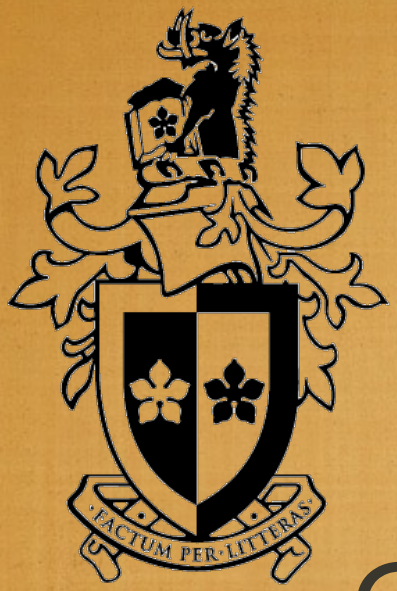


Testing Gravity on Cosmic Scales with WL and RSDs

Shahab Joudaki

Centre for Astrophysics & Supercomputing
Swinburne University

Collaborators: C. Blake, A. Johnson, RCSLenS/KiDS/2dFLenS

Agenda Part 1

- Introduction: Modified Gravity, Weak Lensing, Redshift Space Distortions.
- Combining Overlapping Surveys: (RCSLenS+CFHTLenS)/(WiggleZ+BOSS). Testing gravity and WL systematics with Coherent CosmoMC Pipeline.

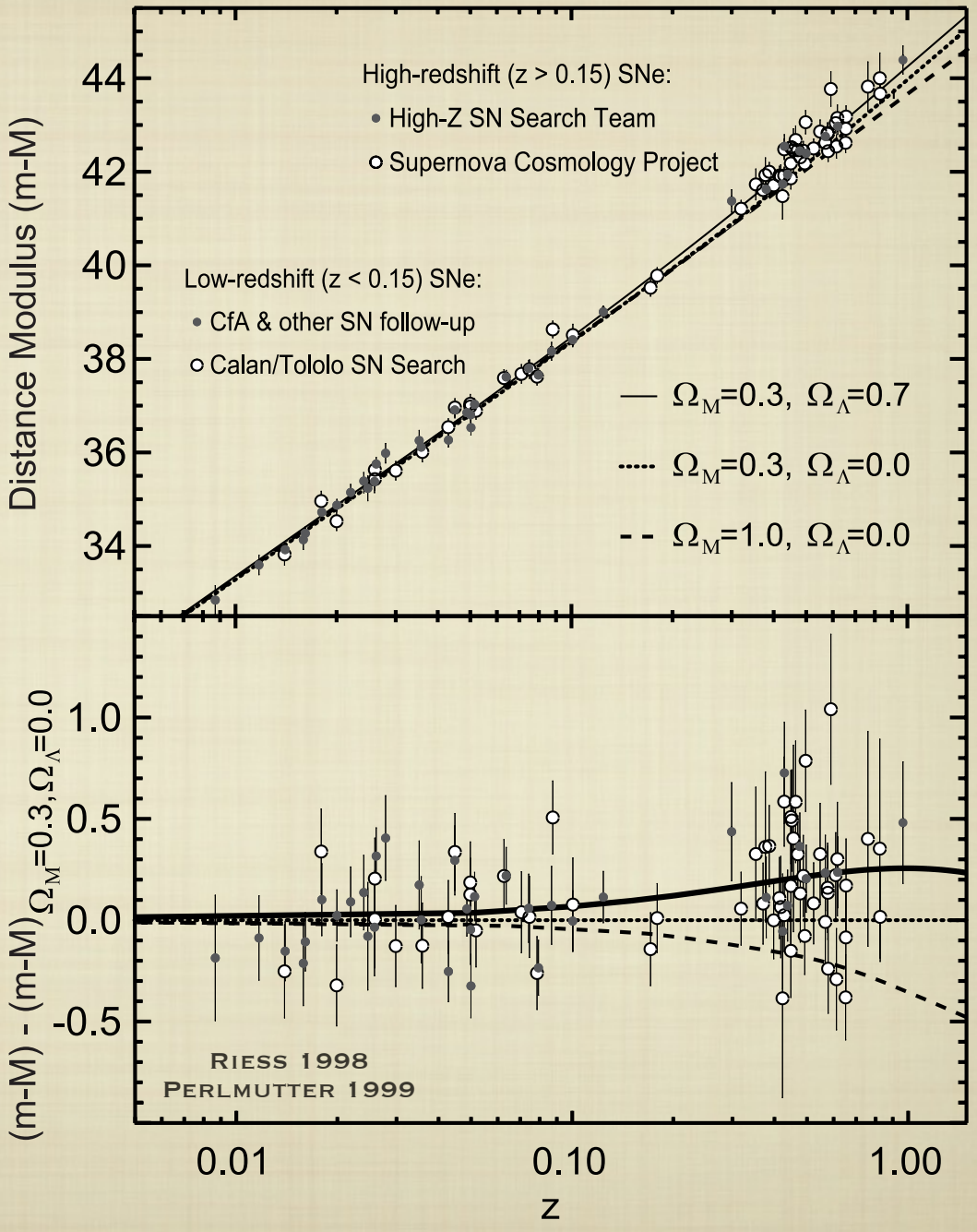
Cosmic acceleration

Universe accelerates

Cosmological constant, DE, or MG?

Expansion: SNe, BAO
Growth: WL, RSD

critical for understanding MG



Perturbed Einstein: Metric Potentials

Newtonian gauge, (small) scalar perturbations:

$$ds^2 = -(1+2\psi)\, dt^2 + (1-2\phi)\, a^2(t)\, d\vec{x}^2$$

Non-relativistic Particles: ψ ⟵ **Newtonian**

Relativistic Particles: $\psi + \phi$

standard GR + no anisotropic stress: $\psi = \phi$

⟹ **Poisson Equation:**

$$\nabla^2\psi = \nabla^2\phi = 4\pi G a^2 \sum \rho_i \Delta_i$$

Ma & Bertschinger 1995

Perturbed Einstein Equations

General Relativity

$$k^2\phi = -4\pi G a^2 \sum \rho_i \Delta_i$$

$$\psi - \phi = -12\pi G a^2 \sum_i \rho_i (1+w_i) \frac{\sigma_i}{k^2}$$

Modified Gravity

$$k^2\phi = -4\pi \underbrace{GQ}_{G_{\rm eff}} a^2 \sum_i \rho_i \Delta_i$$

$$\psi = R\phi$$

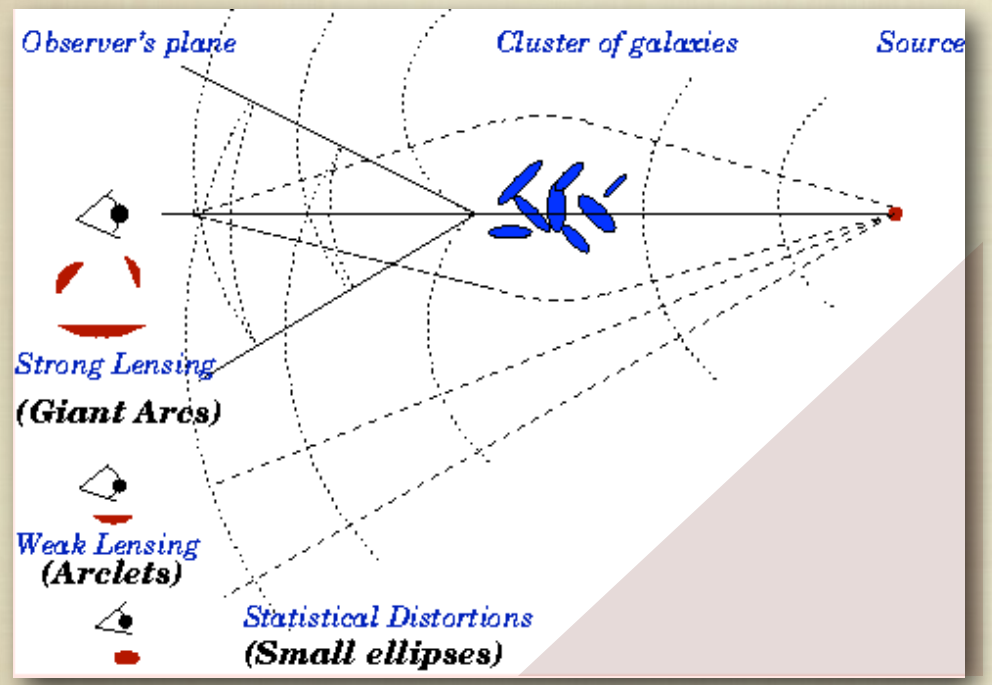
IN GENERAL: Q(*k*,*a*), R(*k*,*a*) → **MANIFESTED IN OBSERVATIONS**

Jain & Zhang 2007
Bean & Tangmatitham 2010

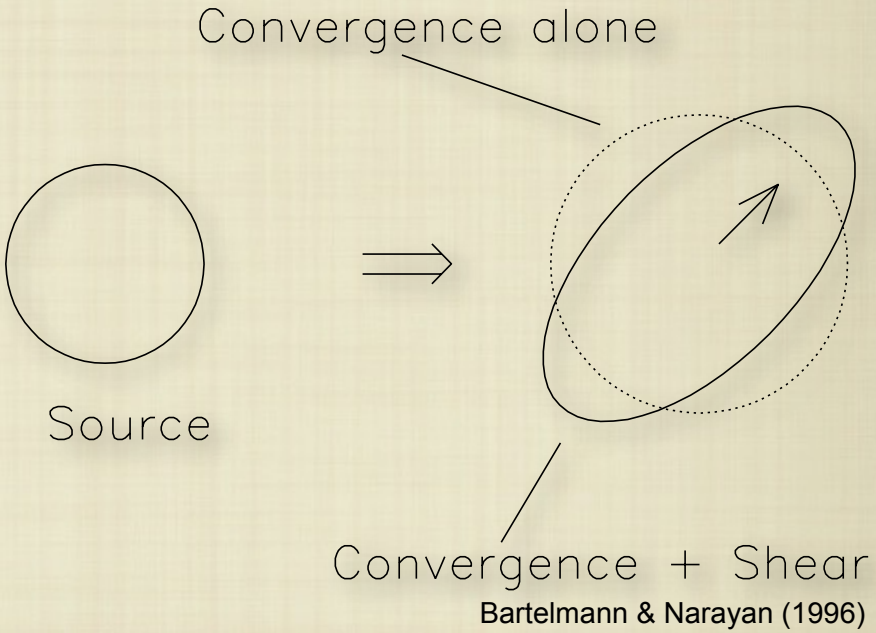
How to probe MG?

1) Weak Gravitational Lensing

Gravitational lensing magnifies (convergence=κ) and distorts shape (shear=γ) of galaxies. Weak lensing limit: $|\gamma|, |\kappa| << 1$.



B. Jain (www.hep.upenn.edu/~bjain/lensing.html)



Bartelmann & Narayan (1996)

$$\kappa = \frac{1}{2}\int_0^{\chi_s} \nabla^2(\psi+\phi) W(\chi,\chi_s) d\chi \longrightarrow C_{\kappa\kappa}(l), C_{\kappa g}(l)$$

