

KIDS-450 + 2DFLENS: OVERLAPPING WL/RSD

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IN COLLABORATION WITH C. BLAKE, A. JOHNSON, KIDS/2DFLENS

ARXIV:1606.05338
ARXIV:1610.04606
ARXIV:1707.06627

Agenda Part 1

- **COMBINING OVERLAPPING SURVEYS: KIDS/(2DFLENS+BOSS). LIKELIHOOD PIPELINE, MEASUREMENTS, COVARIANCE**
- **KIDS-450 ALONE: CONSTRAINTS, TENSIONS, EXTENDED COSMOLOGIES**
- **WL/RSD COMBINED ANALYSIS IN Λ CDM: METHODOICAL COMBINATION OF PROBES**
- **WL/RSD COMBINED ANALYSIS: EXTENDED COSMOLOGY CONSTRAINTS**

COSMIC ACCELERATION, WL & RSD

UNIVERSE
ACCELERATES

?

COSMOLOGICAL
CONSTANT, DE, MG

EXPANSION: SNE, BAO
GROWTH: WL, RSD

CRITICAL FOR
UNDERSTANDING MG

1) WEAK GRAVITATIONAL LENSING

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

2) PECULIAR VELOCITIES

$$\theta \equiv \nabla \cdot \mathbf{v} / H = -\dot{\delta} / H = -\underbrace{f}_{\text{MG}} \delta$$

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

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: (ξ_+ , ξ_- , γ_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.

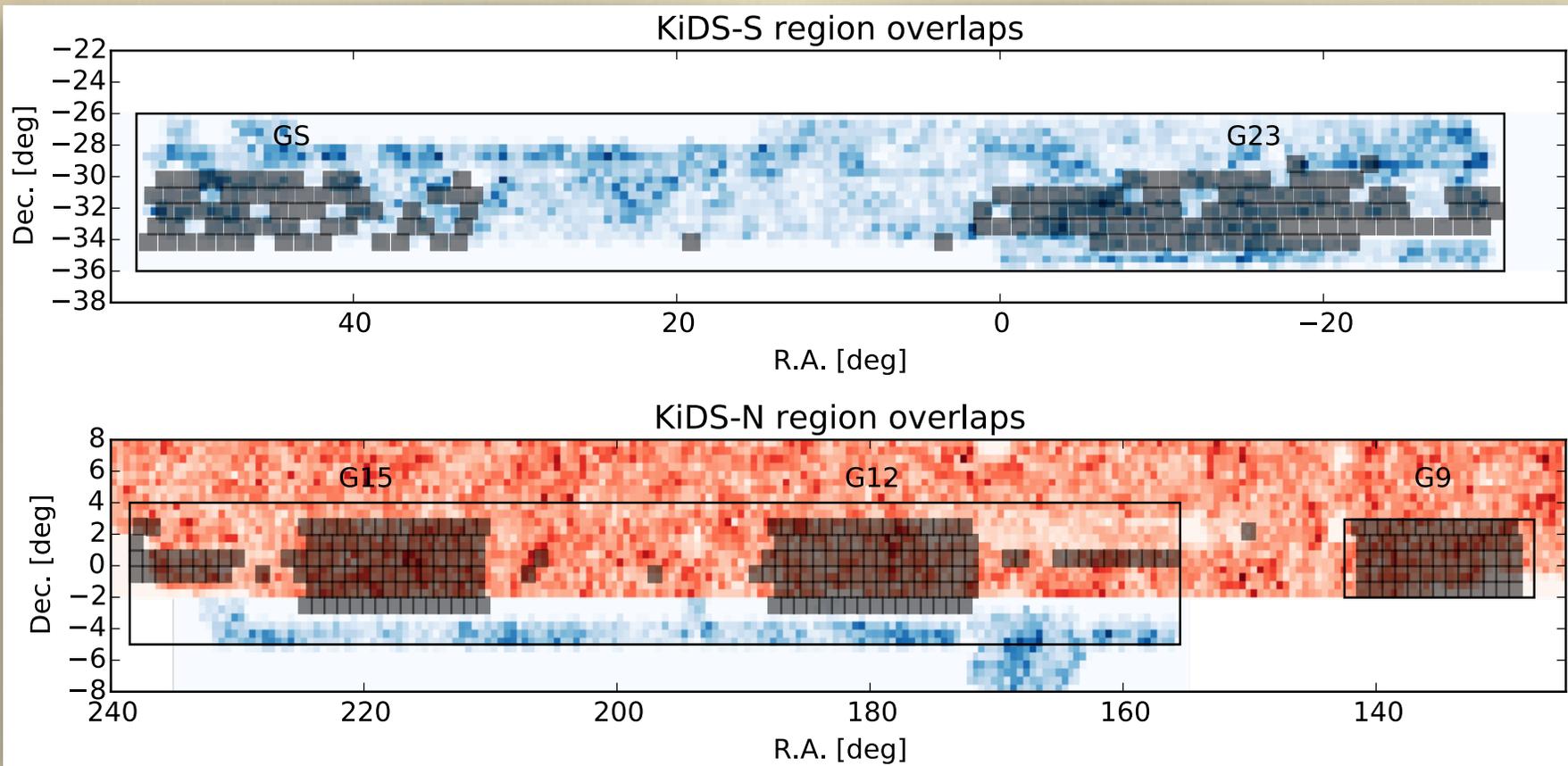
COMBINING WL AND RSD (2)

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](https://github.com/sjoudaki/cosmolss)

KIDS/2DFLENS/BOSS OVERLAPS



2DFLENS (AAT):

70,000 z's

$z < 0.9$

730 DEG²

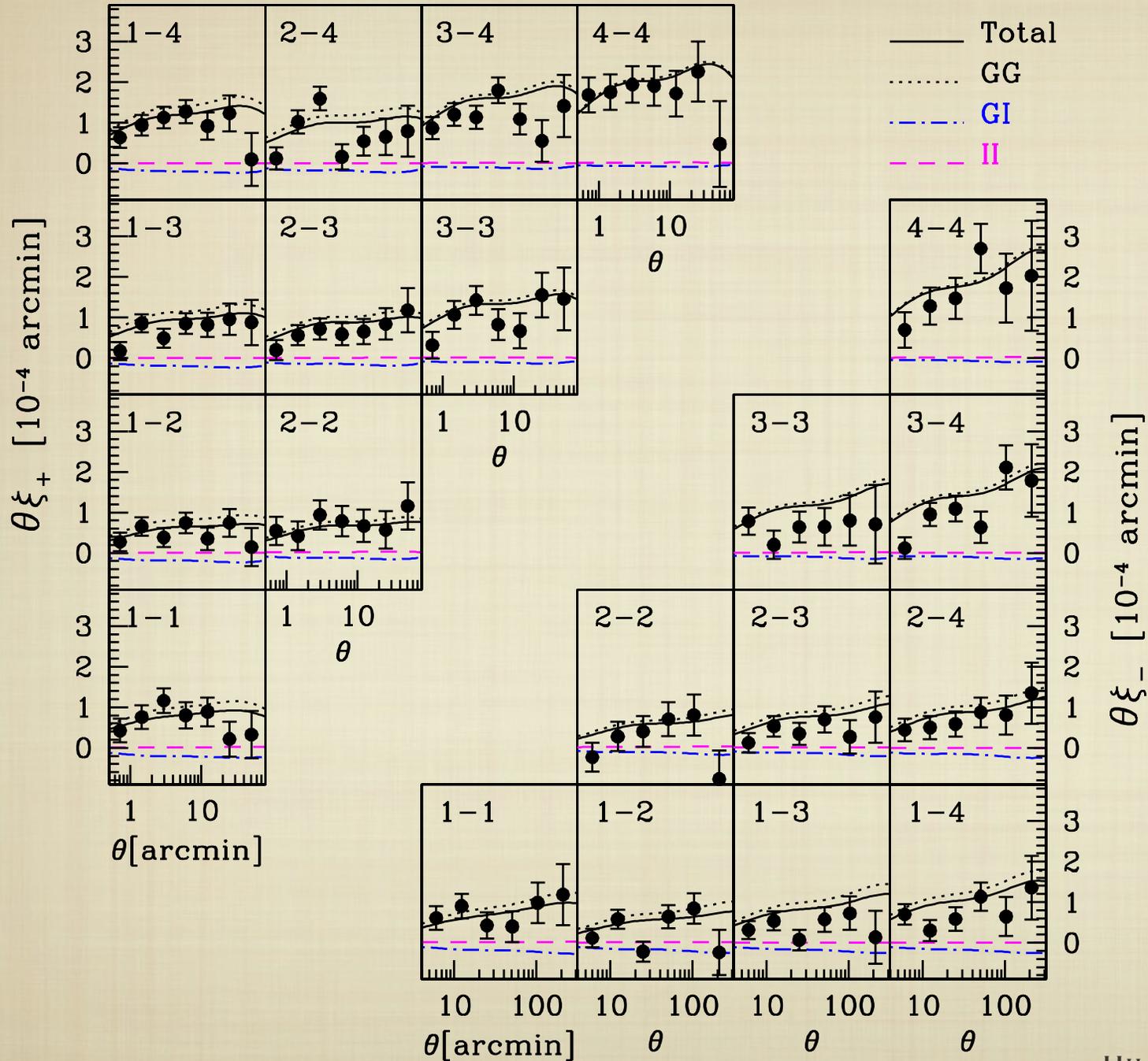
KIDS (VST):

