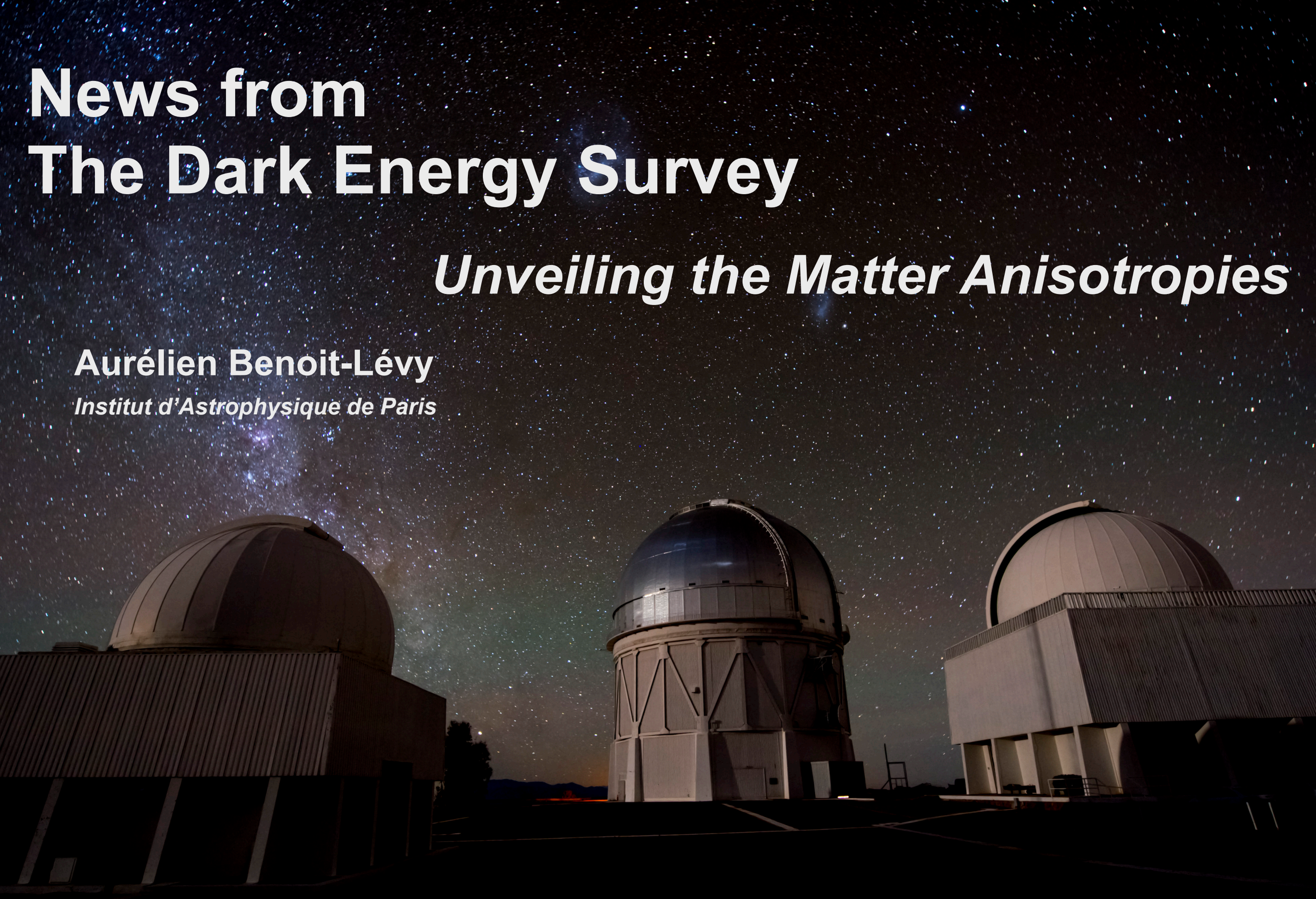
News from The Dark Energy Survey

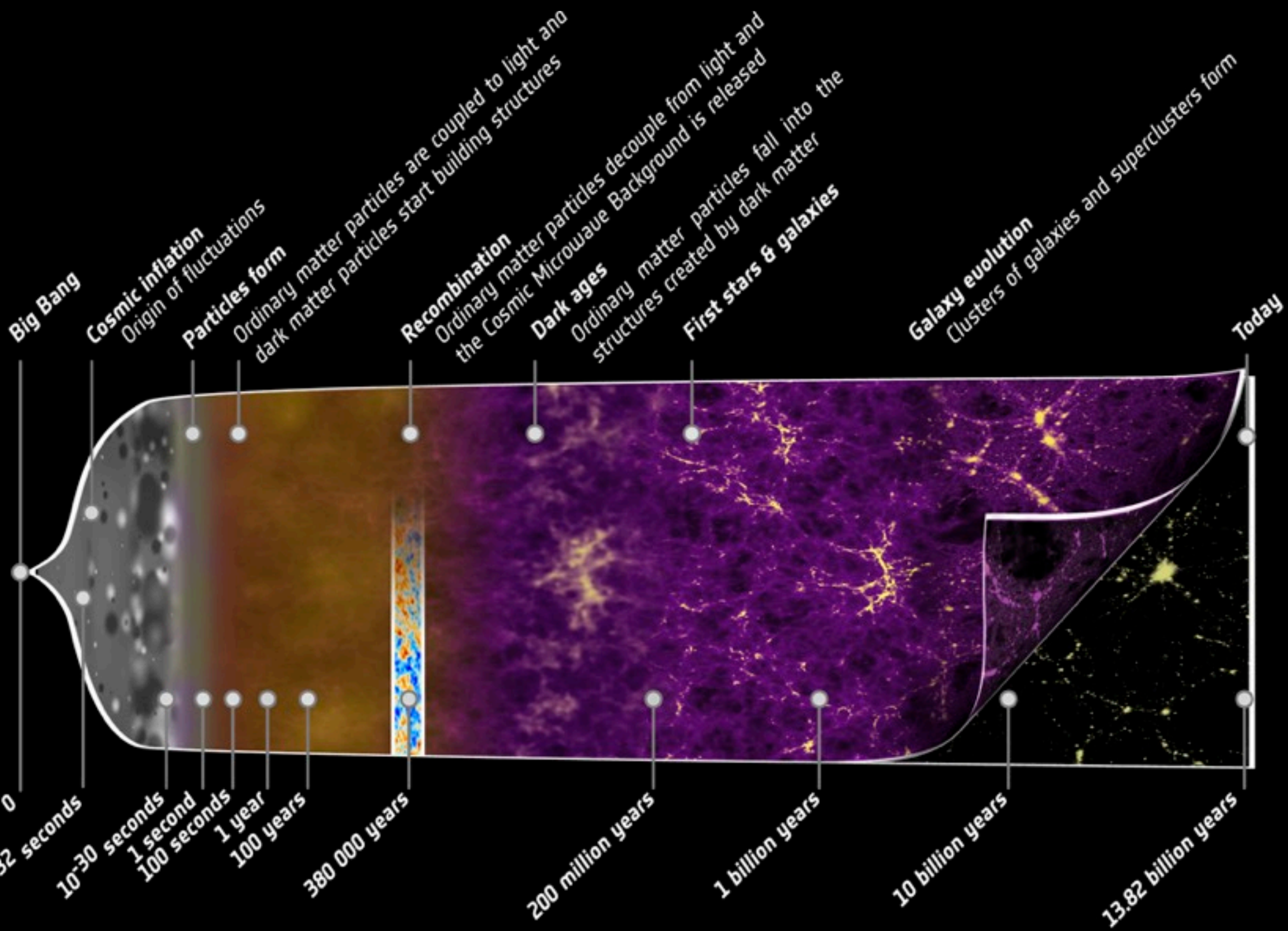
Unveiling the Matter Anisotropies

Aurélien Benoit-Lévy
Institut d'Astrophysique de Paris



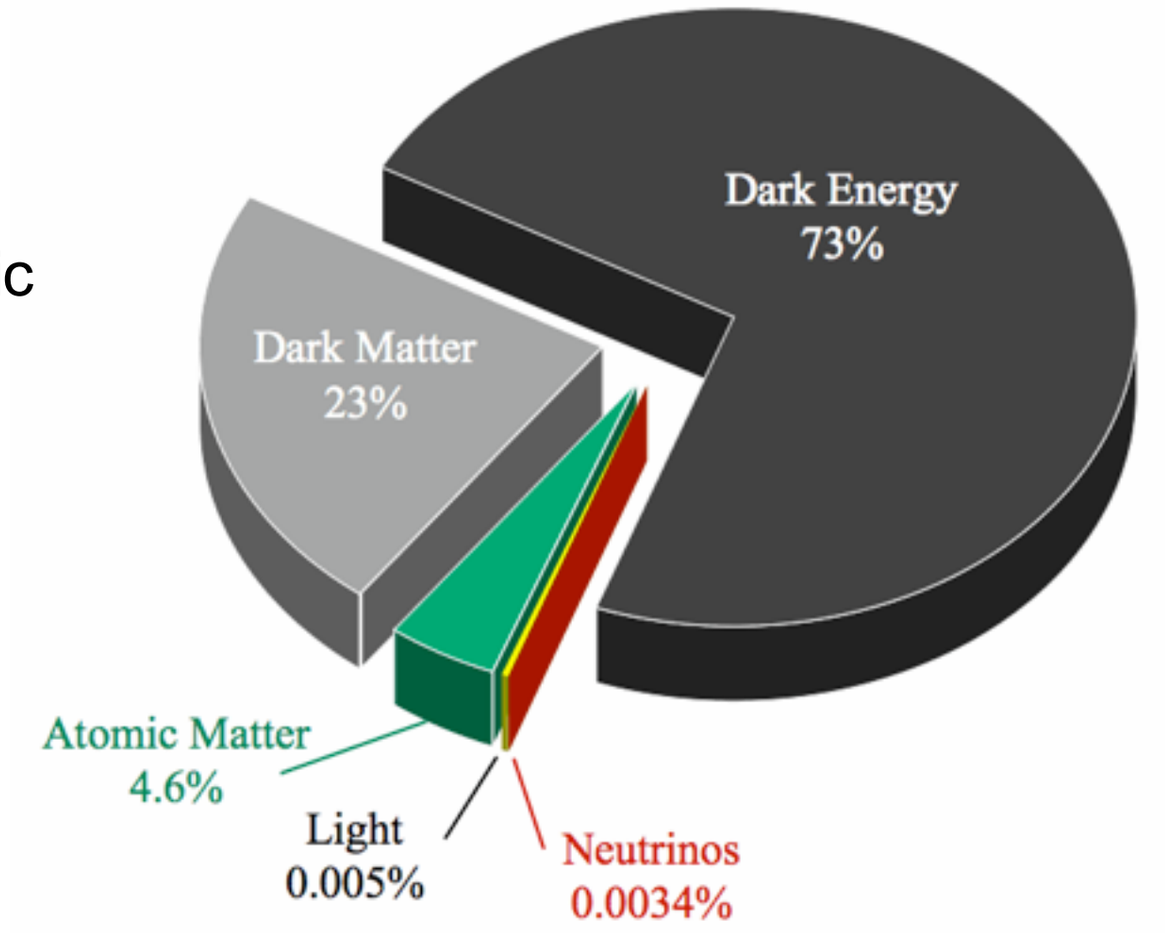
2nd Anisotropic Universe Workshop - April 2016

A quick summary of the current status of cosmology



Dark Energy?

