Cosmology with weak lensing surveys: past, present and future

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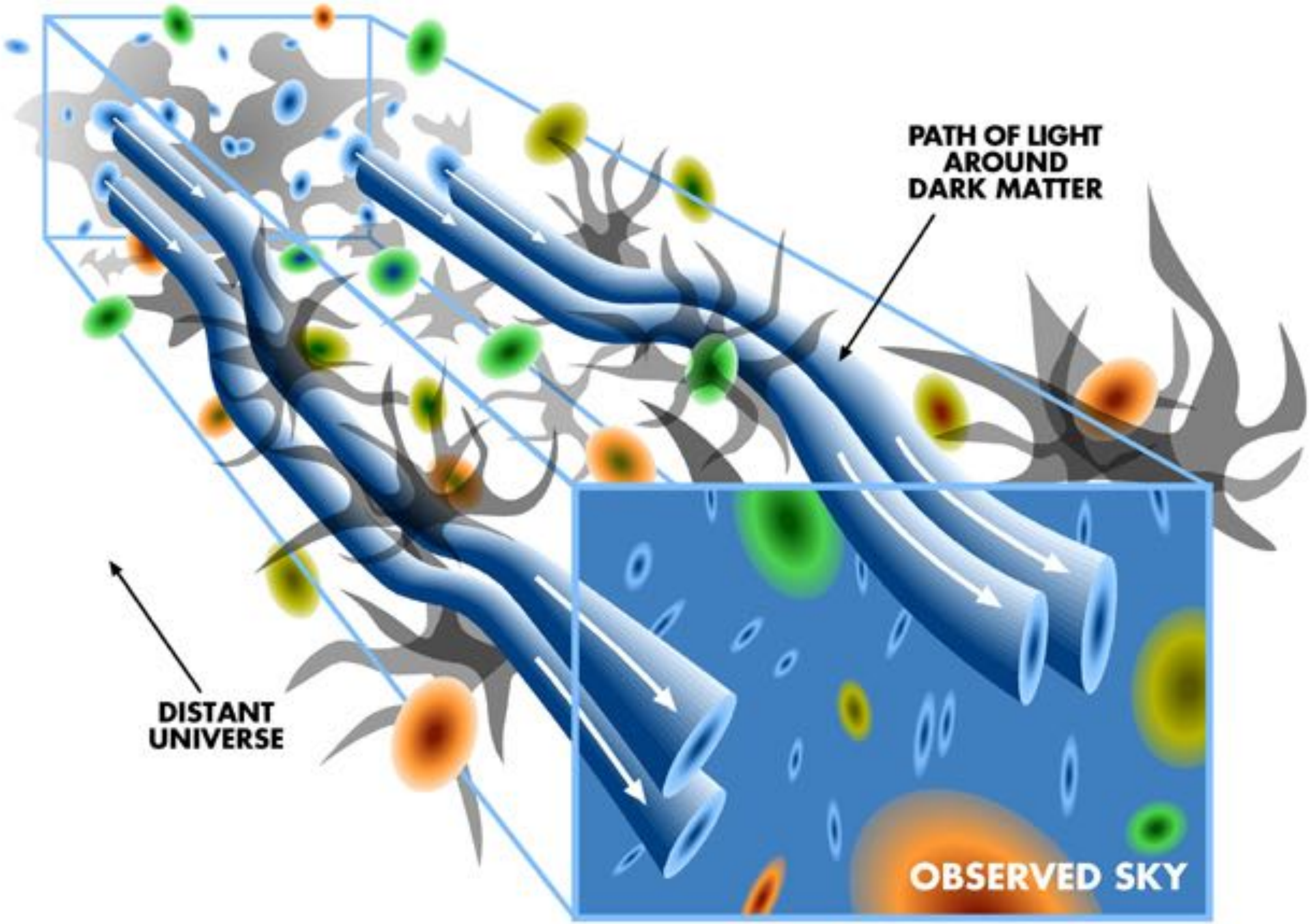
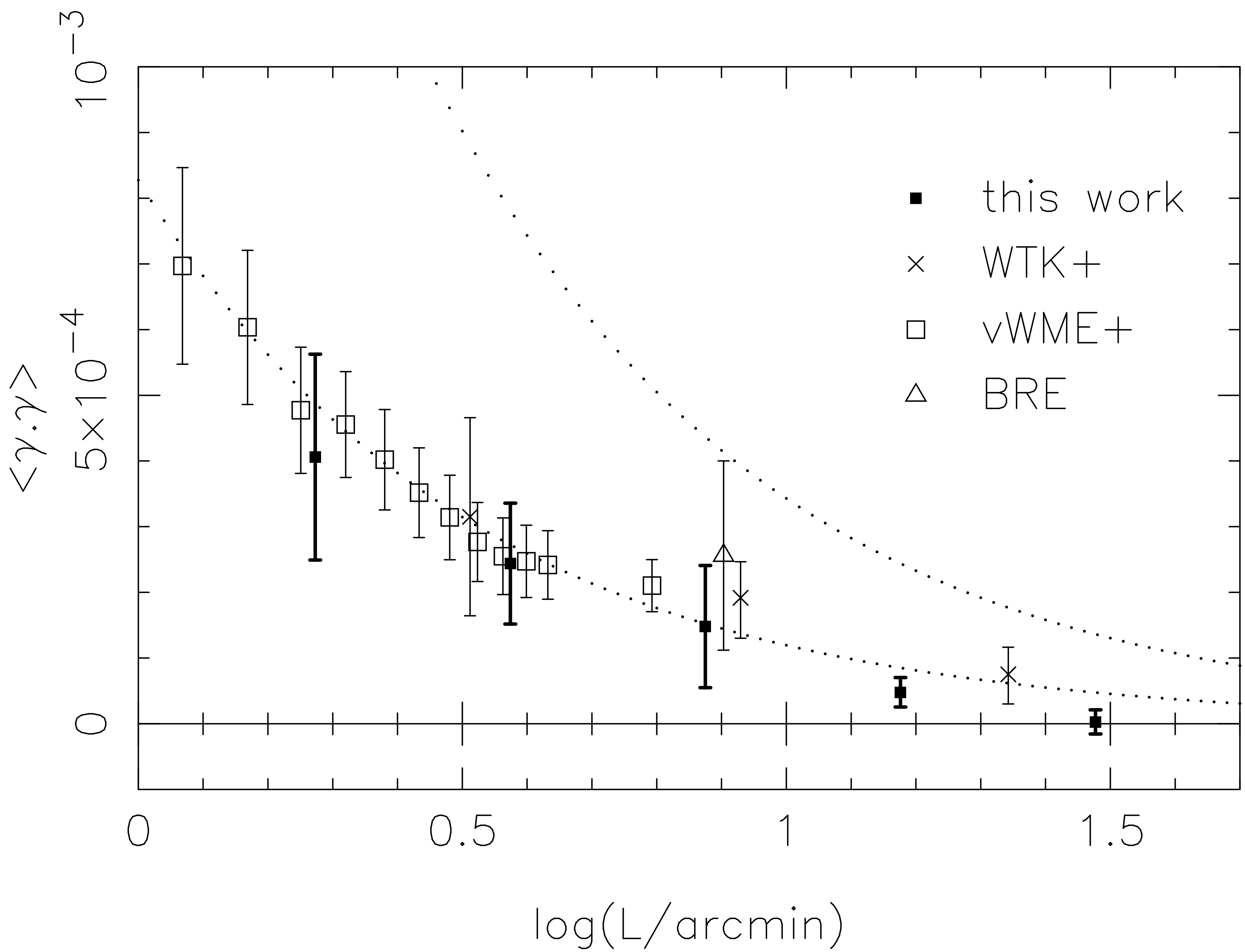


Cosmic shear

Wittman et al. (2000)

First detections in 2000



Kaiser et al. (2000)

Observations -> theory

$$\xi_{\pm}(\theta) = \langle \gamma_{\mathrm{t}} \gamma_{\mathrm{t}} \rangle (\theta) \pm \langle \gamma_{\times} \gamma_{\times} \rangle (\theta)$$

Observations -> theory

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$$\xi_+(\theta) = \int_0^\infty \frac{\mathrm{d}\ell\,\ell}{2\pi}\,\mathrm{J}_0(\ell\theta)\,P_\kappa(\ell)\;;\quad \xi_-(\theta) = \int_0^\infty \frac{\mathrm{d}\ell\,\ell}{2\pi}\,\mathrm{J}_4(\ell\theta)\,P_\kappa(\ell)$$

$$P_\kappa(\ell) = \frac{9H_0^4\Omega_\mathrm{m}^2}{4c^4}\int_0^{\chi_\mathrm{h}} \mathrm{d}\chi\,\frac{g^2(\chi)}{a^2(\chi)}\,P_\delta\left(\frac{\ell}{f_K(\chi)},\chi\right)$$

$$g(\chi) = \int_\chi^{\chi_\mathrm{h}} \mathrm{d}\chi'\,p_\chi(\chi')\,\frac{f_K(\chi'-\chi)}{f_K(\chi')}$$

Observations -> theory

$$\xi_\pm(\theta) = \langle \gamma_\mathrm{t}\gamma_\mathrm{t}\rangle(\theta) \pm \langle \gamma_\times\gamma_\times\rangle(\theta)$$

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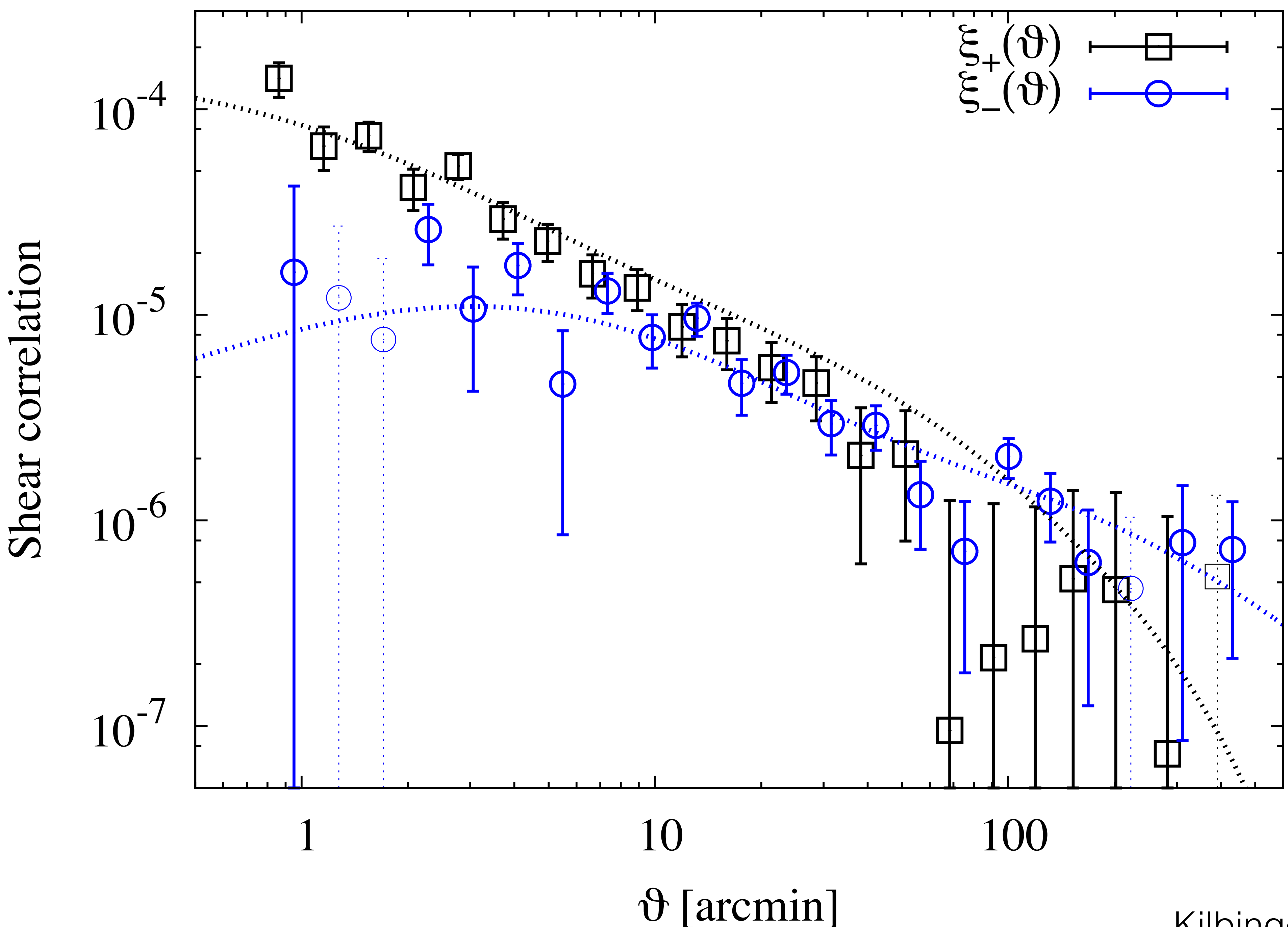
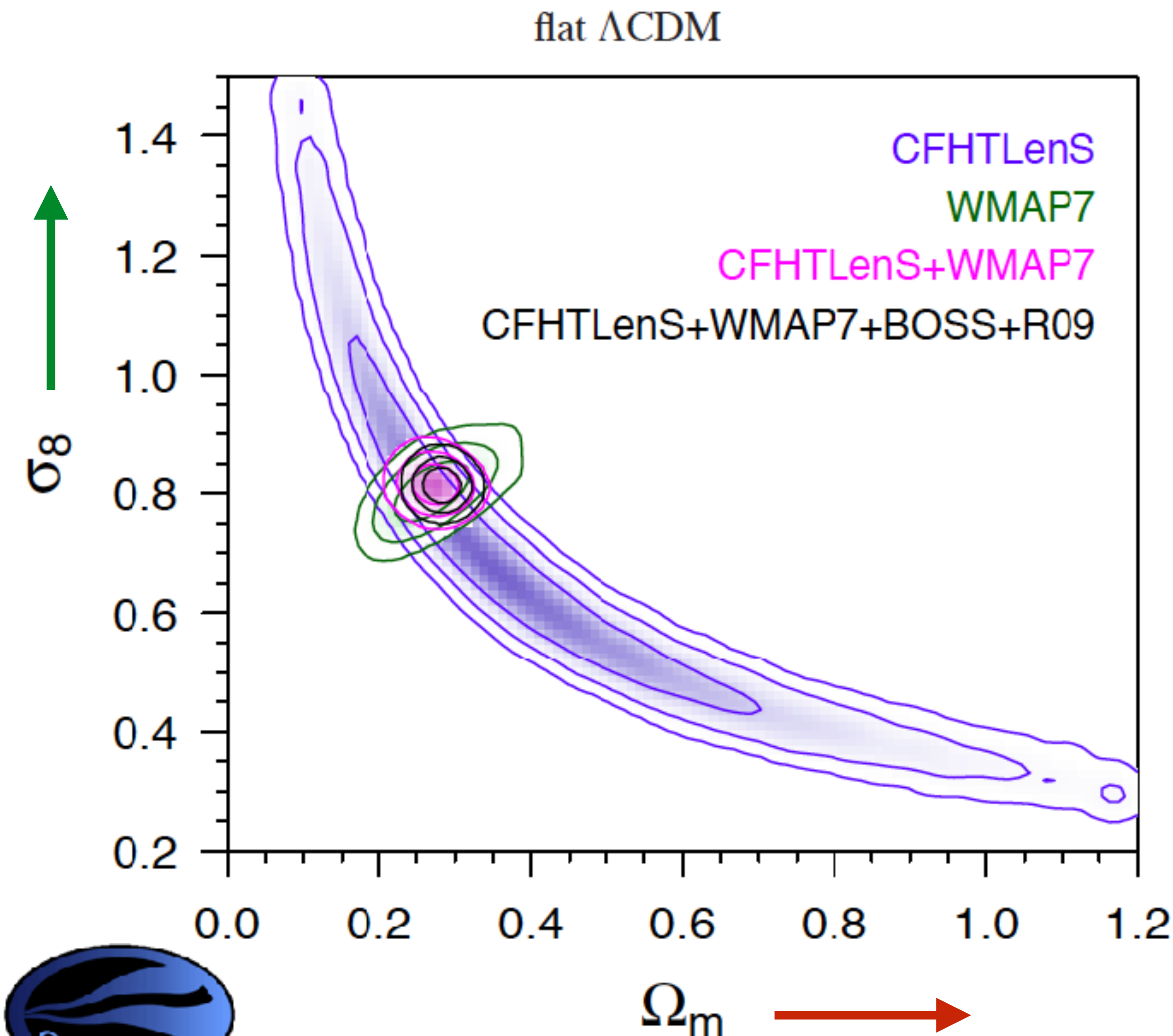
2pt shear correlation functions



