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Constraining modified gravity with redshift space distortions

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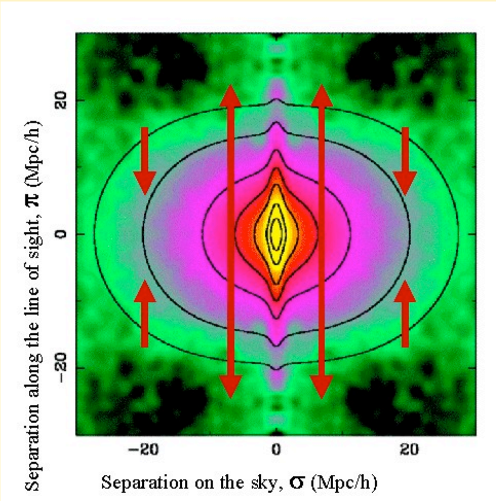

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How do we interpret dark energy?

Is the universe accelerating? — No → Photons see extra dimensions?

↓ Yes

Is General Relativity correct? — No → Modified Gravity?

↓ Yes

Is Dark Energy matter of some form? — No → Inhomogeneous universe?

↓ Yes

Is Dark Energy constant in our observable universe? — No → New matter? Scalar? Interacting fluids?

↓ Yes

Is Dark Energy constant everywhere? — No → Cosmological constant Anthropic arguments?

↓ Yes

Universal Cosmological Constant of unknown origin?

credit: Rachel Bean

How can GR be modified?

- Assume conformal Newtonian gauge

$$ds^2 = a^2[(1 + 2\psi)d\tau^2 + (1 - 2\phi)d\vec{x}^2]$$

ϕ, ψ - Newtonian potentials

τ - conformal time

- Modify Poisson equations

$$\nabla^2\psi = 4\pi G a^2 \delta\rho \times G_{matter}$$

effects on matter growth

$$\nabla^2(\phi + \psi) = 8\pi G a^2 \delta\rho \times G_{light}$$

effects on lensing of light

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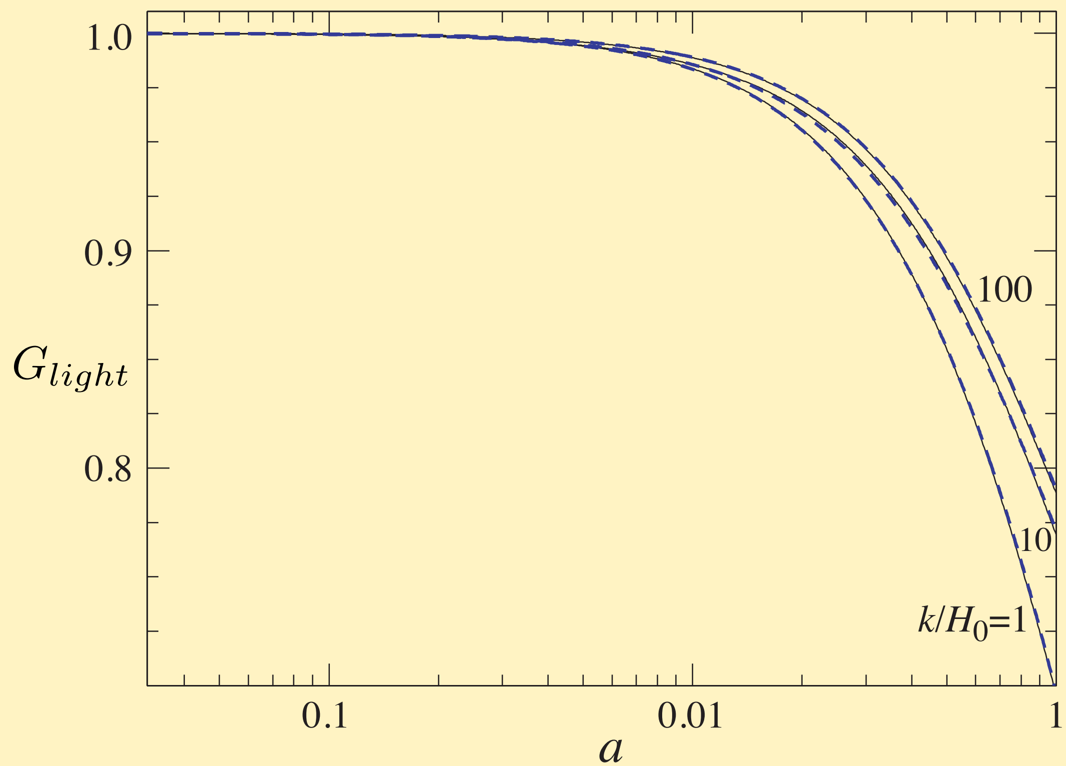
- Phenomenological model

