Weak gravitational lensing as a (3D) probe of gravity

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Statistical challenges for large-scale structure in the era of LSST
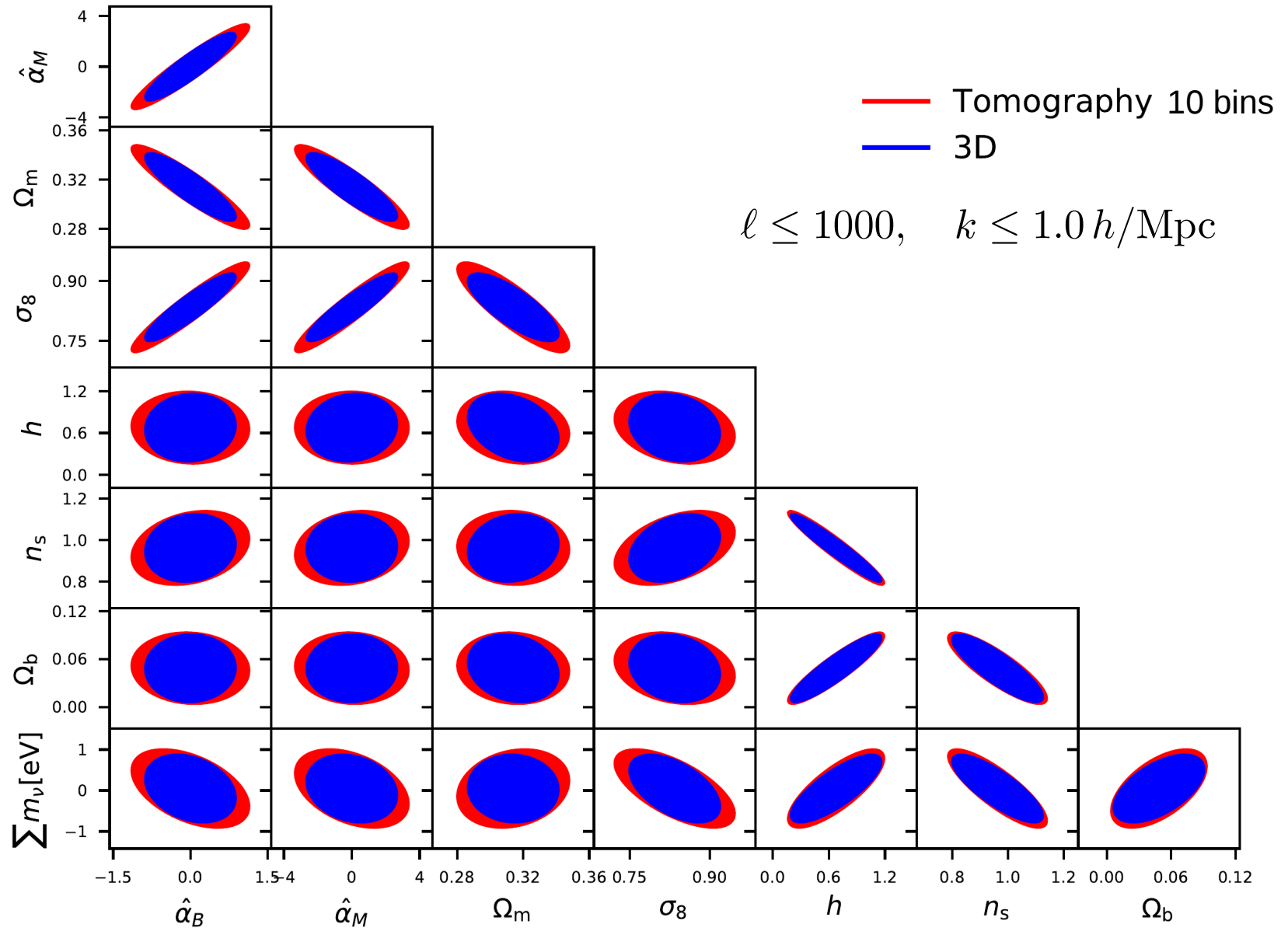Clarendon Laboratory, Oxford
18th April 2018

