Title: Gravitational lensing and cosmology

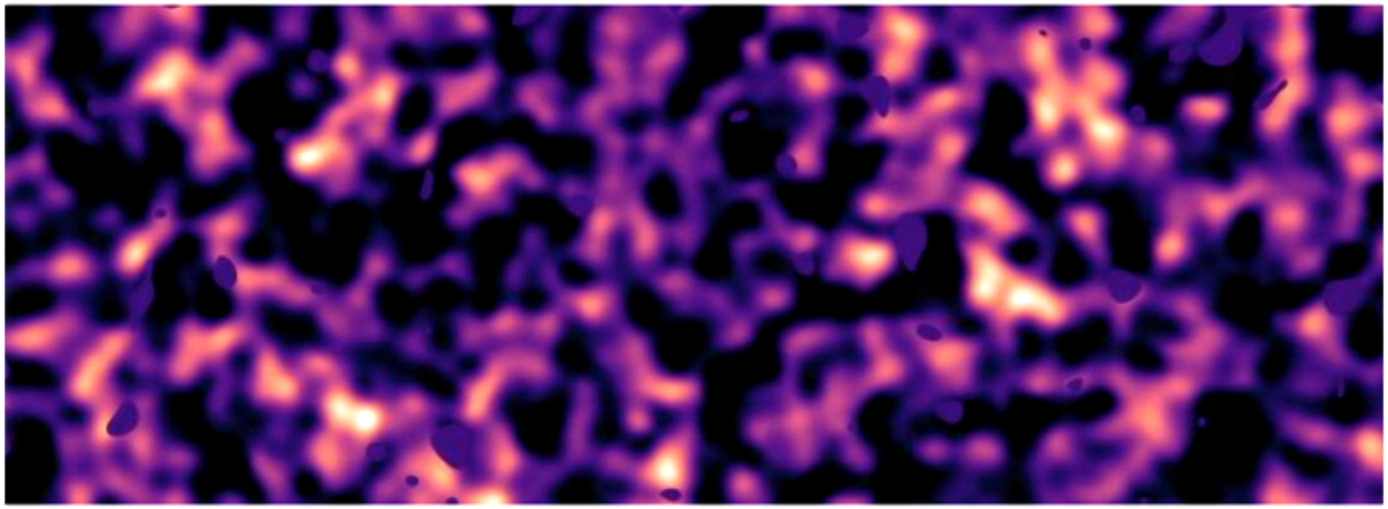
Date: May 11, 2017 11:00 AM

URL: http://pirsa.org/17050073

Abstract: <p>Gravitational lensing is one of the primary investigation tools of all current and future wide field surveys. In this talk I will review its current status (with the Kilo Degree Survey (KiDS)) and show what unique cosmological information it gives us. Lensing is not limited to a, low redshift, dark universe probe, it can also be used as a tool to probe baryons and nicely work in synergy with baryonic probes (e.g. CMB, Xray, tSZ, HI). I will show some of the work in progress to help constraining Active Galactic Nuclei feedback</p>

Gravitational lensing and cosmology

L. Van Waerbeke
(UBC, CIfAR)



Dark matter map with the KiDS-450 survey

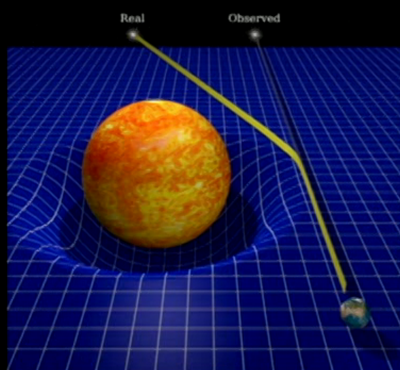
Perimeter Institute May 11th 2017

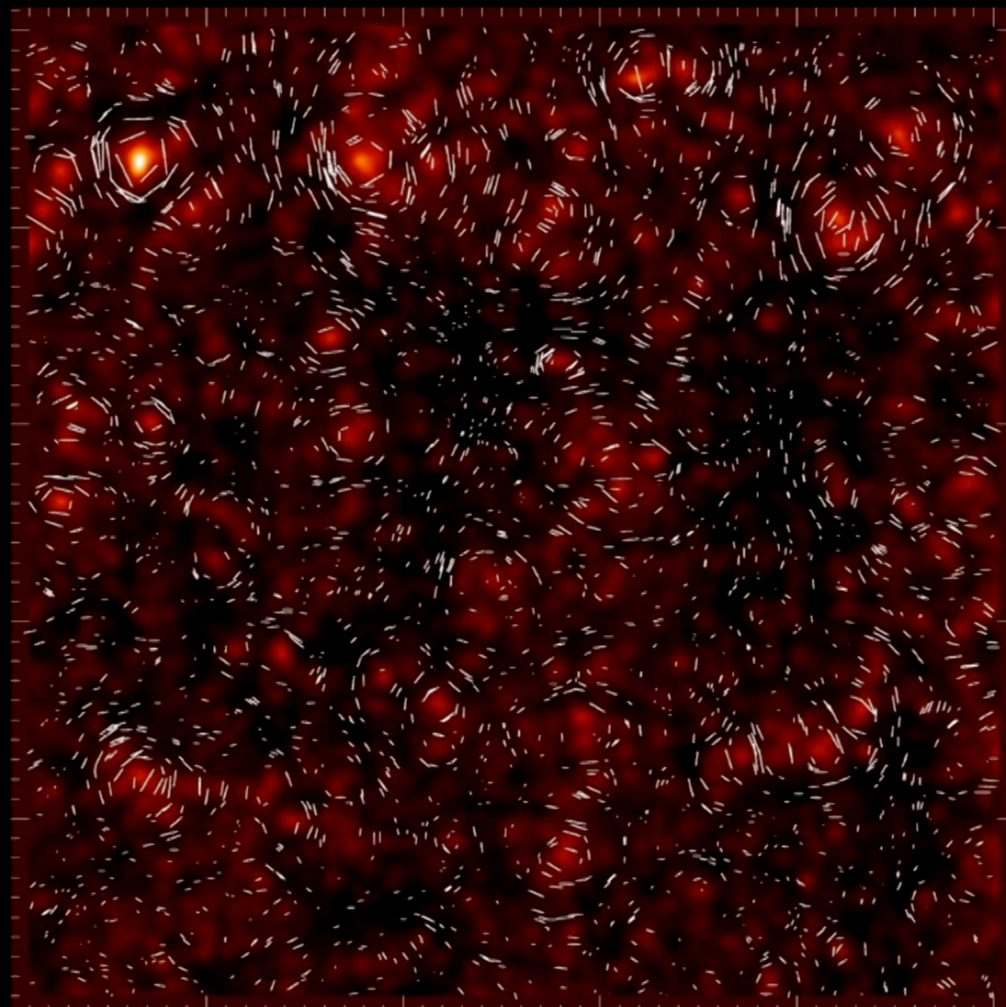
What are the next big questions?

nature of dark matter (modified gravity, interacting DM, neutrino mass, DM particle?,...)

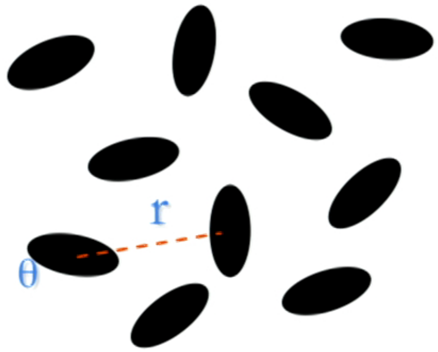
nature of dark energy (equation of state, extra dimensions,...)

Gravitational lensing: lensed galaxies mapping foreground matter

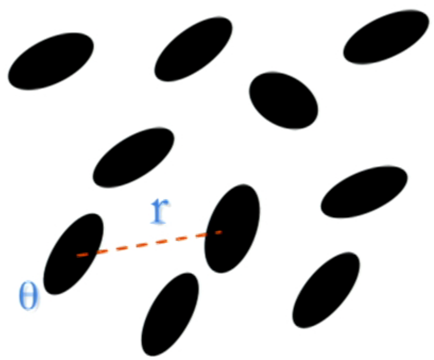




N Galaxies

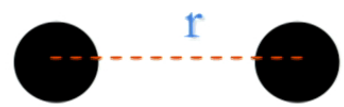


NOT LENSED

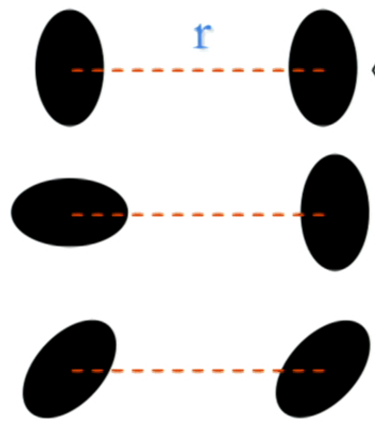


LENSED (sheared)

Averaged pair ellipticities



$$\xi(r)=\langle\gamma(\theta)\gamma(\theta+r)\rangle_\theta$$



$$\langle\gamma_t(\theta)\gamma_t(\theta+r)\rangle_\theta > 0$$

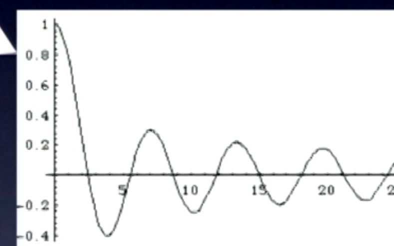
$$\langle\gamma_t(\theta)\gamma_t(\theta+r)\rangle_\theta < 0$$

$$\langle\gamma_r(\theta)\gamma_r(\theta+r)\rangle_\theta > 0$$

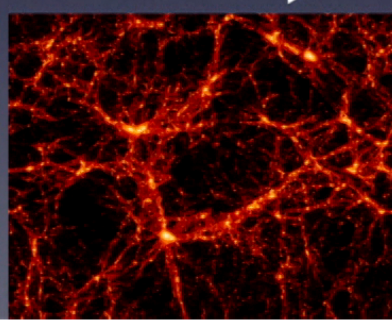
Cosmic Shear two-points Statistics and mass Power Spectrum

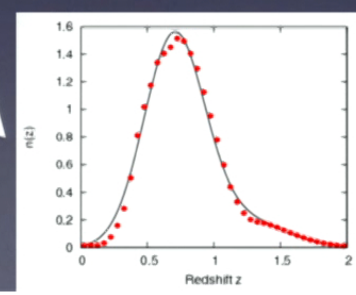
Shear correlation function at separation Θ:

$$\langle \gamma(\mathrm{r})\gamma(\mathrm{r}+\theta)\rangle_{\mathrm{r}} = \frac{1}{2\pi}\int_0^\infty \mathrm{d}k\, k\, P_\kappa(k)\, \mathrm{J}_0(k\theta)$$



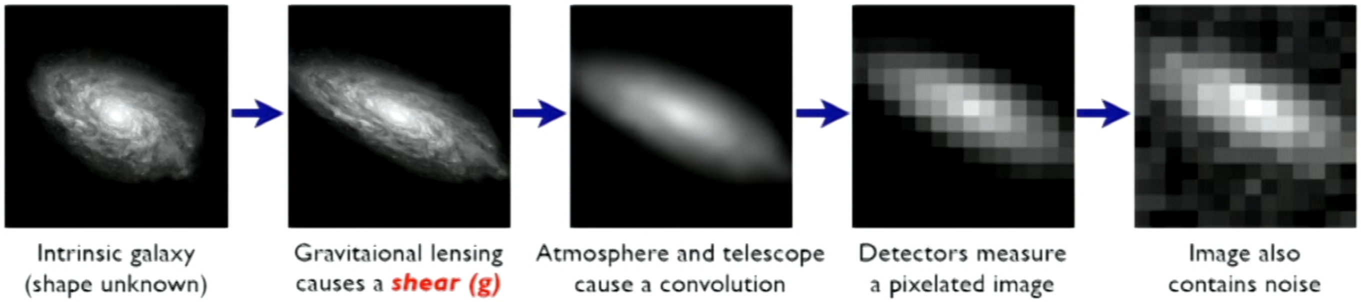
$$P_\kappa(k) = \frac{9}{4}\Omega_0{}^2\int_0^\infty \mathrm{d}\,z\, \mathrm{P}_{3\mathrm{D}}\left(\frac{k}{D_L(z)};z\right) \mathrm{F}\left[z, z_{\mathrm{source}}\right]^2$$