- However a number of well-studied modified gravity models can be expressed in terms of $G_{matter},\ G_{light}$

DGP:

$$G_{light} = \frac{1}{1 + \left(\frac{ma}{k}\right)^{2(1-\alpha)}}$$



Hu and Sawicki ’07
Pogosian et al 1002.2382

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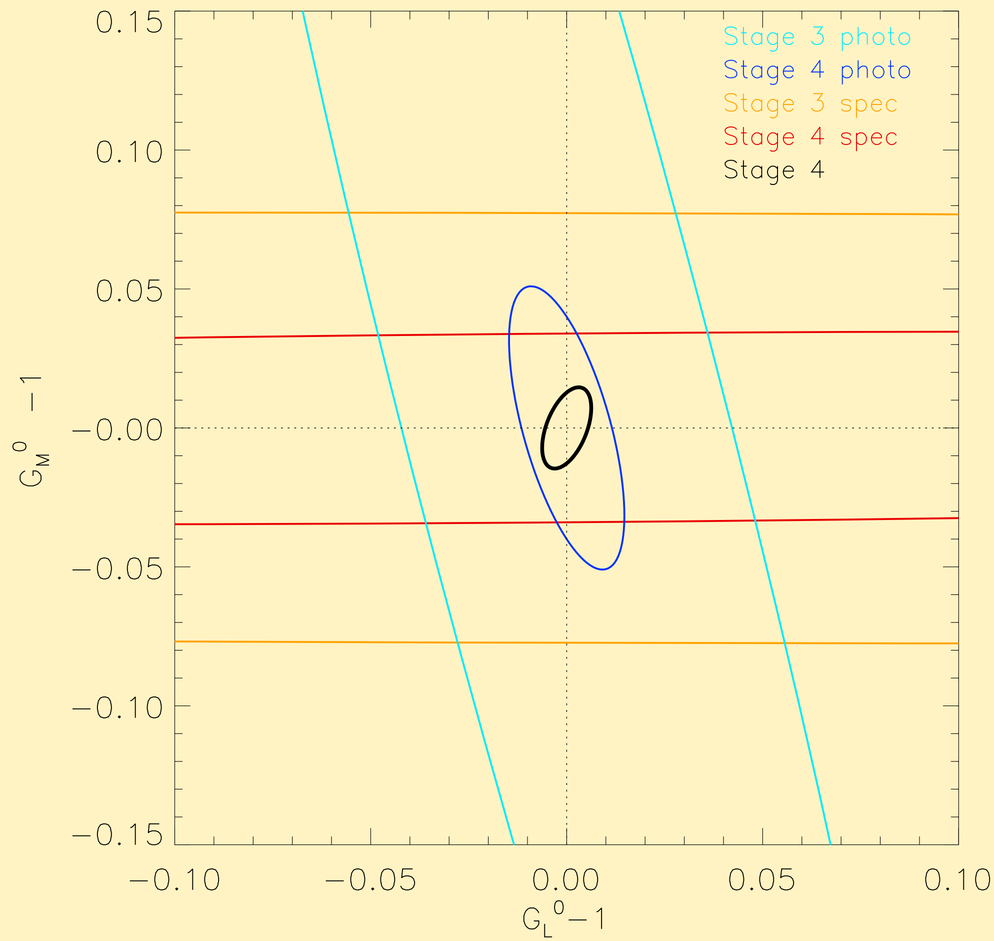

	RSD	WL+GAL+x
Stage 3	BOSS	DES
Stage 4	DESi, Euclid/LSST, AFTA	Euclid/LSST, AFTA

+CMB+SN

$$GR : G_M = 1$$
$$G_L = 1$$

preliminary work, Mueller and Bean in prep

- complementary of photometric and spectroscopic surveys
- 1% level constraints on both parameters

- However most models are z-dependent and k-dependent

- Principle component analysis as an model independent approach:

$$G_{light}(k,z):\ 20\ z\ bins,\ 4\ k\ bins$$
$$G_{matter}(k,z):\ 20\ z\ bins,\ 4\ k\ bins$$
$$w(z):\ 20\ z\ bins$$

- 6 cosmological parameters + 180 extra parameters !