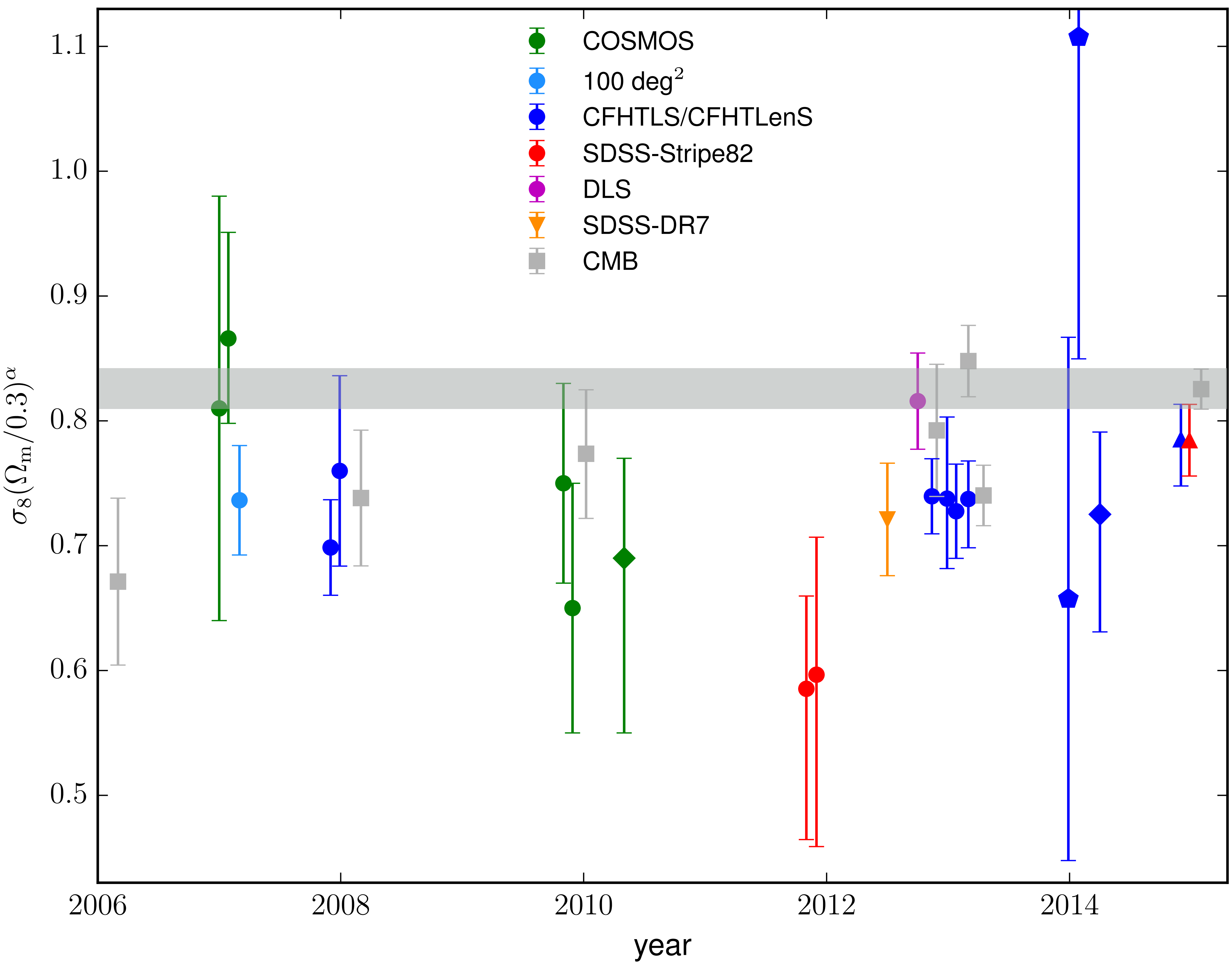
Kilbinger et al. (2013)



- Measure **amount** of **clustered** matter
- $S_8 = \sigma_8\,(\Omega_m/0.3)^{0.5}$
- Dark energy with future surveys.

Cosmological constraints

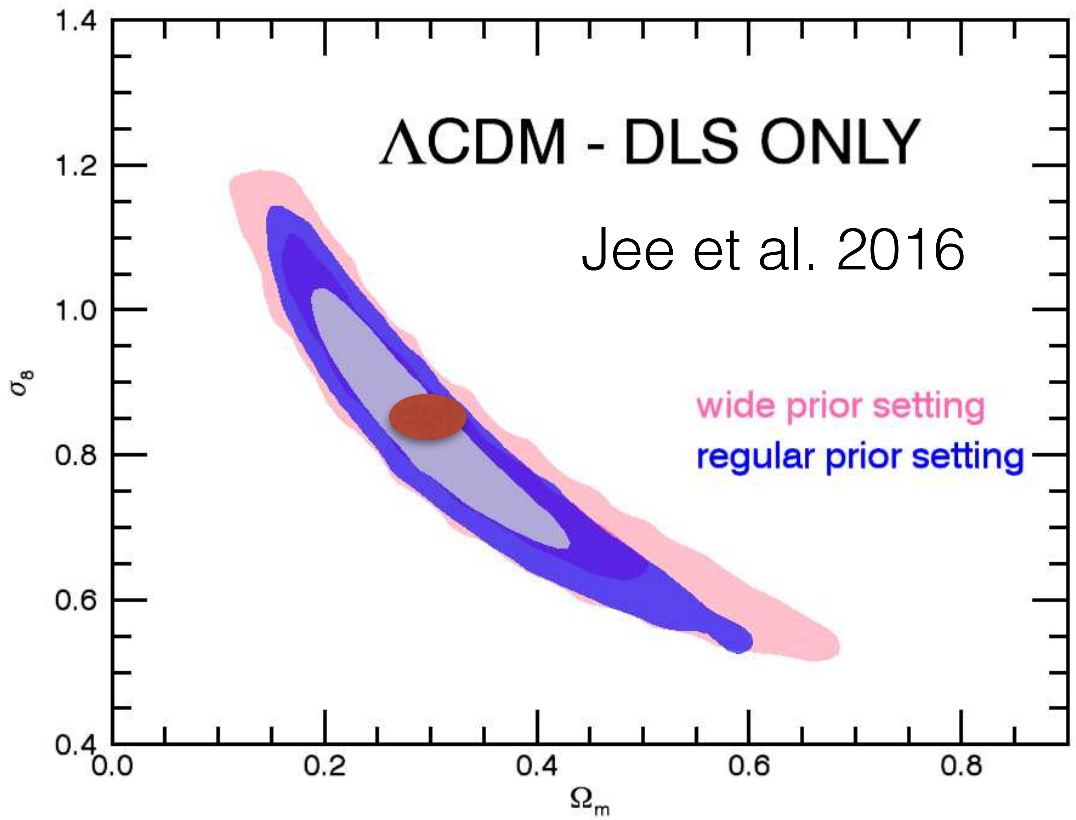
Kilbinger et al. (2013)

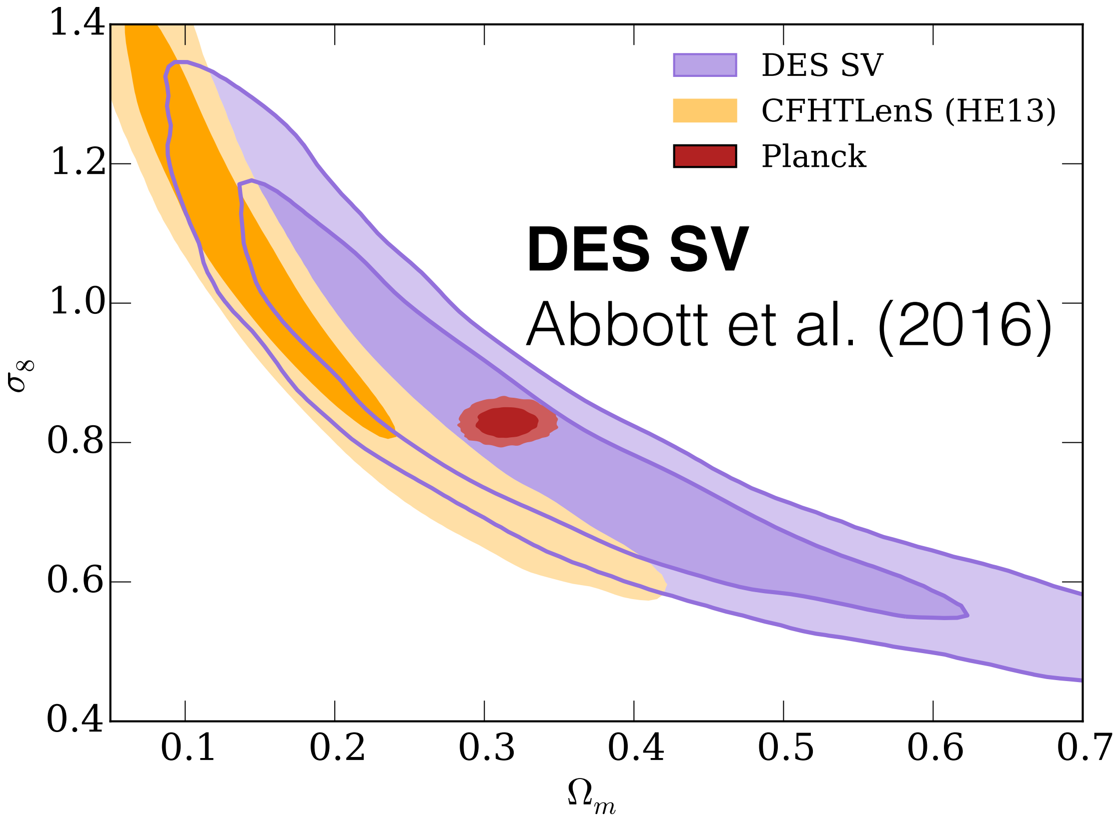


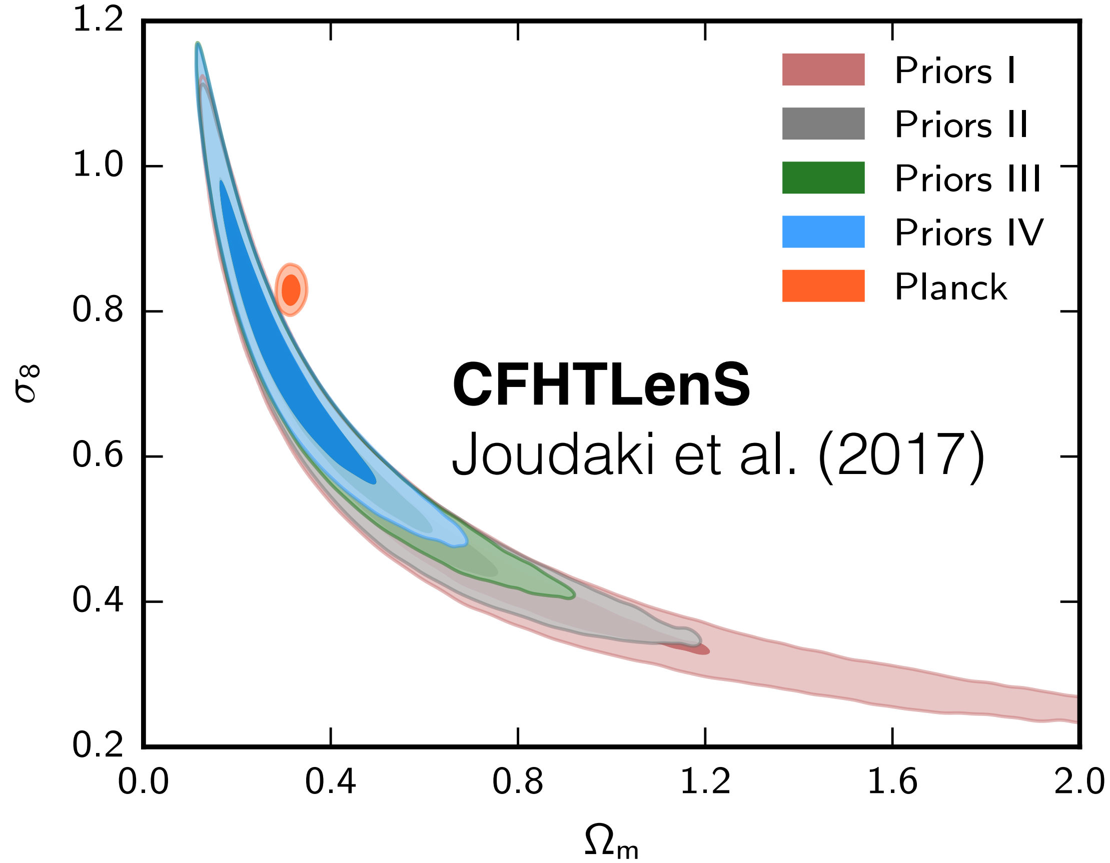
S_8 results over the years

Kilbinger (2015)