Based on   arXiv:1801.04251
arXiv:1804.02441

Introducing Horndeski Gravity

$$S[g_{\mu\nu}, \phi] = \int \mathrm{d}^4 x \sqrt{-g} \left[\sum_{i=2}^{5} \frac{1}{8\pi G_N} \mathcal{L}_i[g_{\mu\nu}, \phi] + \mathcal{L}_m[g_{\mu\nu}, \psi_M] \right],$$

$$\mathcal{L}_2 = G_2(\phi, X), \quad \mathcal{L}_3 = -G_3(\phi, X)\Box\phi, \quad \mathcal{L}_4 = G_4(\phi, X)R + \frac{\partial G_4(\phi, X)}{\partial X}\left[(\Box\phi)^2 - \phi_{;\mu\nu}\phi^{;\mu\nu}\right],$$

$$\mathcal{L}_5 = G_5(\phi, X)G_{\mu\nu}\phi^{;\mu\nu} - \frac{1}{6}\frac{\partial G_5(\phi, X)}{\partial X}\left[(\Box\phi)^3 + 2\phi_{;\mu}^{\nu}\phi_{;\nu}^{\alpha}\phi_{;\alpha}^{\mu} - 3\phi_{;\mu\nu}\phi^{;\mu\nu}\Box\phi\right] \quad X = -\frac{\phi^{;\mu}\phi_{;\mu}}{2}$$

- Covers majority of DE/MG models available

- Description of Perturbation Dynamics: the **Bellini-Sawicki** (2014) parametrization

  - $\alpha_K(\tau)$ kineticity

  - $\alpha_B(\tau)$ braiding

  - $\alpha_M(\tau) \equiv \dfrac{\mathrm{d}\ln M_*^2(\tau)}{\mathrm{d}\ln a}$ Planck-mass run rate

  - $\alpha_T(\tau)$ tensor speed excess

$$M_*^2 \equiv 2\left(G_4 - 2X\frac{\partial G_4}{\partial X} + X\frac{\partial G_5}{\partial \phi} - \frac{H\phi'}{a}X\frac{\partial G_5}{\partial X}\right) \quad \text{Effective Planck Mass}$$

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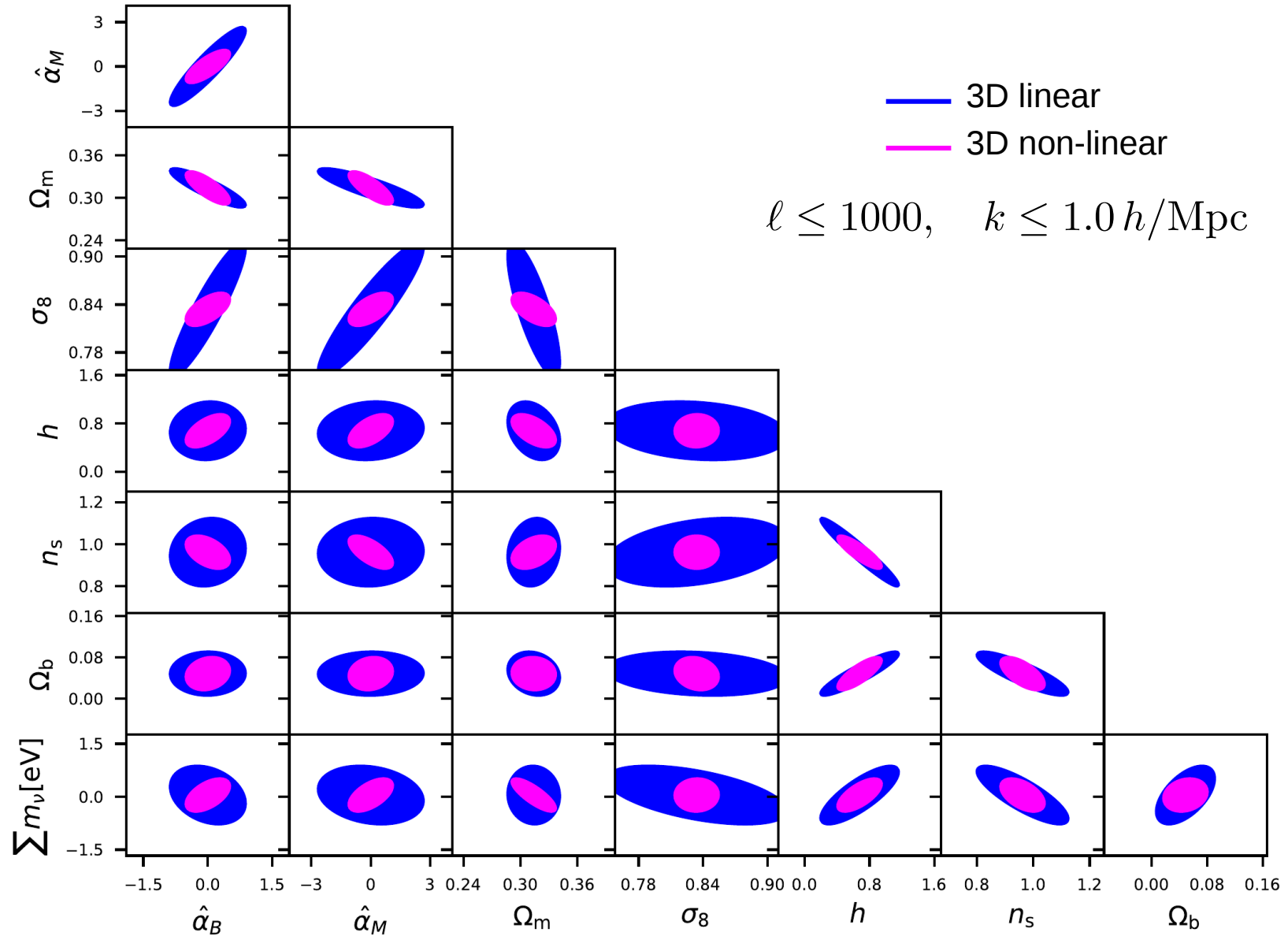
The idea (1)