  (2 x 20 x 4 + 20)

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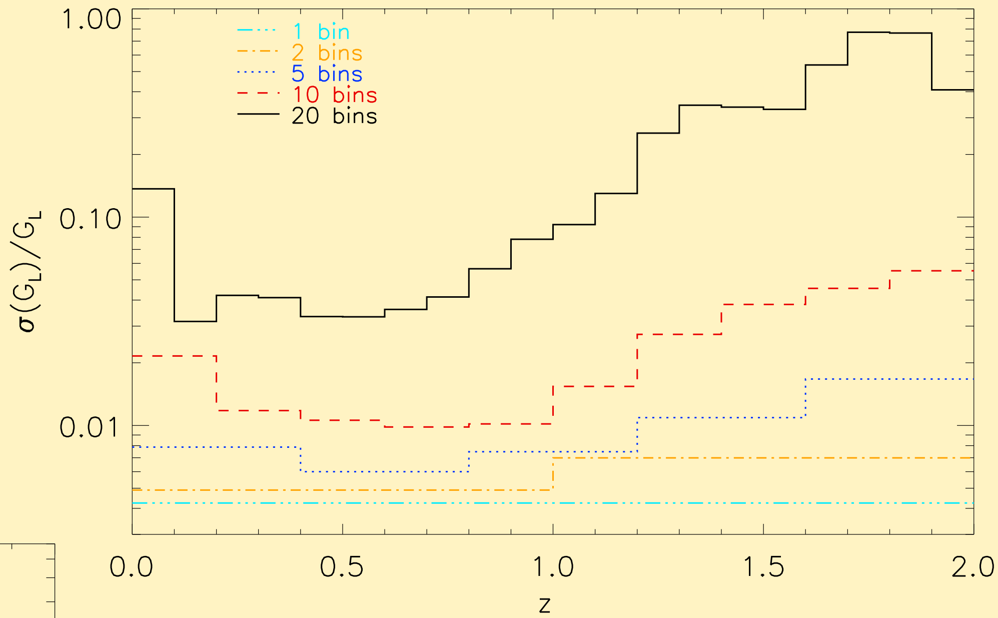
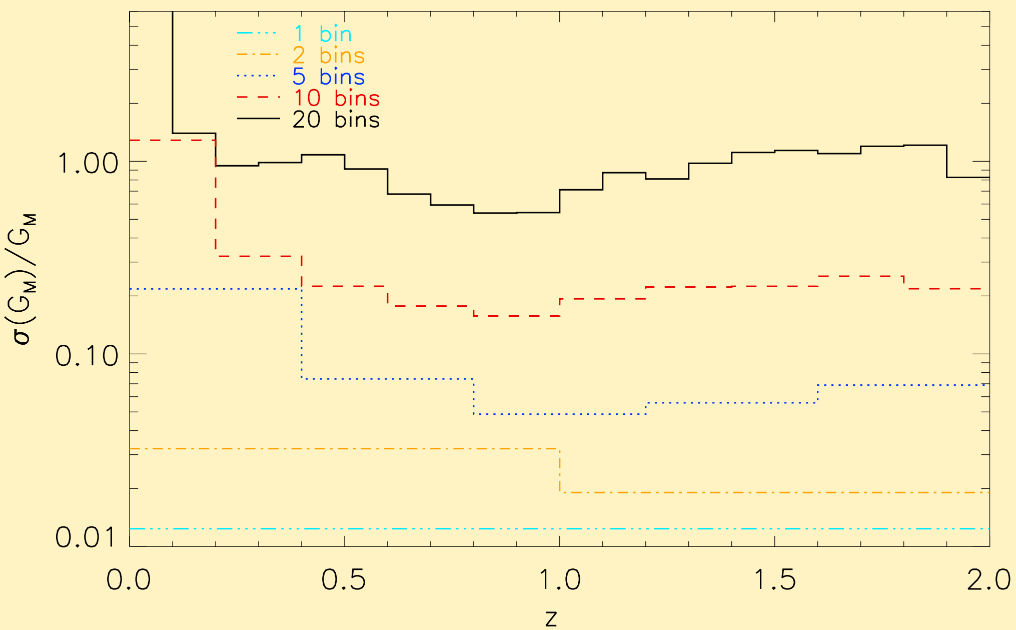
Redshift dependency