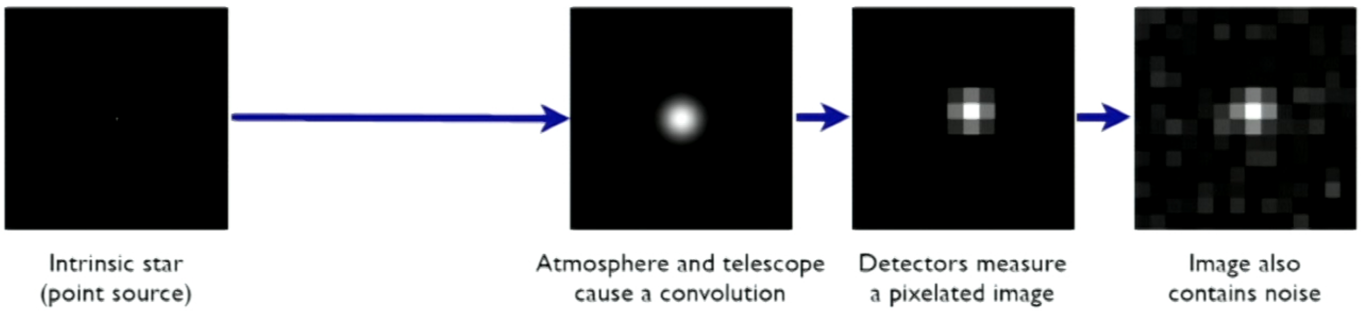


Measuring galaxy shapes

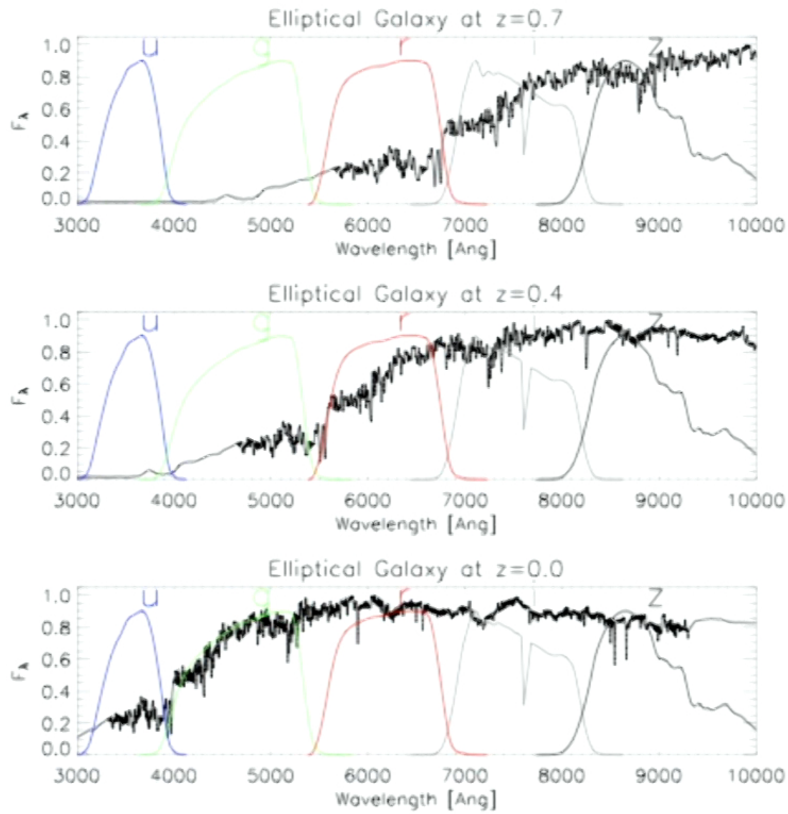
Galaxies: Intrinsic galaxy shapes to measured image:



Stars: Point sources to star images:

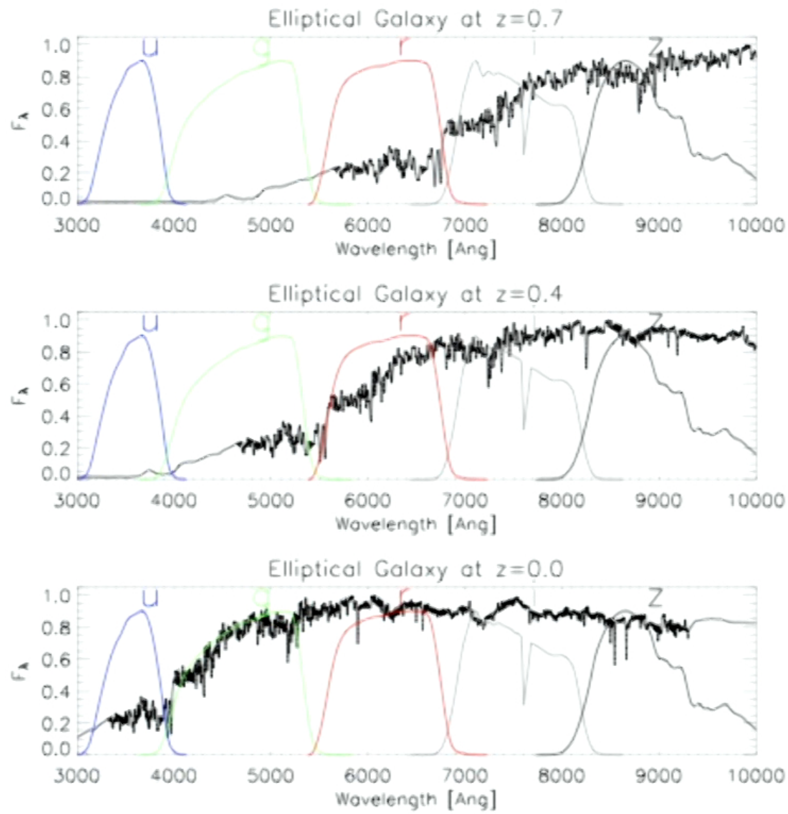


Photometric redshifts



7

Photometric redshifts



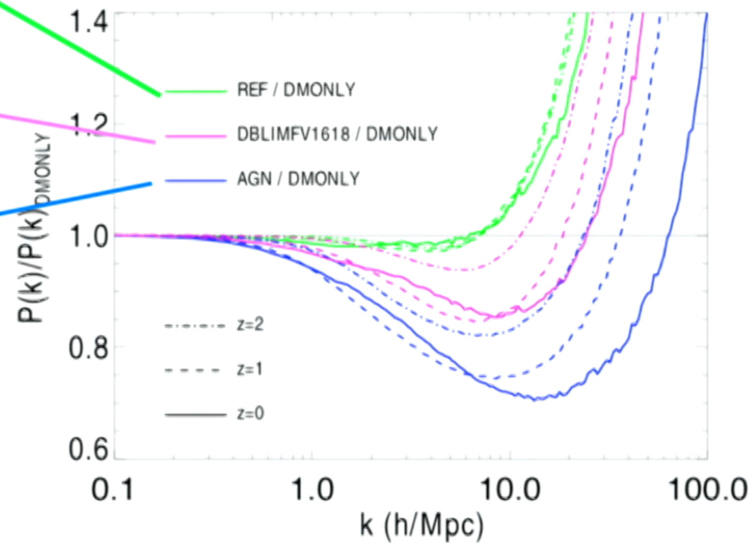
The effects of galaxy formation on the matter power spectrum

Marcel van Daalen, Joop Schaye, Craig Booth & Claudio Dalla Vecchia

REF: SN winds, cooling, SF,…
No AGN feedback

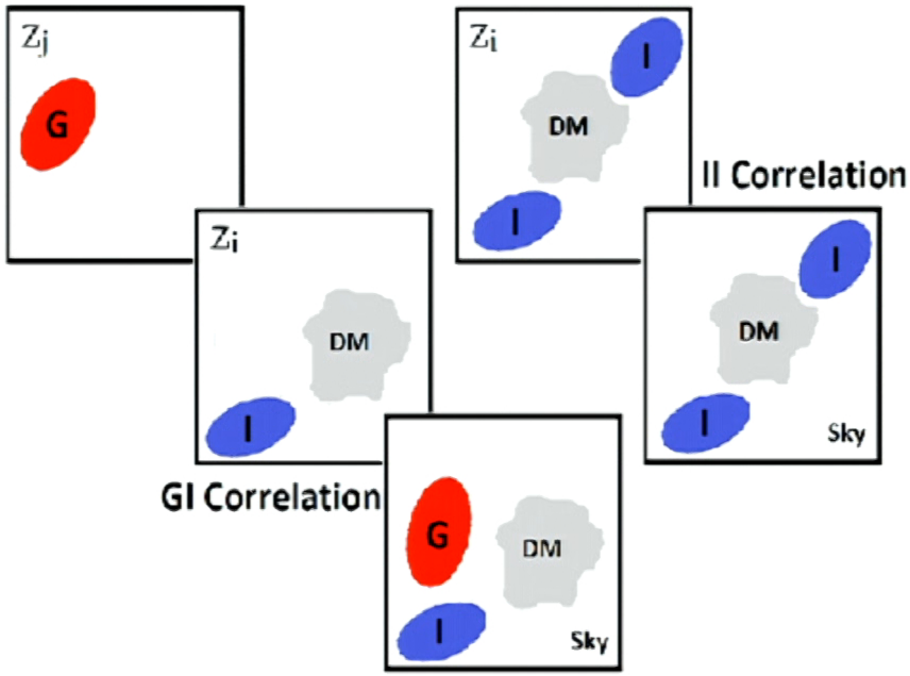
DBLIM: Top heavy IMF

REF+AGN (Booth & Shaye 2009)



Van Daalen et al, 2011
Semboloni et al, 2011,2012

Intrinsic alignment



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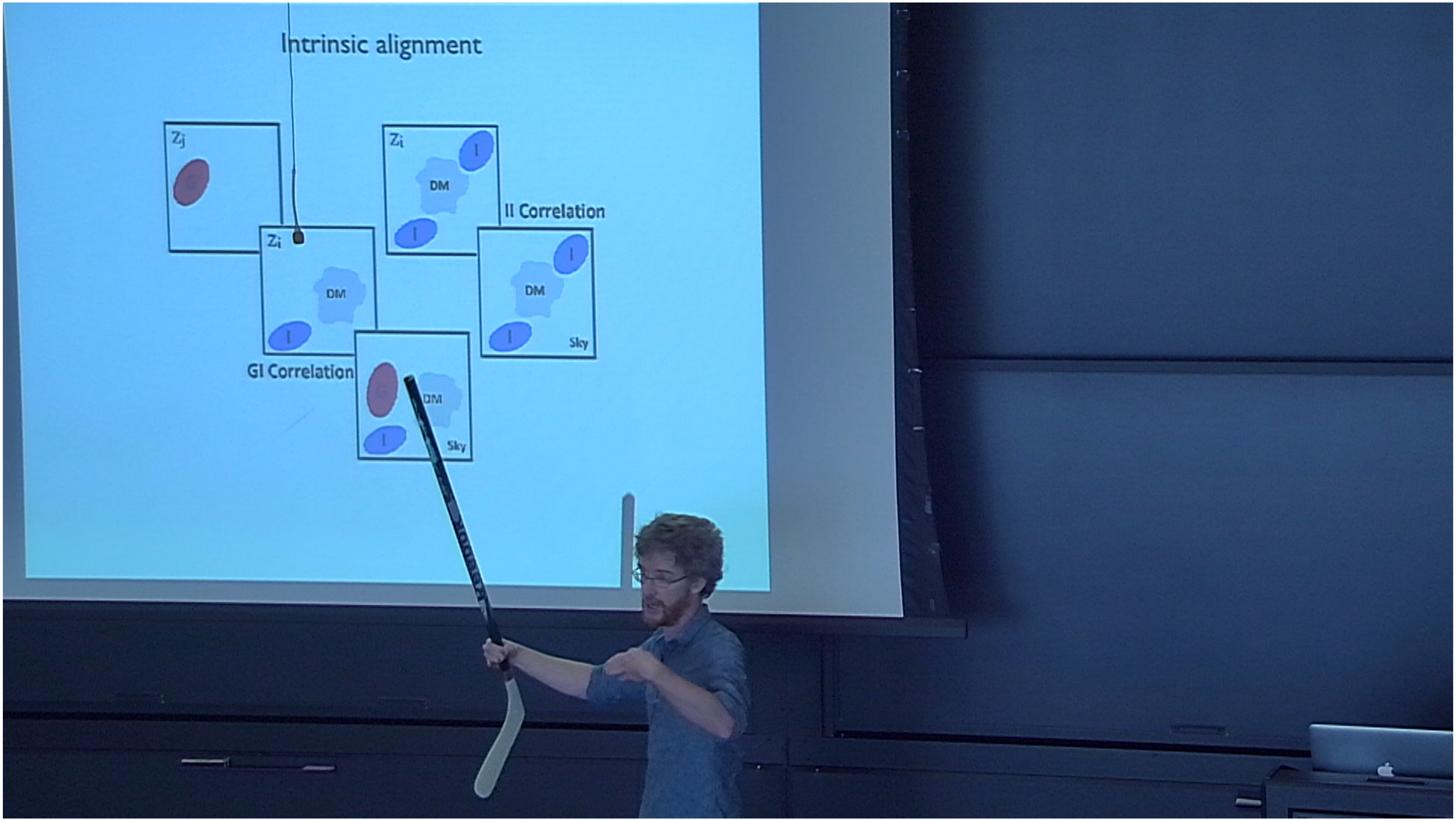

Intrinsic alignment
Zj
Zi
DM
I
II Correlation
Zi
DM
I
DM
I
I
Sky
GI Correlation
DM
I
Sky