450 DEG²

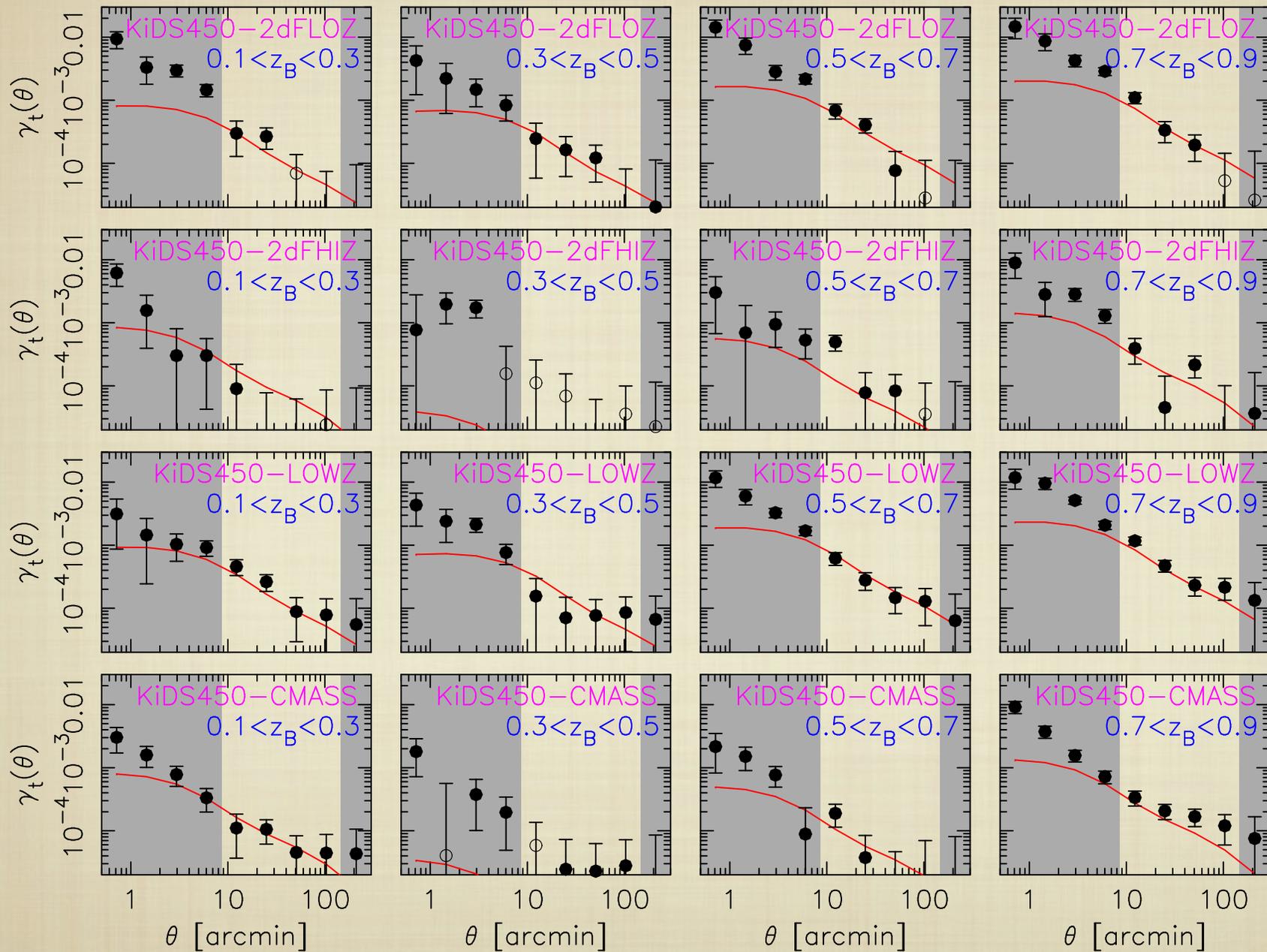
$z_M = 0.55$

$N = 9$ ARCMIN⁻²

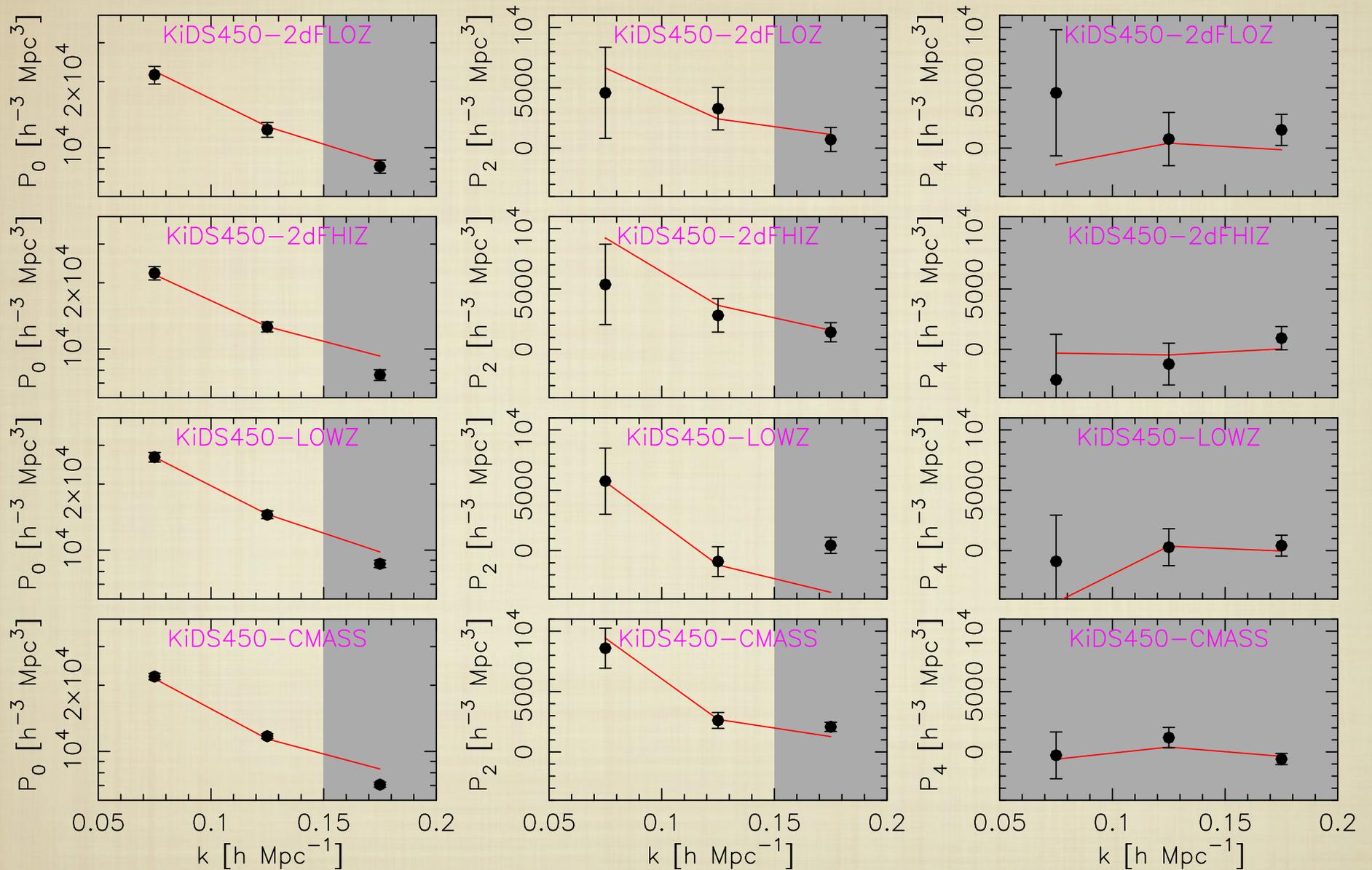
COSMIC SHEAR MEASUREMENTS



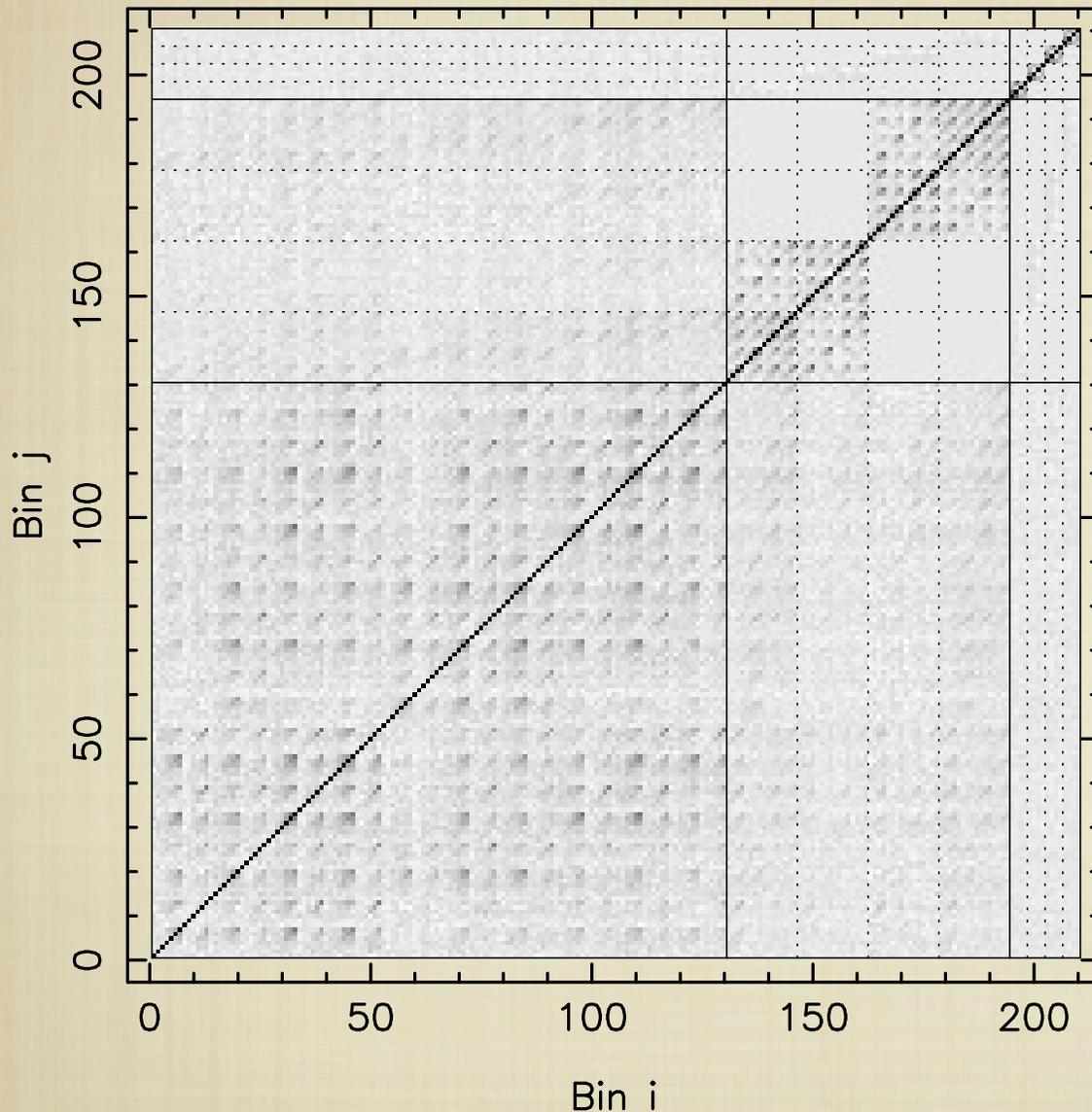
GALAXY-GALAXY LENSING MEASUREMENTS



MULTIPOLE POWER SPECTRUM MEASUREMENTS



COVARIANCE MATRIX $\{\xi_{\pm}^{ij}(\theta), \gamma_t^i(\theta), P_{0,2}(k)\}$



FROM LARGE SUITE OF
N-BODY SIMULATIONS

DOUBLE-BLINDED

COVARIANCE TERMS

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

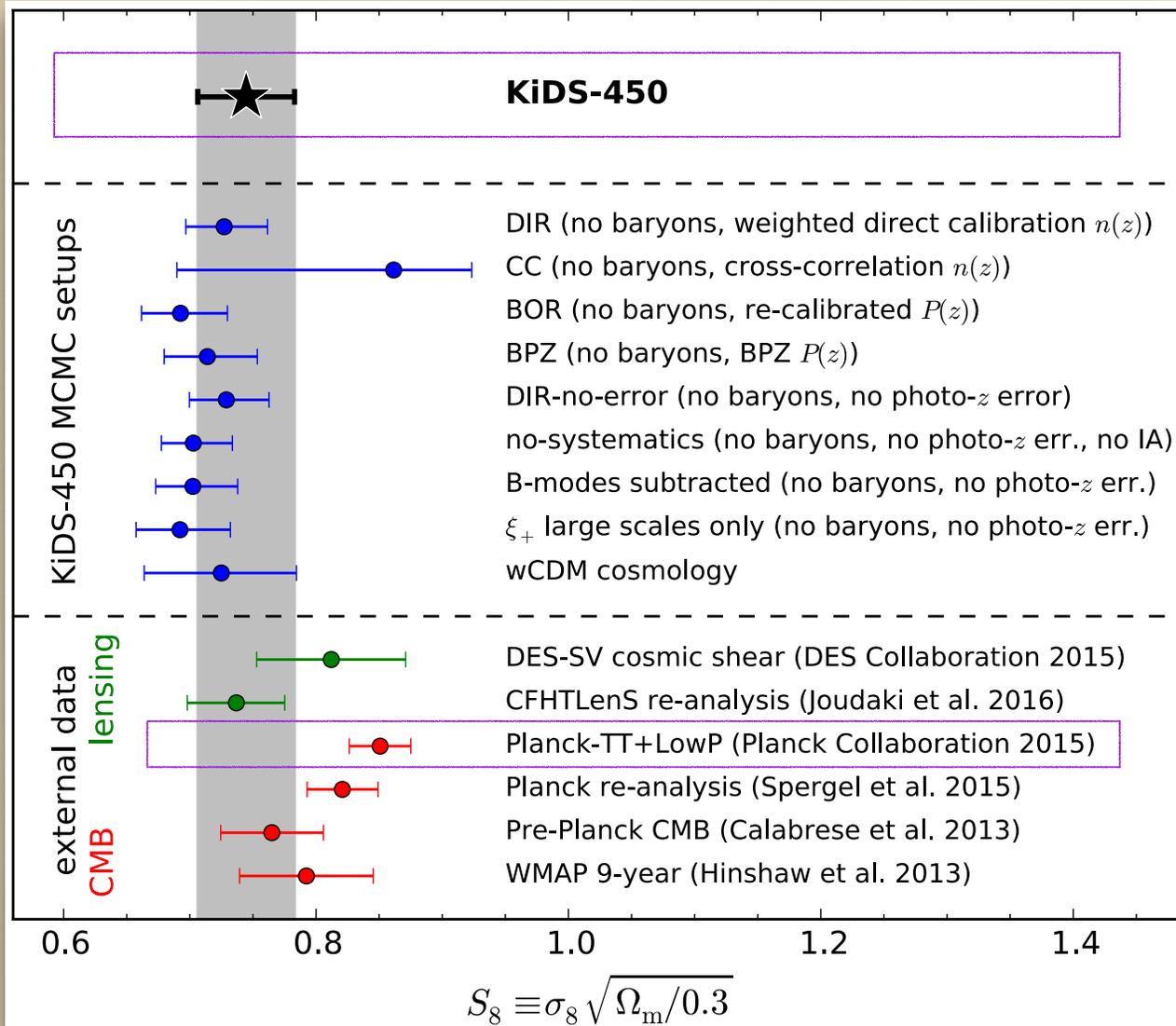
210 / 186 ELEMENTS
POST-MASKING

$$r(i, j) = \text{Cov}(i, j) / \sqrt{\text{Cov}(i, i) \text{Cov}(j, j)}$$

Agenda Part 2

- **COMBINING OVERLAPPING SURVEYS: KIDS/(2DFLENS+BOSS). LIKELIHOOD PIPELINE, MEASUREMENTS, COVARIANCE**
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- **WL/RSD COMBINED ANALYSIS: EXTENDED COSMOLOGY CONSTRAINTS**