- Constraints degrade with the number of z bins





preliminary work, Mueller and Bean in prep

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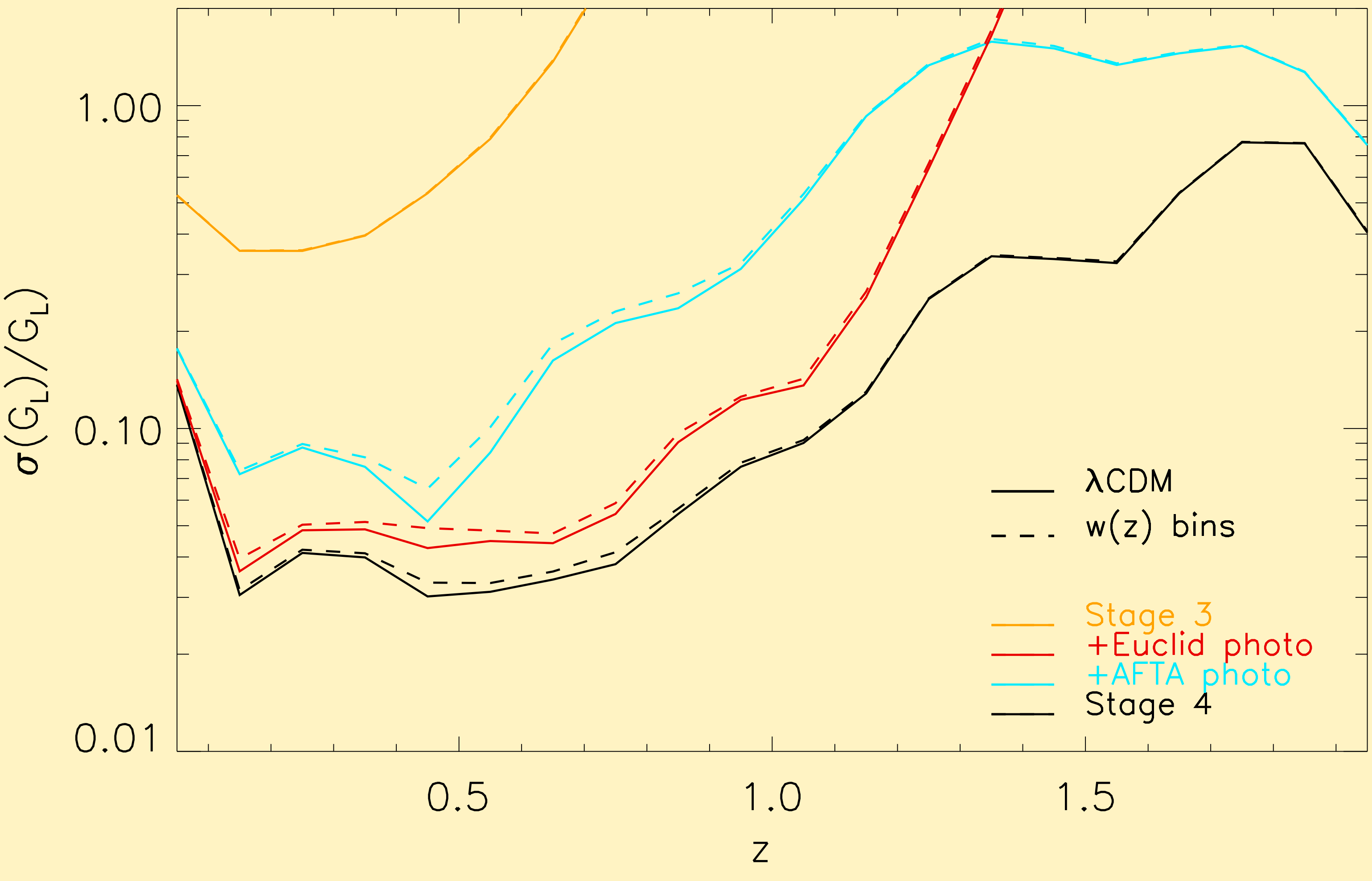
Survey complementarity