Baryonic &
non-baryonic

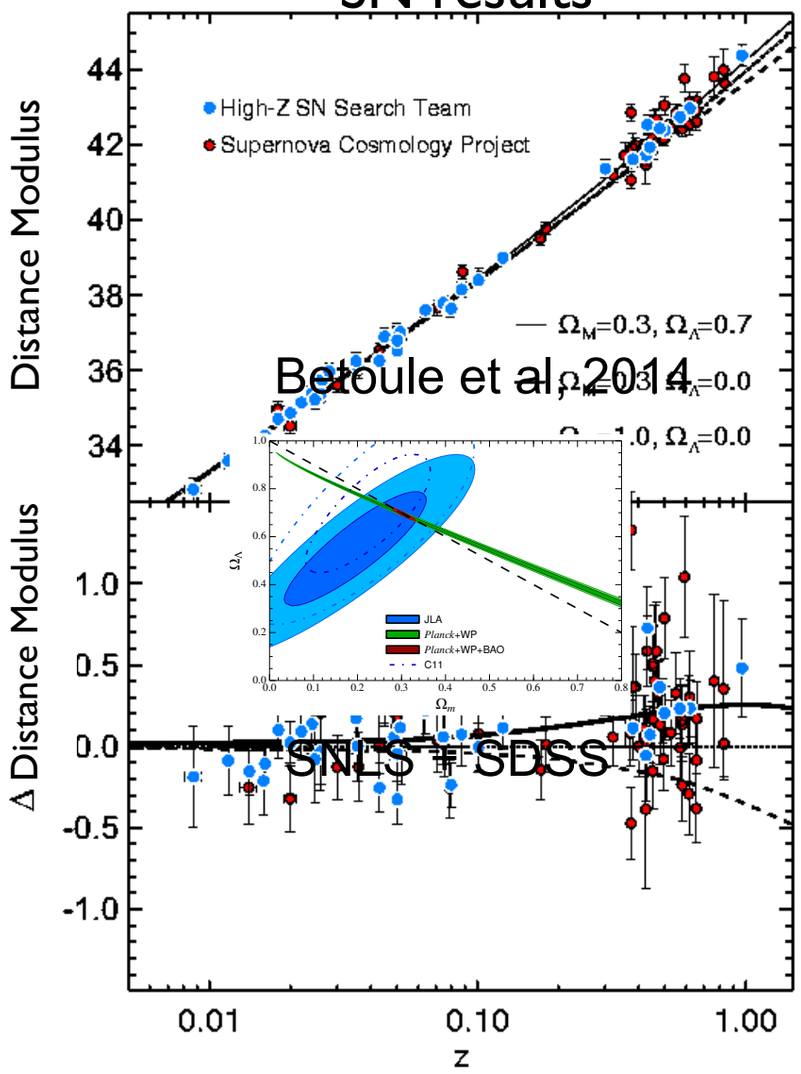


Source of the acceleration
of the expansion

Dark Energy!

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

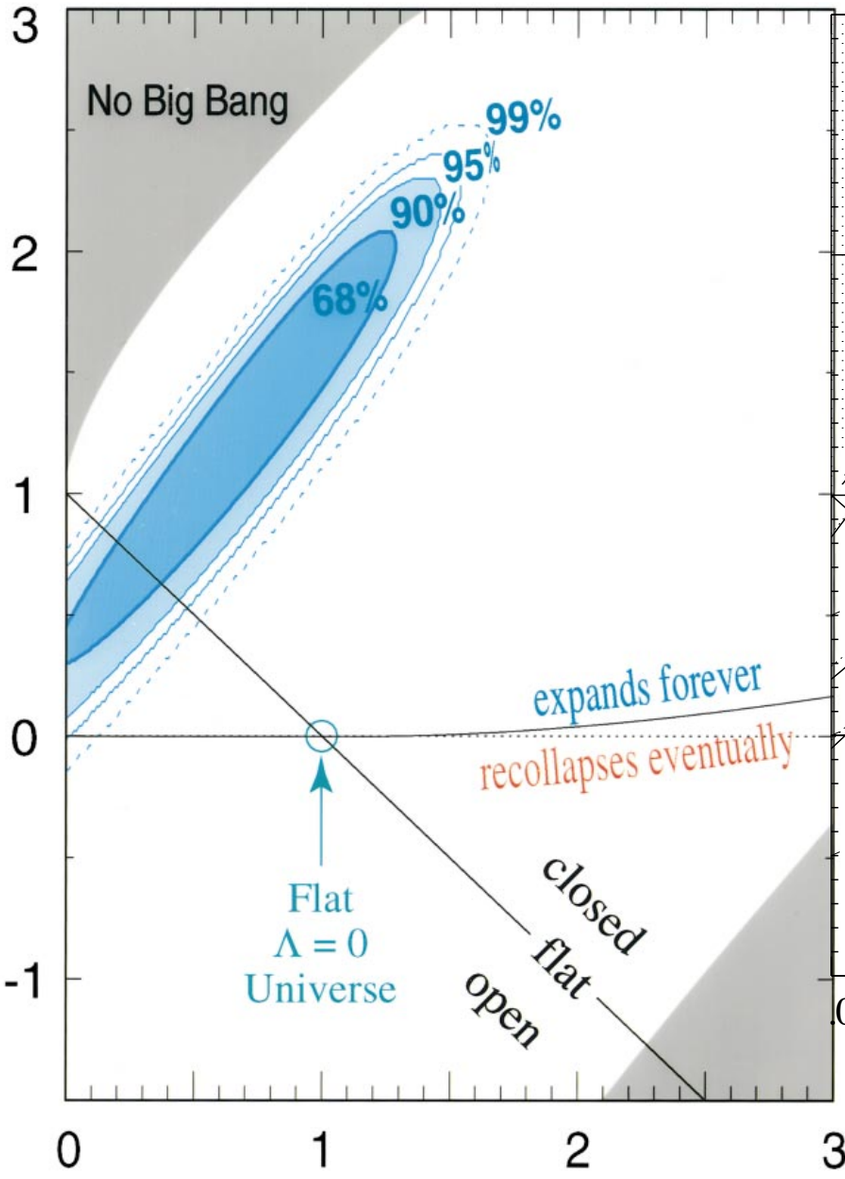
2012 Nobel Prize winning SN results



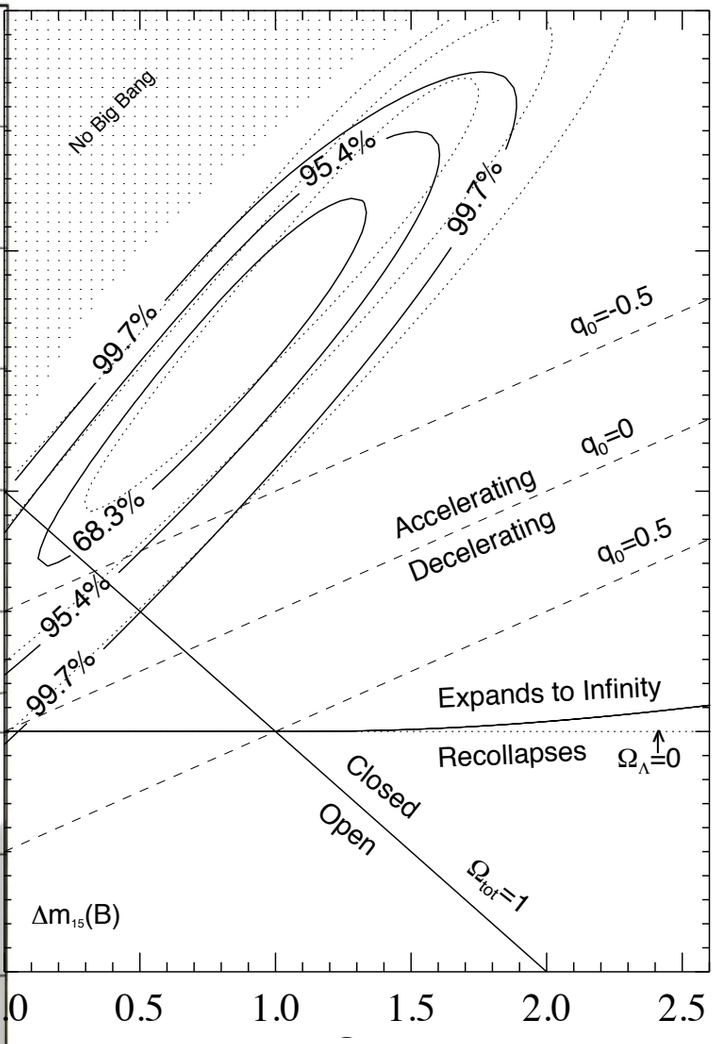
Betoule et al, 2014

SNLS + SDSS

Perlmutter et al, 1999



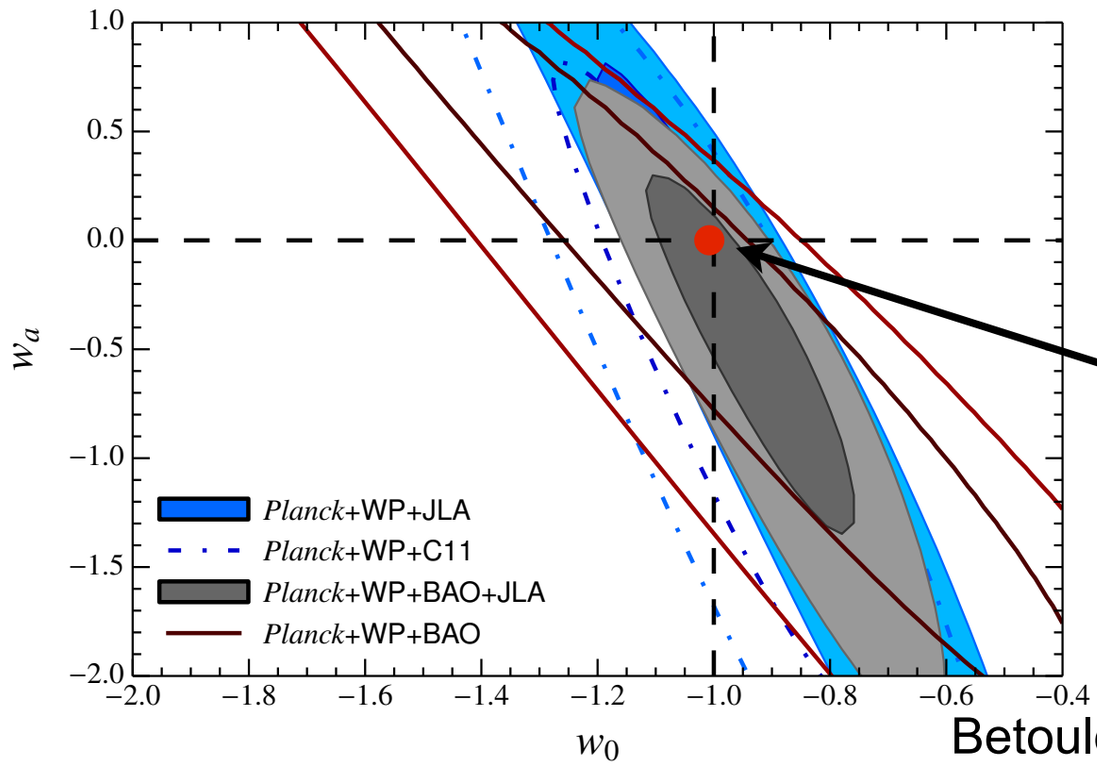
Riess et al, 1998



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

Betoule et al, 2014

Best constraint on DE currently brought by SNIa.

