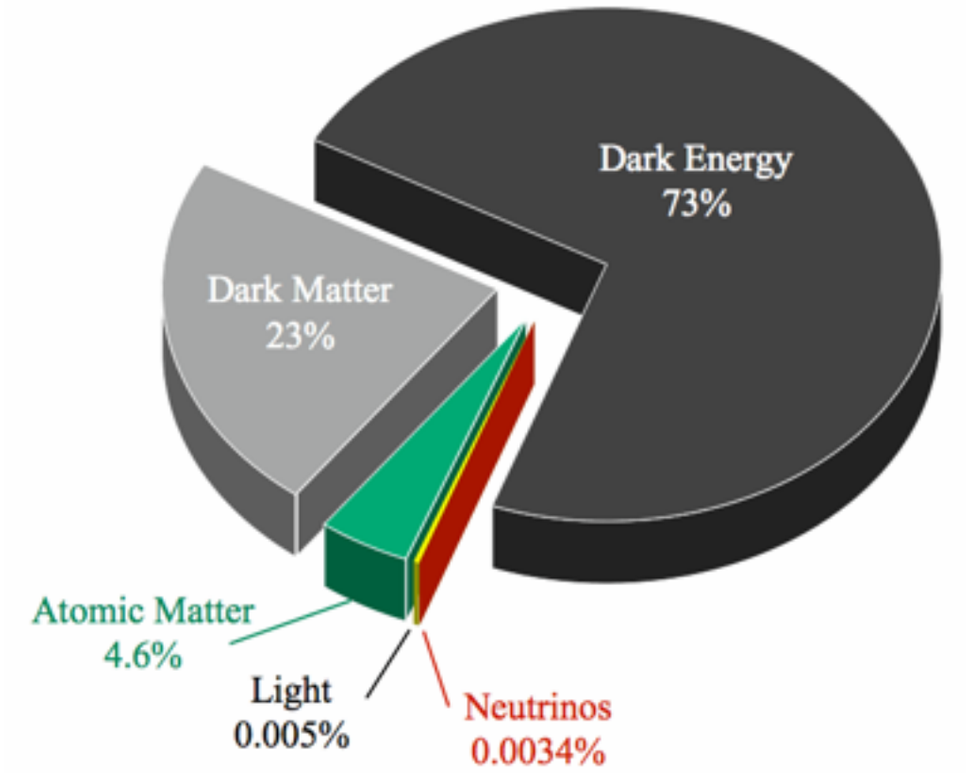
News from The Dark Energy Survey

Aurélien Benoit-Lévy

Institut d'Astrophysique de Paris

Journées LSST France - 20-22 Mars 2017

What is the physical cause of cosmic acceleration?



Dark Energy or modification of General Relativity?

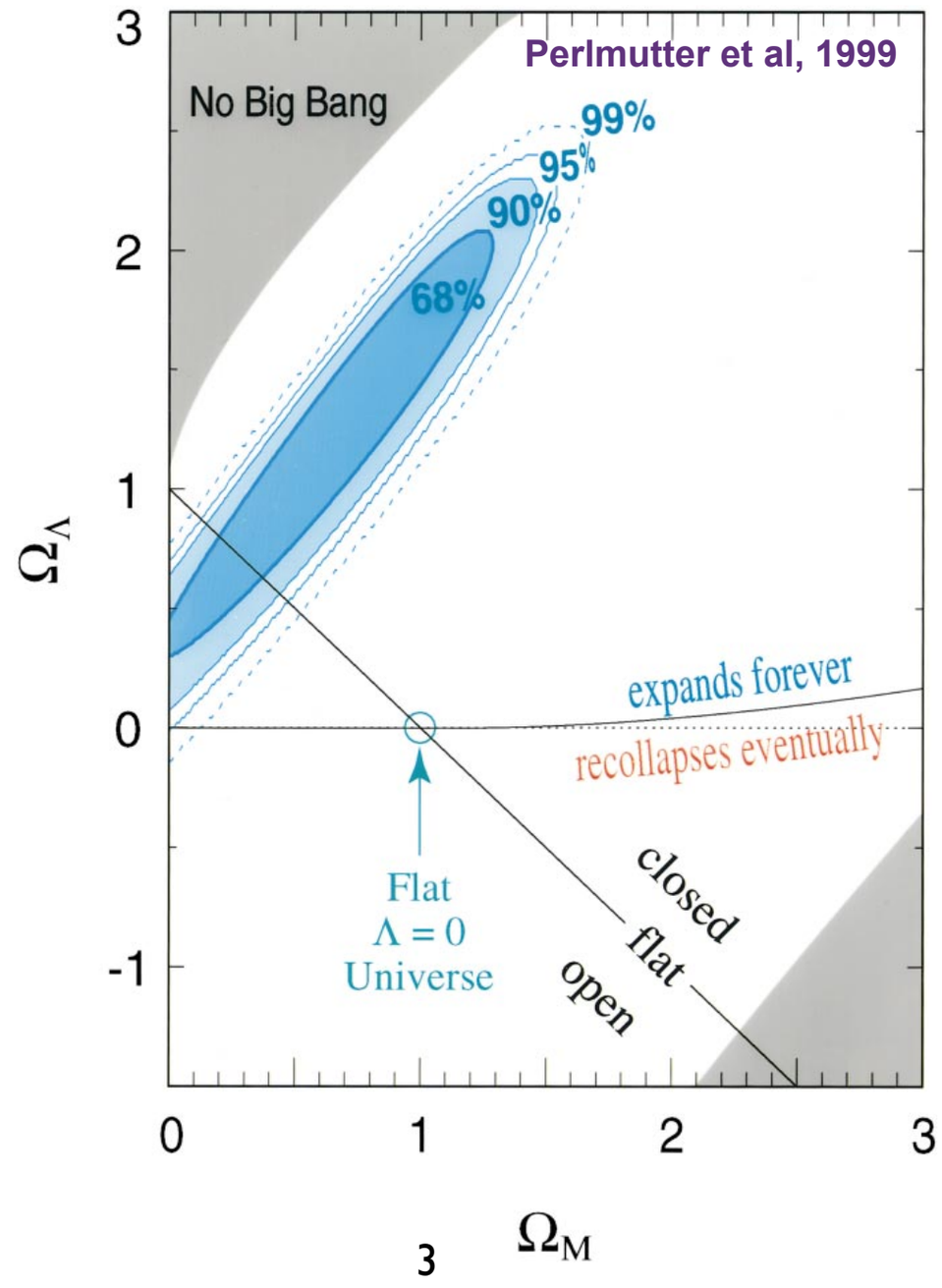
If Dark Energy, is it Λ (the vacuum) or something else?
What is the DE equation of state parameter *w* and (how) does it evolve?

Dark Energy!

Type Ia Supernovae are the main indication for the acceleration of the expansion

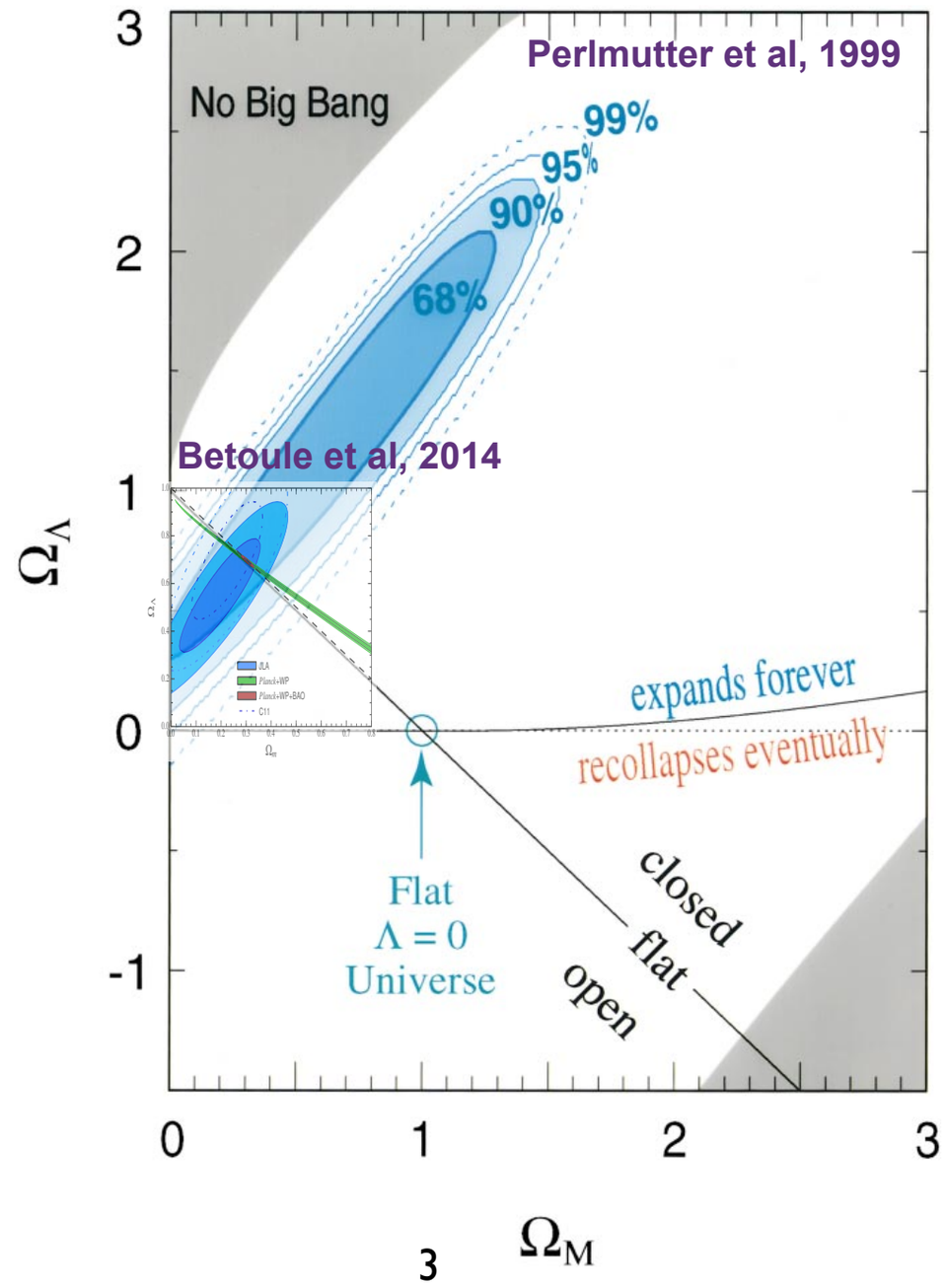
Dark Energy!

Type Ia Supernovae are the main indication for the acceleration of the expansion



Dark Energy!

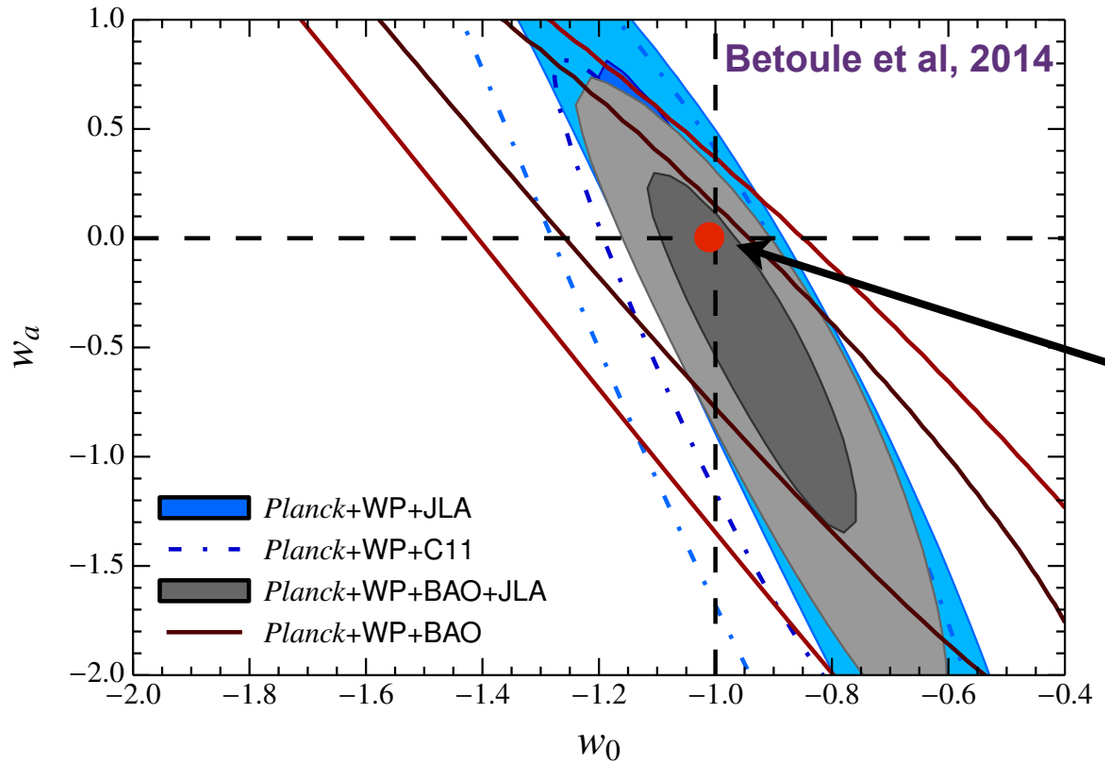
Type Ia Supernovae are the main indication for the acceleration of the expansion



What could be Dark Energy?

Pure cosmological constant?, vacuum energy?, quintessence?, Modification of gravity?, ...

$$p = w\rho \qquad\qquad w(a) = w_0 + w_a(1-a)$$



Pure cosmological constant

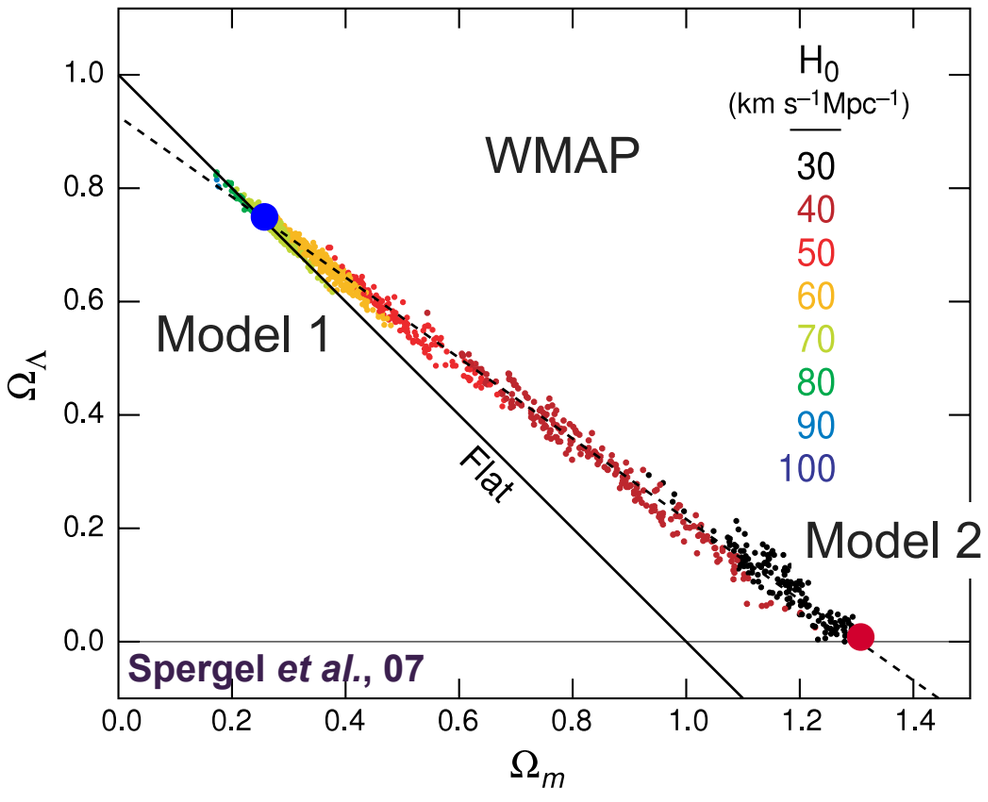
Best constraint on DE currently brought by SNIa.

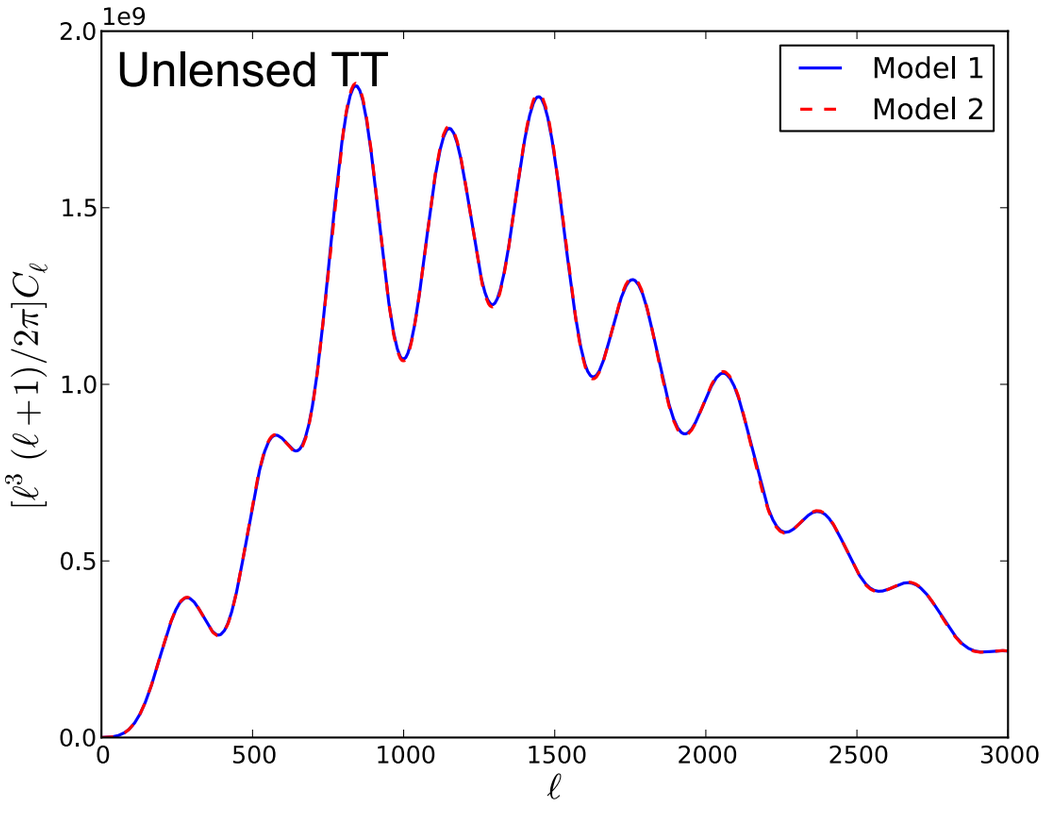
Parameter degeneracies

Dark Energy has no direct effect on the CMB anisotropies at recombination.
Its effect are mainly geometrical but are degenerated with other parameters

Parameter degeneracies

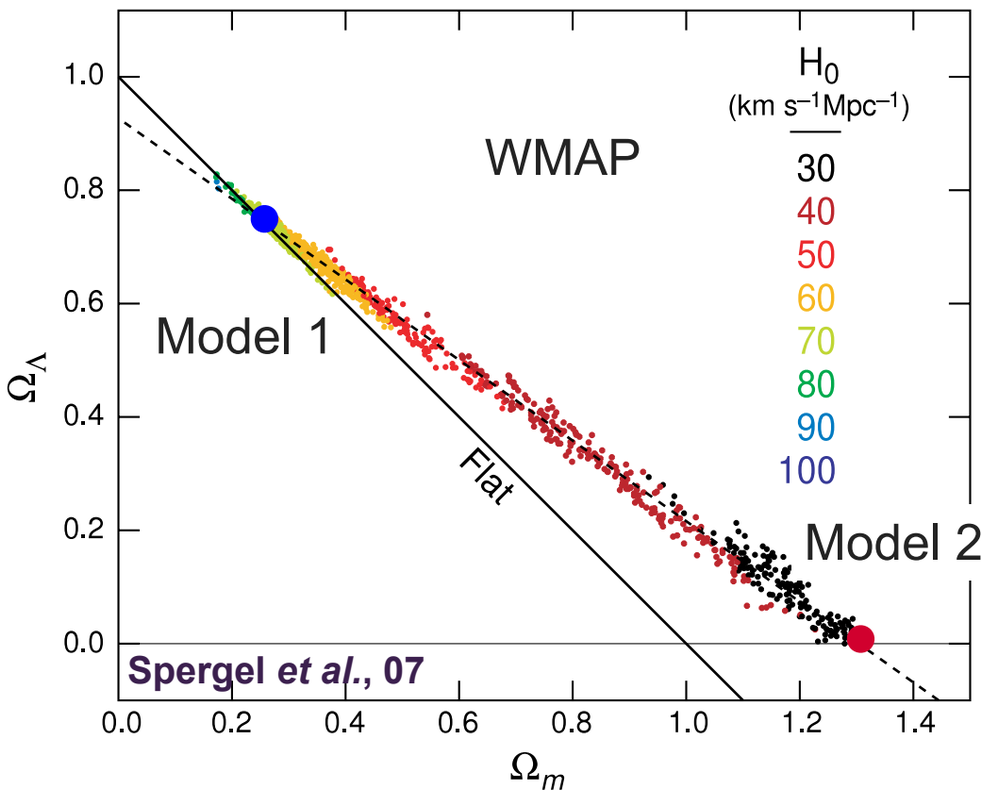
Dark Energy has no direct effect on the CMB anisotropies at recombination.
Its effect are mainly geometrical but are degenerated with other parameters

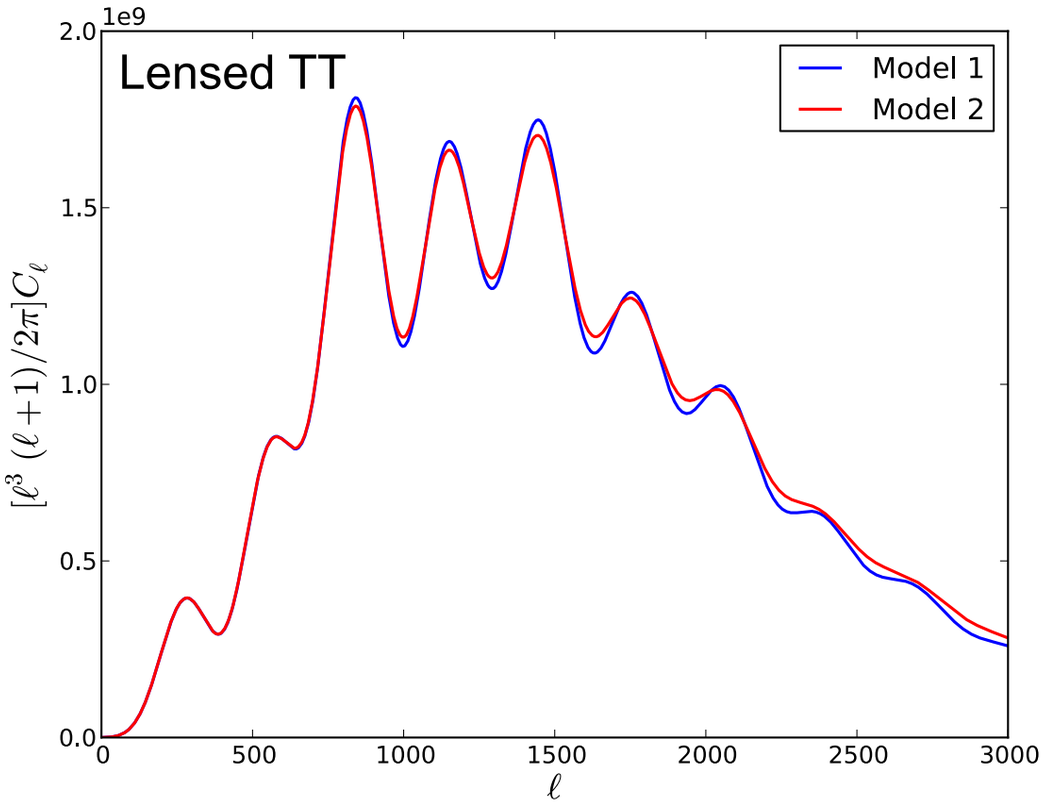




Parameter degeneracies

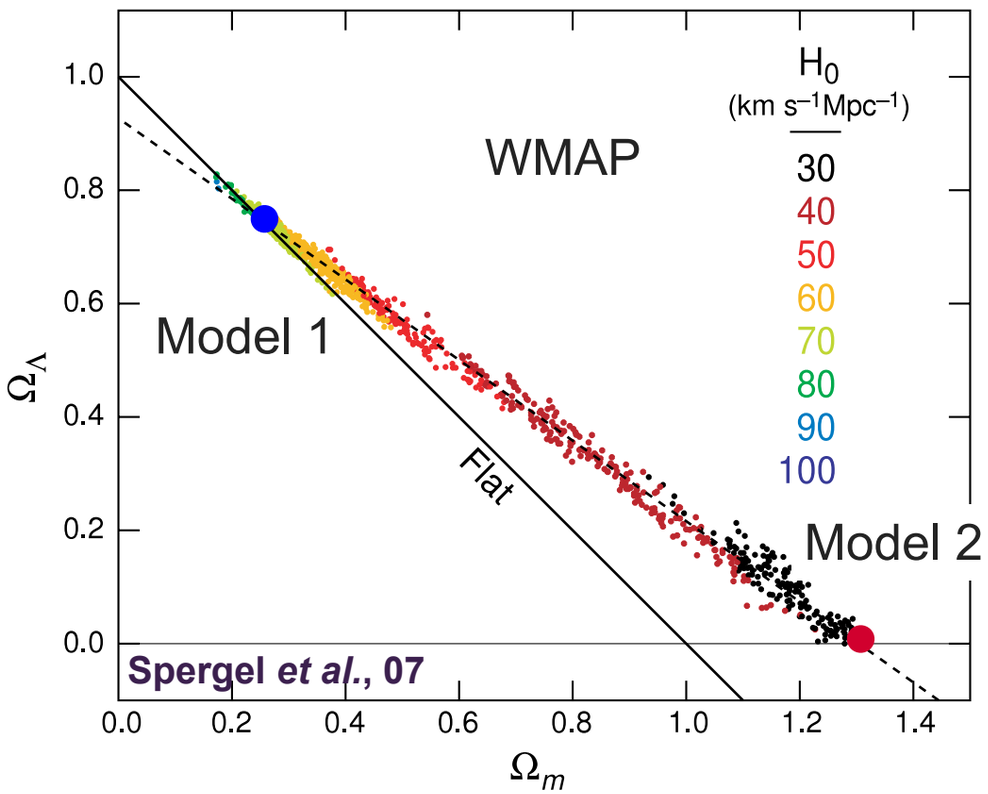
Dark Energy has no direct effect on the CMB anisotropies at recombination.
Its effect are mainly geometrical but are degenerated with other parameters

