



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

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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  $\Lambda$ 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:** ( $\xi_+$ ,  $\xi_-$ ,  $\gamma_t$ ,  $P_0$ ,  $P_2$ ).  
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)

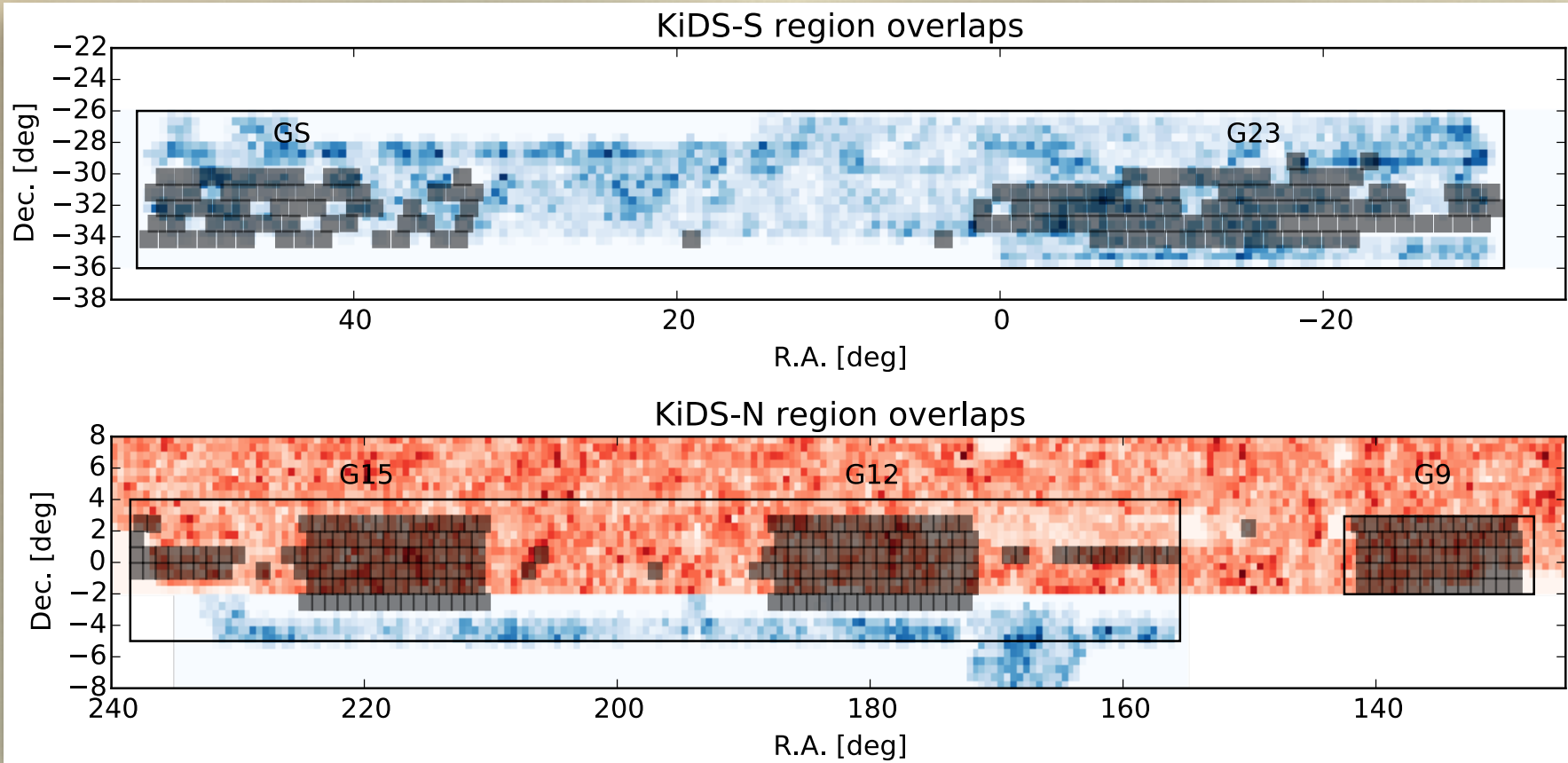
APPLIED TO DATA, FIRST PIPELINE TO SELF-CONSISTENTLY TREAT WL AND RSD (FULL COVARIANCE), AND FIRST TO MARGINALIZE ALL KEY SYSTEMATICS.