Recent constraints on S_8

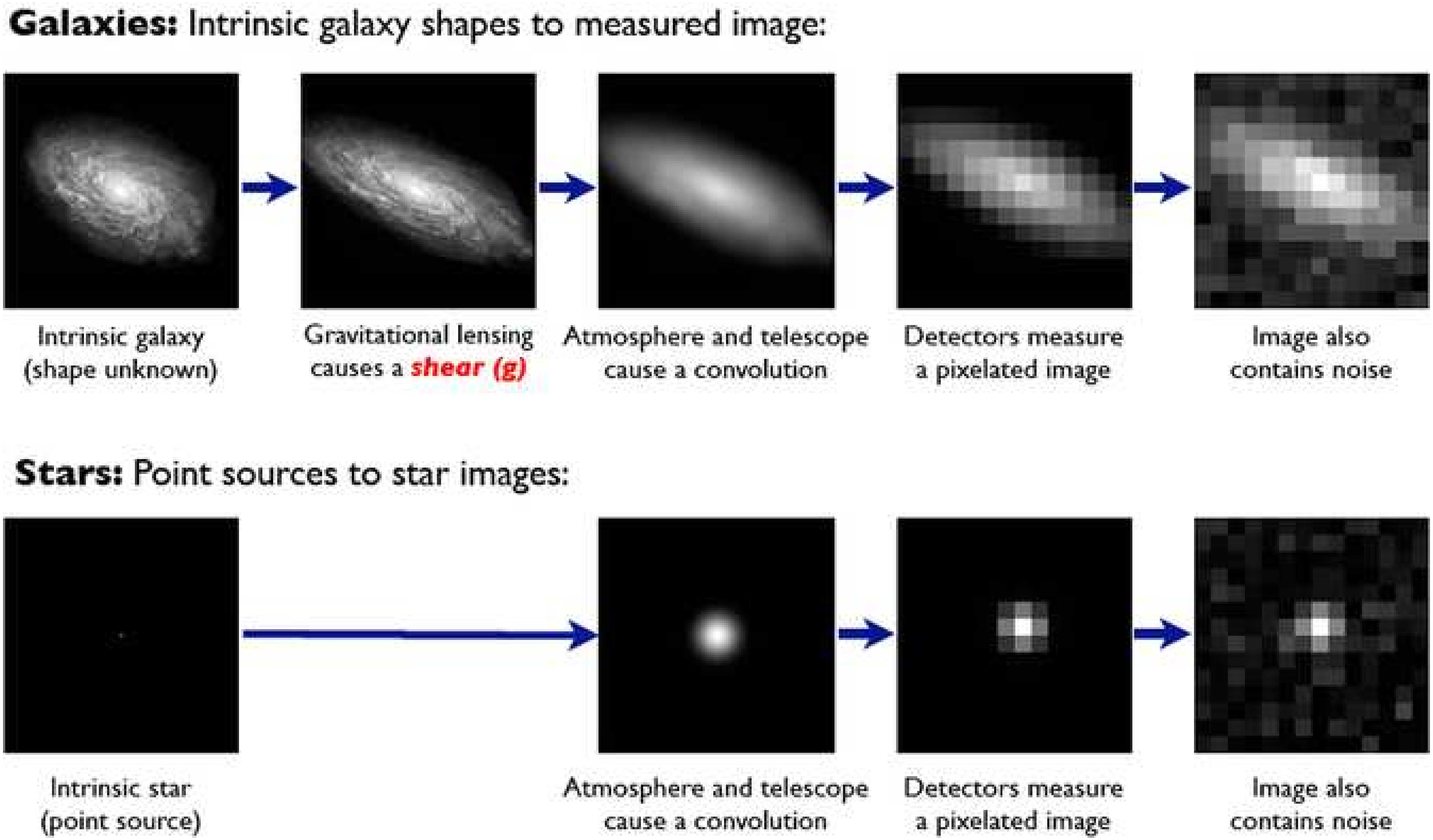






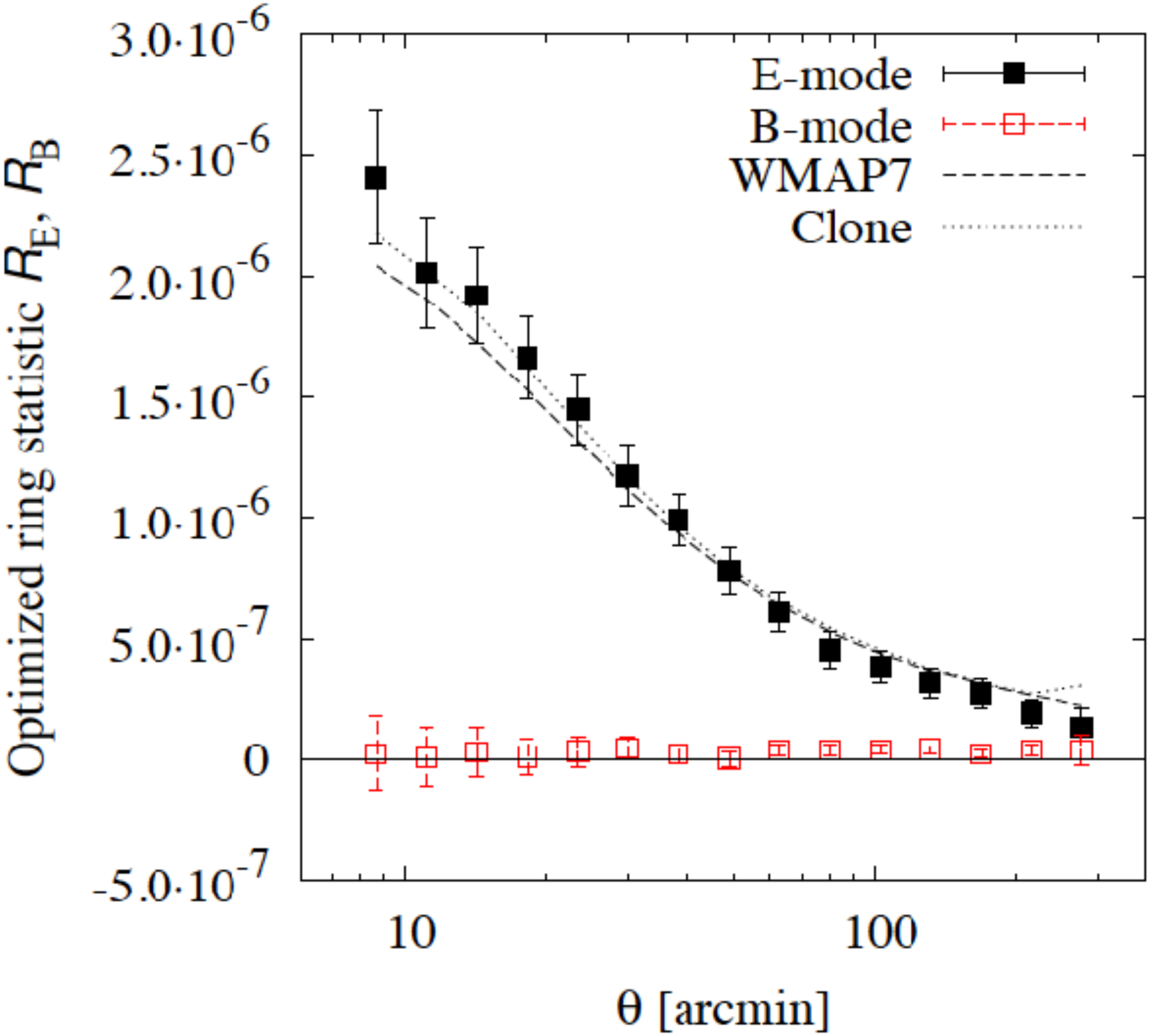
Systematic errors

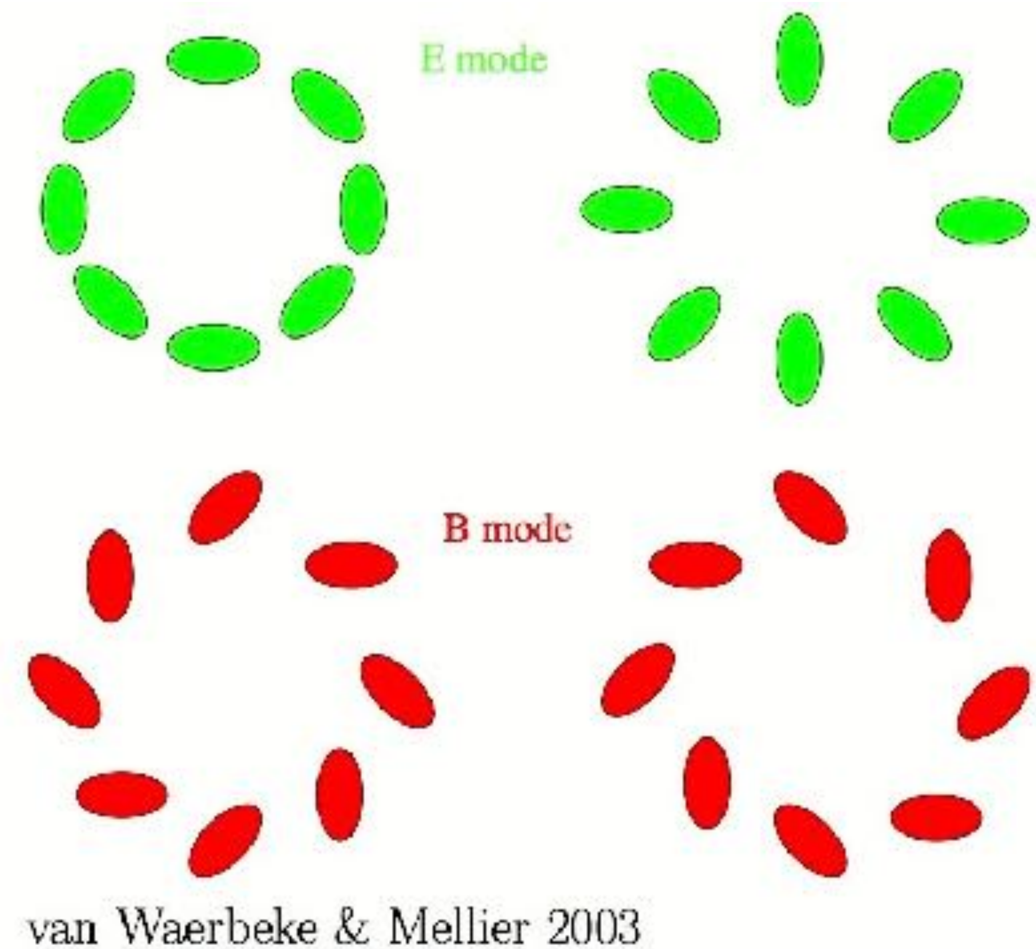
- Shapes measurement systematics:



Shape measurements

Bridle et al. (2009)





E- and B-modes

Kilbinger et al. (2013)

Systematic errors

- Shapes measurement systematics:
  - PSF residuals
  - Multiplicative and additive biases
  - B modes

Systematic errors

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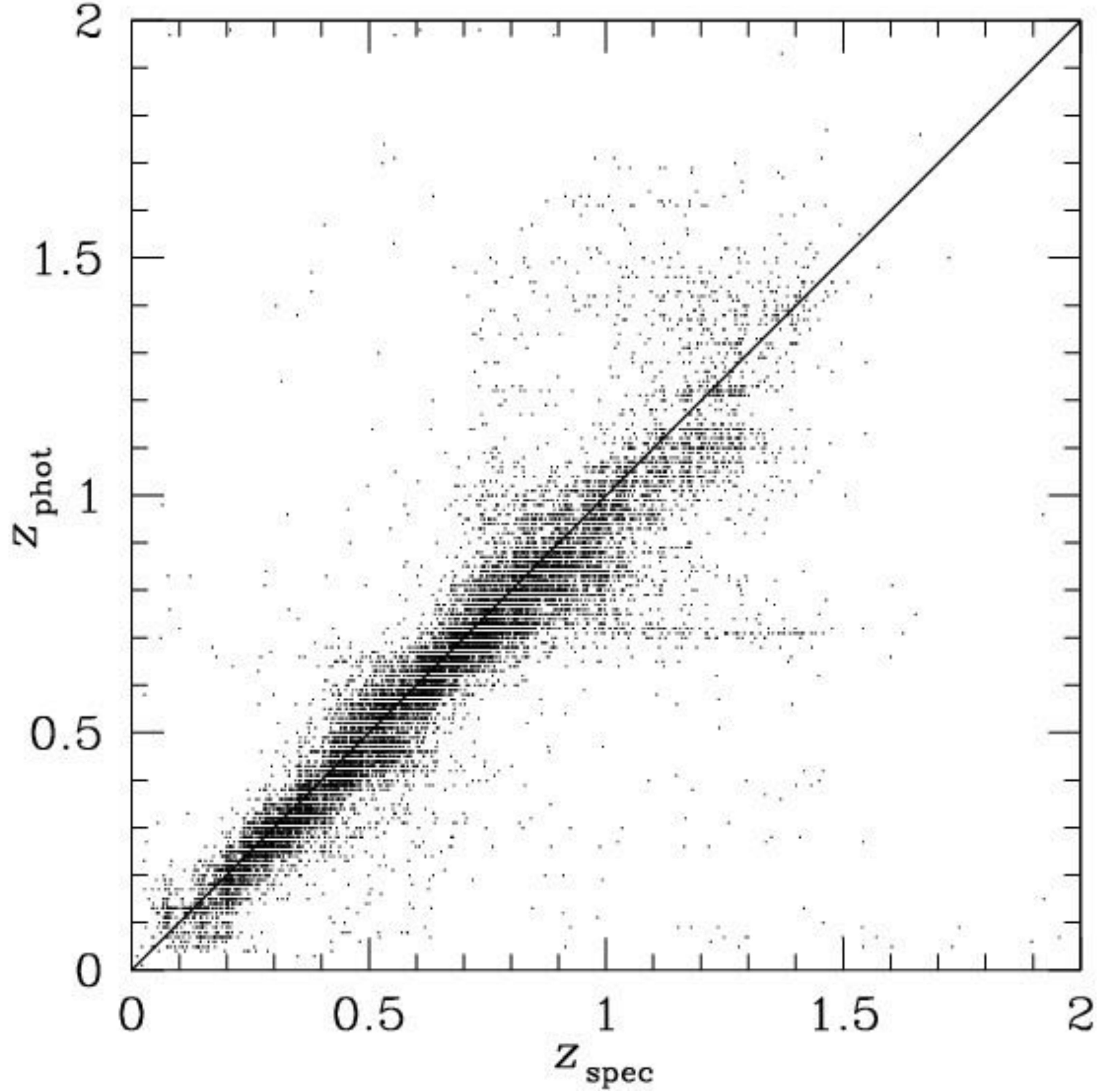
    - PSF residuals
    - Multiplicative and additive biases
    - B modes
- Photo-z systematics:



Photometric redshifts

Hildebrandt et al. (2012)

Systematic errors

- Shapes measurement systematics:
  - PSF residuals
  - Multiplicative and additive biases
  - B modes
- Photo-z systematics:
  - Calibration sample and technique
  - Inhomogeneous multi-band data

Systematic errors

- Shapes measurement systematics:
  - PSF residuals
  - Multiplicative and additive biases
  - B modes
- Photo-z systematics:
  - Calibration sample and technique
  - Inhomogeneous multi-band data

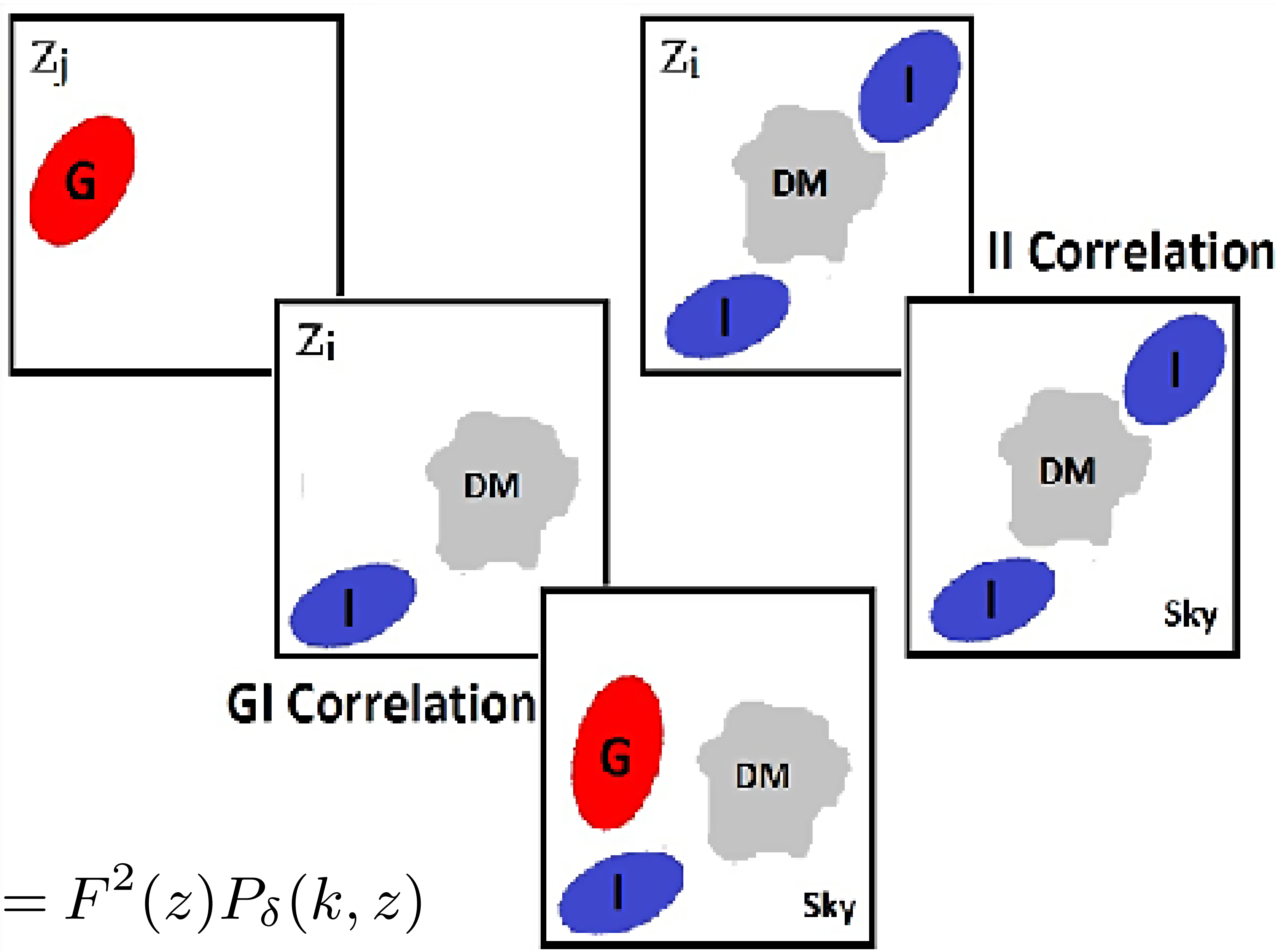
cross-talk

Systematic errors

- Shapes measurement systematics:
  - PSF residuals
  - Multiplicative and additive biases
  - B modes
- Photo-z systematics:
  - Calibration sample and technique
  - Inhomogeneous multi-band data
- Theoretical systematics:

cross-talk

Intrinsic alignments



$$P_{\mathrm{II}}(k,z) = F^2(z)P_\delta(k,z)$$

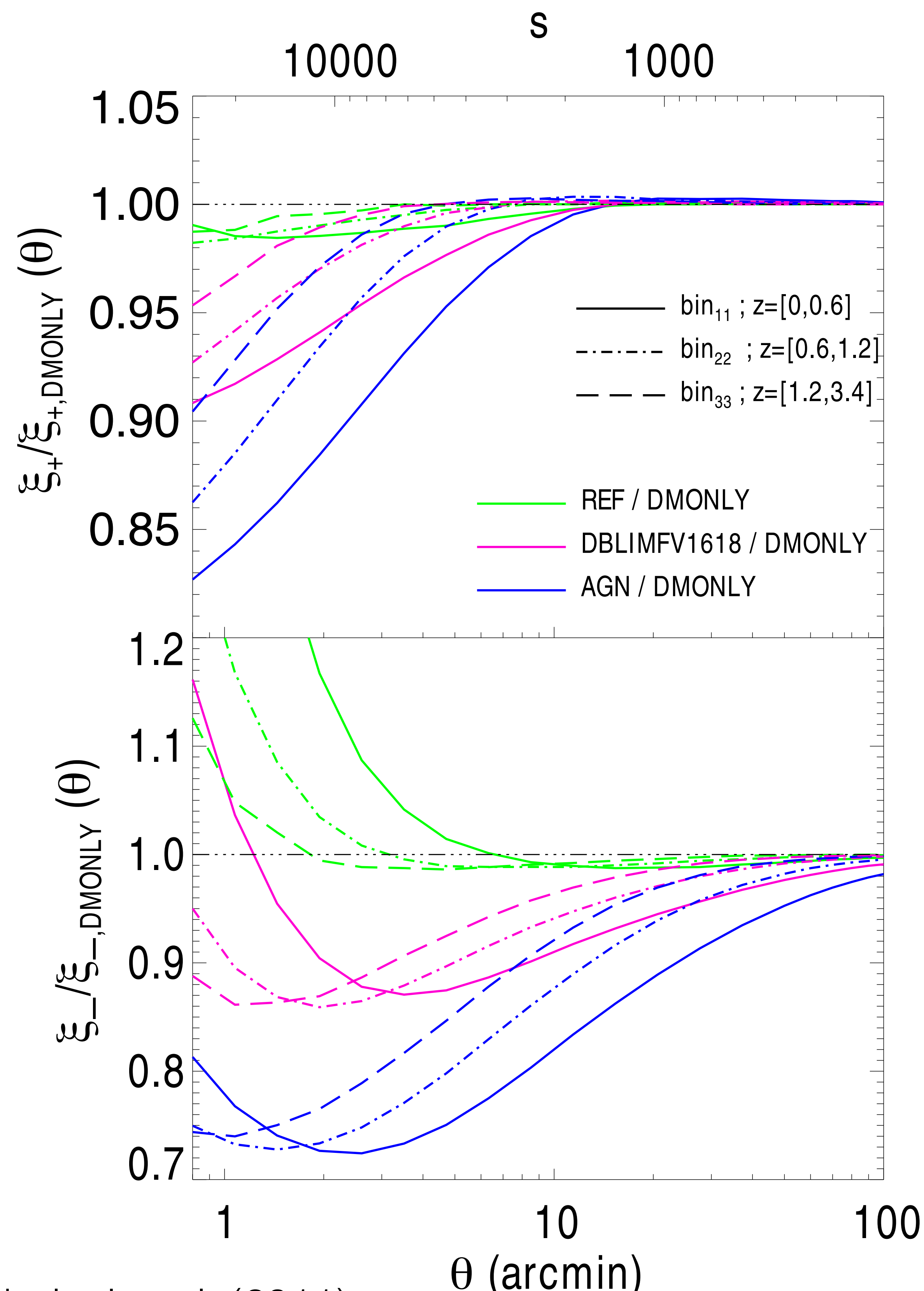
$$P_{\mathrm{GI}}(k,z) = F(z)P_\delta(k,z)\,,$$

Troxel & Ishak (2012)

$$F(z) = -A_{\mathrm{IA}}C_1\rho_{\mathrm{crit}}\frac{\Omega_{\mathrm{m}}}{D_+(z)}\left(\frac{1+z}{1+z_0}\right)^{\eta}\left(\frac{\bar{L}}{L_0}\right)^{\beta}$$

Baryon feedback

- OWLS hydrodynamical simulations.
- At θ~0.5’ the most extreme model yields a 20% decrease in ξ_+.
- Effect captured by amplitude of mass-concentration relation.