We forecast

the ability of future *Euclid*-like experiments

to constrain <u>Horndeski</u> theories of gravity

using <u>3D</u> and <u>tomographic</u> cosmic shear

	$\hat{\alpha}_{\mathrm{B}}$	$\hat{\alpha}_{\mathrm{M}}$	Ω_{m}	σ_8	h	n_{s}	Ω_{b}	$\sum m_\nu$
fiducial value ($\hat{\alpha}_K = 0.01$, $\hat{\alpha}_T = 0$)	0.05	0.05	0.314	0.834	0.678	0.968	0.0486	0.05
1-σ error tomography 10 bins	0.57	1.66	0.017	0.056	0.257	0.088	0.022	0.472
1-σ error 3DWL	0.43	1.32	0.013	0.042	0.239	0.080	0.021	0.408

Tomography 10 bins

3D

$\ell \leq 1000, \quad k \leq 1.0\, h/\mathrm{Mpc}$

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	$\hat{\alpha}_B$	$\hat{\alpha}_M$	Ω_m	σ_8	h	n_s	Ω_b	$\sum m_\nu$
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1-σ error 3DWL	0.43	1.32	0.013	0.042	0.239	0.080	0.021	0.408
1-σ error 3DWL non-linear	0.25	0.55	0.011	0.010	0.134	0.038	0.016	0.229

3D linear

3D non-linear

$\ell \leq 1000, \quad k \leq 1.0\,h/\mathrm{Mpc}$

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The idea (2)