Intrinsic alignment

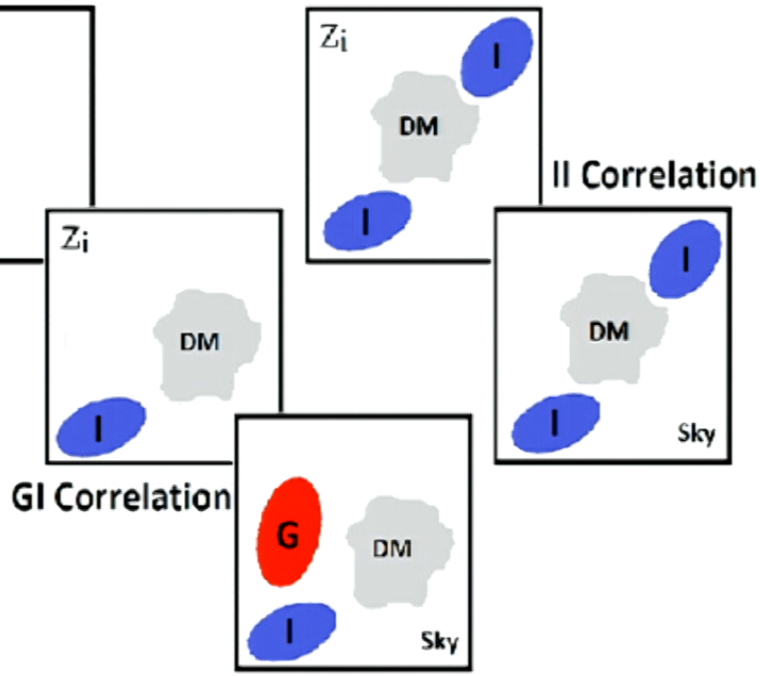
$$\left\langle \hat{\xi}_\pm \right\rangle = \xi_\pm + \xi_\pm^{\rm II} + \xi_\pm^{\rm GI}$$

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

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

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

Intrinsic alignment



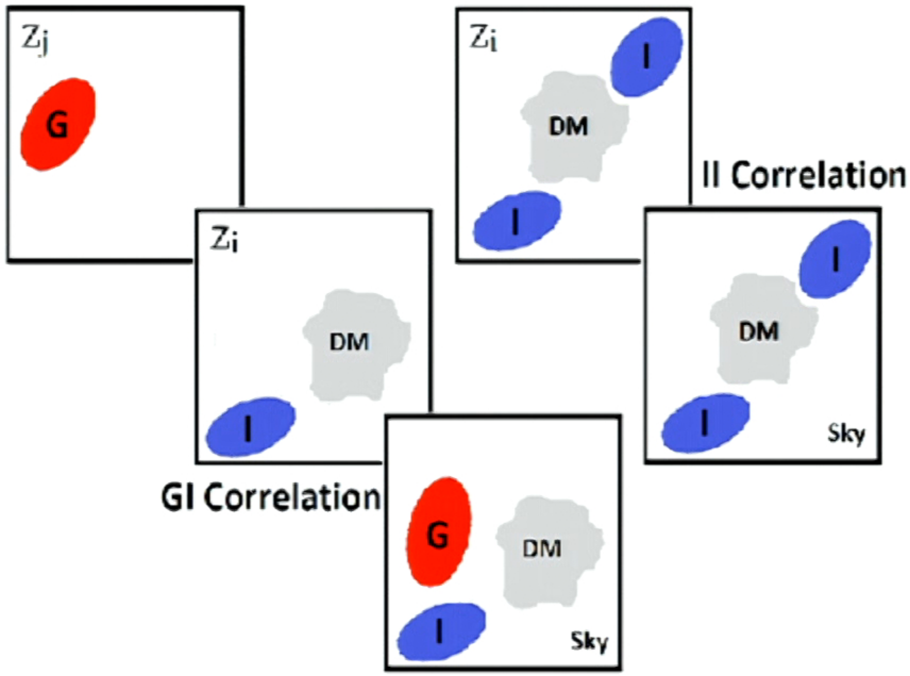
Intrinsic alignment

$$\left\langle \hat{\xi}_{\pm} \right\rangle = \xi_{\pm} + \xi_{\pm}^{\mathrm{II}} + \xi_{\pm}^{\mathrm{GI}}$$

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

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

Intrinsic alignment



9

Intrinsic alignment

$$\left\langle \hat{\xi}_{\pm} \right\rangle = \xi_{\pm} + \xi_{\pm}^{\mathrm{II}} + \xi_{\pm}^{\mathrm{GI}}$$

$$P_{\mathrm{II}}(k,z) = F^2(z) P_{\delta}(k,z)$$
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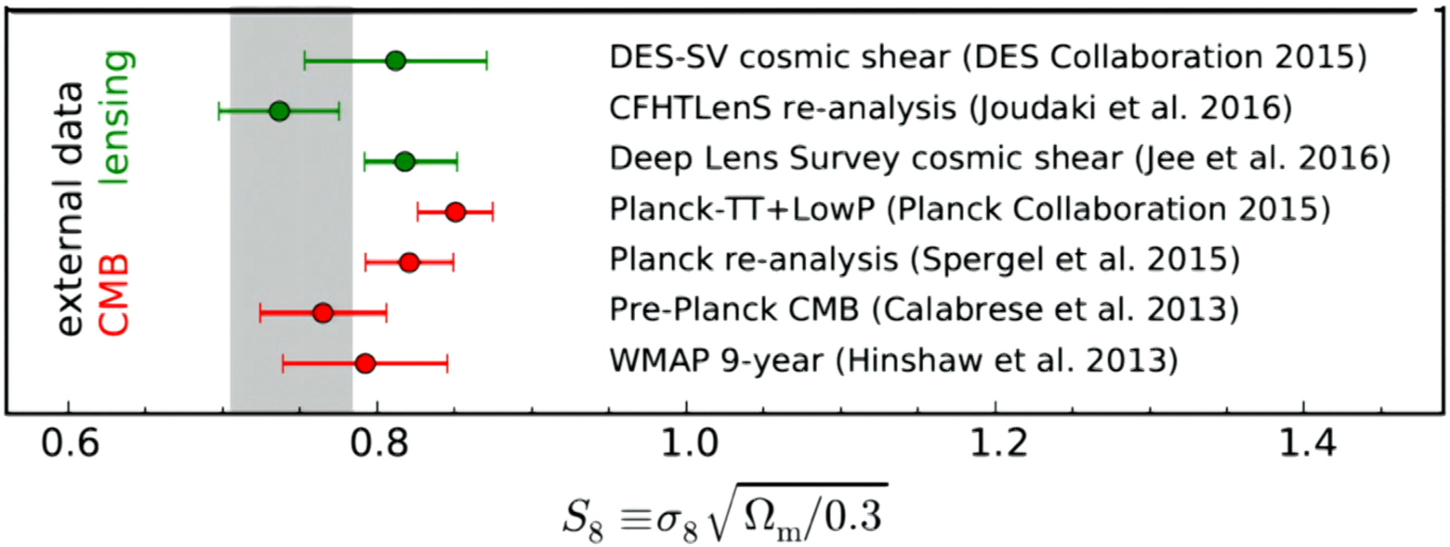
$$F(z) = -A_{\mathrm{IA}} C_1 \rho_{\mathrm{crit}} \frac{\Omega_{\mathrm{m}}}{D_+(z)} \left(\frac{1+z}{1+z_0} \right)^{\eta} \left(\frac{\bar{L}}{L_0} \right)^{\beta}$$

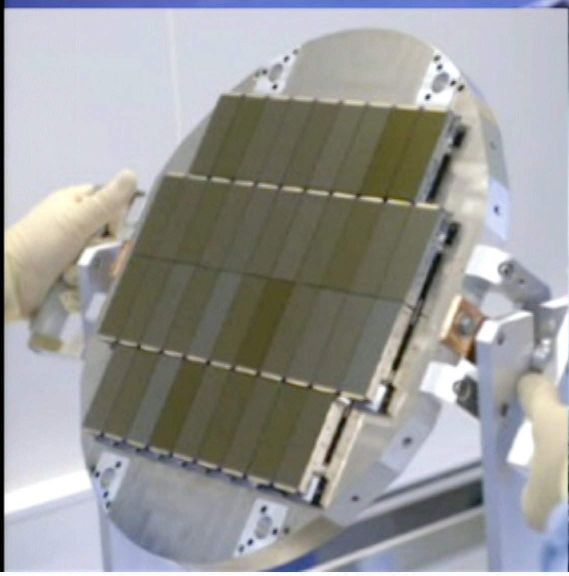
Tension between lensing and CMB Planck

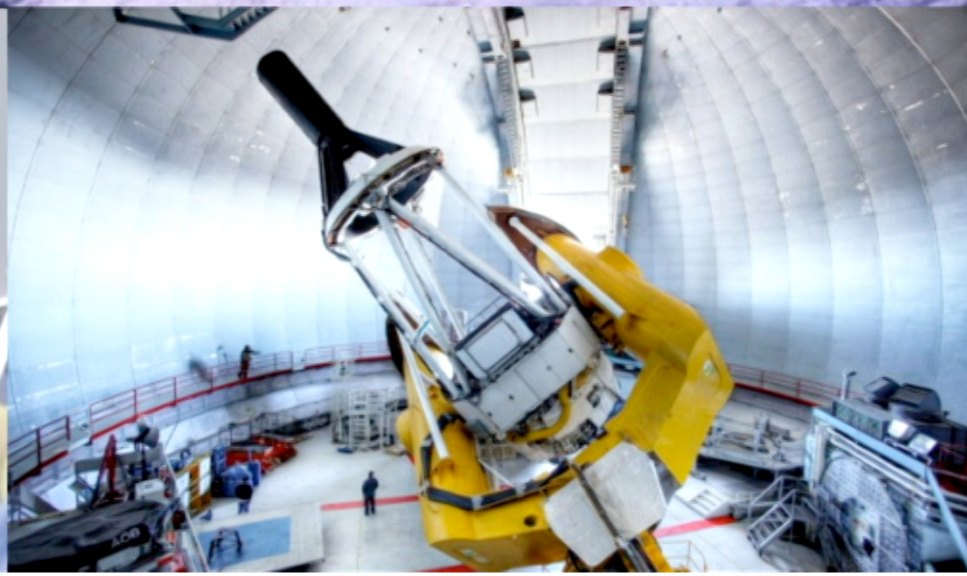


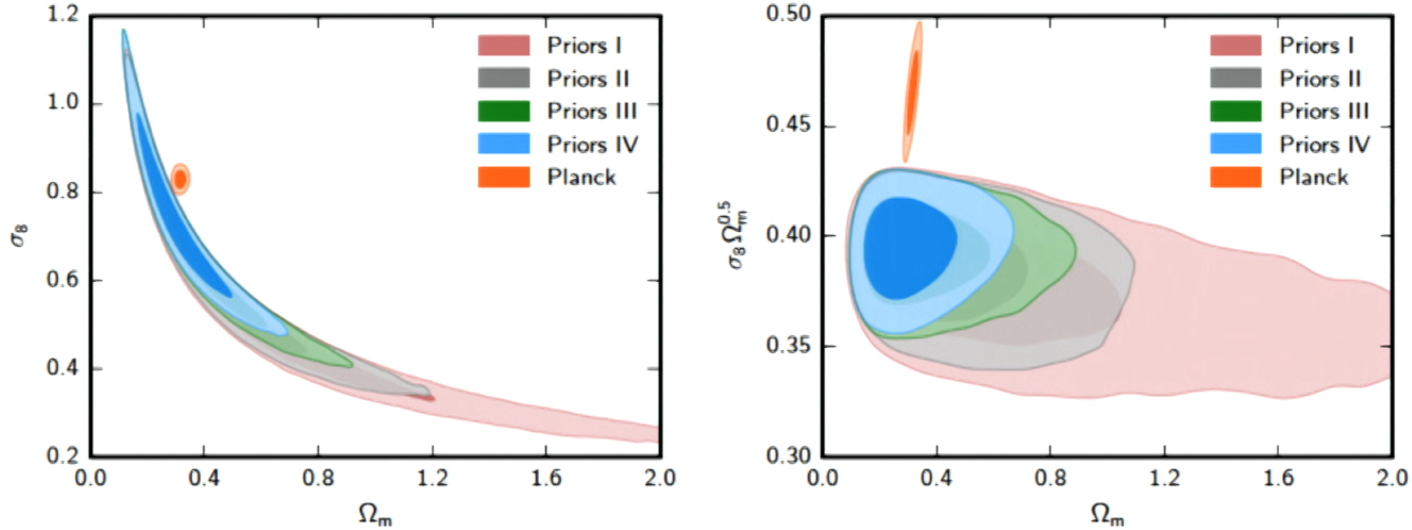
11

CFHTLenS (2008-2013)

- The state-of-the-art cosmological survey with 155 sq degrees, ugriz to i<24.7 (7σ extended source)
- Uses 5 yrs of data from the Deep, Wide and Pre-survey components of the CFHT Legacy Survey







~2σ tension with Planck is robust against relaxing cosmological priors (A_s, n_s, h, k_{pivot})

Extended CFHTLenS analysis includes all identified possible sources of systematics

Joudaki et al. arXiv:1601.05786

Intrinsic alignment: amplitude and z,L slope

Photometric redshifts errors

Baryonic physics and non-linear power spectrum (based on hydro simulations)

