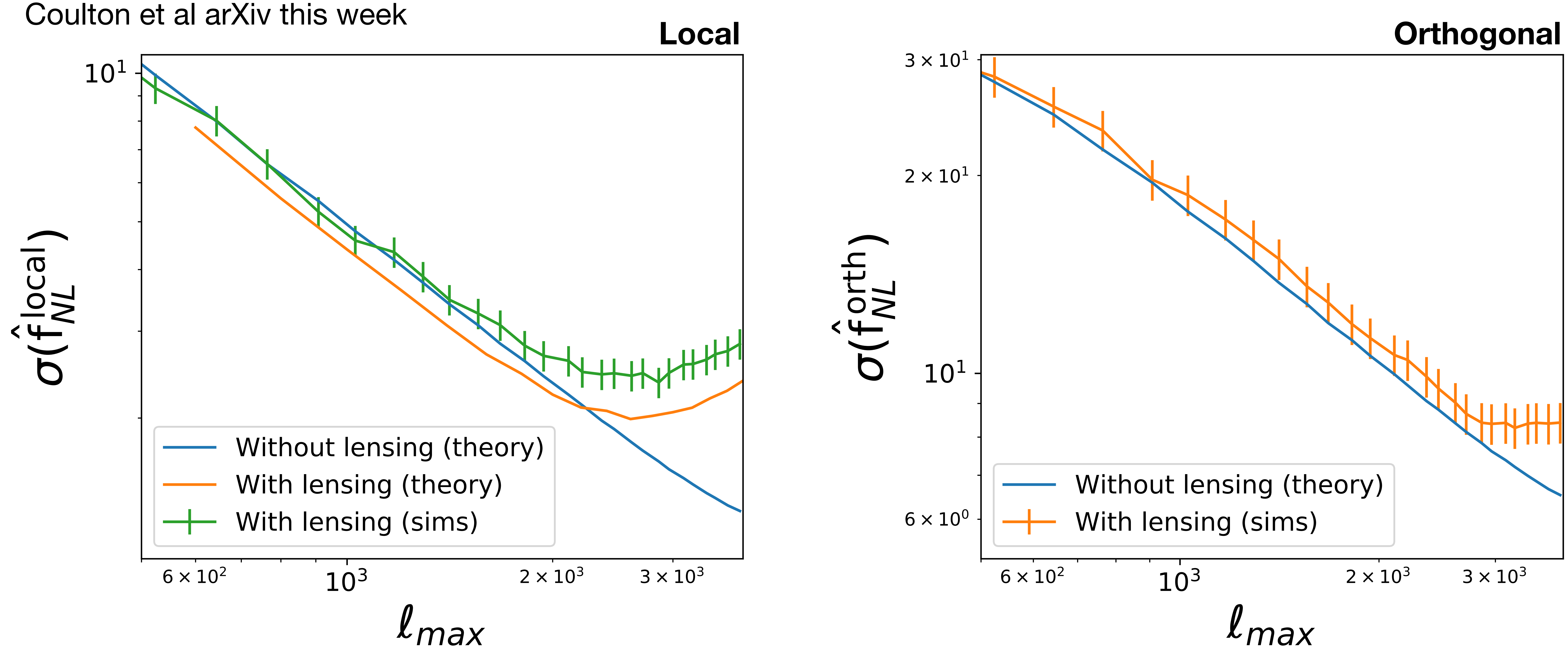

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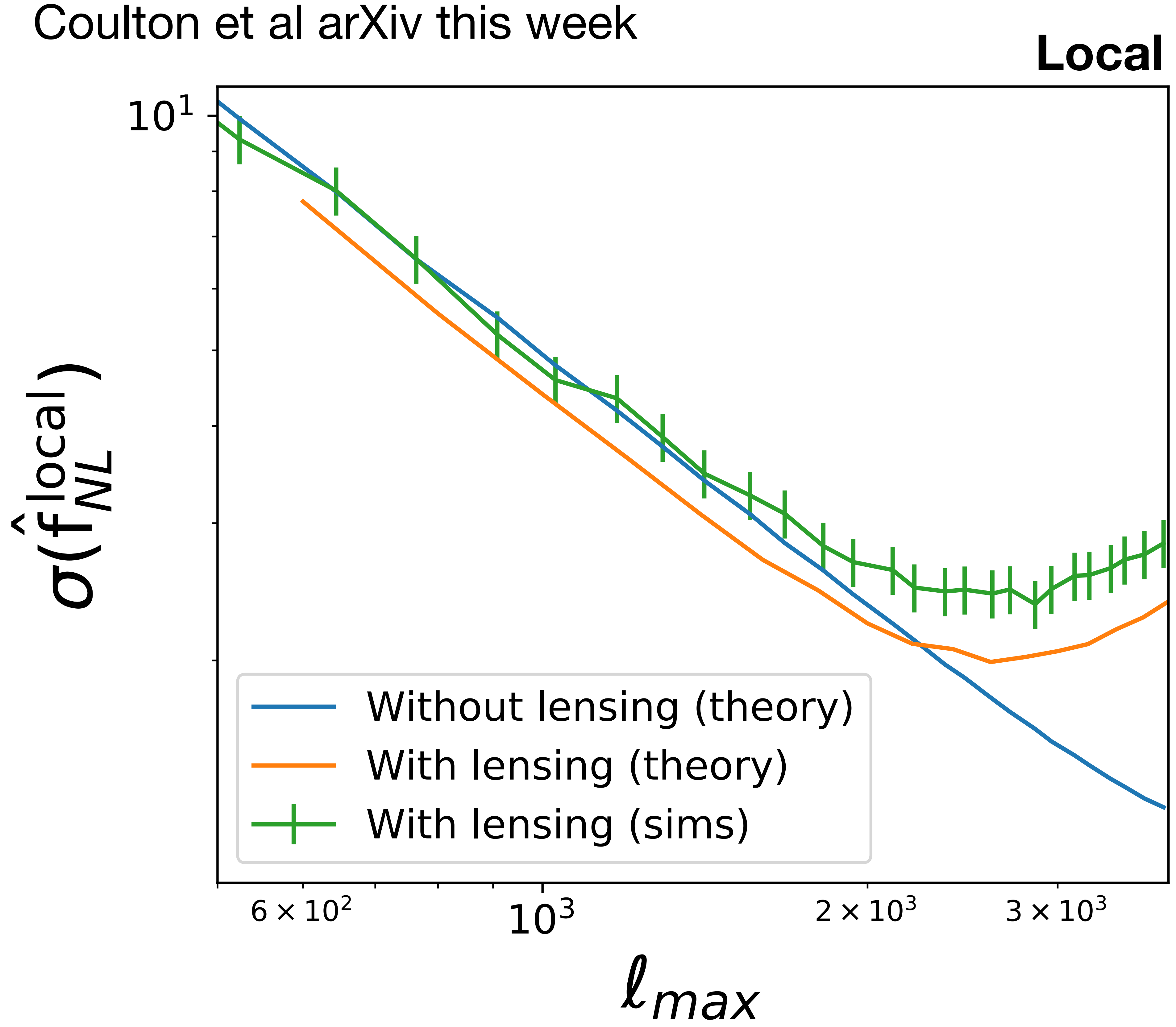