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)

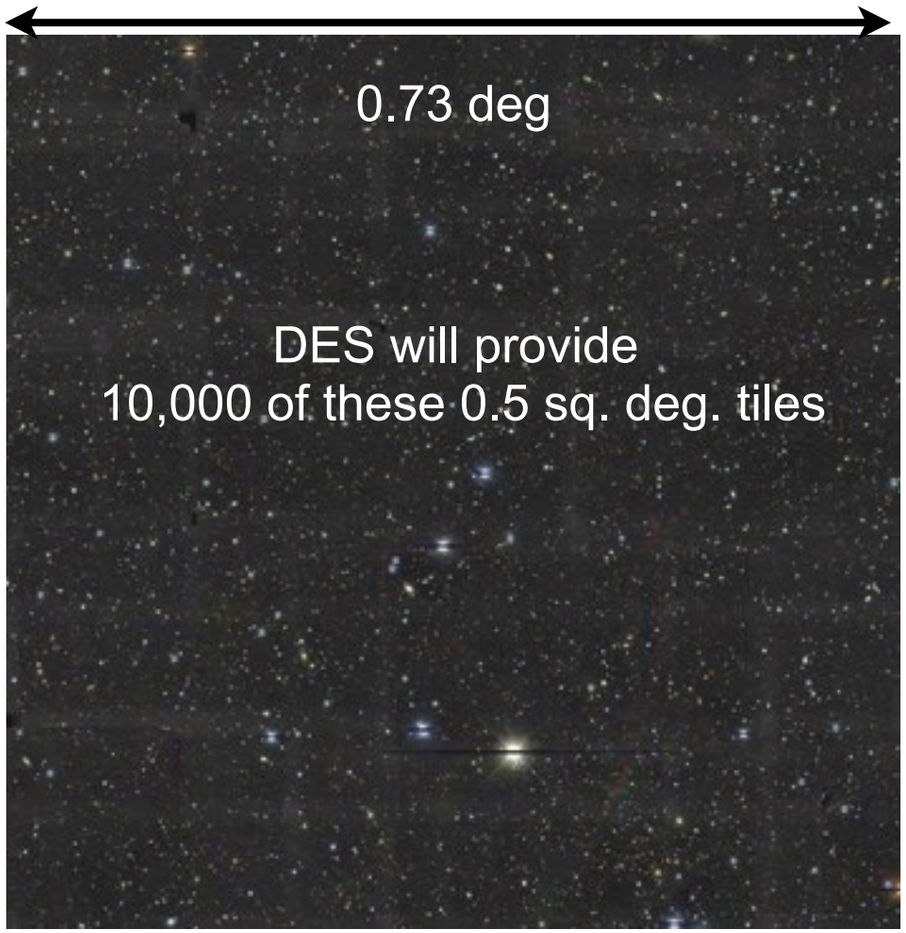
The Dark Energy Survey

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)



~ 1-2 mag deeper than SDSS
25 larger than CFHTlens

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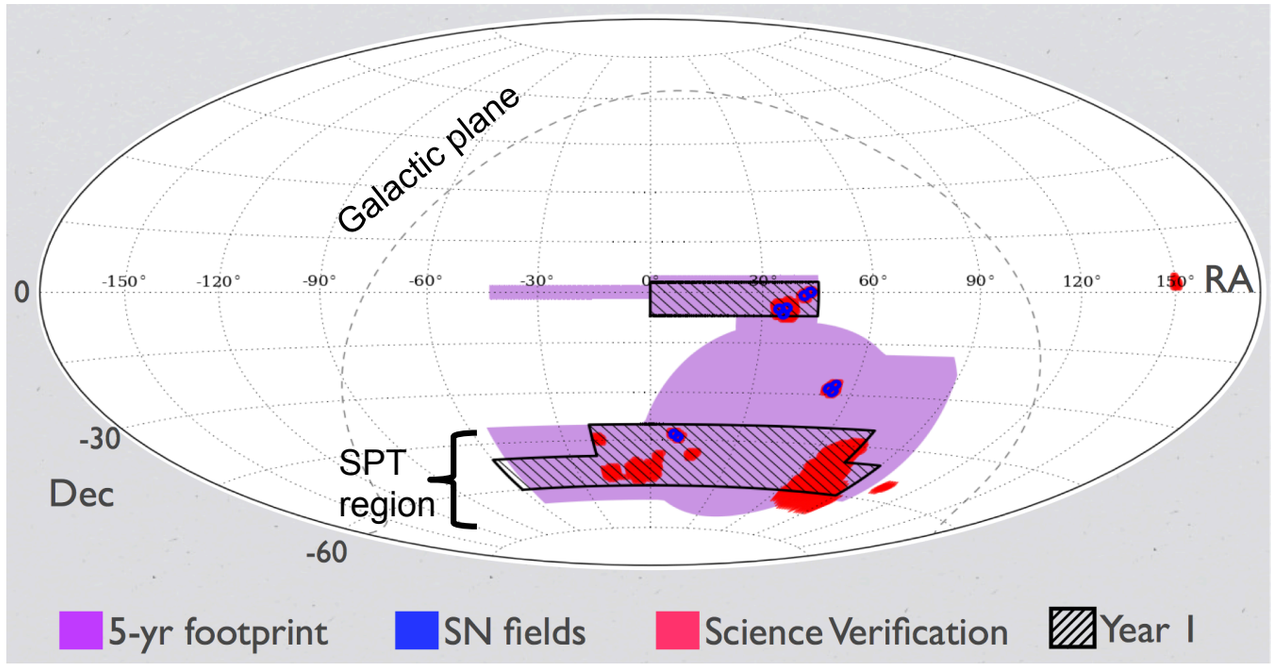
Supplemented by:

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



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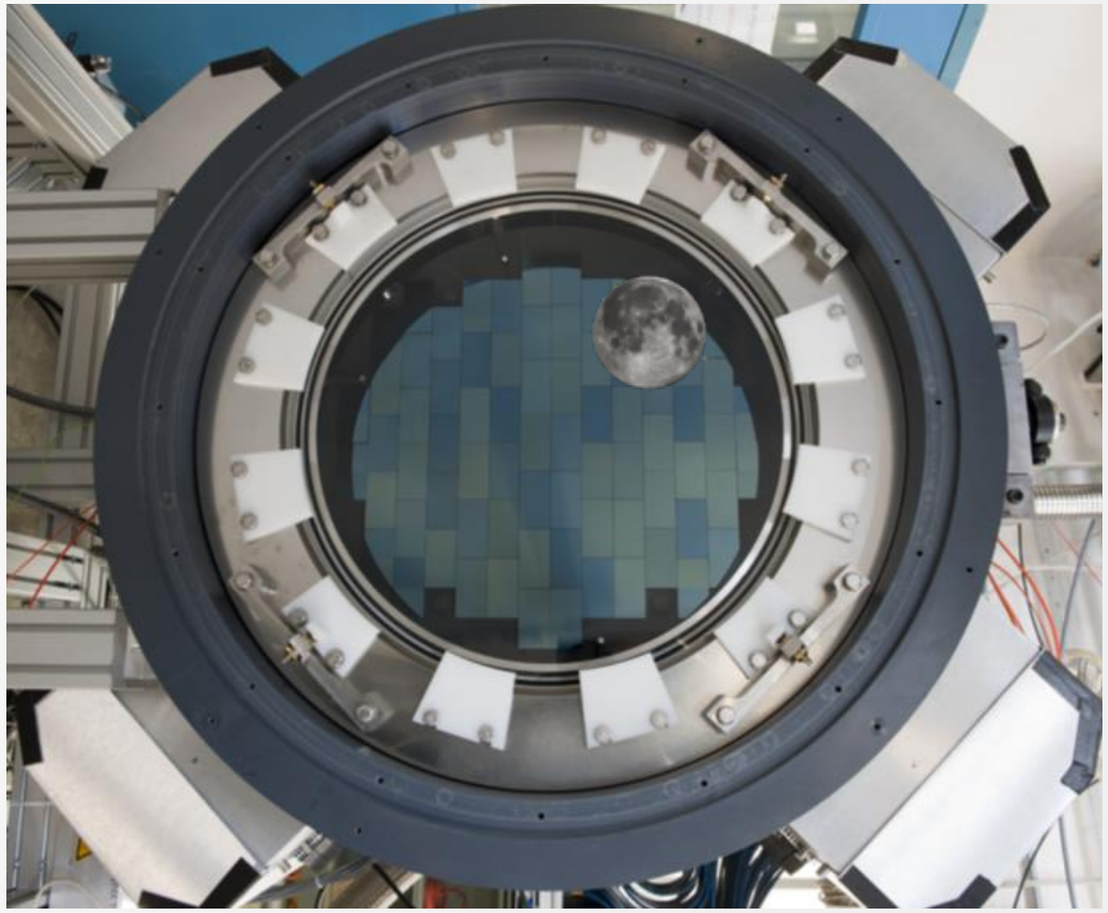

Supplemented by:

- 2500 sq. deg. South Pole Telescope
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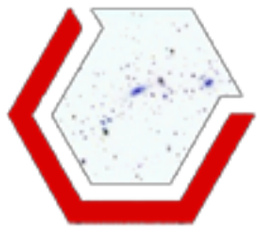
DECam:

- 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

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



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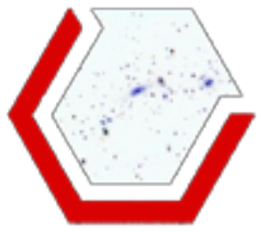
Weak lensing (distance, structure growth)
shape and measurements of 200
millions galaxies

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



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

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

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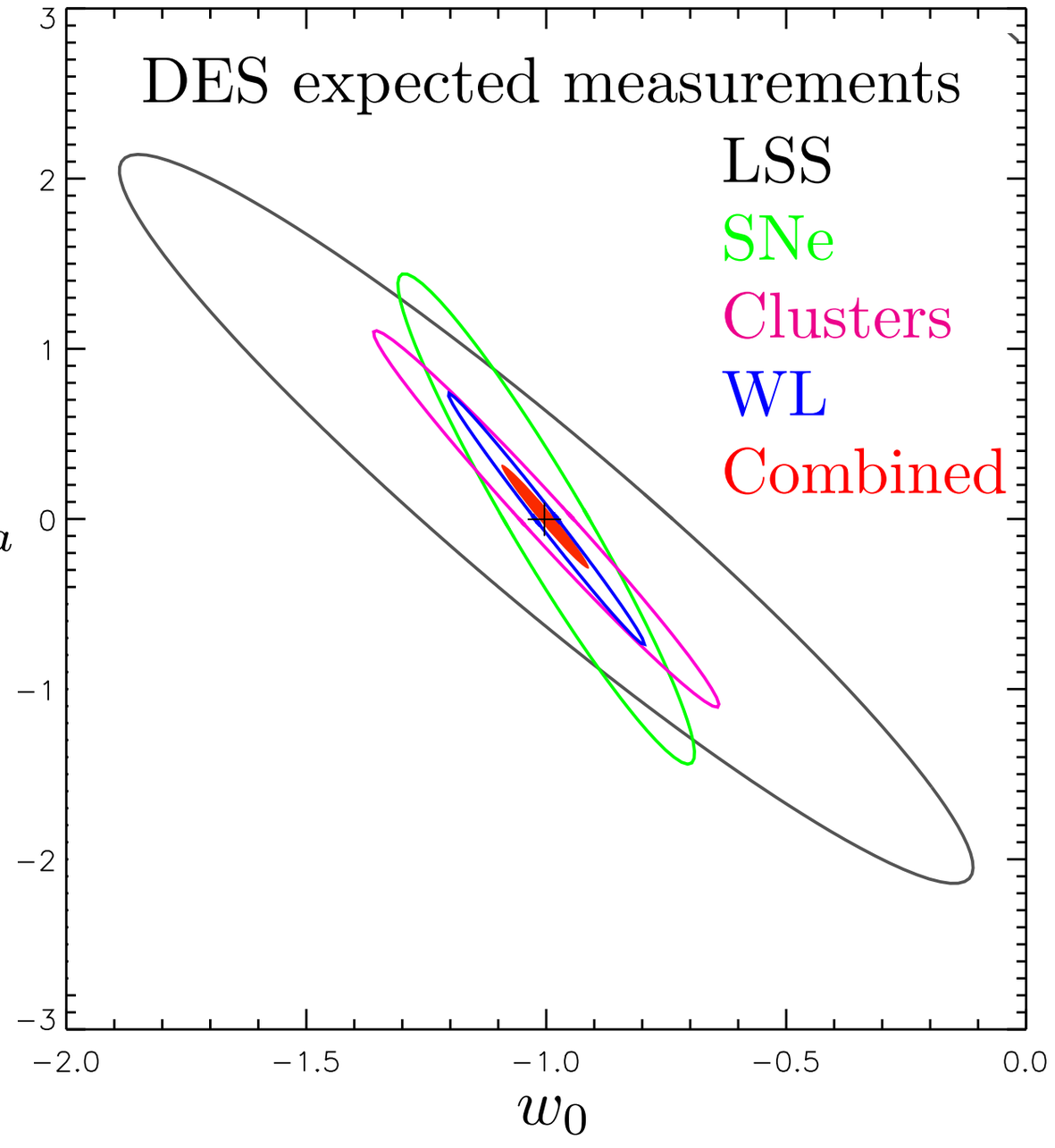
Type Ia supernovae (distance)
30 sq. deg. SN fields
3500 SNIa to z~1