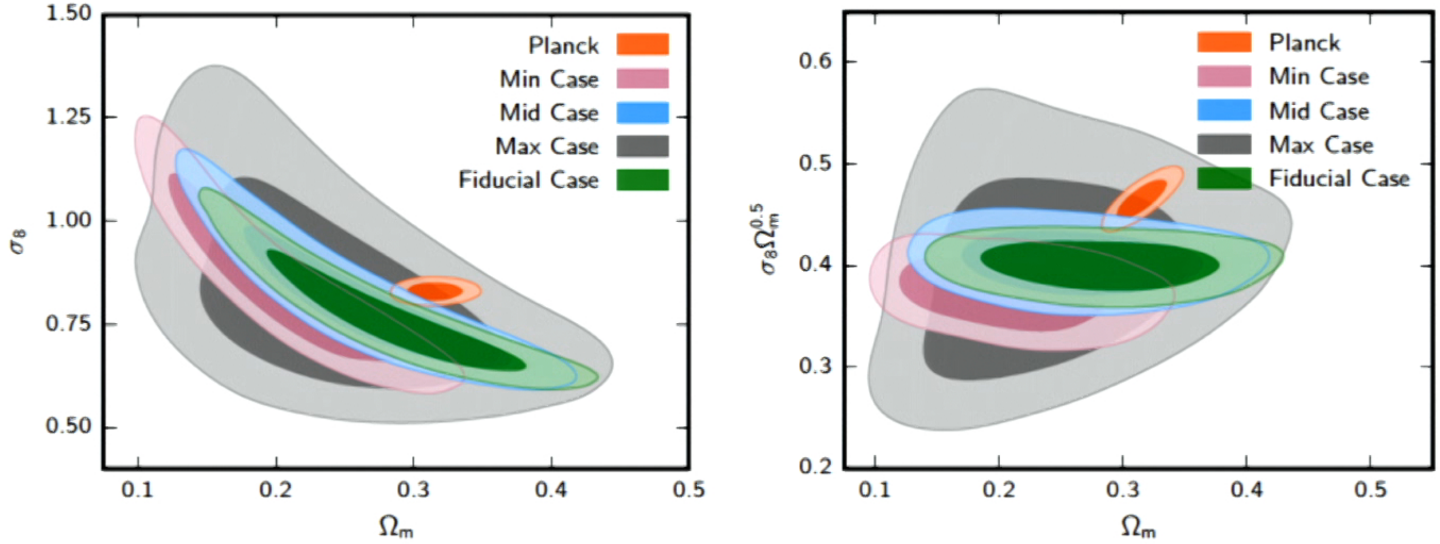
uses a range of large flat priors (non-informative) and strong priors (informative)

Mildly reduces tension

Increases tension

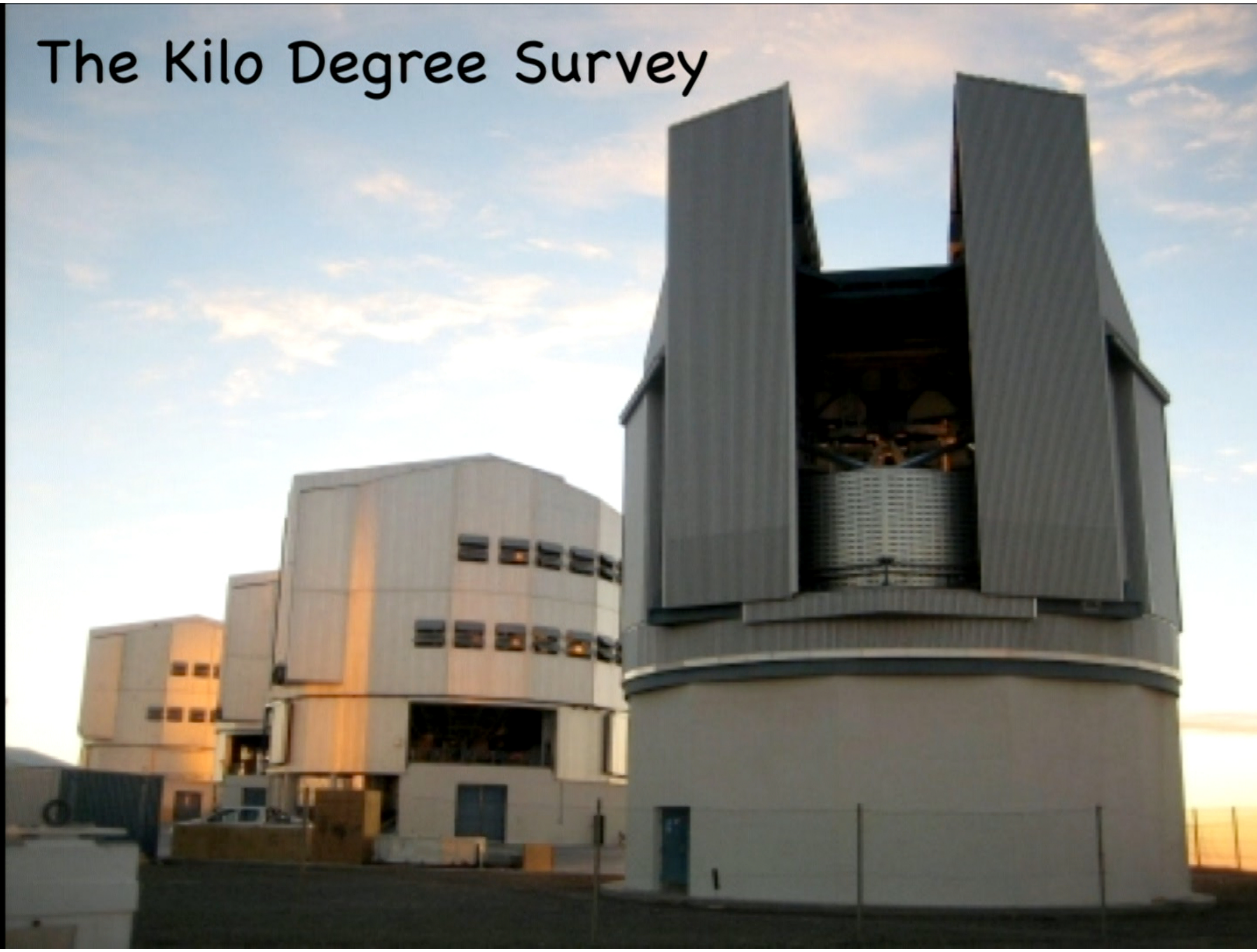
Not informative

Parameter	Symbol	Min Case	Mid Case	Max Case
IA amplitude	A	$-6 \to 6$	$-6 \to 6$	$-50 \to 50$
IA luminosity dependence	β	0	1.13 ± 0.25	$-50 \to 50$
IA redshift dependence	η	0	0	$-50 \to 50$
HMCODE feedback amplitude	$\log B$	$0.3 \to 0.6$	$0.3 \to 0.6$	$0 \to 2$
Photo-z bin 1	Δz_1	-0.045 ± 0.013	-0.045 ± 0.050	$-0.1 \to 0.1$
Photo-z bin 2	Δz_2	-0.014 ± 0.010	-0.014 ± 0.050	$-0.1 \to 0.1$
Photo-z bin 3	Δz_3	0.008 ± 0.008	0.008 ± 0.050	$-0.1 \to 0.1$
Photo-z bin 4	Δz_4	0.042 ± 0.017	0.042 ± 0.050	$-0.1 \to 0.1$
Photo-z bin 5	Δz_5	0.042 ± 0.034	0.042 ± 0.050	$-0.1 \to 0.1$
Photo-z bin 6	Δz_6	$-0.1 \to 0.1$	$-0.1 \to 0.1$	$-0.1 \to 0.1$
Photo-z bin 7	Δz_7	$-0.1 \to 0.1$	$-0.1 \to 0.1$	$-0.1 \to 0.1$
Angular scales	θ	All	All	Large



Tension remains. Two things to improve in the near-future:

Intrinsic alignment
Photometric redshifts


The Kilo Degree Survey

Improvements in the analysis

Compared to previous cosmic shear measurements (CFHTLenS) the KiDS-450 analysis has been improved on a number of key points:

- Better calibration of the shape measurement algorithm
- Direct calibration of the n(z) using deep spectroscopic surveys
- Parametric model for intrinsic alignments
- Model for the effects of baryon physics
- Analytic covariance matrix (tested against mock simulations)

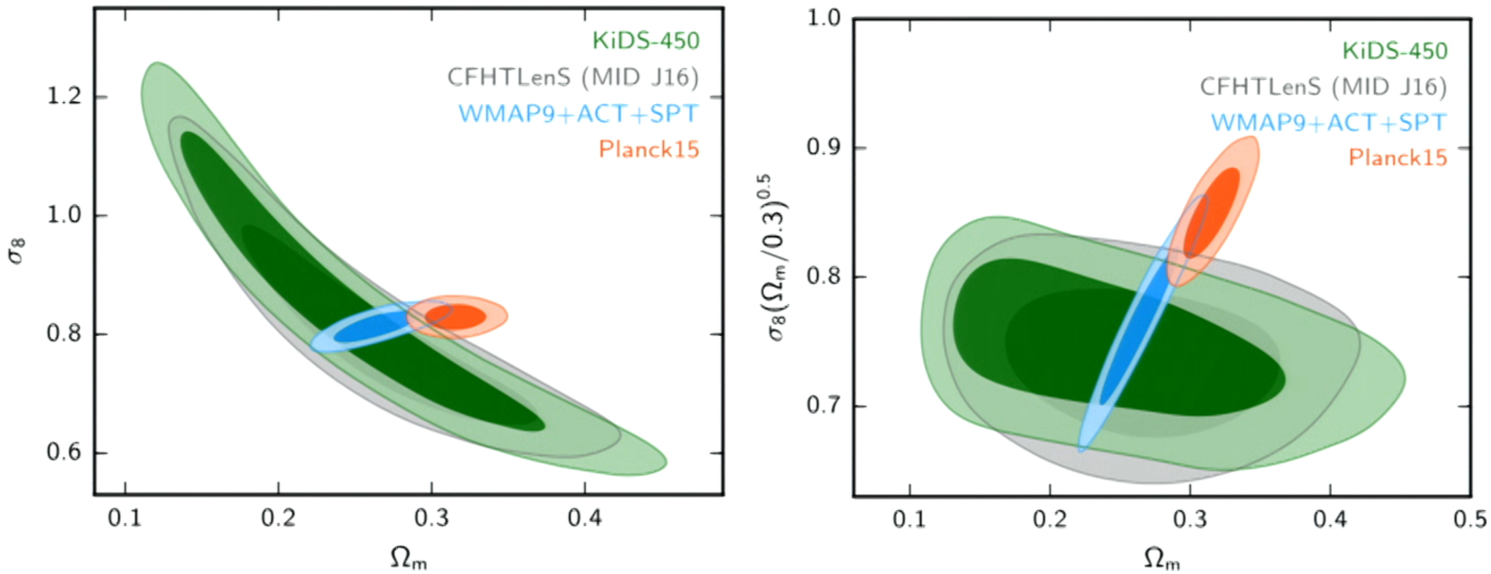
Blinding

SeqNr_field	e1_A	e2_A	weight_A	e1_B	e2_B	weight_B	e1_C	e2_C	weight_C
1231	-0.3011	-0.5646	12.2617	-0.2997	-0.562	12.29	-0.3026	-0.5673	12.2323
1254	-0.1818	-0.0908	1.5473	-0.1047	-0.0523	2.0391	-0.303	-0.1513	1.1986
1259	-0.3941	0.2877	13.9349	-0.3925	0.2865	13.9637	-0.3959	0.289	13.9028
1265	0.3964	0.0018	9.75	0.3685	0.0017	10.1129	0.4317	0.002	9.3431
1268	-0.0094	0.3362	5.9746	-0.0075	0.268	6.6912	-0.0118	0.4235	5.323
1269	0.0358	-0.0995	0.5932	0.0189	-0.0525	0.8166	0.0679	-0.1886	0.4308
1281	0.4033	0.3778	3.6237	0.3496	0.3275	3.8921	0.4461	0.4179	3.4456
1292	0.0733	-0.1648	15.3907	0.0733	-0.1648	15.3922	0.0733	-0.1648	15.3891
1296	-0.0282	0.6359	9.9038	-0.0278	0.627	9.9734	-0.0286	0.6448	9.8354
1298	-0.1557	0.0824	14.9894	-0.1554	0.0822	15.0046	-0.1561	0.0826	14.9716
1304	-0.5998	-0.1541	4.3661	-0.5587	-0.1435	4.5238	-0.6325	-0.1625	4.2519
1310	-0.4662	0.2721	11.3926	-0.4578	0.2672	11.497	-0.4754	0.2775	11.2814
1316	0.189	0.174	15.3931	0.189	0.174	15.3942	0.189	0.174	15.3919

Blinding generated and controlled by M. Bartelmann

KiDS

KiDS-450: Results (blind-1)

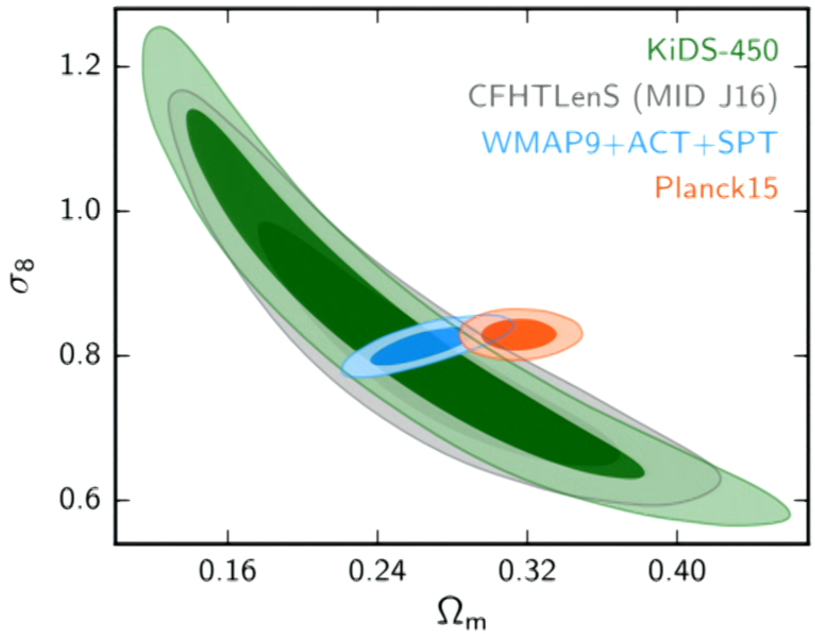


- S_8=0.745±0.039 2.3σ discrepancy with Planck

Hildebrandt, Viola et al. (2017)

