Amplitude and Importance of Relativistic Contributions to the Galaxy Bispectrum

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Relativistic Effects and Novel Observables in Cosmology
University of Geneva
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UNIVERSITAS STUDII TAURINENSIS 1404

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Decoupling Local Primordial non-Gaussianity from Relativistic Effects in the Galaxy Bispectrum

Rossiter *et al.* (2024) - tomorrow!

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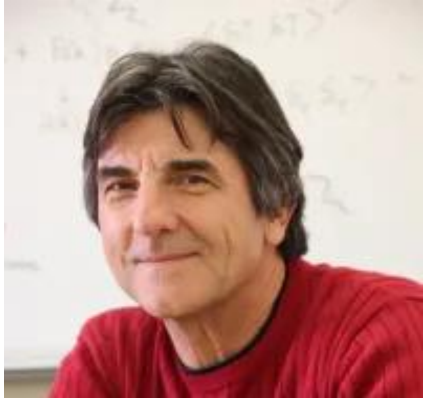
Expert Guidance

Stefano Camera
University of Turin

Chris Clarkson
Queen Mary University of London



Roy Maartens
University of the Western Cape

Background papers

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Local primordial non-Gaussianity in the relativistic galaxy bispectrum

arXiv:2011.13660

Roy Maartens[1,2], Sheean Jolicoeur[1], Obinna Umeh[2],
Eline M. De Weerd[3], Chris Clarkson[3,1]

Detecting the relativistic galaxy bispectrum

arXiv:1911.02398

Roy Maartens[1,2], Sheean Jolicoeur[1], Obinna Umeh[2],
Eline M. De Weerd[3], Chris Clarkson[3,1,4], Stefano Camera[5,6,1]

Contributions to the Galaxy Bispectrum

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- The Universe is not Gaussian: Non-linear evolution of structures and gravitational dynamics, Primordial non-Gaussianity, etc.
- Require higher order statistics such as the Bispectrum

$$\langle \delta_g(\mathbf{k}_1)\delta_g(\mathbf{k}_2)\delta_g(\mathbf{k}_3)\rangle = (2\pi)^3 \mathrm{B}_g(\mathbf{k}_1,\mathbf{k}_2,\mathbf{k}_3)\delta^D(\mathbf{k}_1+\mathbf{k}_2+\mathbf{k}_2)$$

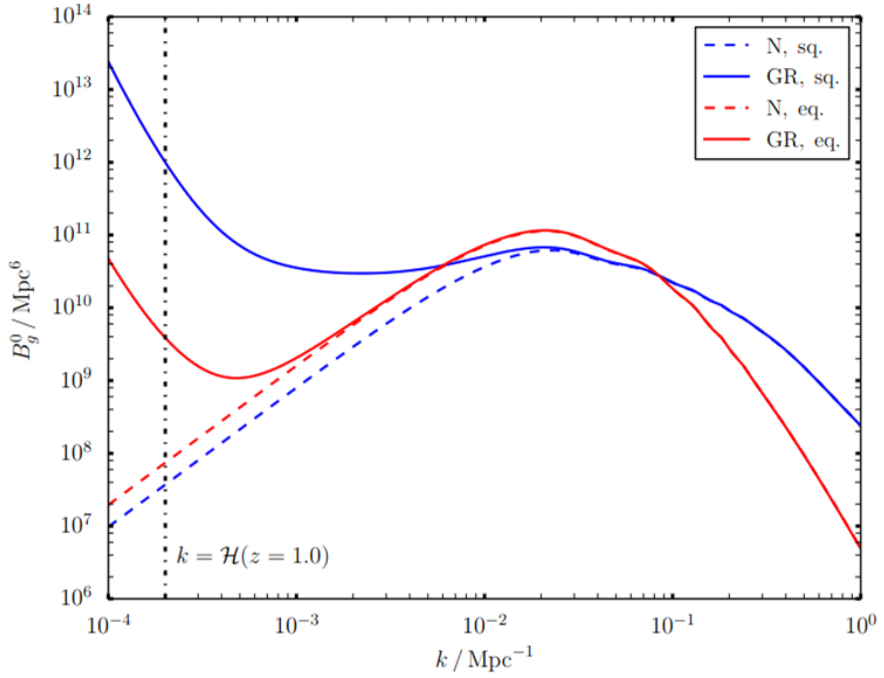
Relativistic effects and local primordial non-Gaussianity

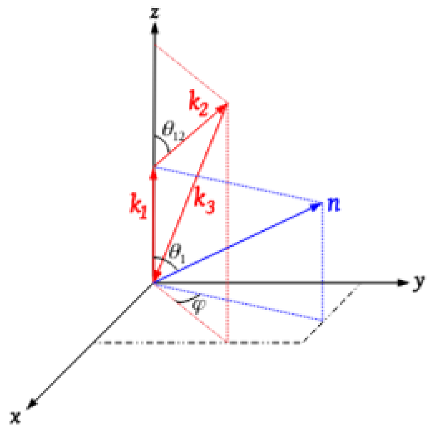
- Source of non-Gaussianity in the observed galaxy distribution
- More accessible in the bispectrum than in the power spectrum - long modes and short modes couple
- Imaginary terms don’t become real when using a single tracer - Smoking gun dipole