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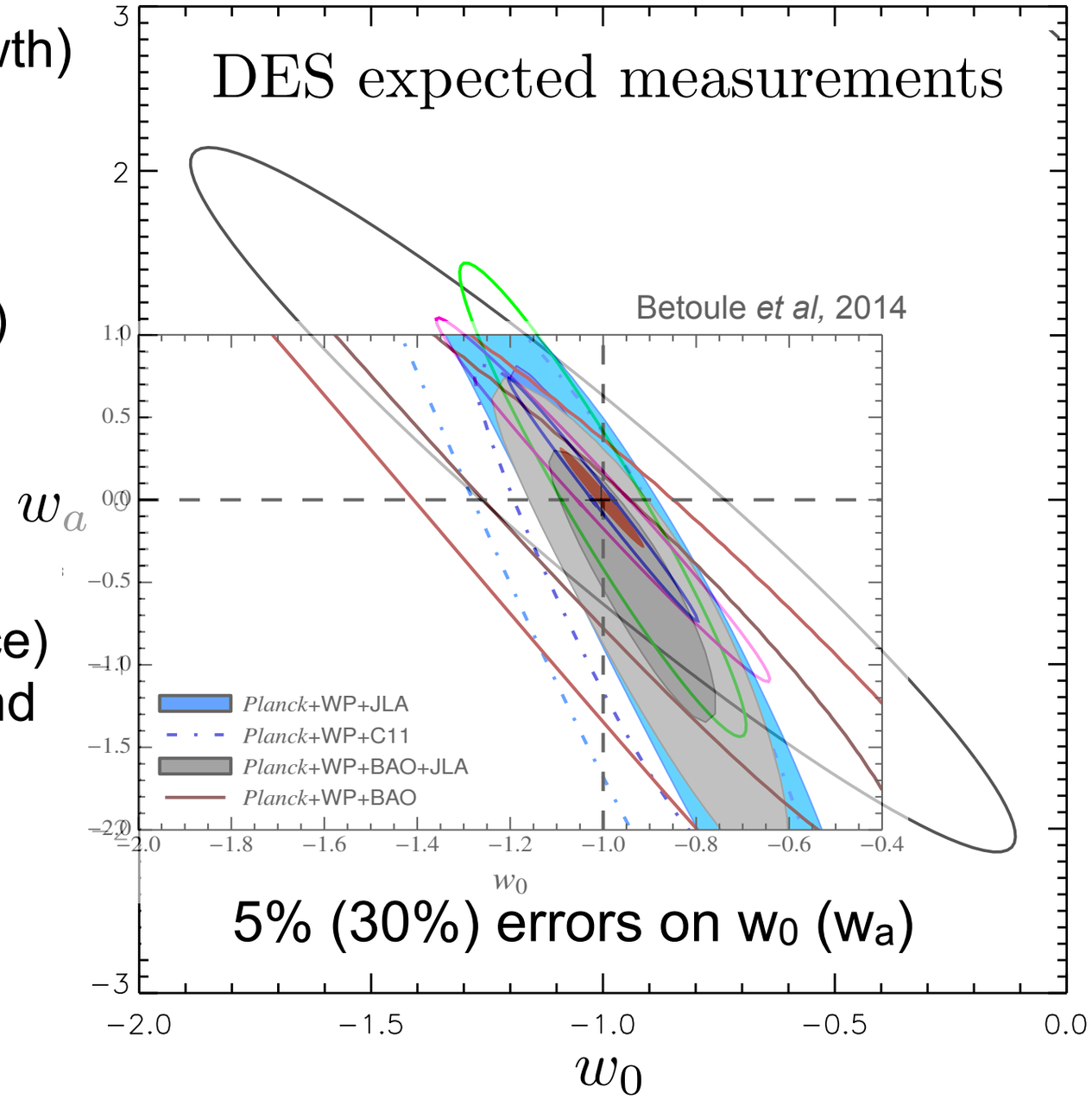
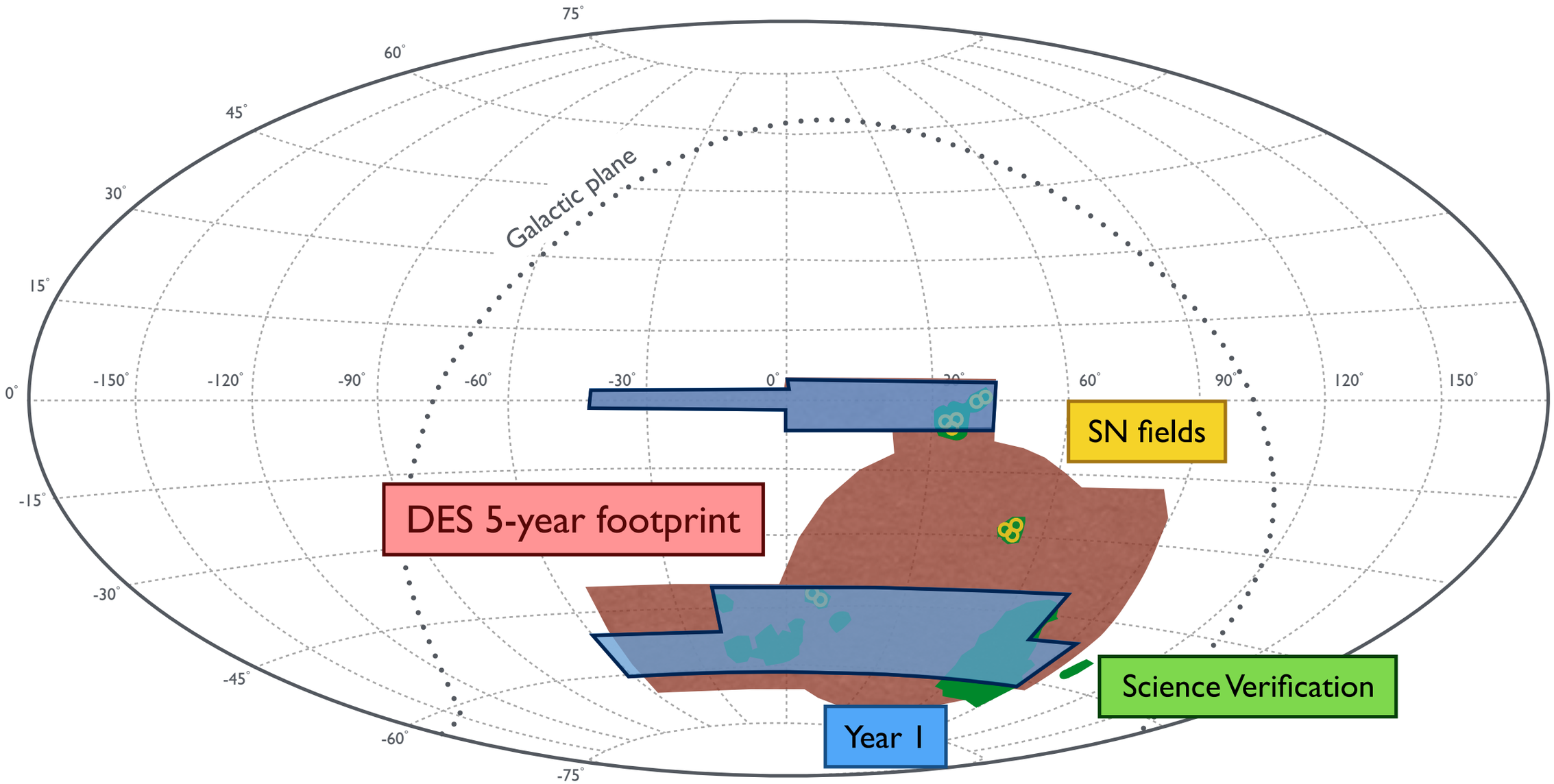
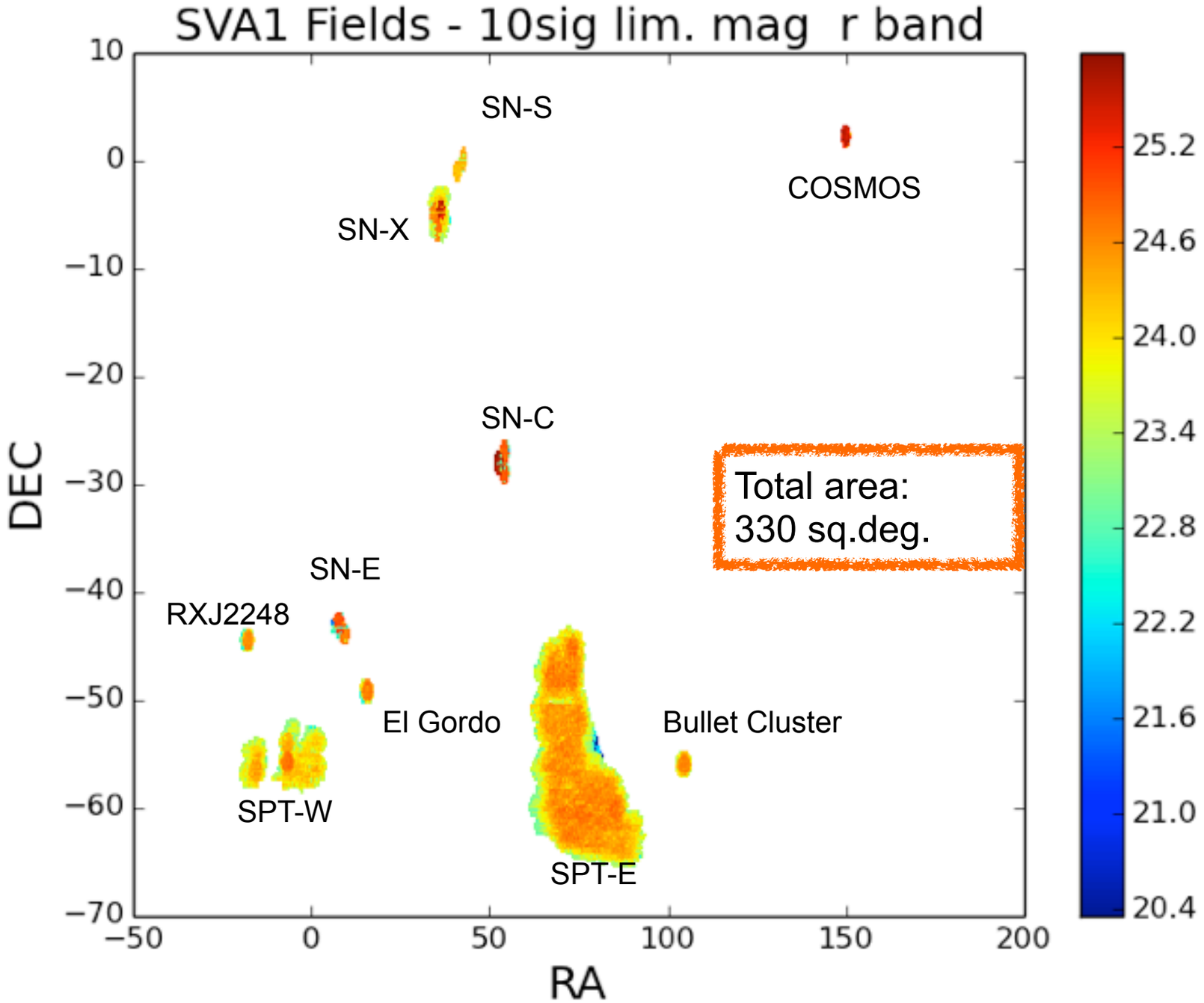