KiDS

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 — $2.7\sigma_{KiDS}$ in S_8
  (2.3σ discrepancy in full parameter space)

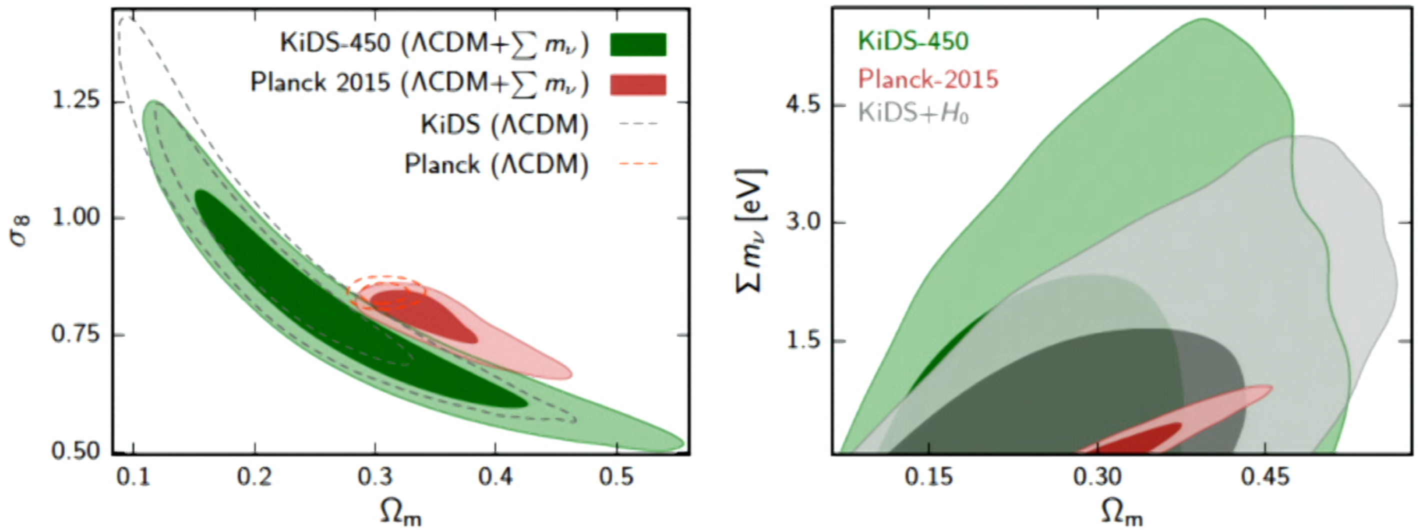
Hildebrandt, Viola et al. (2017)

KiDS-450: Testing extensions to the standard cosmological model (Joudaki et al arXiv:1610.04606)

$S_8 = \sigma_8 \Omega_m^{0.5}$

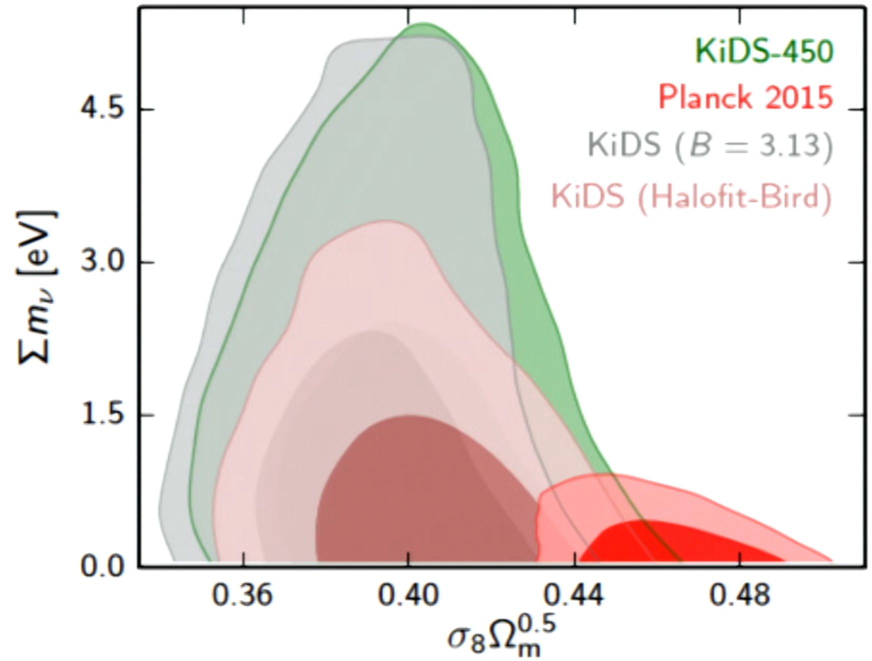
Table 3. Assessing the level of concordance between KiDS and Planck as quantified by $T(S_8)$ defined in equation (2), and $\log \mathcal{I}$ (base 10) defined in equation (3). The ΛCDM results with fiducial treatment of the systematic uncertainties differ marginally from Hildebrandt et al. (2016) due to our wider priors on the Hubble constant and baryon density.

Model	$T(S_8)$	$\log \mathcal{I}$
ΛCDM		
— fiducial systematics	2.1σ	-0.63
— extended systematics	1.8σ	-0.70
— large scales	1.9σ	-0.62
Neutrino mass	2.4σ	-0.011
Curvature	3.5σ	-1.7
Dark energy (constant w)	0.89σ	0.99
Dark energy ($w_0 - w_a$)	0.91σ	0.82
Curvature + dark energy (constant w)	2.5σ	-0.59
Modified gravity (fiducial scales)	0.49σ	0.42
Modified gravity (large scales)	0.83σ	1.4
Running of the spectral index	2.3σ	-0.66



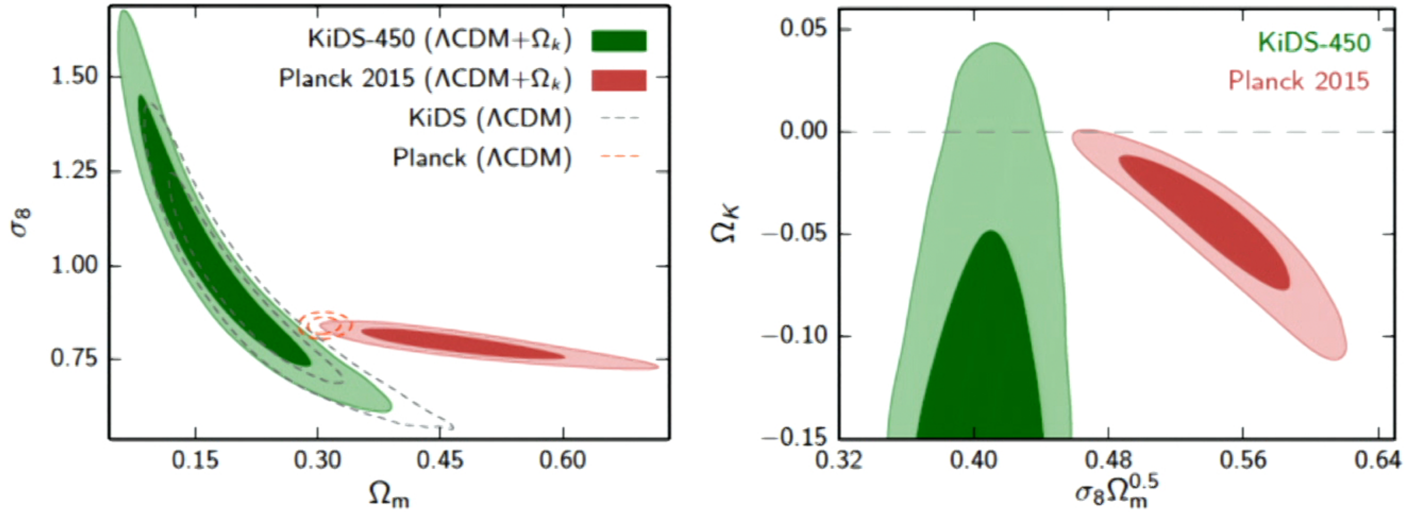
Neutrino mass: total mass free + inf(A_{IA}+B) (HMCODE)

Note: this free parameter is not required by the data



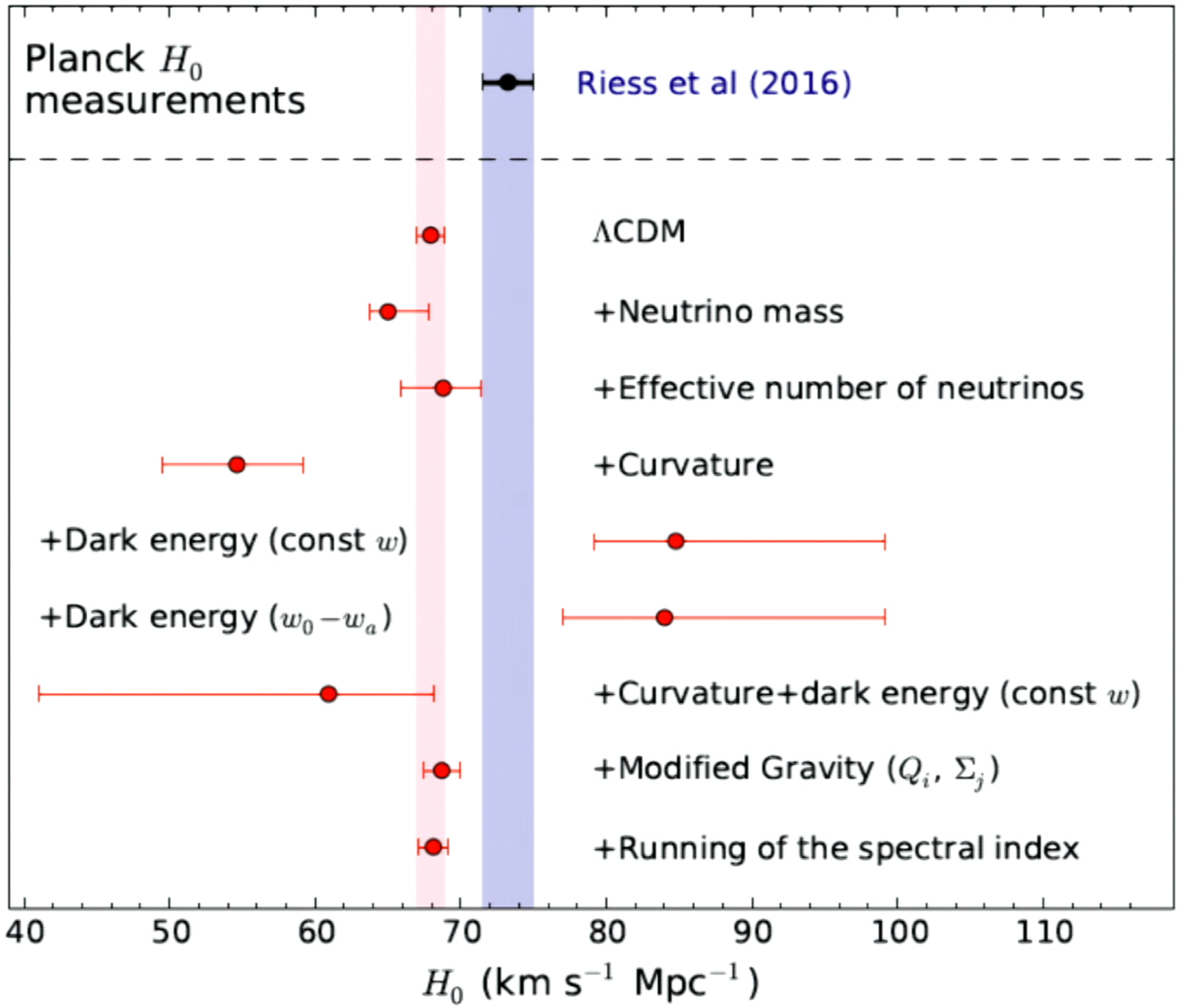
Effect of baryons: DM-only scenario (B=3.13, i.e. DM-only) versus free B (green) and HALOFIT