Relativistic Galaxy Bispectrum

$$B_g(\boldsymbol{k}_{123}) = \mathcal{K}^{(1)}(\boldsymbol{k}_1)\,\mathcal{K}^{(1)}(\boldsymbol{k}_2)\,\mathcal{K}^{(2)}(\boldsymbol{k}_{123})\,P(\boldsymbol{k}_1)\,P(\boldsymbol{k}_2) + 2\ \circlearrowleft$$

$$\mathcal{K}^{(i)} = \mathcal{K}^{(i)}_{\rm N} + \mathcal{K}^{(i)}_{\rm GR}$$





Monopole of the bispectrum for squeezed and equilateral triangles

Shows a significant difference at larger scales i.e small k

From Umeh et al 1610.03351

Galaxy Surveys

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Roman - Hα spectroscopic survey from the Wide Field Instrument (WFI)

DESI - Bright Galaxy Sample (BGS)

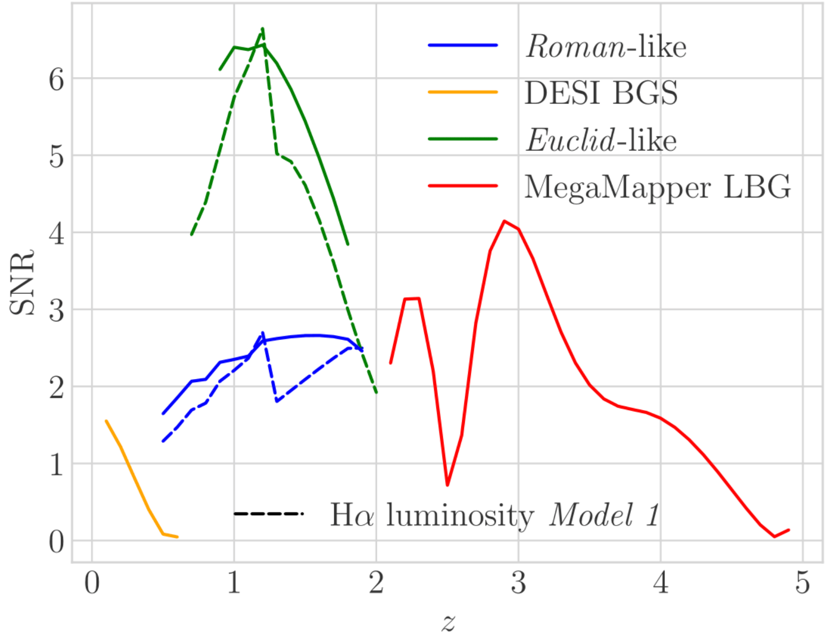
Euclid - Hα sample from the Near Infrared Spectroscopic and Photometric (NISP) instrument

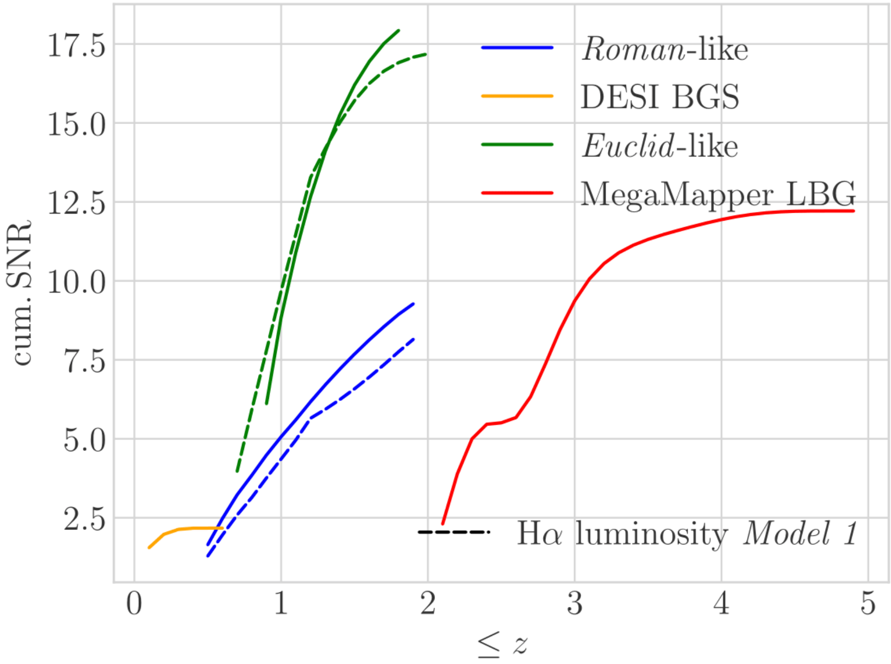
MegaMapper - Future ground based wide field spectroscopic instrument

Survey	Redshift range	Sky area [deg^2]
Roman	**model 1 & 3:** $0.5 \leq z \leq 2$	2000
DESI	$0 \leq z \leq 0.7$	14 000
Euclid	**model 1:** $0.7 \leq z \leq 2$ **model 3:** $0.9 \leq z \leq 1.8$	15 000
MegaMapper	$2 \leq z \leq 5$	20 000