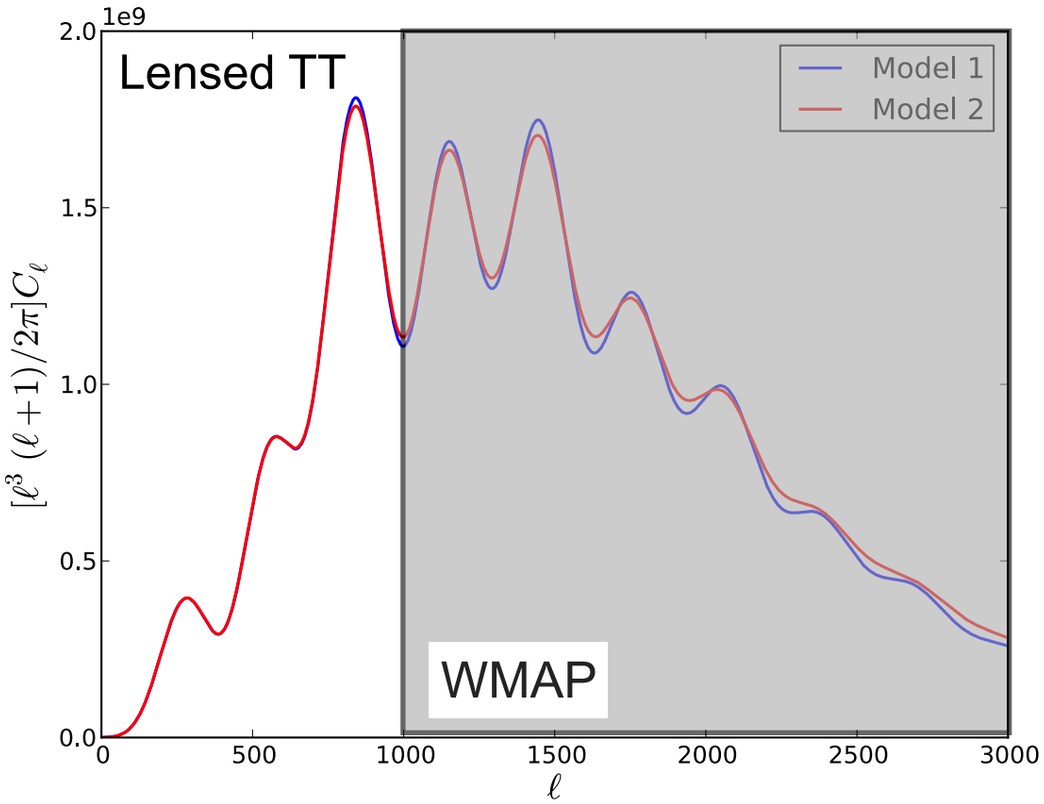




Parameter degeneracies

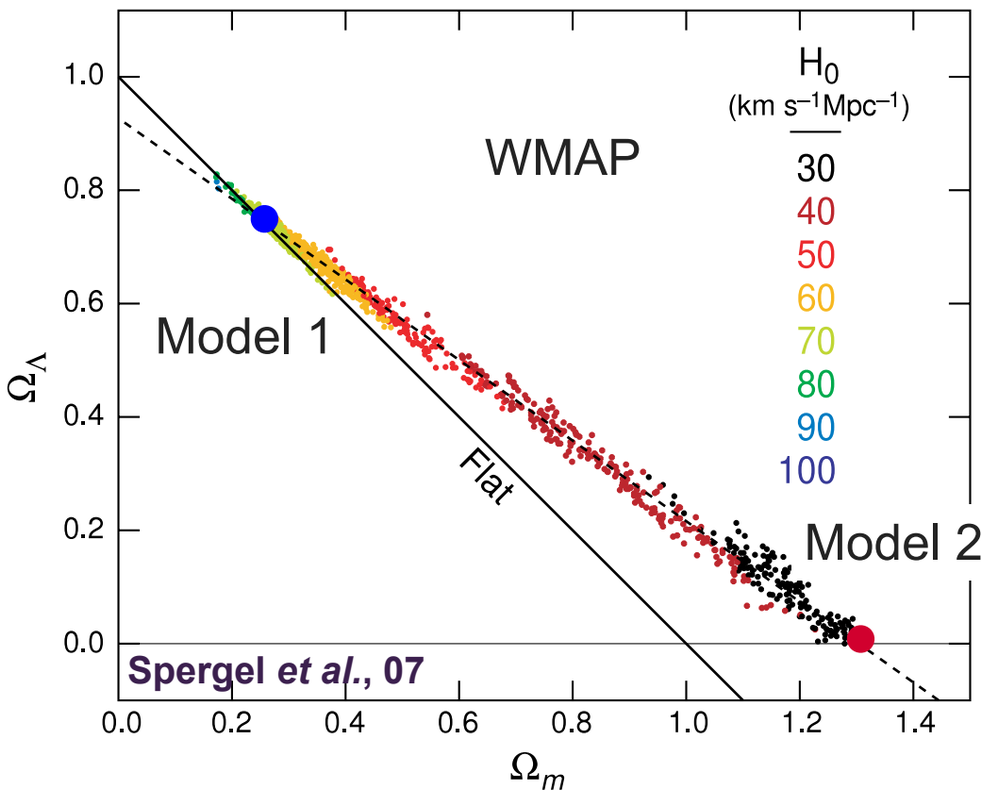
Dark Energy has no direct effect on the CMB anisotropies at recombination.
Its effect are mainly geometrical but are degenerated with other parameters

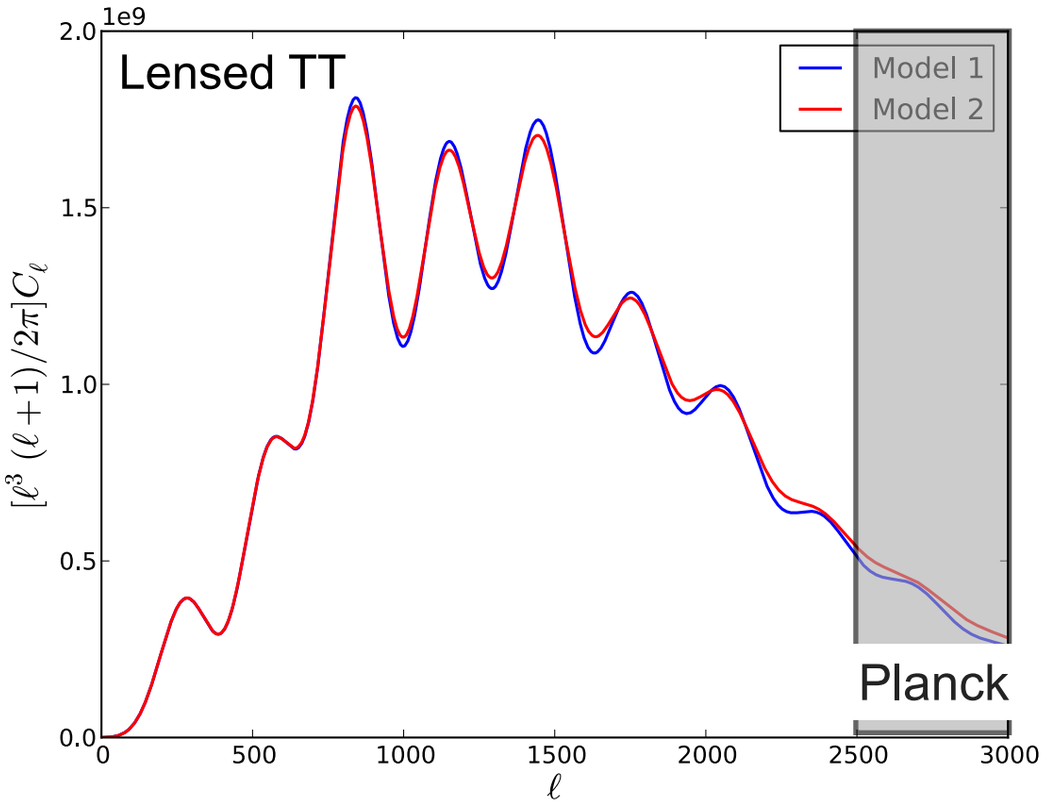




Parameter degeneracies

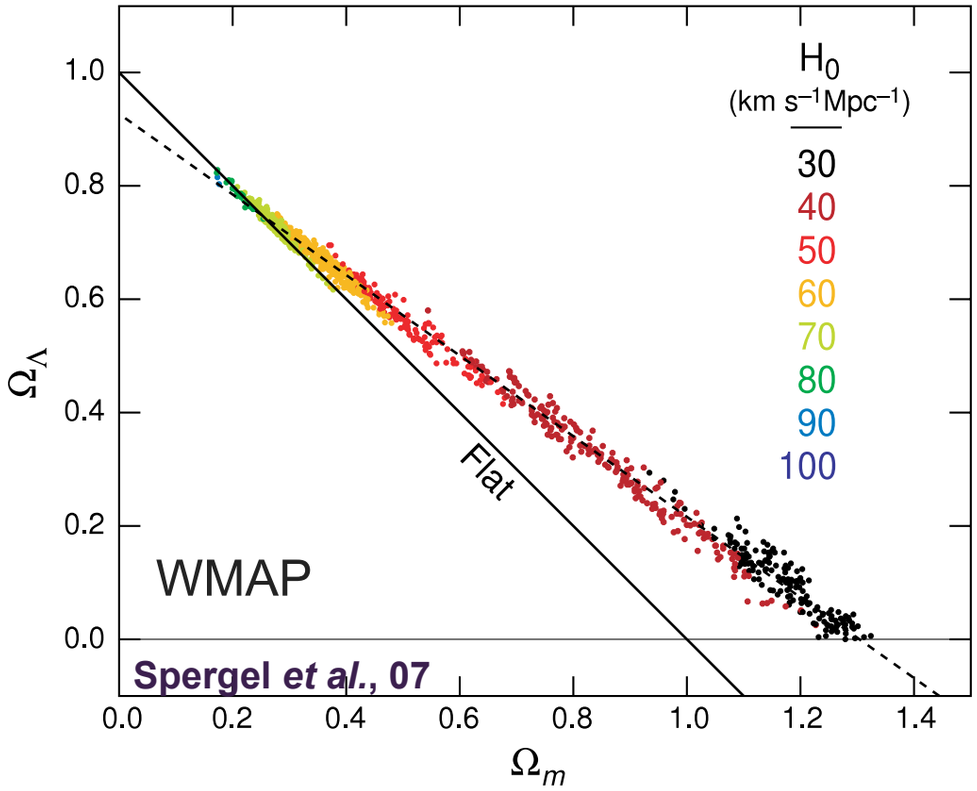
Dark Energy has no direct effect on the CMB anisotropies at recombination.
Its effect are mainly geometrical but are degenerated with other parameters



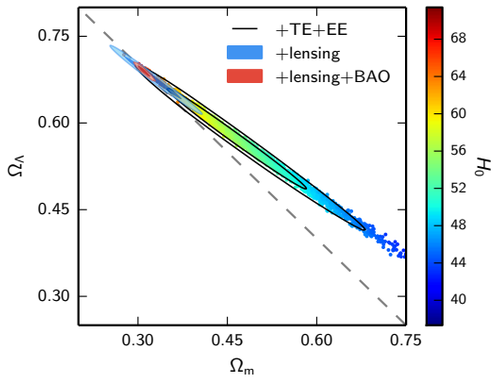


Parameters degeneracies

Information from the large-scale structure can break those degeneracies!



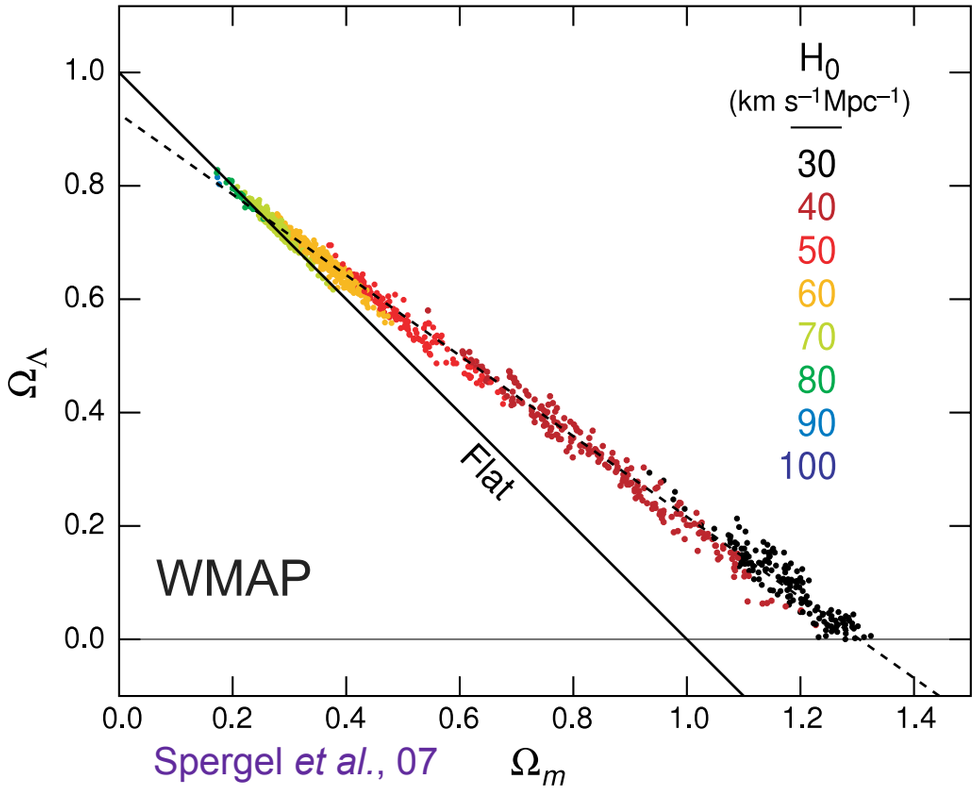
Planck 2015



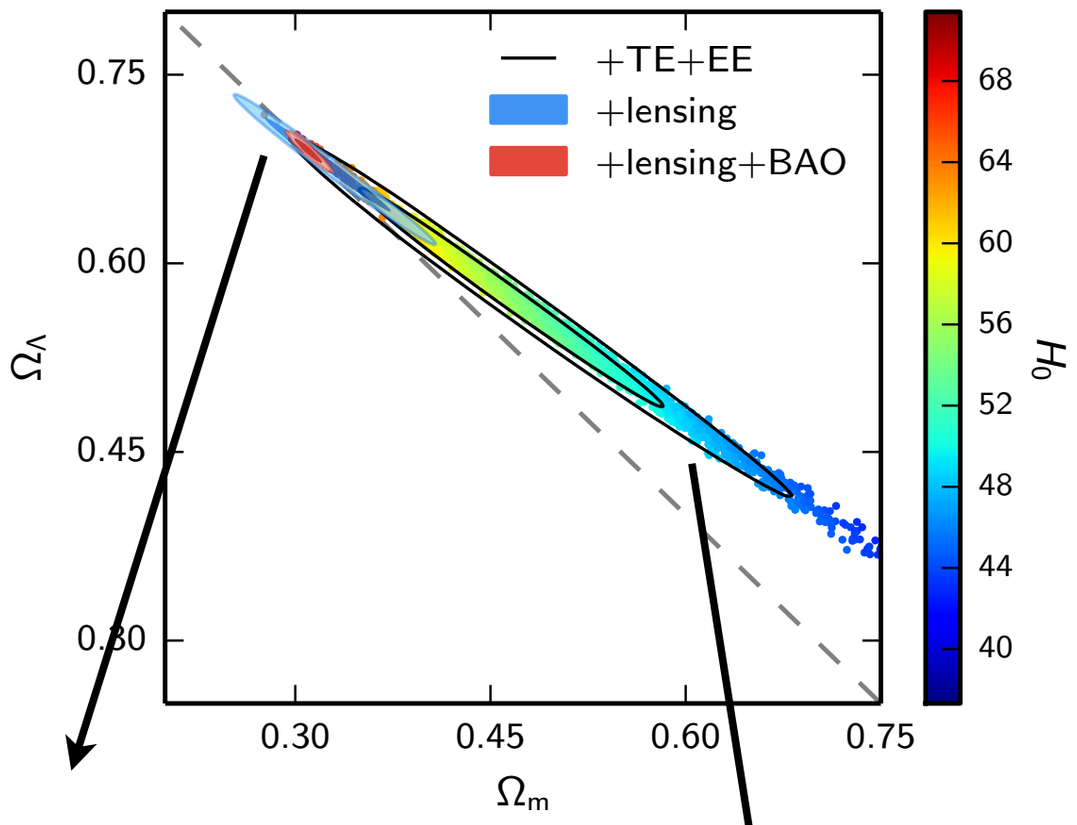
Parameters degeneracies

Information from the large-scale structure can break those degeneracies!

Planck 2015



Spergel *et al.*, 07



Adding CMB lensing reconstruction

Using only T+P power spectra

Parameters degeneracies

Large-scale structure will provide constraints on cosmology from

Geometry

- The scale of the sound horizon at recombination is imprinted in the matter distribution: Baryonic Acoustic Oscillations

- Distances

Structure growth

- Dark Energy, hence acceleration of the expansion will impede structure formation

So... Let’s observe those galaxies!

The DES Collaboration

~300 scientists from 28 institutions from around the world

DARK ENERGY SURVEY

facebook.com/darkenergysurvey
http://darkenergysurvey.org

USA: Fermilab, UIUC/NCSA, University of Chicago, LBNL, NOAO, University of Michigan, University of Pennsylvania, Argonne National Laboratory, Ohio State University, Santa Cruz/ SLAC/Stanford Consortium, Texas A&M University, CTIO (in Chile

UK Consortium: UCL, Cambridge, Edinburgh, Portsmouth, Sussex, Nottingham

Participation from a few individuals...

Germany: Munich

Switzerland: ETH Zurich

4m Blanco telescope at CTIO

Brazil Consortium

Spain Consortium: CIEMAT (Madrid), ICE, IFAE (Barcelona)

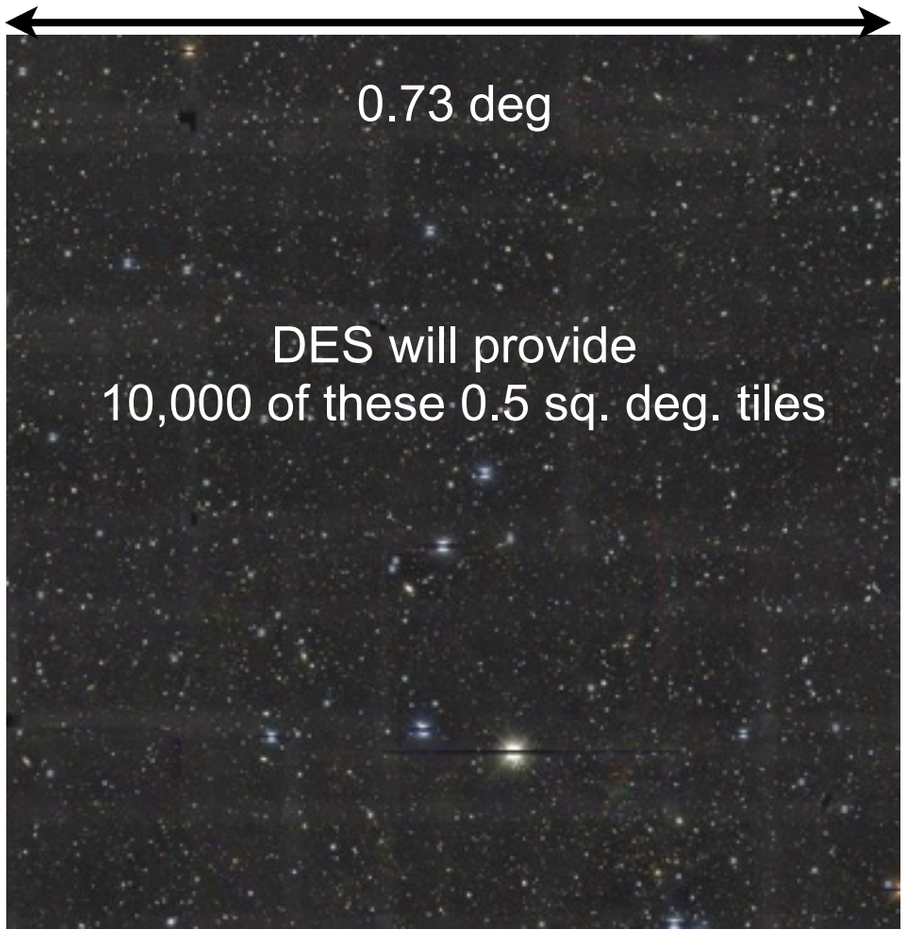
The Dark Energy Survey

New camera mounted on the 4m Blanco telecope at Cerro-Tololo Inter-American Observatory in Chile

What is DES ?

DES is:

- 1” resolution picture of the sky (pixel size 0.26”)
- 5000 sq. deg. (1/8th of the sky)
- Five photometric bands (grizY)
- 24th magnitude (galaxies,10σ)



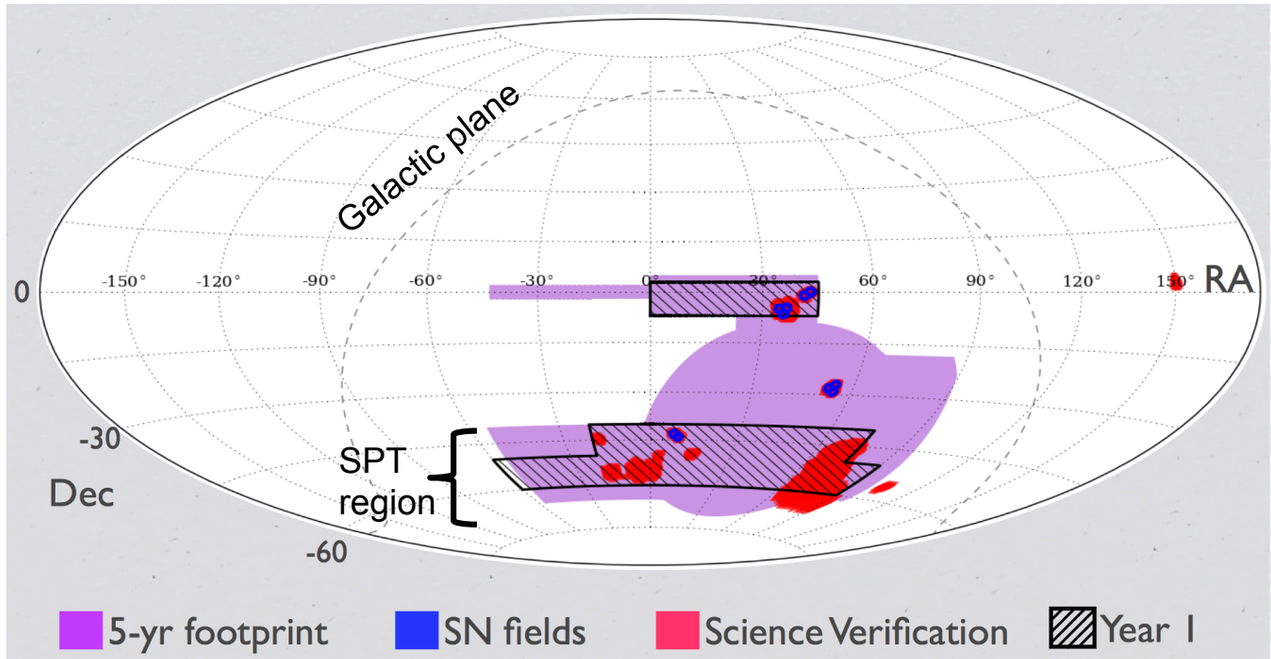
What is DES ?

DES is:

- 1” resolution picture of the sky (pixel size 0.26”)
- 5000 sq. deg. (1/8th of the sky)
- Five photometric bands (grizY)
- 24th magnitude (galaxies,10σ)

Supplemented by:

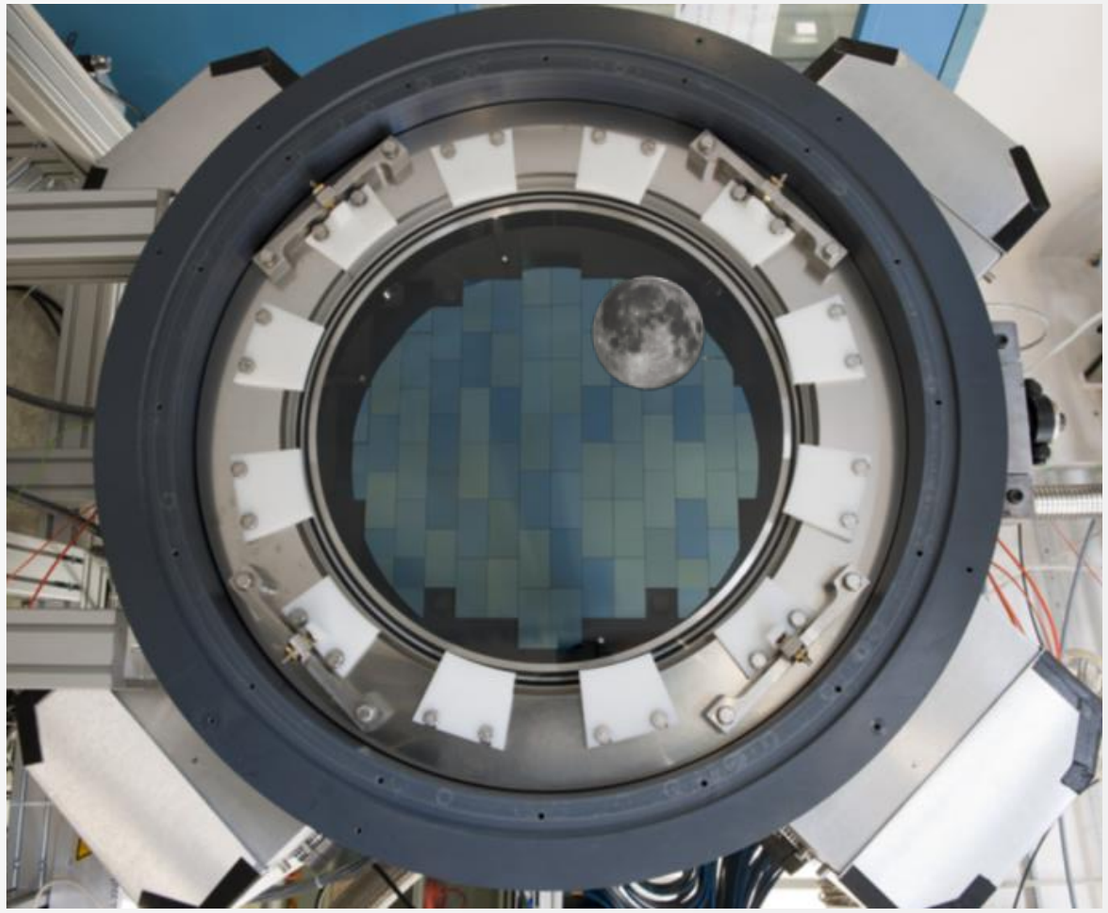
- 2500 sq. deg. South Pole Telescope
- Vista Hemisphere Survey (JHK)



What is DES ?