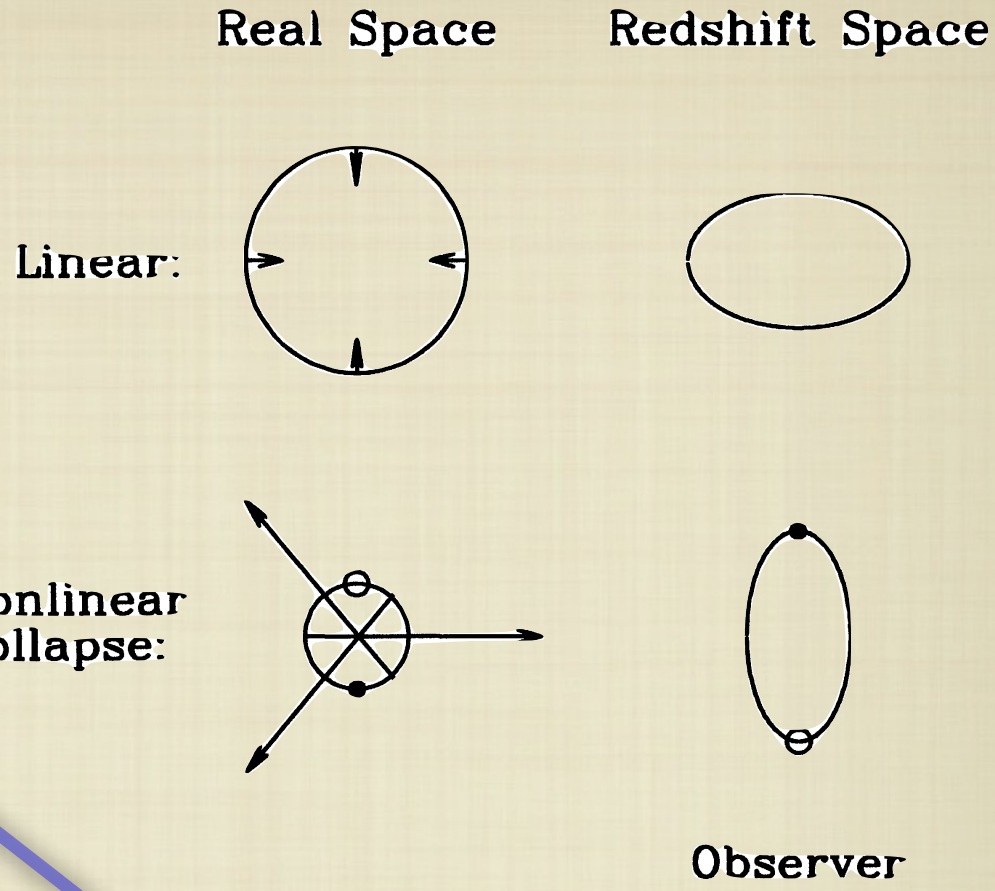
How to probe MG?

2) Peculiar Velocities

$$\theta \equiv \nabla \cdot \mathbf{v}/H$$

$$= -\dot{\delta}/H = -f\delta$$

$$f = d\ln D/d\ln a$$



$$P_g^s(\mathbf{k}) = \left[P_g(k) + 2u^2 P_{g\theta}(k) + u^4 P_\theta(k)\right] F\left(\frac{k^2 u^2 \sigma_v^2}{H^2(z)}\right)$$

Kaiser 1987
Dodelson 2003

Agenda Part 2

- Introduction: Modified Gravity, Weak Lensing, Redshift Space Distortions.
- Combining Overlapping Surveys: (RCSLenS+CFHTLenS)/(WiggleZ+BOSS). Testing gravity and WL systematics with Coherent CosmoMC Pipeline.

Combining WL and RSD (1)

coherent pipeline in CosmoMC constraining cosmology from overlapping spectroscopic & tomographic lensing surveys:
RSD, galaxy-galaxy lensing, cosmic shear.

5 statistics: (ξ_+, ξ_-, γ_t, P_0, P_2).
Full covariance included.

tomography employed. marginalizing over intrinsic alignments, photo-z errors, and baryons (13 nuisance). Internally parallelized.

Combining WL and RSD (2)

Applied to data, first pipeline to self-consistently treat WL and RSD (full covariance), and first to marginalize all key systematics.

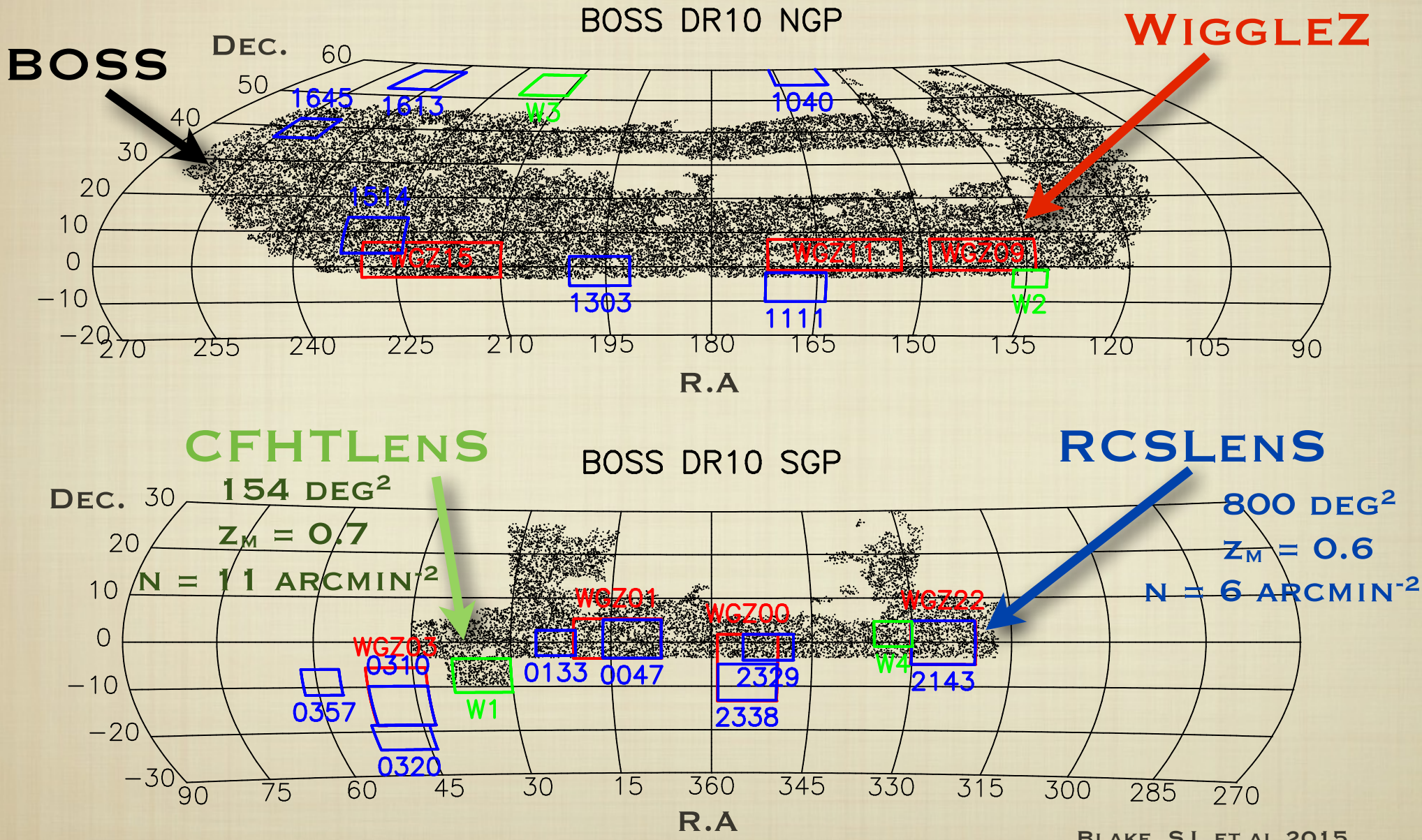
Data: (RCSLenS + CFHTLenS)/(WiggleZ + BOSS).
Also applicable to 2dFLenS/KiDS.
External datasets can be included.