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



# KIDS/2DFLENS/BOSS OVERLAPS



**2DFLENS (AAT):**

**70,000 z's**

**$z < 0.9$**

**730 DEG<sup>2</sup>**

**KIDS (VST):**

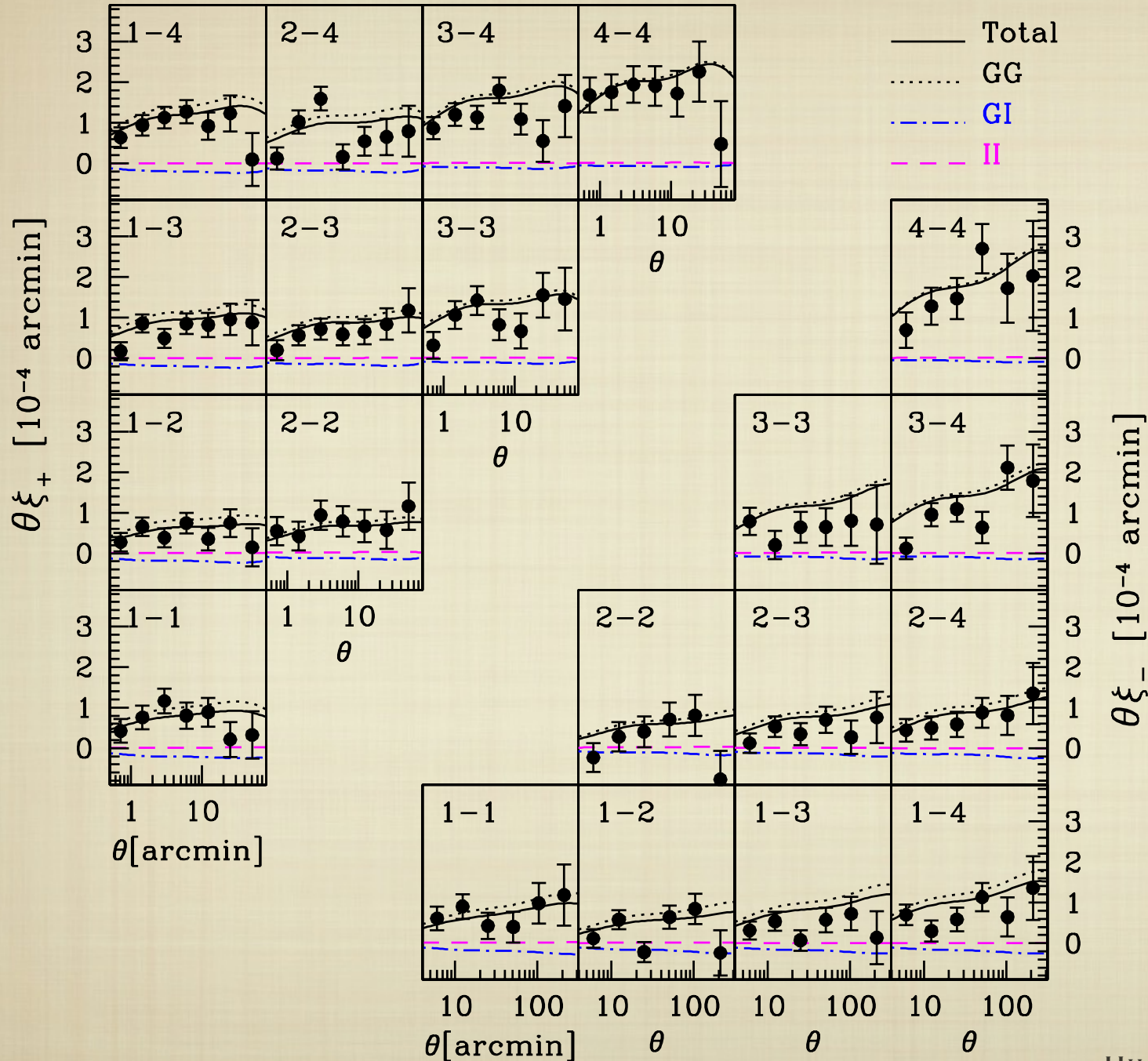
**450 DEG<sup>2</sup>**

**$z_M = 0.55$**

**$N = 9 \text{ ARCMIN}^{-2}$**

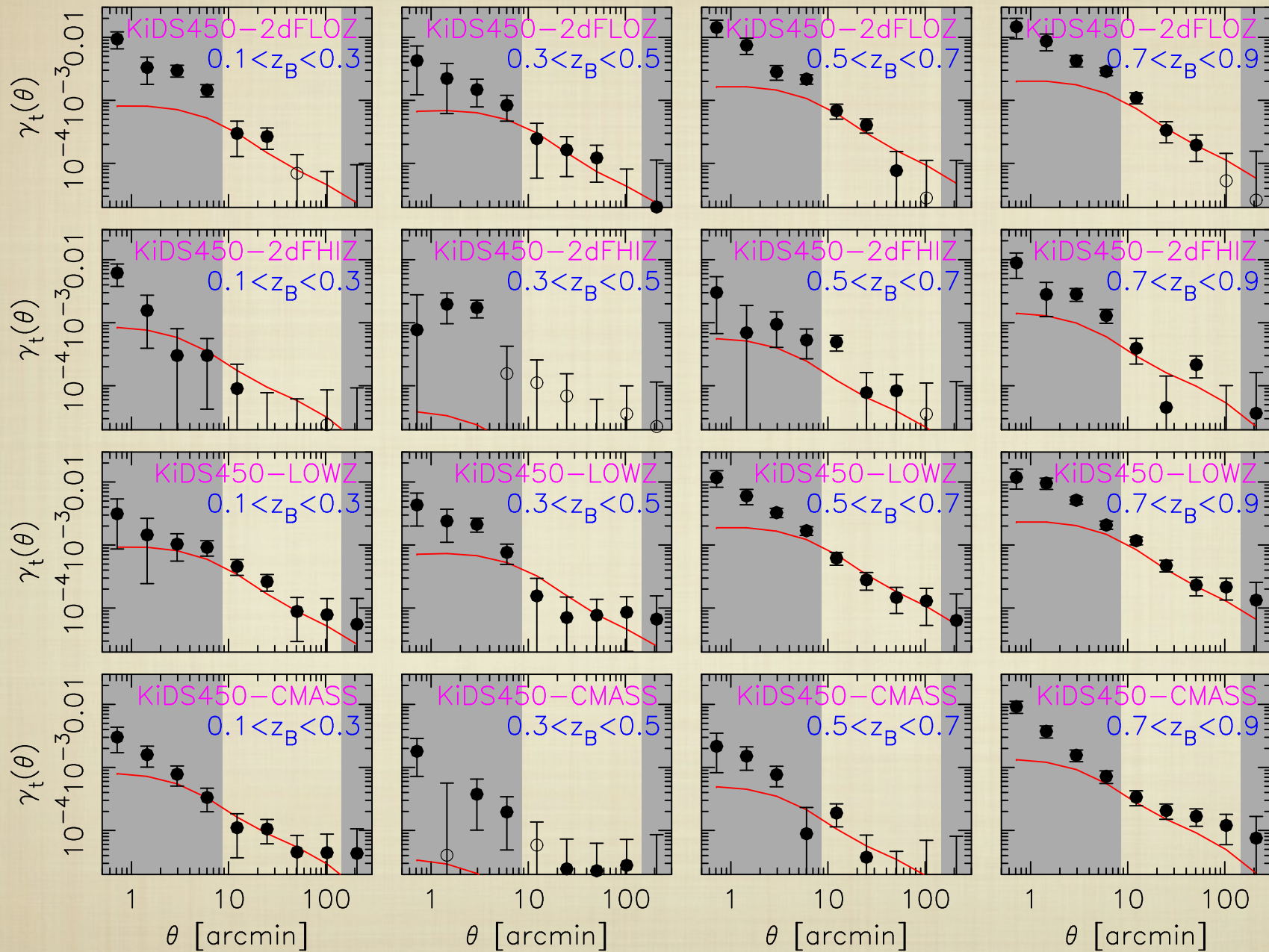


# COSMIC SHEAR MEASUREMENTS

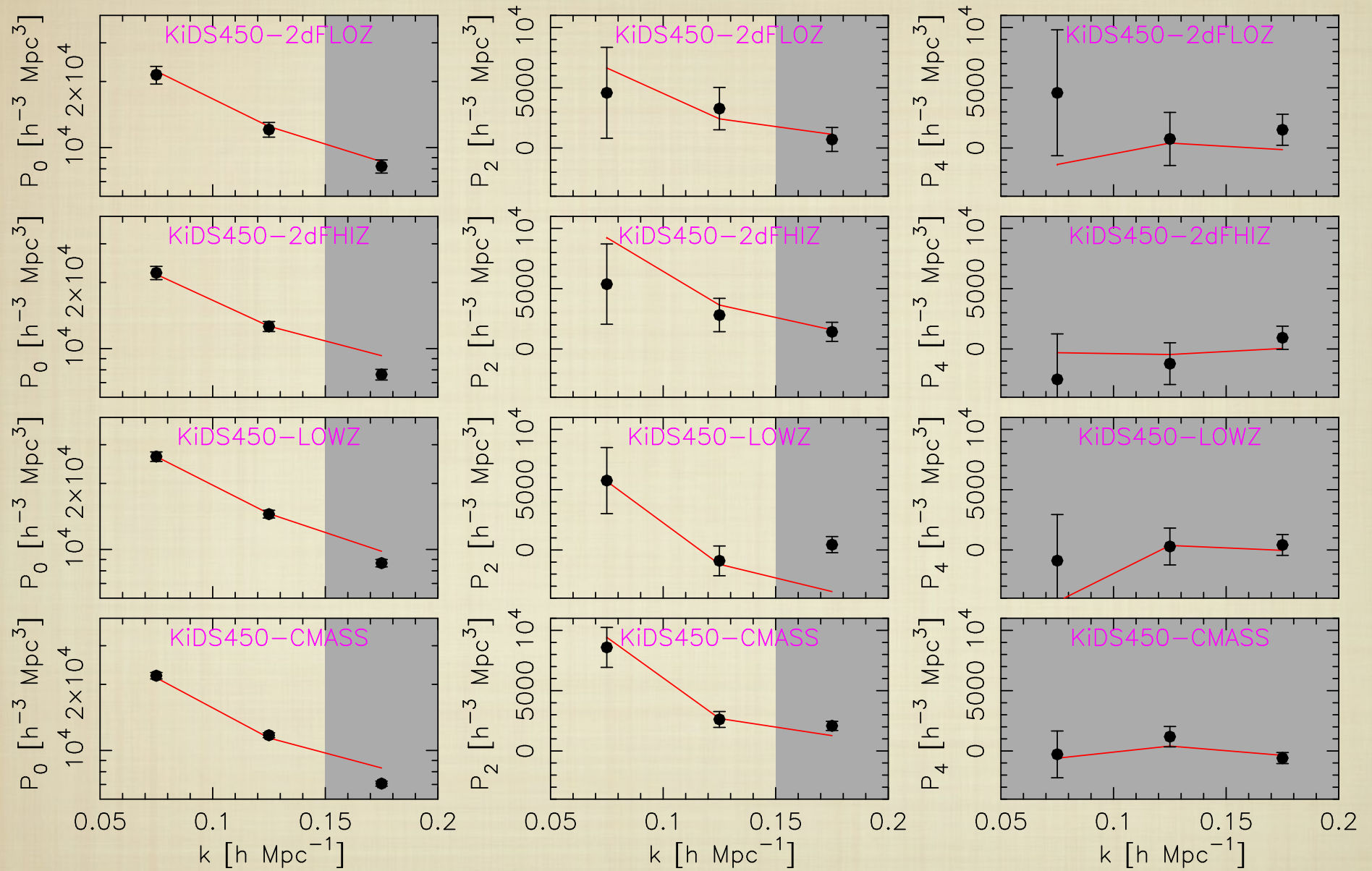




# GALAXY-GALAXY LENSING MEASUREMENTS

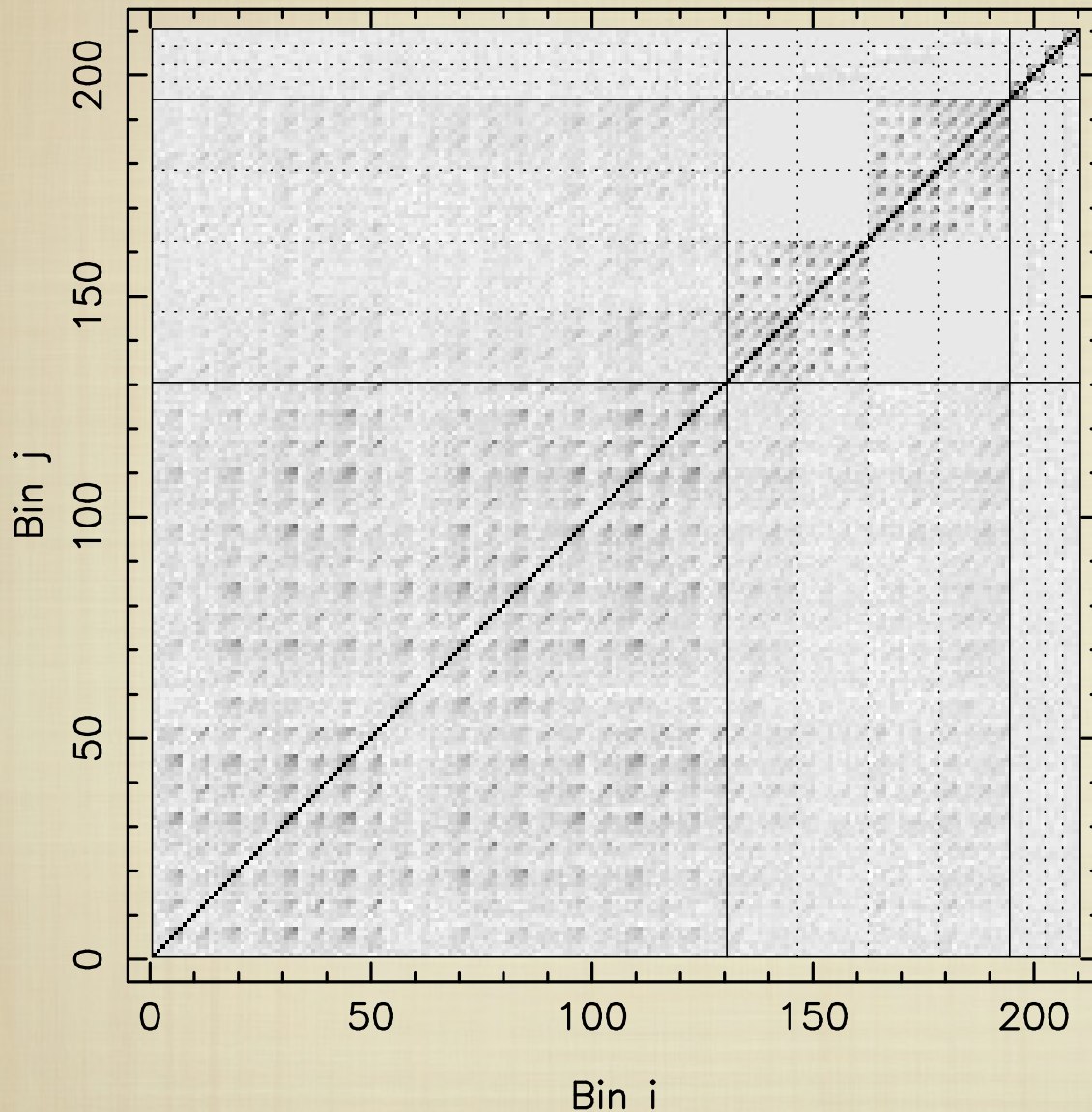


# MULTIPOLE POWER SPECTRUM MEASUREMENTS





# 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

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

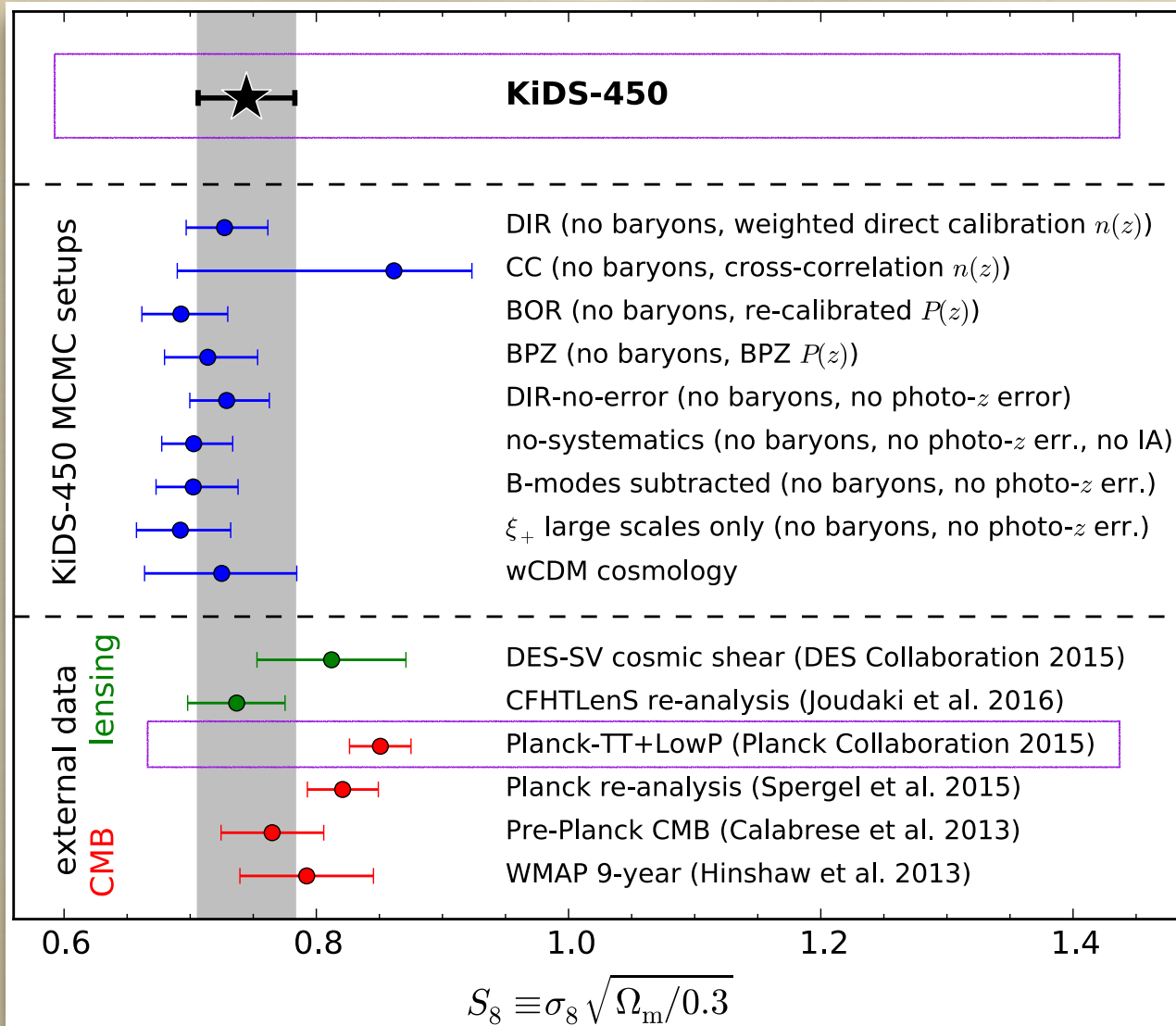


# Agenda Part 2

- COMBINING OVERLAPPING SURVEYS: KIDS/(2DFLENS+BOSS). LIKELIHOOD PIPELINE, MEASUREMENTS, COVARIANCE
- KIDS-450 ALONE: CONSTRAINTS, TENSIONS, EXTENDED COSMOLOGIES
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- WL/RSD COMBINED ANALYSIS: EXTENDED COSMOLOGY CONSTRAINTS