Observing strategy



Nov. 2012 - Feb. 2013: Science Verification campaign



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

Science Verification papers (as of 07/15). Now ~60 papers

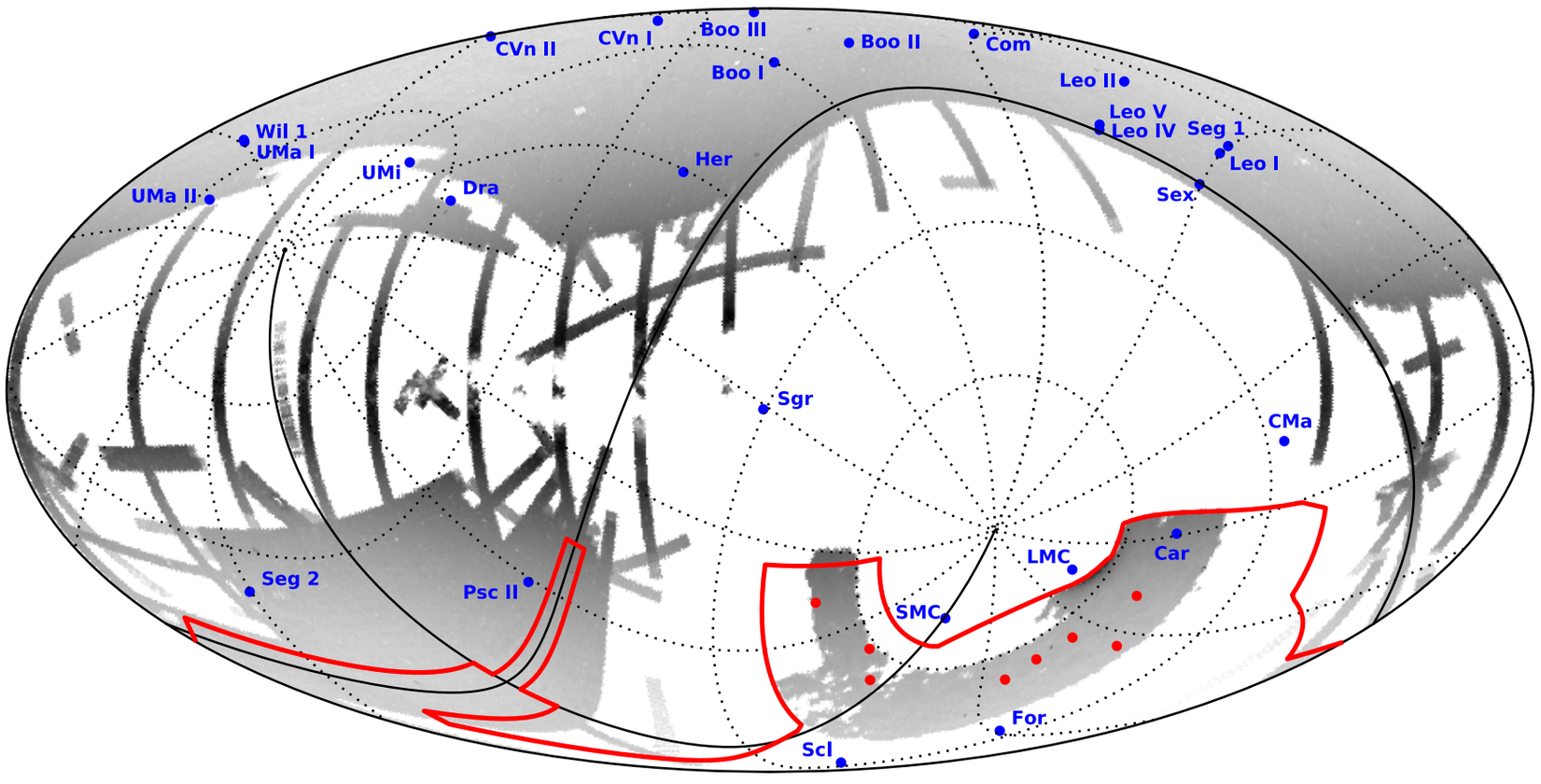
NGC 1398, single DECam tile

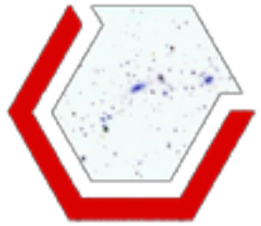
Gerdes et al.	*Observation of Two New L4 Neptune Trojans in the Dark Energy Survey Supernova Fields*	arXiv:1507.05177
Park et al.	*Joint Analysis of Galaxy-Galaxy Lensing and Galaxy Clustering: Methodology and Forecasts for DES*	arXiv:1507.05353
Rozo et al.	*redMaGiC: Selecting Luminous Red Galaxies 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

Eight New Milky Way Companions Discovered in First-Year Dark Energy Survey Data

1503.02584

K. Bechtol[1,†], A. Drlica-Wagner[2,†], E. Balbinot[3,4], A. Pieres[5,4], J. D. Simon[6], B. Yanny[2],



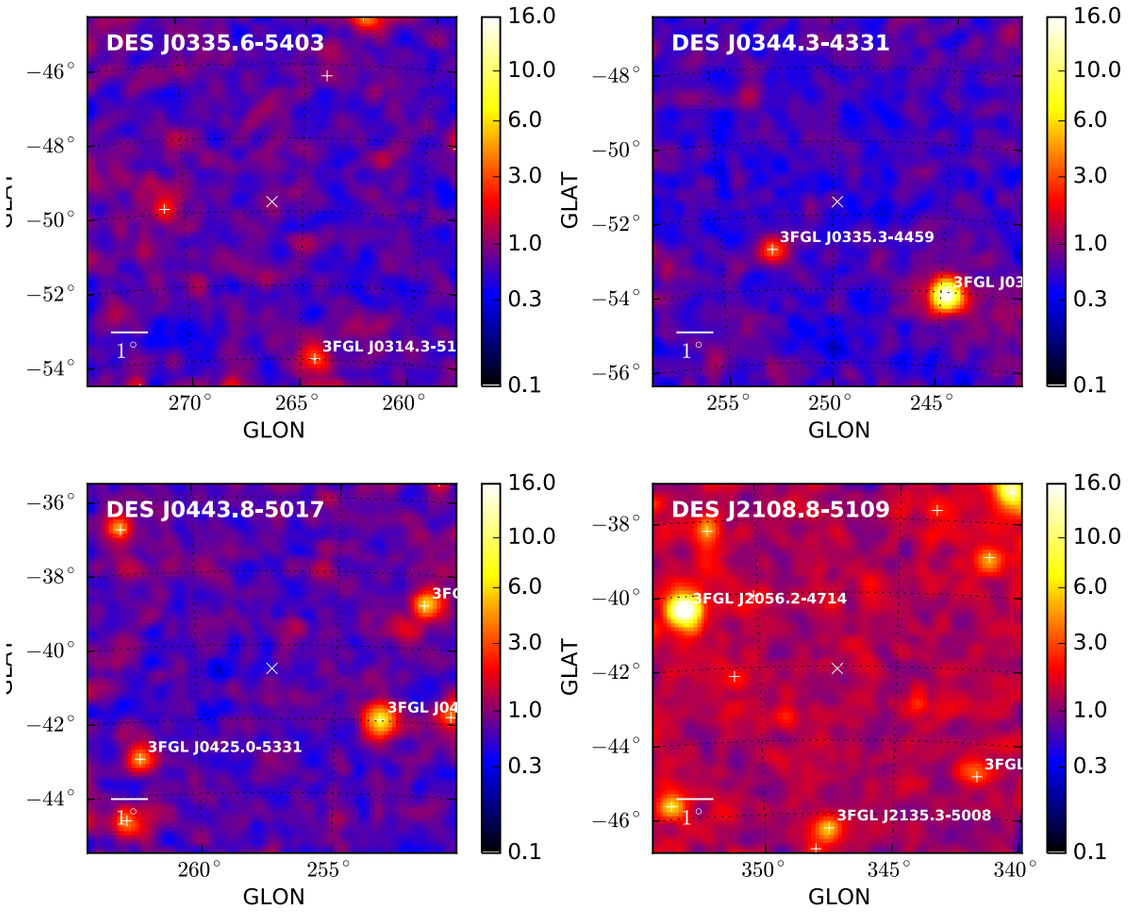


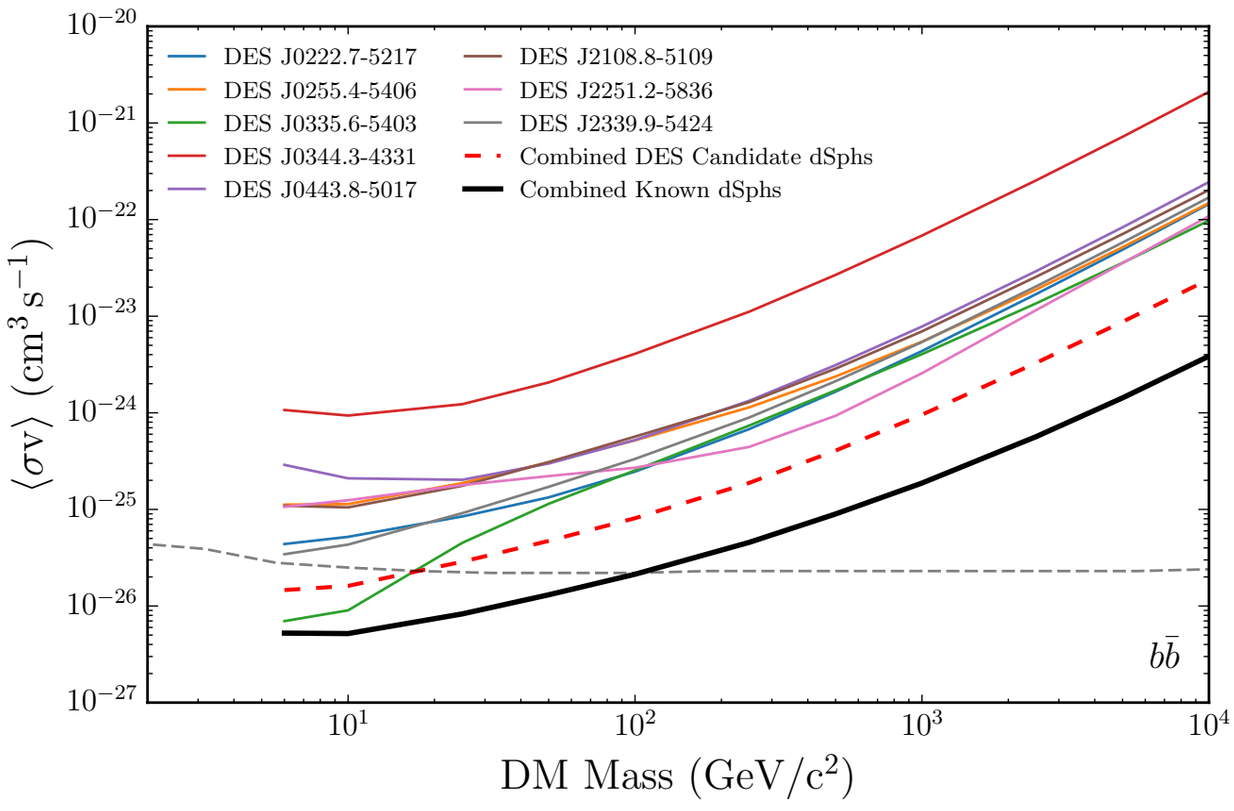
Milky way

Search for Gamma-Ray Emission from DES Dwarf Spheroidal Galaxy Candidates with Fermi-LAT Data