DES is:

- 1” resolution picture of the sky (pixel size 0.26”)
- 5000 sq. deg. (1/8th of the sky)
- Five photometric bands (grizY)
- 24th magnitude (galaxies,10σ)



Supplemented by:

- 2500 sq. deg. South Pole Telescope
- Vista Hemisphere Survey (JHK)

DECam:

- 570 Mpixels, 62 CCD
- 3 sq. deg. field of view

4 probes of Dark Energy

Galaxy Clusters (distance, structure growth)
ten of thousands of clusters up to z~1
synergies with SPT, VHS

$$\frac{d^2N(z)}{dzd\Omega} = \frac{c}{H(z)} D_A^2 (1+z)^2 \int_0^\infty f(M,z) \frac{dn(z)}{dM} dM \ ,$$

4 probes of Dark Energy

Galaxy Clusters (distance, structure growth)
ten of thousands of clusters up to z~1
synergies with SPT, VHS

Weak lensing (distance, structure growth)
shape and measurements of 200
millions galaxies

$$C_l^{x_a x_b} = \int dz \frac{H(z)}{D_A^2} W_a(z) W_b(z) P^{s_a s_b}(k = l/D_A; z) \,,$$

4 probes of Dark Energy

Galaxy Clusters (distance, structure growth)
ten of thousands of clusters up to z~1
synergies with SPT, VHS

Weak lensing (distance, structure growth)
shape and measurements of 200
millions galaxies

Baryonic acoustic Oscillations (distance)
300 millions galaxies to z=1 and beyond

$$C^i_{\rm gal}(l) = \int_0^\infty k^2 dk \, \frac{2}{\pi} f_i^2(l,k) P_{\rm gal}(k),$$

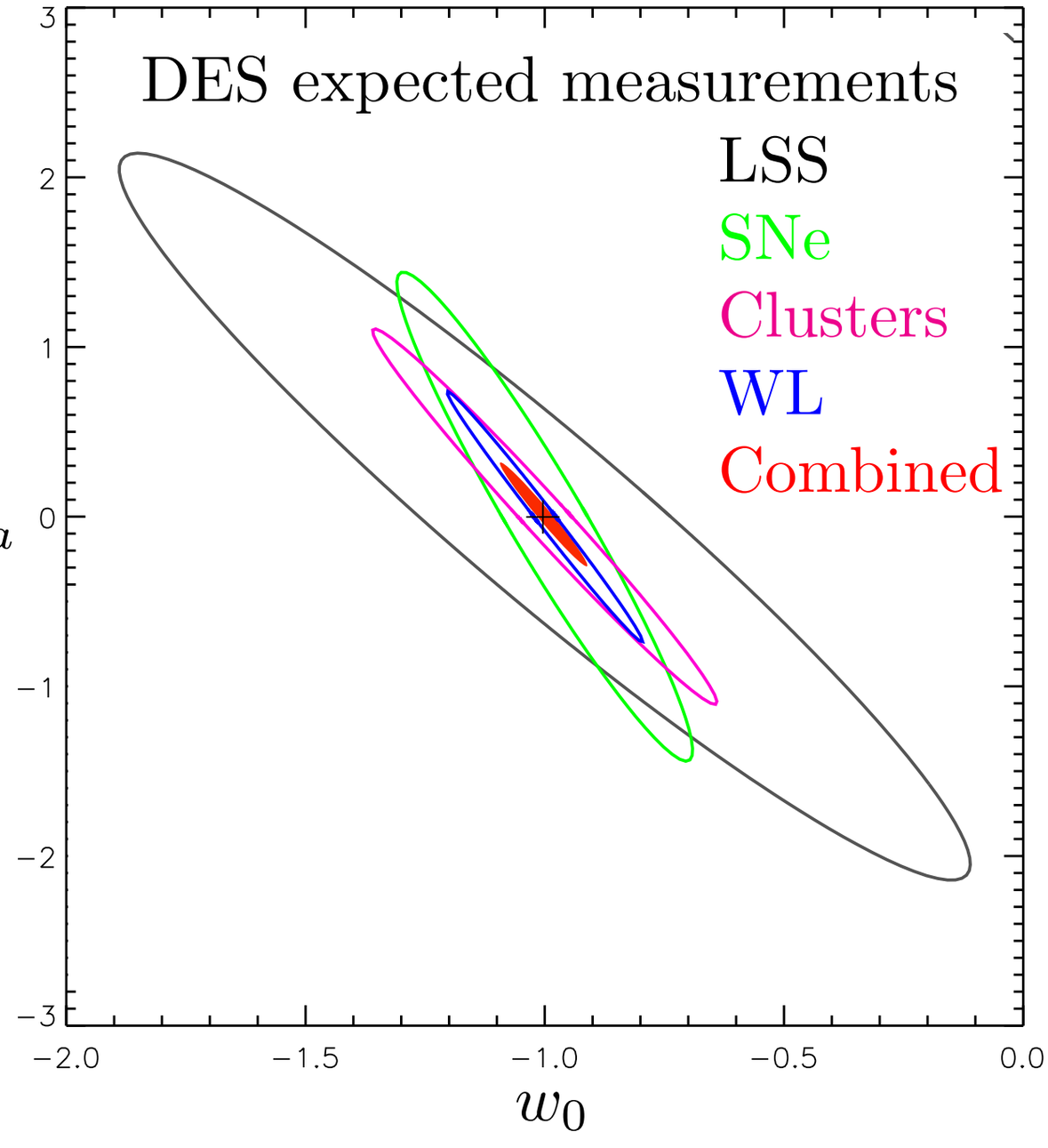
4 probes of Dark Energy

Galaxy Clusters (distance, structure growth)
ten of thousands of clusters up to z~1
synergies with SPT, VHS

Weak lensing (distance, structure growth)
shape and measurements of 200 millions galaxies

Baryonic acoustic Oscillations (distance)
300 millions galaxies to z=1 and beyond

Type Ia supernovae (distance)
30 sq. deg. SN fields
3500 SNIa to z~1



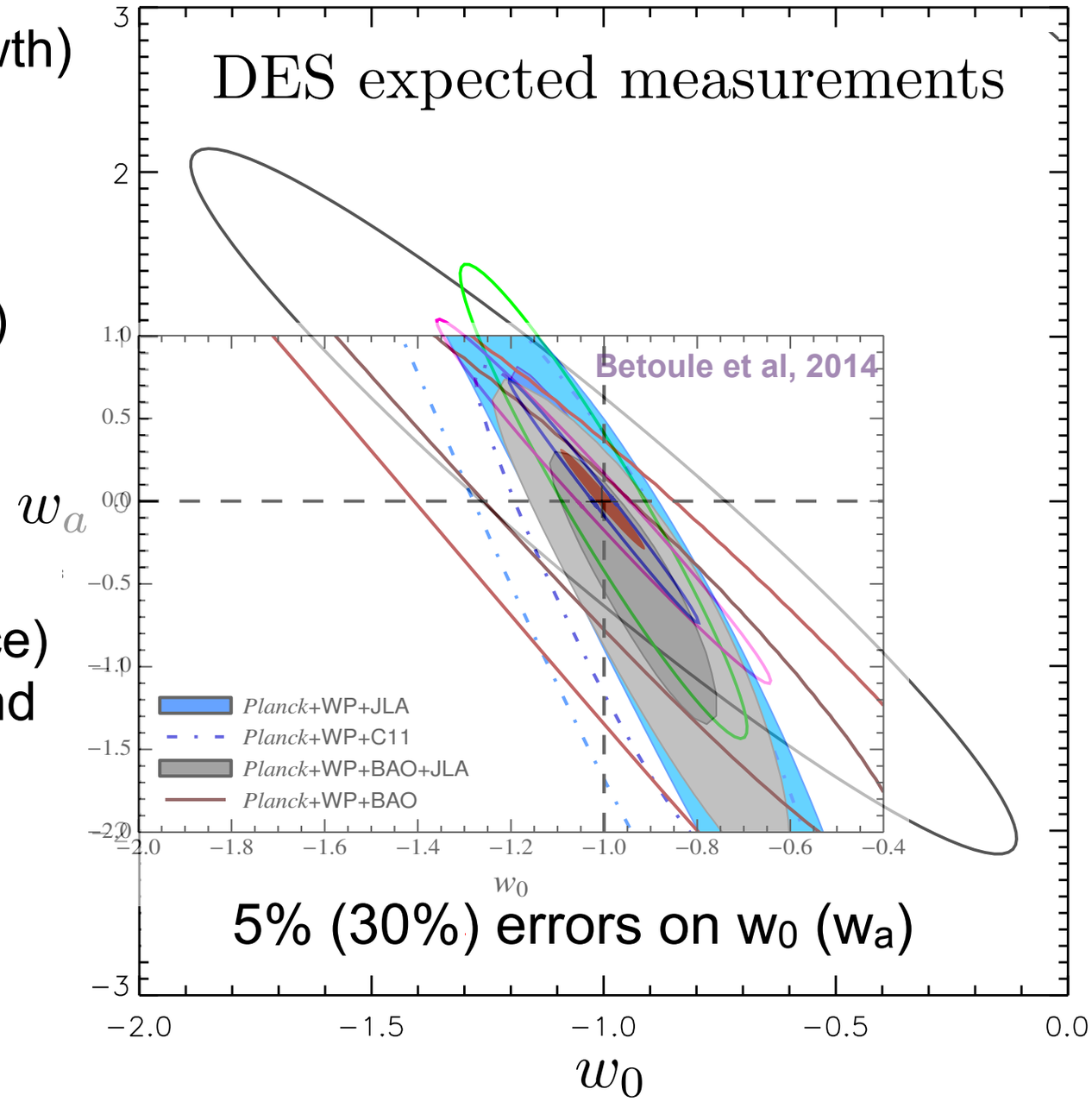
4 probes of Dark Energy

Galaxy Clusters (distance, structure growth)
ten of thousands of clusters up to z~1
synergies with SPT, VHS

Weak lensing (distance, structure growth)
shape and measurements of 200 millions galaxies

Baryonic acoustic Oscillations (distance)
300 millions galaxies to z=1 and beyond

Type Ia supernovae (distance)
30 sq. deg. SN fields
3500 SNIa to z~1

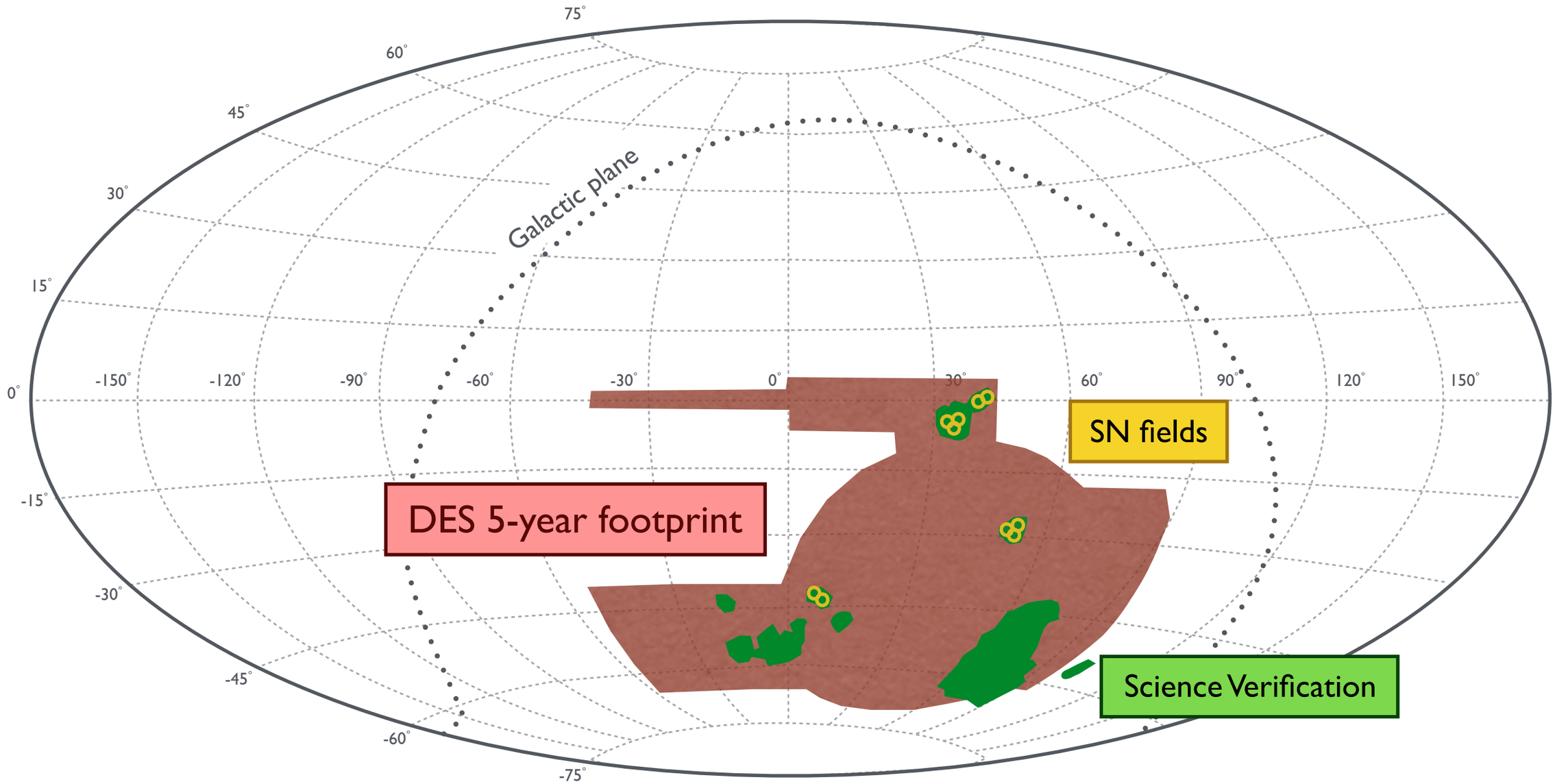


DARK ENERGY SURVEY

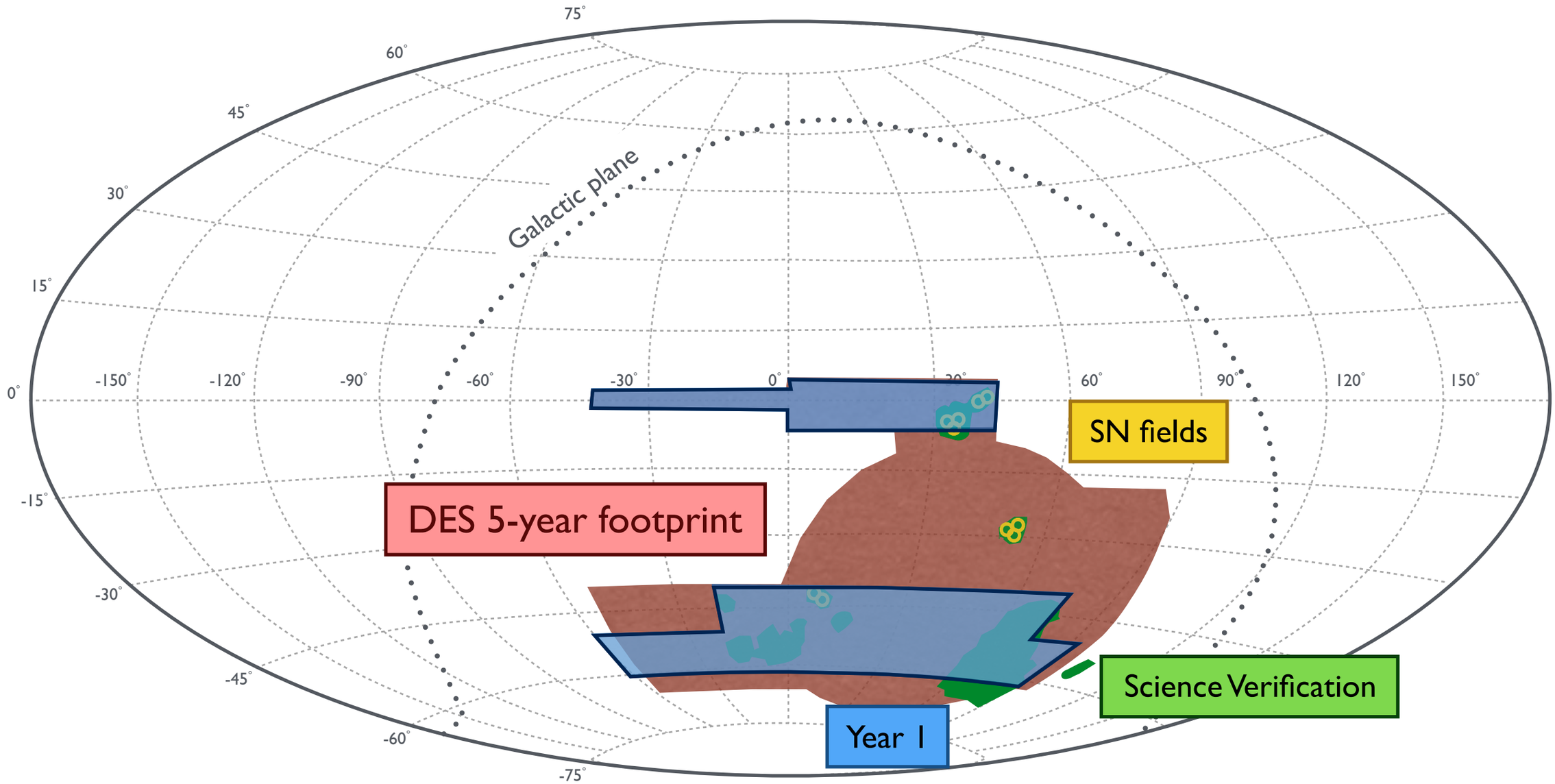
DES Timeline

2003	Project start
2004-8	***R&D***
2008-11	DECam construction
2012 [Sept]	***Installation and first light***
2012 [Sept-Oct]	Commissioning
Nov 2012 - Feb 2013	***Science Verification***
Aug 31 2013 - 9 Feb 2014	**First Season (Y1)**
Aug 15 2014 - Feb 2015	***Second Season (Y2)***
2015-2018	***Third-Fifth Seasons***

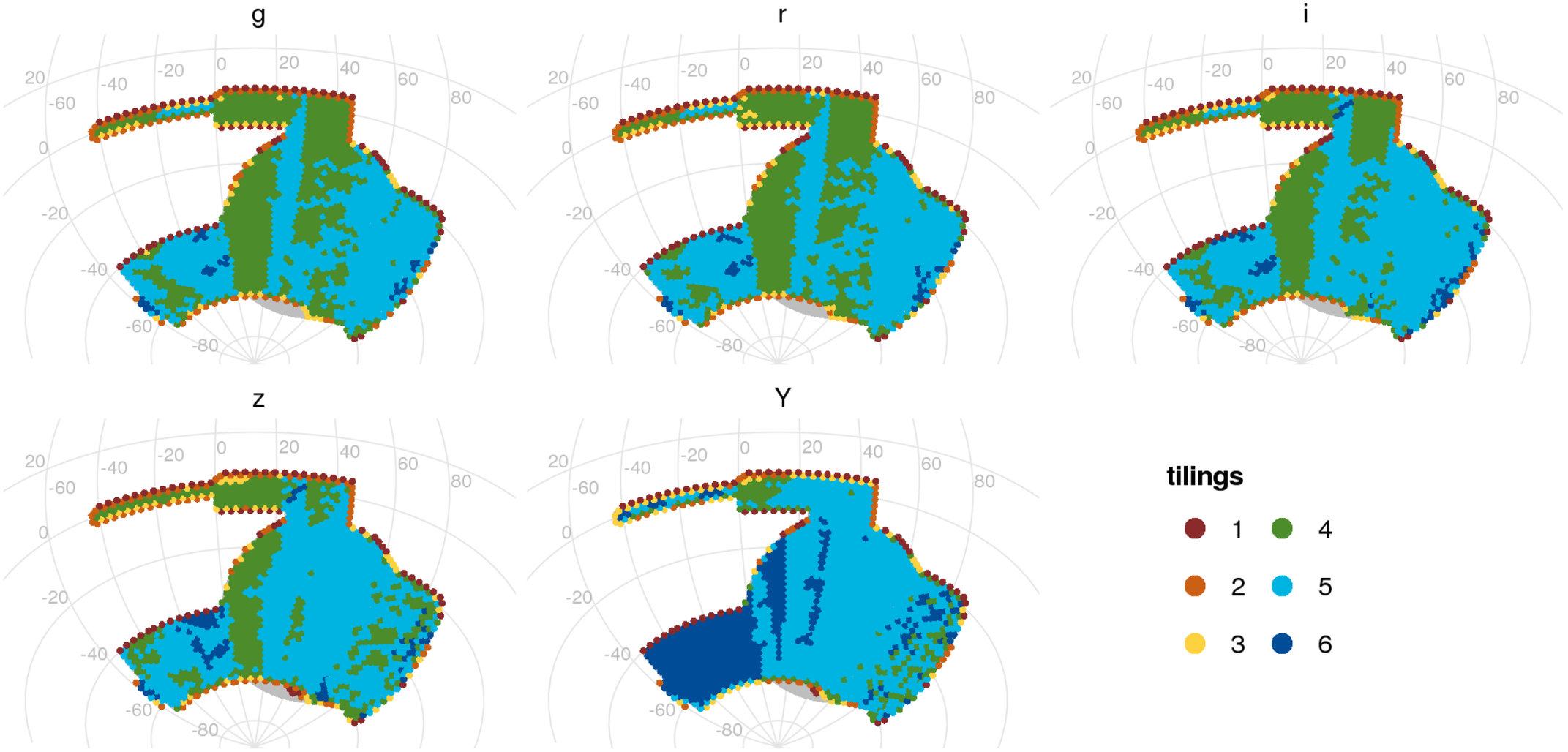
Observing strategy



Observing strategy

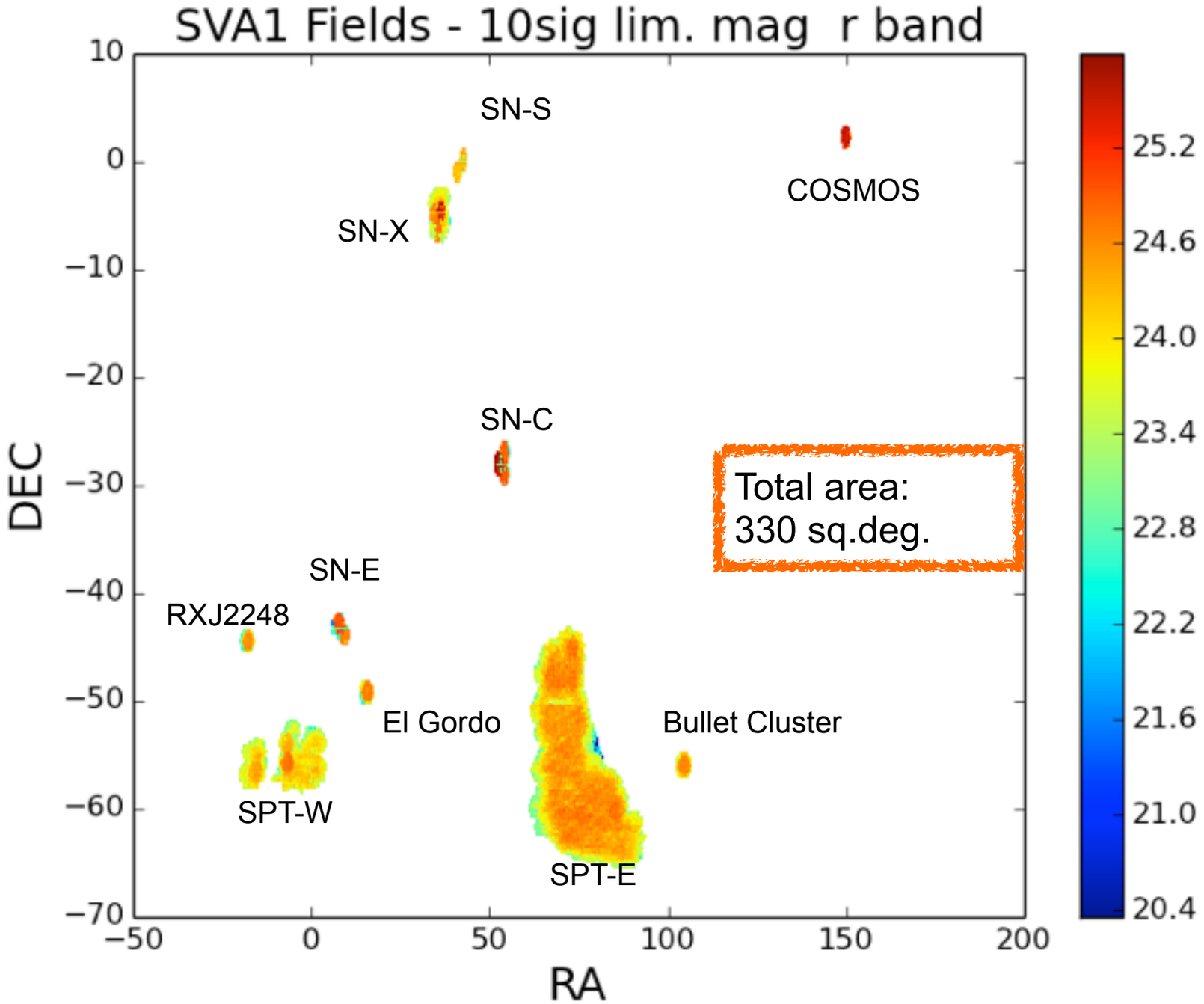


Observing strategy



At end of Year 3 (Feb. 2016), following major El Nino
(Y4 was MUCH better)

Nov. 2012 - Feb. 2013: Science Verification campaign



All the results presented in this talk are based on these pre-survey data

DES Early Results

- 96 publications submitted since May 2014
- Majority of results using Science Verification data
- Various fields of astronomy represented

NGC 1398, single DECam tile

Gerdes et al.	*Observation of Two New L4 Neptune Trojans in the Dark Energy Survey Supernova Fields*	arXiv:1507.05177
Park et al.	*Joint Analysis of Galaxy-Galaxy Lensing and Galaxy Clustering: Methodology and Forecasts for DES*	arXiv:1507.05353
Rozo et al.	*redMaGiC: Selecting Luminous Red Galaxies from the DES Science Verification Data*	arXiv:1507.05460
Giannantonio et al.	*CMB lensing tomography with the DES Science Verification galaxies*	arXiv:1507.05551
Crocce et al.	*Galaxy Clustering, Photometric Redshifts and Diagnosis of Systematics in the Dark Energy Survey Science Verification data*	arXiv:1507.05360
Jarvis et al.	*The Dark Energy Survey Science Verification Shear Catalog*	arXiv:1507.05603
Bonnett et al.	*Photometric redshifts for weak lensing in the DES Science Verification data*	arXiv:1507.05909
Becker et al.	*Cosmic Shear 2 point Measurements with DES Science Verification Data*	arXiv:1507.05598
Leistedt et al.	*Mapping and simulating systematics due to spatially-varying observing conditions in DES Science Verification data*	arXiv:1507.05647
Gruen et al.	*Weak lensing by galaxy troughs in DES Science Verification data*	arXiv:1507.05090
Abbott et al.	*Cosmology from Cosmic Shear with DES Science Verification Data*	arXiv:1507.05552
Kessler et al.	*The Difference Imaging Pipeline for the Transient Search in the Dark Energy Survey*	arXiv:1507.05137
Saro et al.	*Constraints on the Richness-Mass Relation and the Optical-SZE Positional Offset Distribution for SZE-Selected Clusters*	arXiv:1506.07814
Chang et al.	*Wide-Field Lensing Mass Maps from DES Science Verification Data*	arXiv:1505.01871
Reed et al.	*DES J0454-4448: Discovery of the First Luminous z ≥6 Quasar from the Dark Energy Survey*	arXiv:1504.03264
Yuan et al.	*OzDES multi-fibre spectroscopy for the Dark Energy Survey: first-year operation and results*	arXiv:1504.03039
Vikram et al.	*Wide-Field Lensing Mass Maps from DES Science Verification Data: Methodology and Detailed Analysis*	arXiv:1504.03002
Zhang et al.	*Galaxies in X-ray Selected Clusters and Groups in Dark Energy Survey Data: Stellar Mass Growth of Bright Central Galaxies Since z~1.2*	arXiv:1504.02983
Poci et al.	*DESAlert: Enabling Real-Time Transient Follow-Up with Dark Energy Survey Data*	arXiv:1504.02996
Goldstein et al.	*Automated Transient Identification in the Dark Energy Survey*	arXiv:1504.02936
Flaugher et al.	*The Dark Energy Camera*	arXiv:1504.02900
Simon et al.	*Stellar Kinematics and Metallicities in the Ultra-Faint Dwarf Galaxy Reticulum II*	arXiv:1504.02889
Bruderer et al.	*Calibrated Ultra Fast Image Simulations for the Dark Energy Survey*	arXiv:1504.02778
Fermi LAT + DES	*Search for Gamma-Ray Emission from DES Dwarf Spheroidal Galaxy Candidates with Fermi-LAT Data*	arXiv:1503.02632
Bechtol et al.	*Eight New Milky Way Companions Discovered in First-Year Dark Energy Survey Data*	arXiv:1503.02584
Balbinot et al.	*The LMC geometry and outer stellar populations from early DES data*	MNRAS 449 (2015) 1129
Papadopoulos et al.	*DES13S2cmm: The First Superluminous Supernova from the Dark Energy Survey*	MNRAS 449 (2015) 1215
Banerji et al.	*Combining Dark Energy Survey Science Verification Data with Near Infrared Data from the ESO VISTA Hemisphere Survey*	MNRAS 446 (2015) 2523
Sanchez et al.	*Photometric redshift analysis in the Dark Energy Survey Science Verification data*	MNRAS 445 (2014) 1482
Melchior et al.	*Mass and galaxy distributions of four massive galaxy clusters from Dark Energy Survey Science Verification data*	MNRAS 449 (2015) 2219