Semboloni et al. (2011)

Systematic errors

- Shapes measurement systematics:
  - PSF residuals
  - Multiplicative and additive biases
  - B modes

cross-talk

- Photo-z systematics:
  - Calibration sample and technique
  - Inhomogeneous multi-band data
- Theoretical systematics:
  - Intrinsic alignments
  - Baryon feedback
  - Covariance estimate

Systematic errors

- Shapes measurement systematics:
  - PSF residuals
  - Multiplicative and additive biases
  - B modes

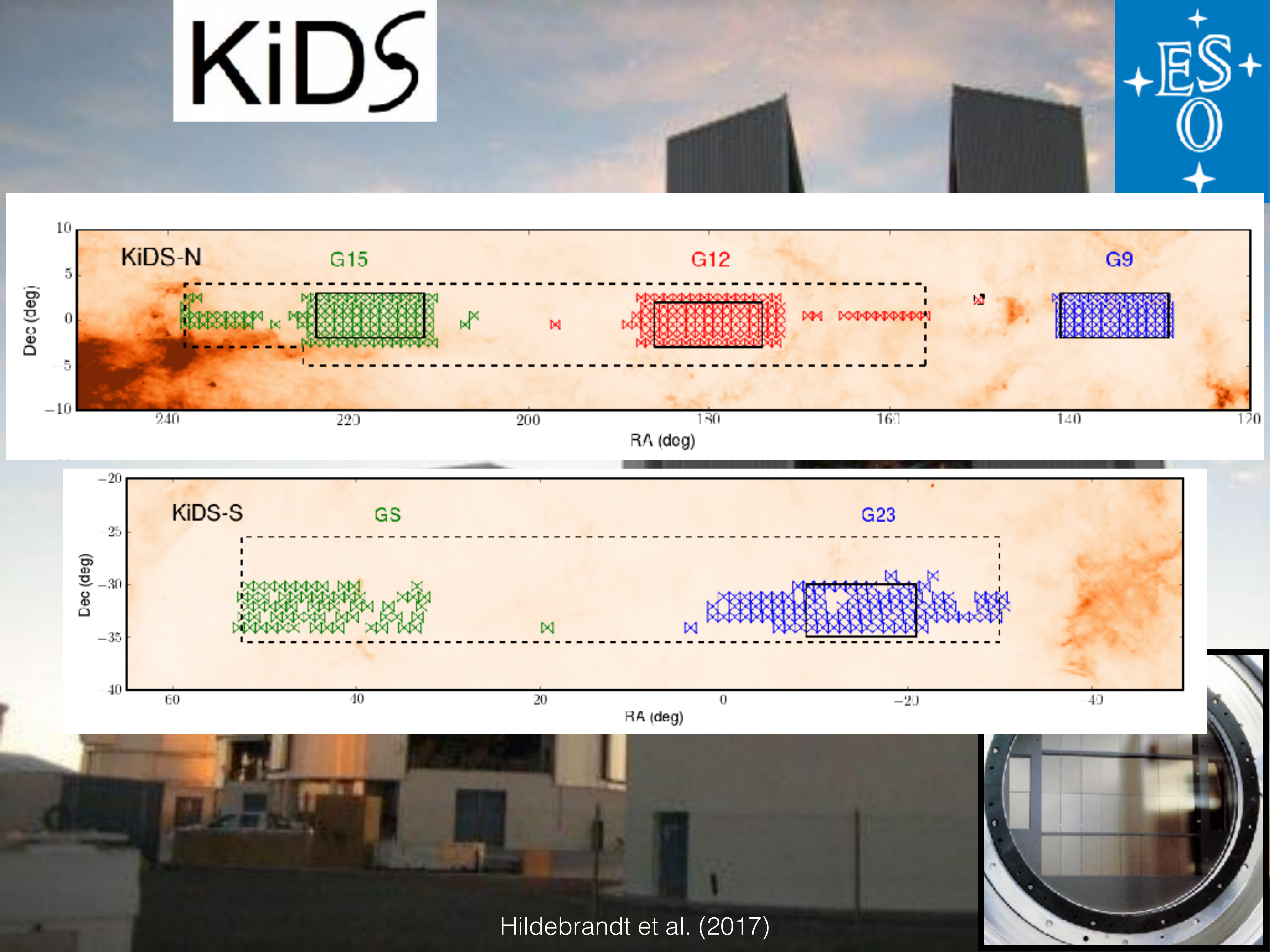
cross-talk

- Photo-z systematics:
  - Calibration sample and technique
  - Inhomogeneous multi-band data
- Theoretical systematics:
  - Intrinsic alignments
  - Baryon feedback
  - Covariance estimate
- Psychological systematics:
  - Blinding

KiDS vs. HSC vs. DES

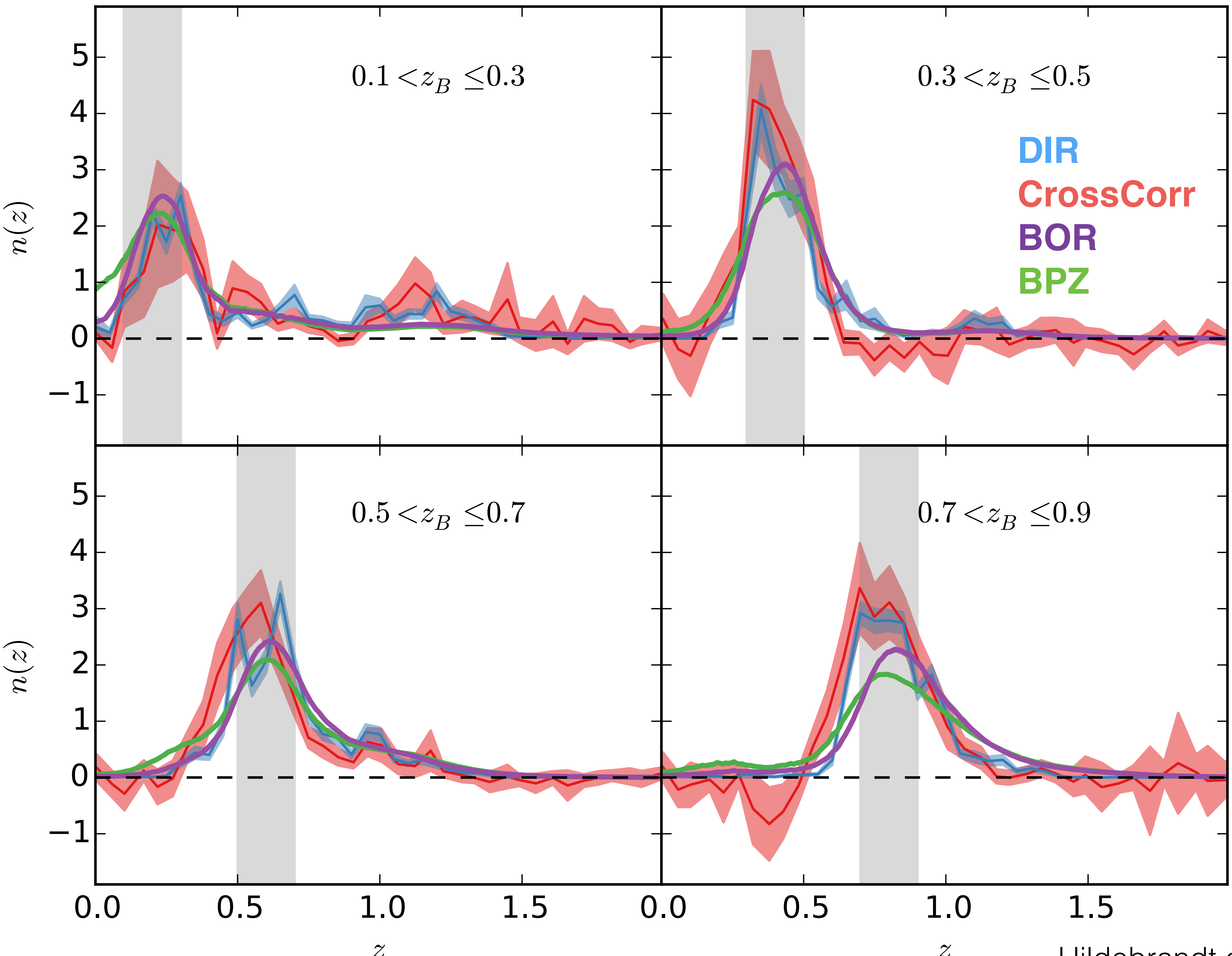
	KiDS(+VIKING)	HSC	DES
Mirror [m]	2.6	**8.2**	4.0
Focus	**Cassegrain**	Prime	Prime
FOV [deg^2]	1.0	1.8	**3.0**
Area [deg^2]	1350	1400	**5000**
Filters	***u****gri***(+***ZY*****JHKs*)**	*grizy*	*griz(y)*
Seeing [arcsec]	**0.68**	**0.58**	0.94
Source density [gal/arcmin^2]	~8	**~22**	~5-7
Depth	***r*~24**	*i*~24.5	***r*~23-24**
WL Team	>30	>30	**>130**


KiDS
ESO



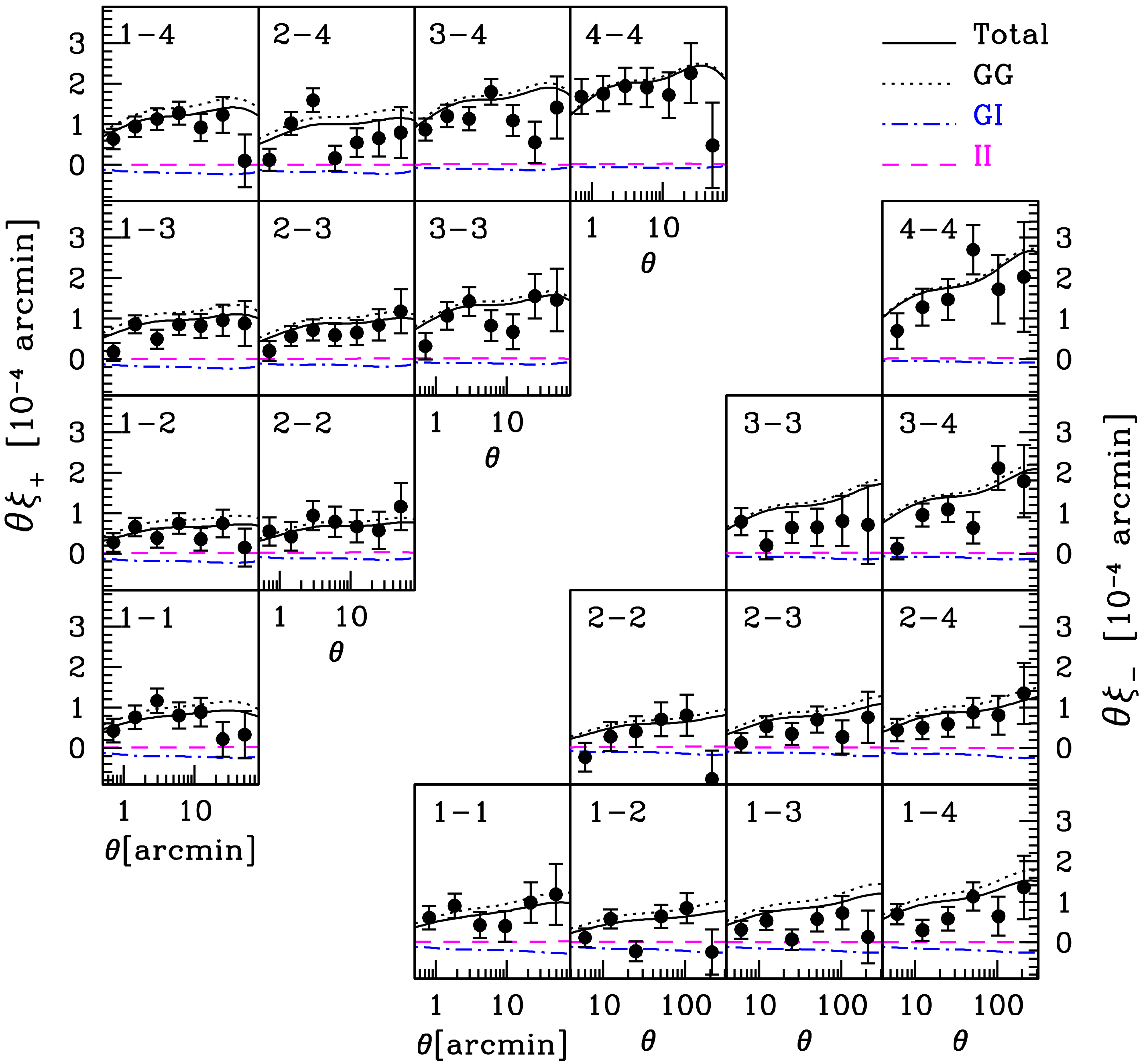
Hildebrandt et al. (2017)

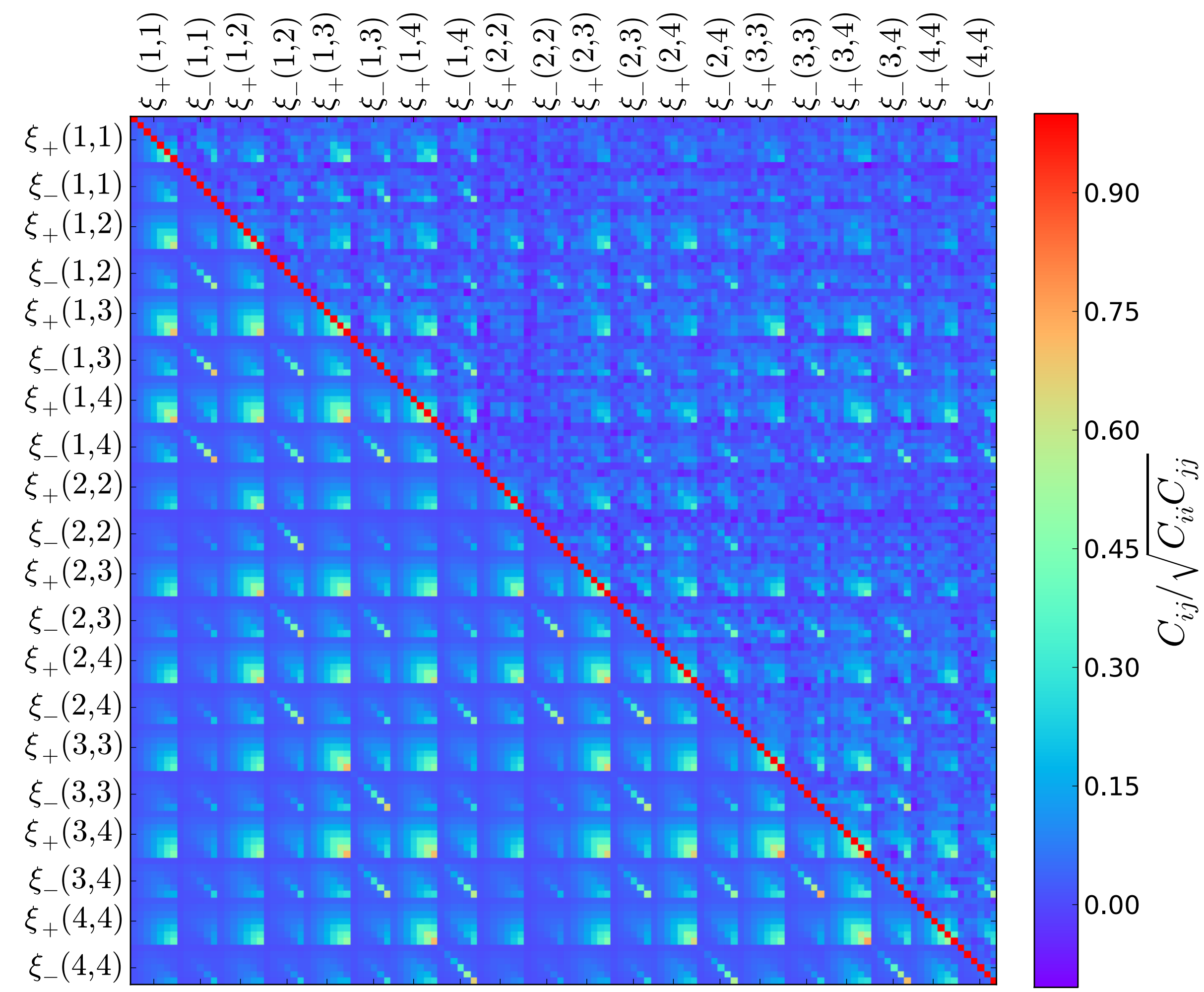
Redshift distributions



Hildebrandt et al. (2017)