Use data vector for MG.
Also dark energy, curvature, neutrino mass, etc.
Plan to make pipeline public later this year.

Current Lensing and RSD Surveys

overlapping galaxy redshift and lensing surveys

(500 sq deg)

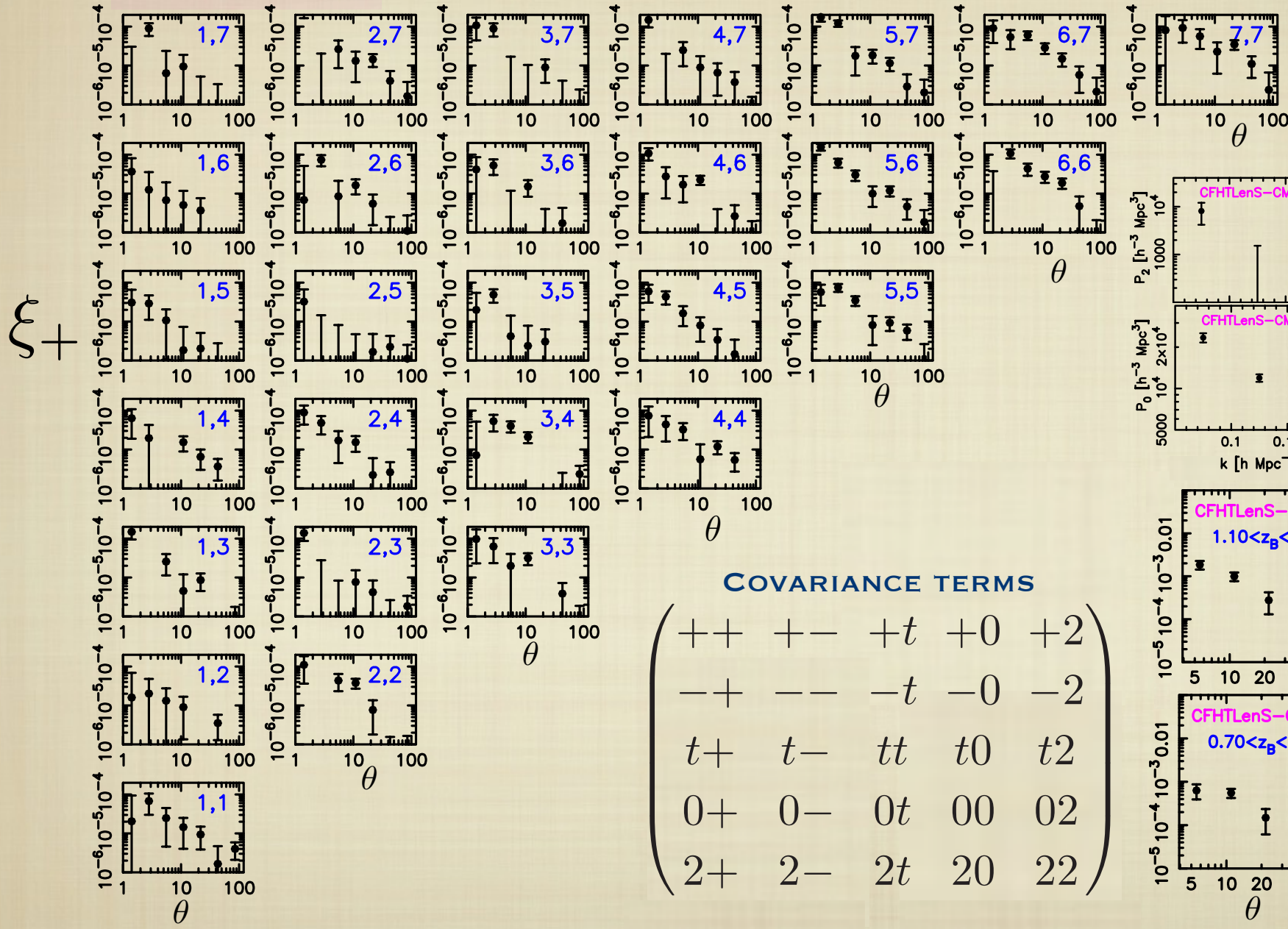


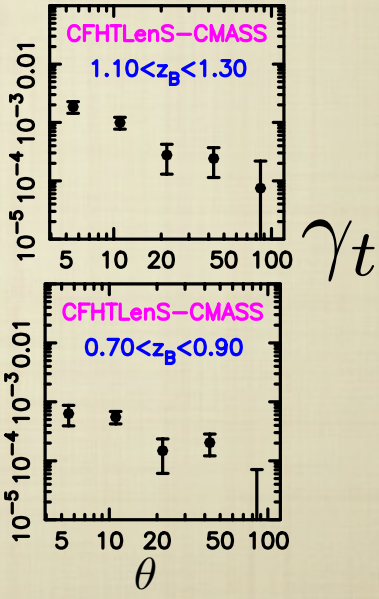
Blake, SJ, et al 2015

Combining WL and RSD $\{\xi_{\pm}^{ij}(\theta), \gamma_t^i(\theta), P_{0,2}(k)\}$