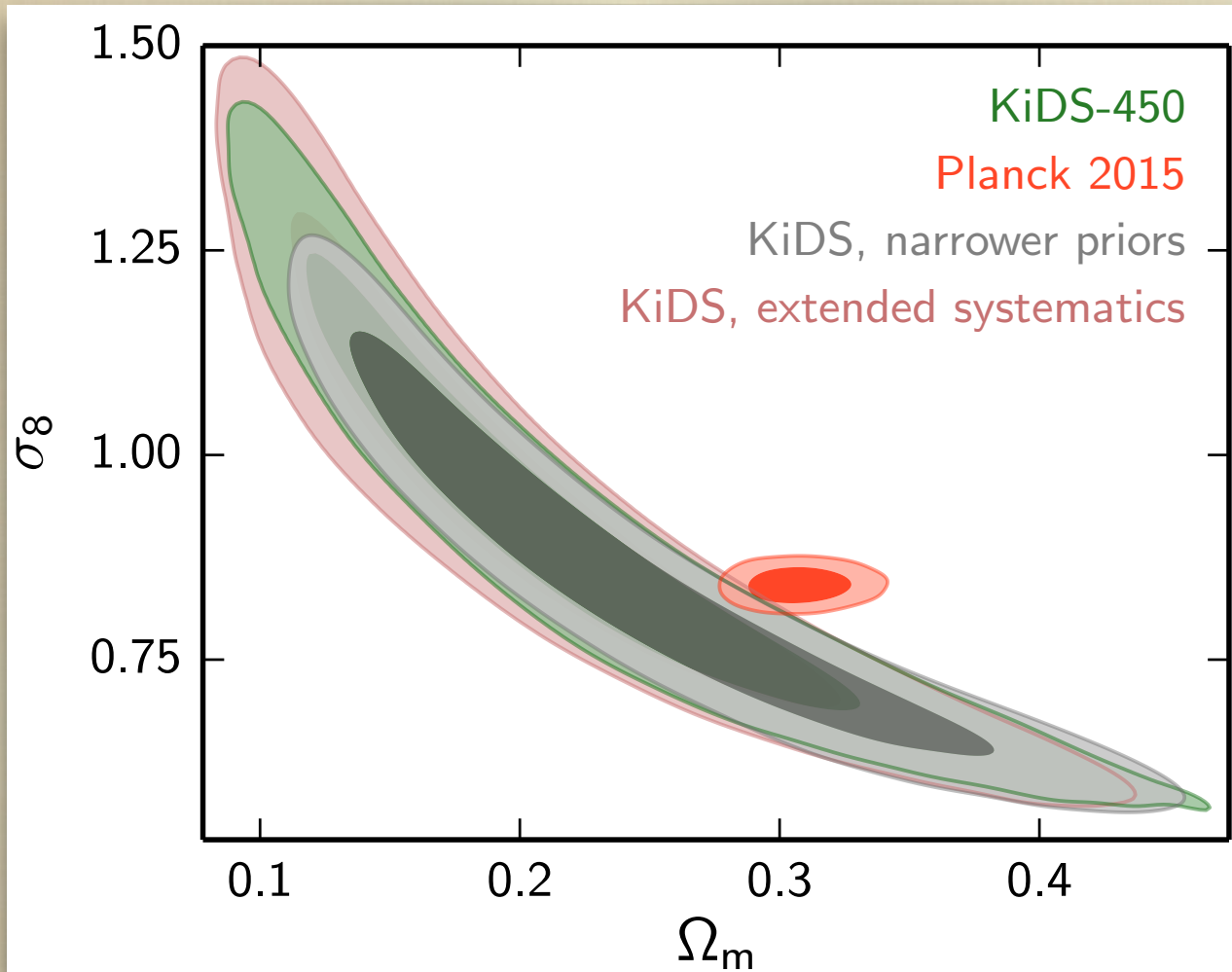
# KIDS-450 CONSTRAINTS AND SYSTEMATICS



## 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

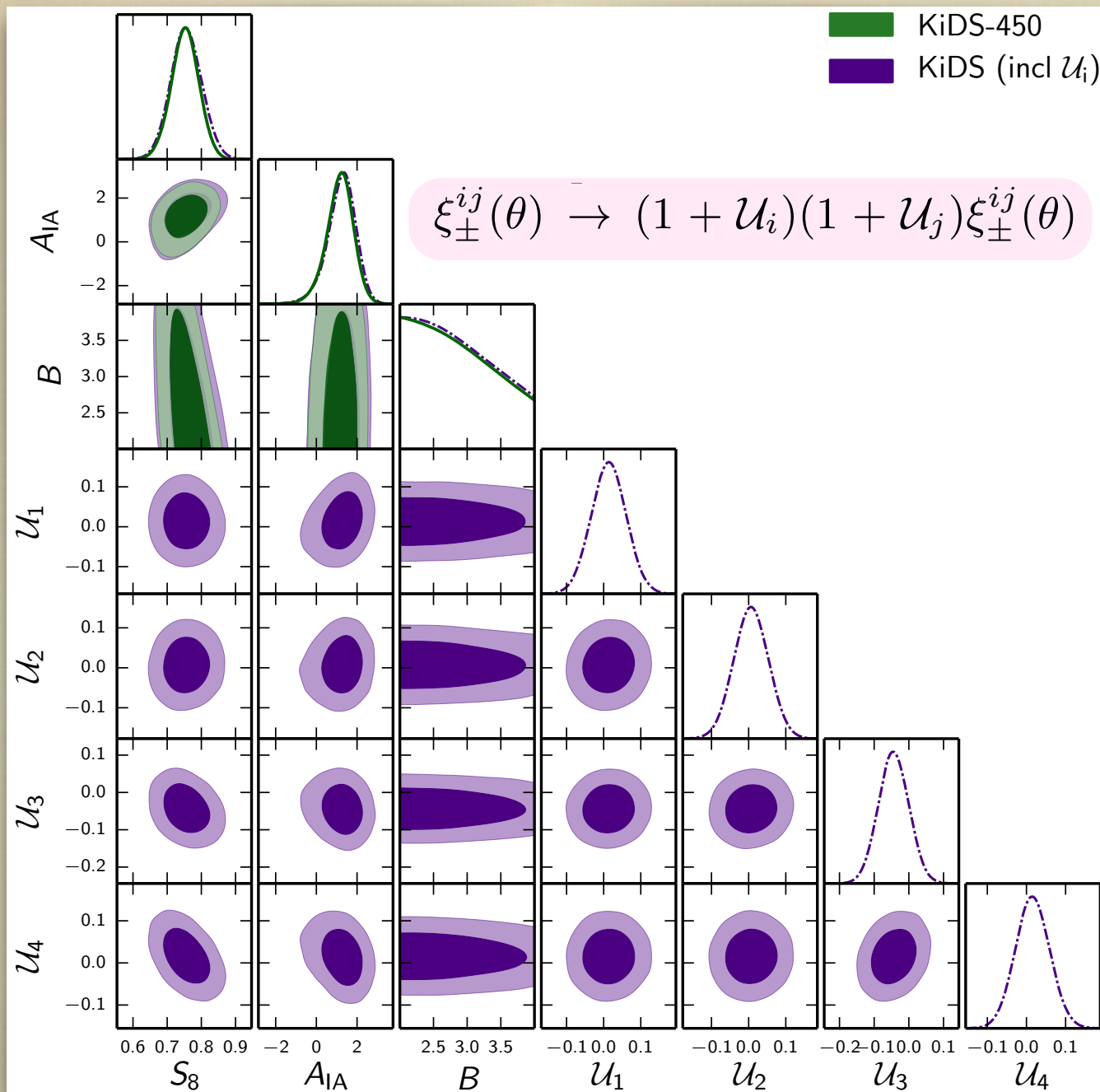


## EXTENSIONS:

- 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



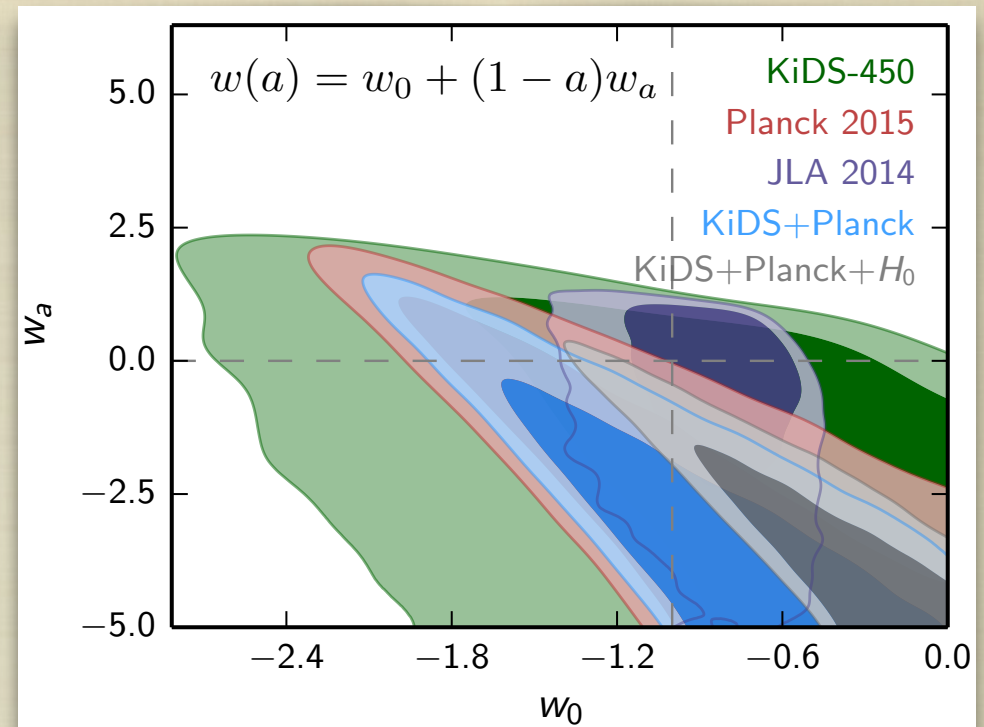
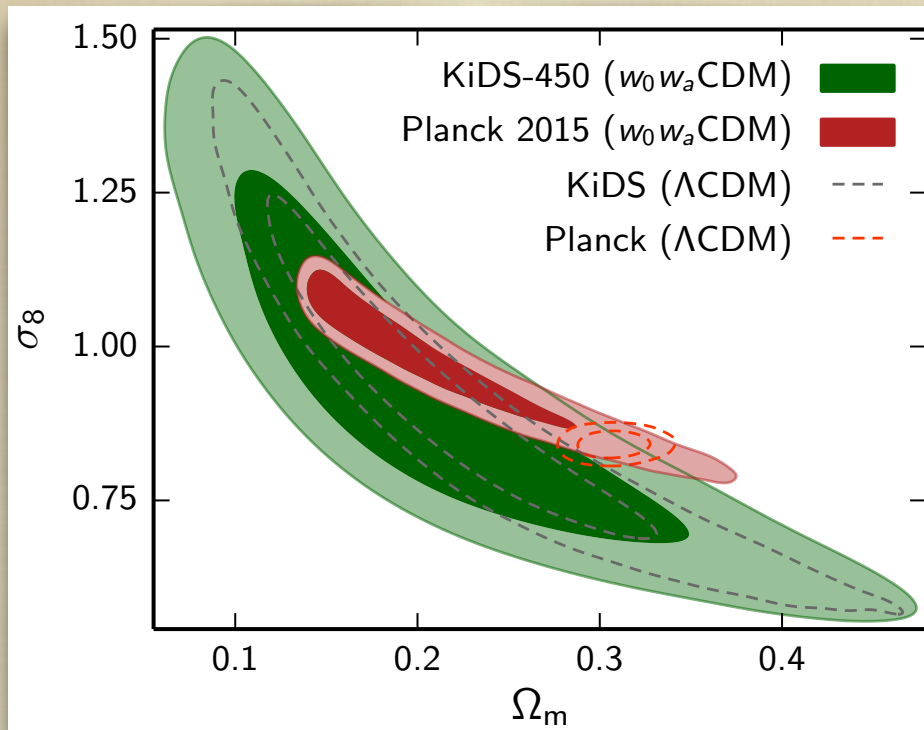
# KIDS-450 “UNKNOWN UNKNOWNNS”