Solar system

Cosmology

photo-z

Cluster

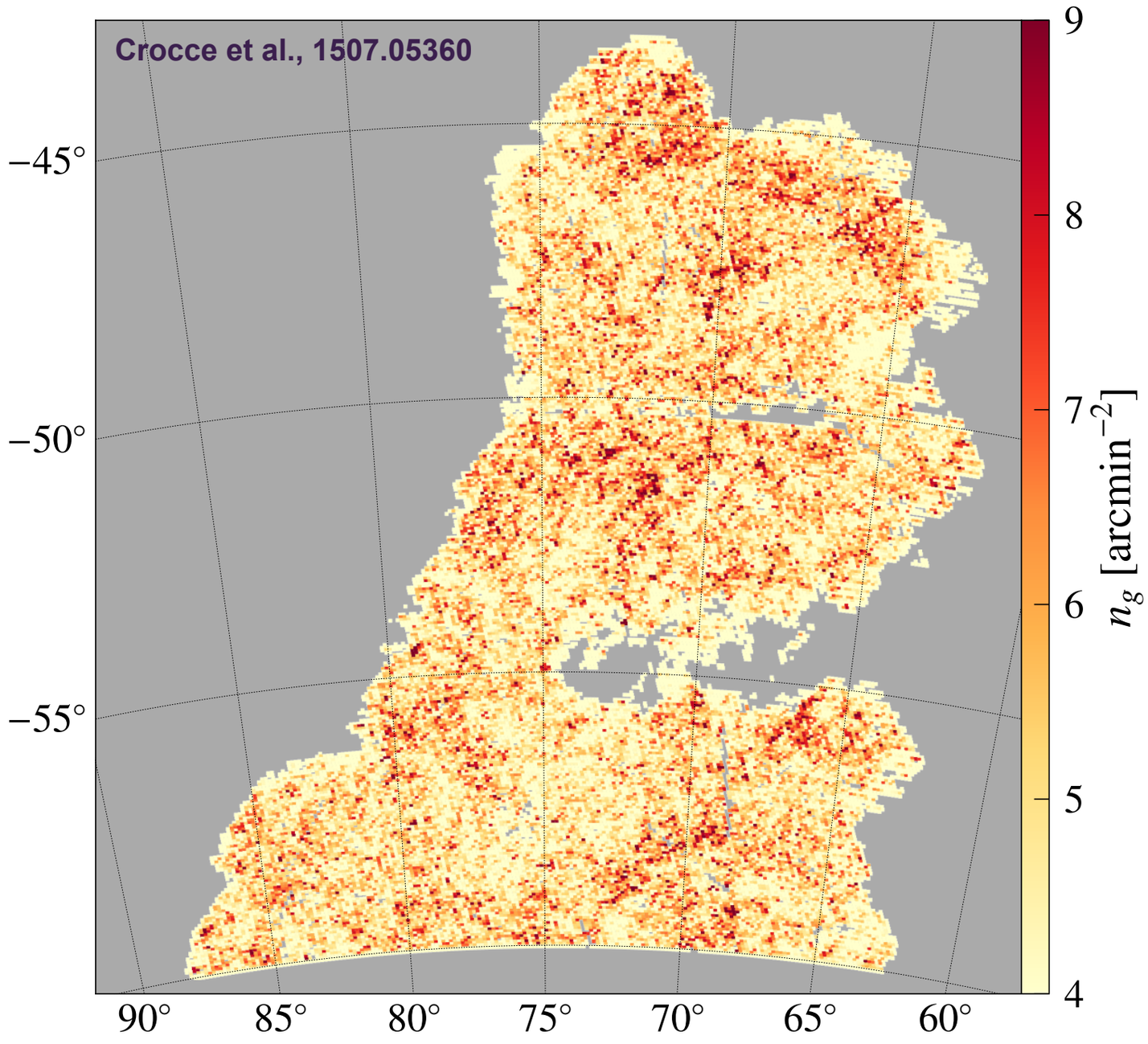
SNIa

QSO& High-z

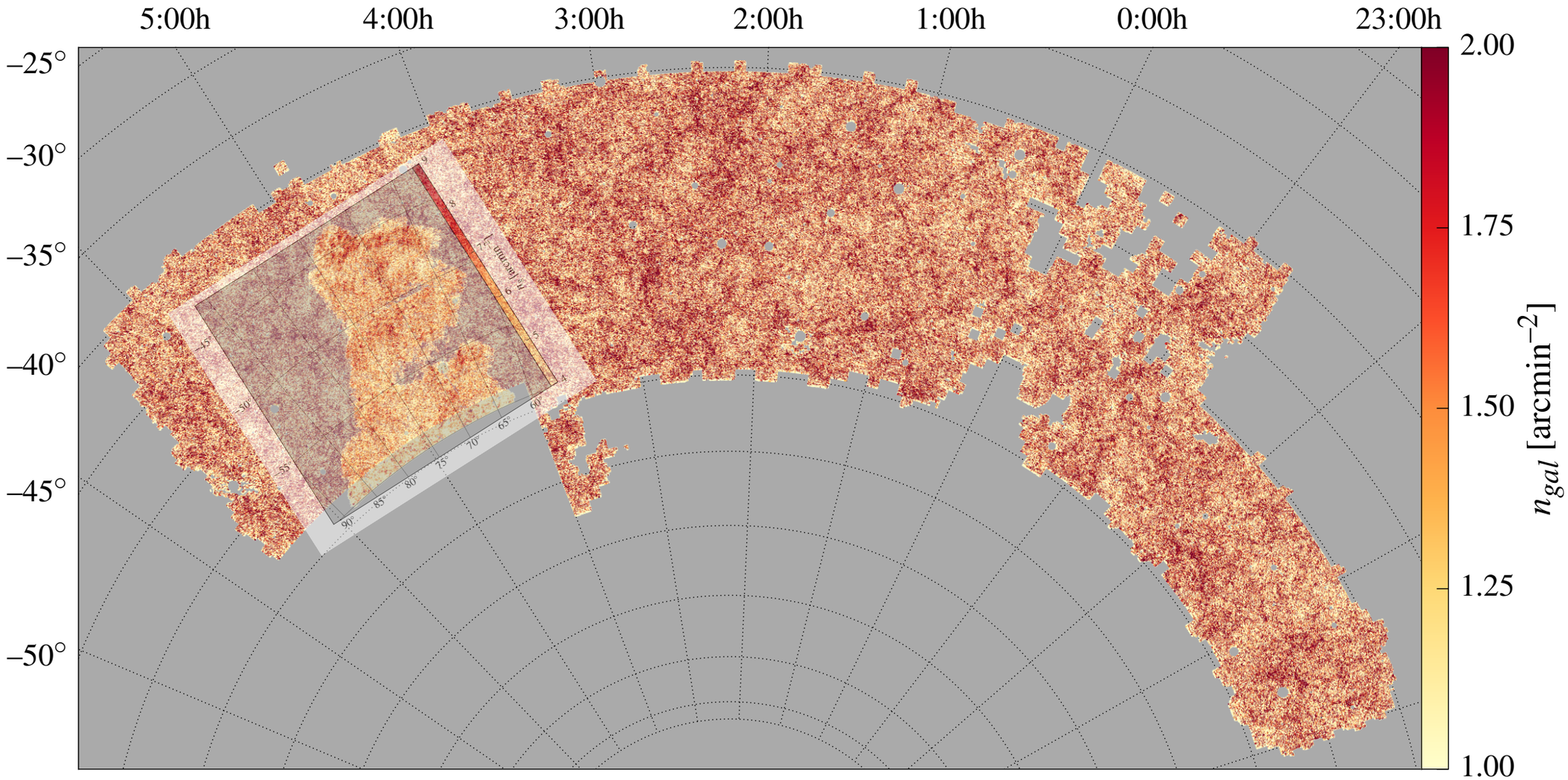
Milky Way

SV papers (as of July 15)

The DES SV galaxy catalog

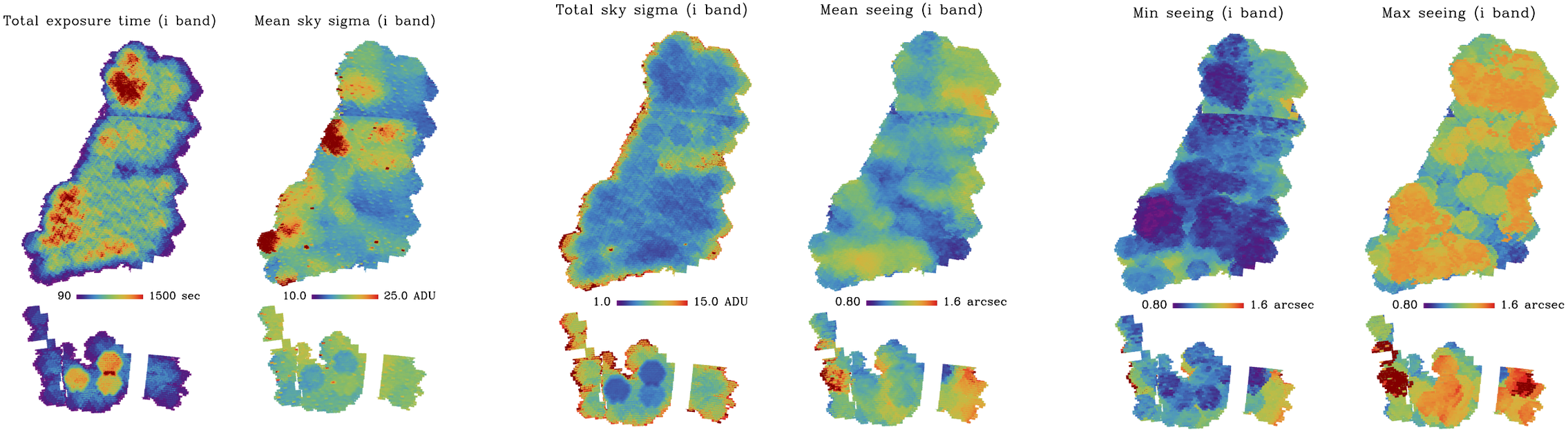


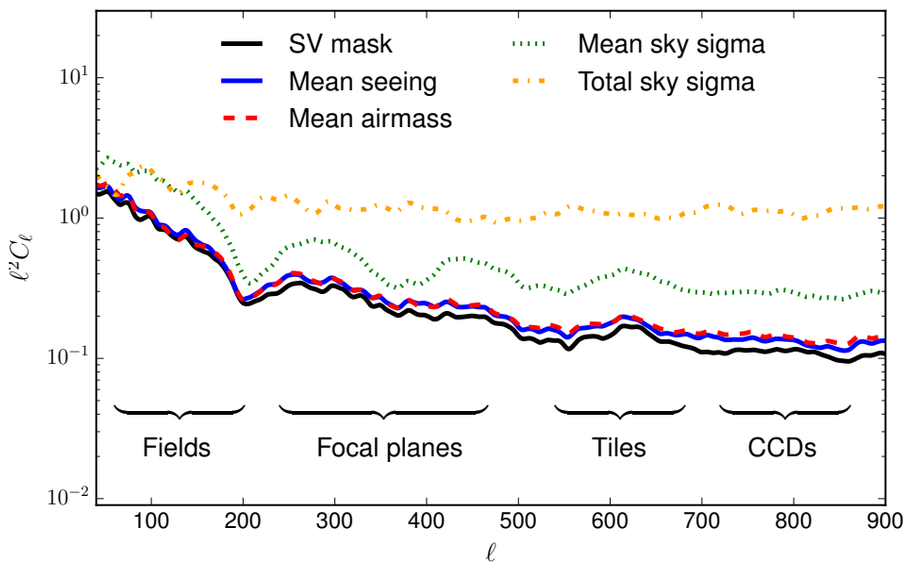
The DES Y1 galaxy catalog

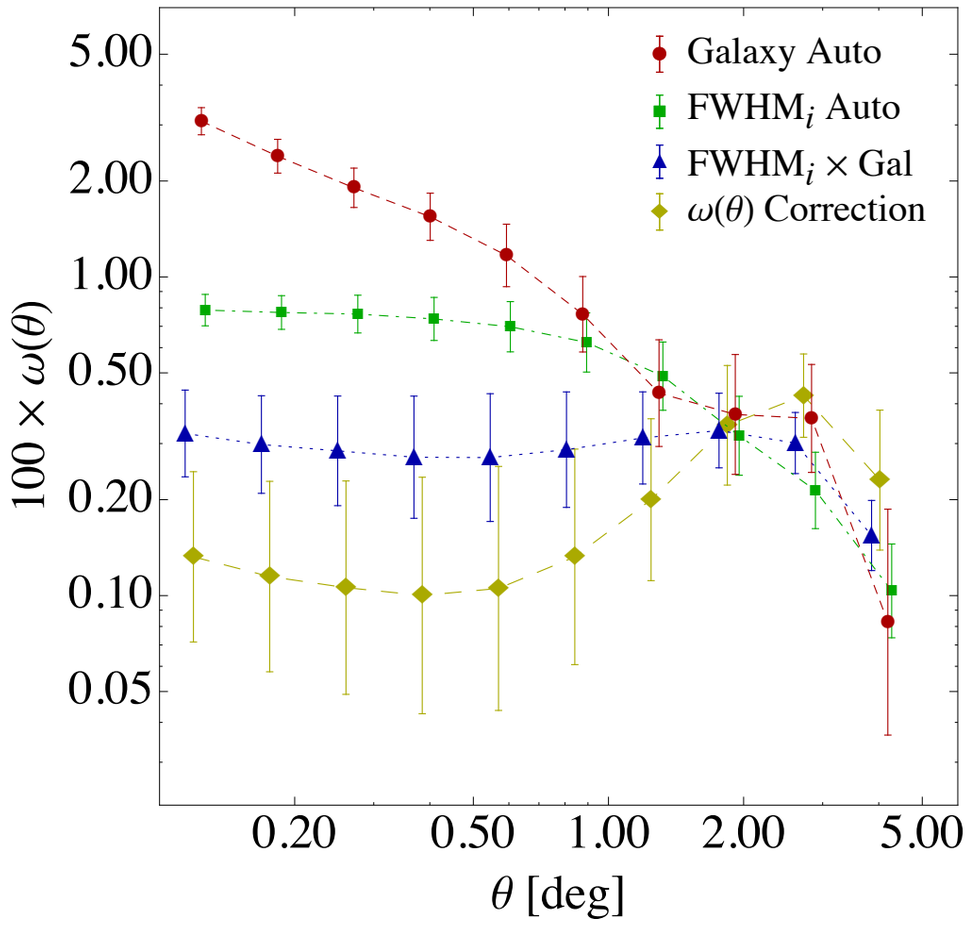


Systematics maps

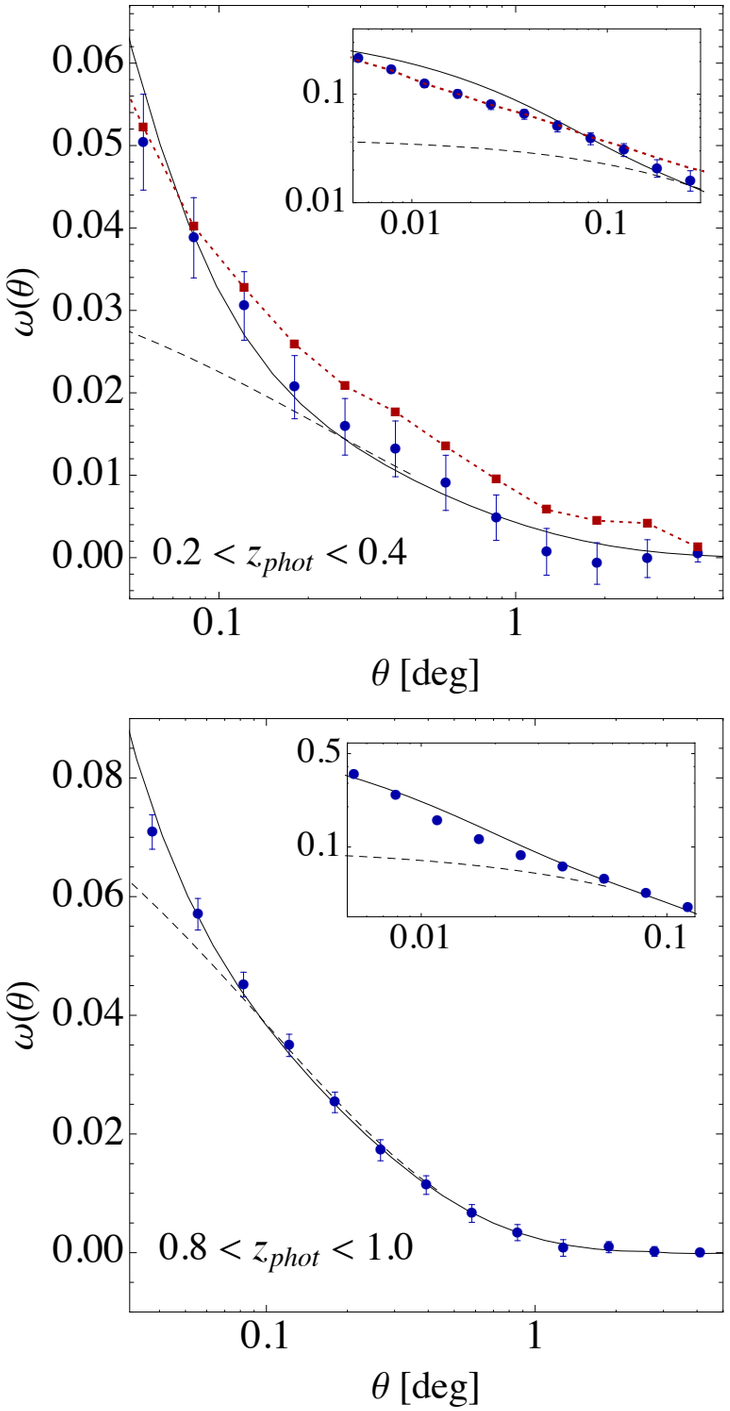
Leistedt, Peiris, Elsner, Benoit-Lévy, *et al.*, 1507.05360



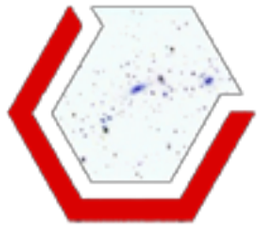




Galaxy clustering, photometric redshifts and diagnosis of systematics in the DES Science Verification data



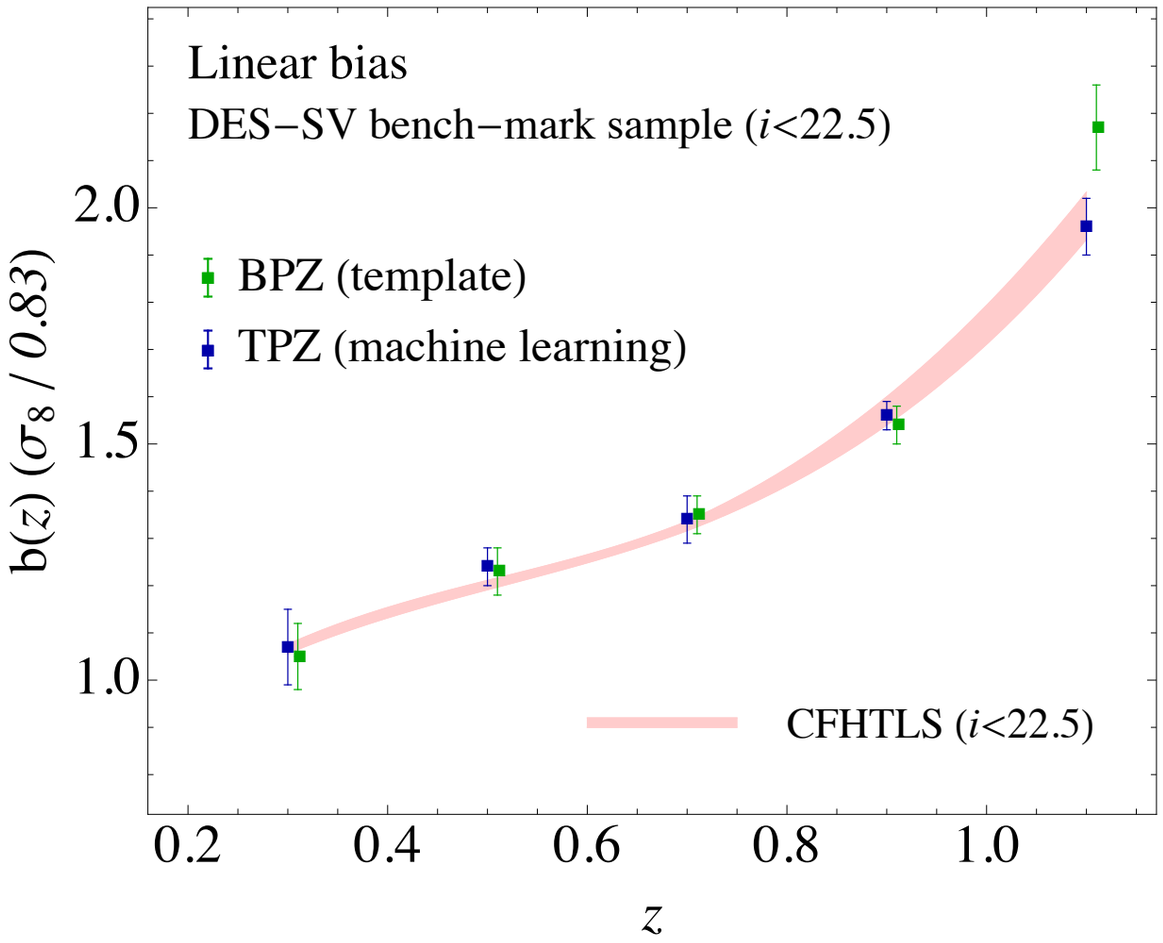
Crocce et al., 1507.05360



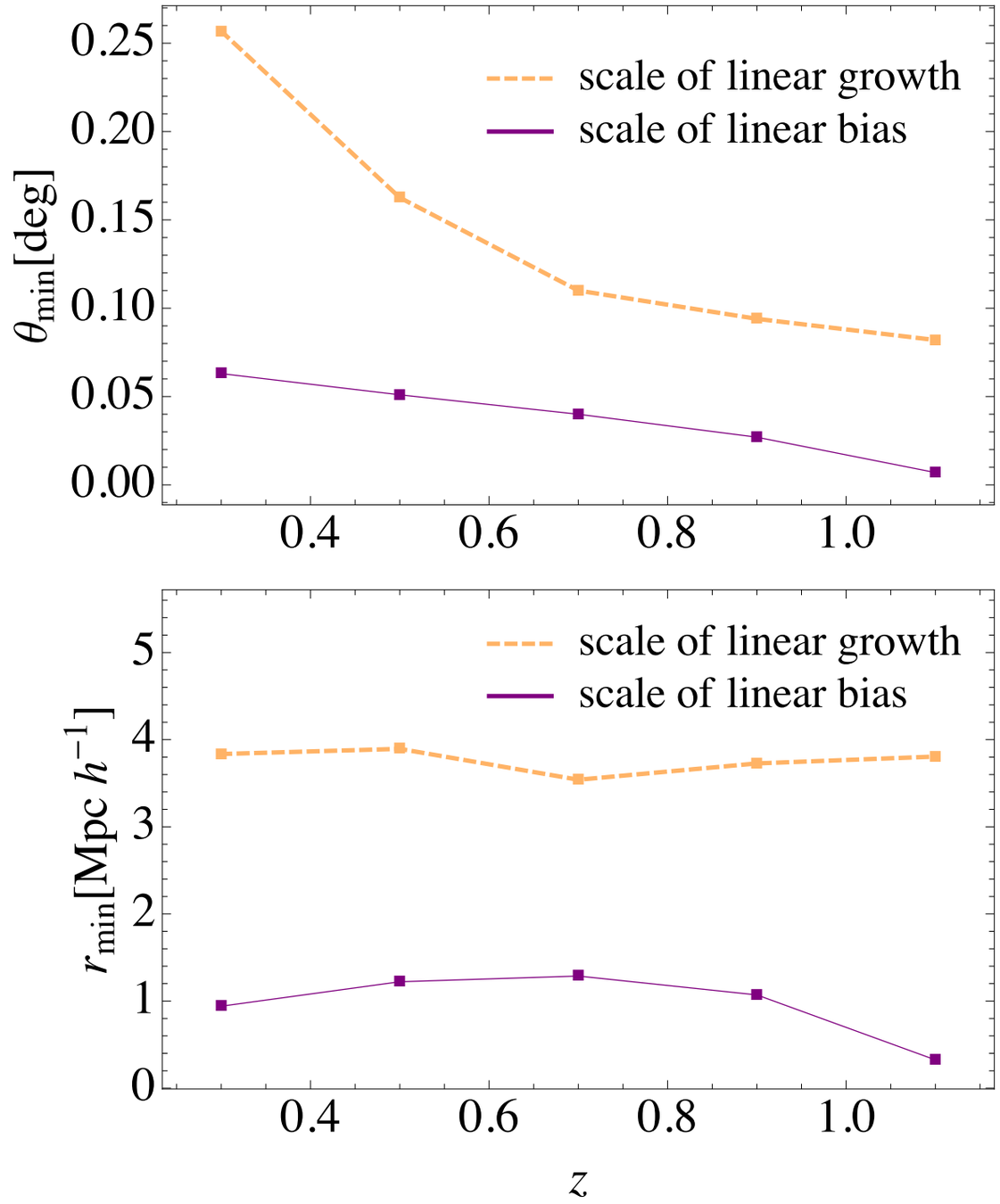
Galaxy clustering, photometric redshifts and diagnosis of systematics in the DES Science Verification data

Comparison with CFHTLS

(**Coupon *et al.* 2012**)



Linear scale "breakings"

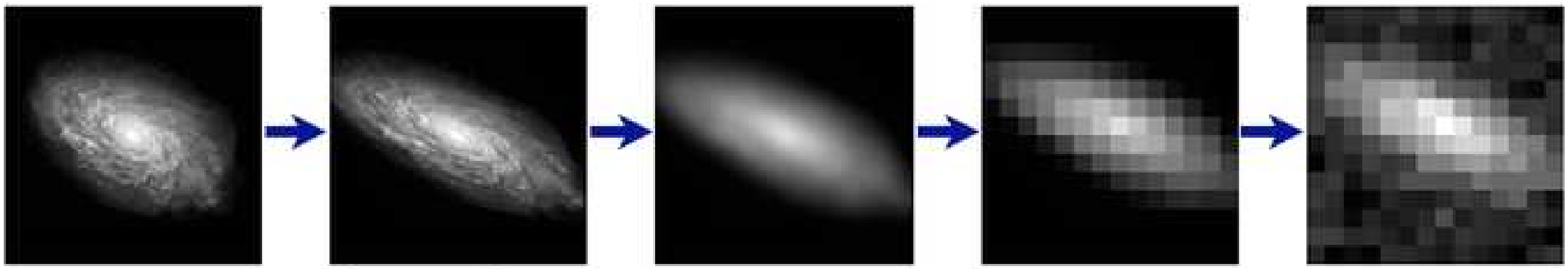


Crocce et al., 1507.05360

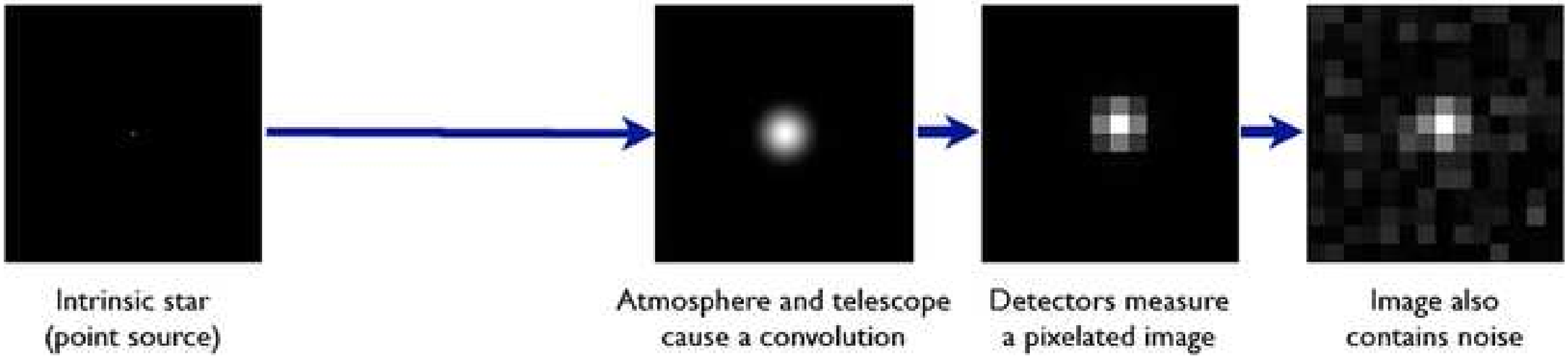
DES Weak lensing

The Forward Process.