Data vector:
392+98+12 = 502

CFHT/{LOWZ, CMASS}





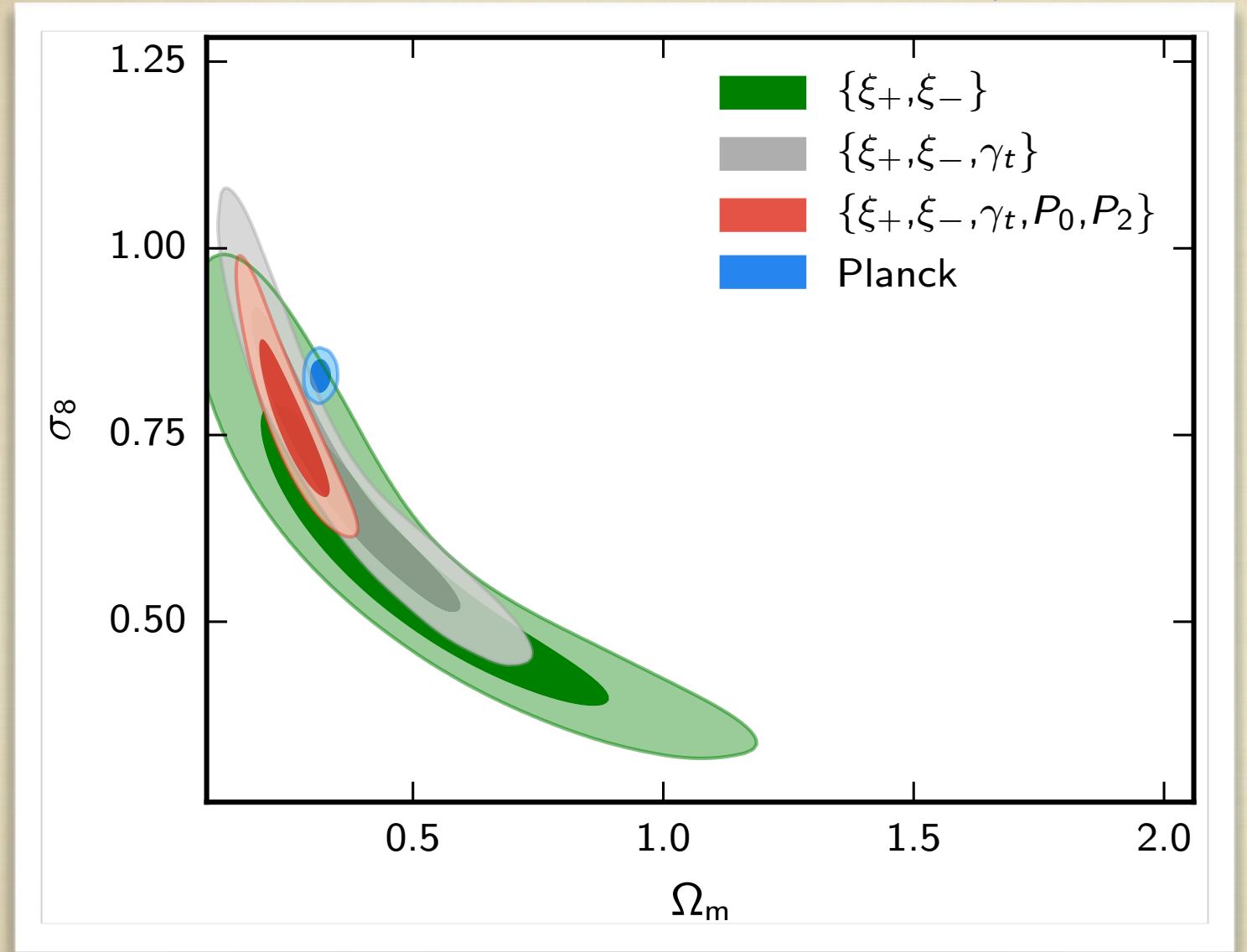
Covariance terms

$$\begin{pmatrix} ++ & +- & +t & +0 & +2 \\ -+ & -- & -t & -0 & -2 \\ t+ & t- & tt & t0 & t2 \\ 0+ & 0- & 0t & 00 & 02 \\ 2+ & 2- & 2t & 20 & 22 \end{pmatrix}$$