**COSMOLOGICAL  
PARAMETERS  
SIMULTANEOUSLY  
VARIED**

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

# DARK ENERGY CONSTRAINTS ( $w_0$ - $w_a$ )



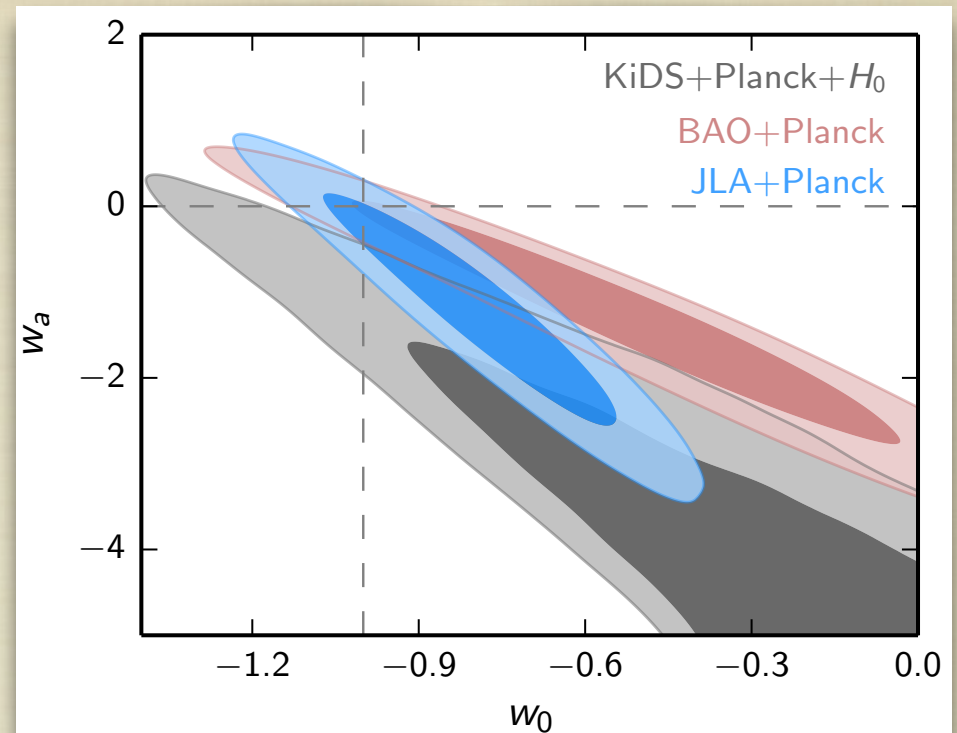
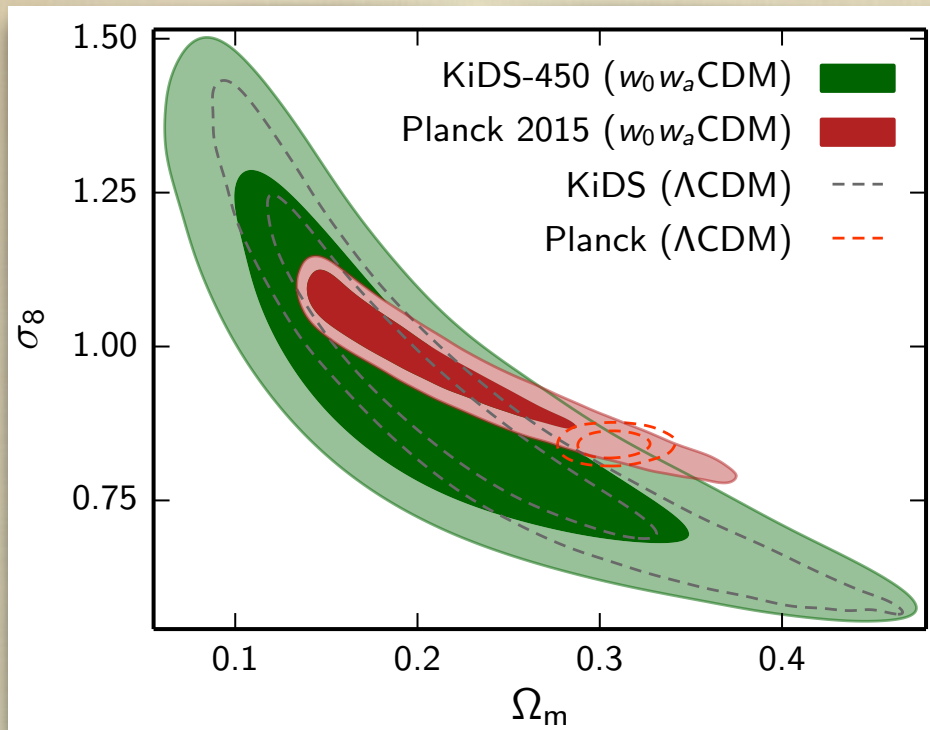
At 95% CL :

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

**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**



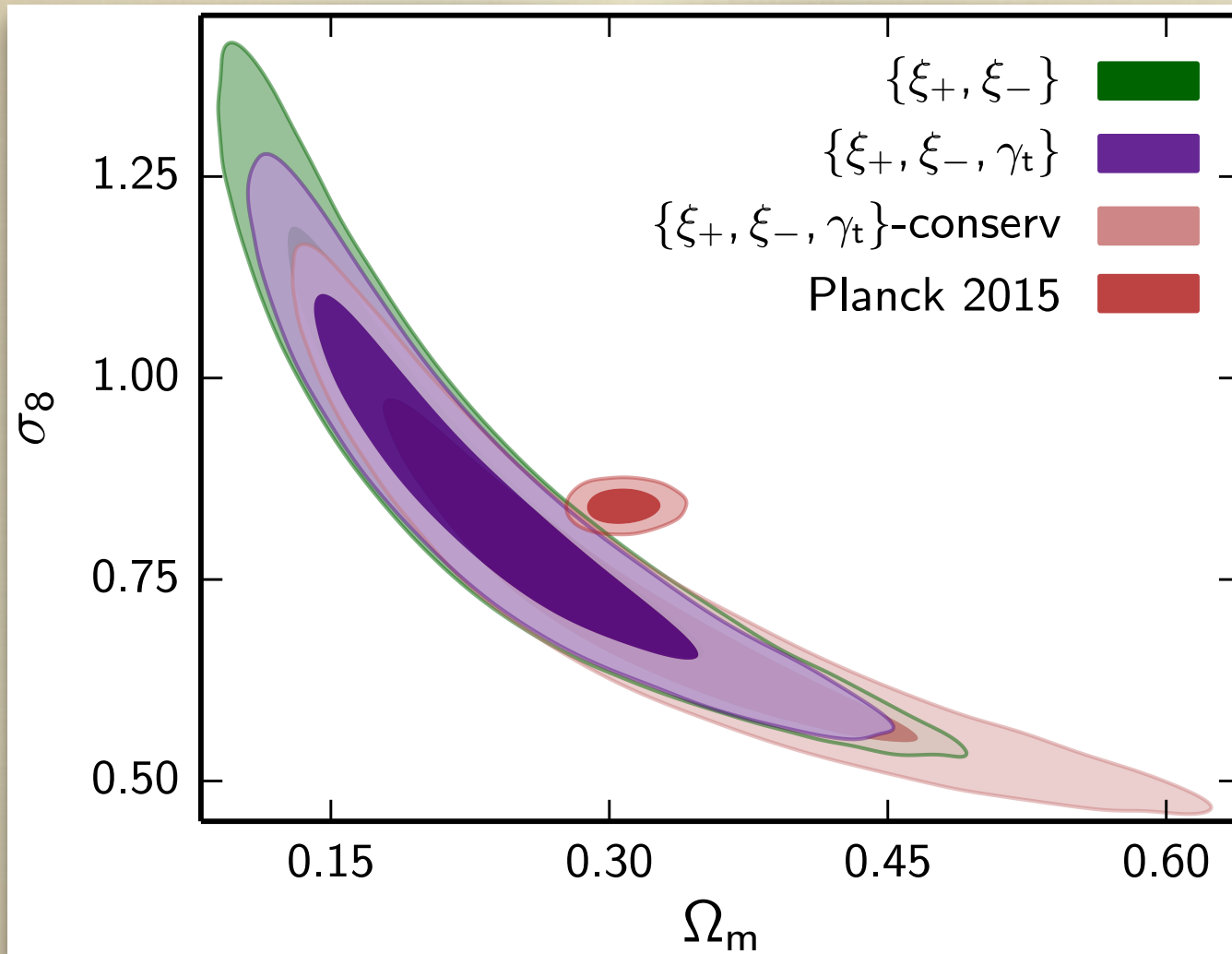
# Agenda Part 3

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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:

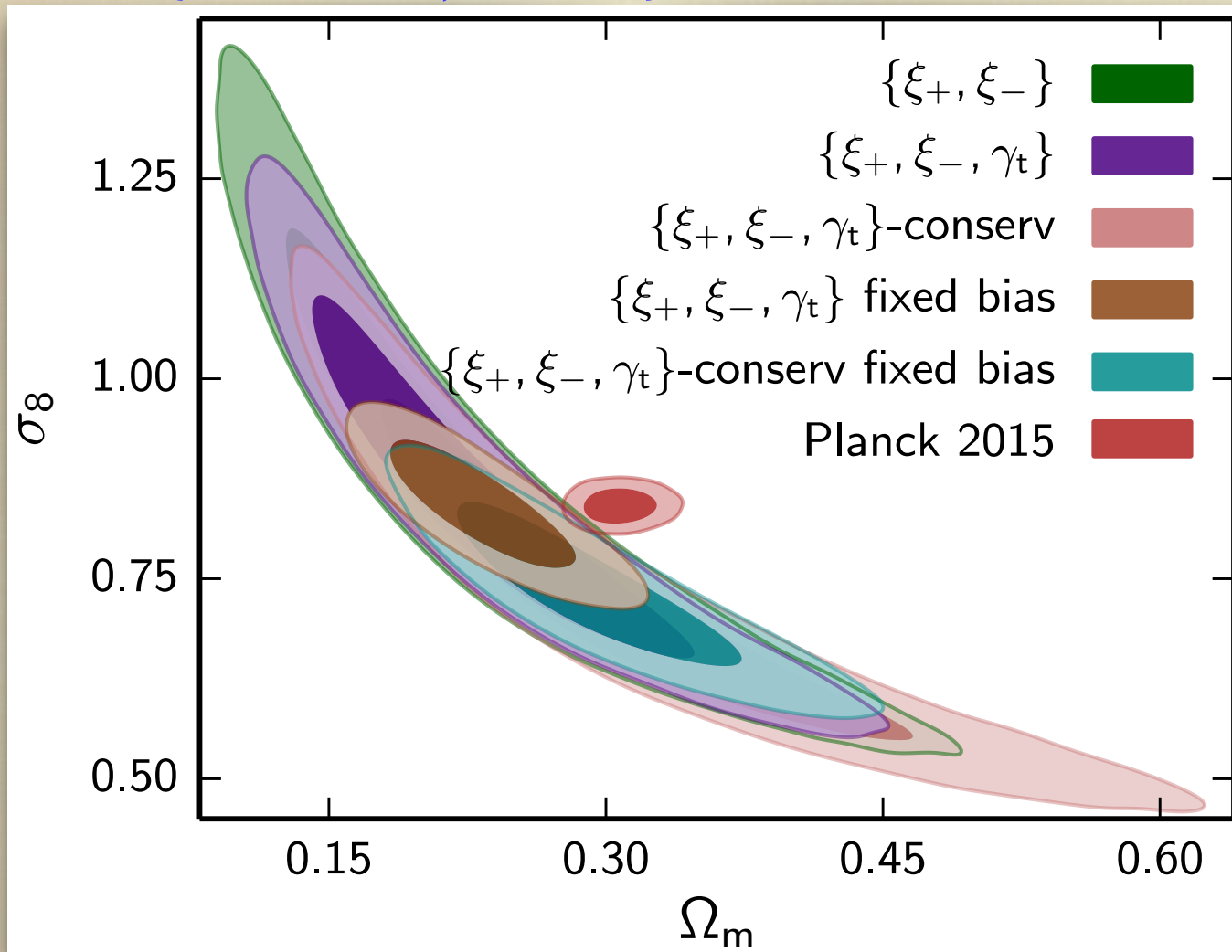
$$S_8 = 0.731^{+0.037}_{-0.042}$$

CONSERVATIVE:

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

# SUB-VECTOR CONSTRAINTS: FIXED BIAS

KIDS/{2DFLENS, BOSS}



NO EXTERNAL  
PRIORS  
ASSUMED

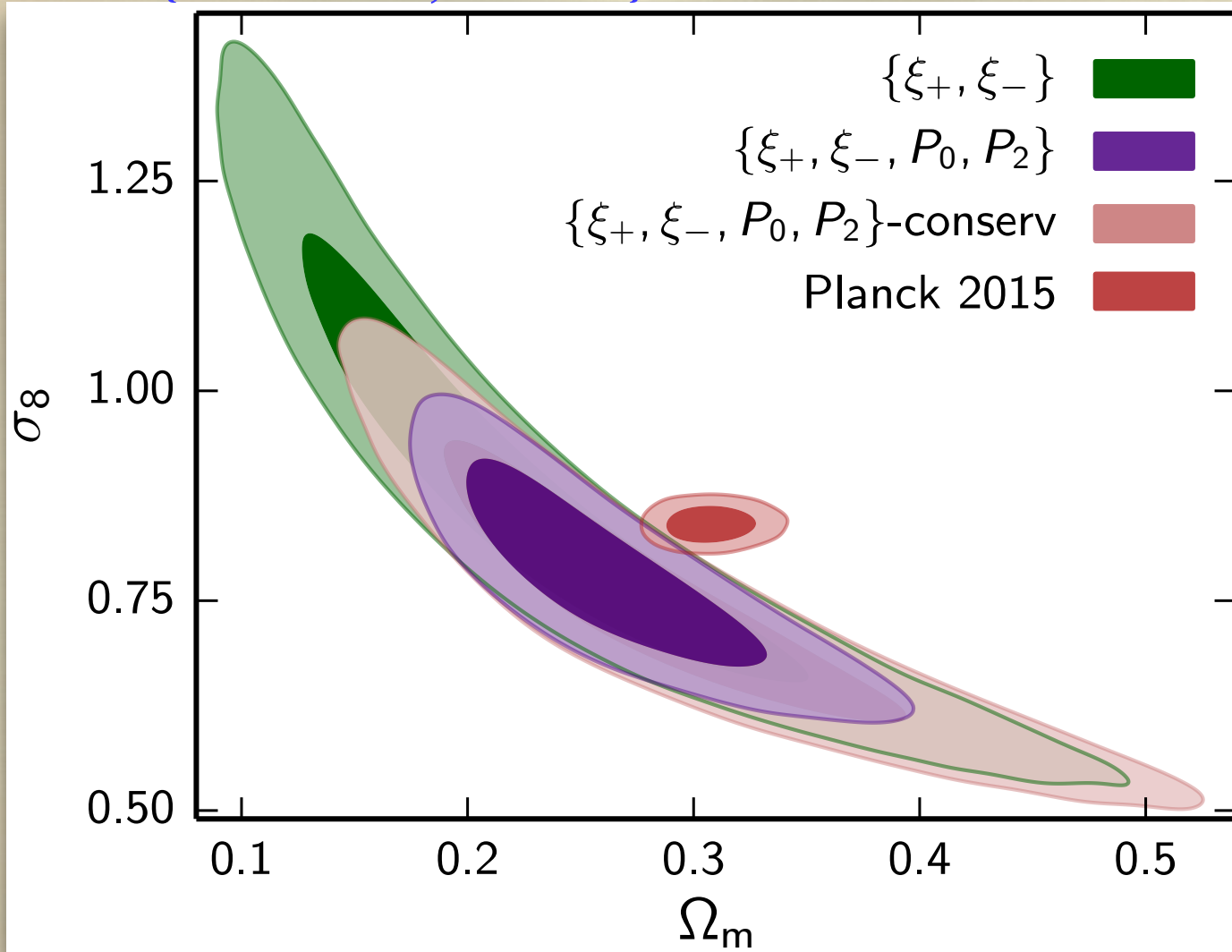
11 / 7 FREE  
PARAMETERS

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:

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

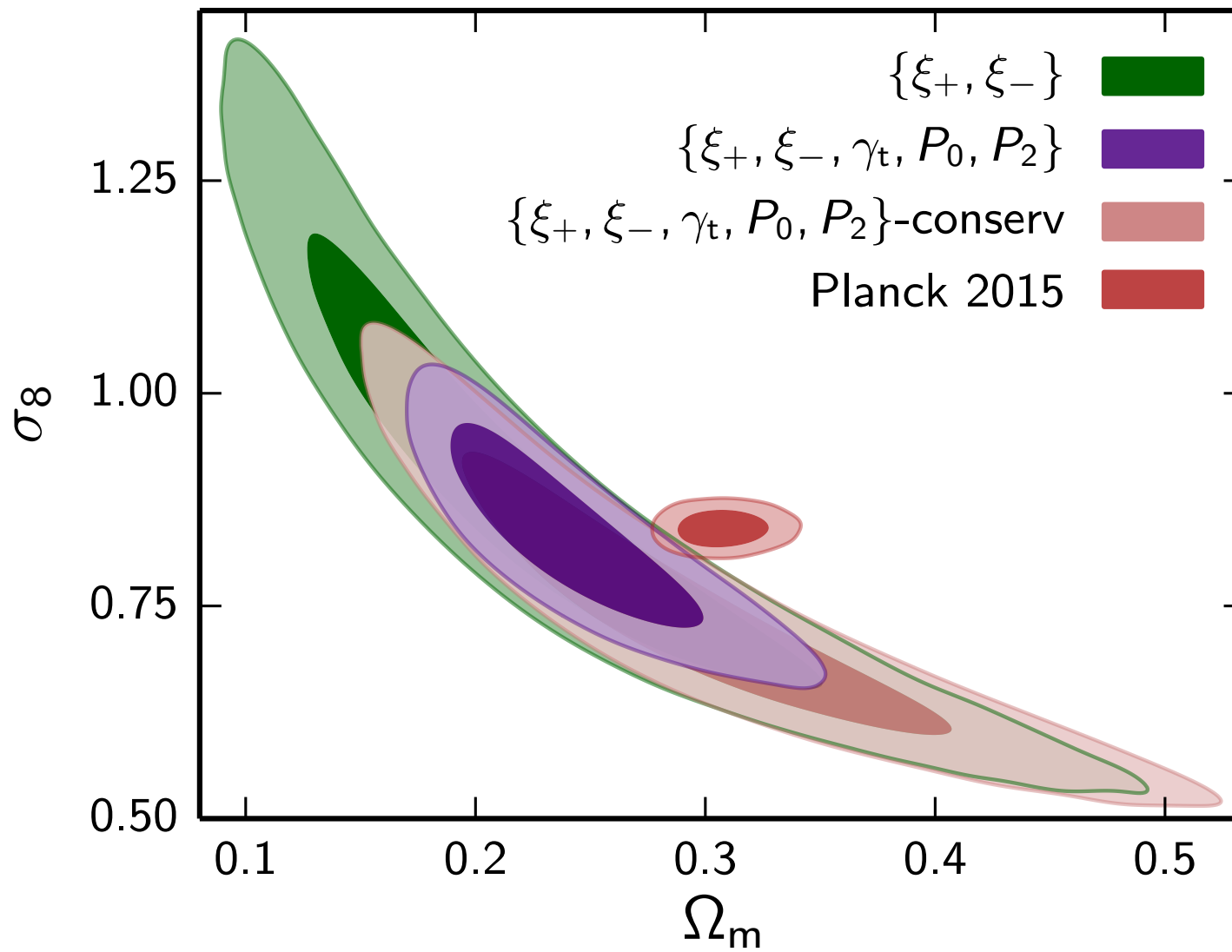
CONSERVATIVE:

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

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:

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

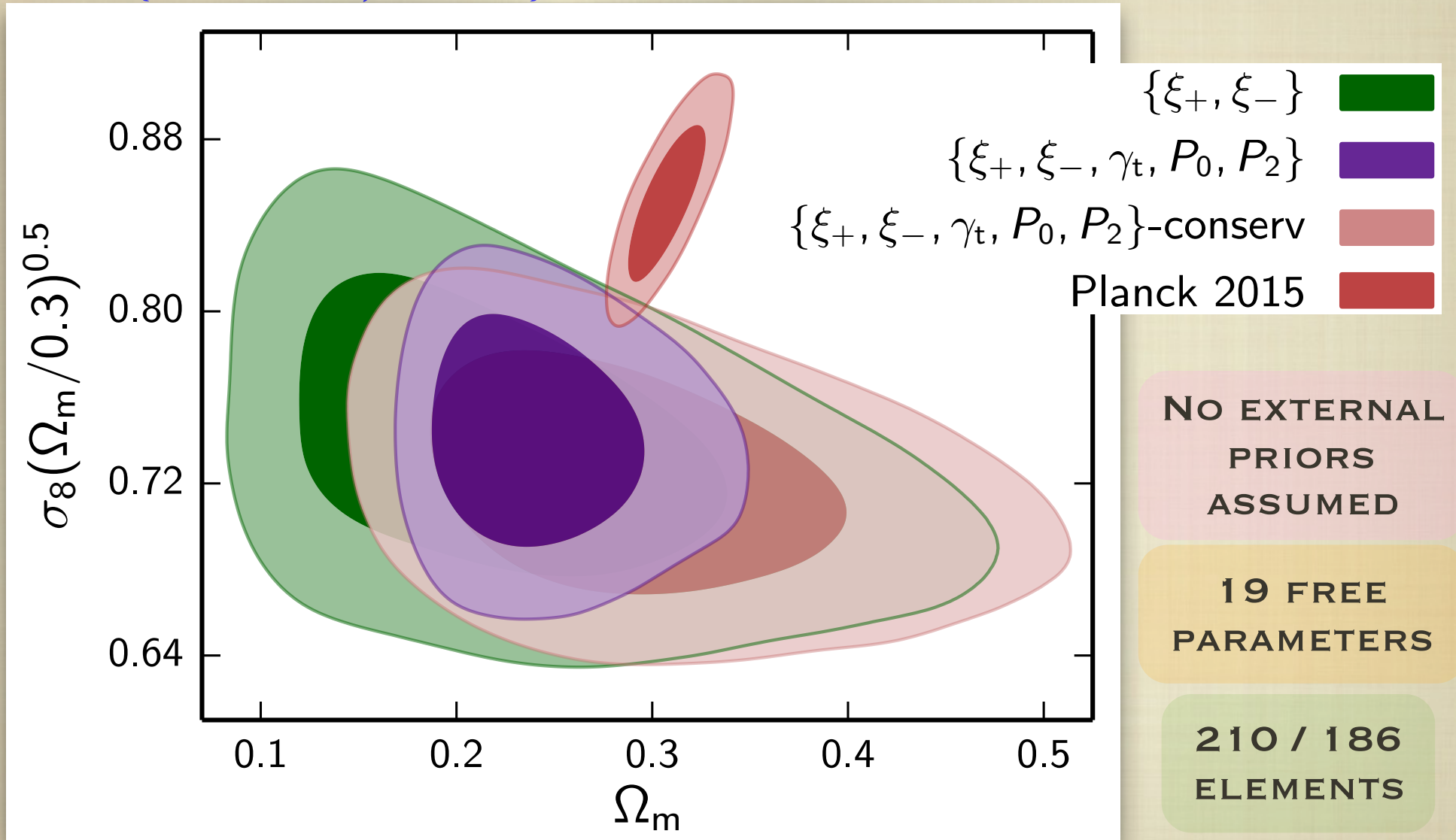
CONSERVATIVE:

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



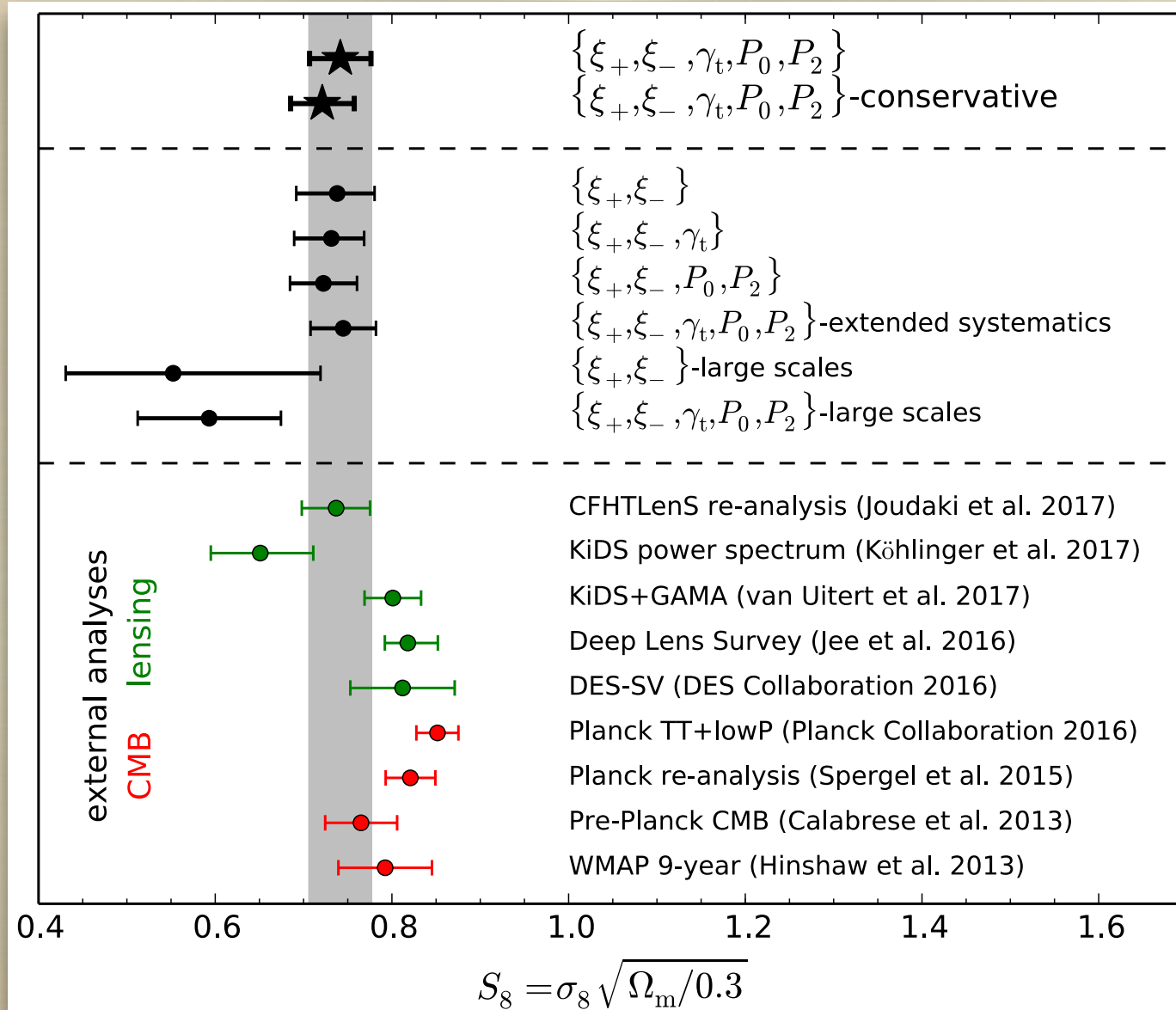
# FULLY JOINT CONSTRAINTS $\{\xi_+, \xi_-, \gamma_t, P_0, P_2\}$