Data vector

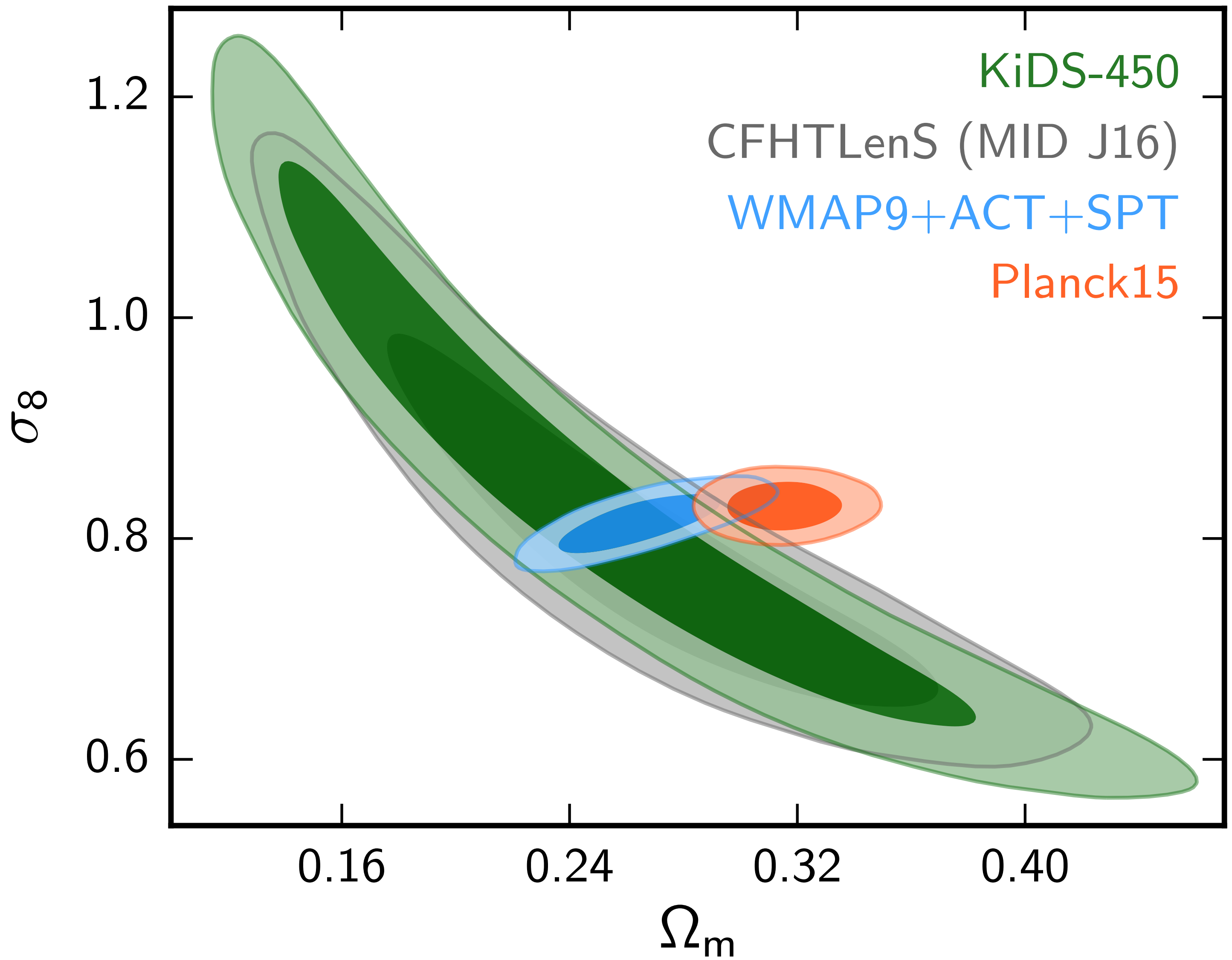




- 130 points from shear-shear correlation functions ξ_+, ξ_-.
- pick radial ranges to avoid small-scale model systematics and large-scale shear systematics

Hildebrandt et al. (2017)

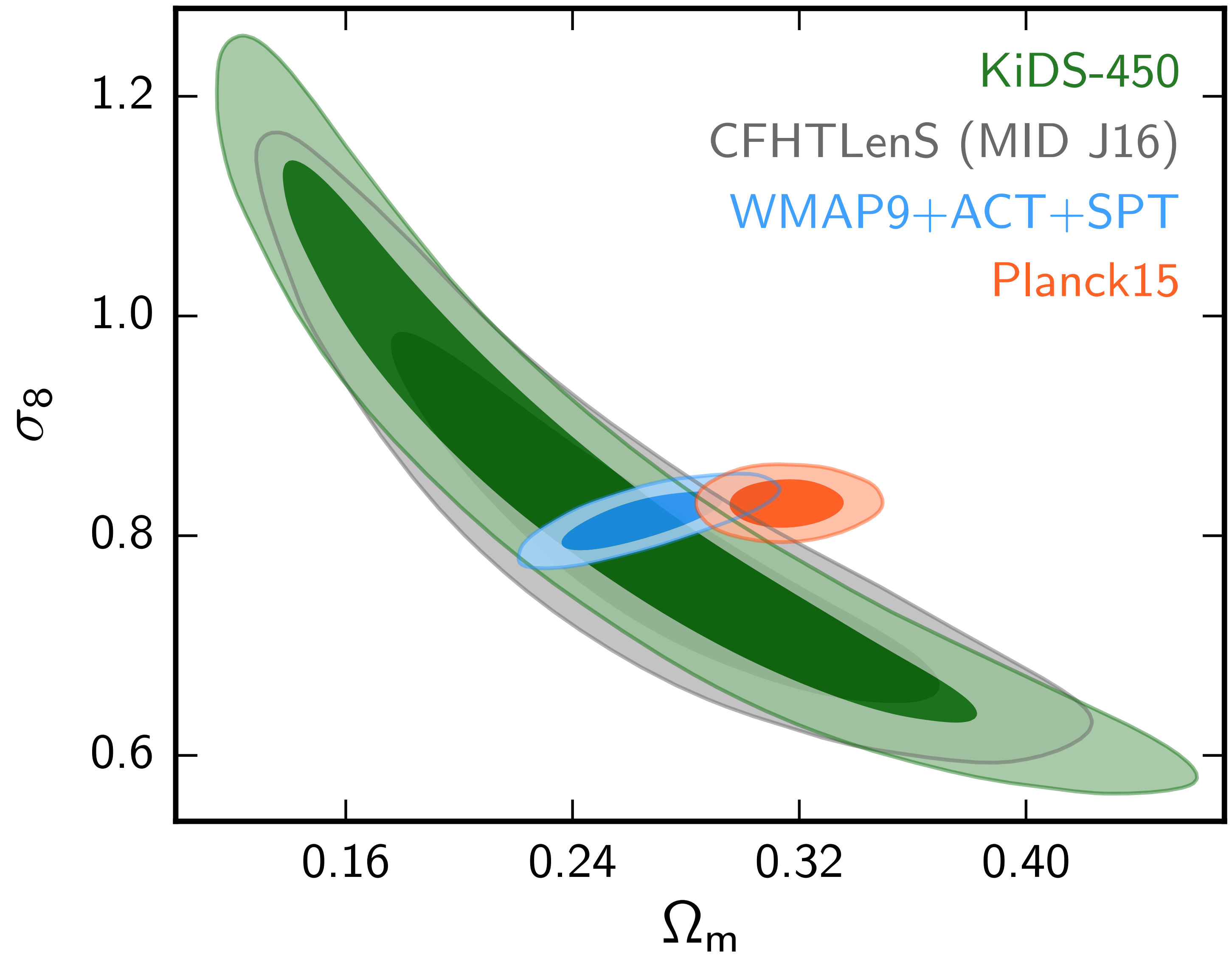
Result



$$\sigma_8\sqrt{(\Omega_m/0.3)}=0.745\pm0.039$$

- S_8 constraint very similar to CFHTLenS, pre-planck CMB
- Tension with Planck — $2.7\sigma_{\rm KiDS}$ in S_8
  (2.3σ discrepancy in full parameter space)

Hildebrandt et al. (2017)



Result

$\sigma_8\sqrt{(\Omega_m/0.3)}=0.745\pm0.039$

Systematics error as big as statistical error (0.027)

- S_8 constraint very similar to CFHTLenS, pre-planck CMB
- Tension with Planck — $2.7\sigma_{\text{KiDS}}$ in S_8 (2.3σ discrepancy in full parameter space)

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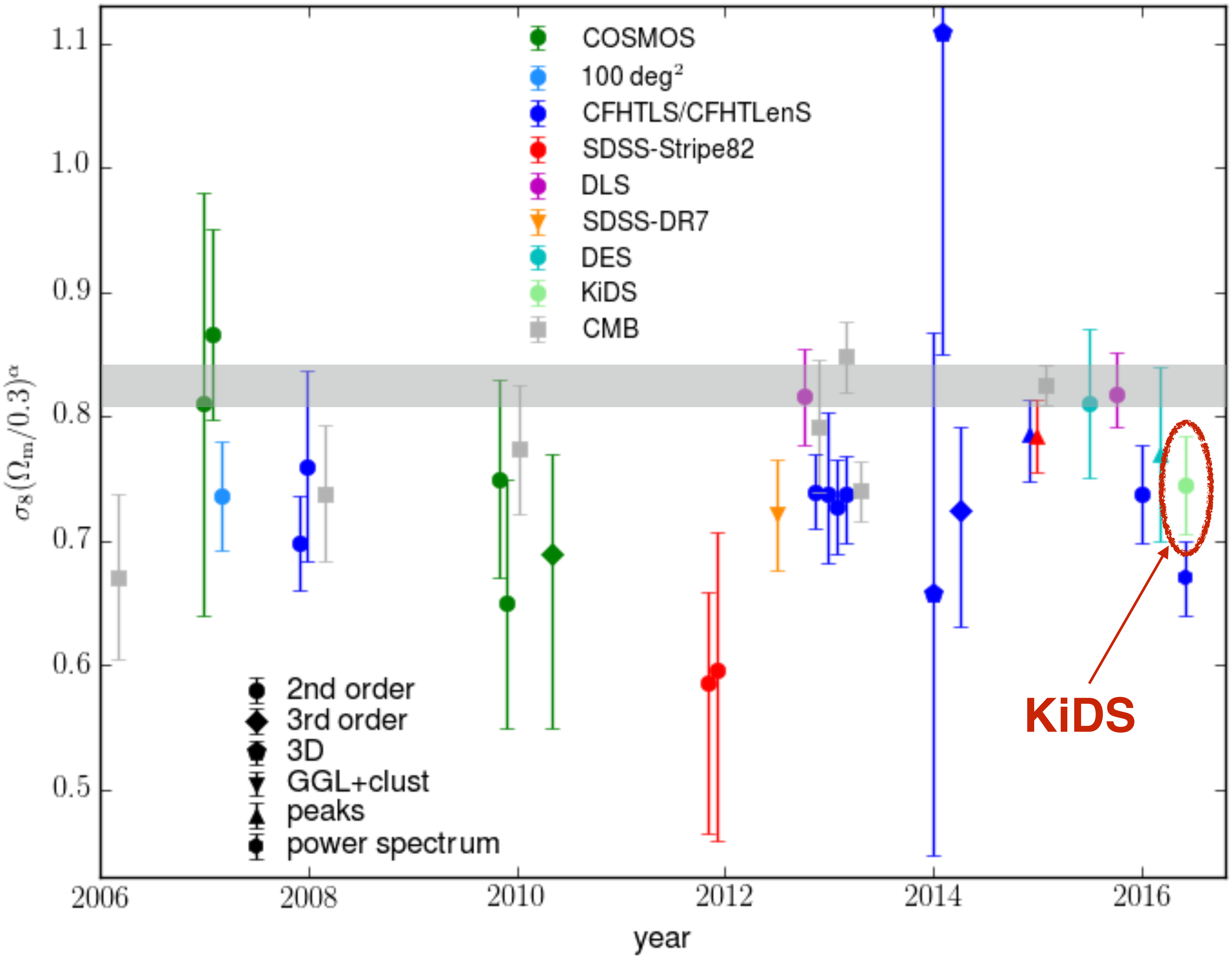


S_8 results over the years

Kilbinger (2015; updated)

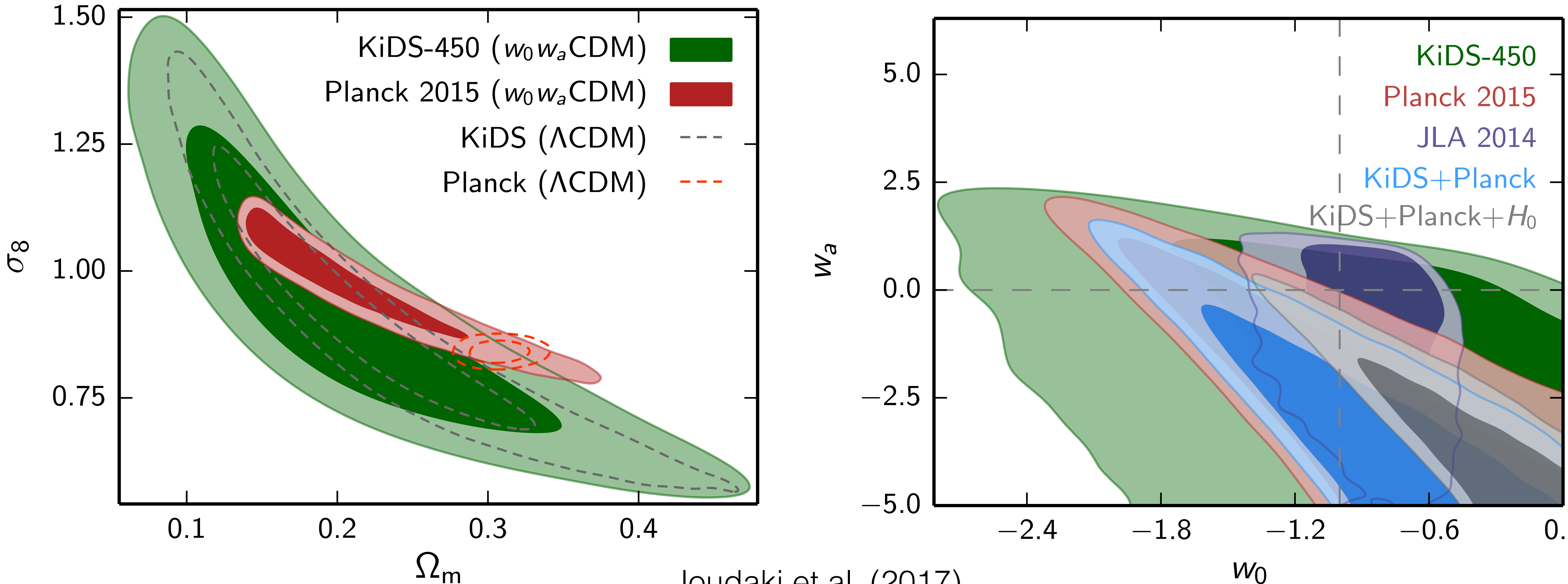
KiDS

Extended cosmologies

- Massive neutrinos.
- Non-zero curvature.
- Evolving dark energy.
- Modified gravity.
- Running spectral index.