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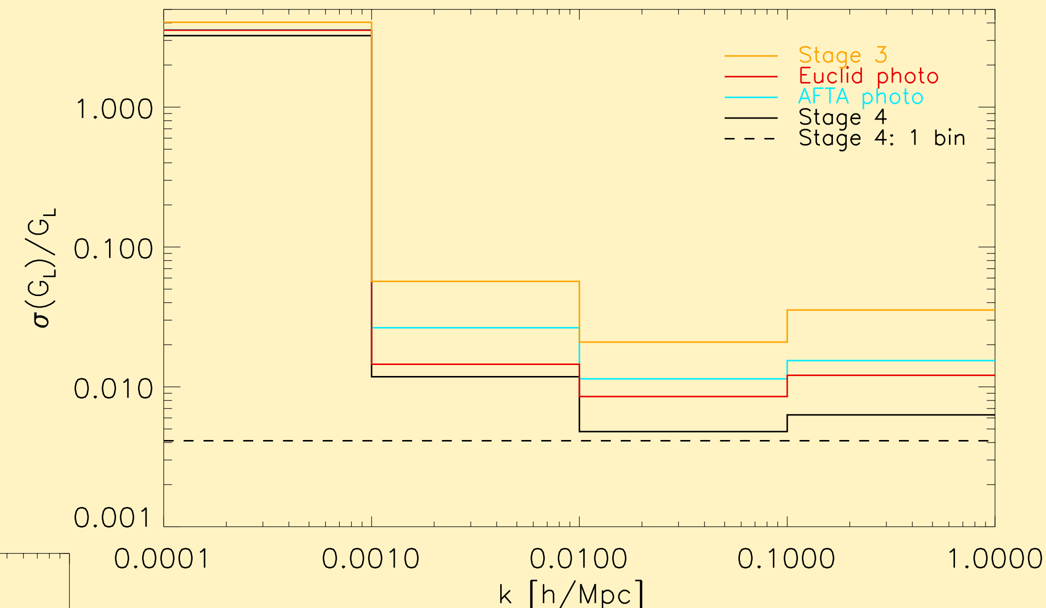
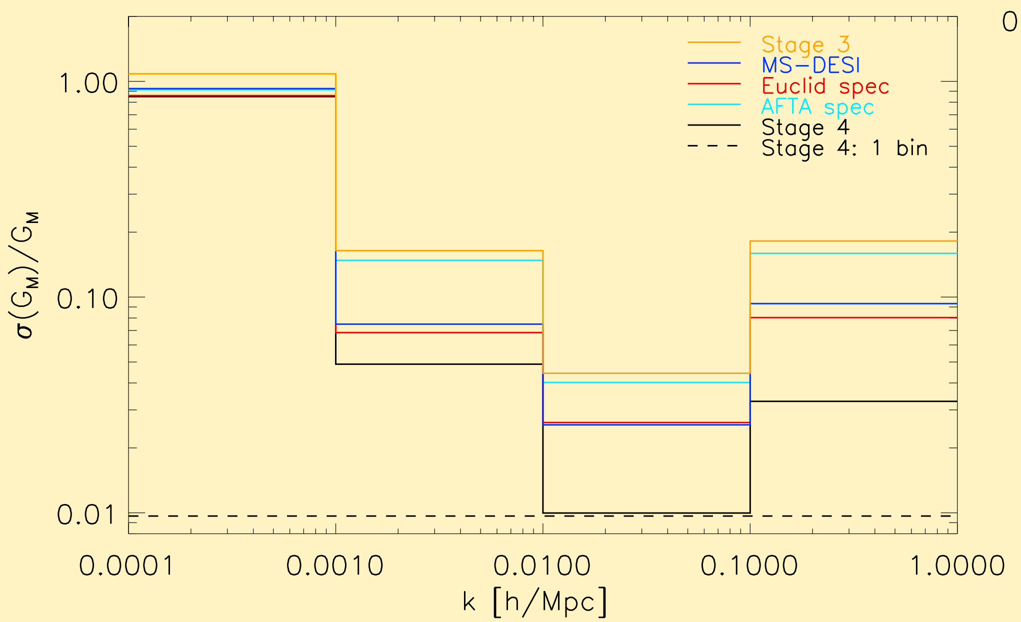
Scale dependency



→ Constraints degrade with the number of k bins

preliminary work, Mueller and Bean in prep



→ How can we improve those constraints?