Galaxies: Intrinsic galaxy shapes to measured image:

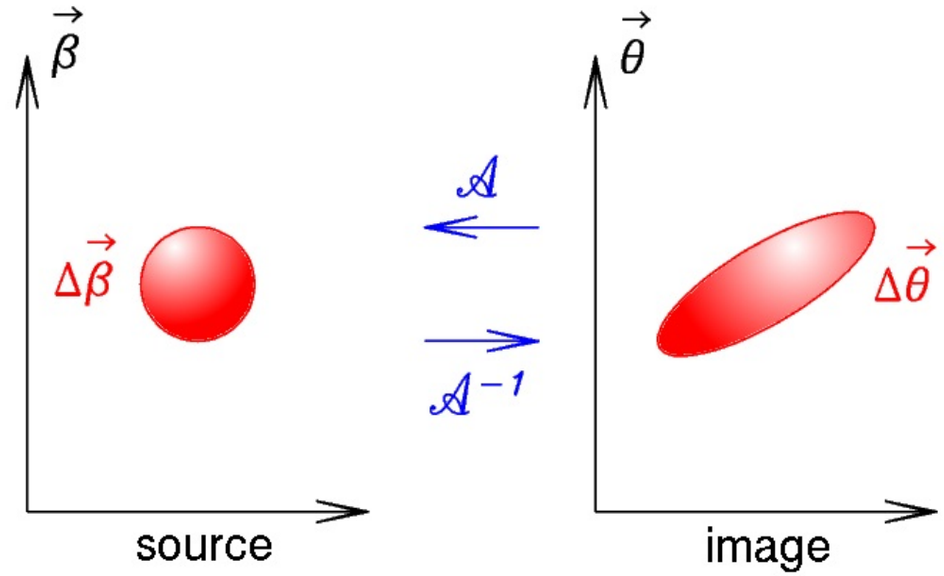


Stars: Point sources to star images:

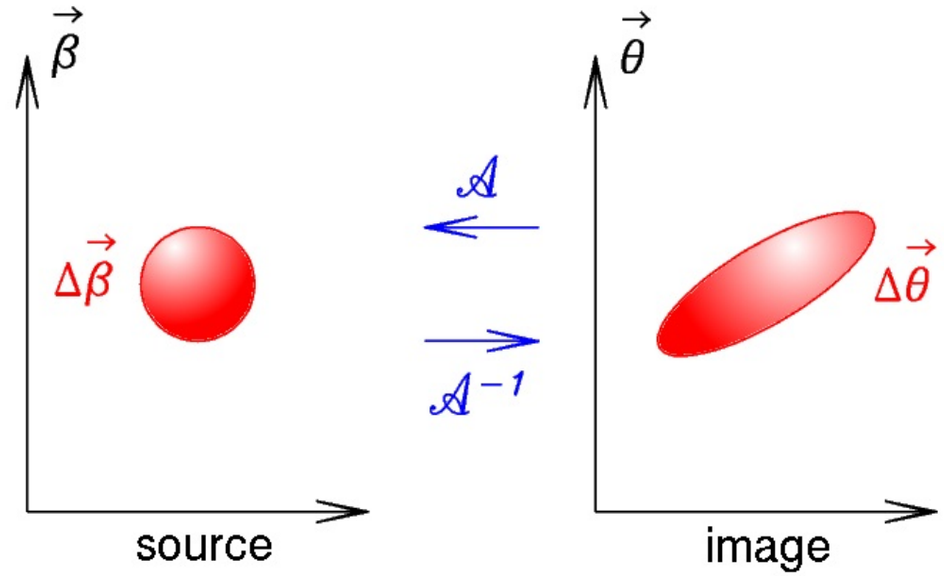


HANDBOOK FOR THE GREAT08 CHALLENGE: AN IMAGE ANALYSIS COMPETITION FOR COSMOLOGICAL LENSING

From measurements to mass maps



From measurements to mass maps

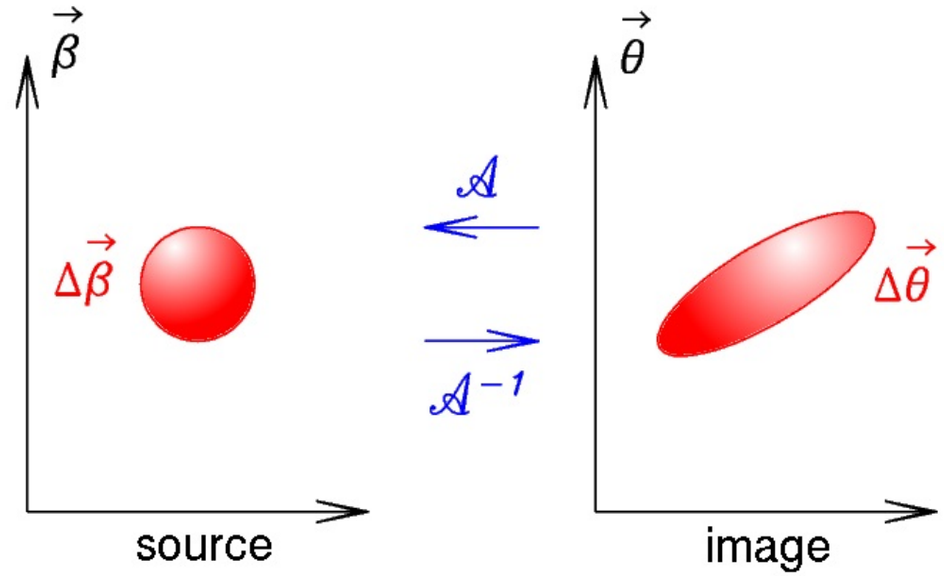


convergence

shear

$$\mathcal{A}(\boldsymbol{\theta}) = \begin{pmatrix} 1-\kappa-\gamma_1 & -\gamma_2 \\ -\gamma_2 & 1-\kappa+\gamma_1 \end{pmatrix}$$

From measurements to mass maps



convergence

shear

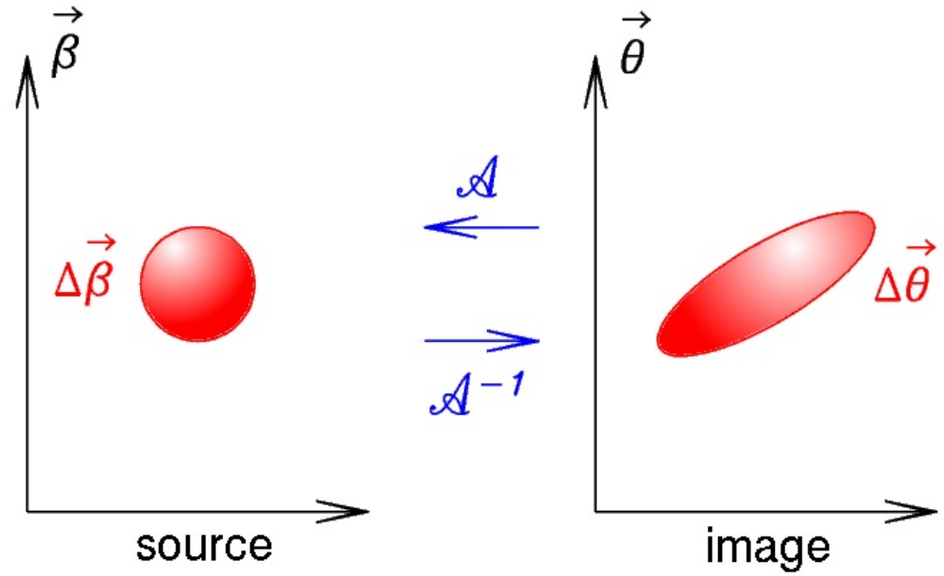
lensing potential

$$\mathcal{A}(\boldsymbol{\theta}) = \begin{pmatrix} 1-\kappa-\gamma_1 & -\gamma_2 \\ -\gamma_2 & 1-\kappa+\gamma_1 \end{pmatrix}$$

$$\gamma = \gamma_1 + i\gamma_2 = \frac{1}{2}\left(\psi_{,11} - \psi_{,22}\right) + i\psi_{,12},$$

$$\kappa = \frac{1}{2}\nabla^2\psi = \frac{1}{2}\left(\psi_{,11} + \psi_{,22}\right).$$

From measurements to mass maps



convergence

shear

lensing potential

$$\mathcal{A}(\boldsymbol{\theta}) = \begin{pmatrix} 1-\kappa-\gamma_1 & -\gamma_2 \\ -\gamma_2 & 1-\kappa+\gamma_1 \end{pmatrix}$$

$$\gamma = \gamma_1 + i\gamma_2 = \frac{1}{2}\left(\psi_{,11} - \psi_{,22}\right) + i\psi_{,12},$$

$$\kappa = \frac{1}{2}\nabla^2\psi = \frac{1}{2}\left(\psi_{,11} + \psi_{,22}\right).$$

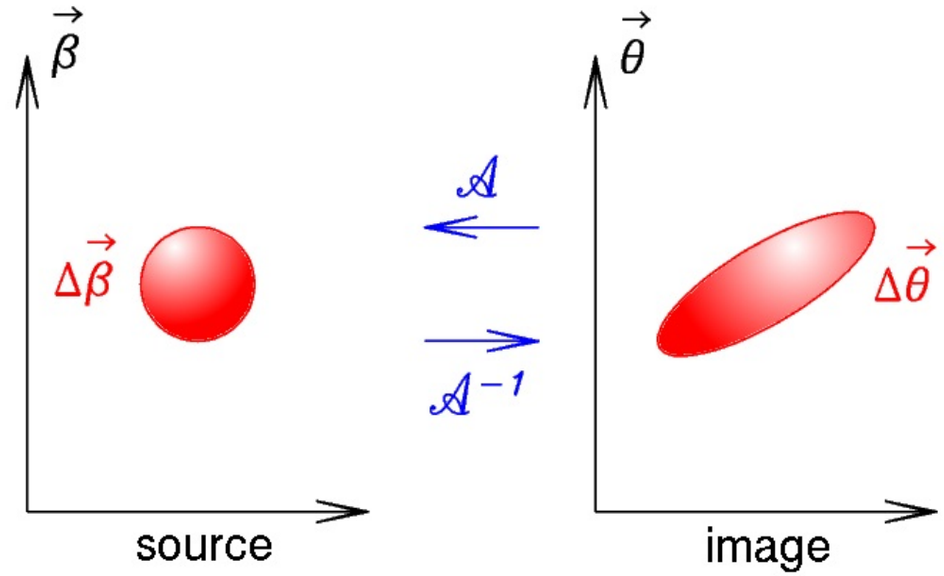
$$\psi(\theta, r) = -2\int_0^r \mathrm{d}r' \frac{r-r'}{rr'}\Phi\left(\theta, r'\right).$$

Gravitational potential of LSS

$$\kappa(\theta, r) = \frac{3H_0^2\Omega_m}{2c^2}\int_0^r \mathrm{d}r' \frac{(r-r')r'}{r}\frac{\delta\left(\theta, r'\right)}{a(r')}.$$

Matter density constrast

From measurements to mass maps



convergence

shear

lensing potential

$$\mathcal{A}(\boldsymbol{\theta}) = \begin{pmatrix} 1-\kappa-\gamma_1 & -\gamma_2 \\ -\gamma_2 & 1-\kappa+\gamma_1 \end{pmatrix}$$

$$\gamma = \gamma_1 + i\gamma_2 = \frac{1}{2}\left(\psi_{,11} - \psi_{,22}\right) + i\psi_{,12},$$

$$\kappa = \frac{1}{2}\nabla^2\psi = \frac{1}{2}\left(\psi_{,11} + \psi_{,22}\right).$$

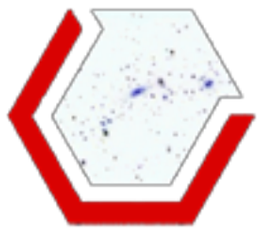
$$\psi(\theta, r) = -2\int_0^r \mathrm{d}r' \frac{r-r'}{rr'}\Phi\left(\theta, r'\right).$$

Gravitational potential of LSS

$$\kappa(\theta, r) = \frac{3H_0^2\Omega_m}{2c^2}\int_0^r \mathrm{d}r' \frac{(r-r')r'}{r}\frac{\delta\left(\theta, r'\right)}{a(r')}.$$

Matter density constrast

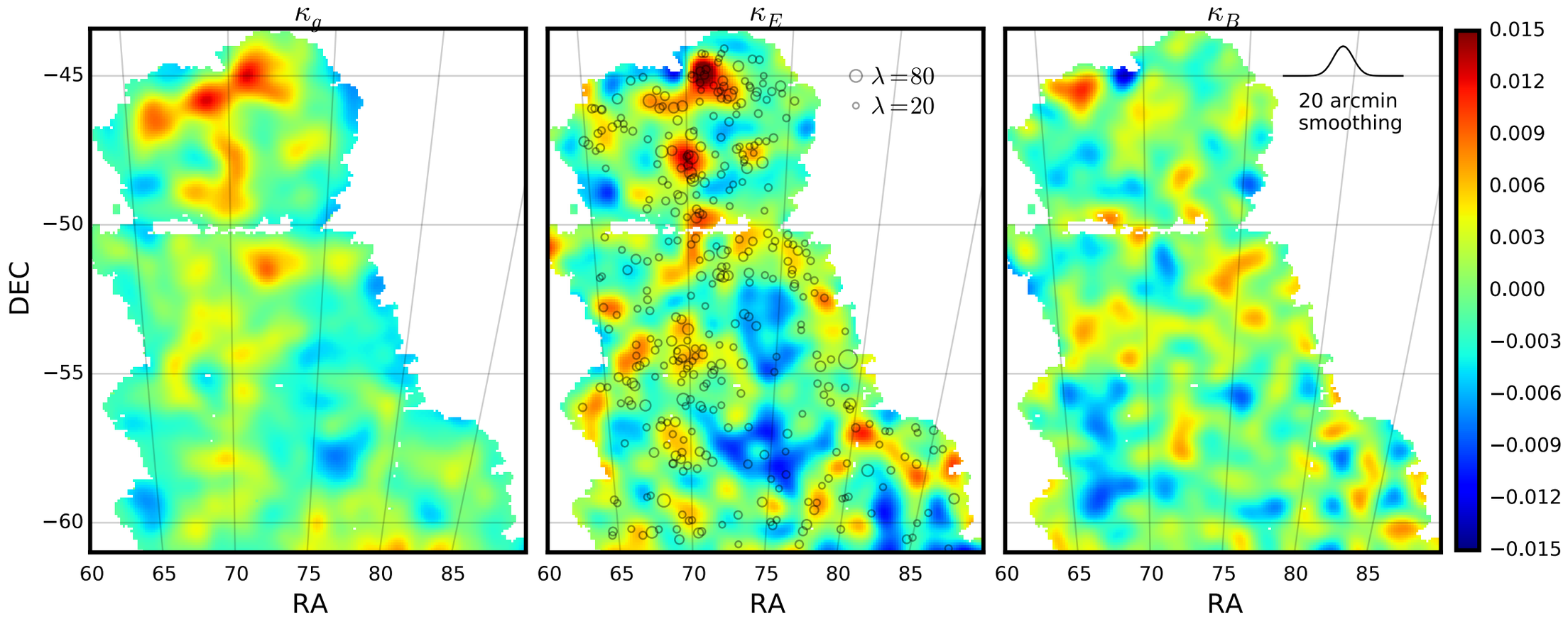
It gets simpler in Fourier space: $\hat{\kappa}_l = D_l^* \hat{\gamma}_l,$ **Kaiser & Squires, 93**



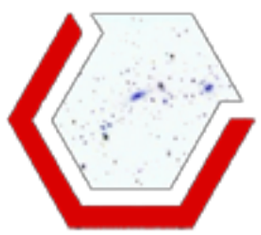
Wide-Field Lensing Mass Maps from DES Science Verification Data

Convergence maps reconstructed from

Galaxy catalog | Shear E-modes | Shear B-modes



C. Chang *et al.*, 1505.01871
V. Vikram *et al.*,1504.03002



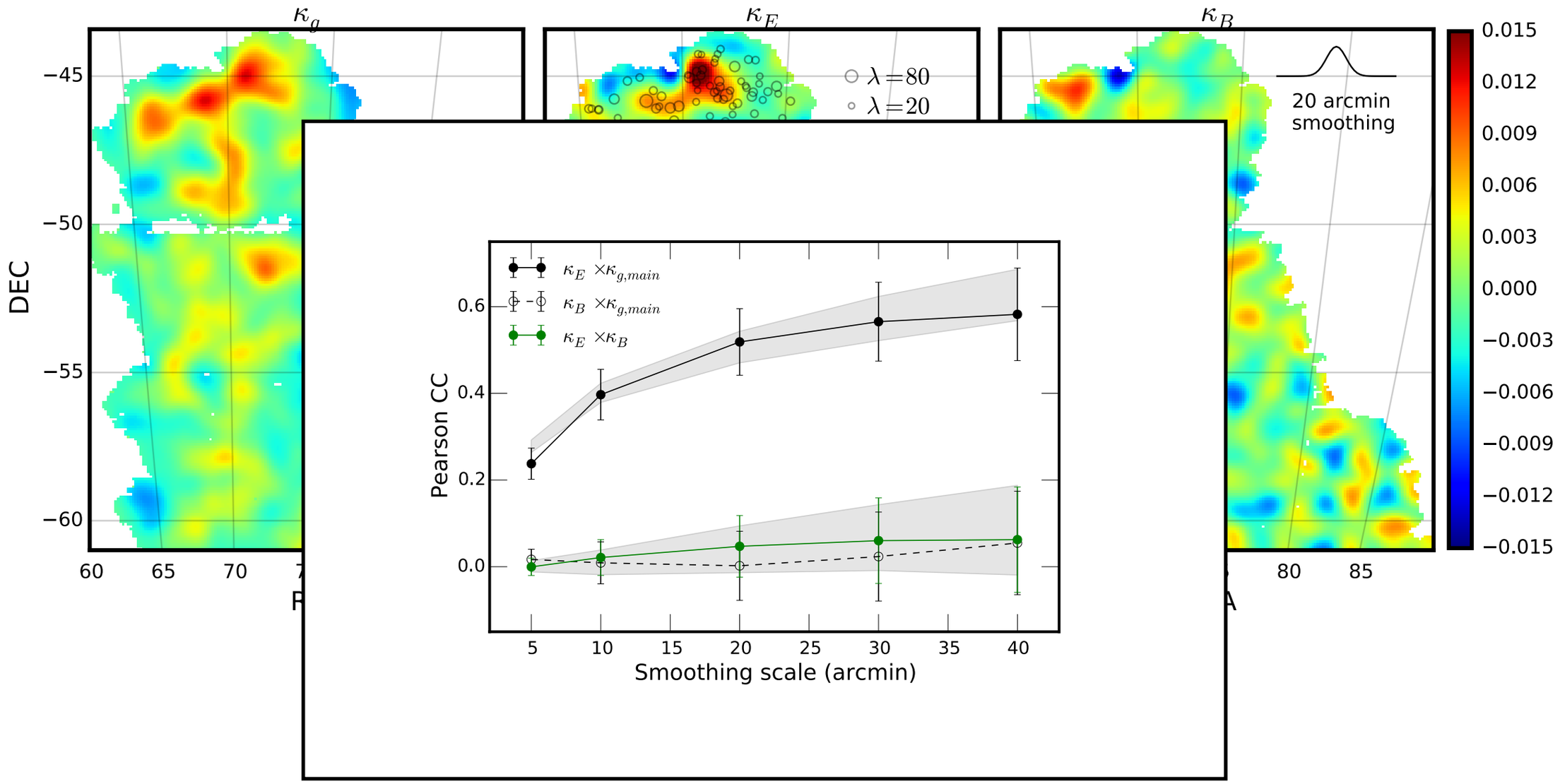
Wide-Field Lensing Mass Maps from DES Science Verification Data

Convergence maps reconstructed from

Galaxy catalog

Shear E-modes

Shear B-modes

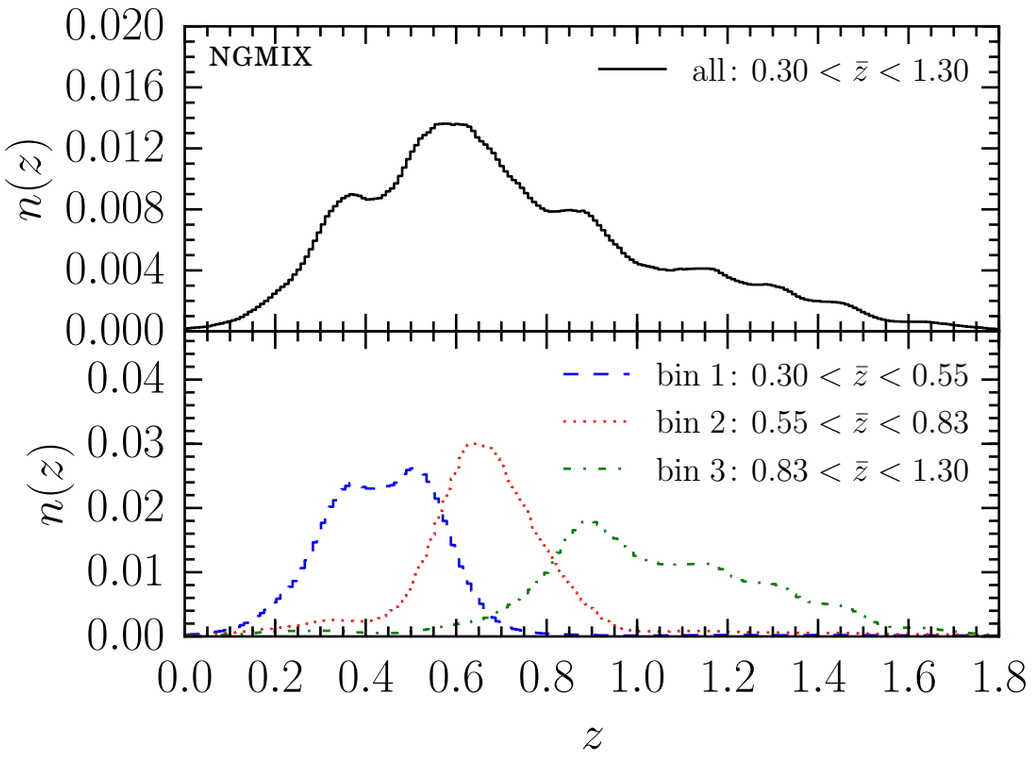


C. Chang *et al.*, 1505.01871
V. Vikram *et al.*,1504.03002

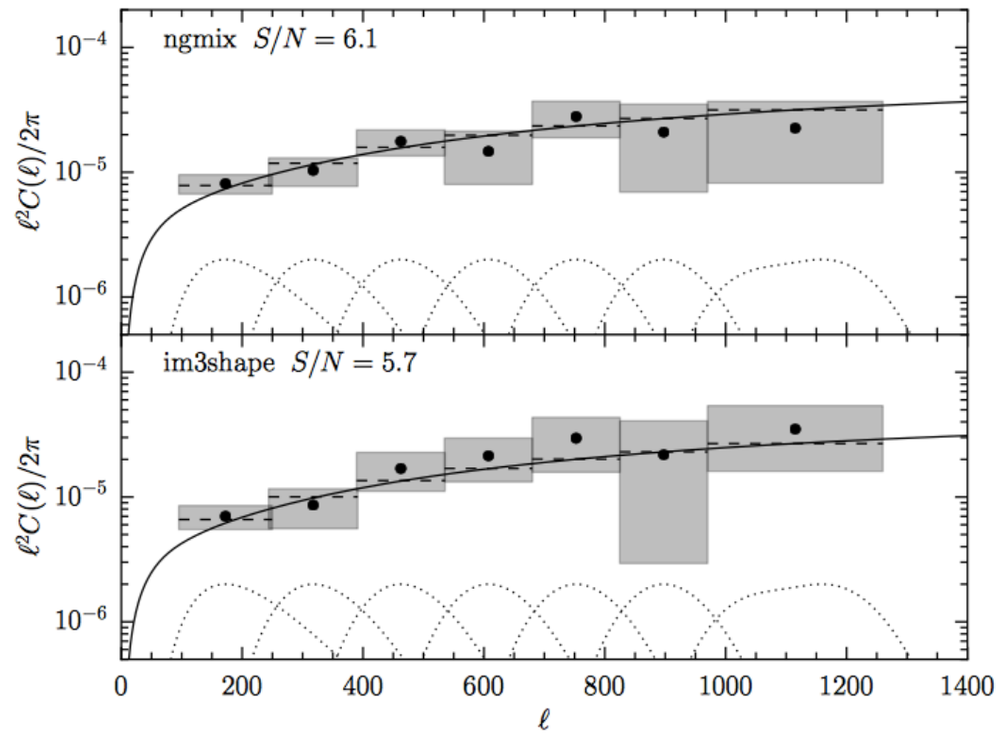
The DES weak lensing catalog

Shape measurements from single-epoch images
Two pipelines: ngmix (3.44m) and im3shape (2.12m) over ~140 sq.deg.