1503.02632

A. Drlica-Wagner,[1,2,*] A. Albert,[3,†] K. Bechtol,[1,4,‡] M. Wood,[3,§] L. Strigari,[5,¶] M. Sánchez-Conde,[6,7]





The DES galaxy catalog

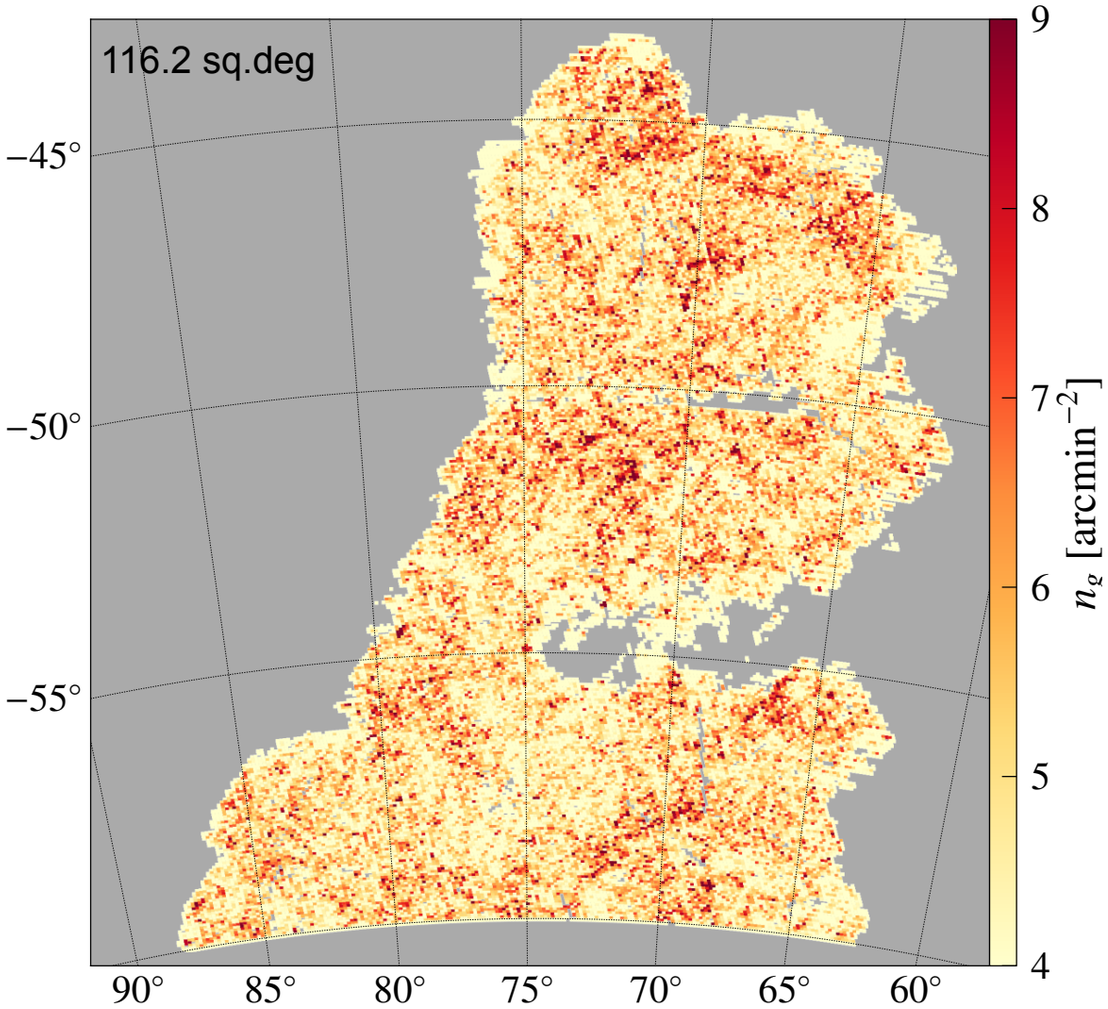
Crocce et al., 1507.05360

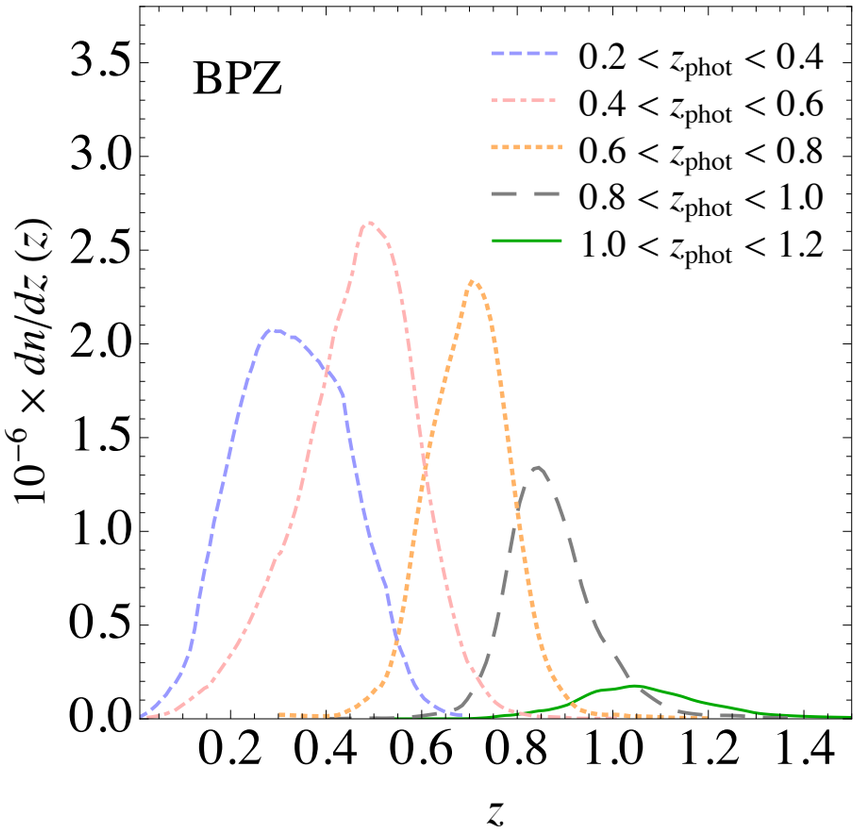
$$60 < ra\,[\mathrm{deg}] < 95$$
$$-60 < dec\,[\mathrm{deg}] < -40$$
$$18 < i < 22.5,$$

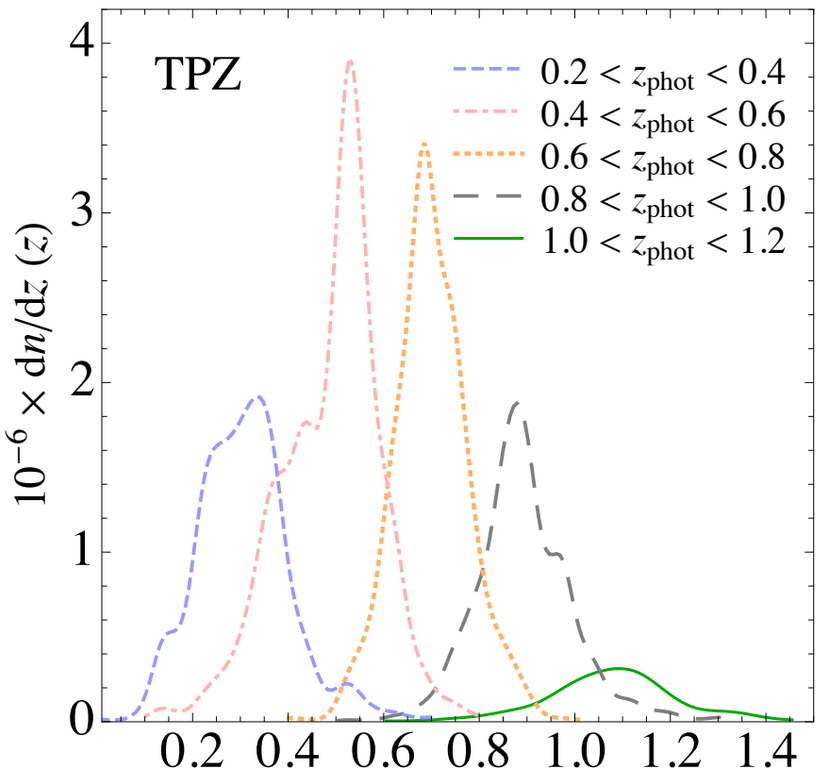
$$-1 < g - r < 3$$
$$-1 < r - i < 2$$
$$-1 < i - z < 2,$$