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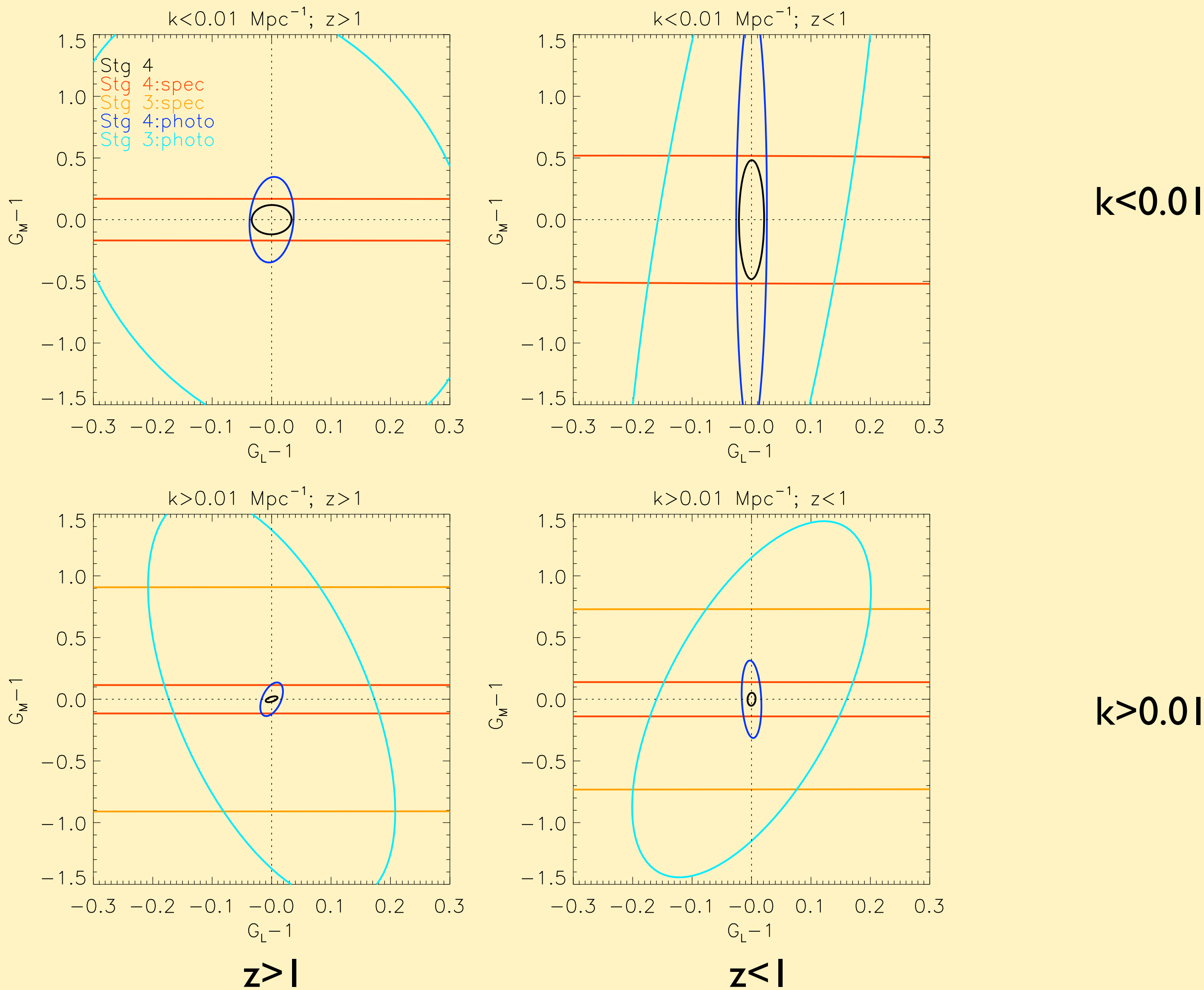
1. Less bins=more restrictive prior



preliminary work, Mueller and Bean in prep

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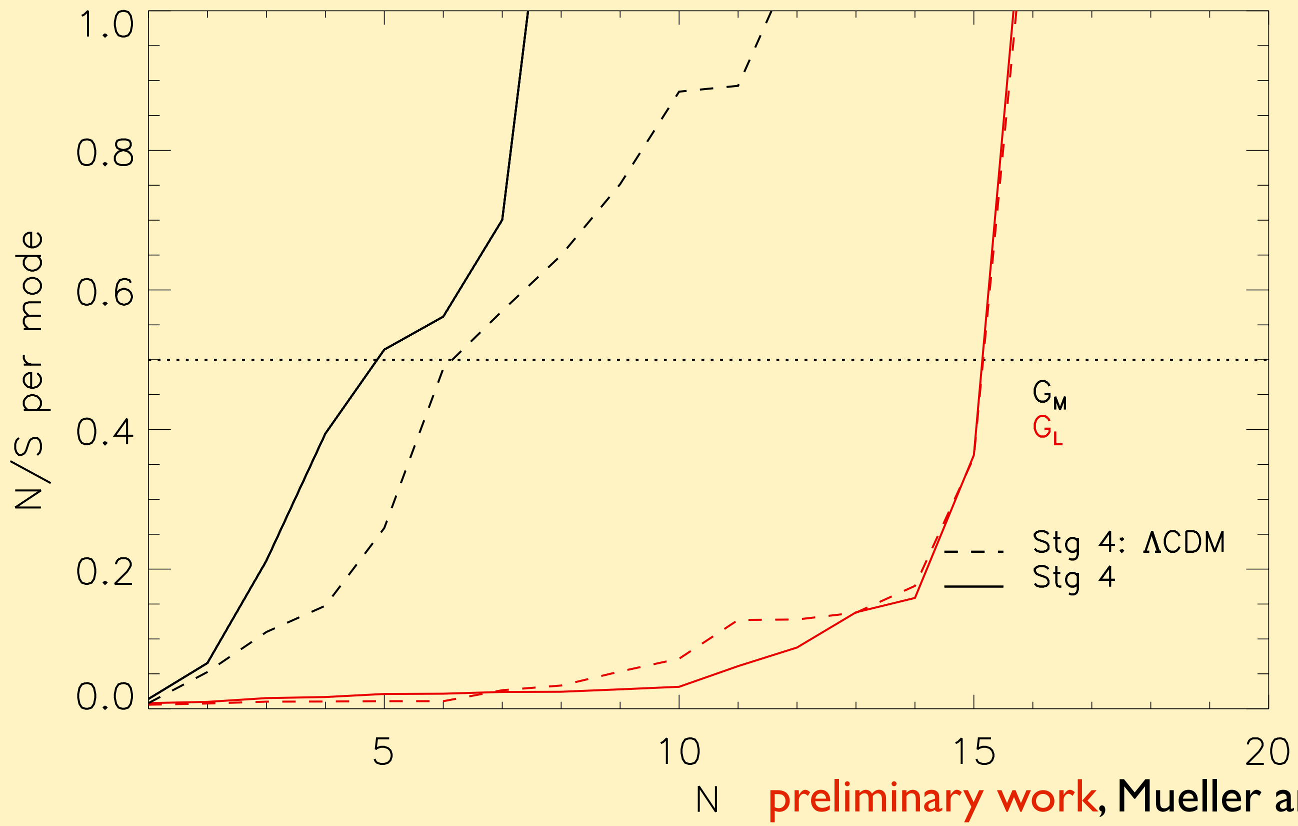
2. Reduce the number of modes