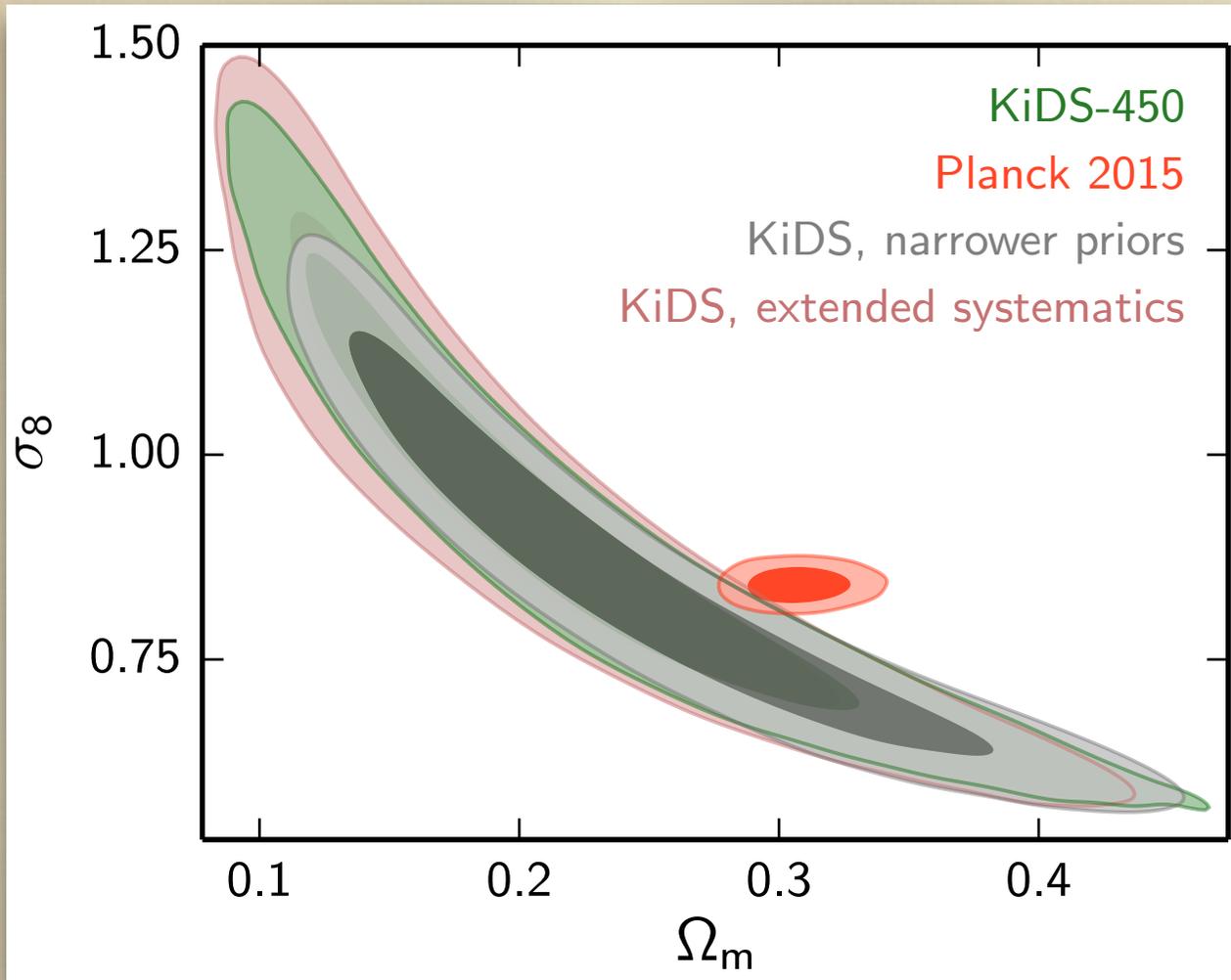
KIDS-450 CONSTRAINTS AND SYSTEMATICS



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

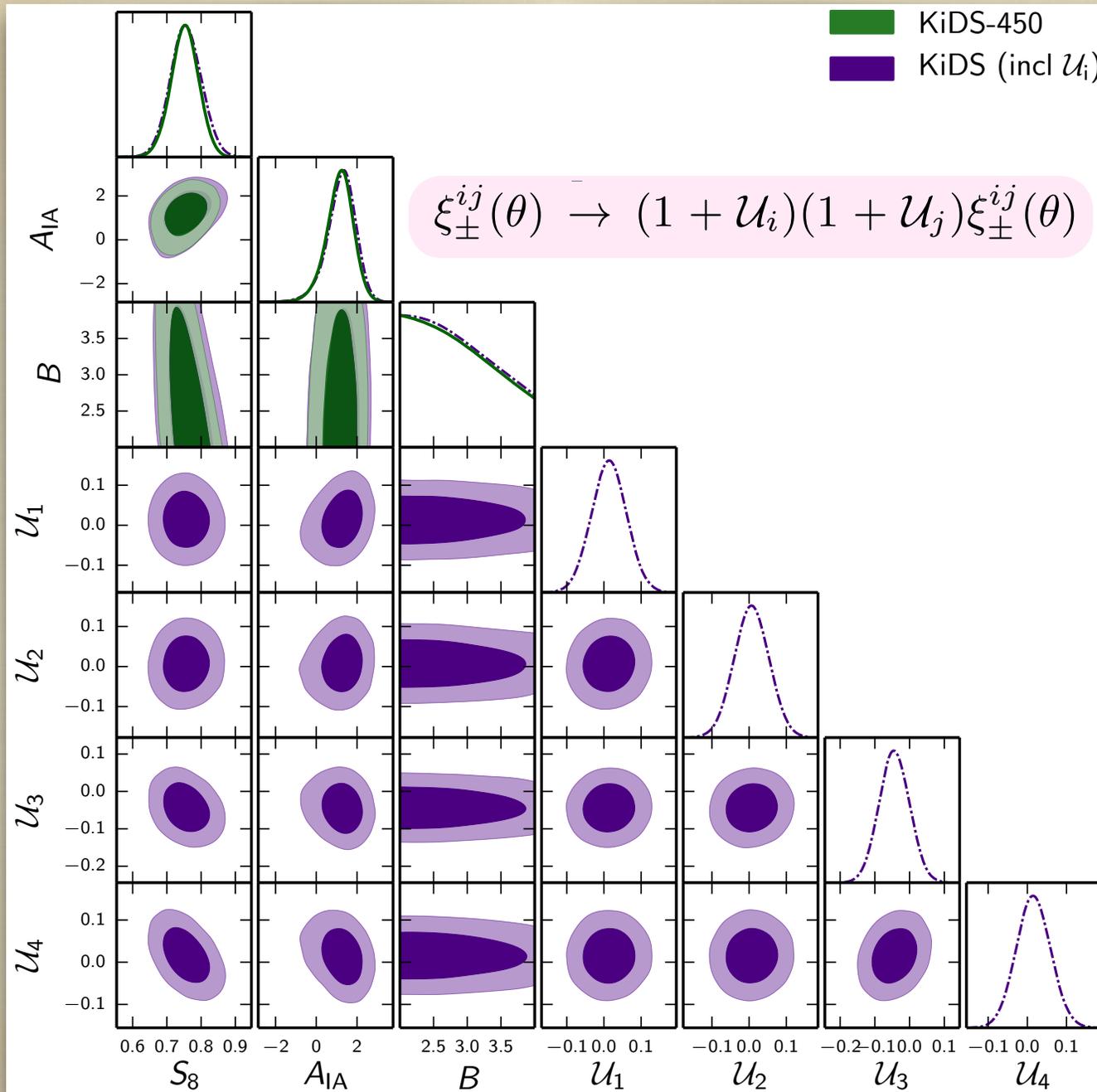
KIDS-450 EXTENDED SETUPS



EXTENSIONS:

- A) EXTENDED SYST
- B) DE (w_0-w_A)
- C) DE (CONST w)
- D) NEUTRINO MASS
- E) CURVATURE
- F) DE+CURVATURE
- G) MG (BINNED)
- H) RUNNING

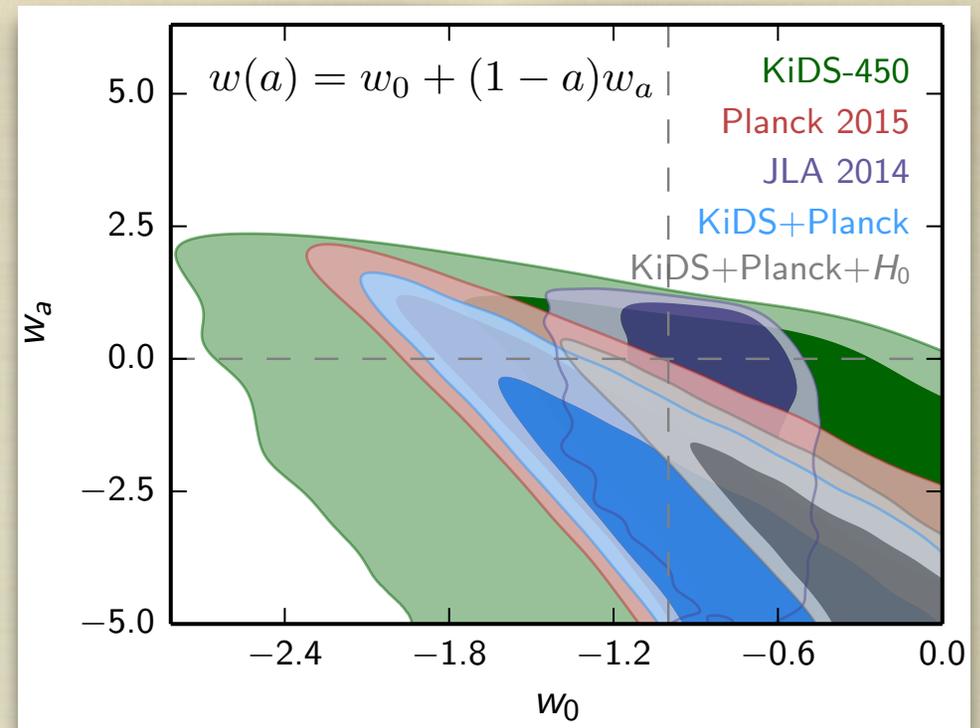
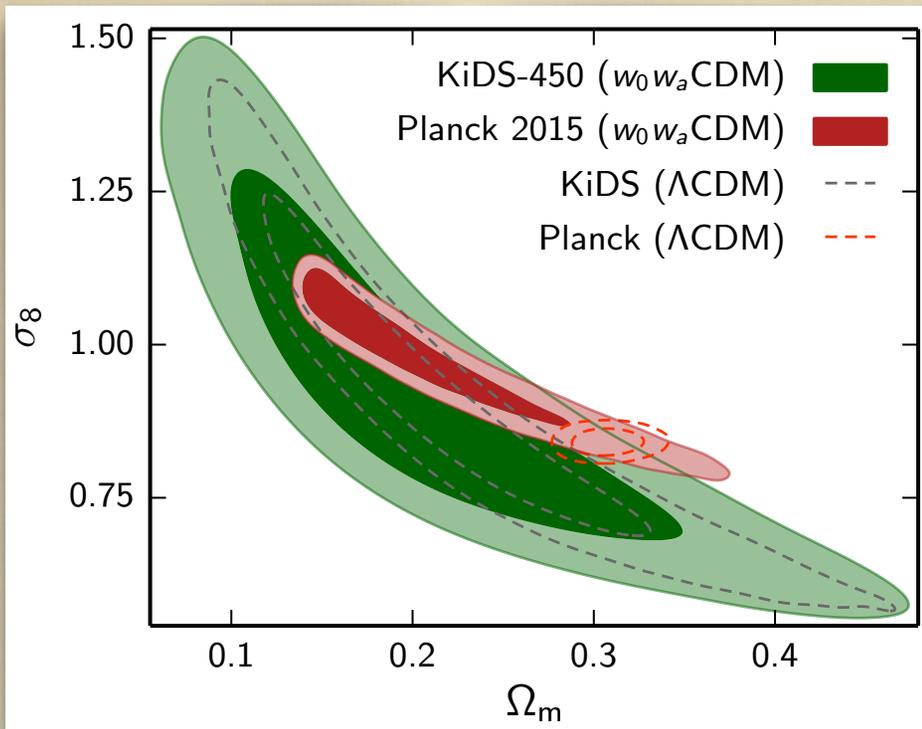
KIDS-450 “UNKNOWN UNKNOWNNS”