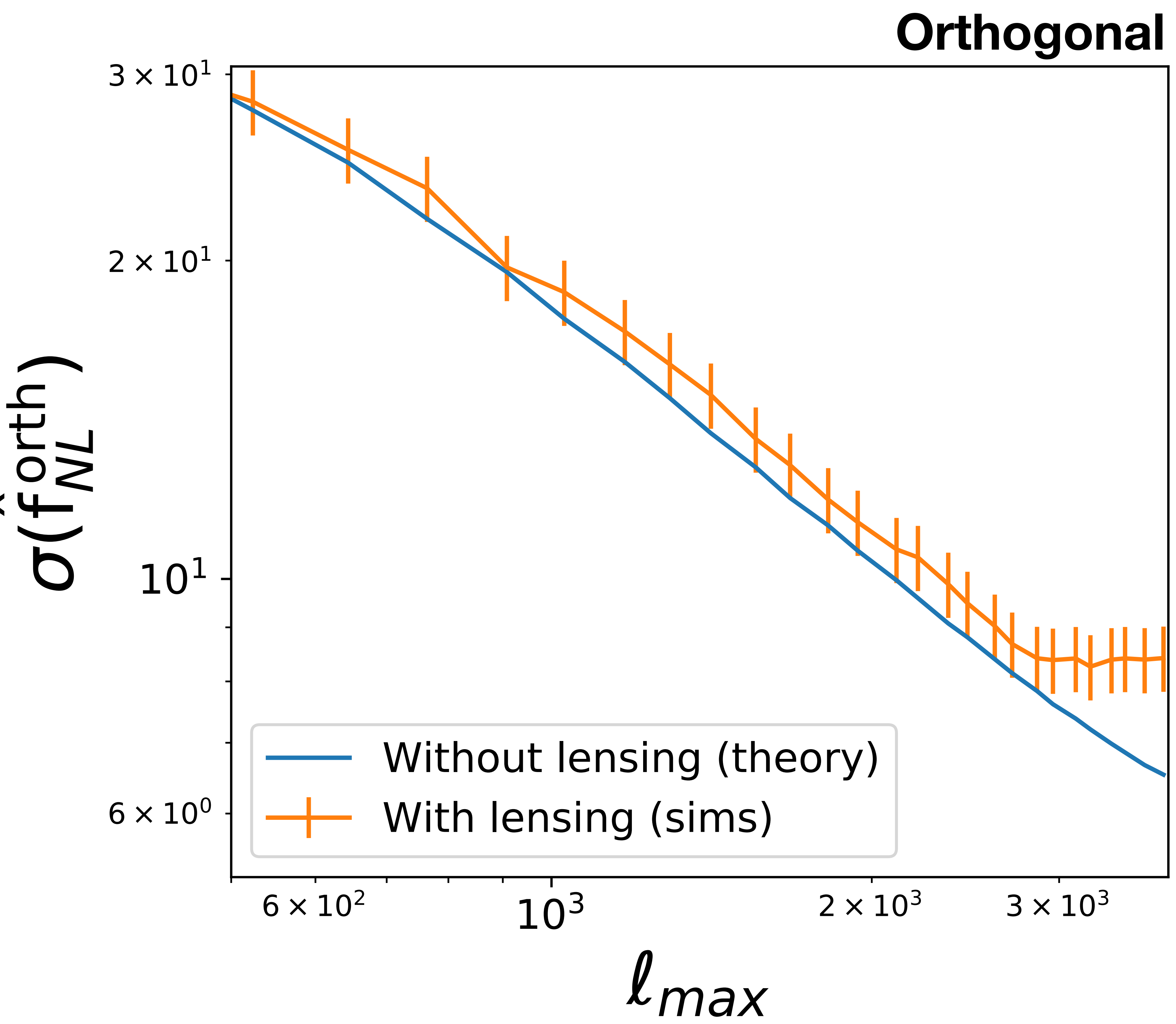

- Computed effect analytically and compared these to simulations (offset due to higher order effects)
- Up to 50% effect for CV limited experiment