DM-only increases tension with Planck

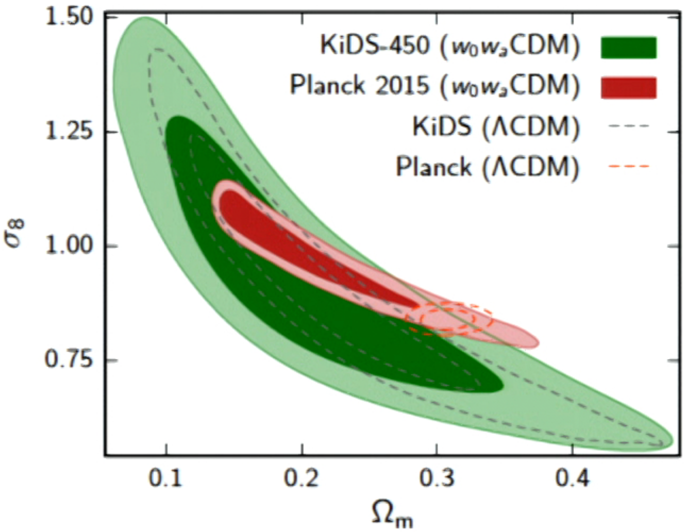


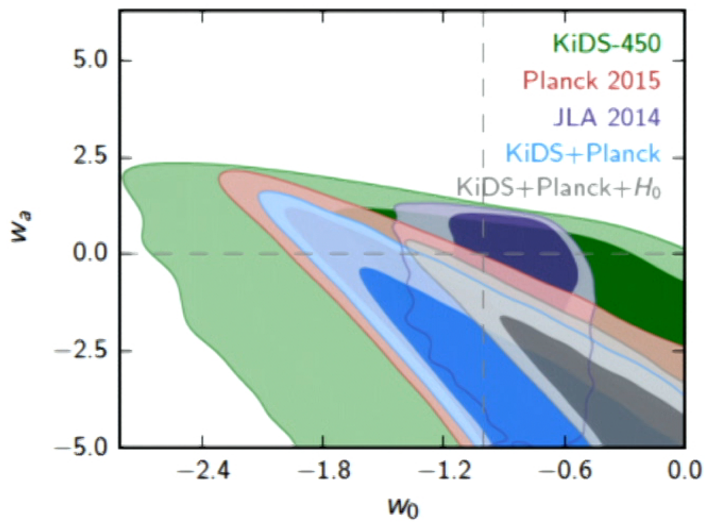
Curvature: H_0 varied to keep the angular sound horizon the same

KiDS contours move along the degeneracy direction, Planck is shifted, tension rises



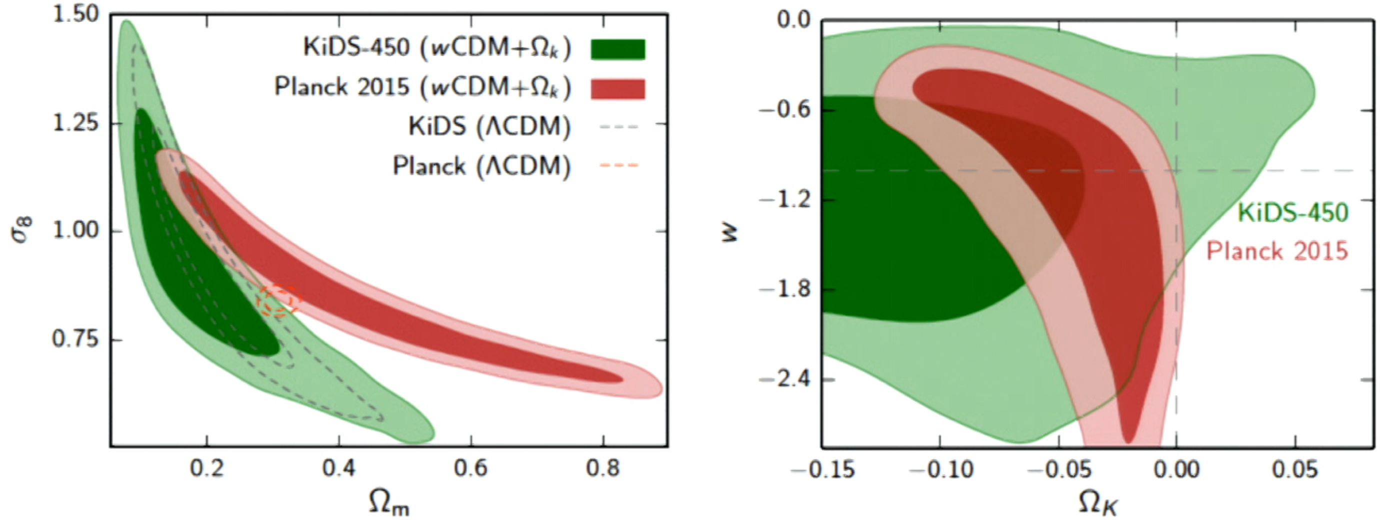
Planck H_0 measurements
Riess et al (2016)
ΛCDM
+Neutrino mass
+Effective number of neutrinos
+Curvature
+Dark energy (const w)
+Dark energy ($w_0 - w_a$)
+Curvature+dark energy (const w)
+Modified Gravity (Q_i, Σ_j)
+Running of the spectral index
40
50
60
70
80
90
100
110
H_0 (km s^{-1} Mpc^{-1})





Evolving dark energy: $w(a) = w_0 + (1-a)w_a$

Tension reduced, but KiDS+Planck favors non-LCDM, in contrast to JLA (Joint Light-curve Analysis) and CFHTLenS+Planck (Ade et al 2016) at the ~3σ level.



Curvature and dark energy: the increased tension from curvature and w ~cancel each other. This results in a poorly constrained H_0: $0.40 < h < 0.91$ (95%) and a loss of constraining power in the (w,Ω_k) due to the underlying tension

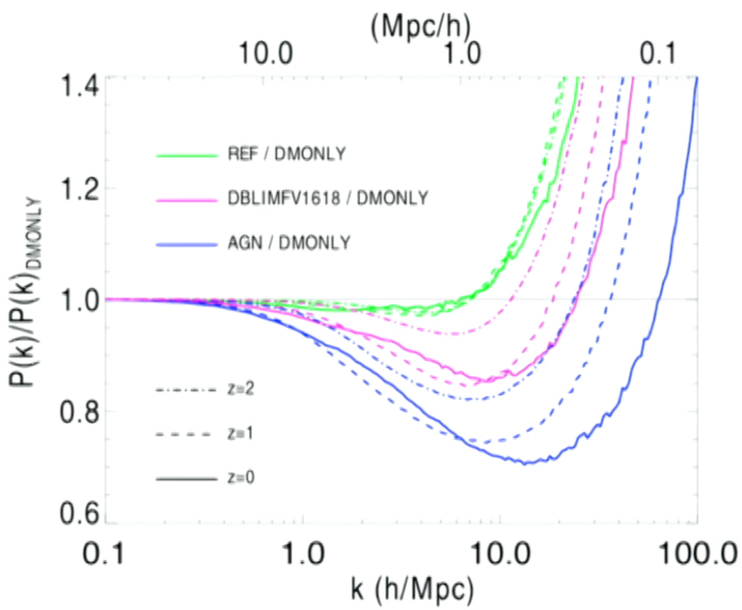
-Planck and low-z lensing is in mild tension with vanilla LCDM

-Releasing curvature and w=-1 helps, but creates other tensions (H_0). **This is $< 3\sigma$ so more data are needed.**

-Instrumental and measurement systematics controlled at 1% level in S_8 and likely don't have any role in the tension.

-Going to higher el values will significantly improve the constraints, but astrophysical uncertainties (baryons, NL modeling, IA) still need work (IA ideally shoud be model independent).

Effects of baryons on the matter power spectrum



Van Daalen et al, 2011
Semboloni et al, 2011,2012

Cross-correlation gal lensing-CMB lensing: effects of neutrino mass and baryons

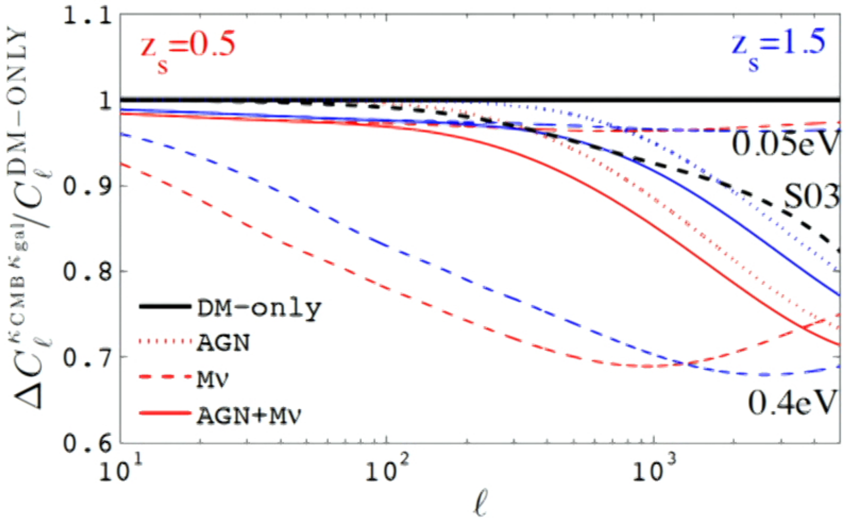
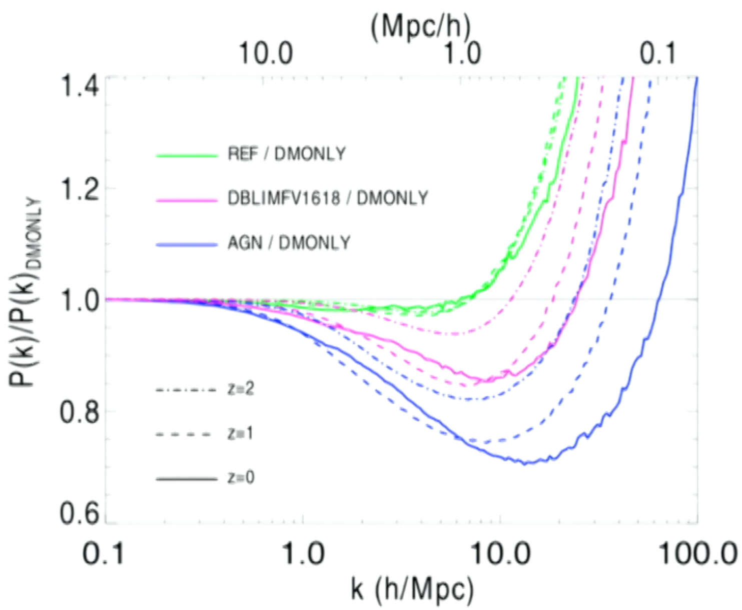


Figure 7. Fractional effect of the AGN baryon feedback and massive neutrinos on the cross-spectra, for different combinations of source planes. The red solid line shows the combined effect on the cross-spectrum for sources placed on a single plane at $z_s = 0.5$. The effect of 0.05eV massive neutrinos and AGN feedback are shown separately by the upper dashed and the dotted line (also in red). The lower dashed redline shows the impact of 0.4eV neutrinos. Blue lines show the same quantities, but for sources placed at $z_s = 1.5$. The dashed black line shows the ratio between the predictions from Smith et al. (2003) and that of Takahashi et al. (2012).

Harnois-Deraps et al
https://arxiv.org/abs/1703.03383

Effects of baryons on the matter power spectrum



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Cross-correlation gal lensing-CMB lensing: effects of neutrino mass and baryons

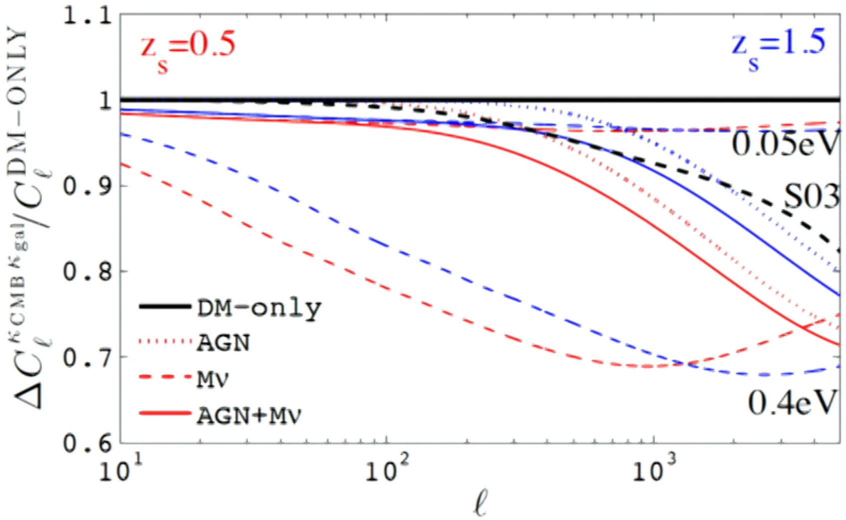
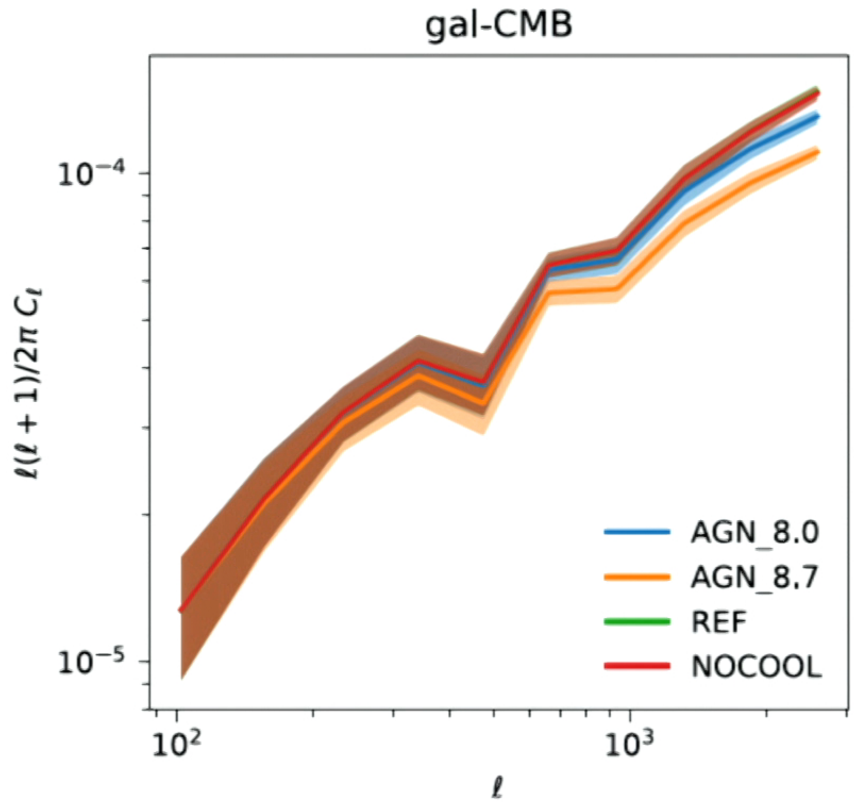


Figure 7. Fractional effect of the AGN baryon feedback and massive neutrinos on the cross-spectra, for different combinations of source planes. The red solid line shows the combined effect on the cross-spectrum for sources placed on a single plane at $z_s = 0.5$. The effect of 0.05eV massive neutrinos and AGN feedback are shown separately by the upper dashed and the dotted line (also in red). The lower dashed redline shows the impact of 0.4eV neutrinos. Blue lines show the same quantities, but for sources placed at $z_s = 1.5$. The dashed black line shows the ratio between the predictions from Smith et al. (2003) and that of Takahashi et al. (2012).