SJ et al 2015, in prep

Joint Cosmology Constraints

Preliminary CFHT/{LOWZ, CMASS}

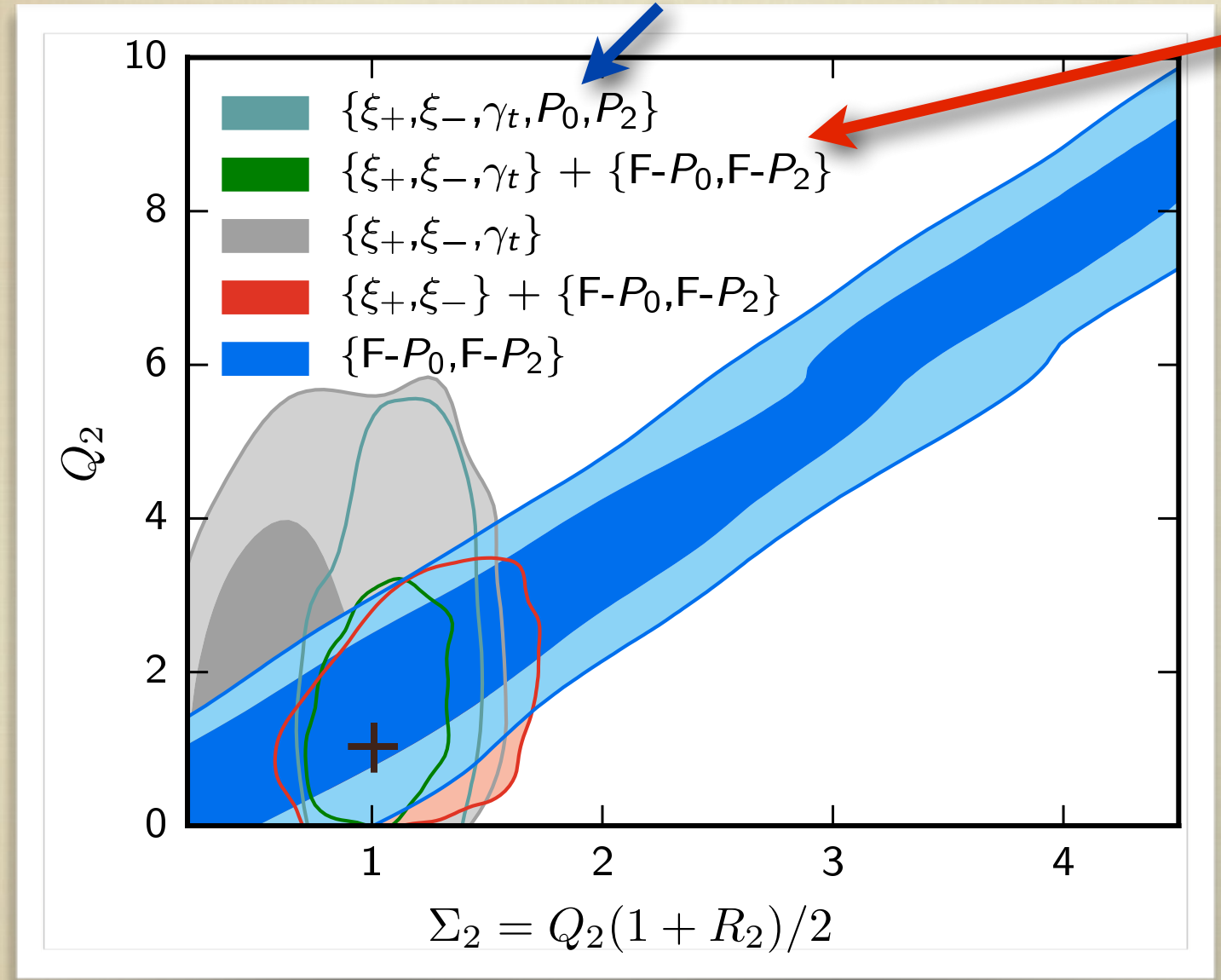


No cmb prior assumed

SJ et al 2015, in prep

Binned Modified Gravity constraints

Preliminary CFHT/{LOWZ, CMASS} {WiggleZ+CMASS}



No cmb prior assumed

1 low z low k	2 low z high k
3 high z low k	4 high z high k

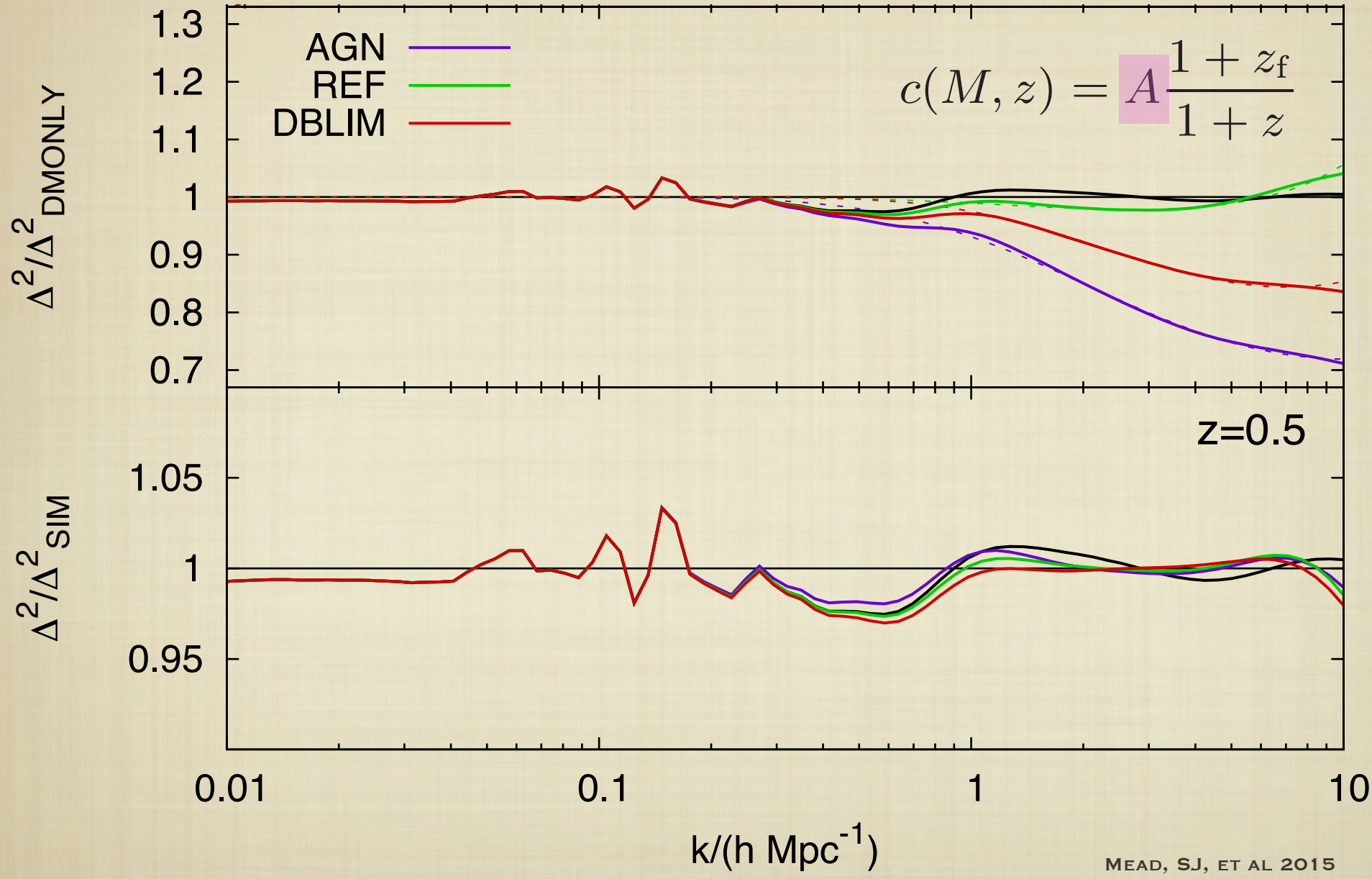
Consistent with GR

Further: Eftcamb, Planck

SJ et al 2015, in prep

WL Systematic 1: Baryons —> HMCode

(new accurate halo model)