$2,333,294$ objects

$n_g = 5.6\,\mathrm{arcmin}^{-2}.$

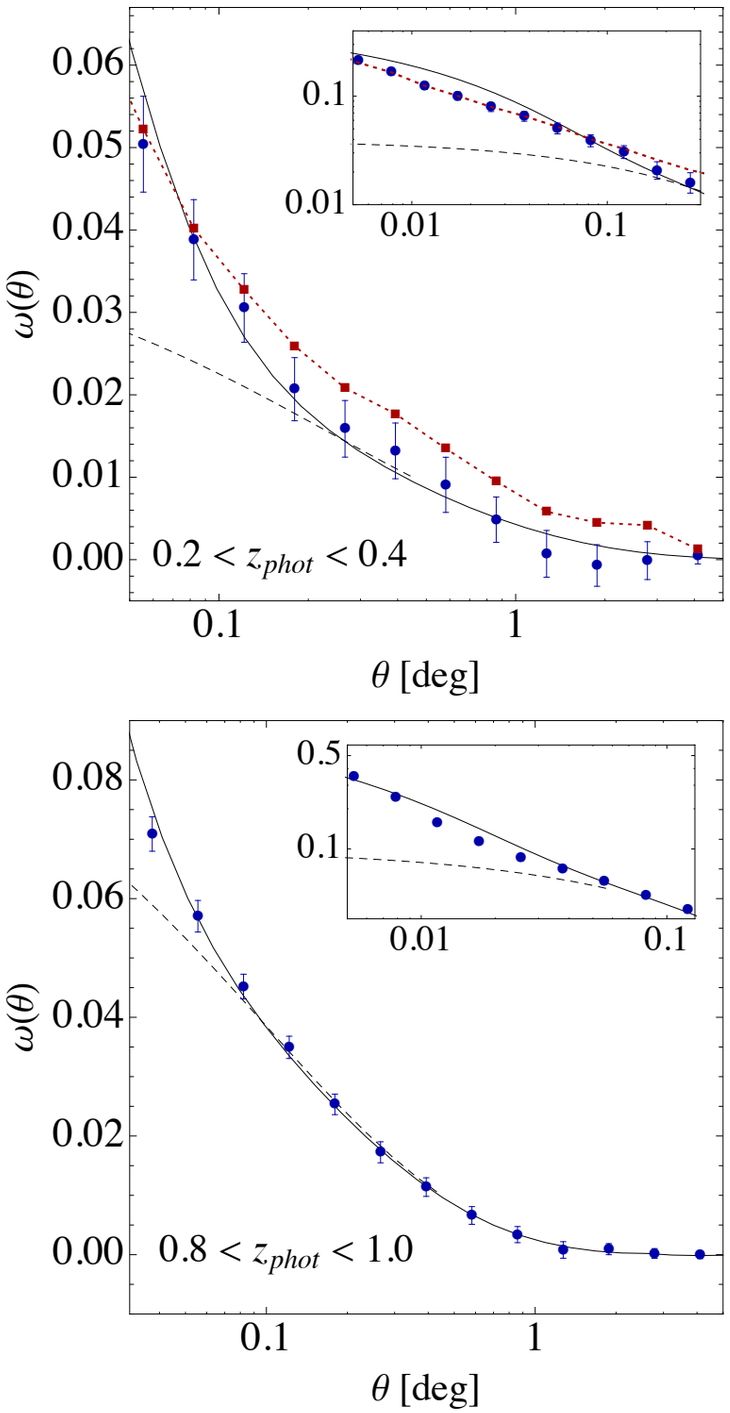


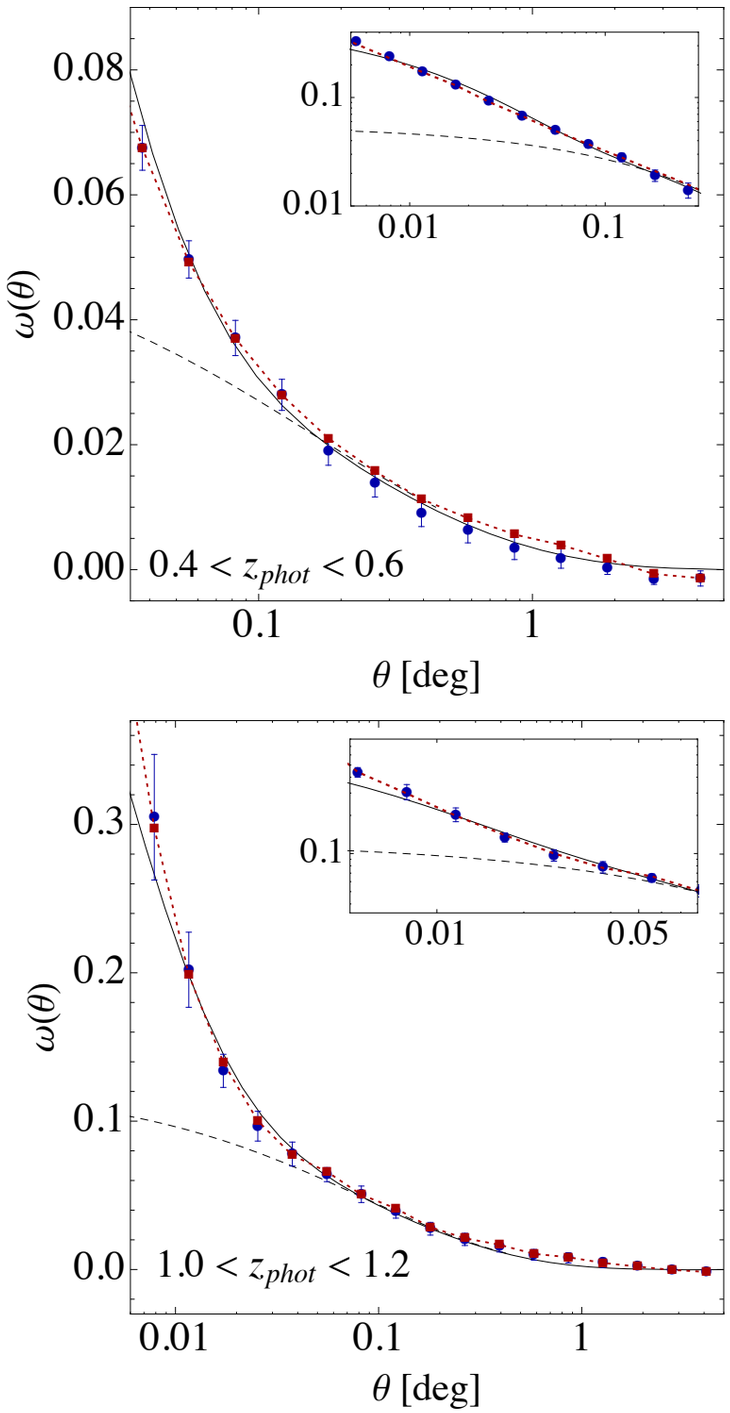


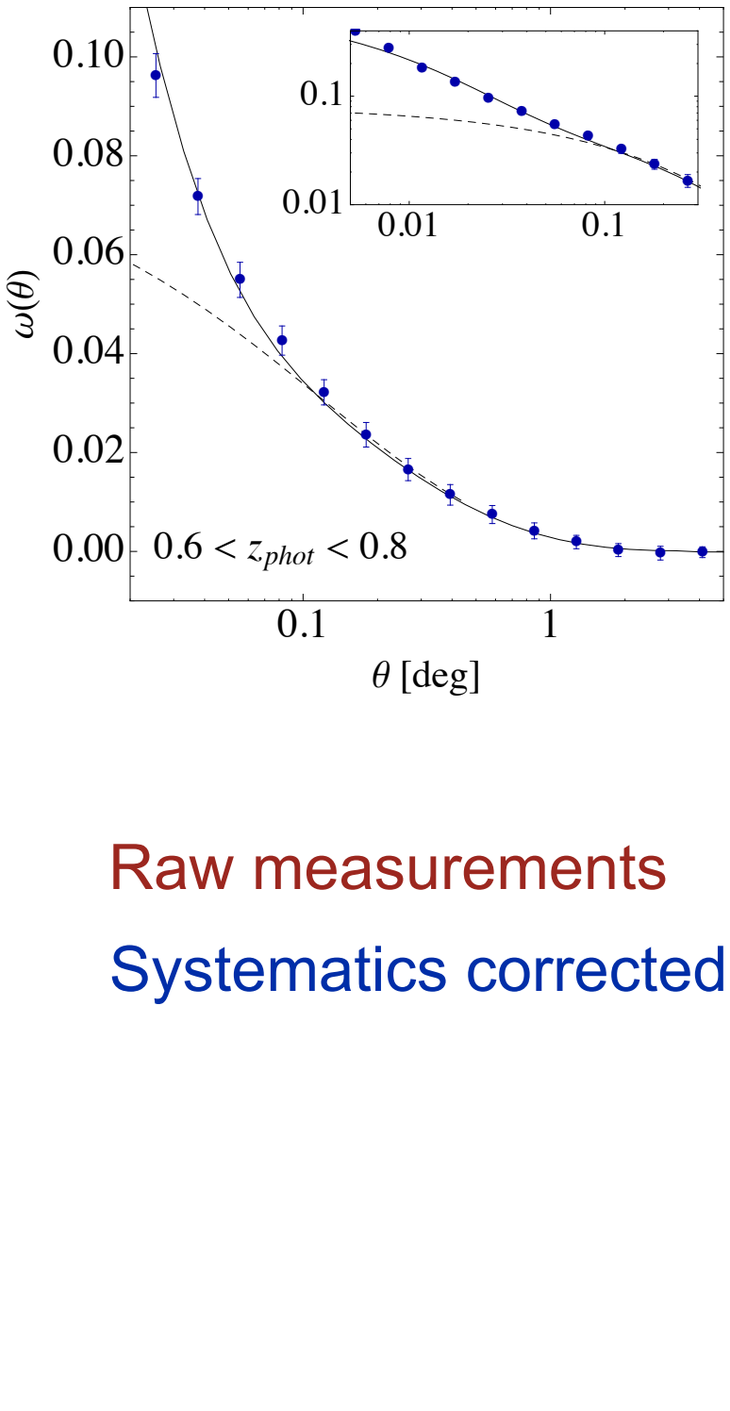


Galaxy clustering, photometric redshifts and diagnosis of systematics in the DES Science Verification data

Crocce et al., 1507.05360





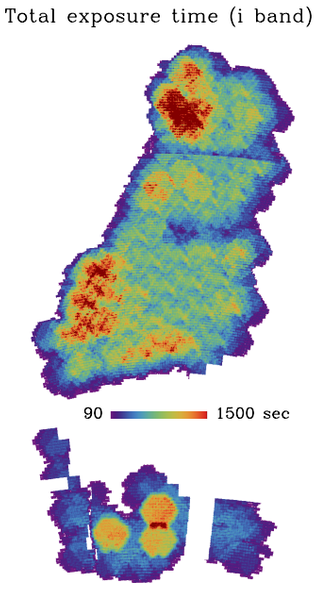


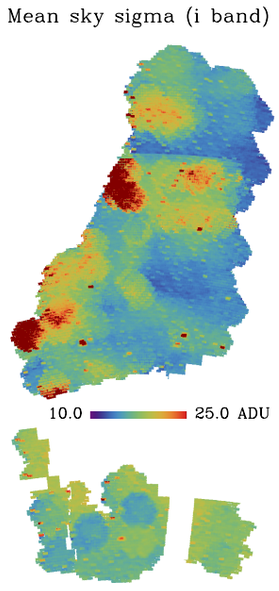
Raw measurements

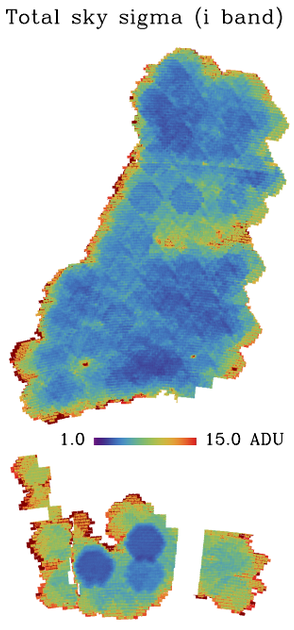
Systematics corrected

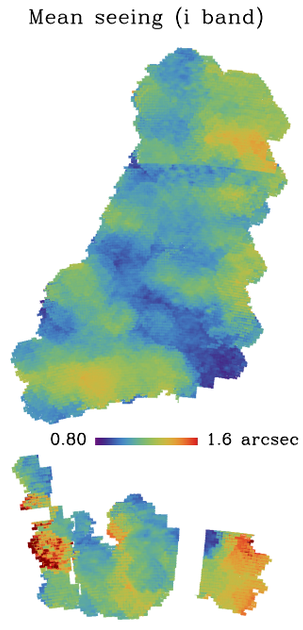
Systematics maps

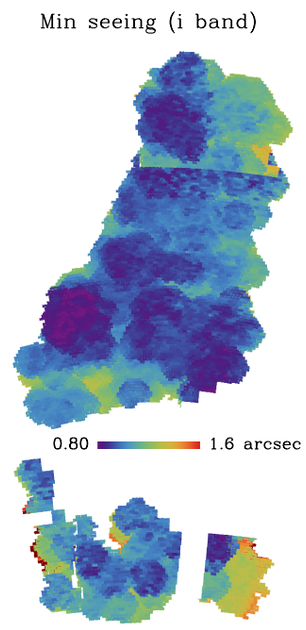
Leistedt, Peiris, Elsner, Benoit-Lévy et al 1507.05647