with $\ell_{\max} \sim 5000$ for local non-Gaussianities

~35% for an experiment like SO

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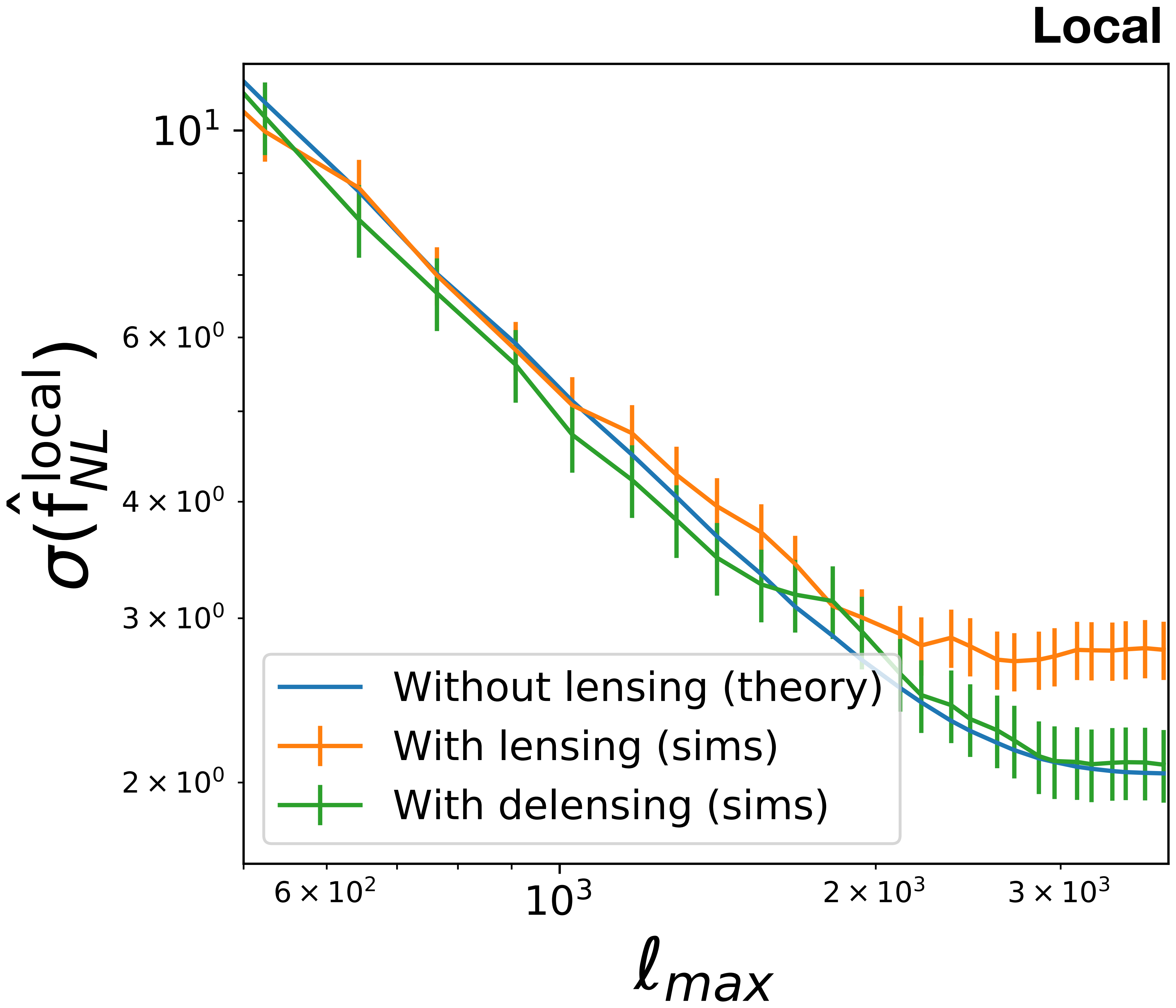