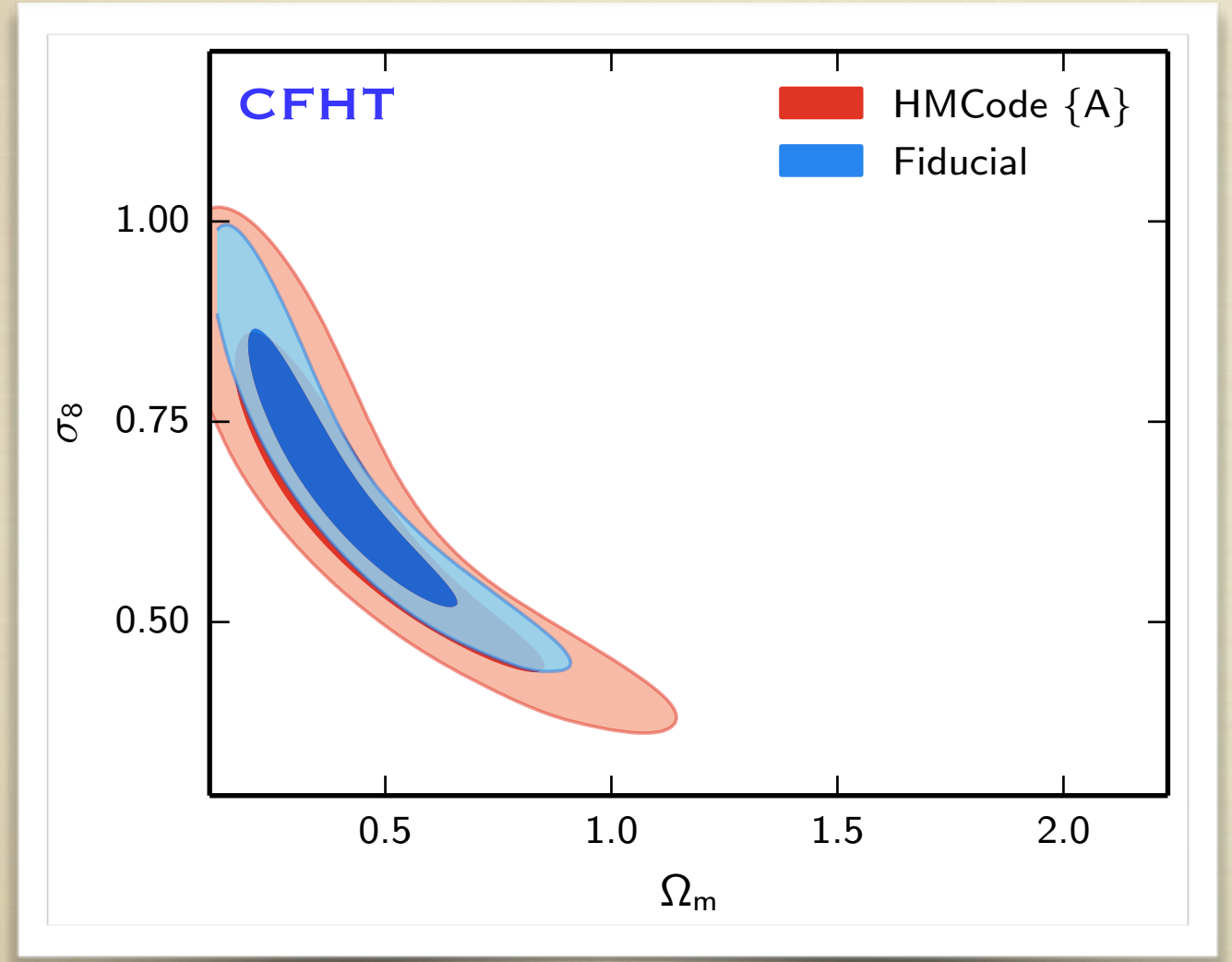


Mead, SJ, et al 2015

WL Systematic 1: Baryons

Incorporated into CosmoMC and internally parallelized for fast MCMC computations

Preliminary



Non-informative prior on A. Best-fit consistent with DMonly.