Signal-to-noise Ratio

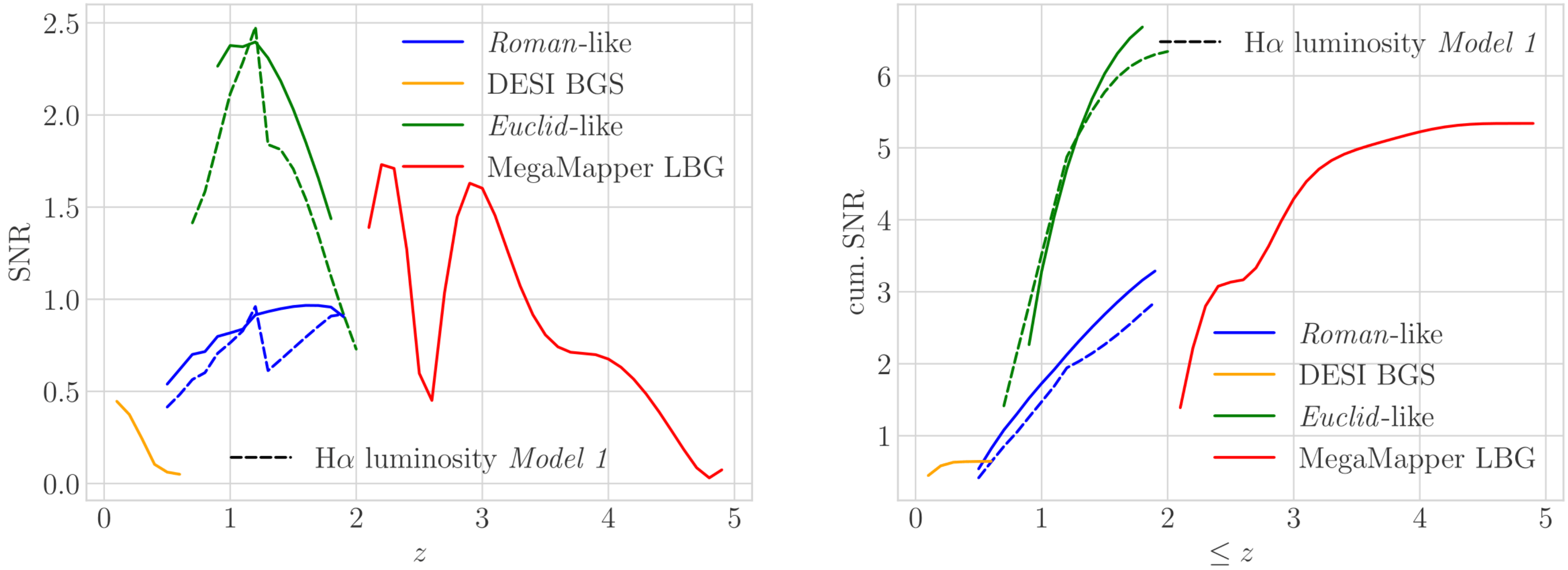
$$\left(\frac{S}{N}\right)^2_{GR} = \sum_{k_a,\mu_1,\varphi} \frac{(B_g - B_N)(B_g - B_N)^*}{\mathrm{Var}[B_{gN}]}$$





Signal-to-noise Ratio

$$\left(\frac{S}{N}\right)^2_{GR^{(2)}} = \sum_{k_a,\mu_1,\varphi} \frac{\left(B_g - (B_N + B_{GR^{(1)}})\right)\left(B_g - (B_N + B_{GR^{(1)}})\right)^*}{\mathrm{Var}[B_{gN}]}$$



Marginal errors

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- We want to see how precisely we can measure the local PNG and relativistic contributions

$$\mathcal{K}^{(i)} = \mathcal{K}_{\rm N}^{(i)} + \mathcal{K}_{\rm GR}^{(i)} + \mathcal{K}_{\rm nG}^{(i)}$$