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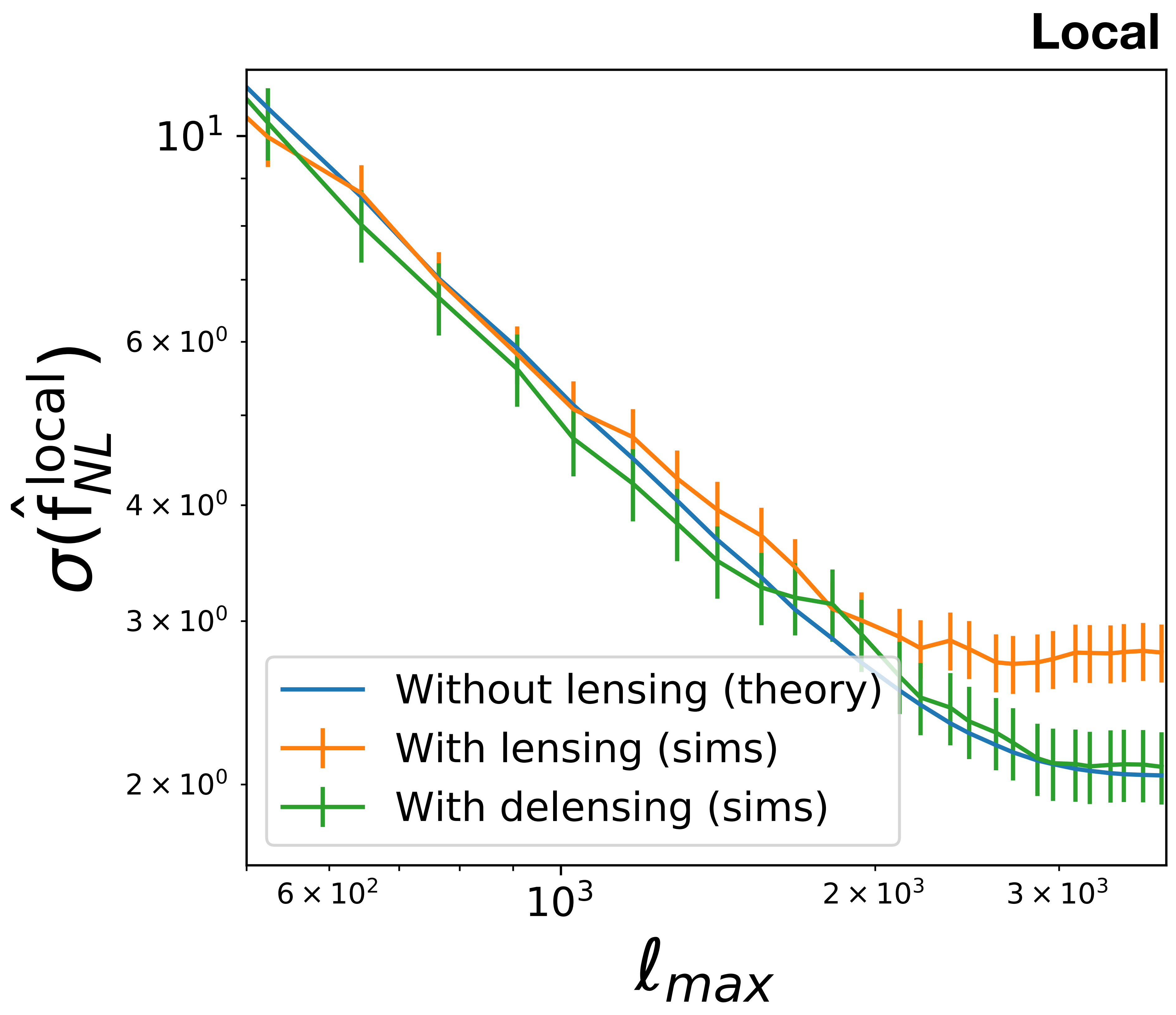