We forecast the ability of future Stage IV experiments (including *Euclid*)
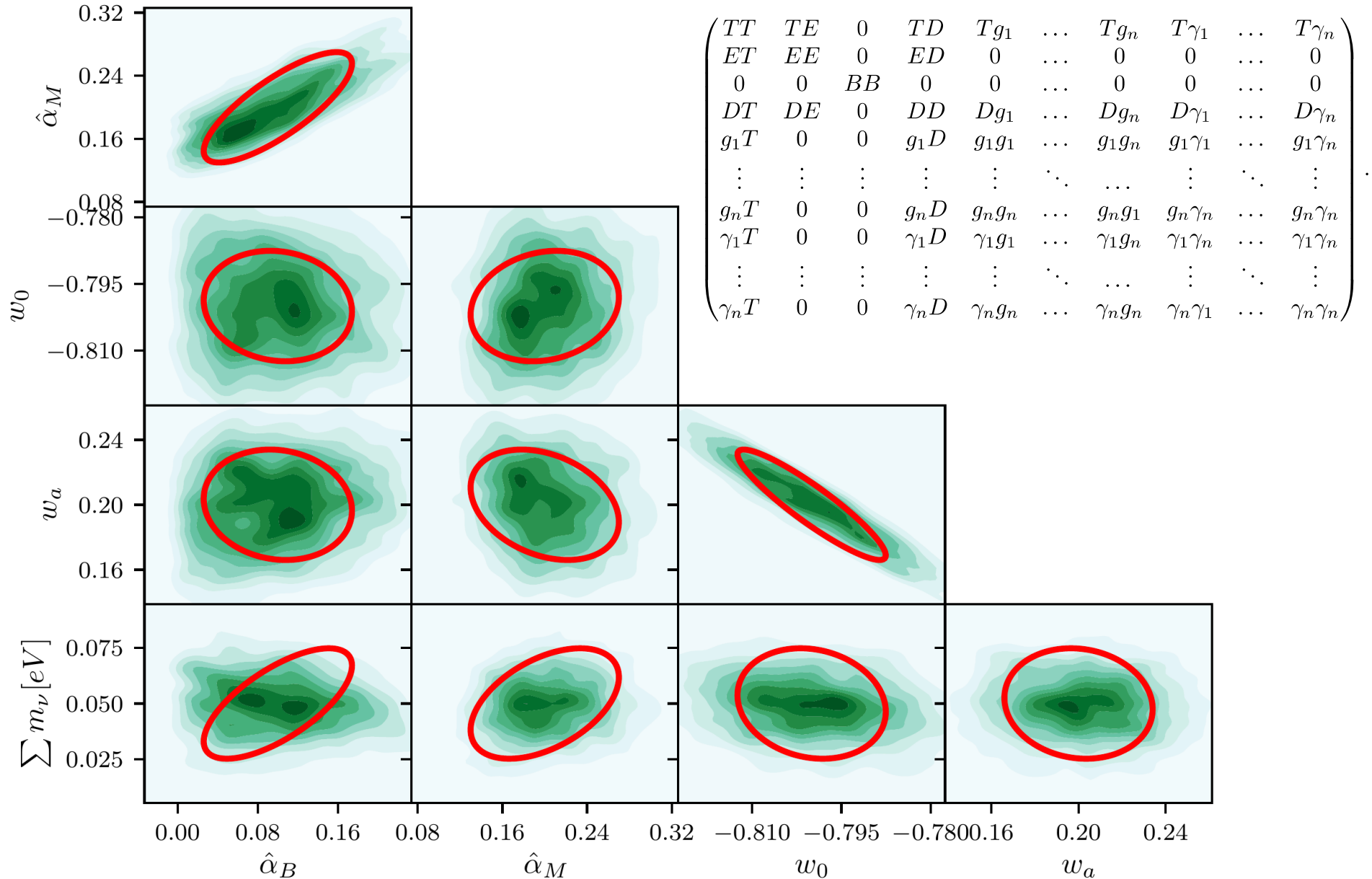
to constrain <u>Horndeski</u> theories of gravity using <u>cross-correlations</u> of cosmic shear, galaxy clustering, CMB primaries and CMB lensing