Redshift distributions

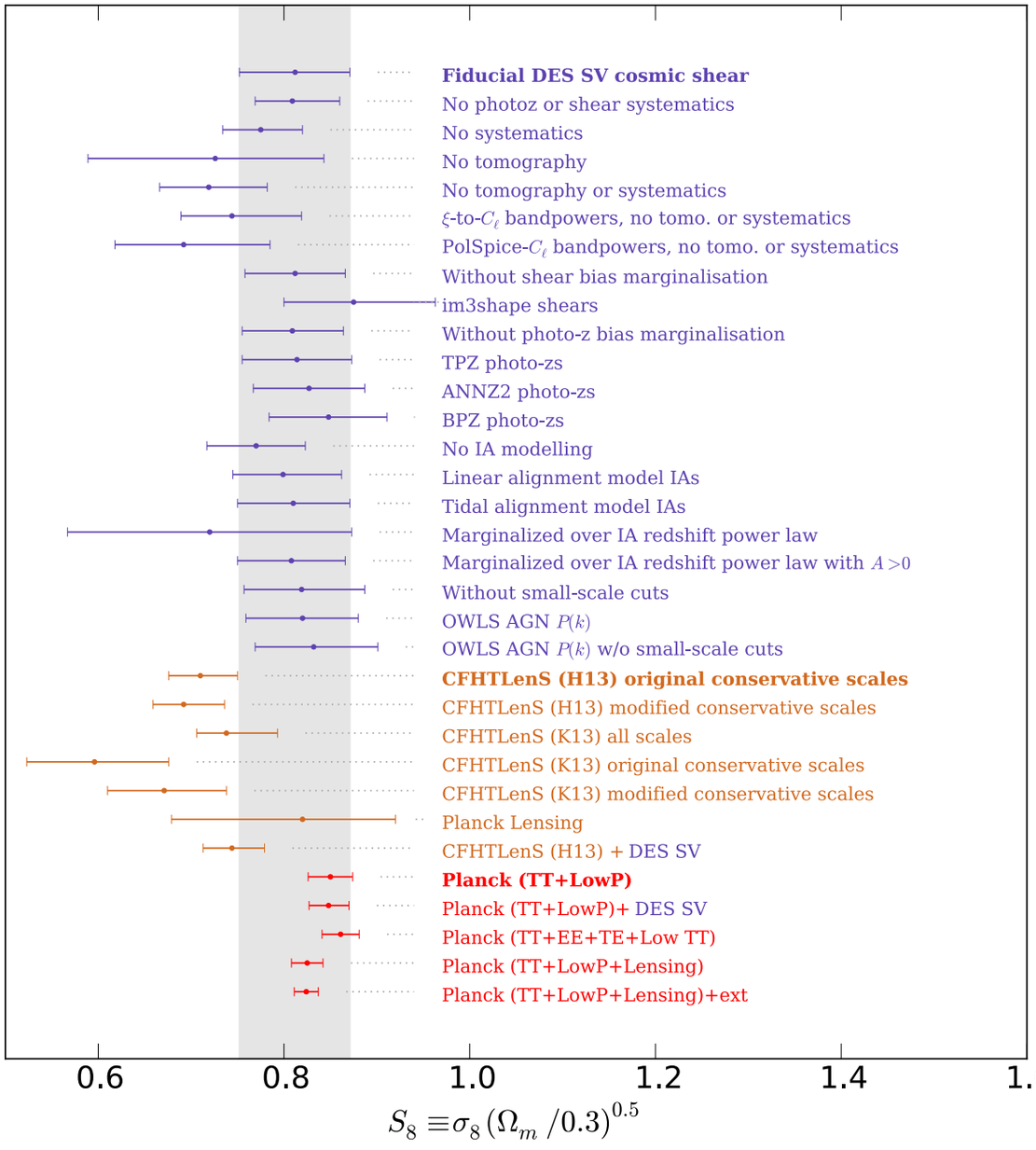


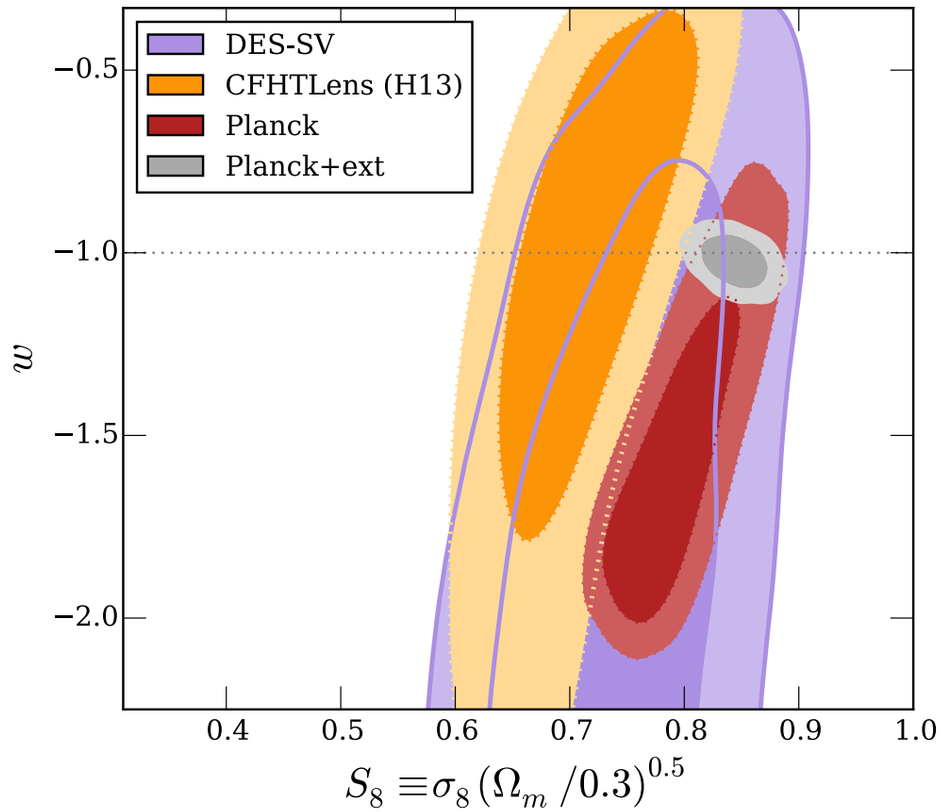
Shear-Shear power spectrum

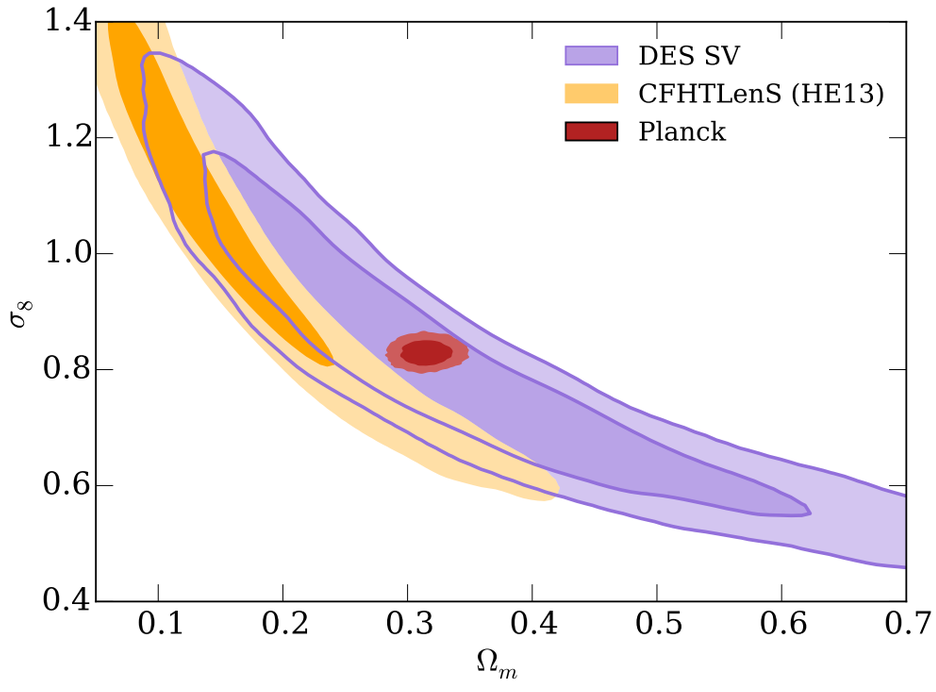


Jarvis et al., 1507.05603
Becker et al, 1507.05598
Bonnet et al, 1507.05909
DES collaboration, 1507.05552

Weak lensing: cosmology results



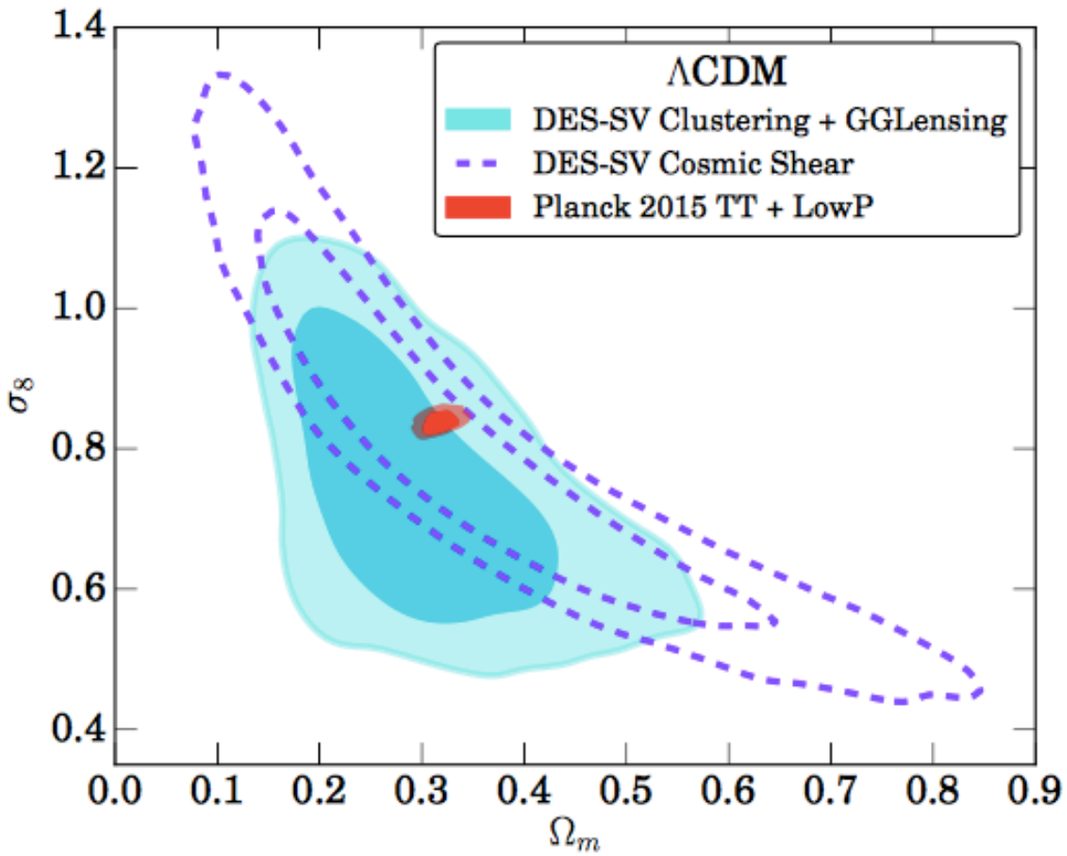


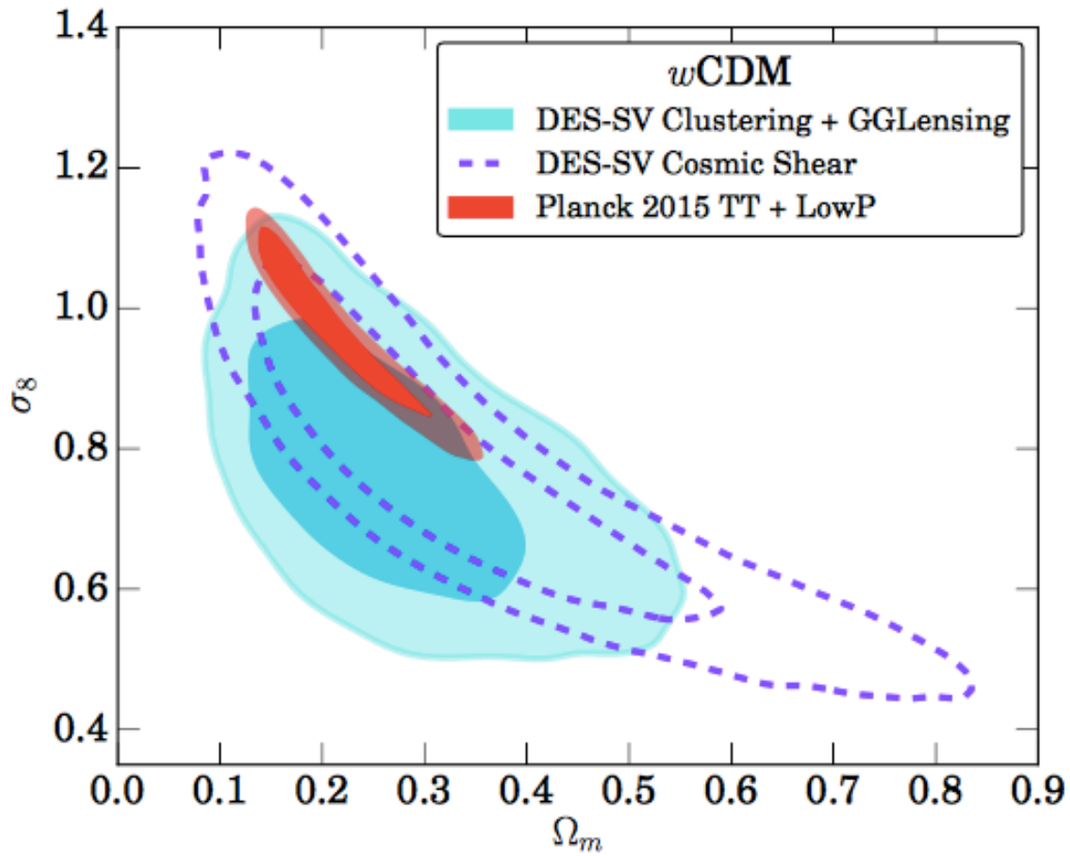


Abbott et al., 1507.05552

Combining probes

Using galaxy clustering + galaxy-galaxy lensing



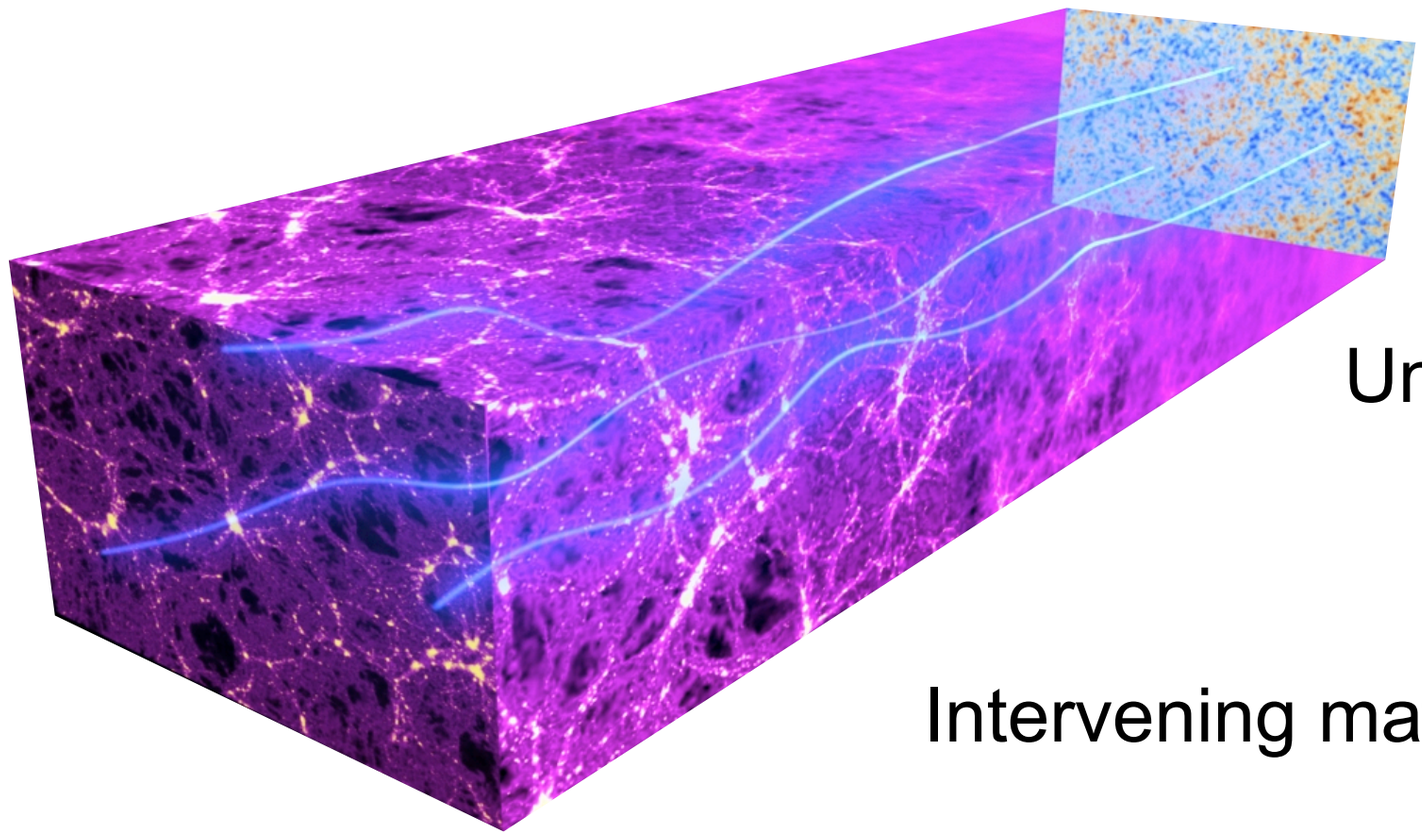


Next Y1 analysis will consider galaxy clustering + galaxy-galaxy lensing + galaxy lensing

Kwan et al., 1604.07871

CMB lensing

Photons from last scattering surface deflected by gravitational potential of large-scale structure



Unlensed CMB

Intervening matter

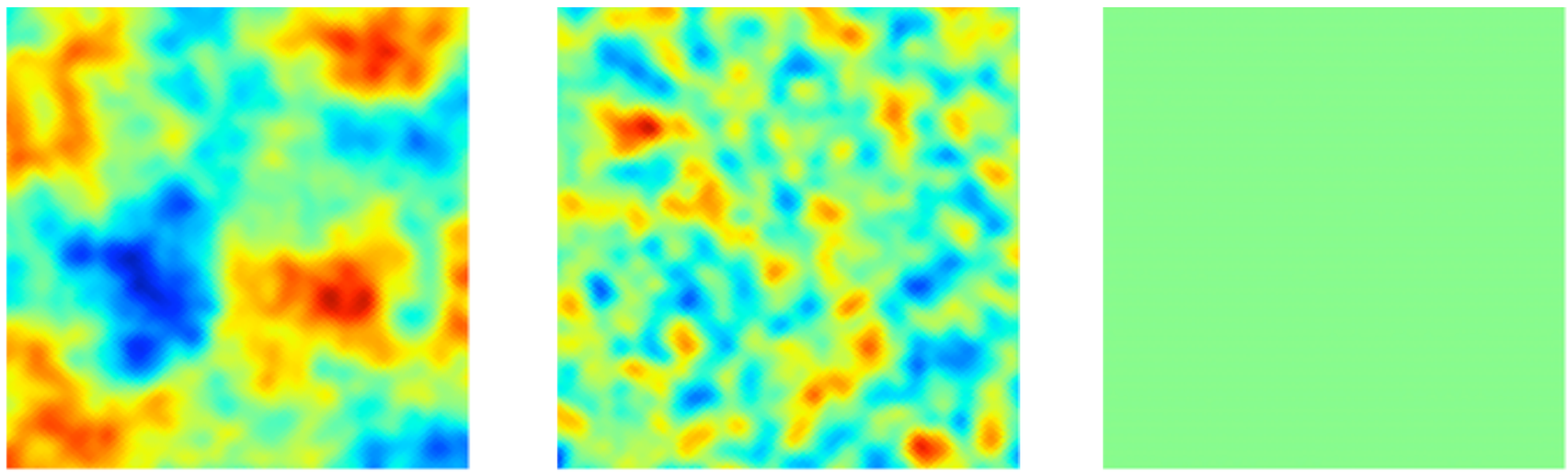
Observed CMB is lensed

CMB lensing

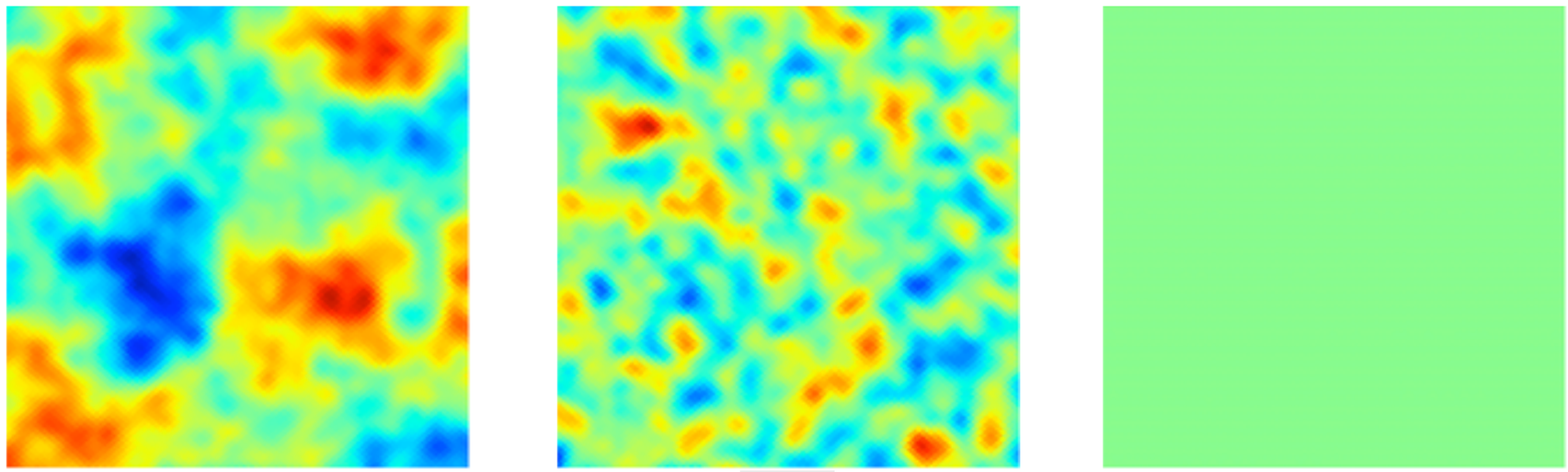
$$\Theta[\hat{\mathbf{n}}] = \tilde{\Theta}[\hat{\mathbf{n}} + \nabla\phi(\hat{\mathbf{n}})]$$

Temperature | E-modes | B-modes

Unlensed

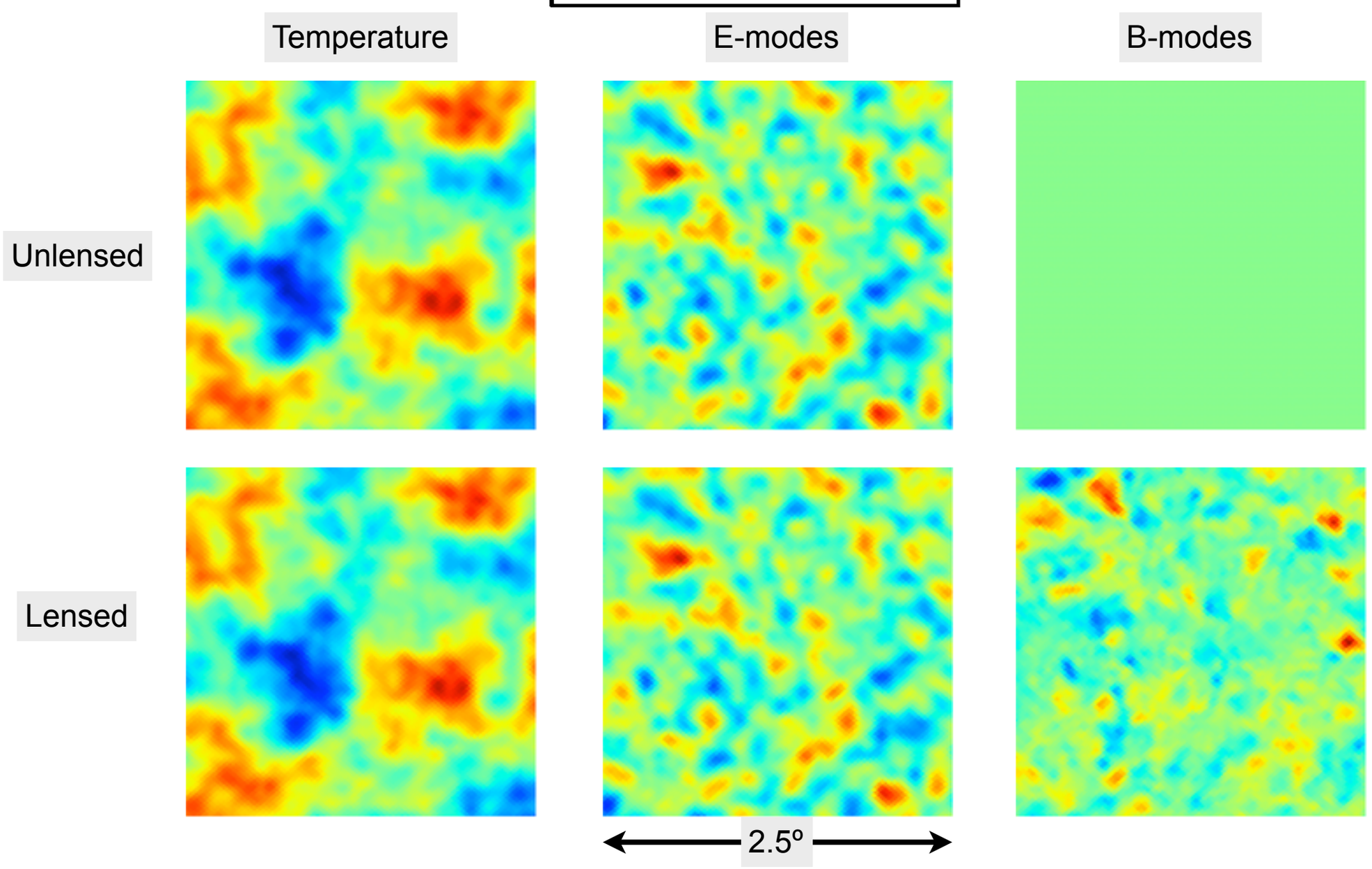


Unlensed



CMB lensing

$$\Theta[\hat{\mathbf{n}}] = \tilde{\Theta}[\hat{\mathbf{n}} + \nabla\phi(\hat{\mathbf{n}})]$$

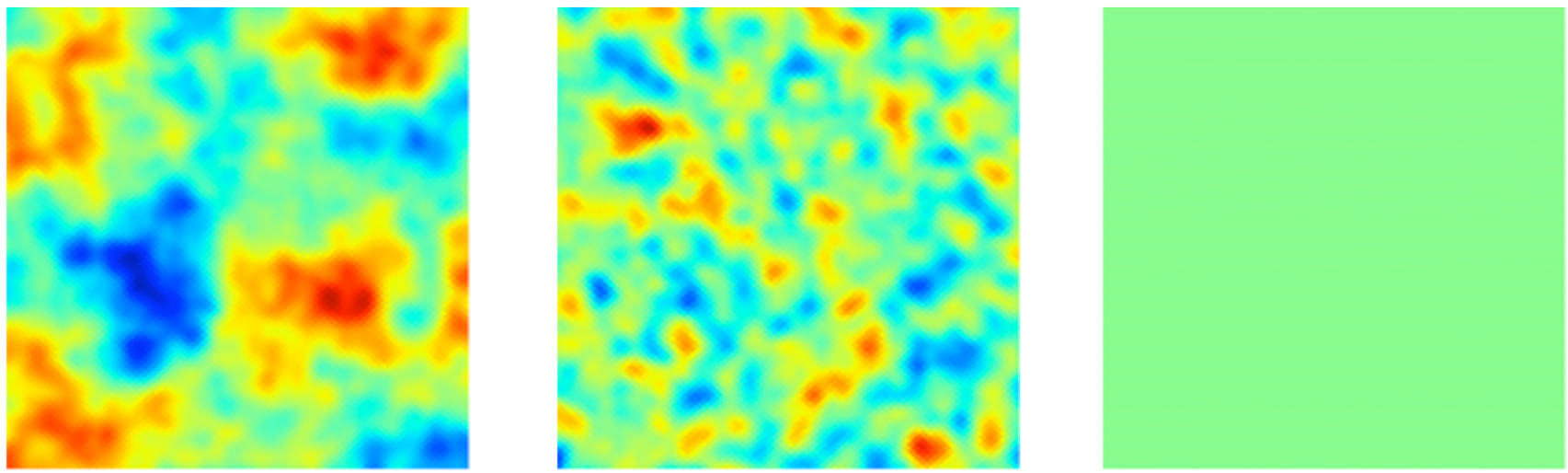


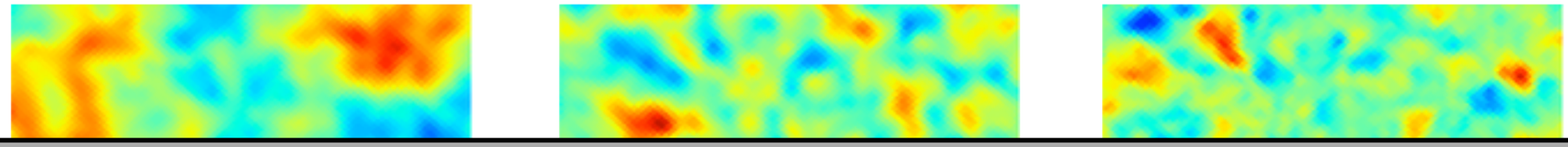
CMB lensing

$$\Theta[\hat{\mathbf{n}}] = \tilde{\Theta}[\hat{\mathbf{n}} + \nabla\phi(\hat{\mathbf{n}})]$$

Temperature | E-modes | B-modes

Unlensed





- Typical deflections: ~2.5 arcmin
- Coherent on the degree scale
- CMB lensing induces temperature-gradient correlations