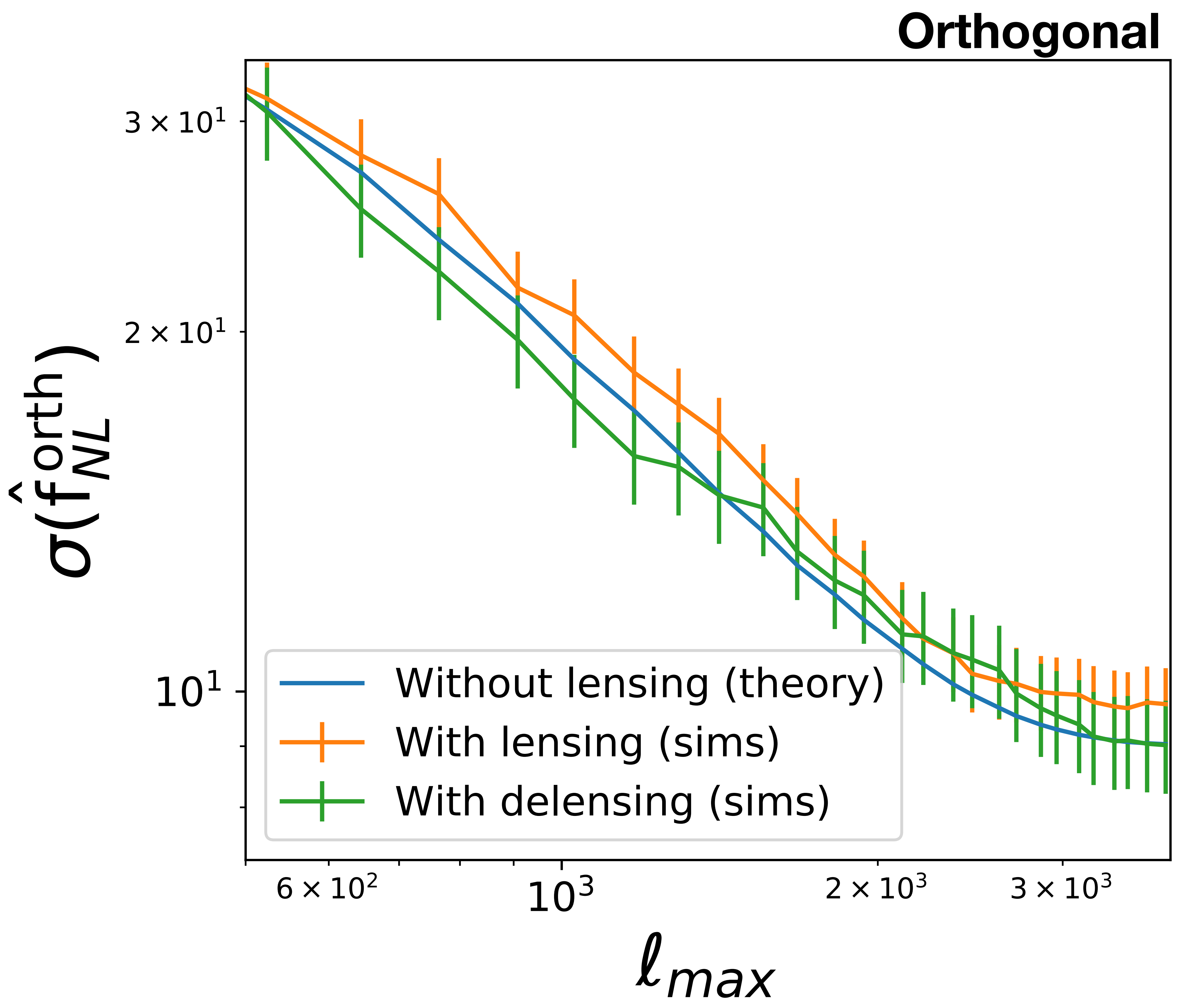

CMB: new observables

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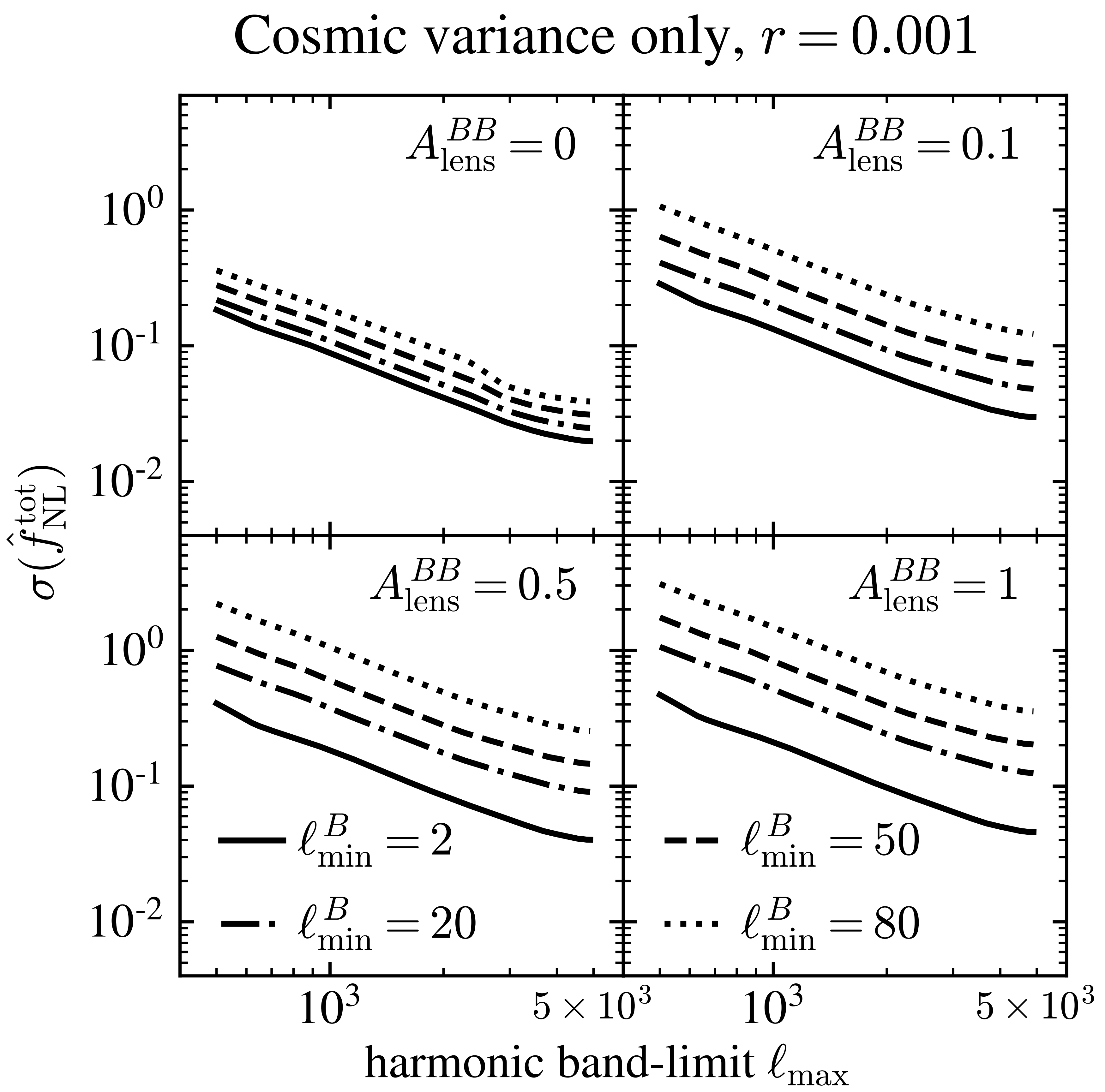
- Figure shows forecasts for local-like hzz template (using BTT, BTE and BEE)

Duivenvoorden, Meerburg, Freese, 2019



Are there other ways to probe the ‘primary modes’ with the CMB?
Possibly….