KIDS/{2DFLENS, BOSS}



# FULLY COMBINED CONSTRAINTS

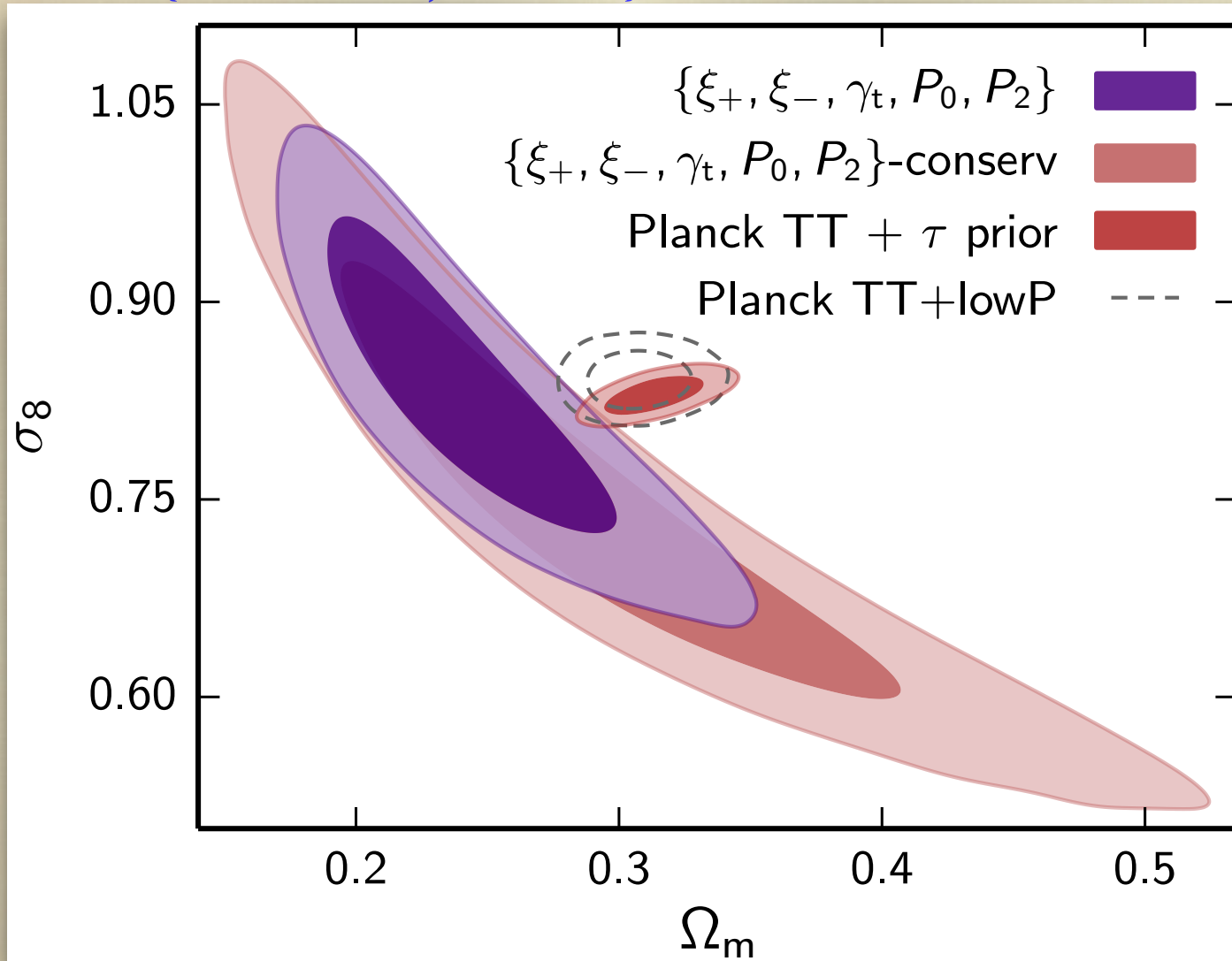
KIDS/{2DFLENS, BOSS}





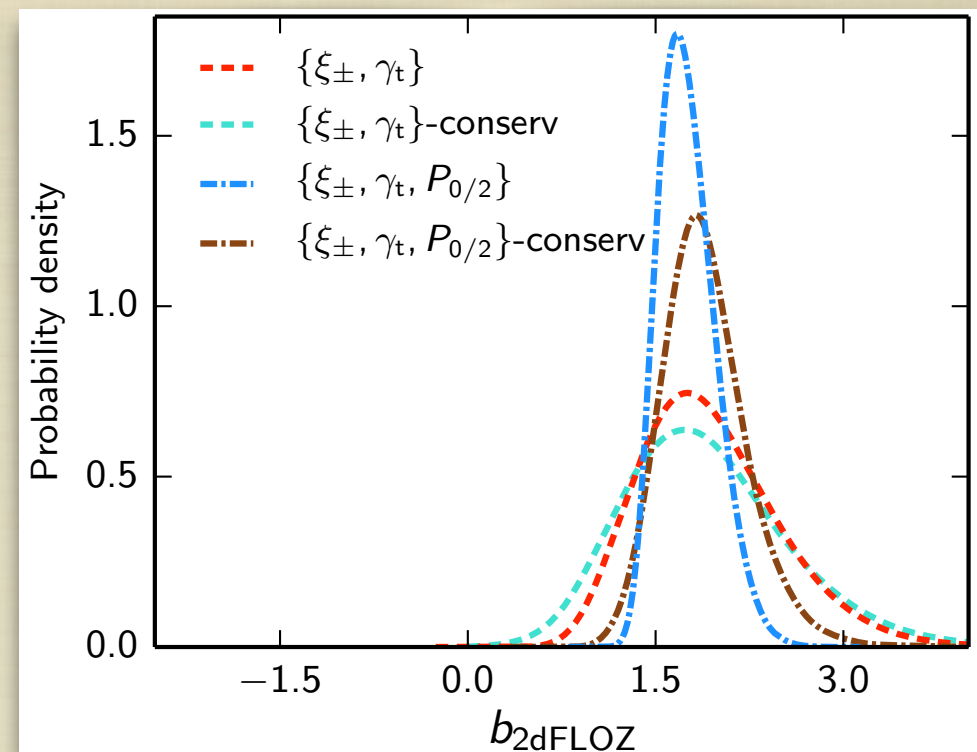
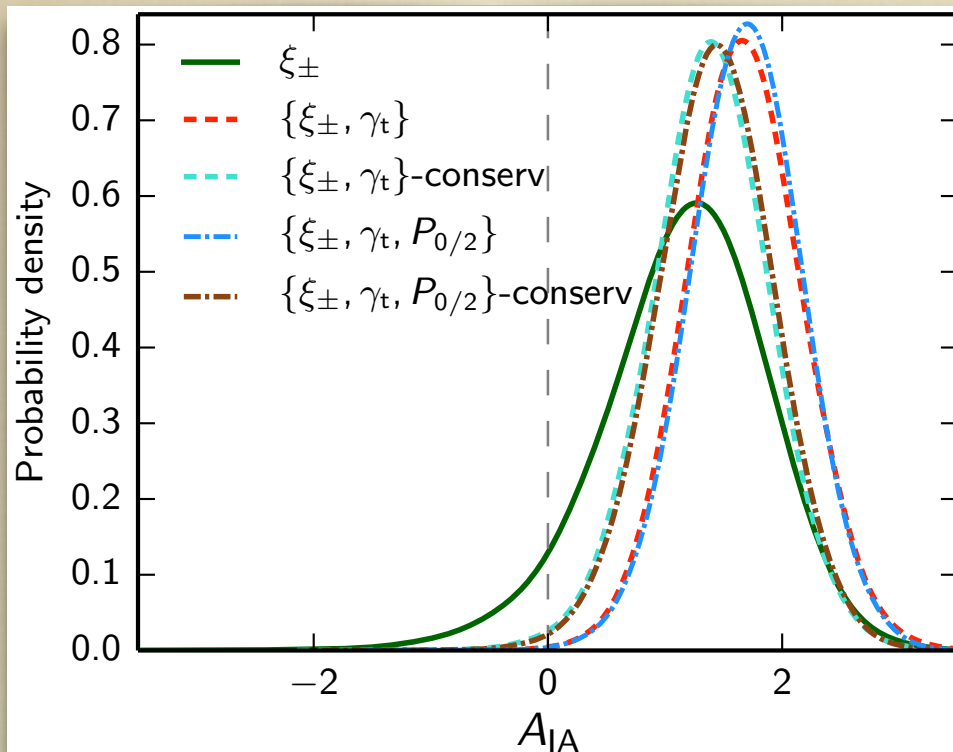
# IMPACT OF PLANCK WITH $\tau$ PRIOR

KIDS/{2DFLENS, BOSS}



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

# ASTROPHYSICAL CONSTRAINTS



**FIDUCIAL:**

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

**CONSERVATIVE:**

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

**BARYONIC FEEDBACK**

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

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

**COSMOLOGICAL**

**CONSTRAINTS**

**ROBUST TO**

**EXTENDED**

**SYSTEMATICS**

**TREATMENT**

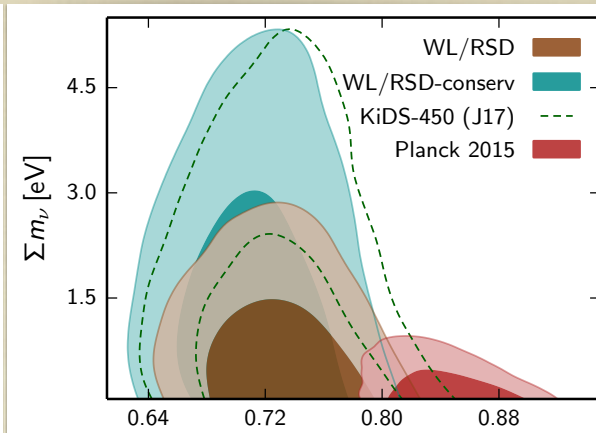
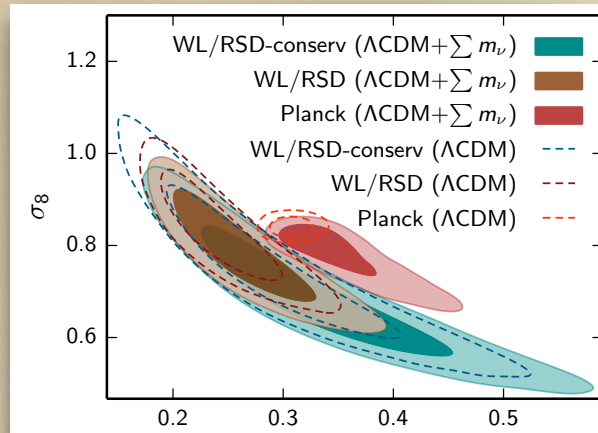


# Agenda Part 4

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

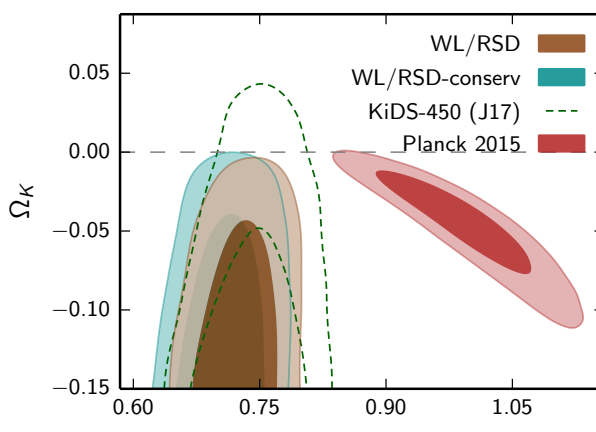
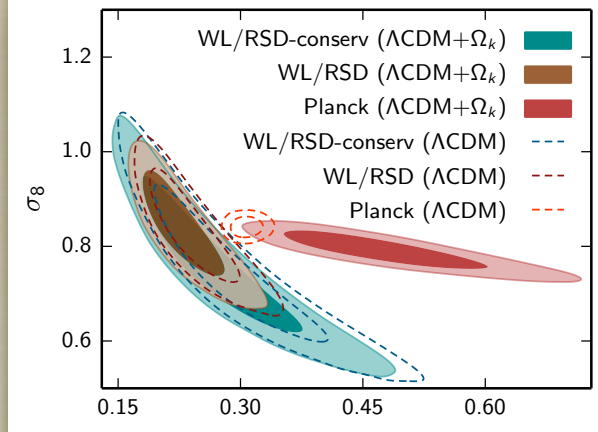


## NEUTRINO MASS

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

## CURVATURE

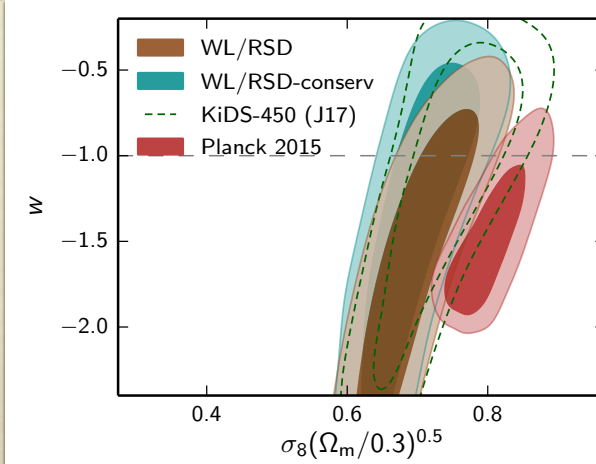
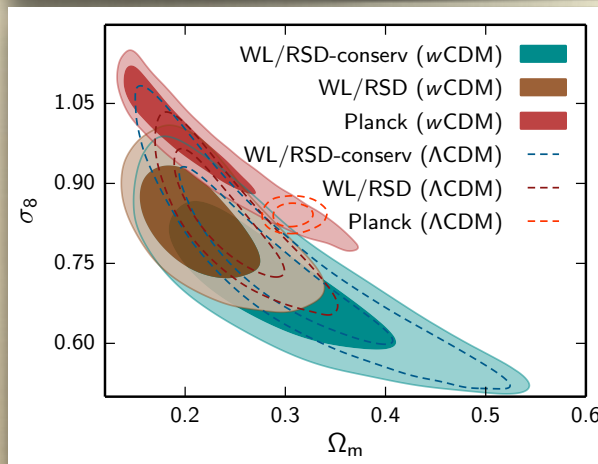
$$\Omega_k < -0.026 \text{ (95\% CL)}$$