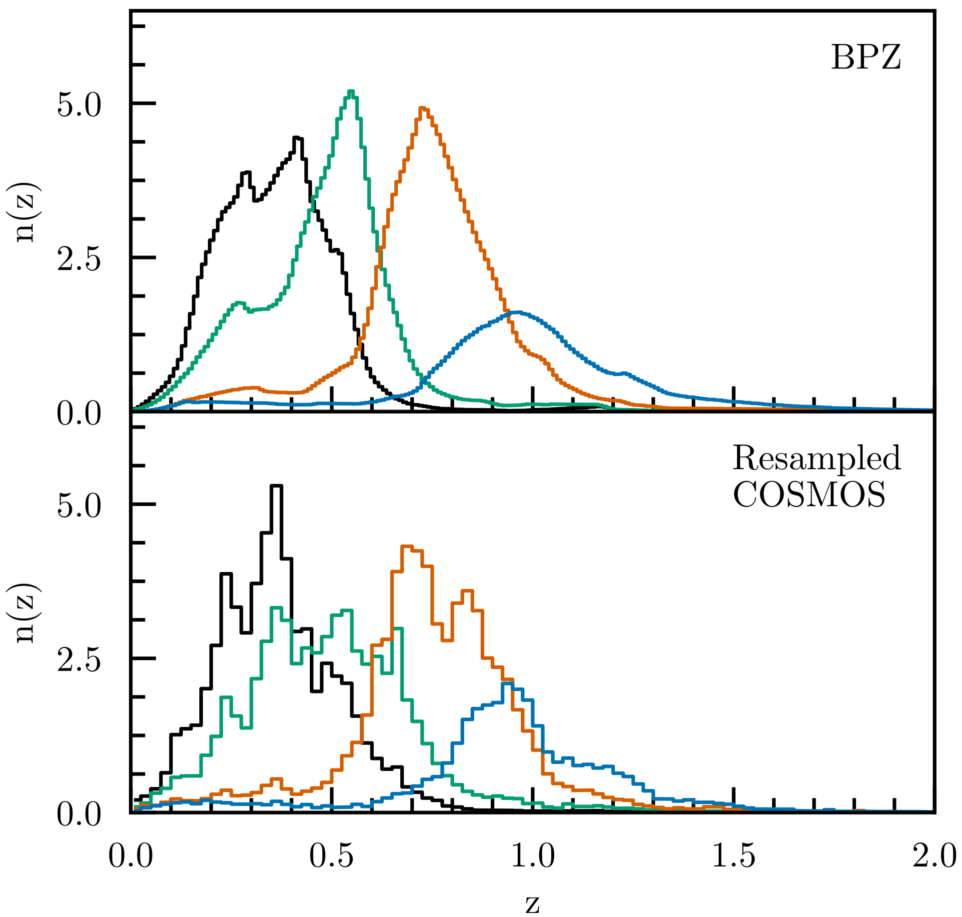
Joudaki et al. (2017)

Evolving dark energy



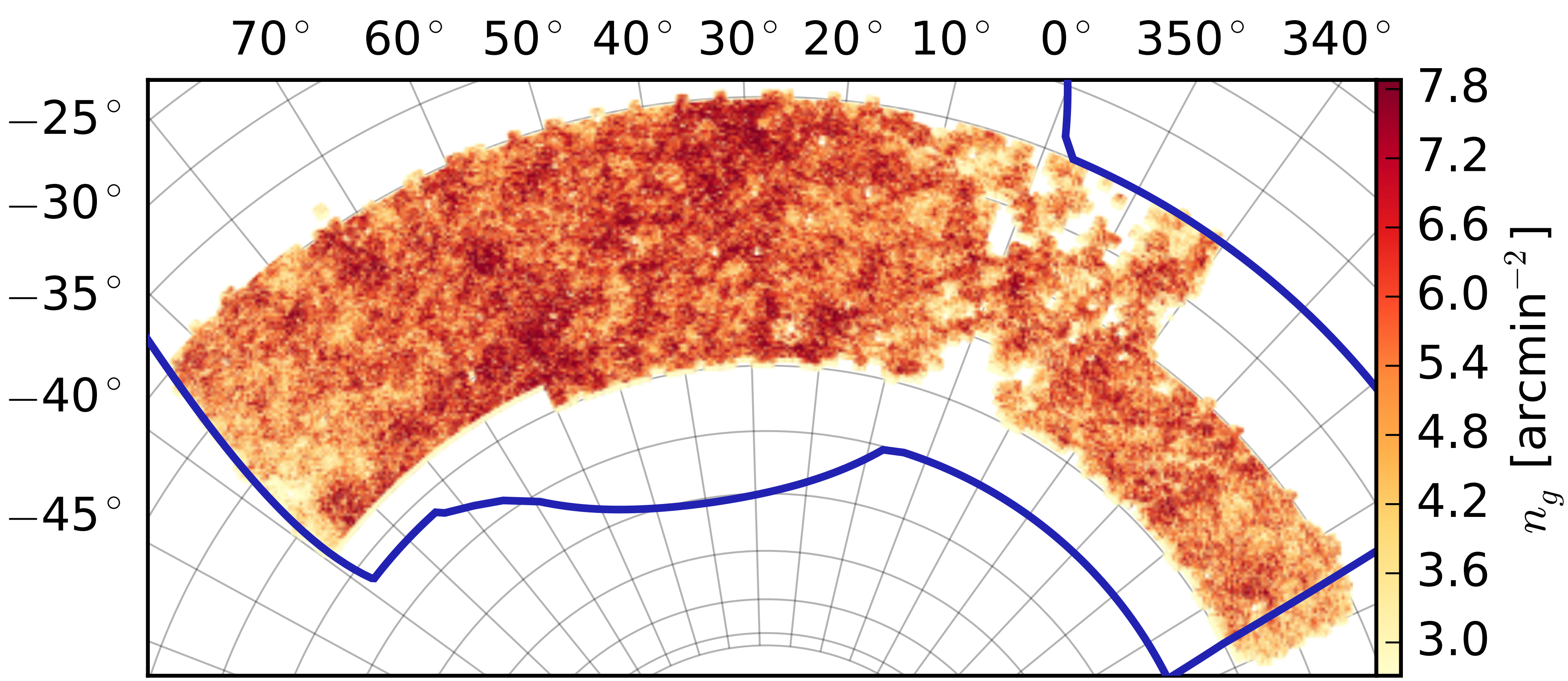
Joudaki et al. (2017)

- Resolves tension between KiDS and Planck.
- Only extensions that is moderately favoured by the data.
- 3-σ deviation from a cosmological constant.
- Resolves tension between Riess et al. (2016) and Planck.



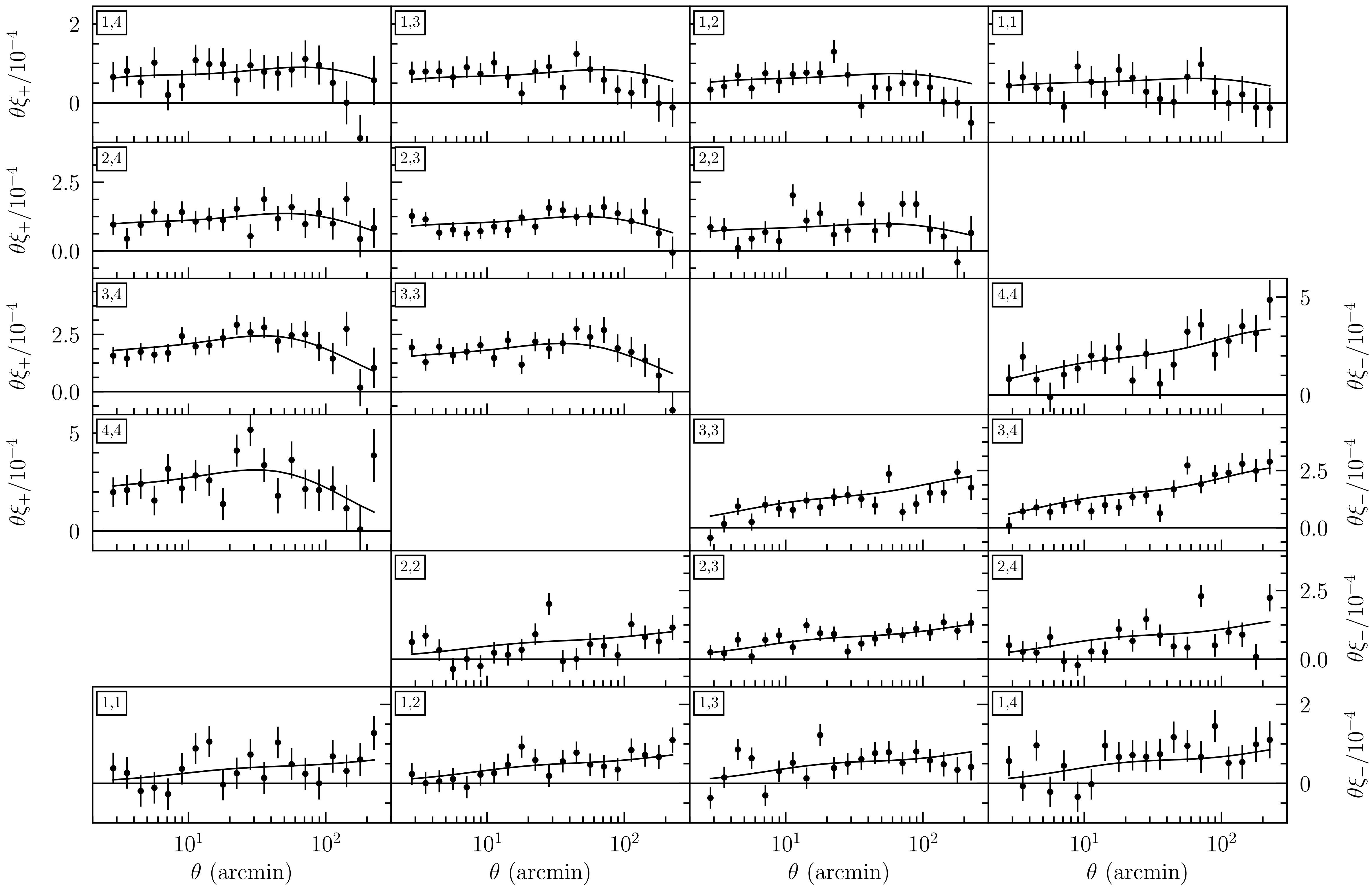
DES year 1

- 1321 deg^2
- half depth
- 5 gal./arcmin^2
- 4-bin tomography analysis

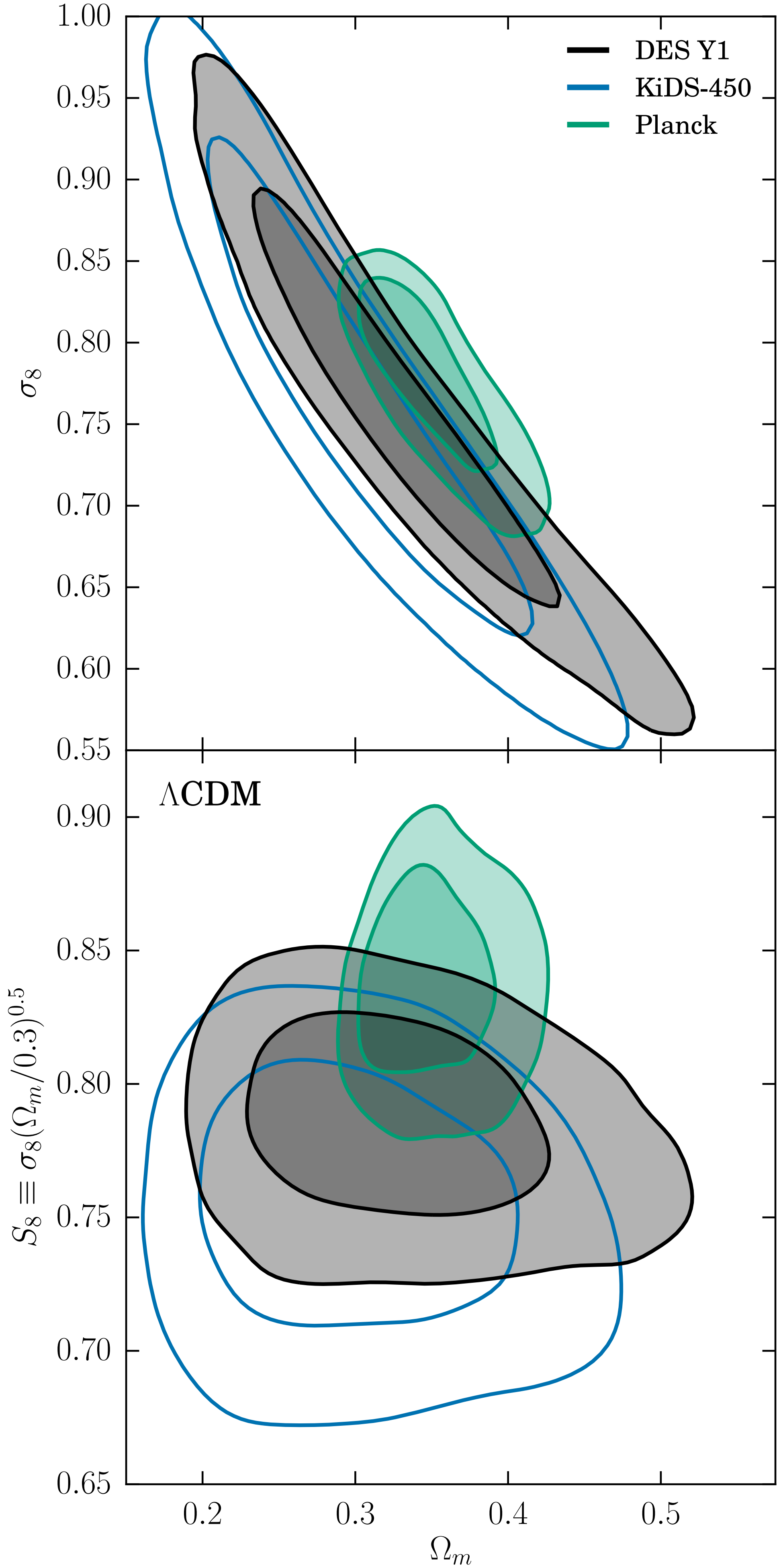


Troxel et al. (2017)

DES year 1



Troxel et al. (2017)

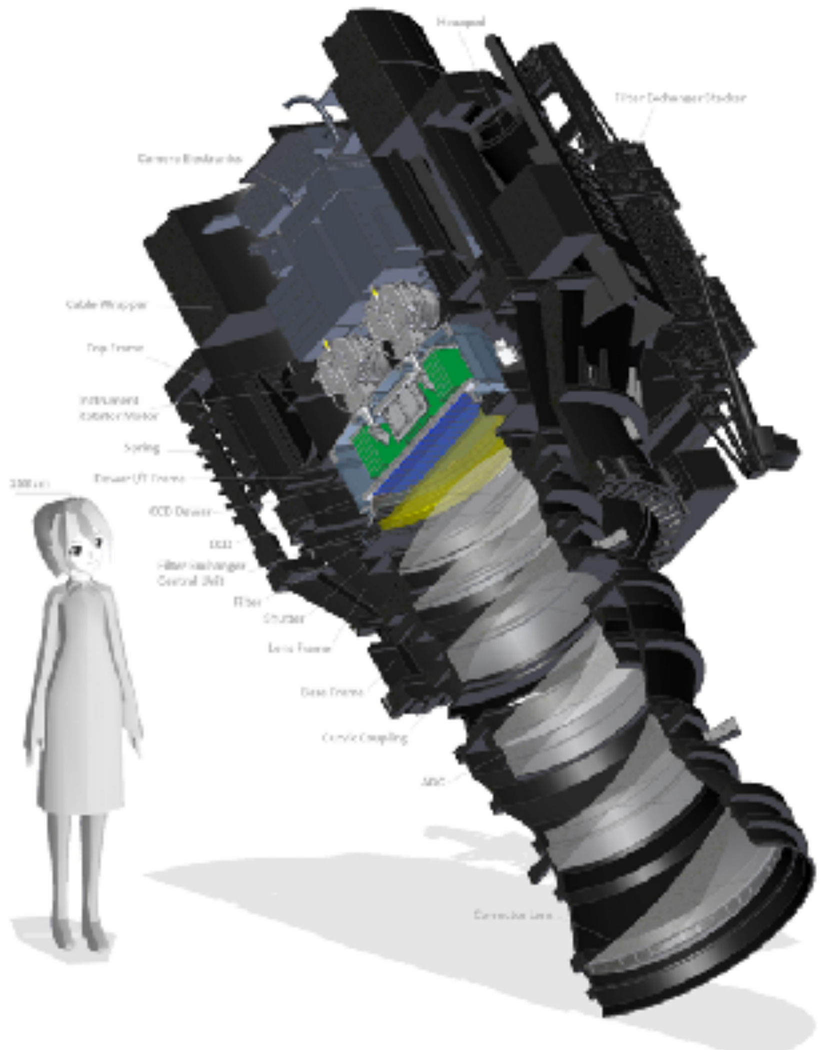


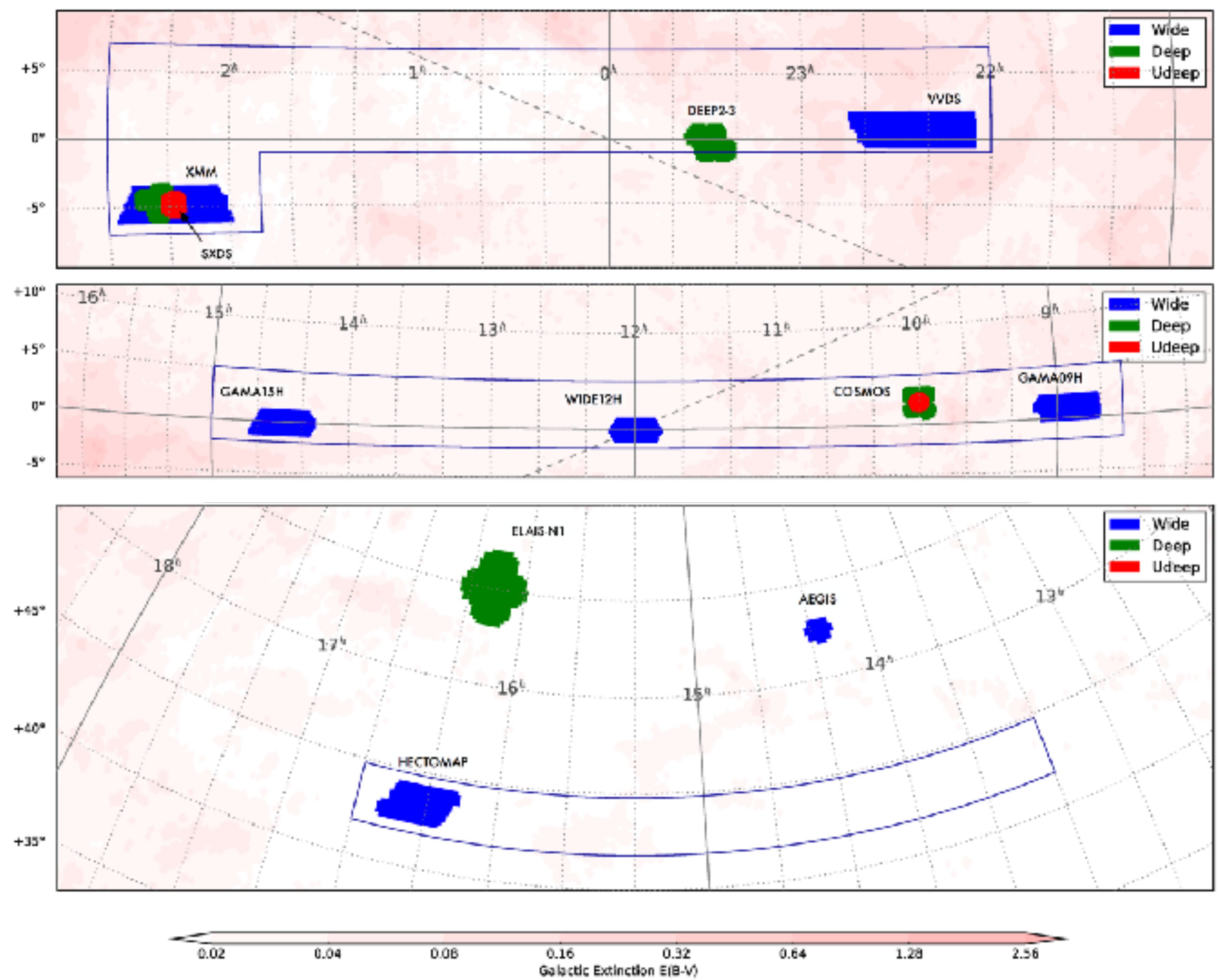
DES year 1

- Most powerful cosmic shear measurement to date
- S_8 constraint between Planck and KiDS
- Significant differences in the analysis
- Shows the potential of the full Dark Energy Survey