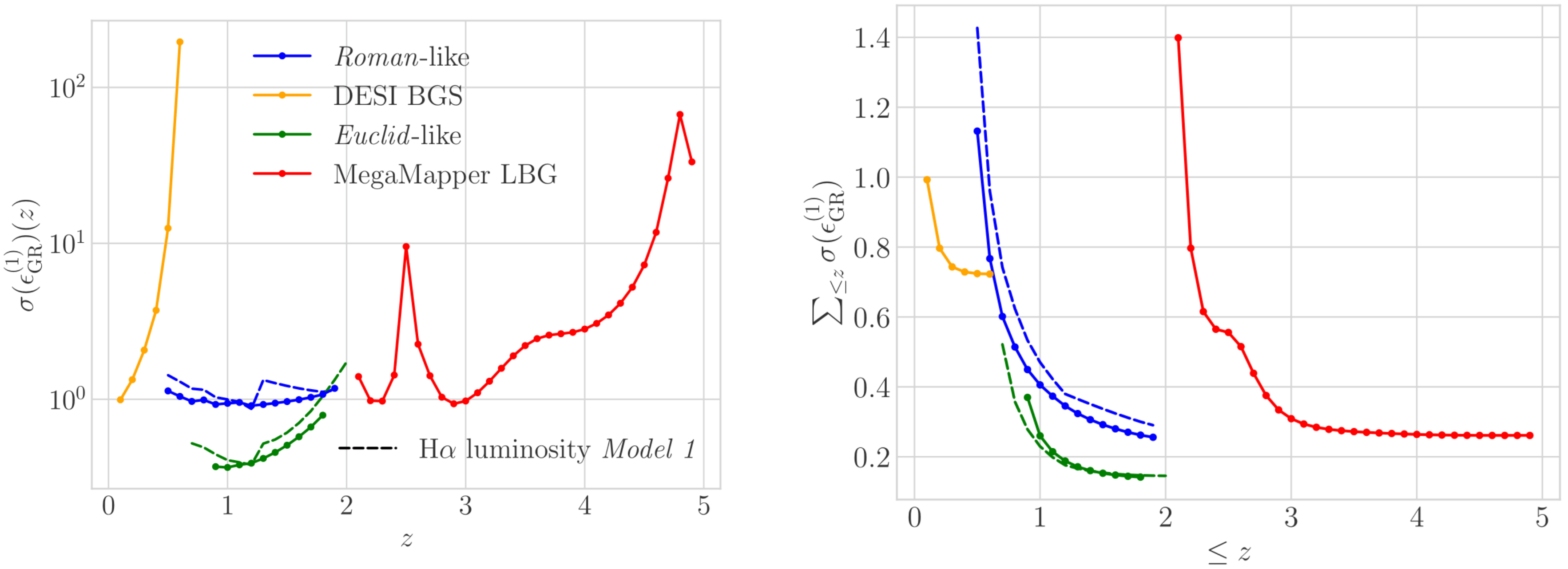
Fisher matrix formalism:

$$F_{\alpha\beta} = \sum_{z,k_a,\mu_a,\varphi} \frac{\partial_{(\alpha} B_g \, \partial_{\beta)} B_g^*}{\mathrm{Var}[B_g, B_g]}$$

- From this we can get the marginal errors on our parameters $\theta = \{\epsilon_{\rm GR}^{(1)}, \epsilon_{\rm GR}^{(2)}, f_{\rm NL}\}$