Harnois-Deraps et al
https://arxiv.org/abs/1703.03383

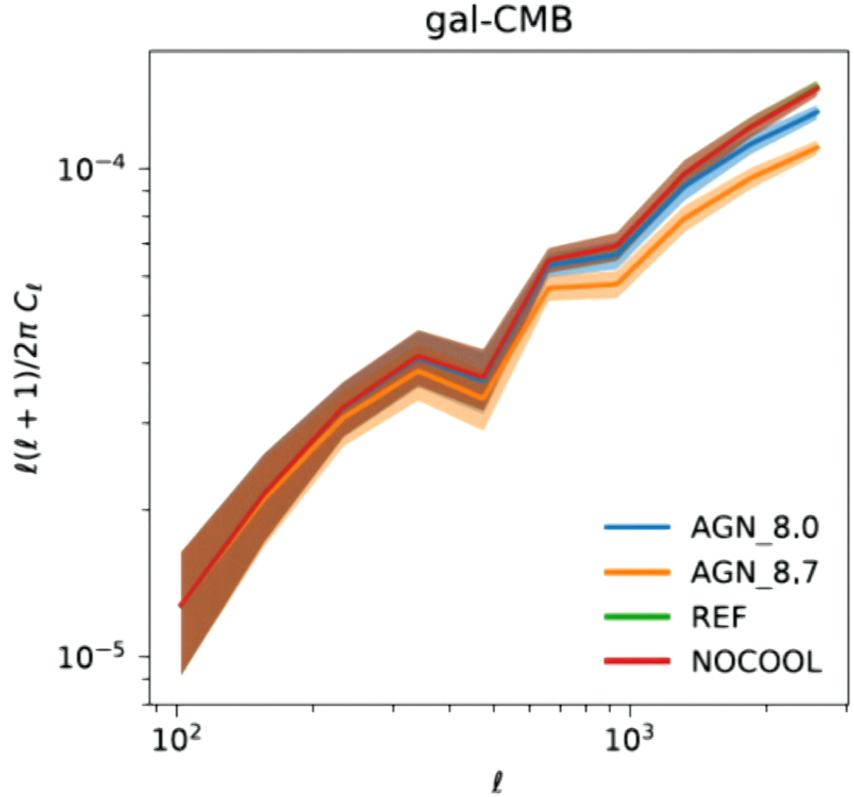
36

Cross-correlation gal lensing-CMB lensing: effects of baryons



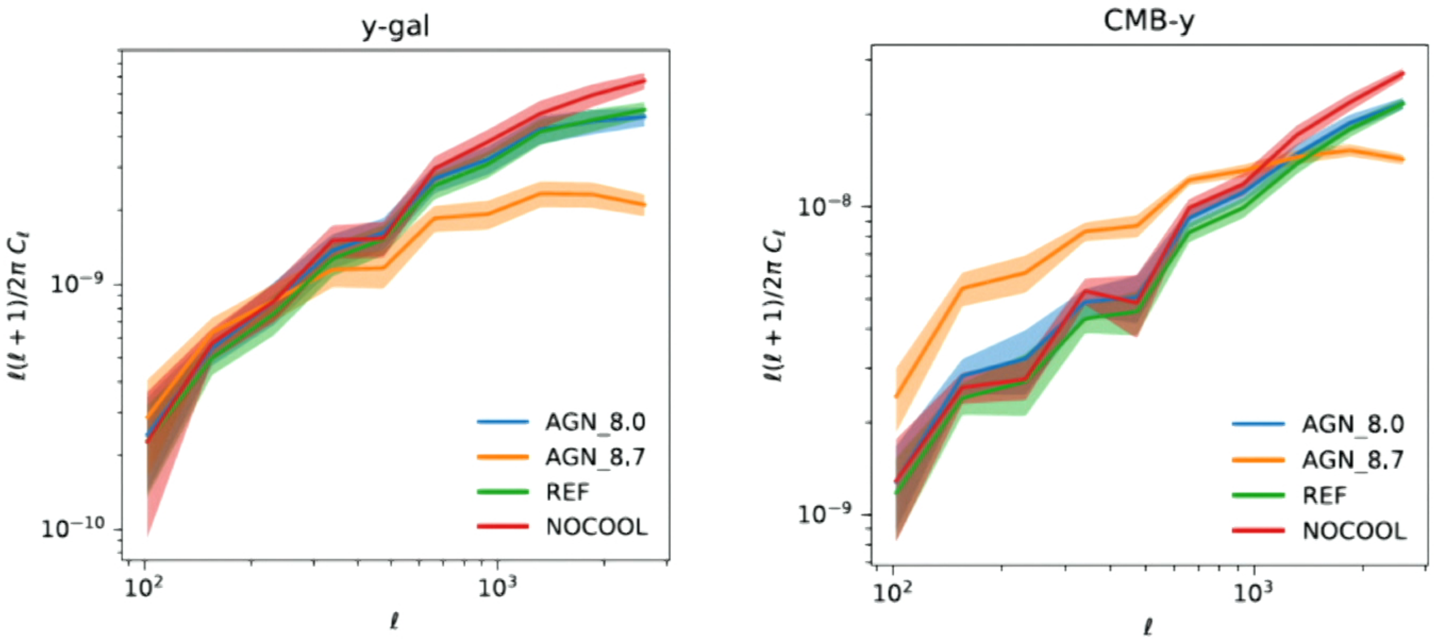
T. Troester based on the OWLS (OverWhelmingly Large Simulations) by McCarthy et al

Cross-correlation gal lensing-CMB lensing: effects of baryons

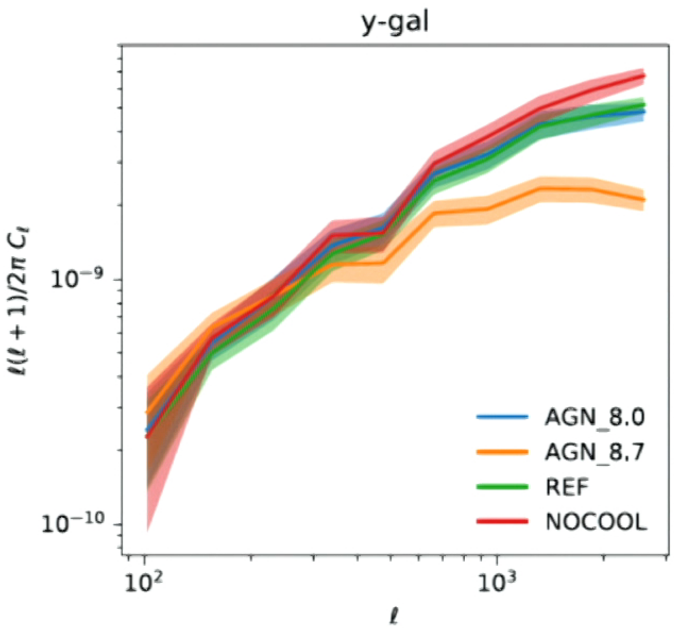


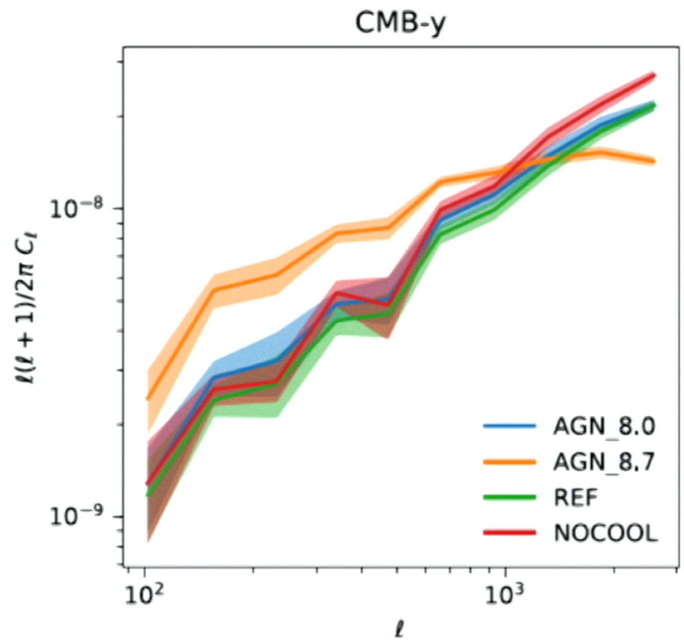
T. Troester based on the OWLS (OverWhelmingly Large Simulations) by McCarthy et al