Cross-correlations
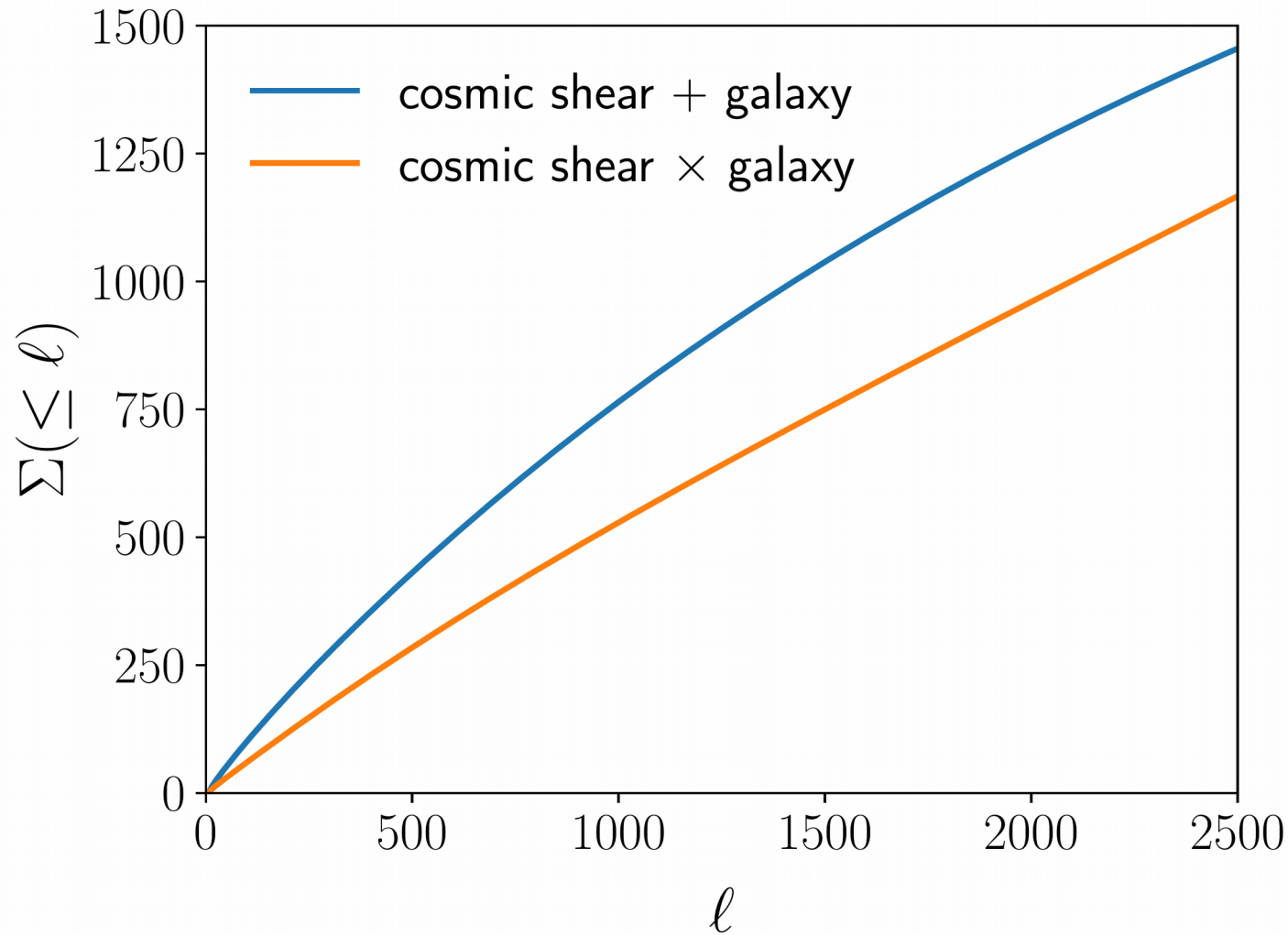
$$\Sigma^2(\leq \ell) = f_{\text{sky}} \sum_{\ell'=\ell_{\text{min}}}^{\ell} \frac{2\ell'+1}{2} \text{Tr} \left[(\boldsymbol{S}_{\ell'} + \boldsymbol{N}_{\ell'})^{-1} \boldsymbol{S}_{\ell'} (\boldsymbol{S}_{\ell'} + \boldsymbol{N}_{\ell'})^{-1} \boldsymbol{S}_{\ell'} \right]$$

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Cross-corrcorrelations

Conclusions & The Road Ahead

- 3D cosmic shear analysis based on *Euclid* data has **more constraining power** than tomography on Horndeski and standard cosmological parameters (~20% sensitivity gain for α`s)

- Non-linear scales will increase even further the constraining power $\rightarrow$ need a formalism to construct **non-linear corrections** in general MG setting (see e.g. Lombriser 2016, Cataneo et al. *in prep*)

- **Cross-correlations of cosmic shear with other observables,** combining *Euclid* and other Stage IV surveys, can provide even tighter constraints on Horndeski parameters

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Thank you!