$$\sigma_\alpha = \sqrt{\left(\mathsf{F}^{-1}\right)_{\alpha\alpha}}$$

Marginal errors on $\epsilon_{\mathrm{GR}}^{(1)}$



Marginal errors on $\epsilon_{\mathrm{GR}}^{(2)}$

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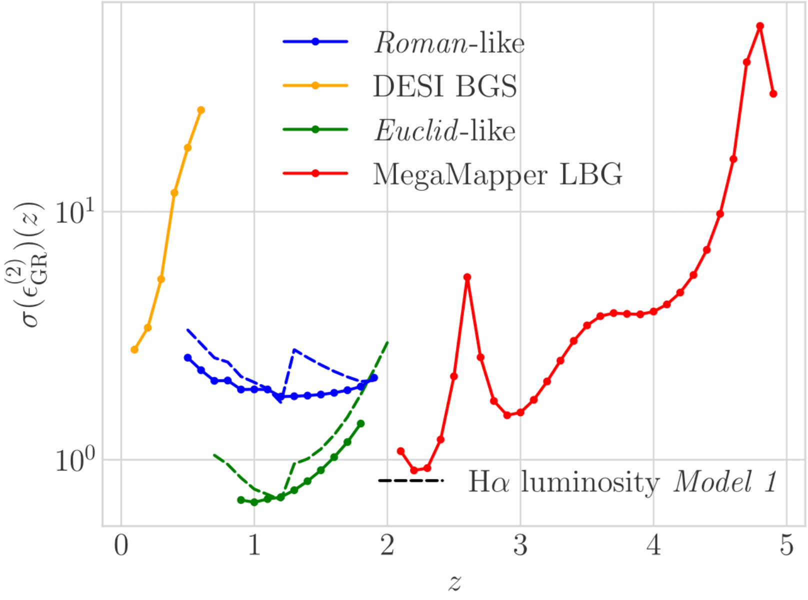
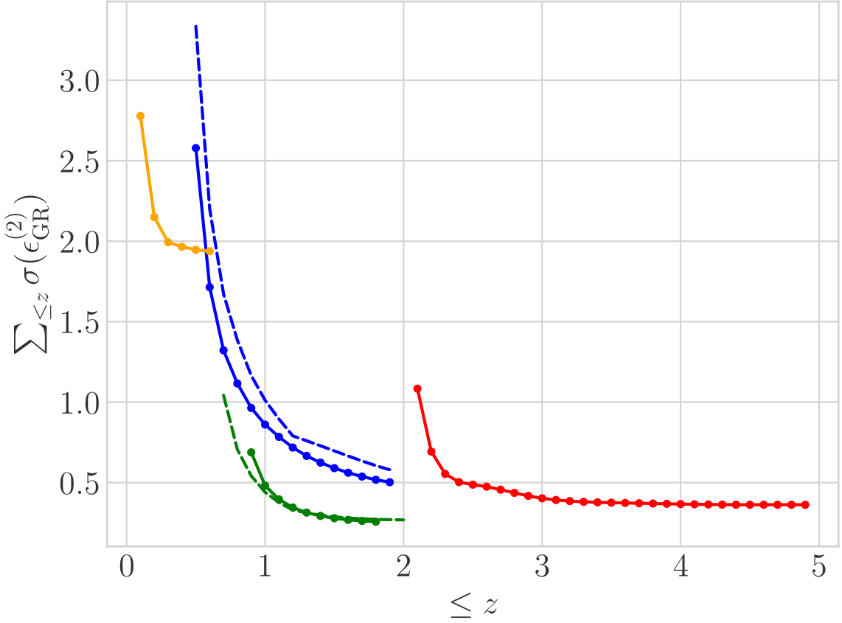
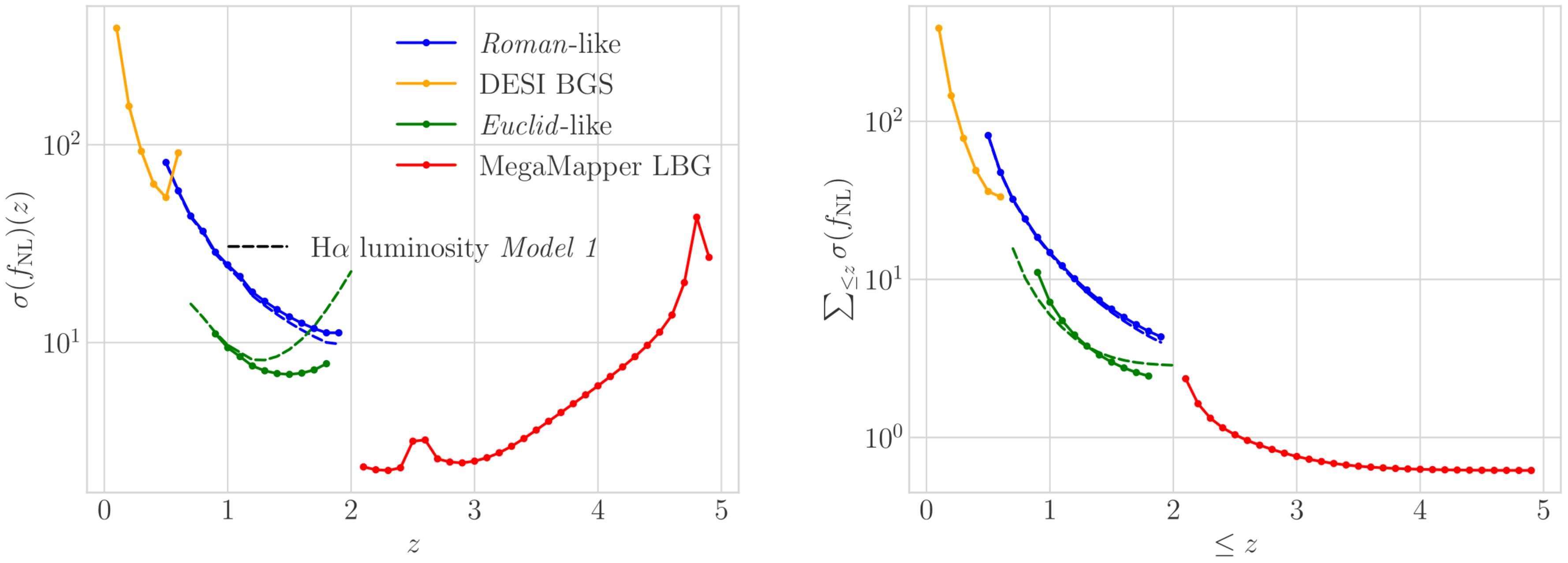
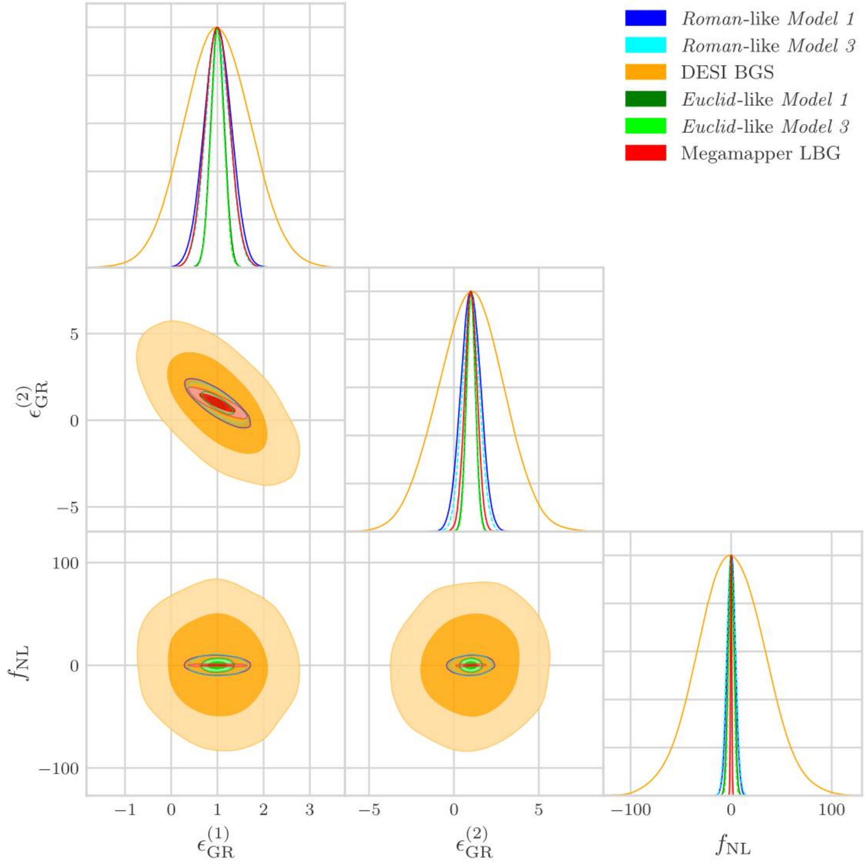