Troxel et al. (2017)

HSC DR1



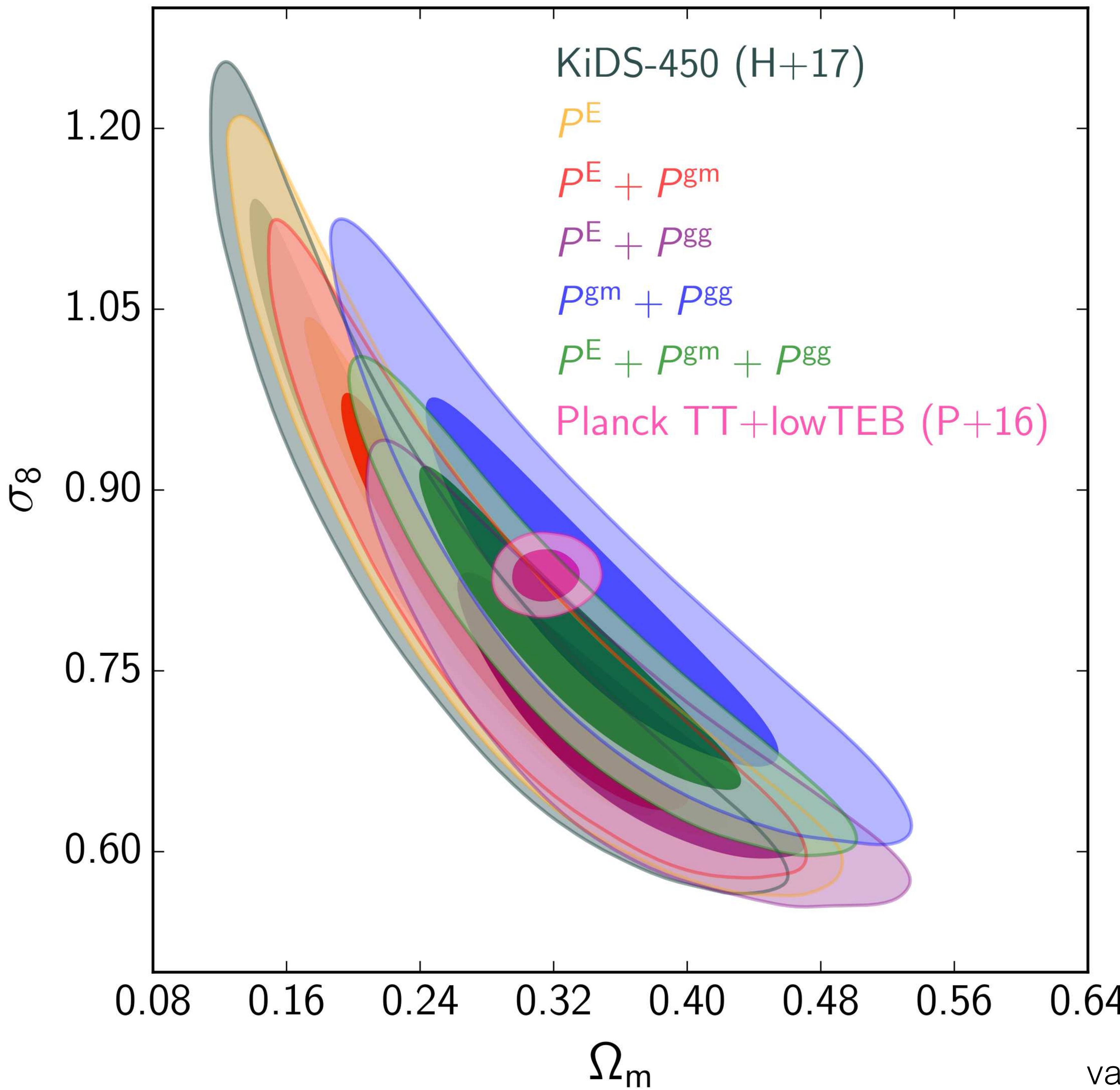


Wide
Deep
Udeep
XMM
SXDS
DEEP2-3
VVDS
GAMA15H
WIDE12H
COSMOS
GAMA09H
ELAIS-N1
AEGIS
HECTOMAP
Galactic Extinction E(B-V)

Combined probes

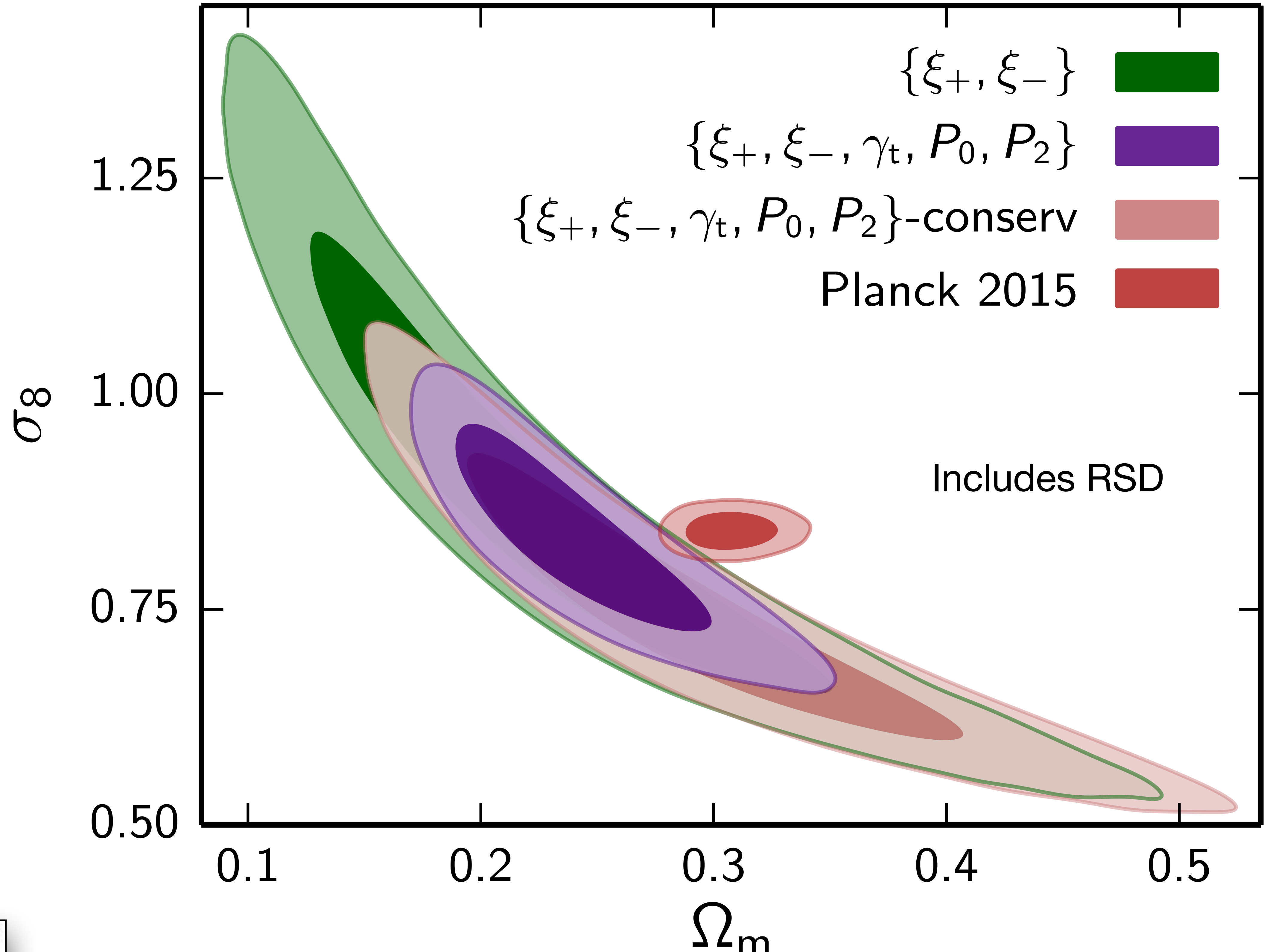
- Cosmic shear <γγ>
- Galaxy-galaxy lensing <δγ>
- Galaxy clustering (photometric or spectroscopic samples) <δδ>
- Break degeneracies
- Increase precision
- Lose some of the benefits of cosmic shear

KiDS + GAMA



van Uitert et al. (2017)

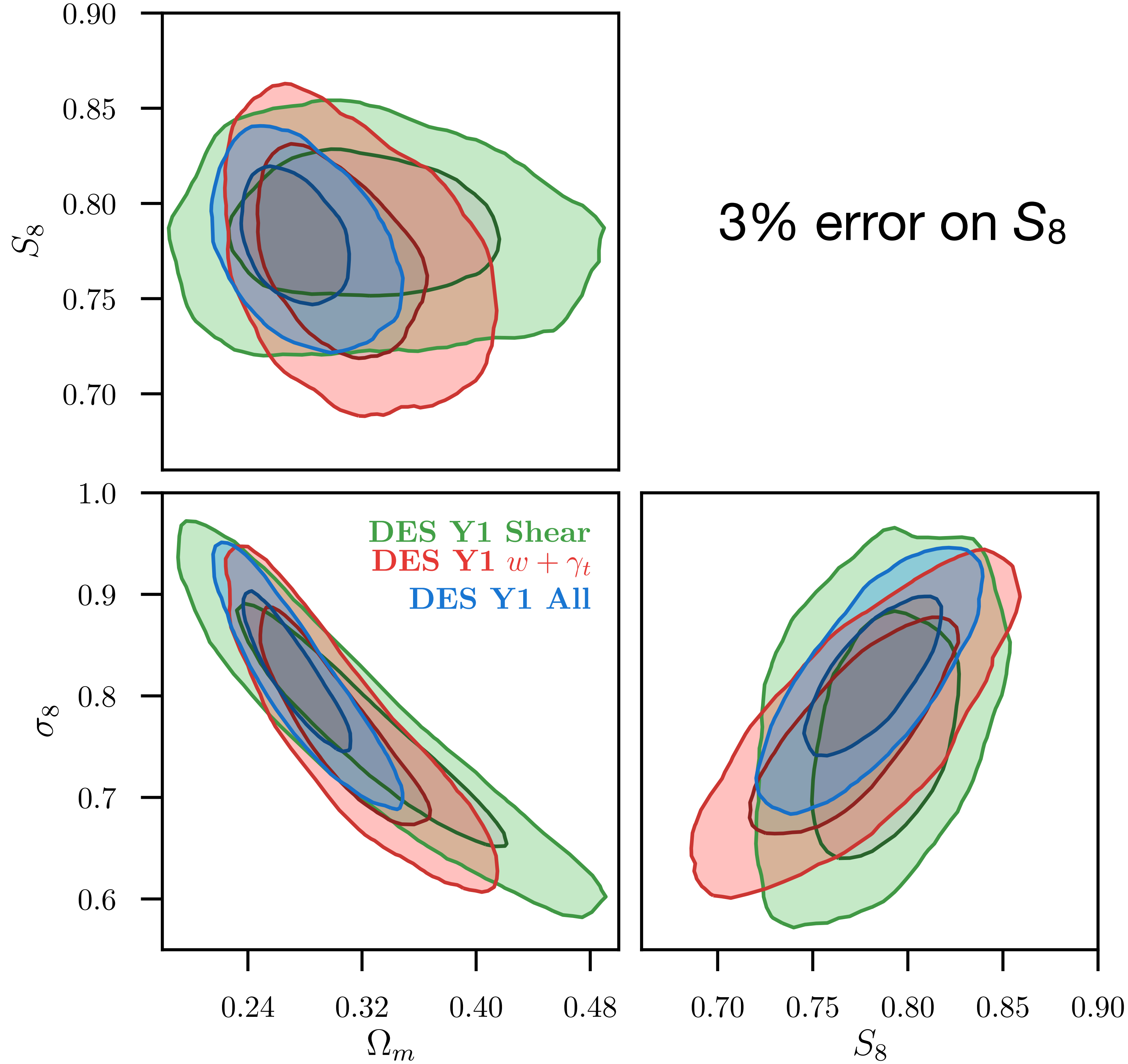
KiDS + 2dFLenS/BOSS



KiDS

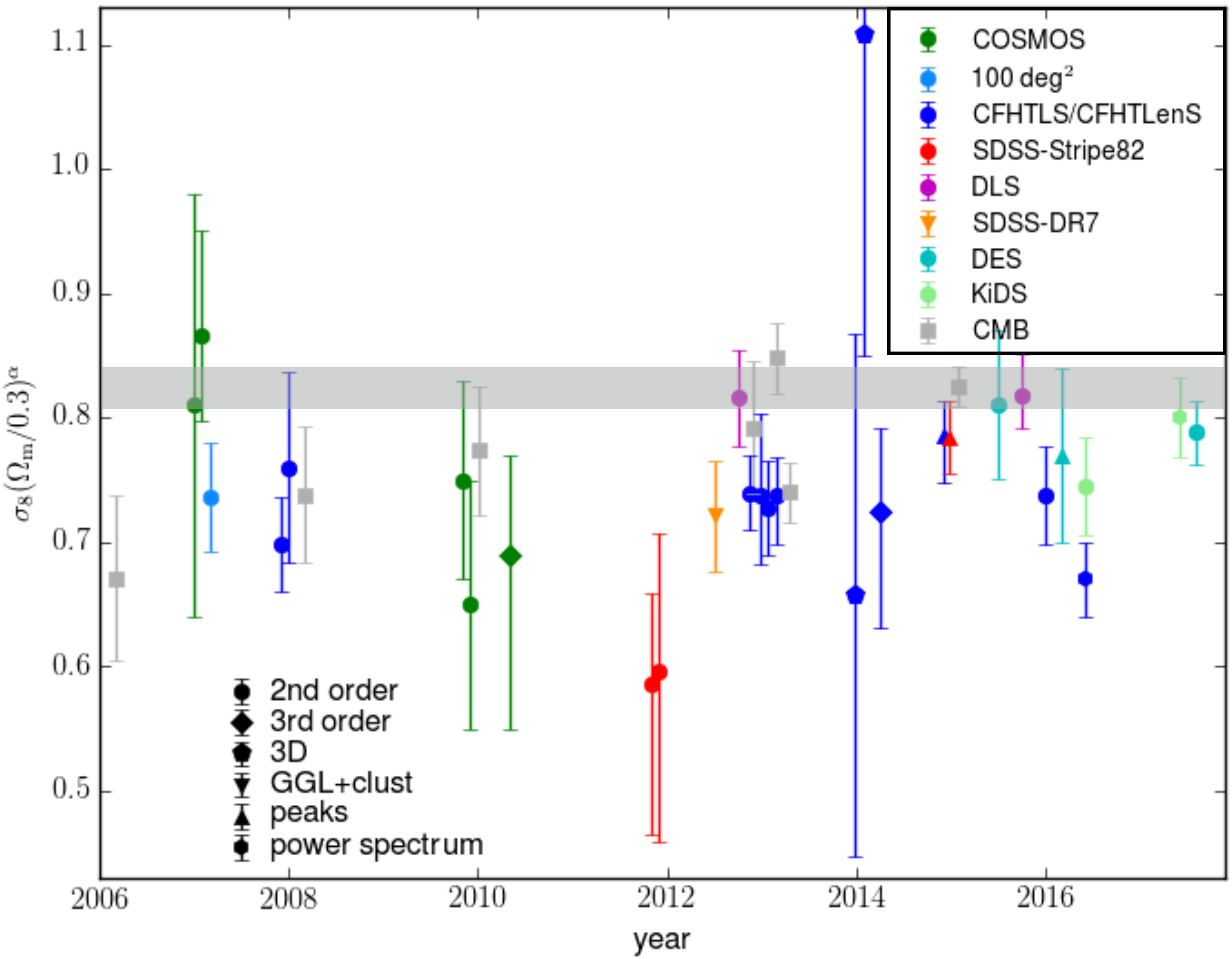
Joudaki et al. (2017b)