➡ How many well constrained modes are there?



preliminary work, Mueller and Bean in prep

$$N/S < 0.5 \ (or\ more\ conservative?)$$

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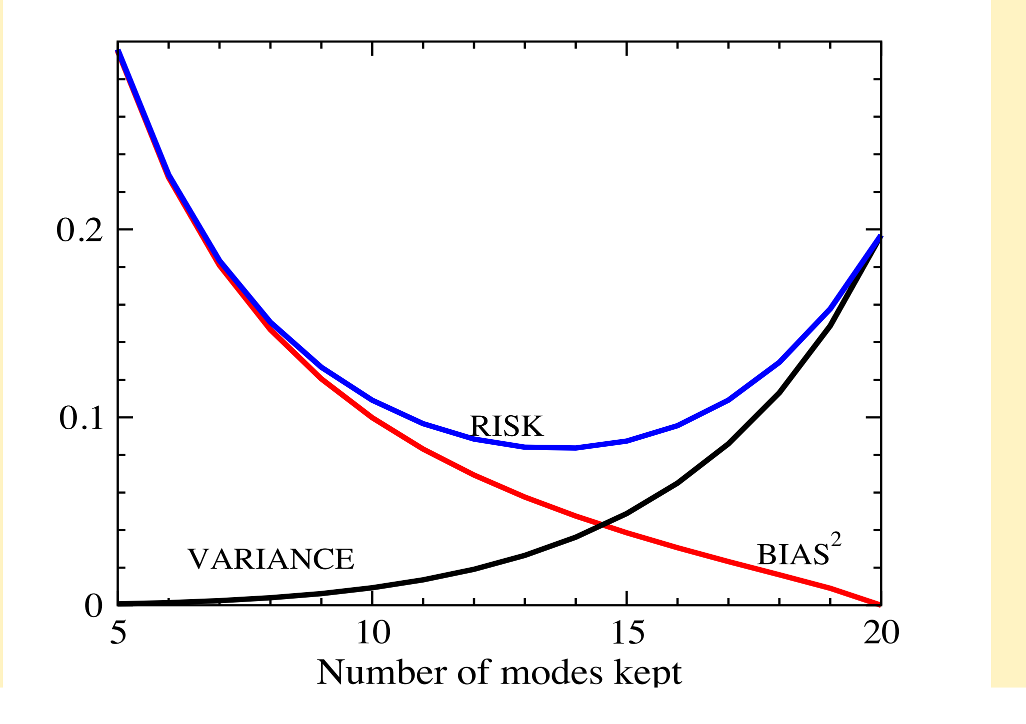
How big is the bias?