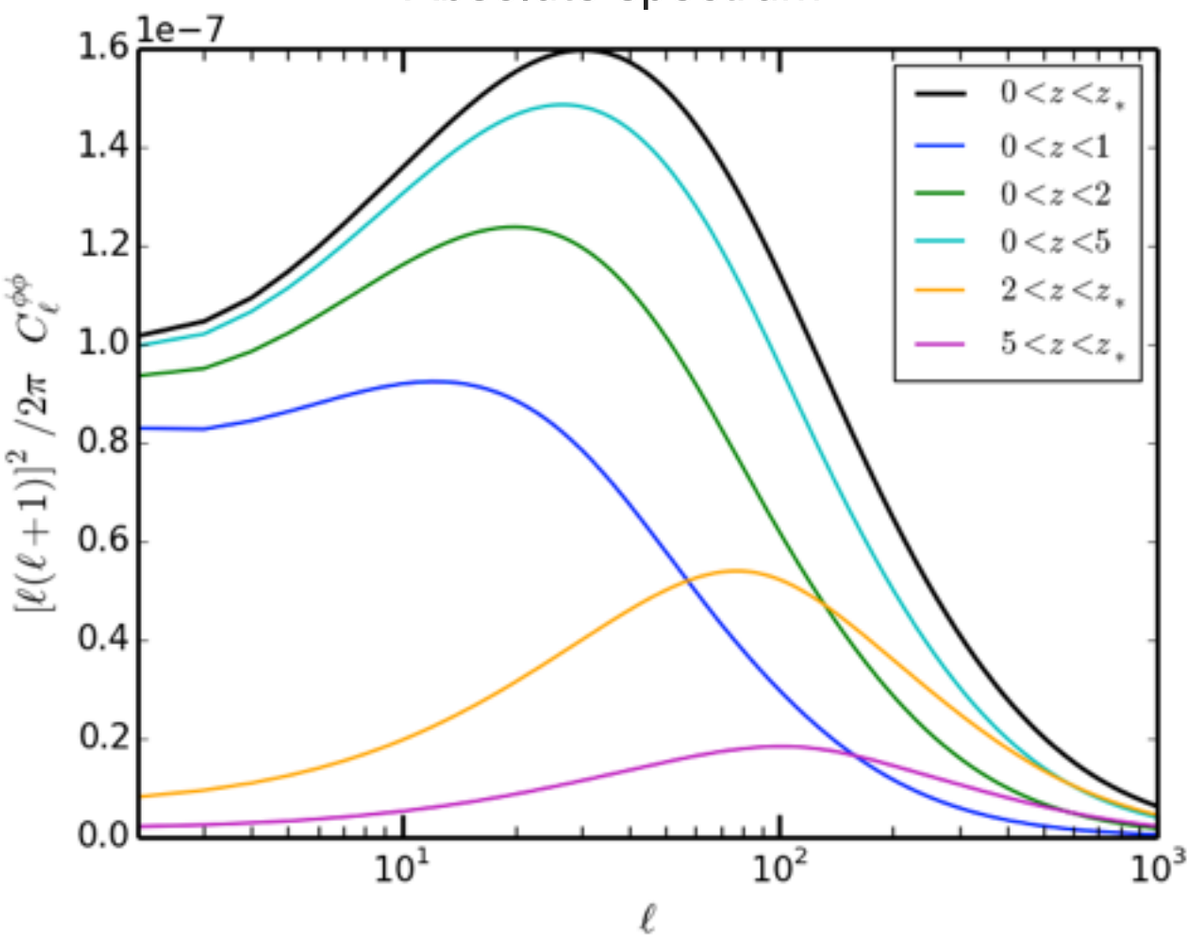
$$\Theta[\hat{\mathbf{n}}] = \tilde{\Theta}[\hat{\mathbf{n}} + \nabla\phi(\hat{\mathbf{n}})] \approx \tilde{\Theta}[\hat{\mathbf{n}}] + \nabla\phi[\hat{\mathbf{n}}]\ \nabla\tilde{\Theta}[\hat{\mathbf{n}}] + \cdots$$

CMB lensing potential

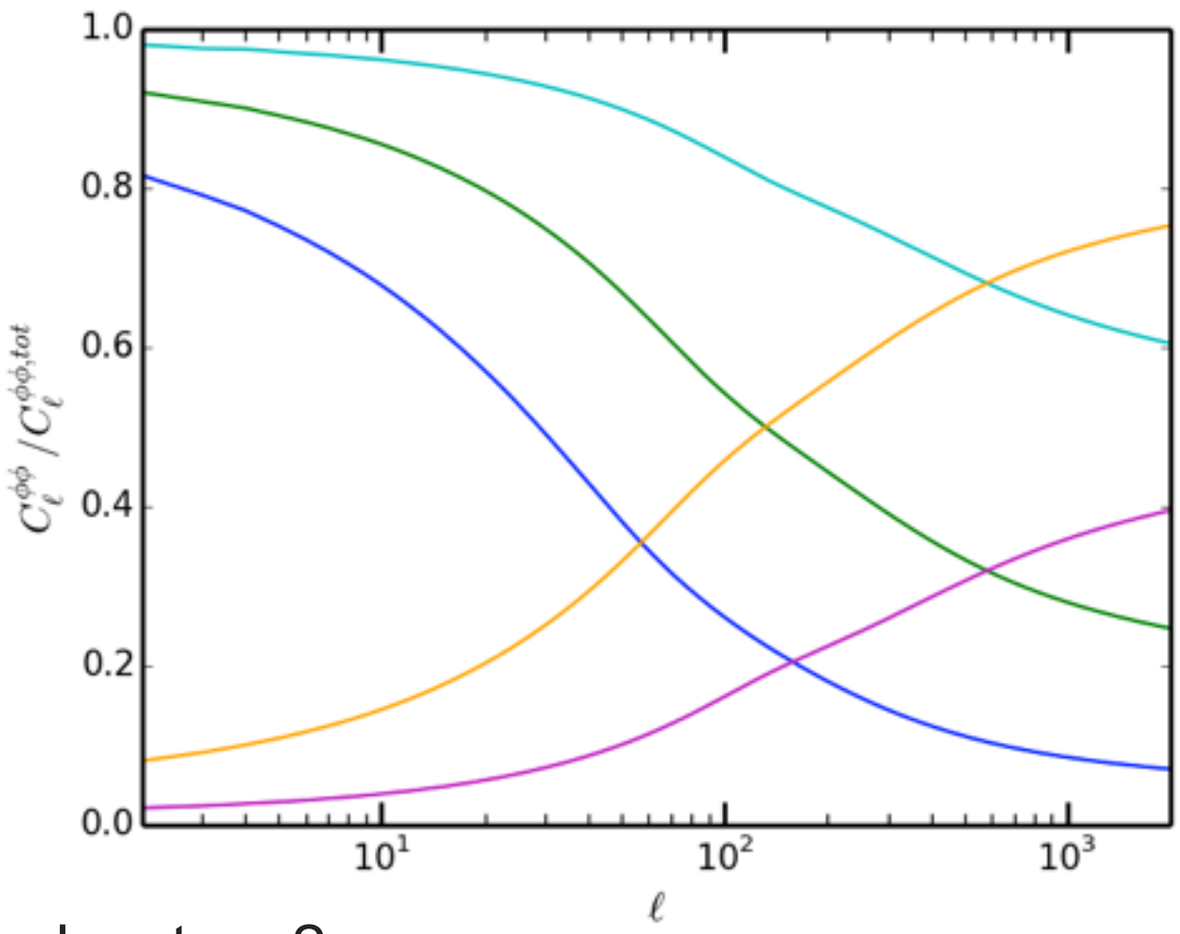
CMB lensing potential is an unbiased tracer of all the matter distribution up to z~1100

$$\phi(\hat{\boldsymbol{n}}) = -2\int_0^{\chi_*} d\chi \frac{f_K(\chi_* - \chi)}{f_K(\chi_*) f_K(\chi)} \Psi(\chi\hat{\boldsymbol{n}}; \eta_0 - \chi).$$

Absolute spectrum



Ratio



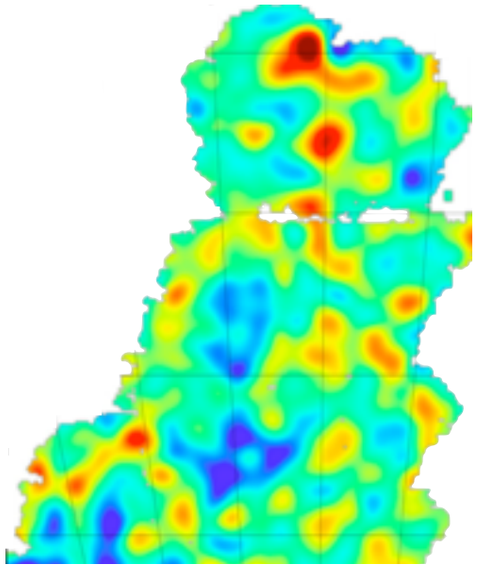
CMB Lensing kernel is wide and peaks at z ~2

DES will enable CMB lensing tomography

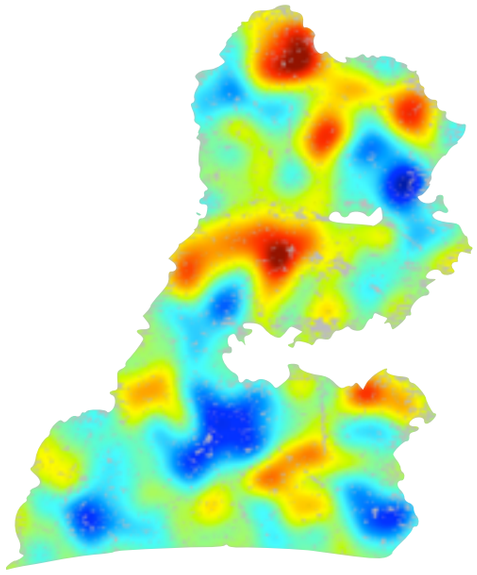
CMB lensing from South Pole Telescope and Planck

Same structure seen by different techniques

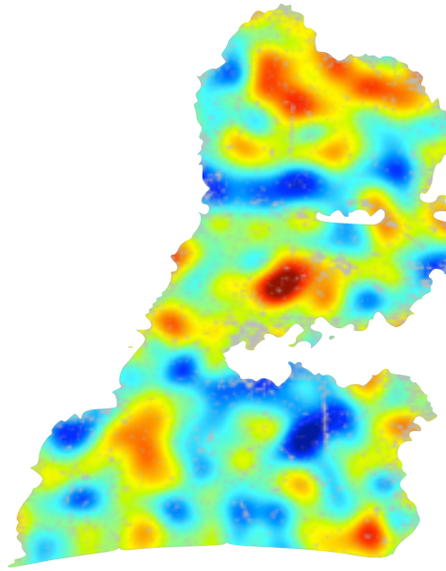
Cosmic shear
(données DES-SV)



DES-galaxies



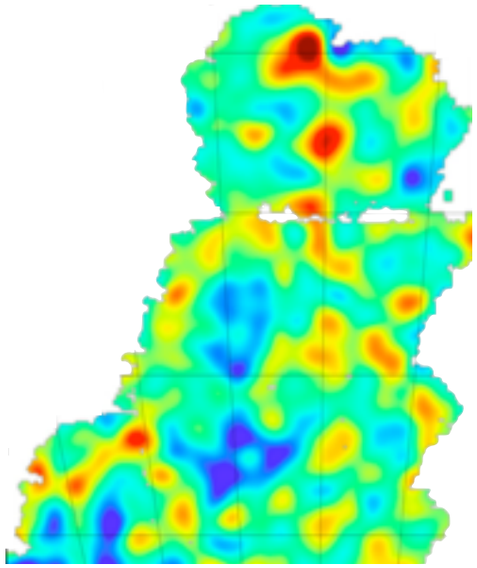
CMB lensing
(SPT data)



CMB lensing from South Pole Telescope and Planck

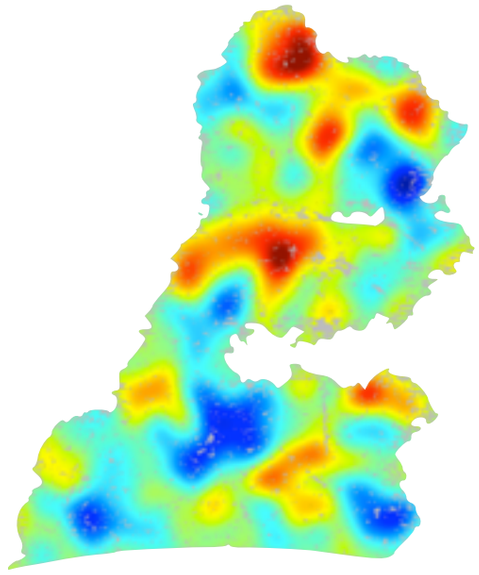
Same structure seen by different techniques

Cosmic shear
(données DES-SV)



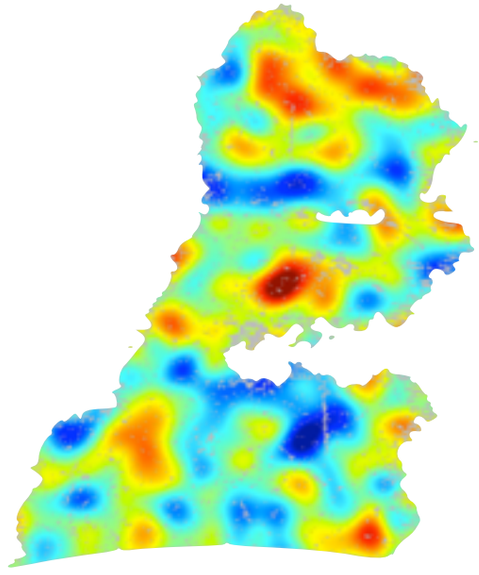
$$\int_0^{\chi_*} d\chi\ \chi \int_\chi^{\chi_*} d\chi' \frac{dn}{d\chi'} \frac{\chi' - \chi}{\chi'} \frac{\delta(\chi\hat{\mathbf{n}}, \chi)}{a}$$

DES-galaxies



$$\int_0^{\infty} dz\ b(z) \frac{dn}{dz}(z) \delta(\chi\hat{\mathbf{n}}, \chi)$$

CMB lensing
(SPT data)



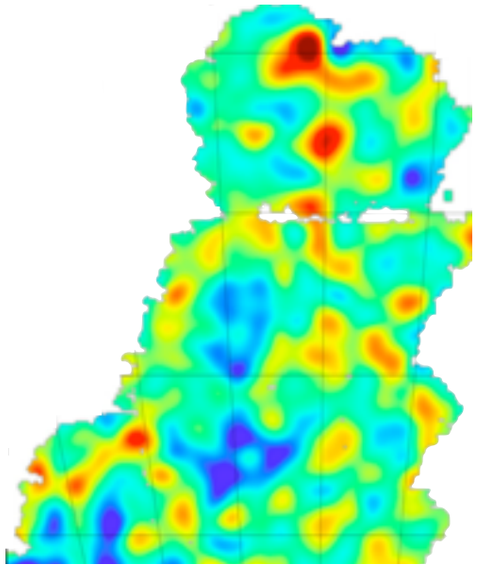
$$\int_0^{\chi_*} d\chi\ \chi^2 \frac{\chi_* - \chi}{\chi_* \chi} \frac{\delta(\chi\hat{\mathbf{n}}, \chi)}{a}$$

matter density contrast

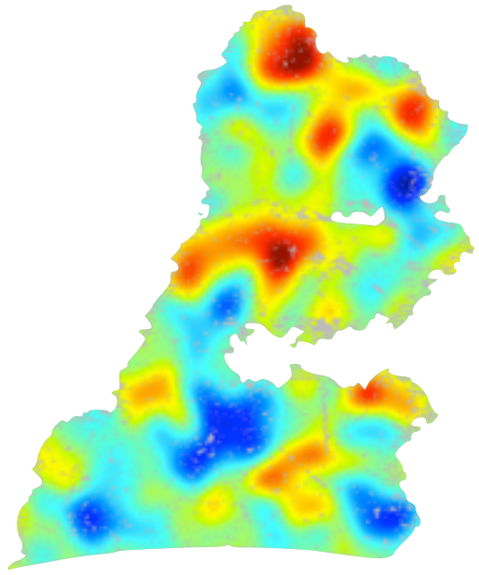
CMB lensing from South Pole Telescope and Planck

Same structure seen by different techniques

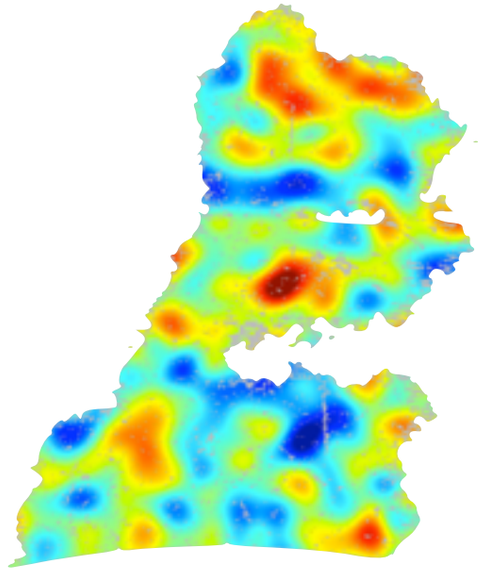
Cosmic shear
(données DES-SV)



DES-galaxies



CMB lensing
(SPT data)



Source redshift distribution

$$\int_0^{\chi_*} d\chi\, \chi \int_\chi^{\chi_*} d\chi' \frac{dn}{d\chi'} \frac{\chi' - \chi}{\chi'} \frac{\delta(\chi\hat{\mathbf{n}}, \chi)}{a}$$

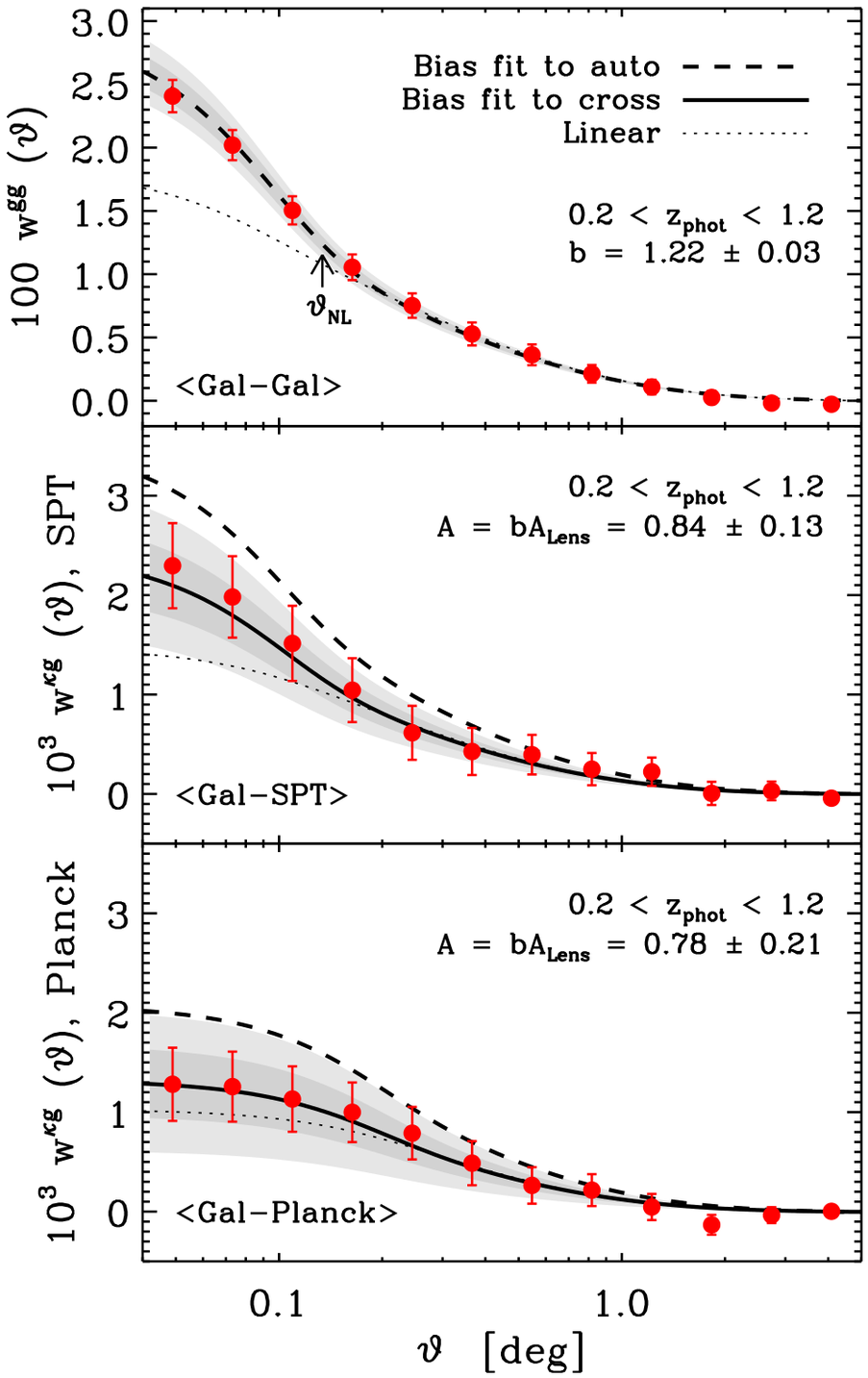
$$\int_0^{\infty} dz\, b(z) \frac{dn}{dz}(z)\, \delta(\chi\hat{\mathbf{n}}, \chi)$$

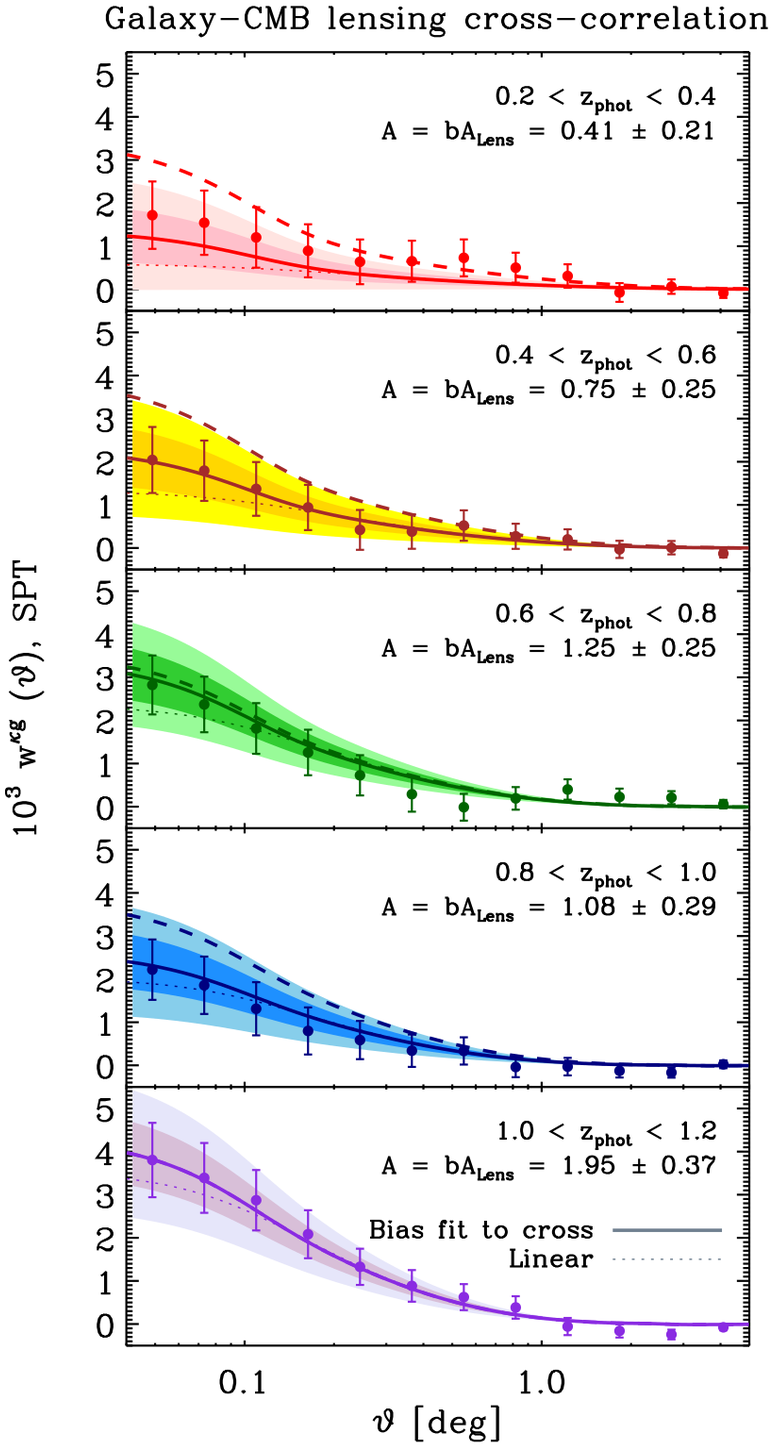
bias

$$\int_0^{\chi_*} d\chi\, \chi^2 \frac{\chi_* - \chi}{\chi_* \chi} \frac{\delta(\chi\hat{\mathbf{n}}, \chi)}{a}$$

matter density contrast

CMB lensing tomography





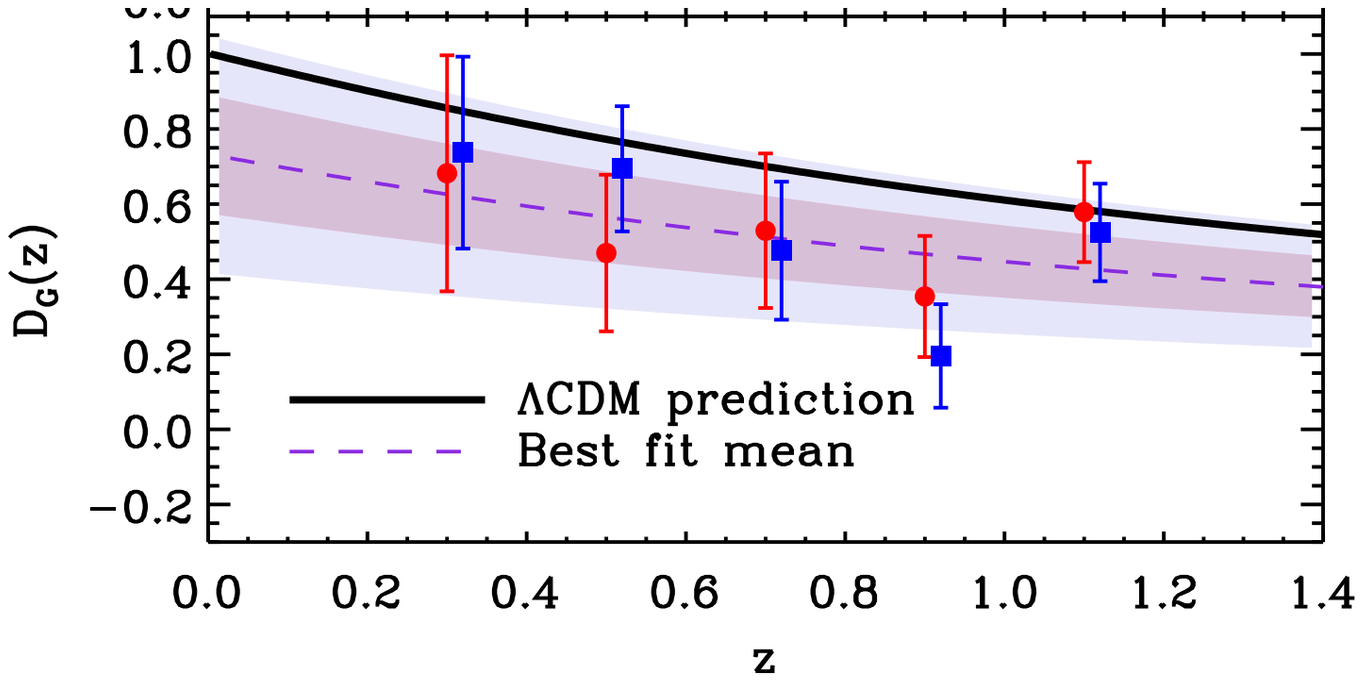
Giannantonio et al., 1507.05551

CMB lensing tomography

Measuring the linear growth function with photometric surveys

$$C_\ell^{gg}(z) \propto b^2(z)\, D^2(z)\,, \qquad C_\ell^{\kappa g}(z) \propto b(z)\, D^2(z)\,,$$

$$\left(\hat{D}_G\right)_i \equiv \left\langle \frac{\left(C_\ell^{\kappa g}\right)^i_{\rm obs}}{\left(\not{C}_\ell^{\kappa g}\right)^i_{\rm the}} \sqrt{\frac{\left(\not{C}_\ell^{gg}\right)^i_{\rm the}}{\left(C_\ell^{gg}\right)^i_{\rm obs}}} \right\rangle_\ell .$$