## EVOLVING DE (CONST w)

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

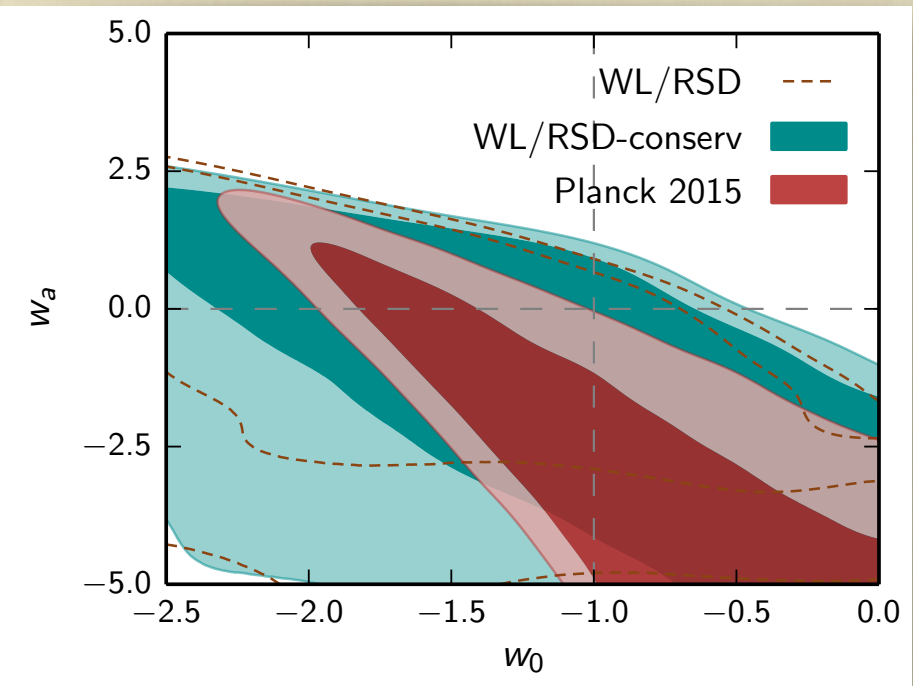
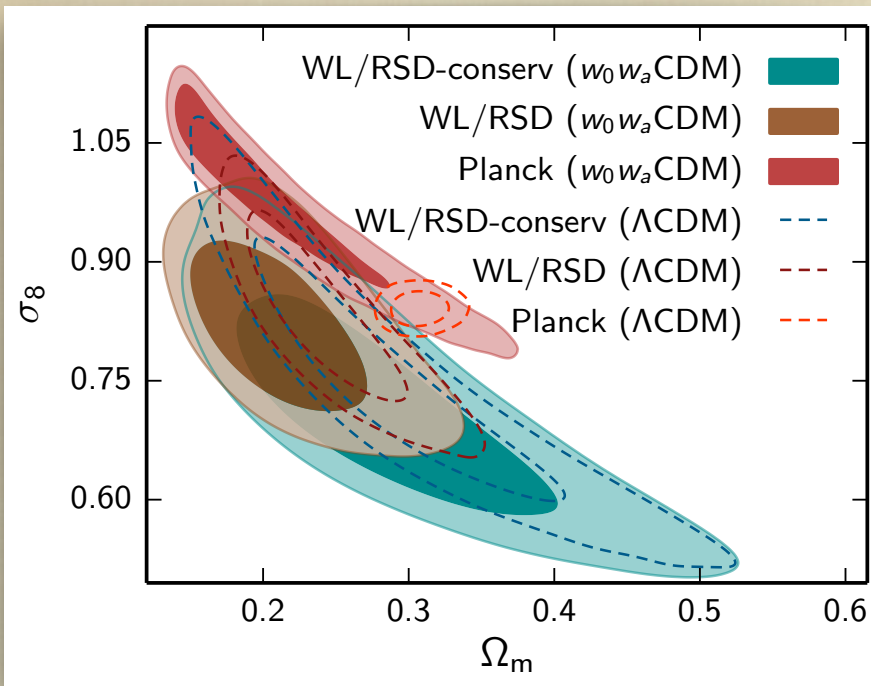
$$w < -1/3 \text{ (99.93\% CL)}$$



**EXTENSIONS  
NOT FAVORED,  
DISCORDANCES PERSIST**



# EVOLVING DARK ENERGY ( $w_0$ - $w_a$ )



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

**FIDUCIAL:**

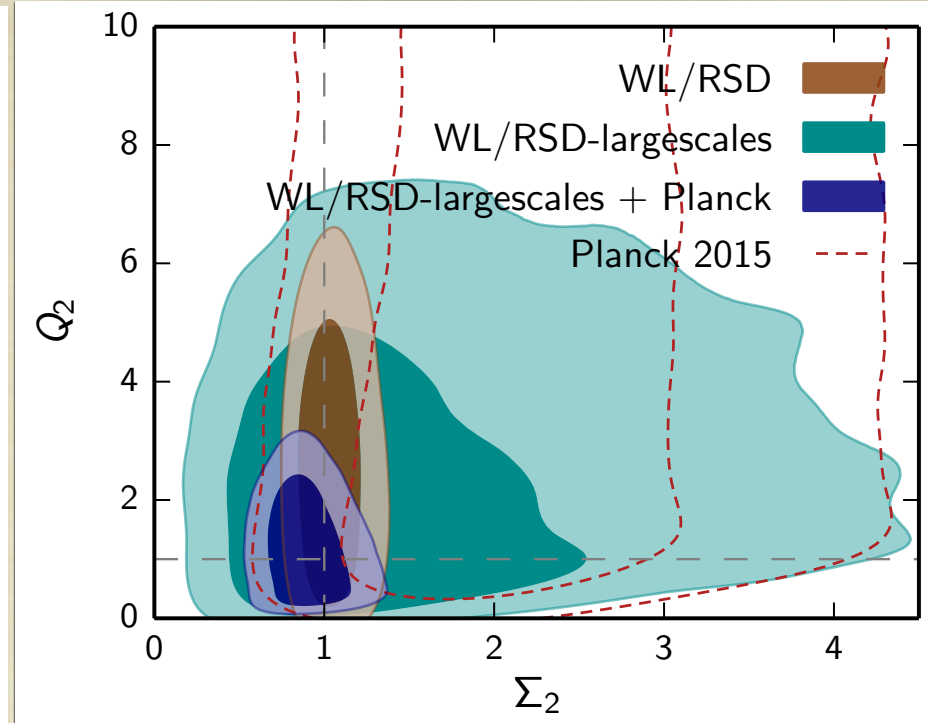
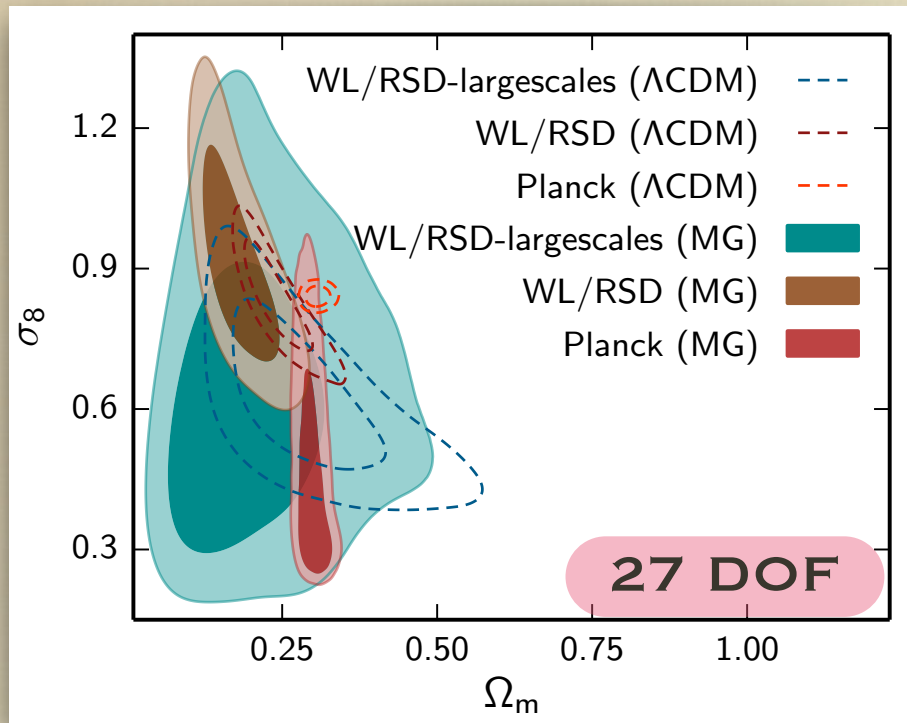
$$T(S_8) = 1.7\sigma$$

**CONSERVATIVE:**

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

**$\sim 1\sigma$  WORSE  
AGREEMENT  
WITH PLANCK  
THAN KIDS  
ALONE**

# MODIFIED GRAVITY



$Q(k, z)$  MODIFIES POISSON EQUATION

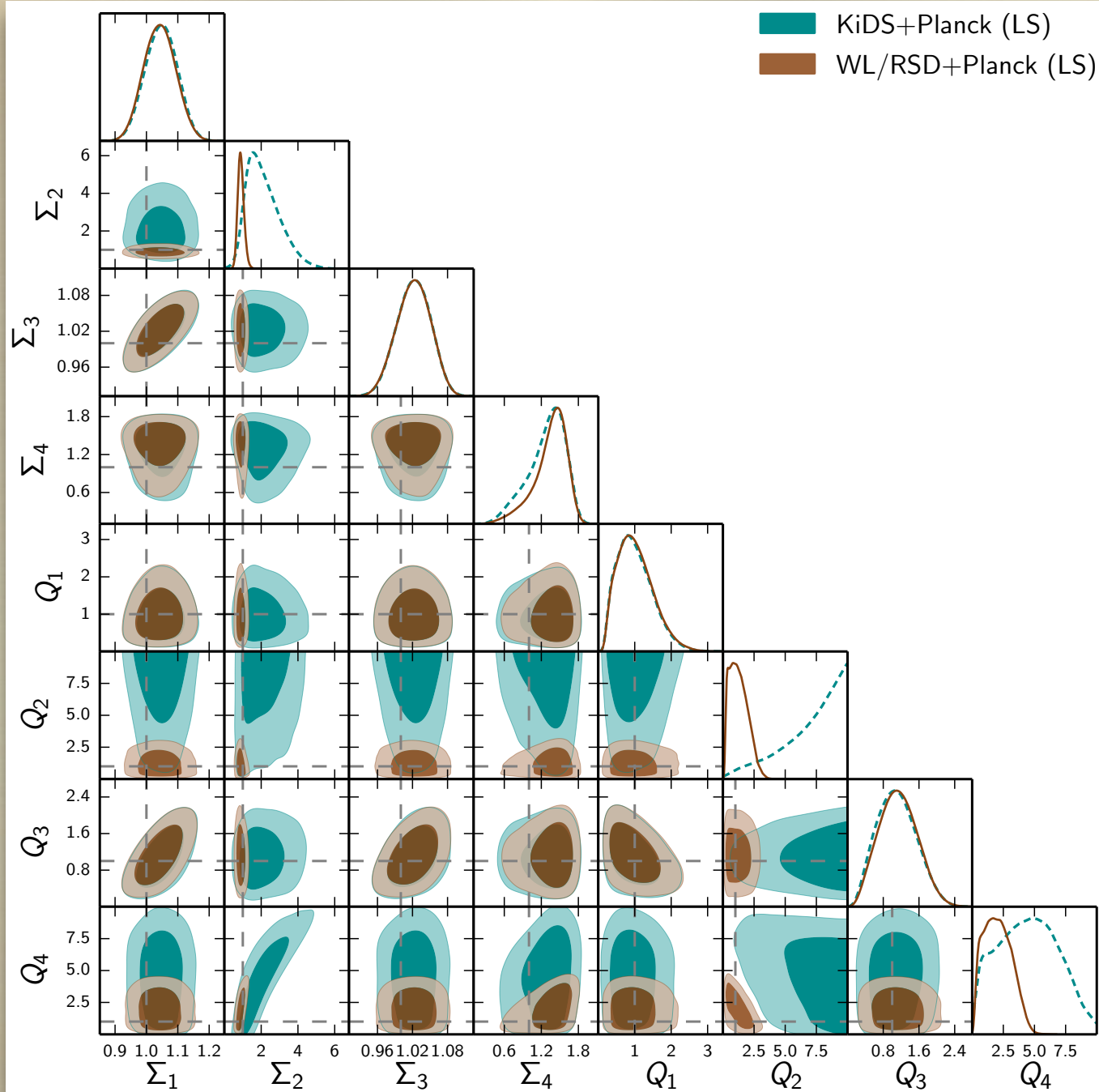
$\Sigma(k, z)$  MODIFIES LIGHT DEFLECTION

<b>1</b> LOW Z LOW K	<b>2</b> LOW Z HIGH K
<b>3</b> HIGH Z LOW K	<b>4</b> HIGH Z HIGH K

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



# 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,  $2.6\sigma$  DISCORDANT WITH PLANCK. IA AMPLITUDE  $3.5\sigma$  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.**