

# KIDS-450 + 2DFLENS: OVERLAPPING WL/RSD

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> ARXIV:1606.05338 ARXIV:1610.04606 ARXIV:1707.06627



COMBINING OVERLAPPING SURVEYS: KIDS/(2DFLENS+BOSS). LIKELIHOOD PIPELINE, MEASUREMENTS, COVARIANCE

WL/RSD COMBINED ANALYSIS: CONSTRAINTS, TENSIONS, AND EXTENDED COSMOLOGIES.

#### COSMIC ACCELERATION, WL & RSD

UNIVERSE?COSMOLOGICALACCELERATES?CONSTANT, DE, MG

EXPANSION: SNE, BAO GROWTH: WL, RSD -

CRITICAL FOR UNDERSTANDING MG

1) WEAK GRAVITATIONAL LENSING

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

(2) PECULIAR VELOCITIES  $\theta \equiv \nabla \cdot \mathbf{v}/H = -\dot{\delta}/H = -f_{0}\delta$   $P_{g}^{s}(\mathbf{k}) = \left[P_{g}(k) + 2u^{2}P_{g\theta}(k) + u^{4}P_{\theta}(k)\right]F\left(\frac{k^{2}u^{2}\sigma_{v}^{2}}{H^{2}(z)}\right)$ 

#### 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: ( $\xi_+$ ,  $\xi_-$ ,  $\gamma_t$ ,  $P_0$ ,  $P_2$ ). Full covariance included.

TOMOGRAPHY EMPLOYED. MARGINALIZING OVER INTRINSIC ALIGNMENTS, PHOTO-Z ERRORS, BARYONS, GALAXY BIAS, VELOCITY DISPERSION, SHOT NOISE. 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: KIDS/(2DFLENS + BOSS). EXTERNAL DATASETS CAN BE INCLUDED.

USE DATA VECTOR FOR MG. ALSO DARK ENERGY, CURVATURE, NEUTRINO MASS, ETC. FULL PIPELINE PUBLIC: GITHUB.COM/SJOUDAKI/COSMOLSS

### KIDS/2DFLENS/BOSS OVERLAPS



2DFLENS (AAT): 70,000 z's z<0.9 730 deg<sup>2</sup> **KIDS (VST):** 450  $DEG^2$   $Z_M = 0.55$  $N = 9 ARCMIN^{-2}$ 

#### COSMIC SHEAR MEASUREMENTS



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#### GALAXY-GALAXY LENSING MEASUREMENTS



#### MULTIPOLE POWER SPECTRUM MEASUREMENTS



# COVARIANCE MATRIX $\{\xi^{ij}_{\pm}(\theta), \gamma^{i}_{t}(\theta), P_{0,2}(k)\}$



# Agenda Part 2

COMBINING OVERLAPPING SURVEYS: KIDS/(2DFLENS+BOSS). LIKELIHOOD PIPELINE, MEASUREMENTS, COVARIANCE

WL/RSD COMBINED ANALYSIS: CONSTRAINTS, TENSIONS, AND EXTENDED COSMOLOGIES.

#### KIDS-450 CONSTRAINTS AND SYSTEMATICS



WL SYSTEMATICS:
A) PHOTO-Z ERRORS
B) BARYONS
C) MULT. BIAS
D) INTR. ALIGN.
E) HMCODE: MATTER
P(K) DARK ENERGY & NEUTRINO MASS
F) CONF. BIAS

## FULLY JOINT CONSTRAINTS $\{\xi_+, \xi_-, \gamma_t, P_0, P_2\}$

#### KIDS/{2DFLENS, BOSS}



FACTOR OF 2 IMPROVEMENT ALONG LDD

### FULLY JOINT CONSTRAINTS $\{\xi_+, \xi_-, \gamma_t, P_0, P_2\}$

#### KIDS/{2DFLENS, BOSS}



#### ASTROPHYSICAL CONSTRAINTS



FIDUCIAL:  $A_{IA} = 1.69^{+0.48}_{-0.48}$ Conservative:

 $A_{\rm IA} = 1.42^{+0.50}_{-0.50}$ 

Baryonic feedback B < 3.3 (95% CL) $B_{\text{peak}} = \{1.6, 2.0\}$  COSMOLOGICAL CONSTRAINTS ROBUST TO EXTENDED SYSTEMATICS TREATMENT

#### EXTENDED COSMOLOGY CONSTRAINTS



EVOLVING DARK ENERGY ( $W_0$ - $W_a$ )



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

At 95% CL :  $0.65 < h_{\rm Planck} < 1.0$  ~1σ worse S<sub>8</sub> AGREEMENT WITH PLANCK THAN KIDS ALONE

#### MODIFIED GRAVITY



Q(k,z) modifies poisson equation  $\begin{bmatrix} 2 & 1 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 2 \\ 1 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & K \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$   $\begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 1 & 0 &$ 

10-15% level constraints on  $\Sigma_2$  in fiducial and LS+Planck cases,  $Q_2$  bounded from above,  $S_8$  constraint improves by up to factor of 3

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#### MODIFIED GRAVITY SUBSPACE



#### CONCLUSIONS

- SELF-CONSISTENT COSMOLOGICAL ANALYSIS OF WEAK LENSING TOMOGRAPHY AND OVERLAPPING REDSHIFT-SPACE GALAXY CLUSTERING: KIDS/2DFLENS/BOSS.
- COMBINED PROBES IMPROVE S<sub>8</sub> = 0.742 +/- 0.035 CONSTRAINT BY 20%. IN AGREEMENT WITH KIDS ALONE, 2.6σ DISCORDANT WITH PLANCK. IA AMPLITUDE 3.5σ POSITIVE, AND FACTOR OF 2 IMPROVEMENT IN MATTER DENSITY.
- GIVEN THE TIGHTENING OF THE PARAMETER SPACE, DISCORDANCE NO LONGER RESOLVED BY EVOLVING DE, OR ANY OTHER EXTENDED COSMOLOGICAL/SYSTEMATICS MODEL, WHILE SIMULTANEOUSLY FAVORED IN MODEL SELECTION SENSE.
- NOVEL CONSTRAINTS ON EXTENDED COSMOLOGIES, IN PARTICULAR MODIFIED GRAVITY. MEASUREMENTS, COVARIANCE, LIKELIHOOD CODE PUBLIC: GITHUB.COM/SJOUDAKI/COSMOLSS