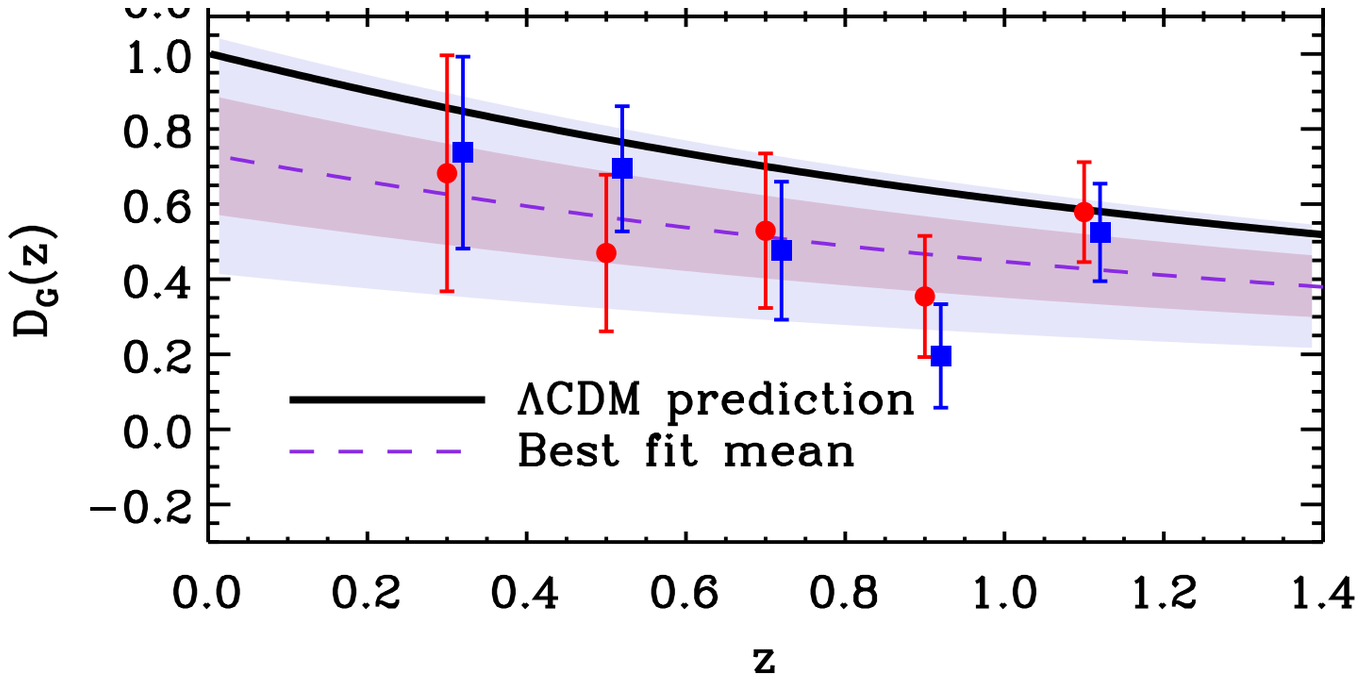
Giannantonio et al., 1507.05551

CMB lensing tomography

Measuring the linear growth function with photometric surveys

$$C_\ell^{gg}(z) \propto b^2(z)\, D^2(z)\,, \qquad C_\ell^{\kappa g}(z) \propto b(z)\, D^2(z)\,,$$

$$\left(\hat{D}_G\right)_i \equiv \left\langle \frac{\left(C_\ell^{\kappa g}\right)^i_{\rm obs}}{\left(\mathcal{C}_\ell^{\kappa g}\right)^i_{\rm the}} \sqrt{\frac{\left(\mathcal{C}_\ell^{gg}\right)^i_{\rm the}}{\left(C_\ell^{gg}\right)^i_{\rm obs}}} \right\rangle_\ell .$$

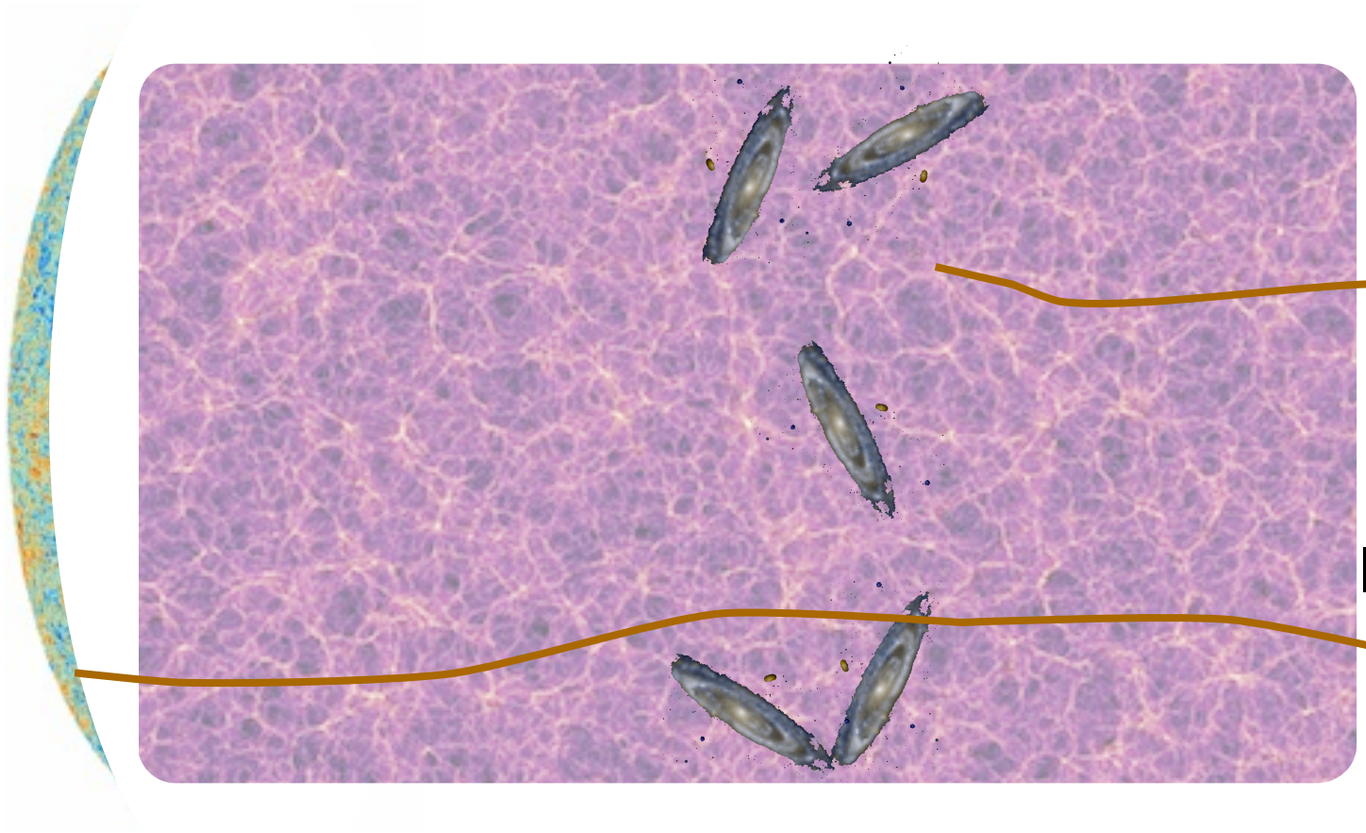


$$C_\ell^{gg} = \frac{2}{\pi}\int_0^\infty dk\, k^2\, P(k)\, W_\ell^g(k)\, W_\ell^g(k) \qquad W_\ell^g(k) = \int_0^\infty dz\, b(z) \frac{dn}{dz}(z)\, D(z)\, j_\ell[k\chi(z)]$$

$$C_\ell^{\kappa g} = \frac{2}{\pi}\int_0^\infty dk\, k^2\, P(k)\, W_\ell^\kappa(k)\, W_\ell^g(k)\,, \qquad W_\ell^\kappa(k) = \frac{3\Omega_m H_0^2}{2}\int_0^\infty dz\, \frac{\chi_* - \chi}{\chi_* \chi}(z)\, D(z)\, j_\ell[k\chi(z)]\,,$$

Giannantonio et al., 1507.05551

CMB lensing and Cosmic shear



sheared galaxies

DES

lensed CMB

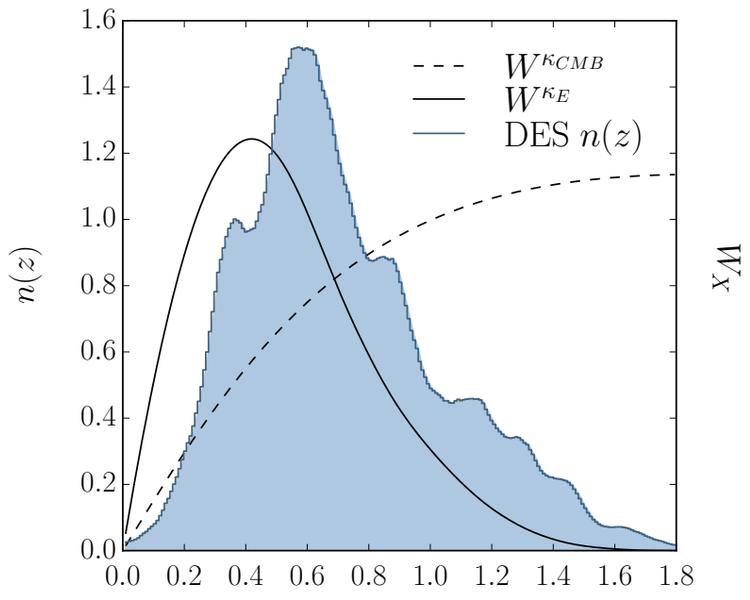
Planck

SPT

$$C_{\mathrm{GWL,CMBWL}}(\ell) = \int_0^{\chi_{\mathrm{hor}}} \frac{d\chi}{\chi(z)^2} W_{\mathrm{GWL}}\left[\chi(z)\right] W_{\mathrm{CMBWL}}[\chi(z)] P_{\delta\delta}\left(\frac{\ell}{\chi(z)}, z\right),$$

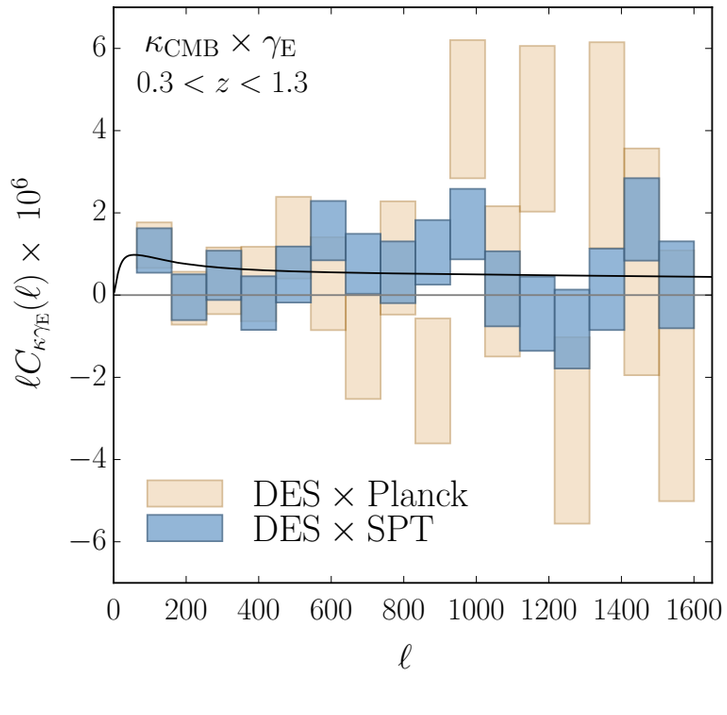
$$W_{\mathrm{GWL}}\left[\chi(z)\right] = \frac{3H_0^2\Omega_{\mathrm{m}}}{2c^2}\frac{\chi}{a(\chi)}\int_{\chi}^{\chi_{\mathrm{hor}}} d\chi' n(\chi')\frac{\chi'-\chi}{\chi'}, \qquad W_{\mathrm{CMBWL}}\left[\chi(z)\right] = \frac{3H_0^2\Omega_{\mathrm{m}}}{2c^2}\frac{\chi}{a(\chi)}\frac{\chi_*-\chi}{\chi_*},$$

CMB lensing x DES shear



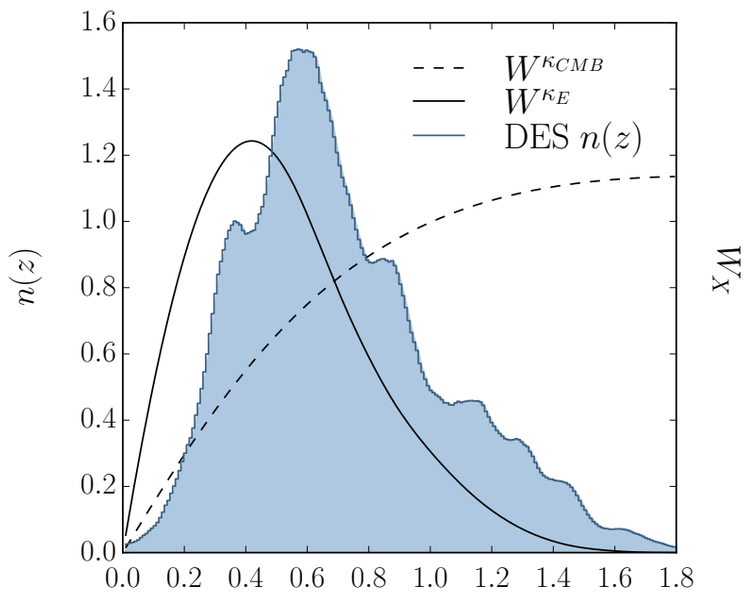
Considered galaxy ellipticities (γ_1,γ_2) as spin-2 field, and use CMB tools (PolSPICE)

Redshift Range	$0.3 < z < 1.3$	
$\kappa_{\rm CMB}\gamma_{\rm E}$	A	χ^2/d.o.f.
`ngmix` × SPT	$0.88^{+0.30}_{-0.30}$	0.93
`ngmix` × *Planck*	$0.86^{+0.39}_{-0.39}$	1.52



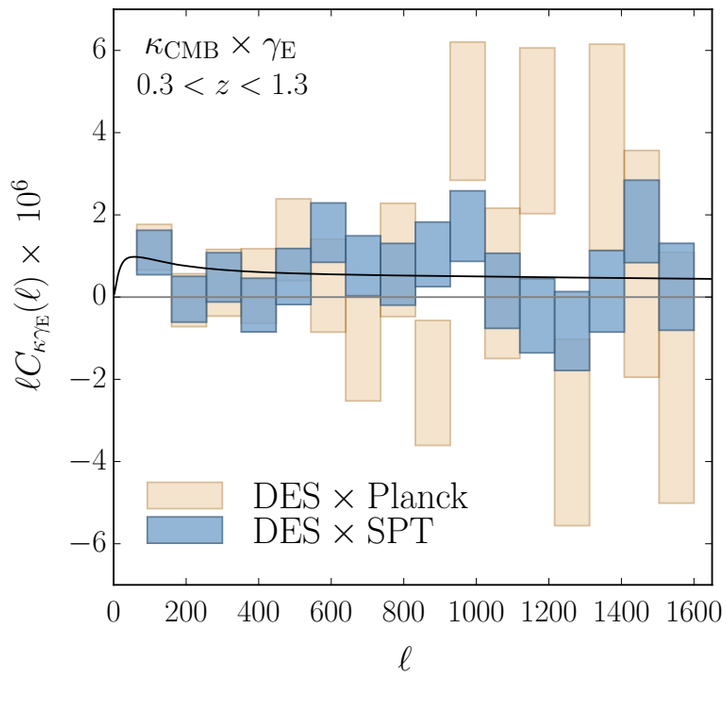
Kirk, Omori, Benoit-Lévy, *et al (the DES coll.) MNRAS, 2016*

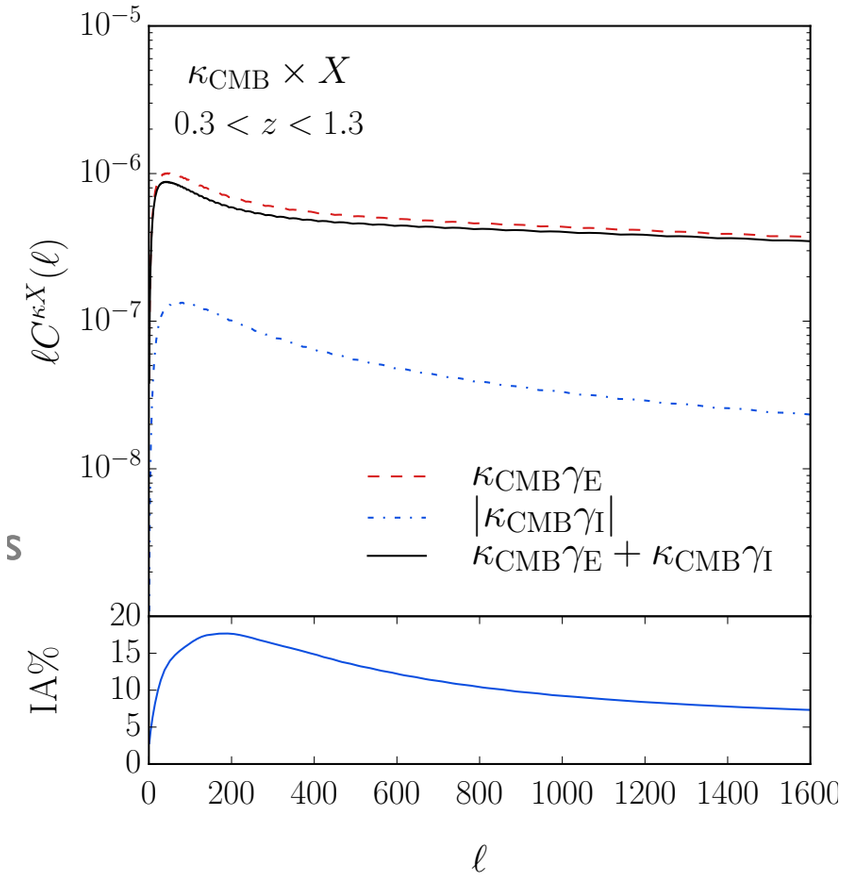
CMB lensing x DES shear



Considered galaxy ellipticities (γ_1,γ_2) as spin-2 field, and use CMB tools (PolSPICE)

Redshift Range	$0.3 < z < 1.3$	
$\kappa_{\rm CMB}\gamma_{\rm E}$	A	χ^2/d.o.f.
`ngmix` × SPT	$0.88^{+0.30}_{-0.30}$	0.93
`ngmix` × *Planck*	$0.86^{+0.39}_{-0.39}$	1.52





Intrinsic alignments are a major contaminant for cosmic shear

unsheared ellipticities are correlated with gravitational potential

Assume no IAs: A=0.88±0.30

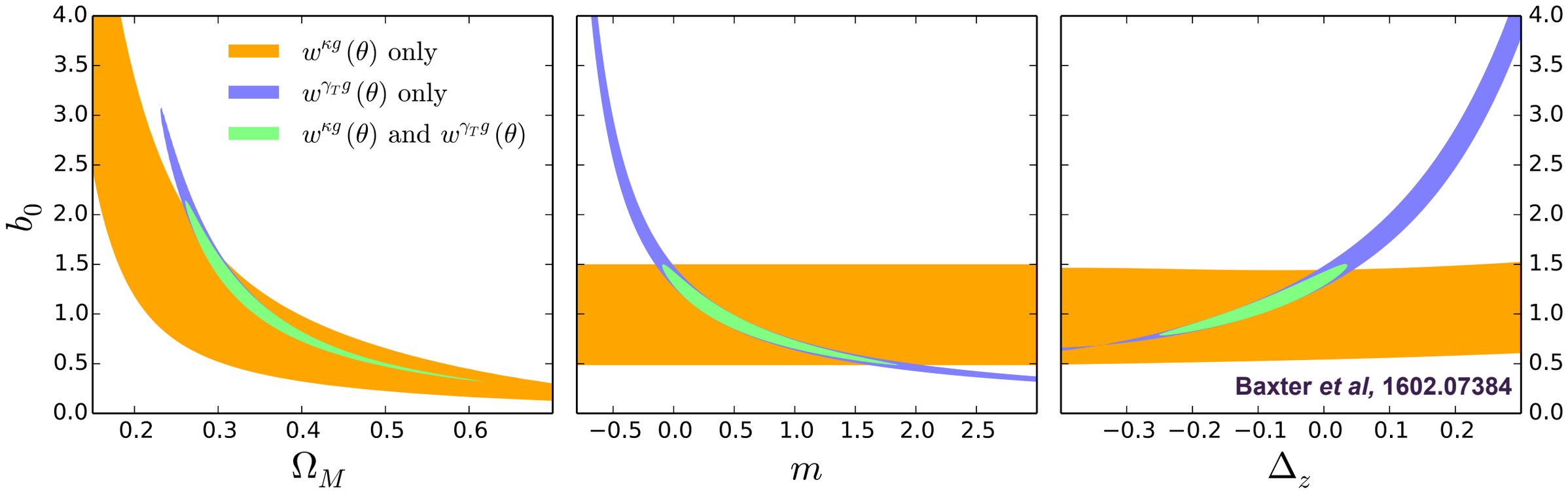
Assume NLA model: A=1.08±0.36

CMB lensing will provide an additional handle to probe/constrain/alleviate IAs.

Kirk, Omori, Benoit-Lévy, *et al (the DES coll.) MNRAS, 2016*

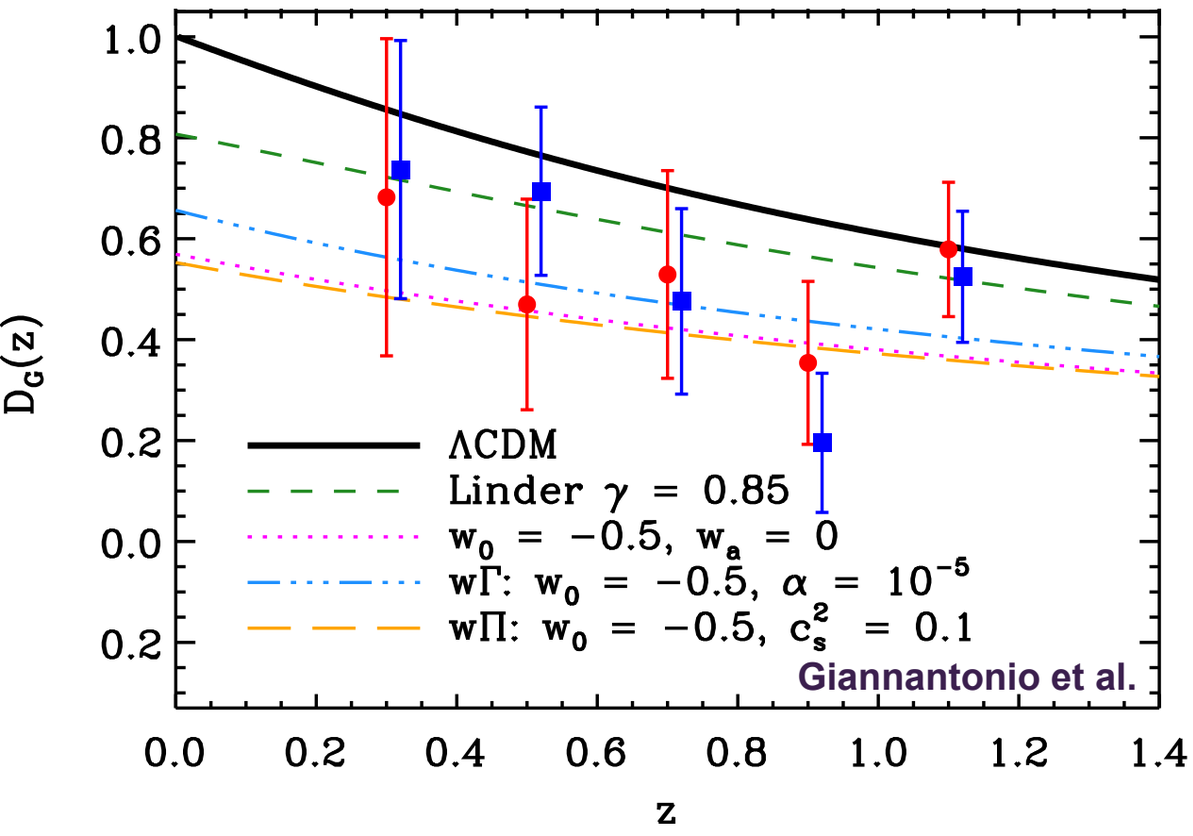
Combining probes

Using galaxy clustering + galaxy-galaxy lensing
and galaxy clustering + CMB lensing

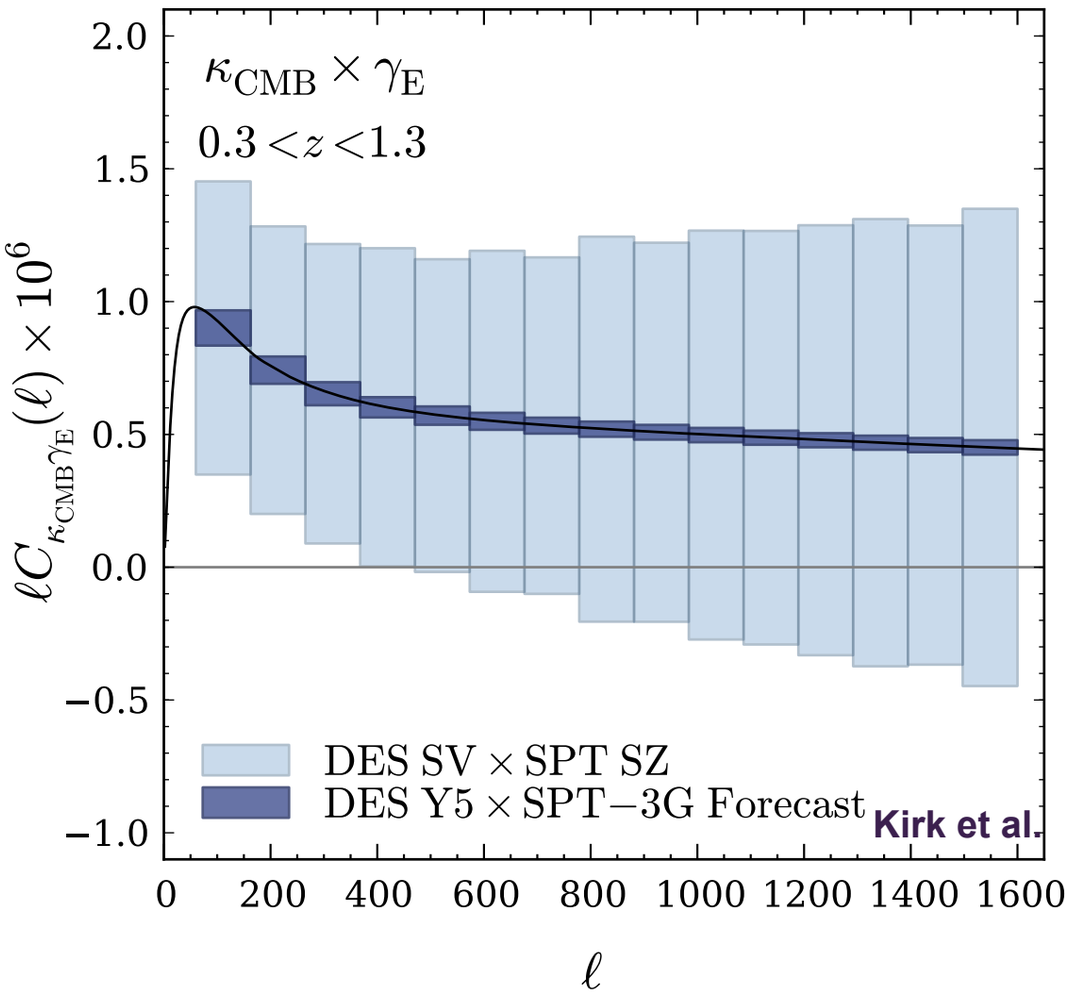


CMB lensing x DES: prospects

galaxy - CMB lensing



galaxy lensing - CMB lensing



Complementarity between surveys (LSST, Euclid) and CMB (S4, COrE) must be exploited

Conclusion

SV analysis is finished, now public:

http://des.ncsa.illinois.edu/releases/sva1

Y1 reduced images are now public:

http://data.darkenergysurvey.org/aux/releasenotes/DESDMrelease.html

First results from Y1. More in the coming months

Collaboration is working on Y1 and Y1-3 data (>1500 sq.deg.)

10sig. limiting magnitude in a 2” diameter aperture (made with Mangle)