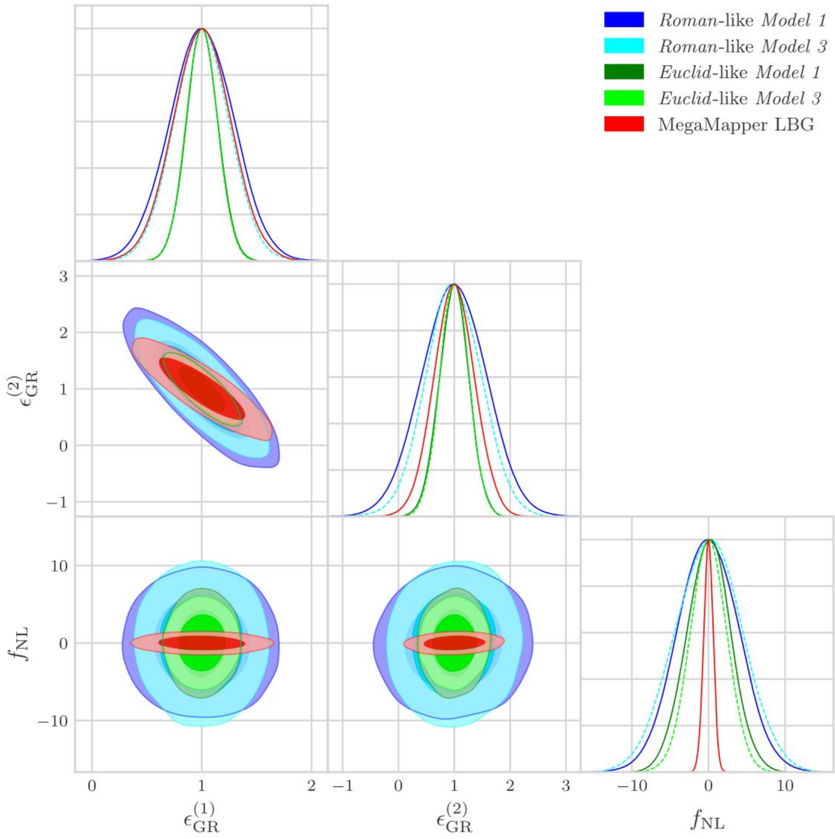
Marginal errors on $f_{\rm NL}$



Constraints on all parameters

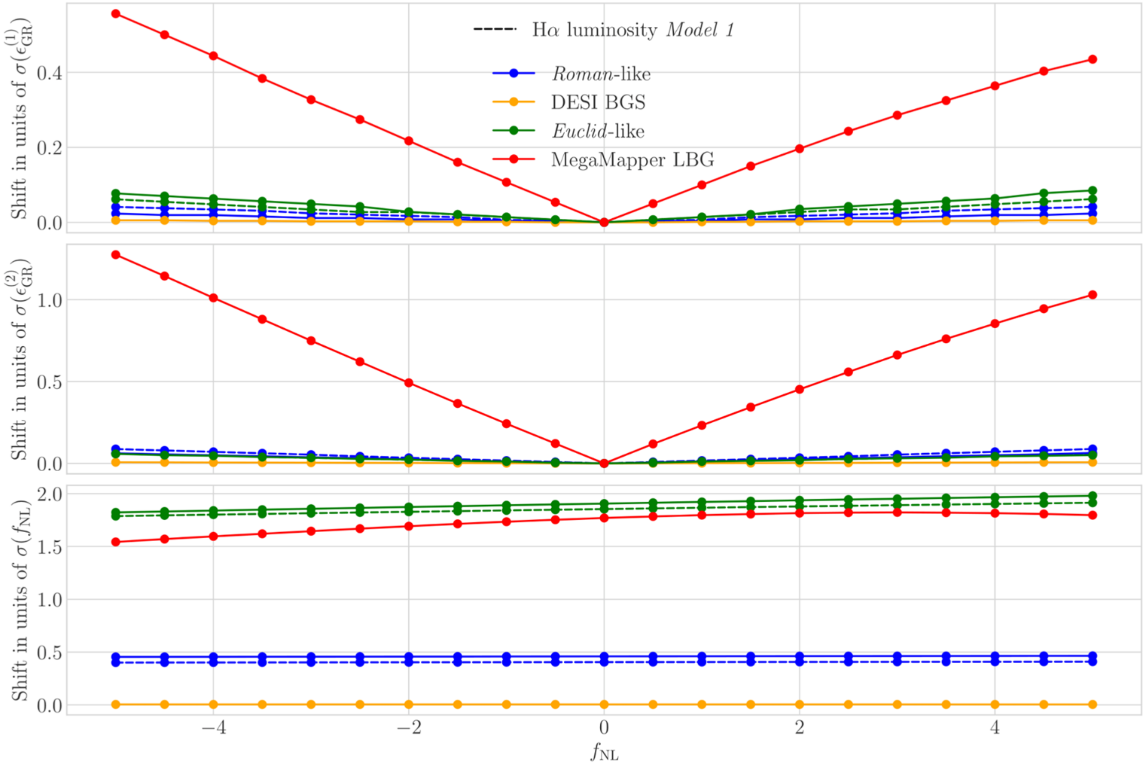


Constraints on all parameters



Bias on parameters

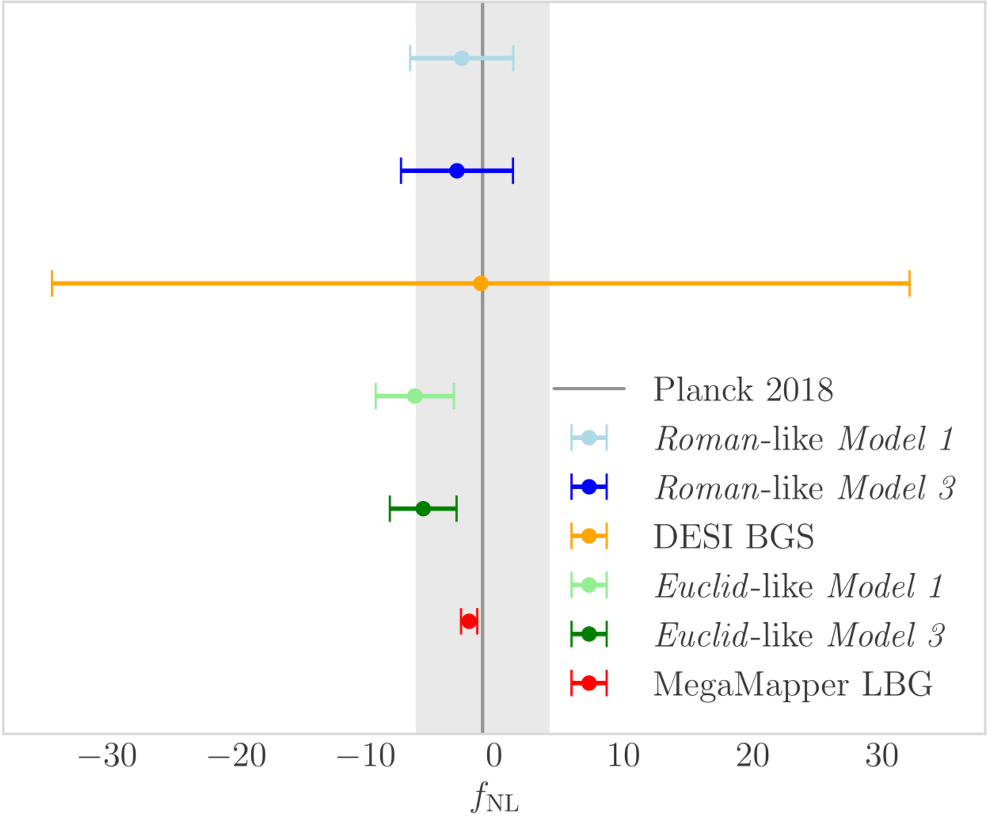
$$\Delta\theta_\alpha = \sum_\beta \left(F^{\theta_{GR}\theta_{GR}}\right)^{-1}_{\alpha\beta} F^{\theta f_{NL}}_\beta \, \delta f_{NL}$$



Uncertainty on f_{NL} makes little difference to the observed value we get on the relativistic contributions

Neglecting Relativistic contributions would impact our observed value of fnl significantly.

Bias on parameters



- The shift on the value of $f_{\rm NL}$ with error bars in the Newtonian regime.
- We have included the measured fnl with error bars as from Planck 2018 as a reference (greyed out area).

Cross Correlation Bispectrum ⟹ Multi-tracer ⟹ P + B