**COSMOLOGICAL
PARAMETERS
SIMULTANEOUSLY
VARIED**

**5% GAUSSIAN
PRIORS ON \mathcal{U}_i ,
15% INCREASE IN
 S_8 UNCERTAINTY,
0.3 σ DECREASE
IN DISCORDANCE**

DARK ENERGY CONSTRAINTS (w_0 - w_a)

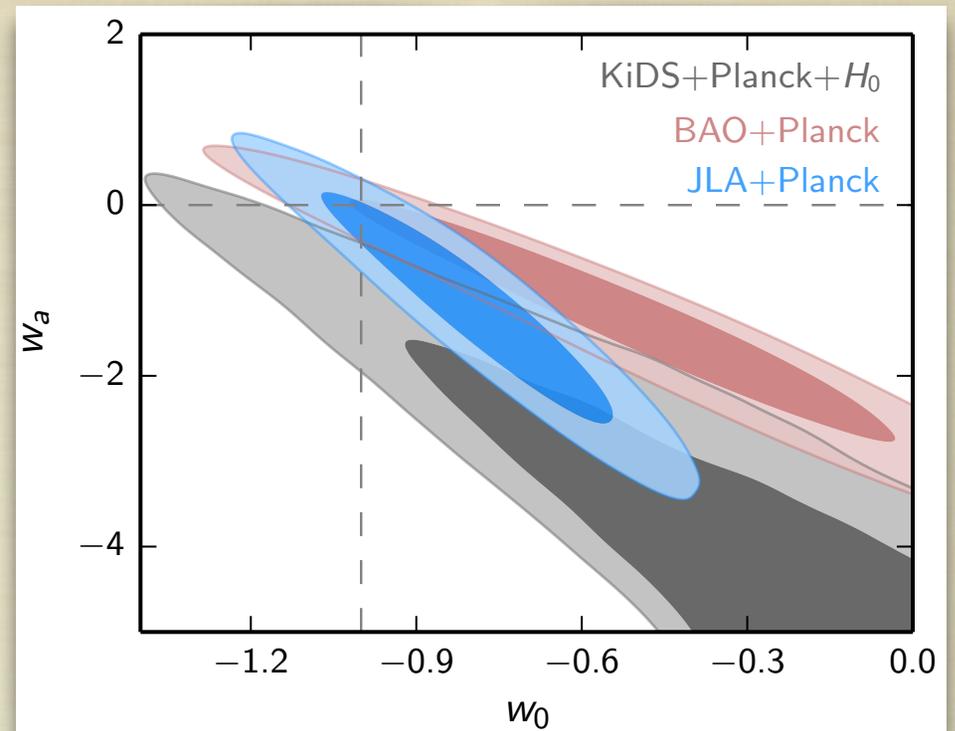
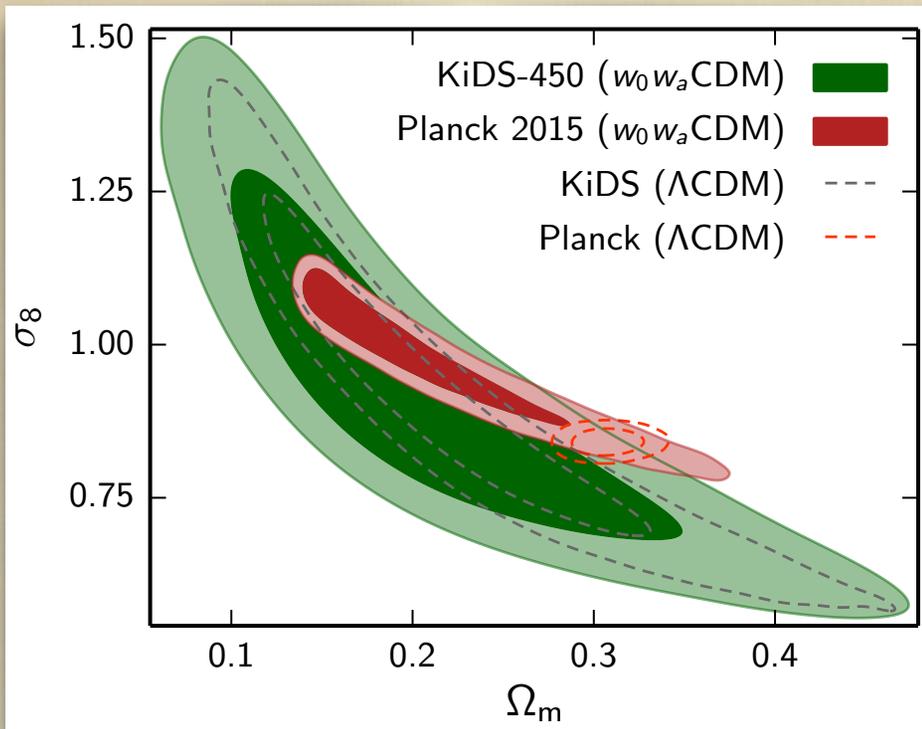


At 95% CL :

$$0.65 < h_{\text{Planck}} < 1.0$$

**EXTENSION
MODERATELY
FAVORED BY
KIDS+PLANCK**

DARK ENERGY CONSTRAINTS (w_0 - w_a)



At 95% CL :

$$0.66 < h_{\text{JLA+Planck}} < 0.74$$

$$0.59 < h_{\text{BAO+Planck}} < 0.69$$

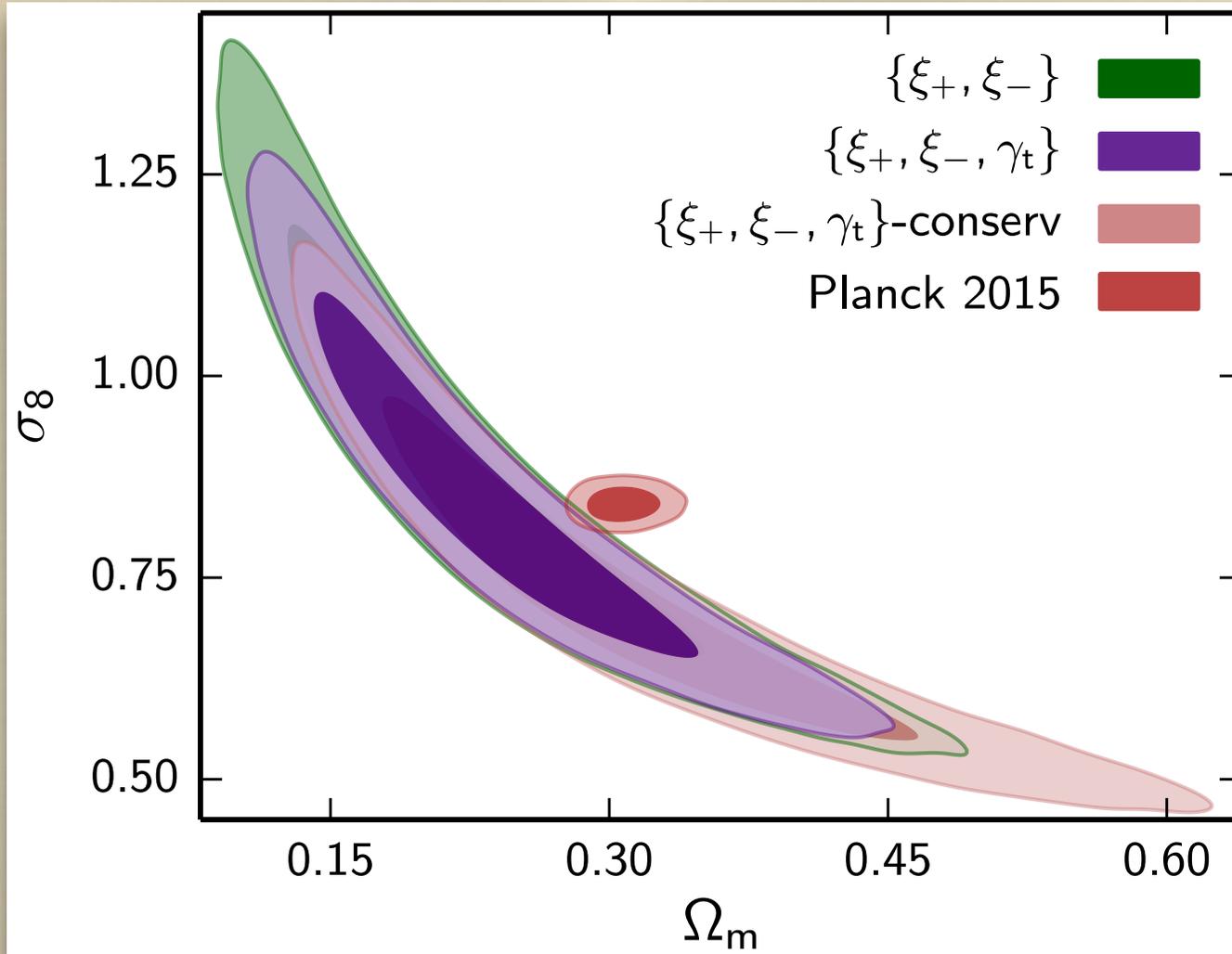
**EXTENSION
MODERATELY
FAVORED BY
KIDS+PLANCK**

Agenda Part 3

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SUB-VECTOR CONSTRAINTS: $\{\xi_+, \xi_-, \gamma_t\}$

KIDS/{2DFLENS, BOSS}



NO EXTERNAL PRIORS ASSUMED

11 FREE PARAMETERS

194 / 178 ELEMENTS

FIDUCIAL:

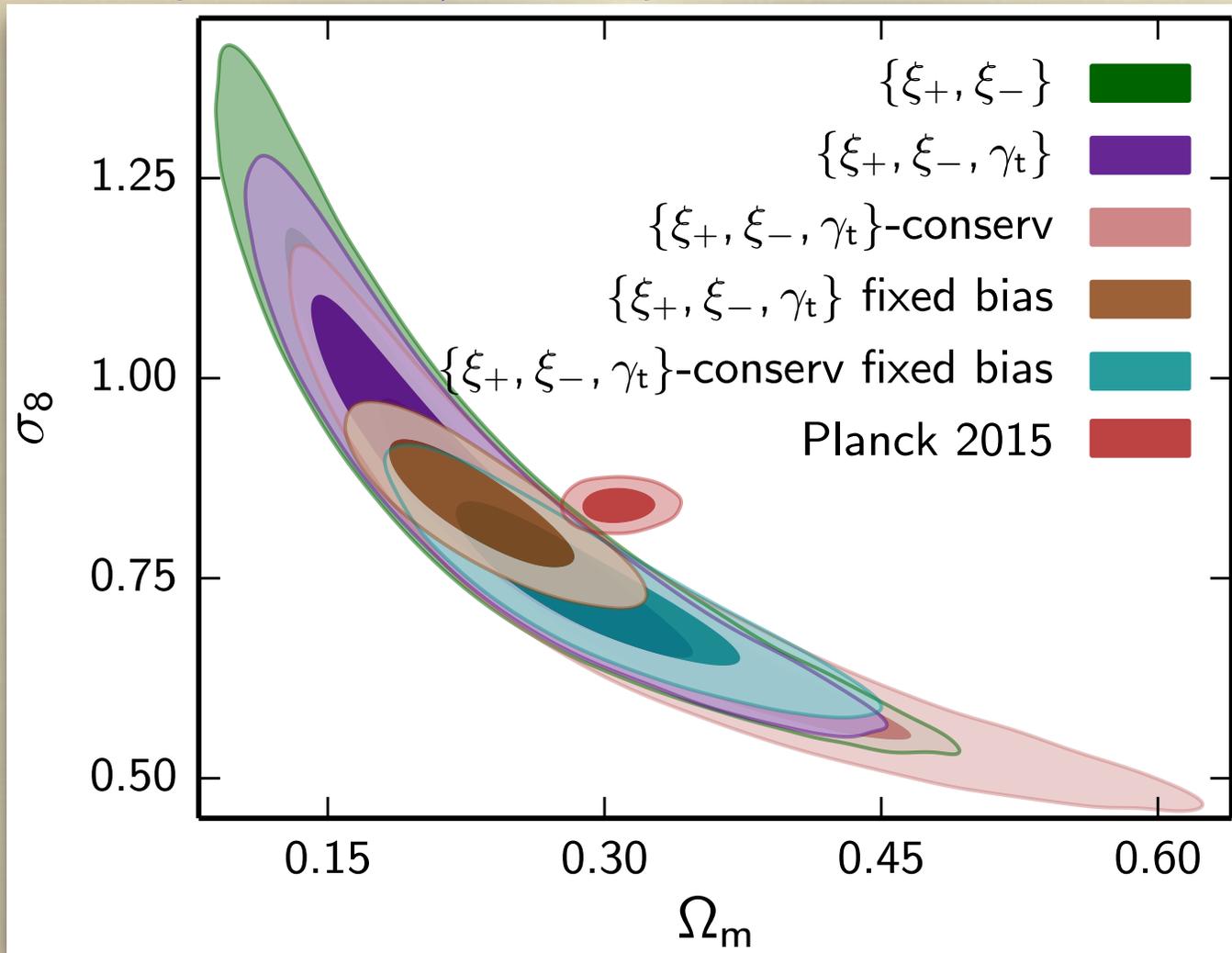
$$S_8 = 0.731^{+0.037}_{-0.042}$$

CONSERVATIVE:

$$S_8 = 0.715^{+0.037}_{-0.042}$$

SUB-VECTOR CONSTRAINTS: FIXED BIAS

KIDS/{2DFLENS, BOSS}



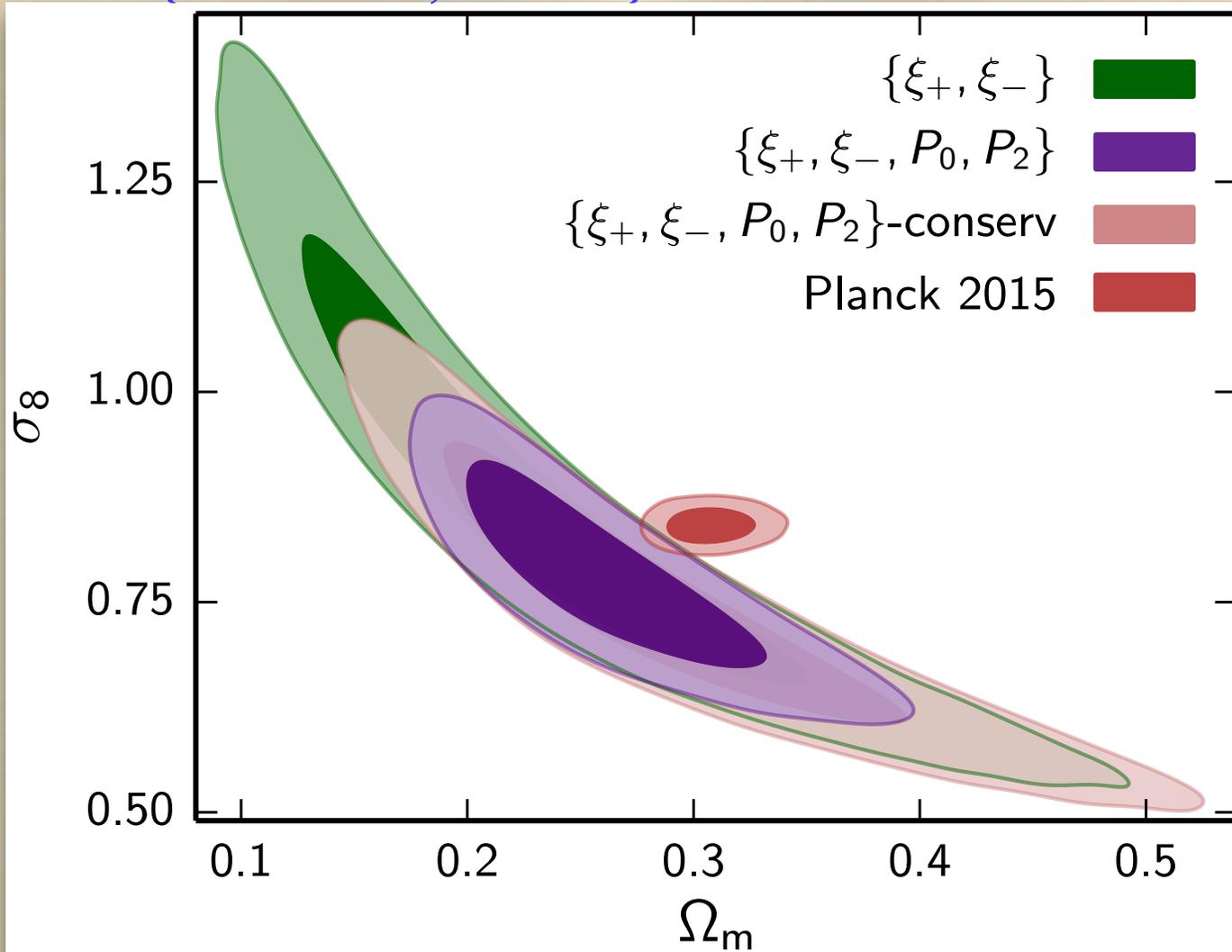
NO EXTERNAL
PRIORS
ASSUMED

11 / 7 FREE
PARAMETERS

194 / 178
ELEMENTS

SUB-VECTOR CONSTRAINTS: $\{\xi_+, \xi_-, P_0, P_2\}$

KIDS/{2DFLENS, BOSS}



NO EXTERNAL
PRIORS
ASSUMED

19 FREE
PARAMETERS

146 / 138
ELEMENTS

FIDUCIAL:

$$S_8 = 0.722^{+0.038}_{-0.037}$$

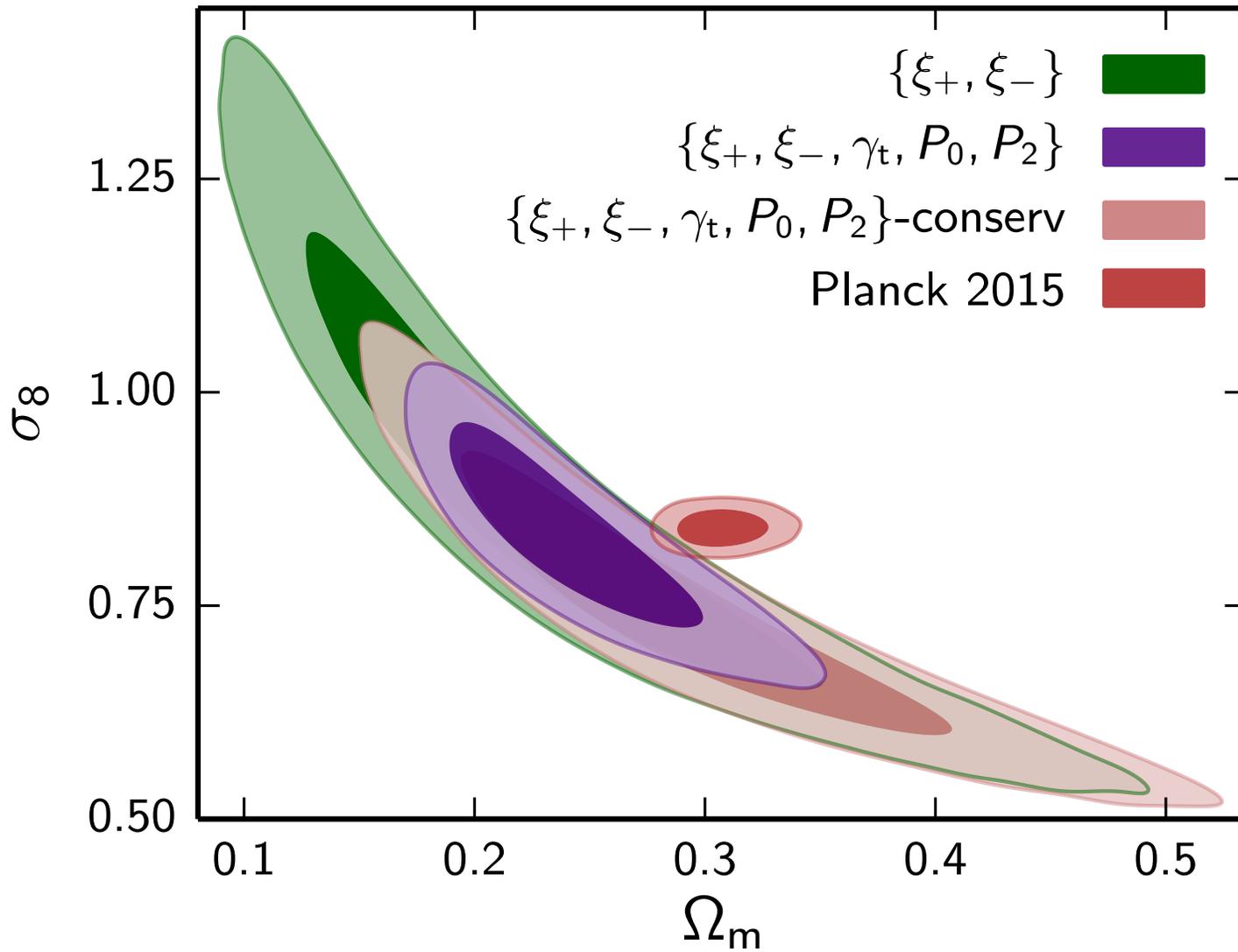
CONSERVATIVE:

$$S_8 = 0.717^{+0.039}_{-0.039}$$

FACTOR OF 2 IMPROVEMENT ALONG BANANA

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

KIDS/{2DFLENS, BOSS}



NO EXTERNAL
PRIORS
ASSUMED

19 FREE
PARAMETERS

210 / 186
ELEMENTS

FIDUCIAL:

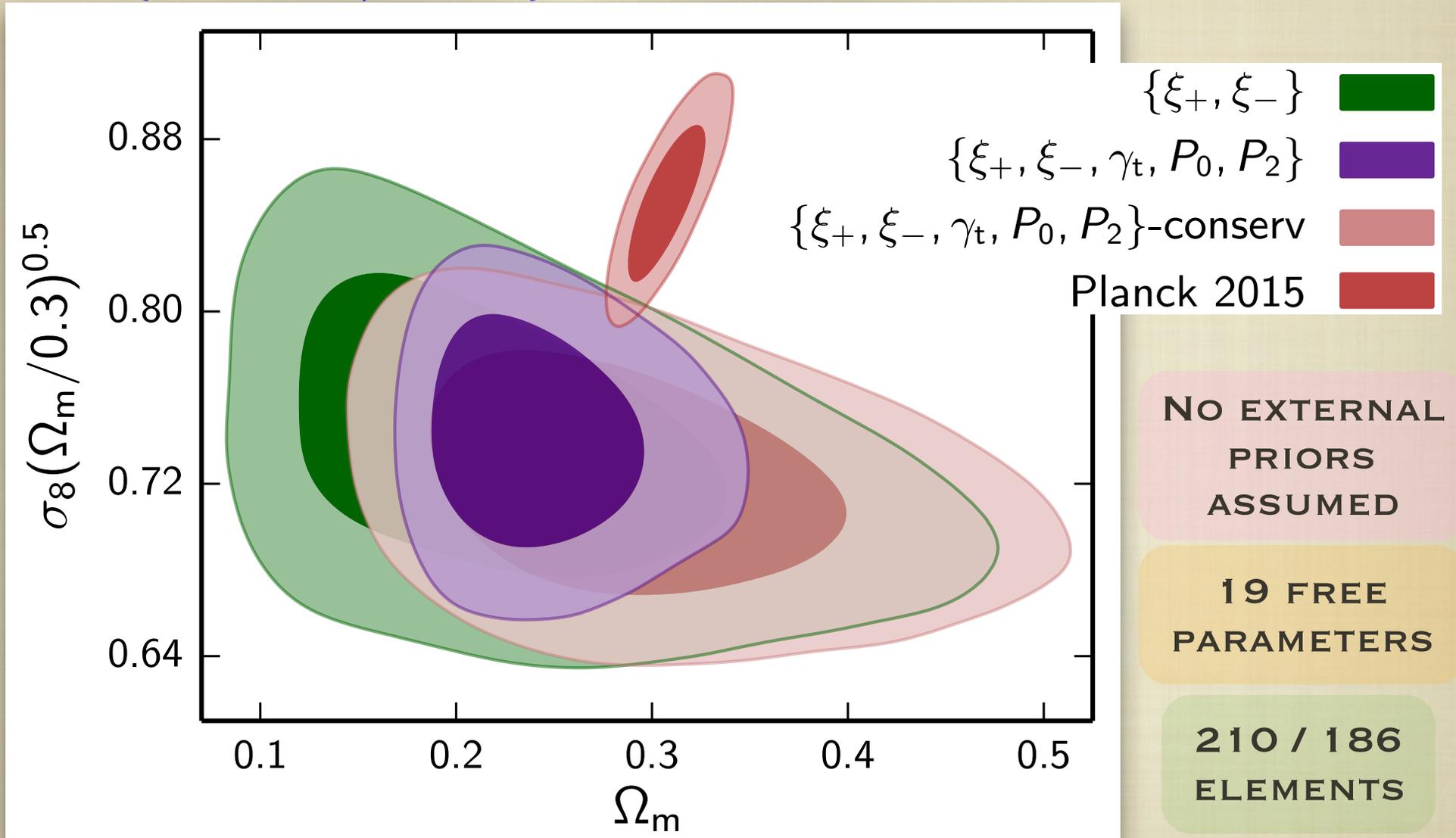
$$S_8 = 0.742^{+0.035}_{-0.035}$$

CONSERVATIVE:

$$S_8 = 0.721^{+0.036}_{-0.036}$$

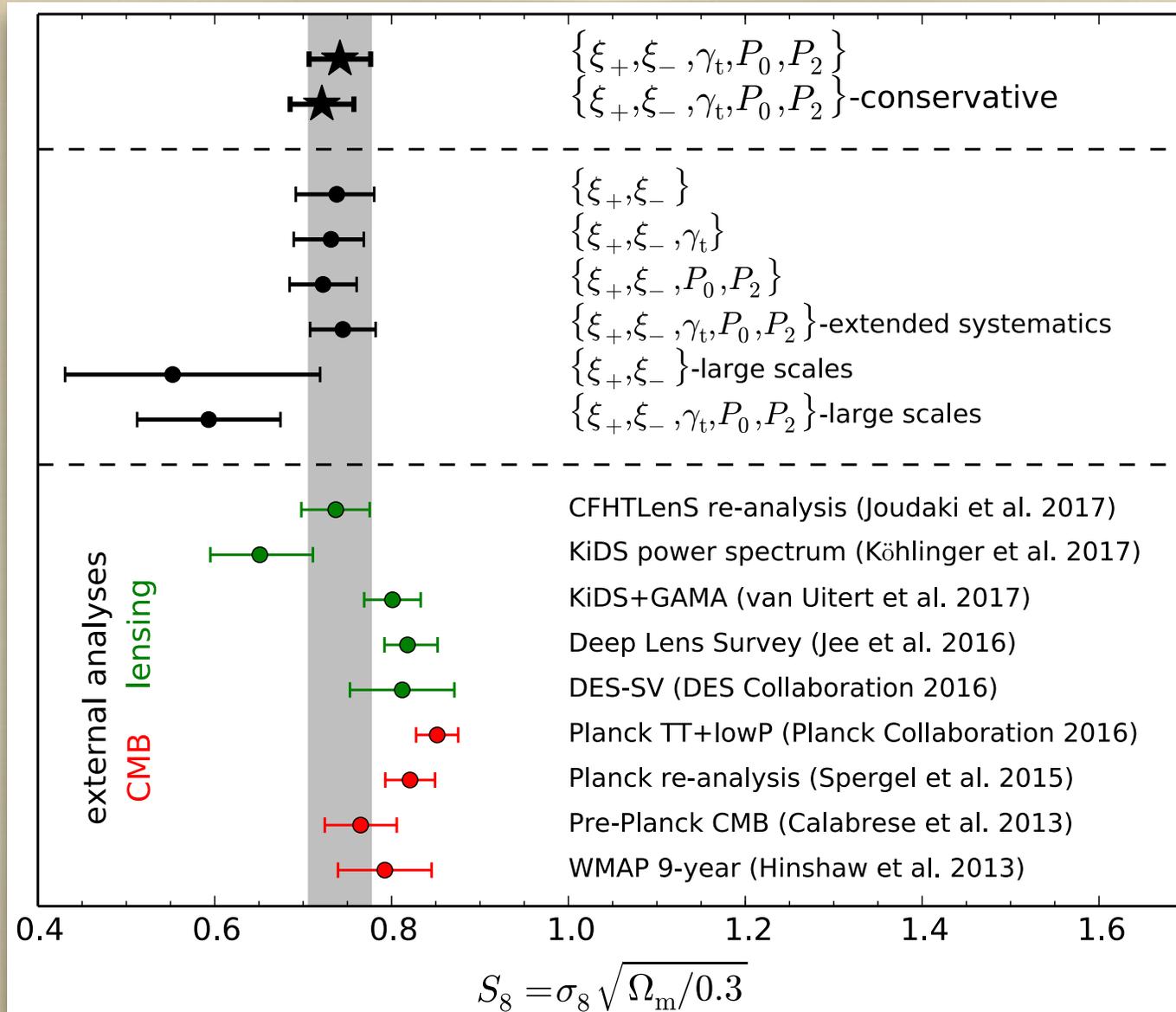
FULLY JOINT CONSTRAINTS $\{\xi_+, \xi_-, \gamma_t, P_0, P_2\}$