DES year 1



3% error on S_8

Abbott et al. (2017)

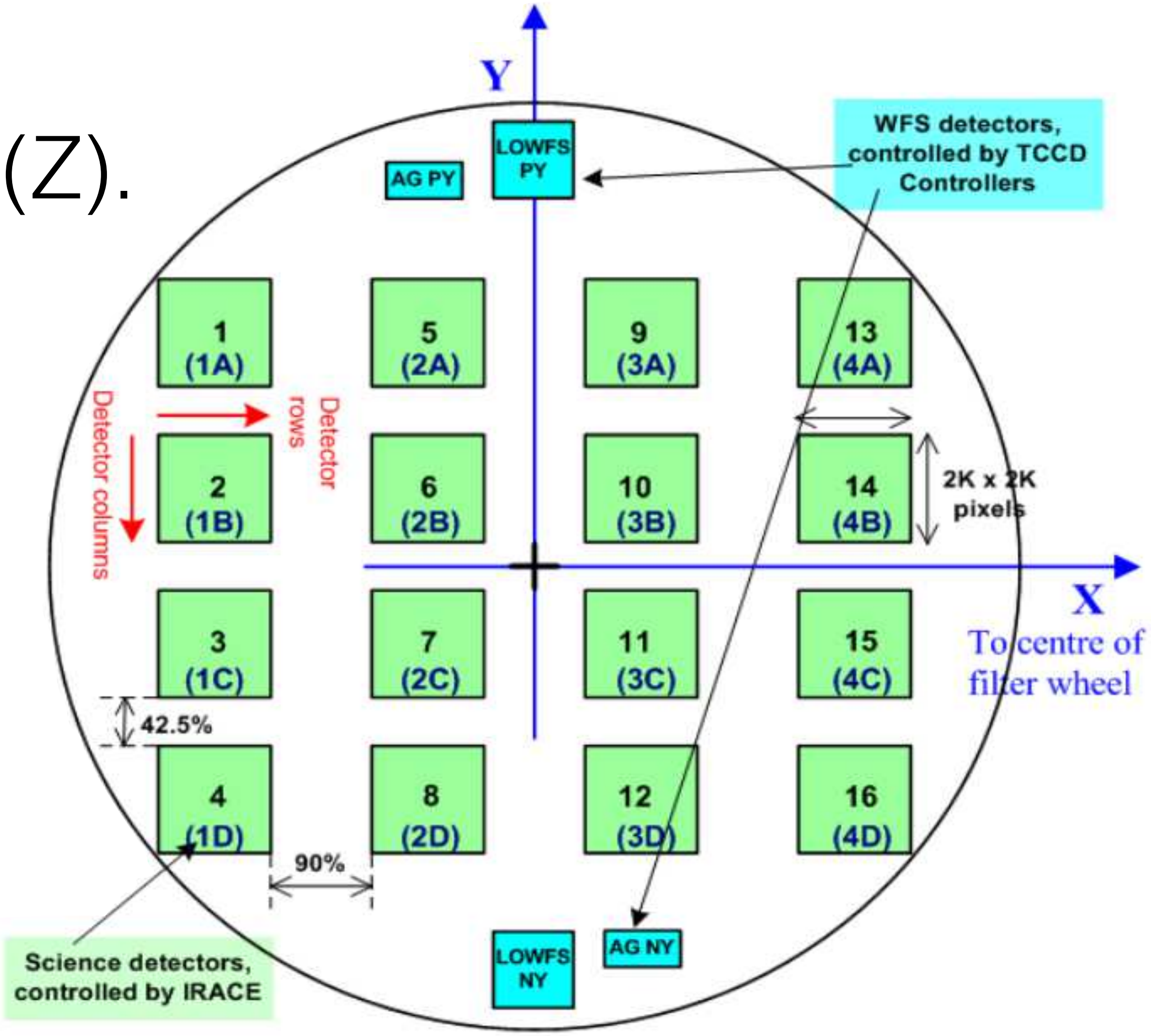


S_8 results over the years

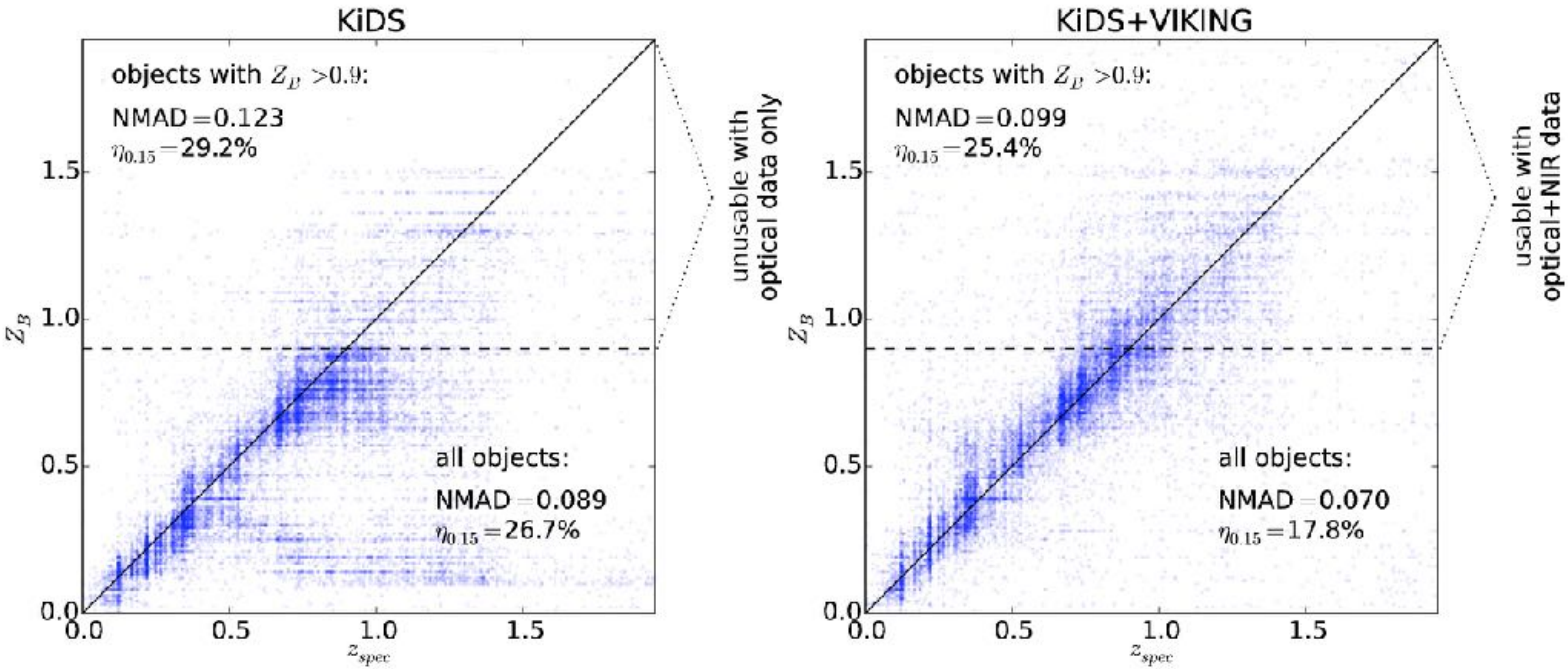
Kilbinger (2015; updated)

VIKING@VISTA

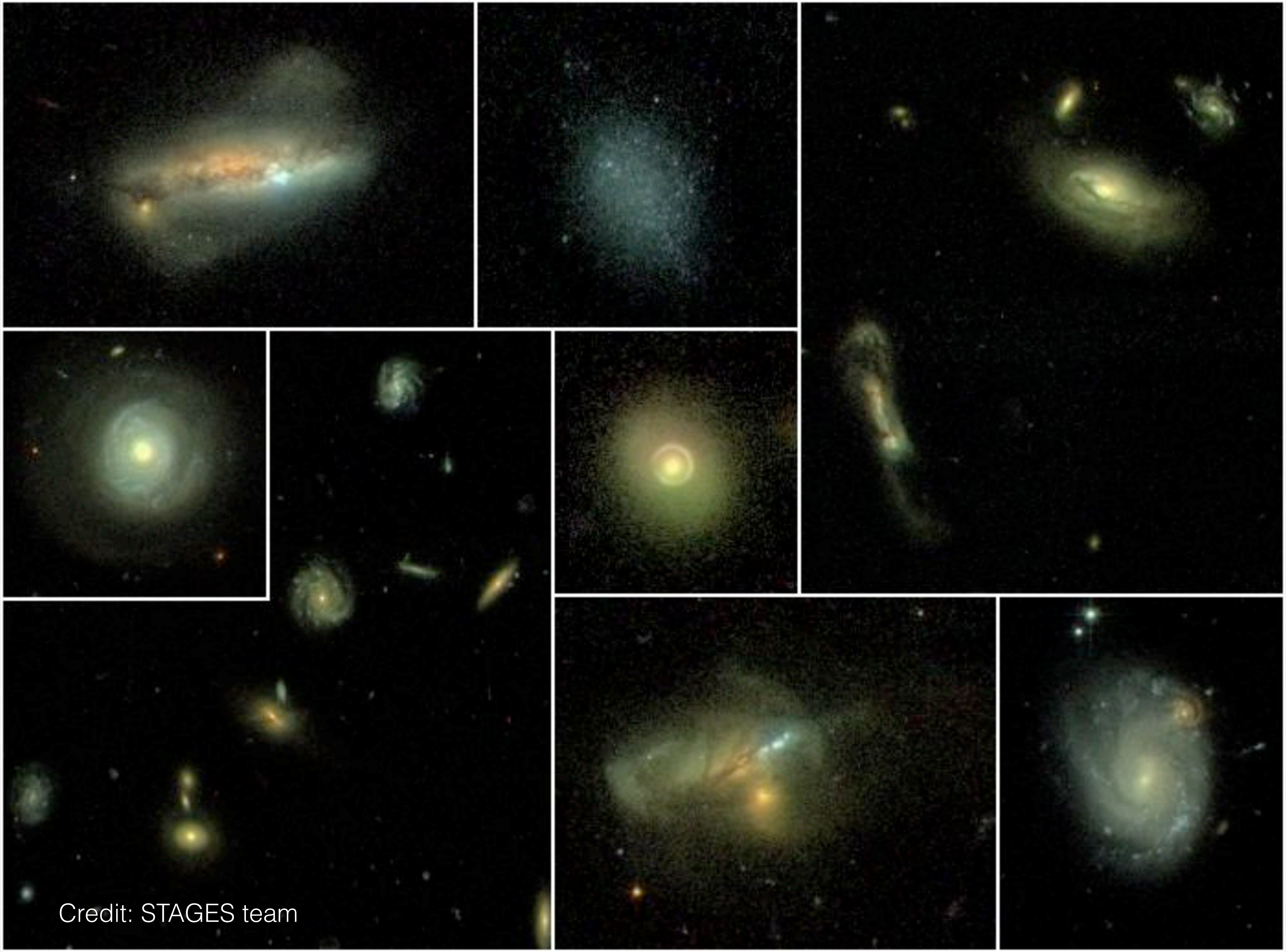
- Same footprint as KiDS.
- Already finished (1350deg^2).
- ZYJHKs images.
- 5σ depths of 21.2 (Ks) to 23.1 (Z).



Benefits of NIR

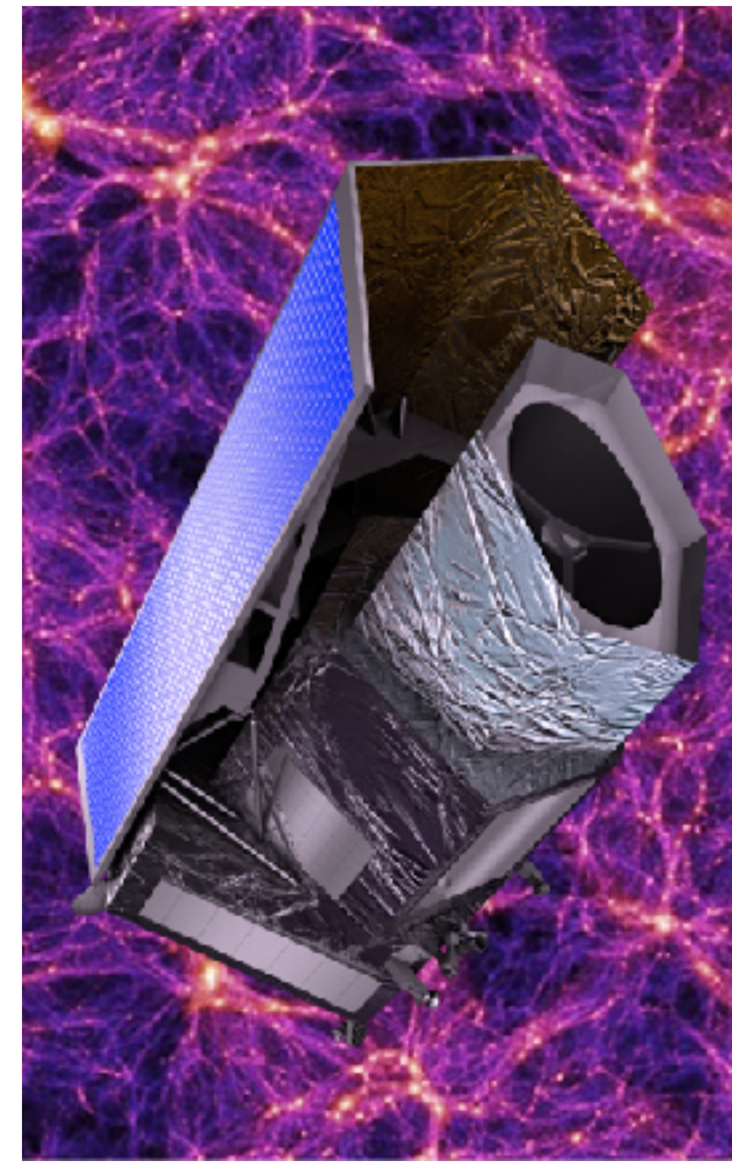



Credit: STAGES team


Credit: STAGES team

Euclid

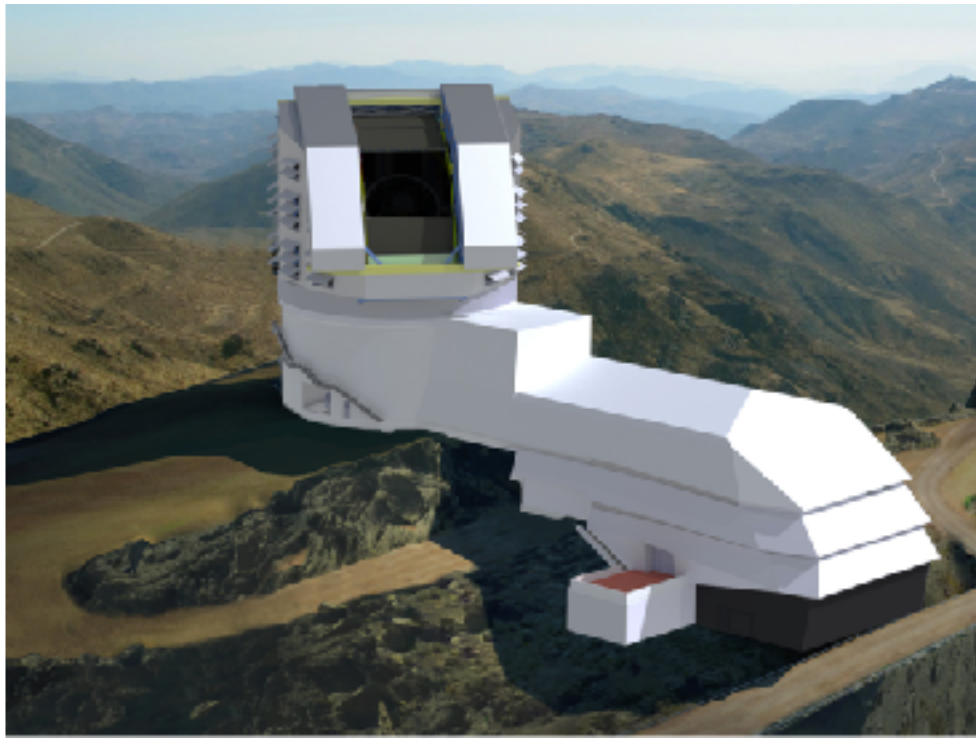
- ESA/NASA Space Telescope.
- Launch in ~2020.
- optical+NIR imaging of 15k deg^2.
- Measure w_0 to <2% and w_a to <10%.
- Open huge parameter space.



- Needs to be complemented by ground-based data.
- LSST is crucial in the South. North is patchwork.

LSST

- 8.4m optical wide-field imaging telescope
- Huge camera, rapid survey speed, 18,000deg^2 total
- Deep multi-band photometry (also time domain)
- Crucial complement to Euclid
- Very challenging data rate
- US-led with international partners



Summary & Outlook

- Cosmic shear measures S_8 with CMB-like precision.
- Tension between Planck and some cosmic shear measurements. Systematics? New physics??
- Very exciting times:
    - KiDS+VIKING >900deg^2 now, 1350deg^2 by end 2018.
    - DES will (has) triple area and double(d) depth.
    - Waiting for first HSC cosmic shear results.
- Requires excellent calibration data (ESO LP, Keck).
- Prepare with today's surveys for Euclid/LSST/WFIRST.