Cross-correlation of thermal Sunyaev-Zeldovich and lensing

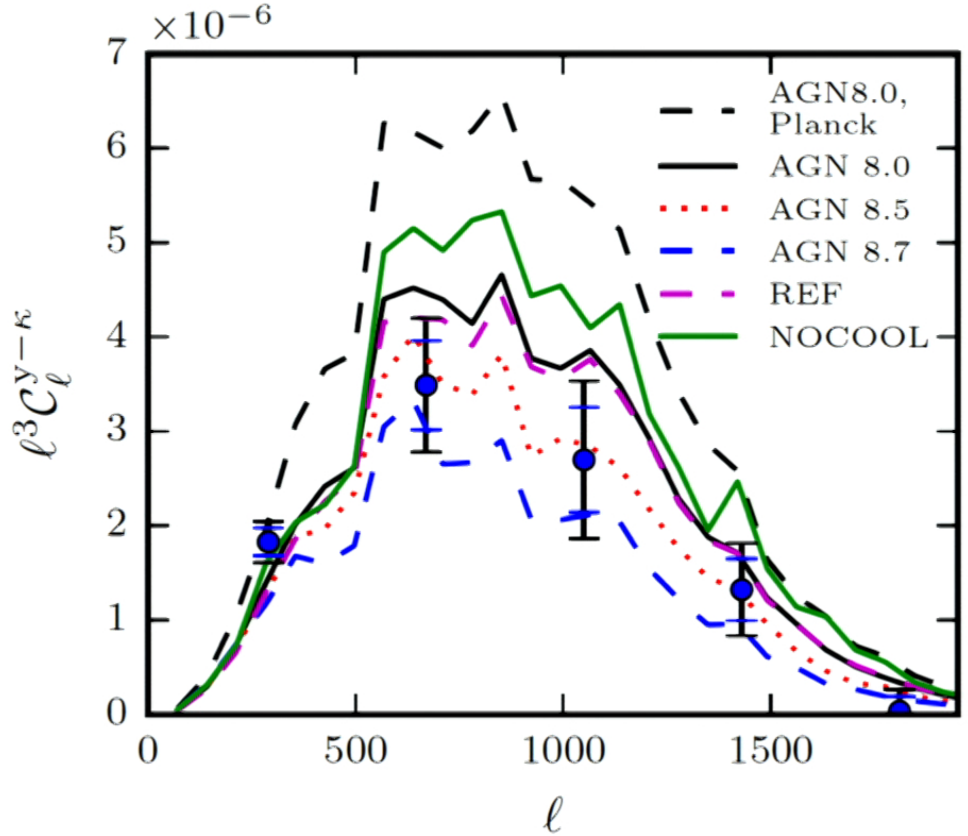


Cross-correlation of thermal Sunyaev-Zeldovich and lensing



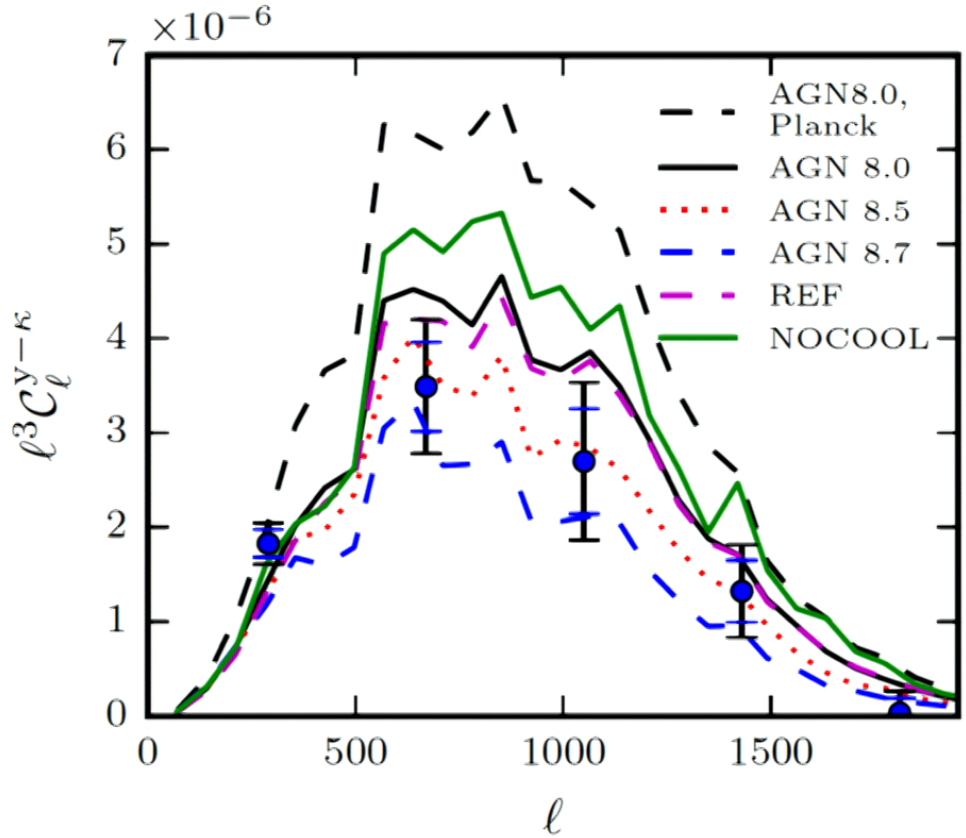


Cross-correlation of thermal Sunyaev-Zeldovich and lensing: RCSLenS



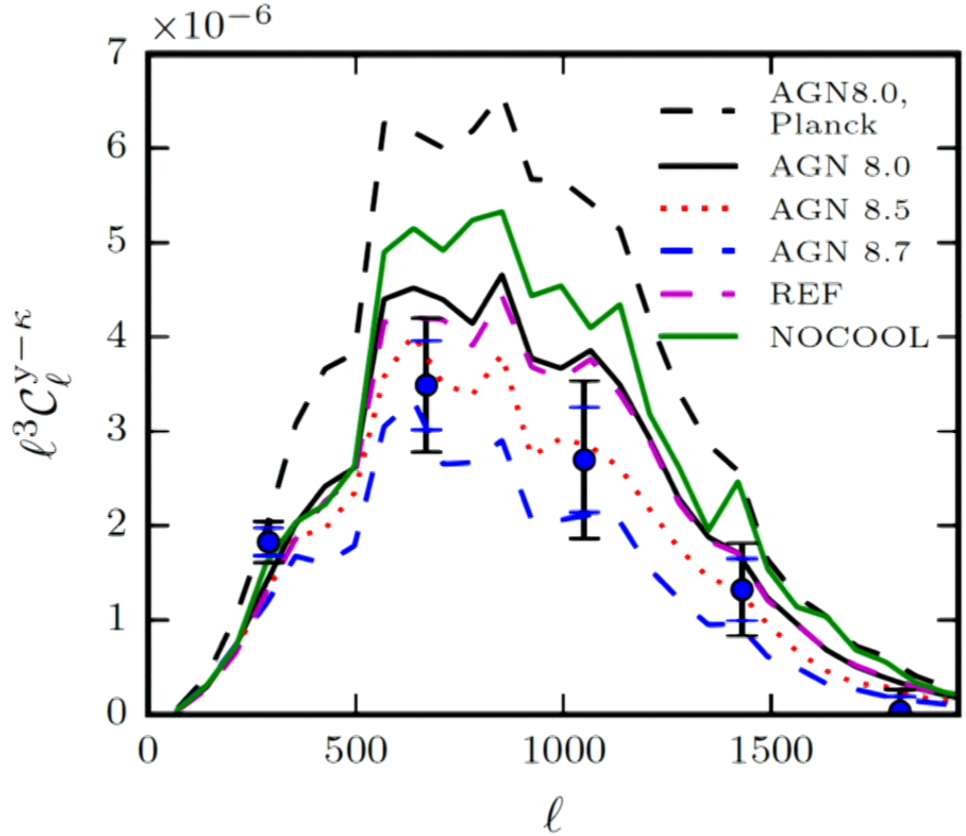
Hojjati et al. 2014 (arXiv:1412.6051)

Cross-correlation of thermal Sunyaev-Zeldovich and lensing: RCSLenS



Hojjati et al. 2014 (arXiv:1412.6051)

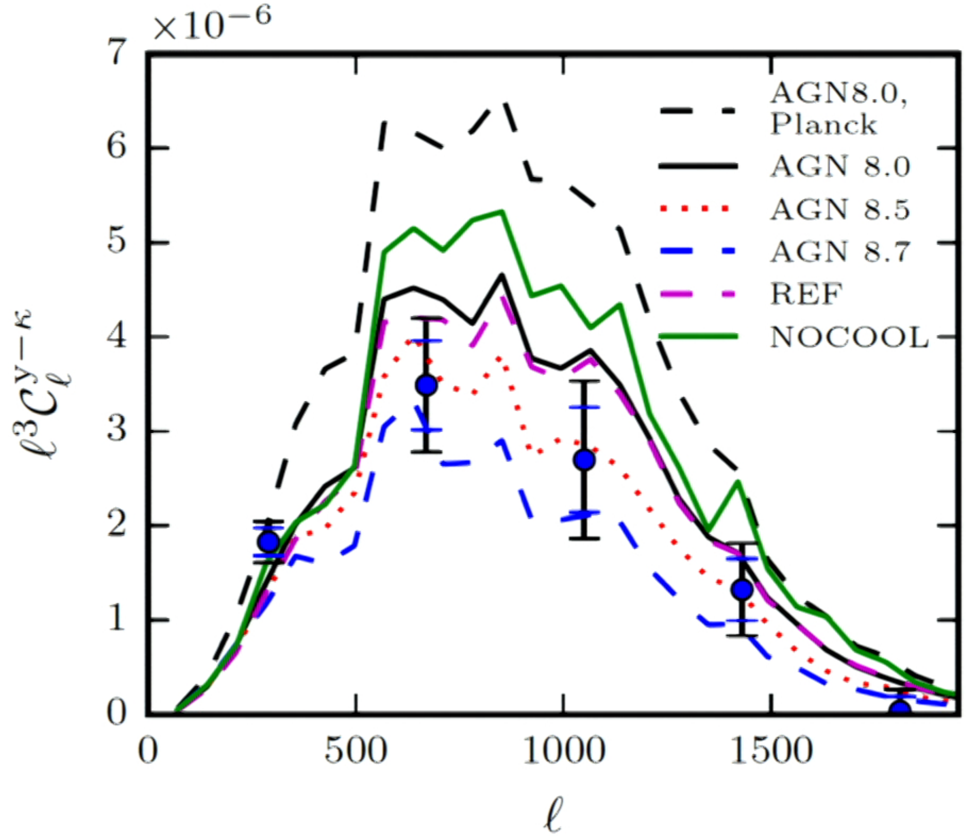
Cross-correlation of thermal Sunyaev-Zeldovich and lensing: RCSLenS



Hojjati et al. 2014 (arXiv:1412.6051)

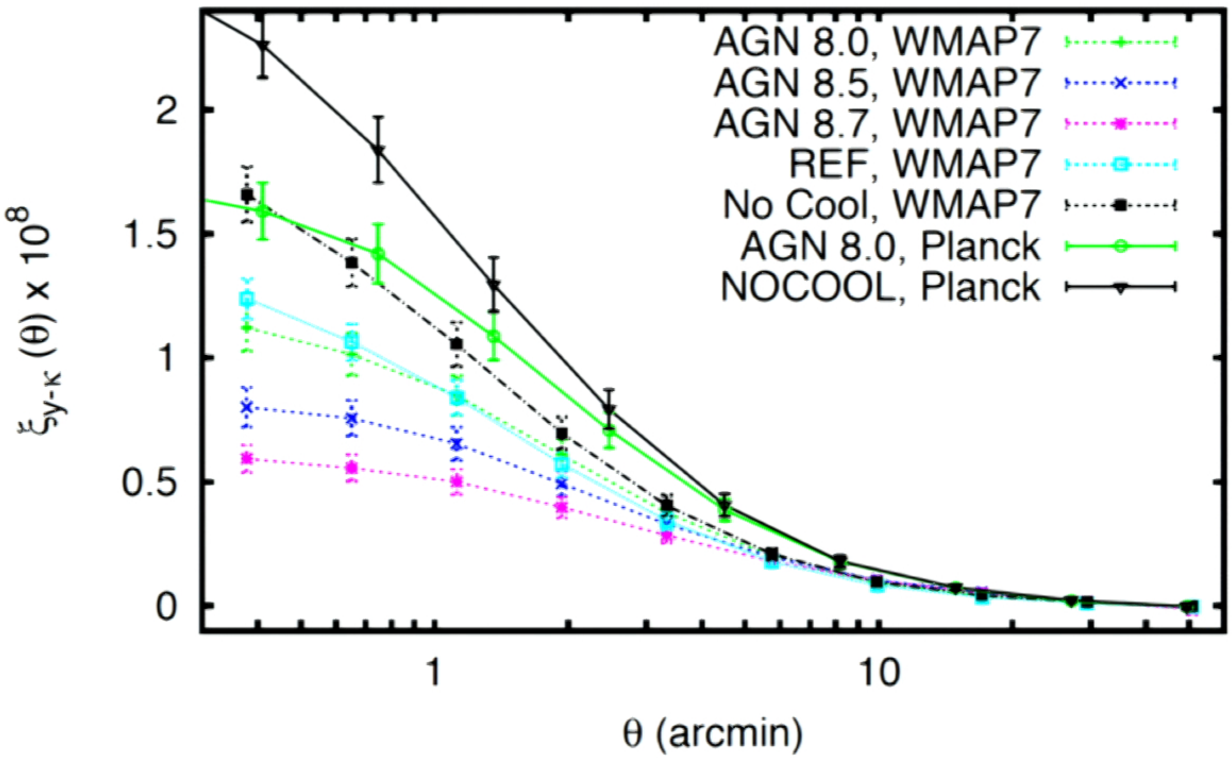
39

Cross-correlation of thermal Sunyaev-Zeldovich and lensing: RCSLenS



Hojjati et al. 2014 (arXiv:1412.6051)

-> Excellent prospect with e.g. AdvACT (30-230 GHz, 10<el<10000)



Hojjati et al. 2014 (arXiv:1412.6051)

Tomographic cross-correlation between KiDS-450 gal lensing and CMB lensing

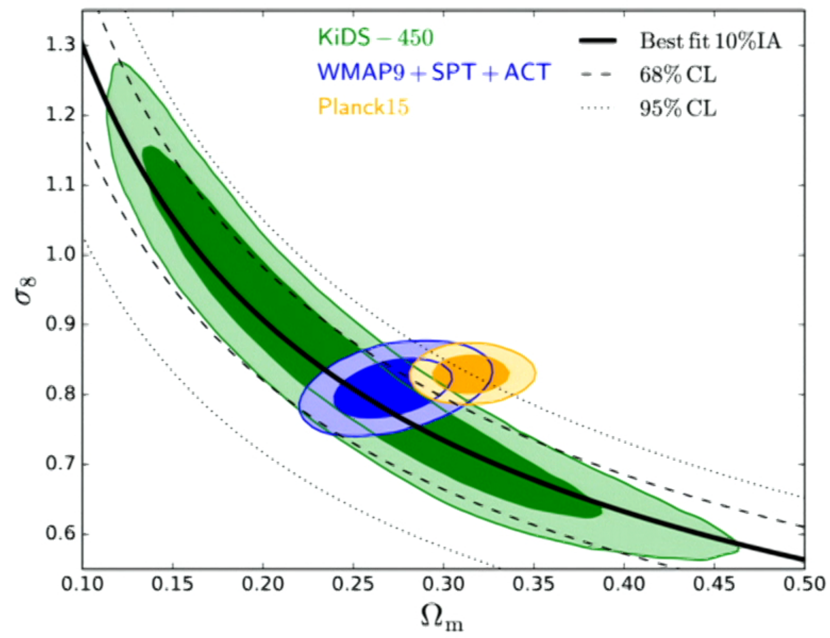


Figure 9. Same as Fig. 8, but here assuming 10% contamination from IA in the cross-correlation measurement (equation 17), consistent with both the 'HT-IA' and the 'f_{red}-IA' models.

Harnois-Deraps et al https://arxiv.org/abs/1703.03383

41

Take away remarks...

The next step is to see if the ~2.5σ tension with Planck survives future analysis (full KiDS, DES, LSST, Euclid)

Gravitational lensing combined with baryonic can simultaneously constrain astrophysics and cosmological parameters.

Baryonic effects kick in at large scale el~100-200 for the gal lensing-CMB lensing cross-correlation.

Unless extremely conservative cuts in k space are applied, baryonic physics must be modeled to maximise SNR and break degeneracies.

There is tremendous **synergy** between lensing and multiwavelength surveys (CHIME, tSZ, CMB lensing, CIB, Xray). Cross-correlations is the key to understanding high k modes.

Additional information can be found in high **order statistics** and **tomography**.