KIDS/{2DFLENS, BOSS}



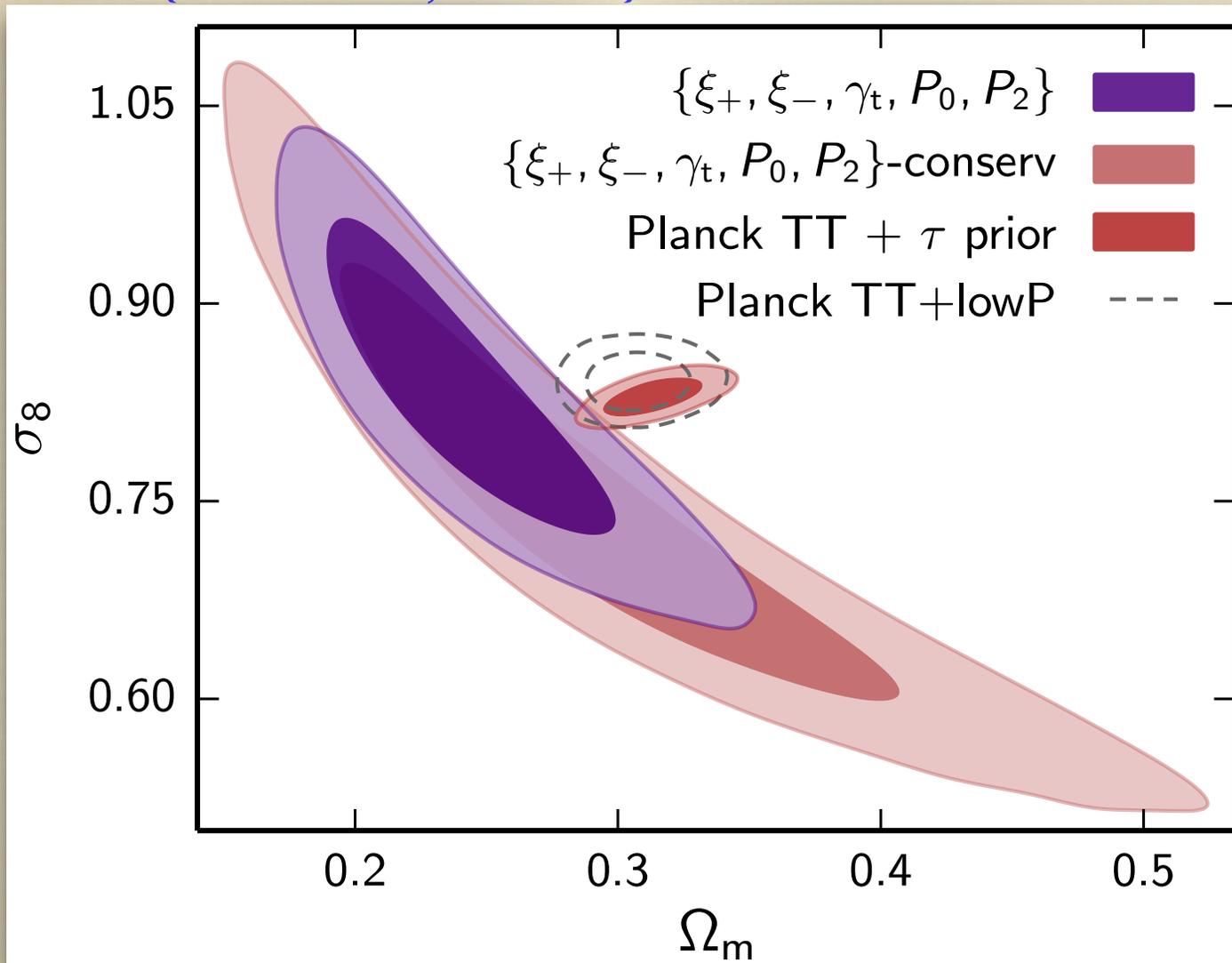
FULLY COMBINED CONSTRAINTS

KIDS/{2DFLENS, BOSS}



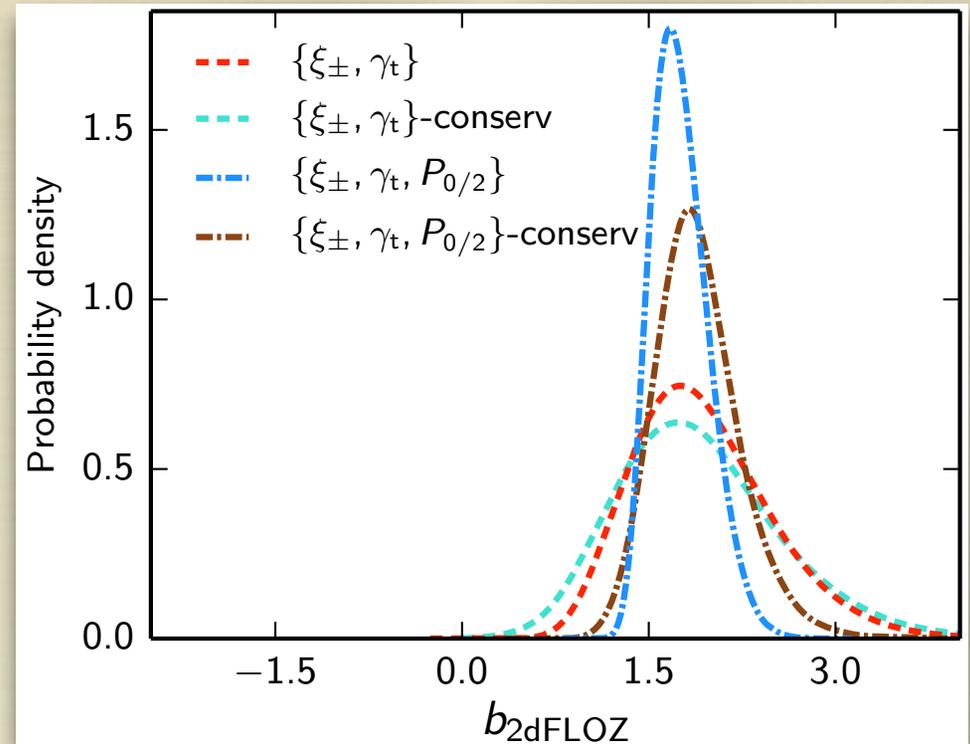
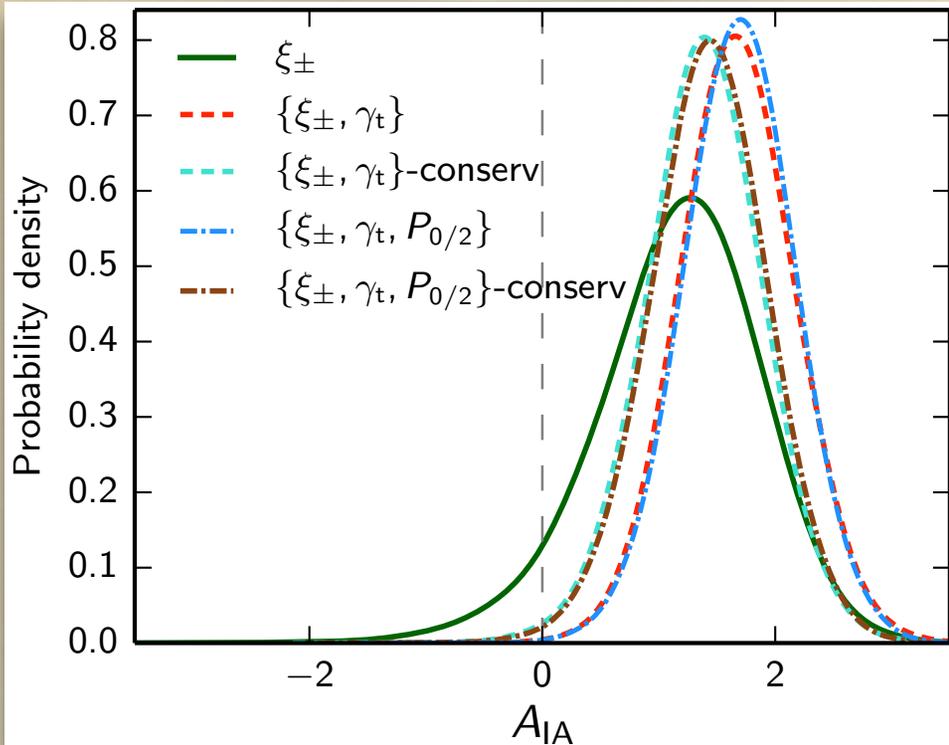
IMPACT OF PLANCK WITH τ PRIOR

KIDS/{2DFLENS, BOSS}



$$\tau = 0.055 \pm 0.009 \text{ (SIMLOW)}$$

ASTROPHYSICAL CONSTRAINTS



FIDUCIAL:

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

CONSERVATIVE:

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

BARYONIC FEEDBACK

$$B < 3.3 \text{ (95\% CL)}$$

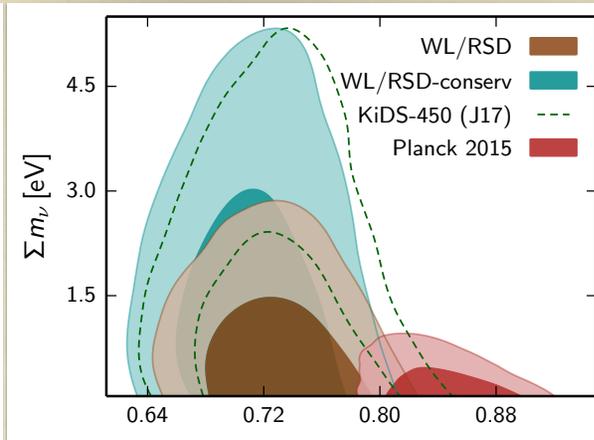
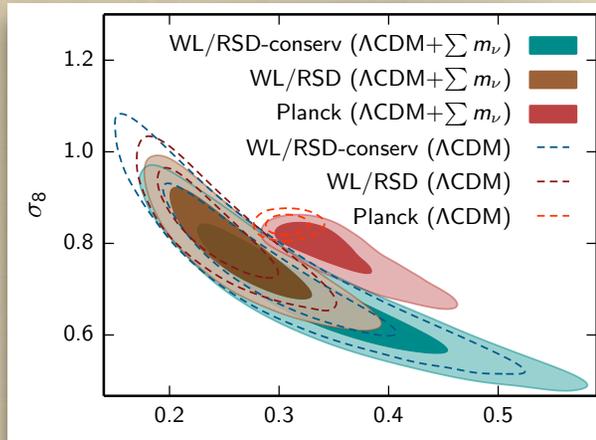
$$B_{\text{peak}} = \{1.6, 2.0\}$$

**COSMOLOGICAL
CONSTRAINTS
ROBUST TO
EXTENDED
SYSTEMATICS
TREATMENT**

Agenda Part 4

- **COMBINING OVERLAPPING SURVEYS: KIDS/(2DFLENS+BOSS). LIKELIHOOD PIPELINE, MEASUREMENTS, COVARIANCE**
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EXTENDED COSMOLOGY CONSTRAINTS

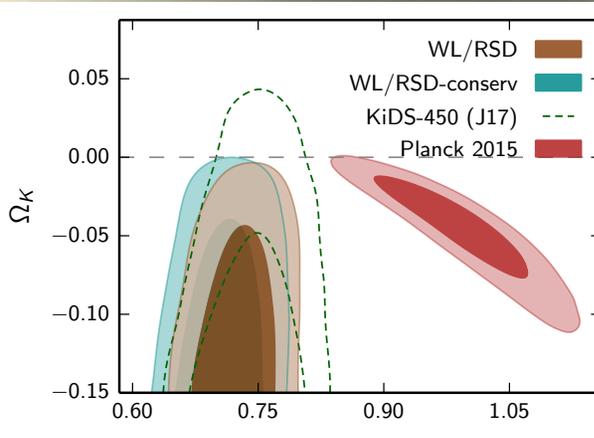
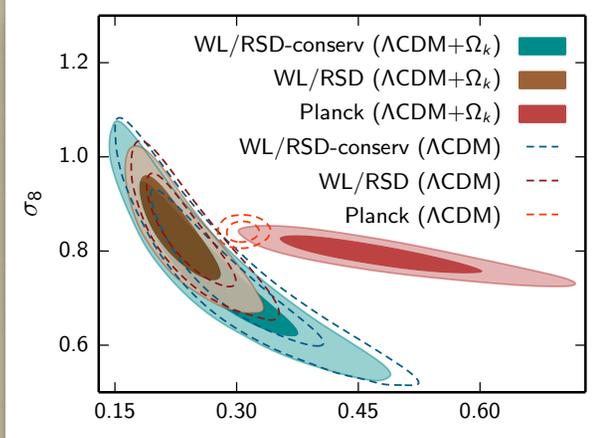


NEUTRINO MASS

$$\sum m_\nu < 2.2 \text{ eV (95\% CL)}$$

CURVATURE

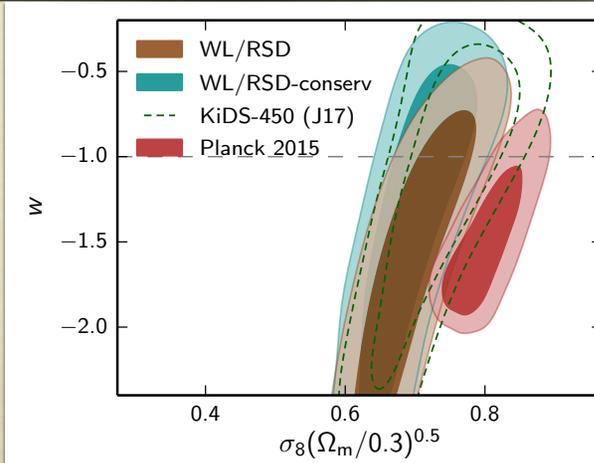
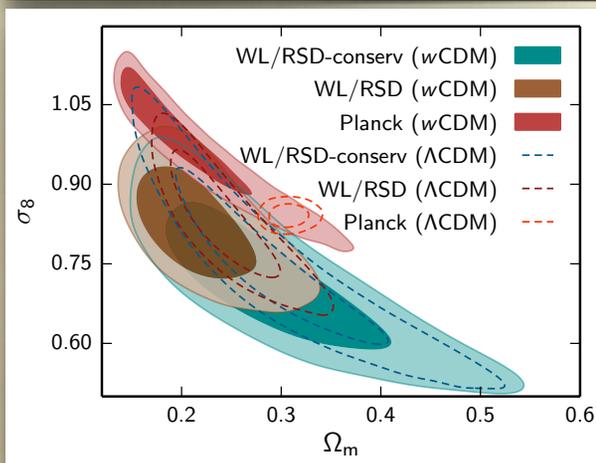
$$\Omega_k < -0.026 \text{ (95\% CL)}$$



EVOLVING DE (CONST w)