$$B^{XXY}(\boldsymbol{k}_1,\boldsymbol{k}_2,\boldsymbol{k}_3) = \frac{1}{3}\{\mathcal{D}_B[\{\mathcal{K}_1^X(\boldsymbol{k}_1)\mathcal{K}_1^Y(\boldsymbol{k}_2)+\mathcal{K}_1^Y(\boldsymbol{k}_1)\mathcal{K}_1^X(\boldsymbol{k}_2)\}\mathcal{K}_2^X(\boldsymbol{k}_1,\boldsymbol{k}_2) + \mathcal{K}_1^X(\boldsymbol{k}_1)\mathcal{K}_1^X(\boldsymbol{k}_2)\mathcal{K}_2^Y(\boldsymbol{k}_1,\boldsymbol{k}_2)]\,P(k_1)\,P(k_2) + 2\boldsymbol{k}\text{-perm}\}\,,$$

$$B^{XYY}(\boldsymbol{k}_1,\boldsymbol{k}_2,\boldsymbol{k}_3) = \frac{1}{3}\{\mathcal{D}_B[\{\mathcal{K}_1^X(\boldsymbol{k}_1)\mathcal{K}_1^Y(\boldsymbol{k}_2)+\mathcal{K}_1^Y(\boldsymbol{k}_1)\mathcal{K}_1^X(\boldsymbol{k}_2)\}\mathcal{K}_2^Y(\boldsymbol{k}_1,\boldsymbol{k}_2) + \mathcal{K}_1^Y(\boldsymbol{k}_1)\mathcal{K}_1^Y(\boldsymbol{k}_2)\mathcal{K}_2^X(\boldsymbol{k}_1,\boldsymbol{k}_2)]\,P(k_1)\,P(k_2) + 2\boldsymbol{k}\text{-perm}\}\,,$$