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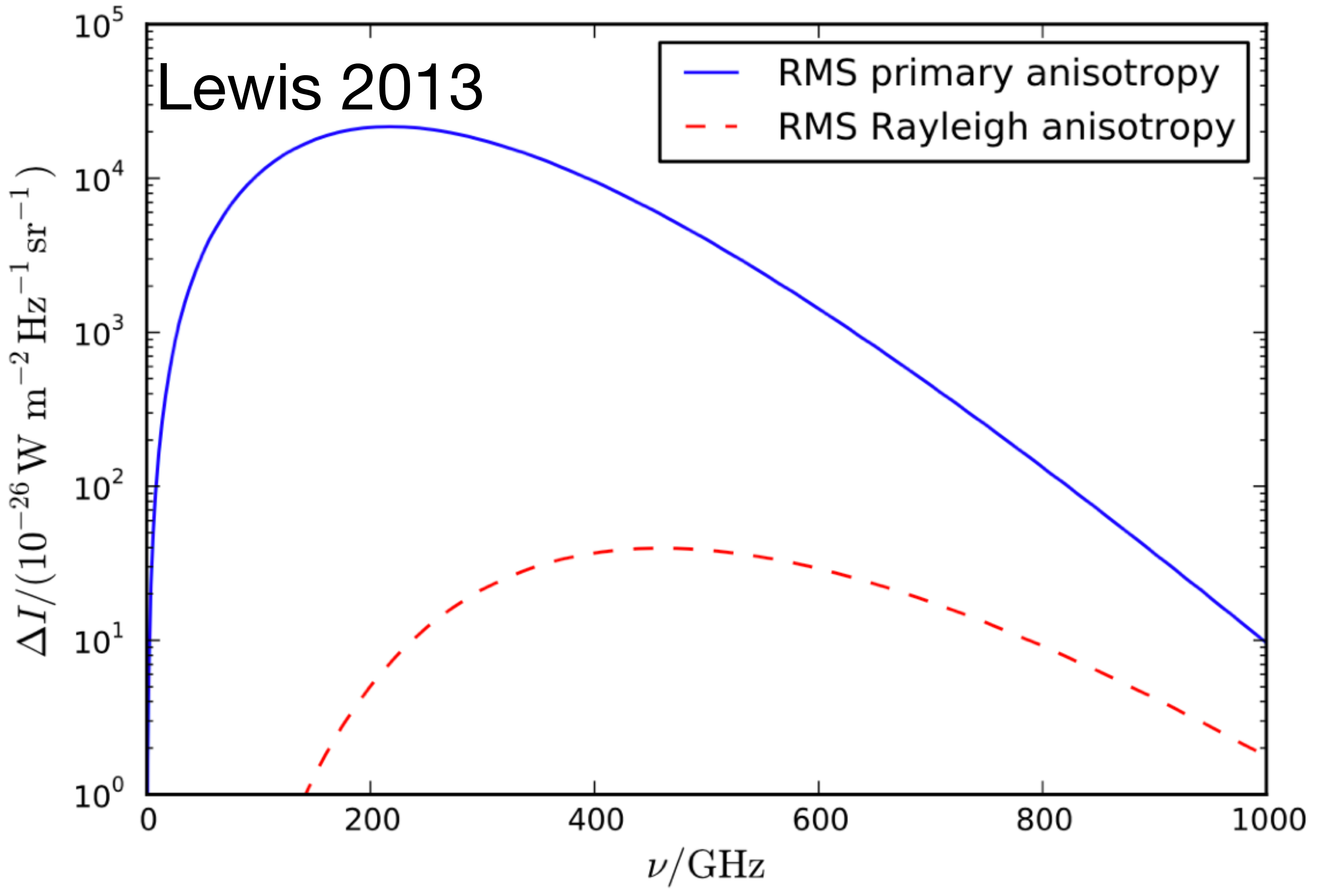
- Several key aspects
  - Negligible at CMB frequencies (200 GHz)
  - At high frequencies, it will become more important, but fewer photons to scatter (peak at ~500 GHz). Brightness still ~3%
  - The Rayleigh visibility function is shifted (closer to us)