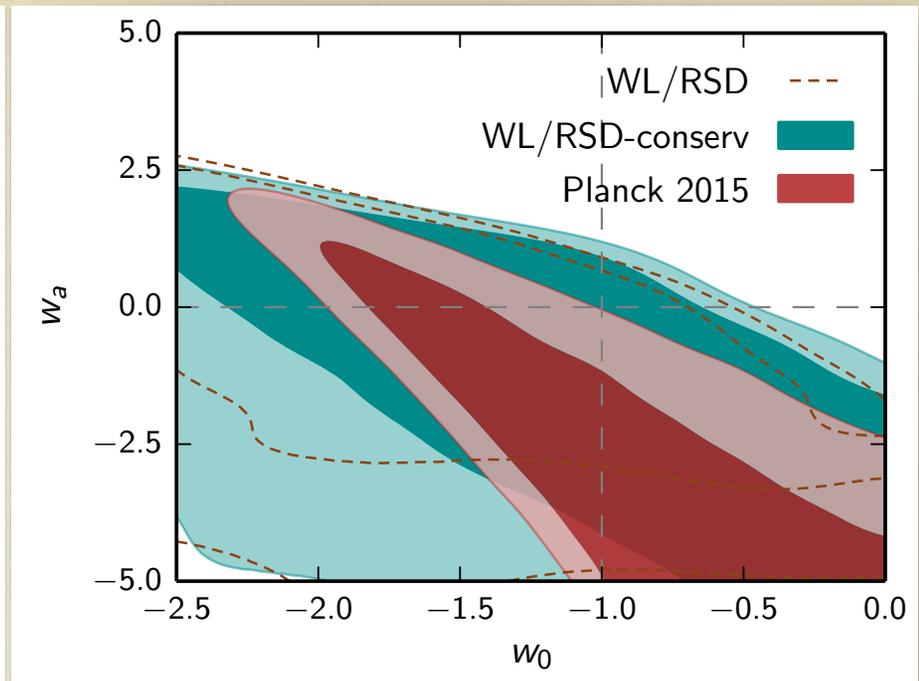
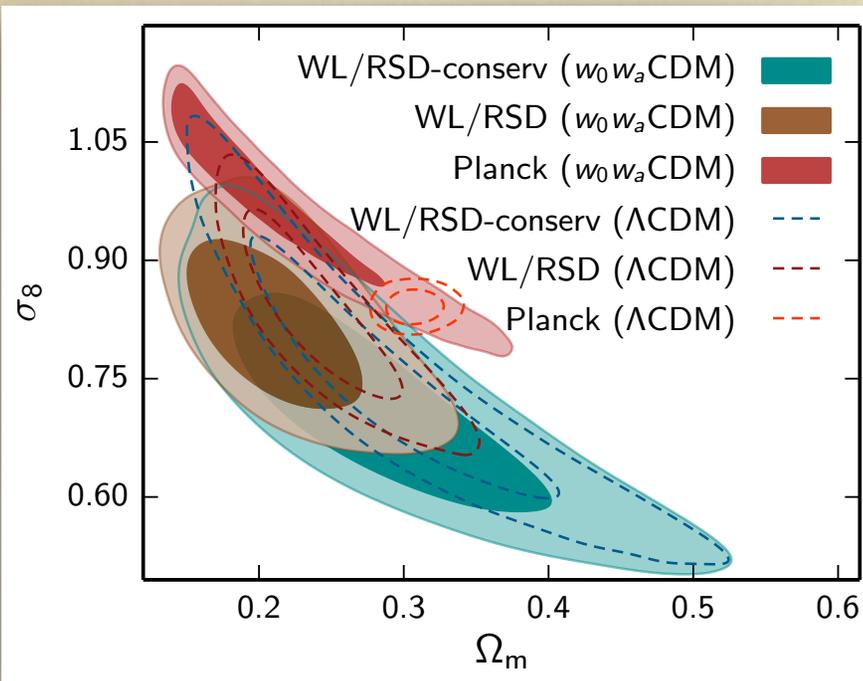
$$w < -0.73 \text{ (95\% CL)}$$

$$w < -1/3 \text{ (99.93\% CL)}$$



**EXTENSIONS
NOT FAVORED,
DISCORDANCES PERSIST**

EVOLVING DARK ENERGY (w_0-w_a)



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

FIDUCIAL:

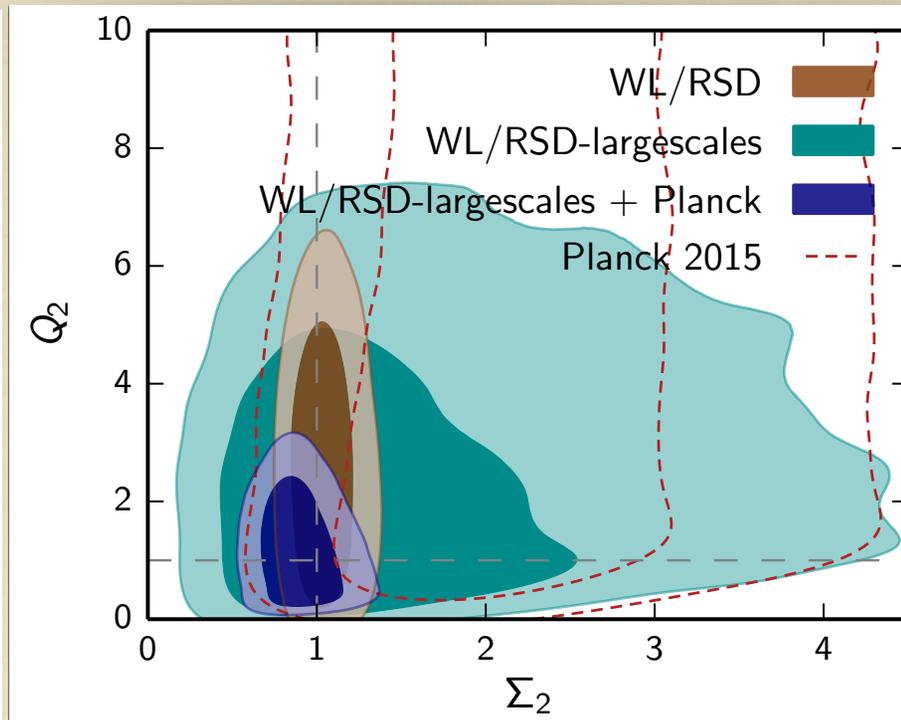
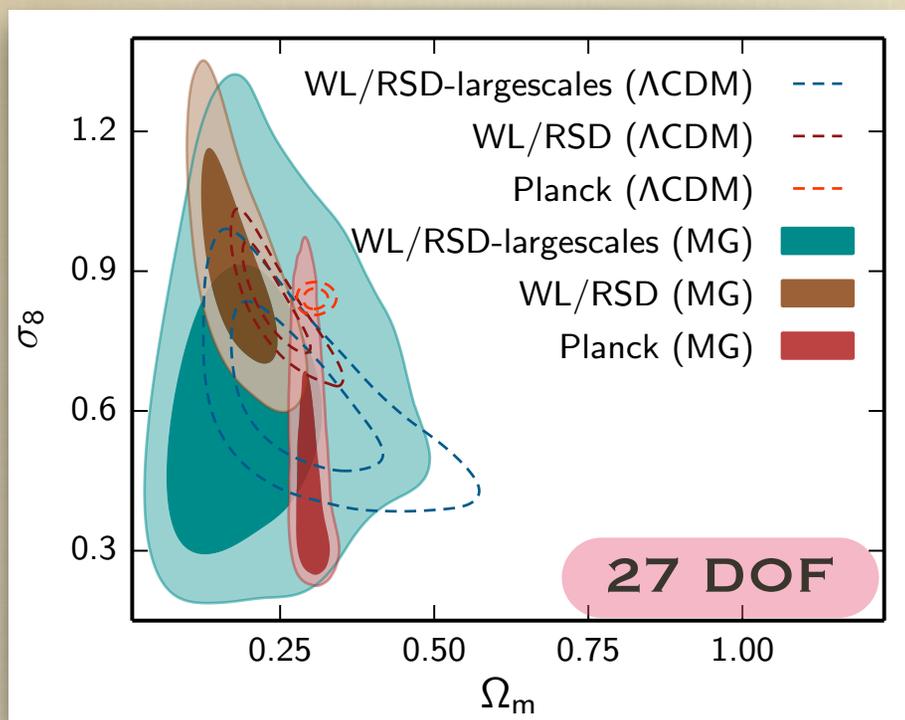
$$T(S_8) = 1.7\sigma$$

CONSERVATIVE:

$$T(S_8) = 1.9\sigma$$

**~1 σ WORSE
AGREEMENT
WITH PLANCK
THAN KIDS
ALONE**

MODIFIED GRAVITY



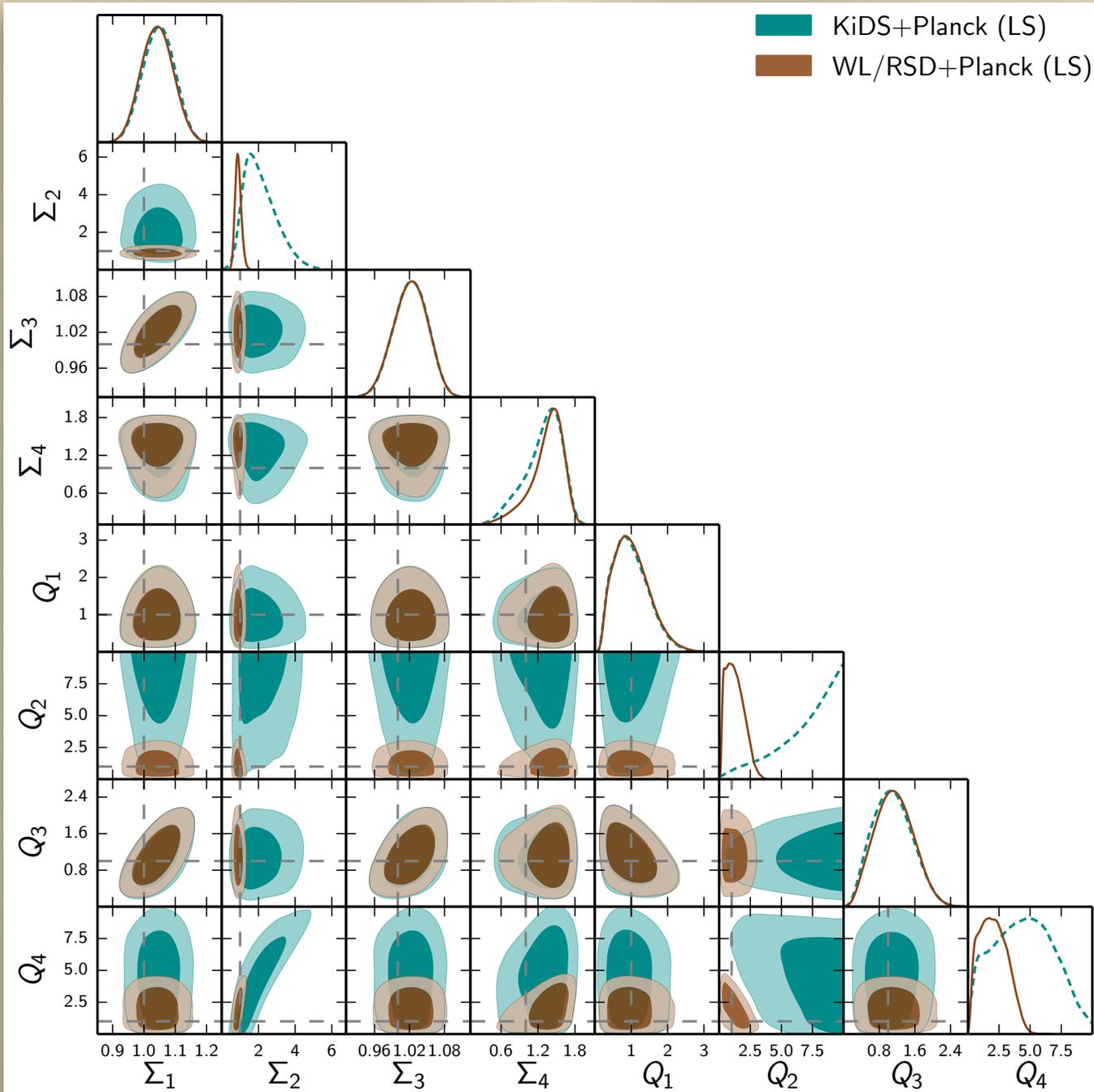
$Q(k, z)$ MODIFIES POISSON EQUATION

$\Sigma(k, z)$ MODIFIES LIGHT DEFLECTION

1 LOW Z LOW K	2 LOW Z HIGH K
3 HIGH Z LOW K	4 HIGH Z HIGH K

10-15% LEVEL CONSTRAINTS ON Σ_2 IN FIDUCIAL AND LS+PLANCK CASES, Q_2 BOUNDED FROM ABOVE, S_8 CONSTRAINT IMPROVES BY UP TO FACTOR OF 3

MODIFIED GRAVITY SUBSPACE



LARGE-SCALE
DATA CUTS

COMPLETE
AGREEMENT
WITH GR

GOODNESS OF FIT
IMPROVES, BUT
DIC IS POSITIVE

ALEX AMON: E_G

CONCLUSIONS

- SELF-CONSISTENT COSMOLOGICAL ANALYSIS OF WEAK LENSING TOMOGRAPHY AND OVERLAPPING REDSHIFT-SPACE GALAXY CLUSTERING: KIDS/2DFLENS/BOSS.
- COMBINED PROBES IMPROVE $S_8 = 0.742 \pm 0.035$ 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](https://github.com/sjoudaki/CosmoLSS)

THANKS FOR LISTENING.