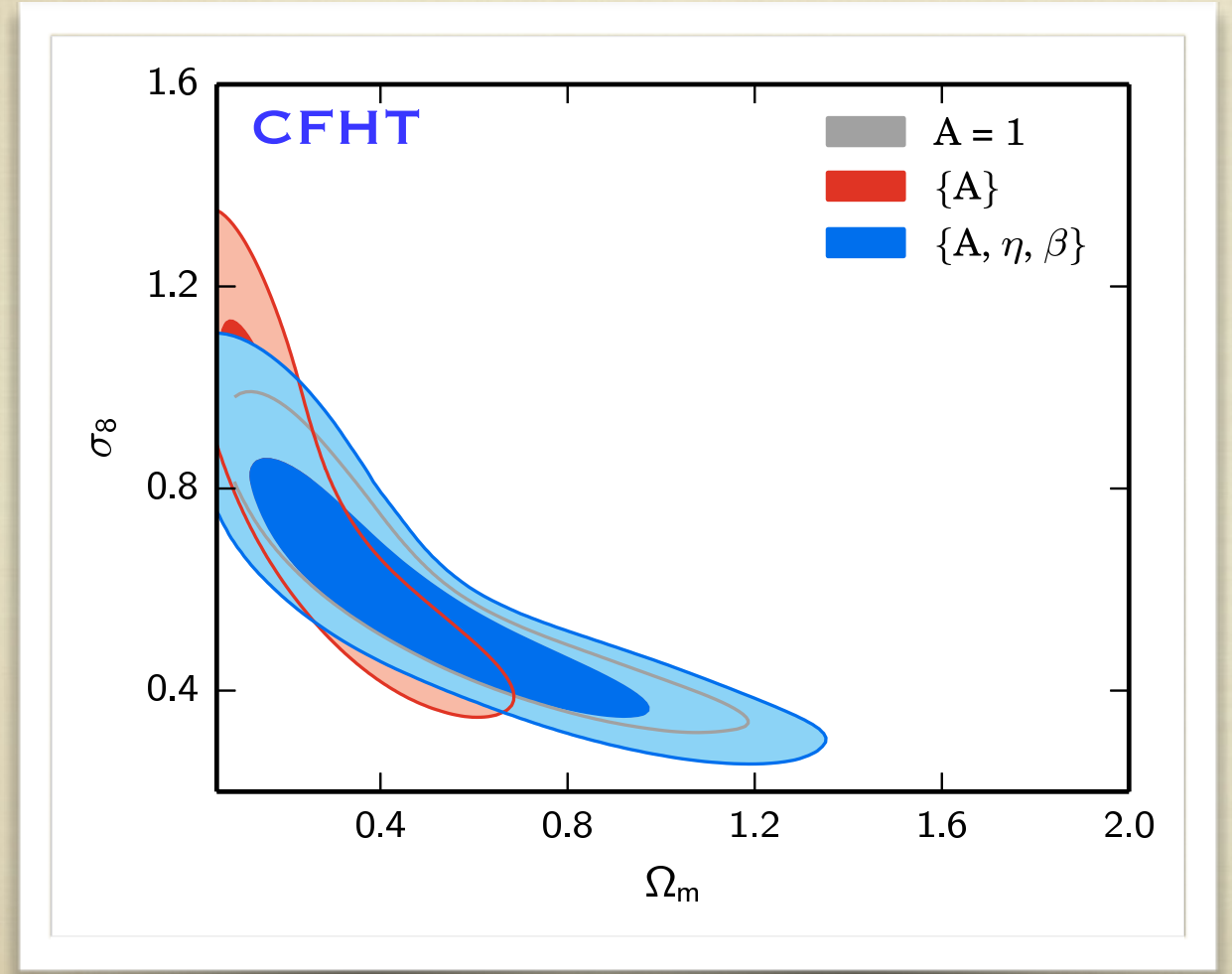
SJ et al 2015, in prep

WL Systematic 2: Intrinsic Alignments

$$P_{\delta \mathrm{I}}^{\mathrm{model}}(k,z,L) = -A\, C_1\, \rho_{\mathrm{cr}} \frac{\Omega_{\mathrm{m}}}{D(z)}\, P_\delta(k,z) \times \left(\frac{1+z}{1+z_0}\right)^{\eta} \left(\frac{L}{L_0}\right)^{\beta}$$

Hirata & Seljak 2004 — Joachimi et al 2013

Preliminary



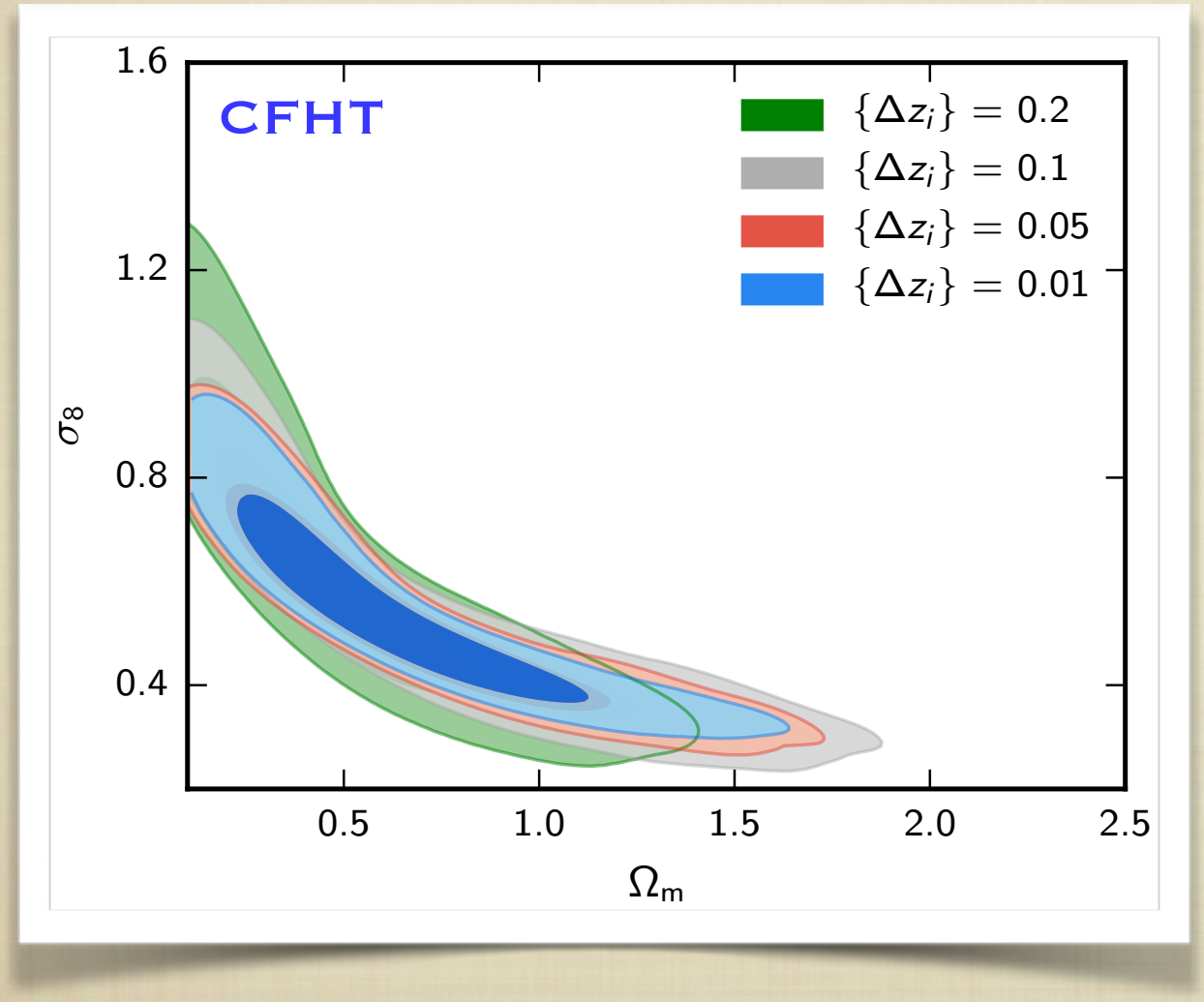
No detection of IA with current data from CFHTLenS

SJ et al 2015, in prep

WL Systematic 3: Photo-z Errors

Allowing for a distinct prior in each tomographic bin to account for photo-z uncertainties

Preliminary



7 additional free params

Constraints consistent with fiducial distribution given $\Delta z_i \leq 0.2$

SJ et al 2015, in prep

Conclusions

- Need to test laws of gravity in multiple ways. gravitational lensing and galaxy velocities, may help pin down physics of gravity.
- CosmomC pipeline for joint analyses of WL and RSD. Applied to CFHTLenS overlapping with BOSS to obtain MG constraints and test WL systematics. Preliminary constraints seem consistent with standard model.
- Will further apply pipeline to RCSLenS overlapping with BOSS and WiggleZ to test MG, and plan to explore other interesting physics (massive neutrinos).
- Will explore WL systematics in greater detail, allowing for multiple systematics simultaneously and using joint statistics. Plan to make pipeline and data public this year.

Thanks for listening.