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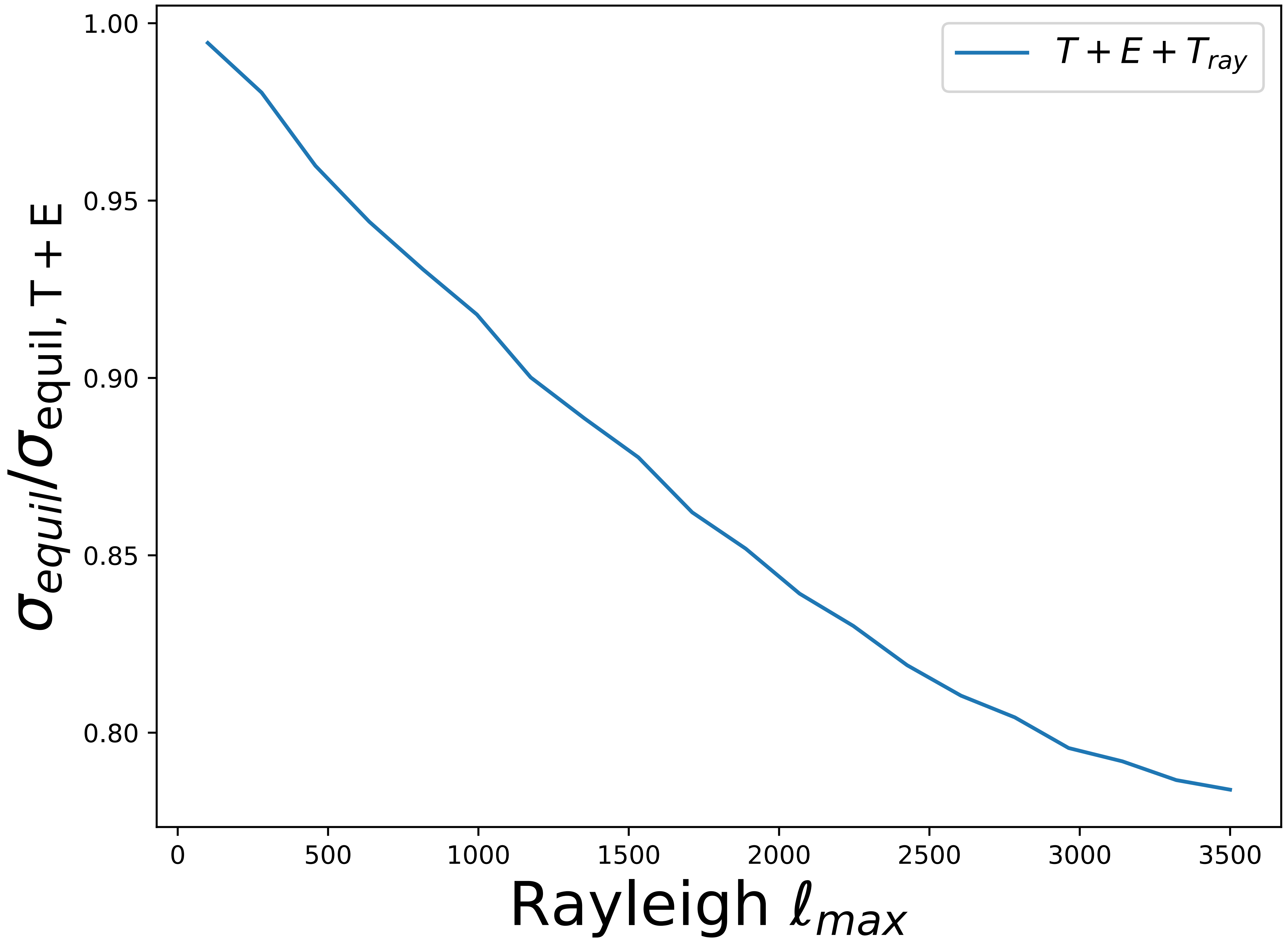
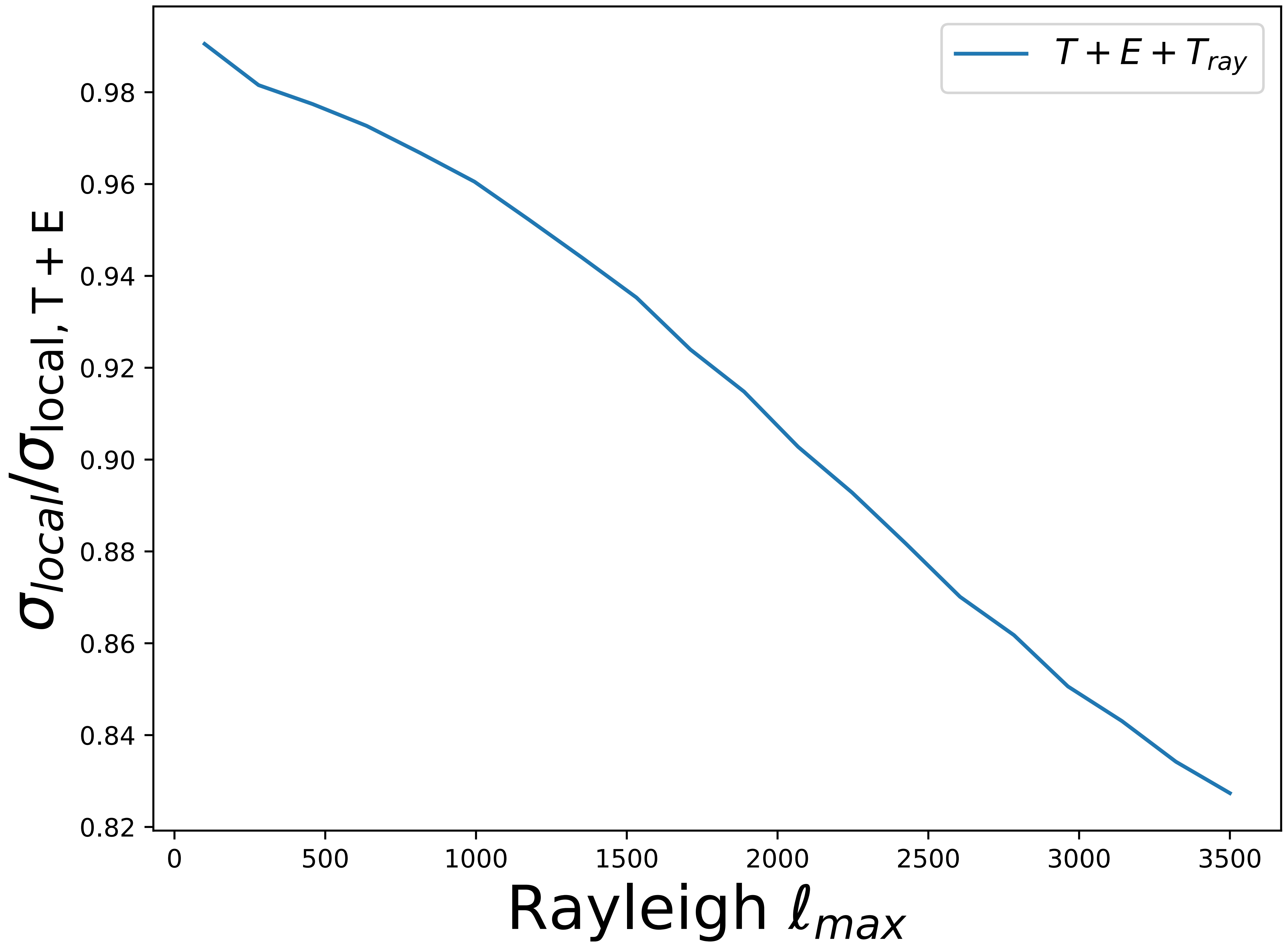
- Third, would allow to go to much smaller scales in T (kSZ cleaned signal)

Rayleigh scattering and NGs

Coulton, Beringue in progress





- Lmax = 3500 for primary. Equilateral more improvement then local (a first!). No noise.
- Very preliminary. Need to understand this better.

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- Beyond the bispectrum: spectral distortions and cosmic variance mitigation. Both only applicable to local but could reach fnl = 1.