Multi-tracer power spectra and bispectra: Formalism

arXiv:2305.04028

Dionysios Karagiannis,[1] Roy Maartens,[1,2,3] José Fonseca,[4,5,1] Stefano Camera,[6,7,8,1] Chris Clarkson[9,1]

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Summary

- Relativistic effects couple with local PNG on large scales
- Without including relativistic effects, $f_{\rm NL}$ cannot be measured accurately
- The evolution bias leaves a big imprint on the detection of relativistic effects
- The modelling of the luminosity functions of surveys is crucial for decoupling
- Working with cross-correlations of different samples of the same survey may allow us to reduce the degeneracies within even the least promising surveys

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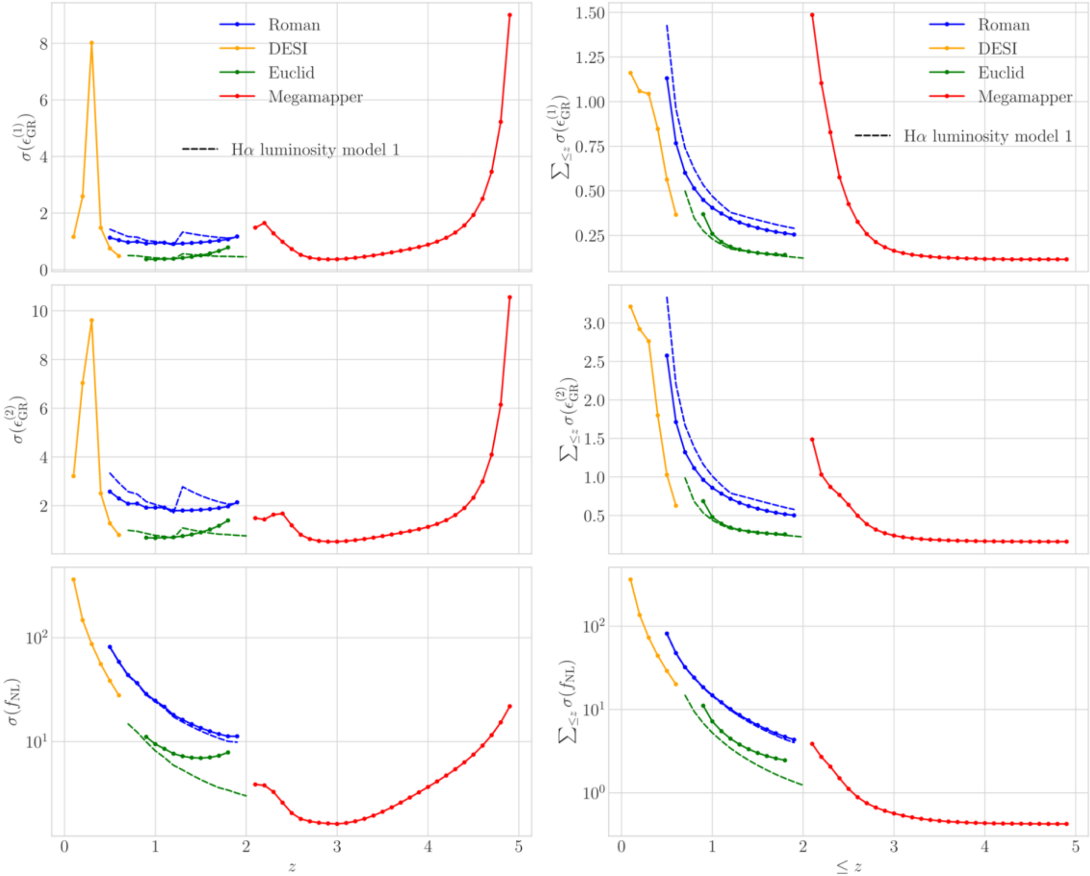
Thank you.

Any questions?

Backup slides

Marginal errors



Survey	$\sigma(\epsilon_{GR}^{(1)})$	$\sigma(\epsilon_{GR}^{(2)})$	$\sigma(f_{NL})$
Roman model 1	0.290	0.579	4.007
Roman model 3	0.255	0.502	4.344
DESI	0.366	0.627	20.123
Euclid model 1	0.123	0.233	1.234
Euclid model 3	0.141	0.256	2.458
MegaMapper	0.116	0.161	0.424

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Signal-to-noise Redone

- Discontinuity in luminosity function causes steep drop in signal at z~1.3
- Check against an improved luminosity model with updated Euclid specs