$$bias = \sum_{i}^{N} \left(G_{M/L}(z_i) - G^{fid}_{M/L}(z_i) \right)$$

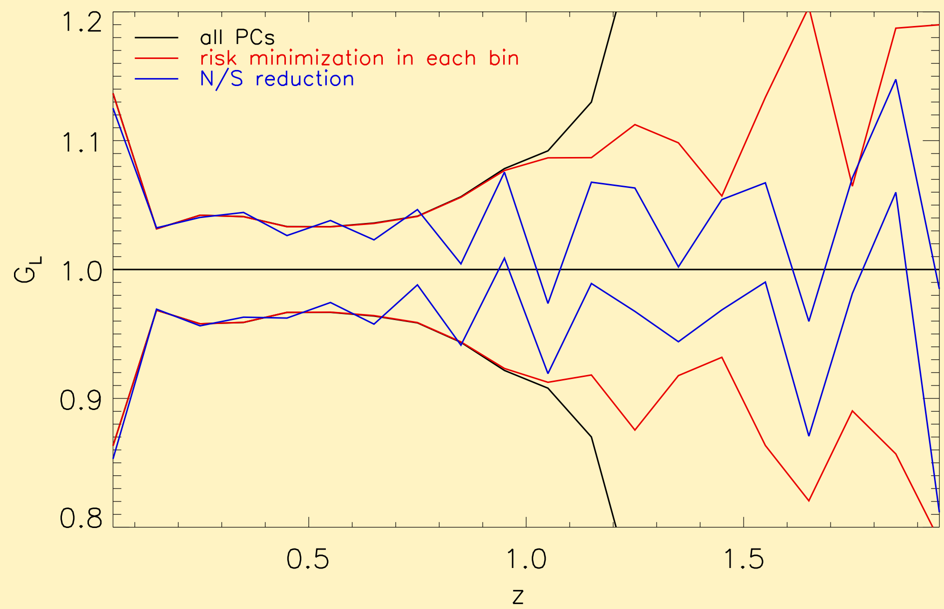
reconstructed value using a subset of all modes

Minimize the risk!



Huterer and Starkman '02

Fewer modes lead to tighter constraints but higher bias



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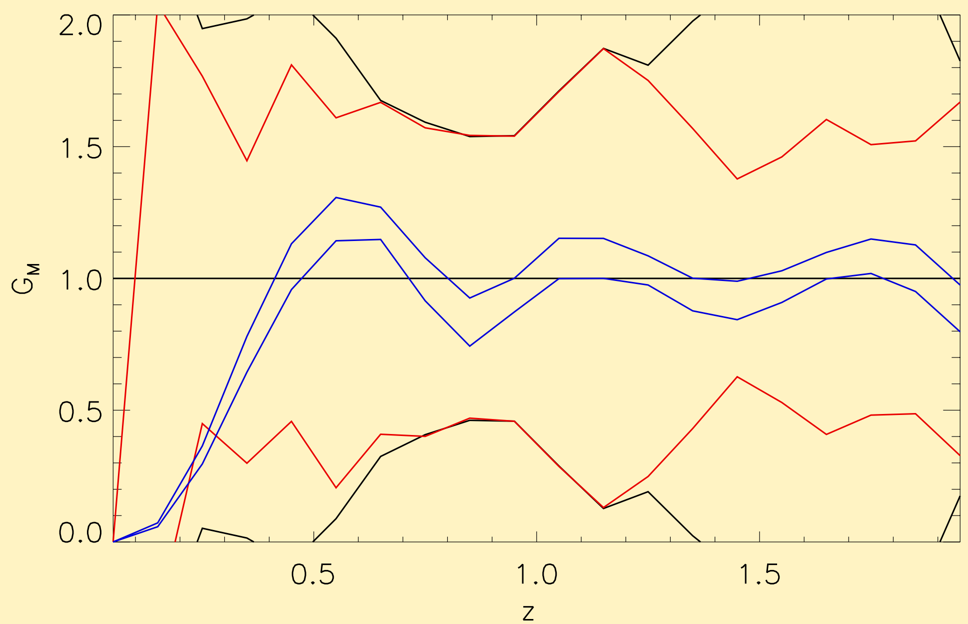

Reduction method	G_M	G_L
N/S reduction	5	16
risk minimization	16	18

Alternative Approach

Dark energy (background) is often modeled as:

$$w(a) = w_0 + (1 - a)w_a$$

⇨ Simple parametrization for modified gravity?

$$G_{matter}(k, a) = ?$$
$$G_{light}(k, a) = ?$$

A variety of models considered in the literature

A bit of caution with forecasts!

➡ Forecasting is sensitive to assumptions!

- Galaxy number densities n(z)
- Galaxy bias
- Minimum scale k=0.12h/Mpc
- Smith et al nonlinear power spectrum
- Kaiser approximation
- photometric redshift errors
- intrinsic alignment modeling
- ...
- ...

Summary

- Phenomenological bridge between theory and observation: G_{matter}, G_{light}

- Spectroscopic surveys are going to be the key to measuring G_{matter}

- Photometric weak lensing and galaxy surveys will enable strong measurements of G_{light}

- Upcoming decade offers unprecedented opportunity to test gravity con cosmic scales

- The more freedom allowed in the model the looser the constraints