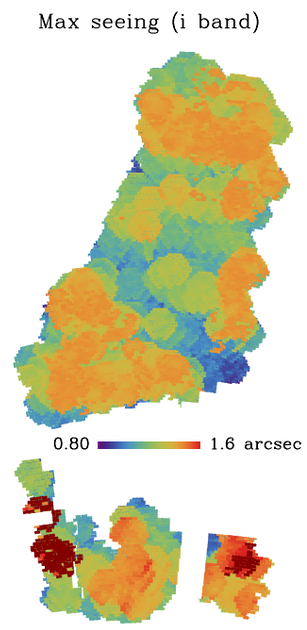


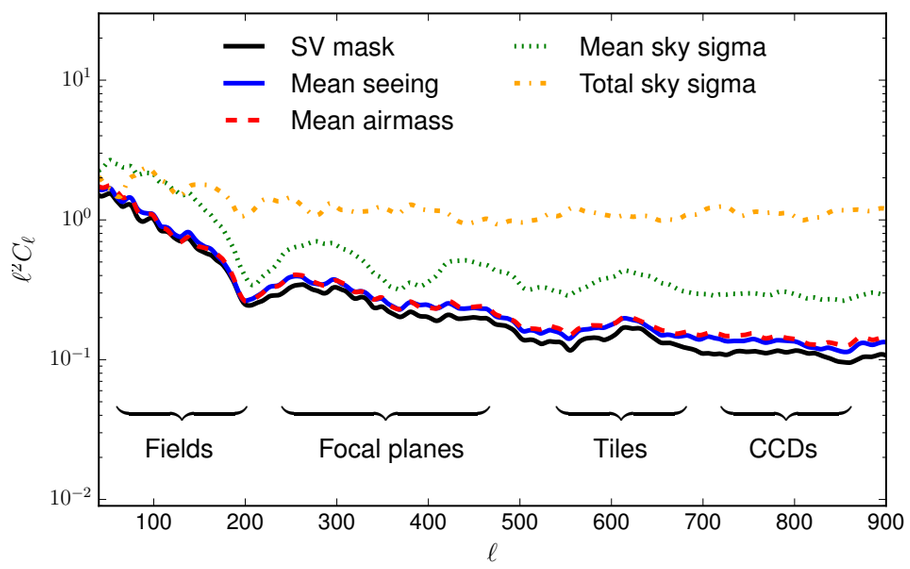


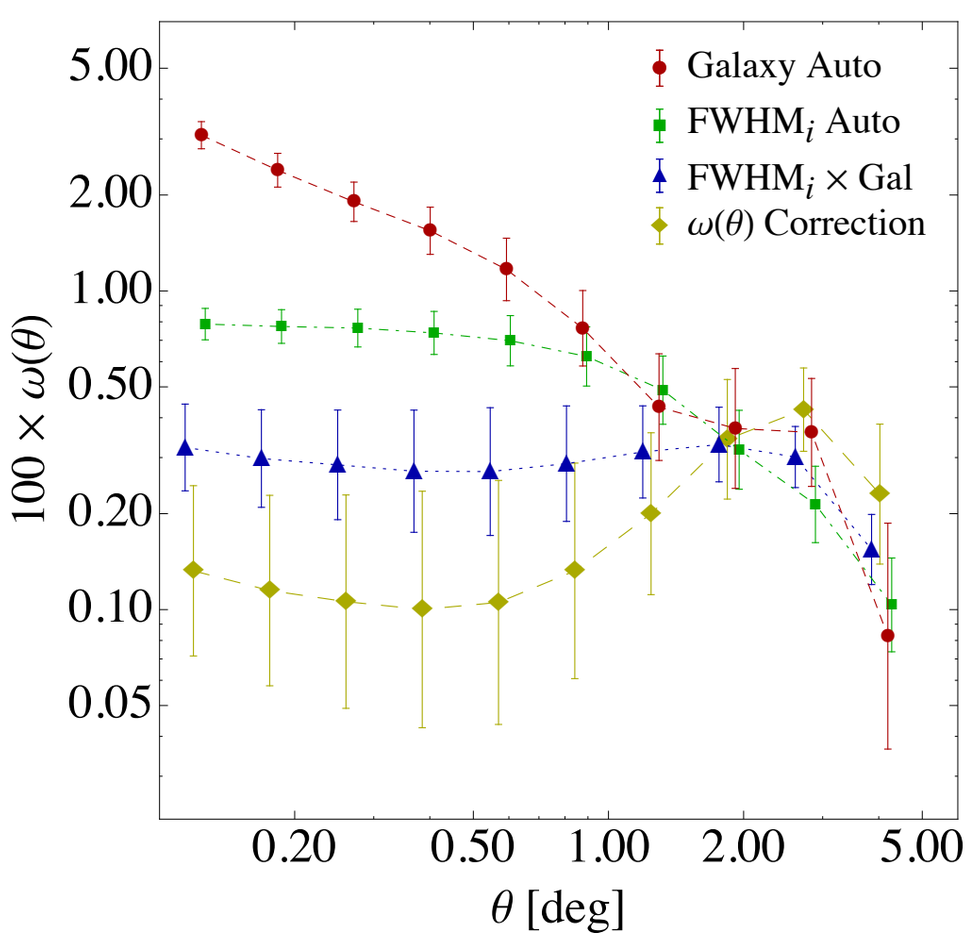


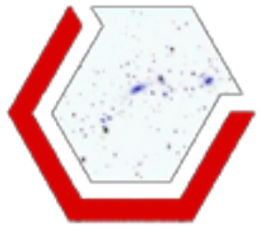








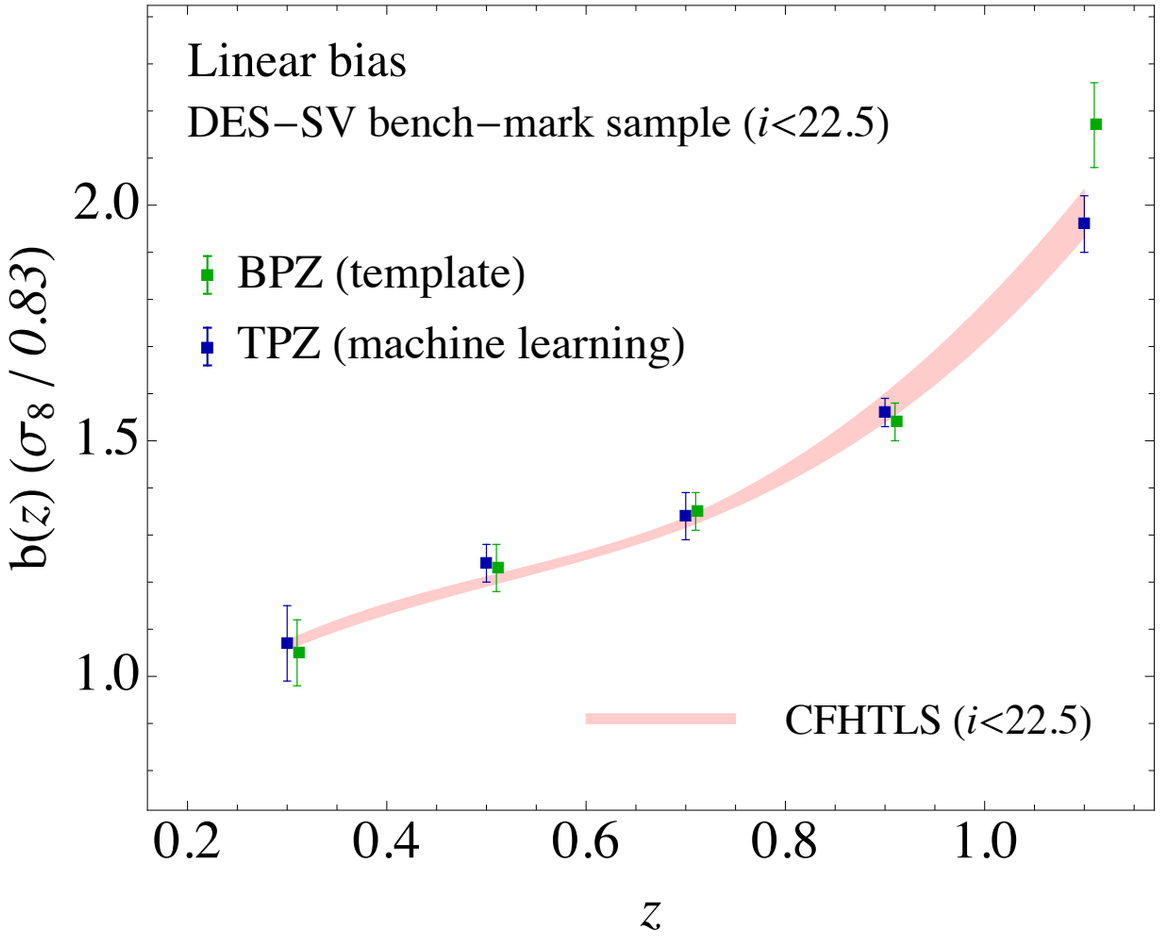




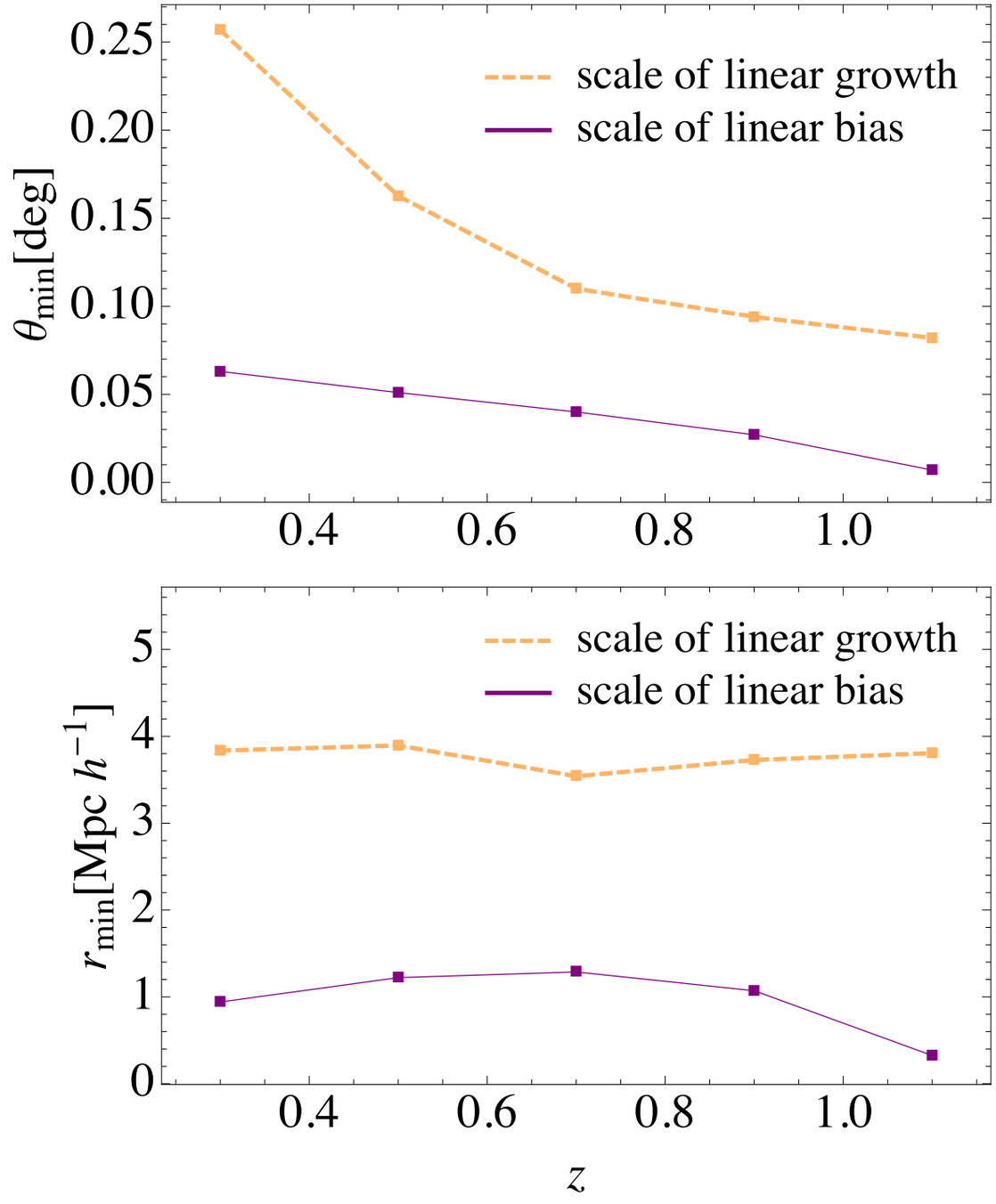
Galaxy clustering, photometric redshifts and diagnosis of systematics in the DES Science Verification data

Crocce et al., 1507.05360

Comparison with CFHTLS
(Coupon *et al.* 2012)



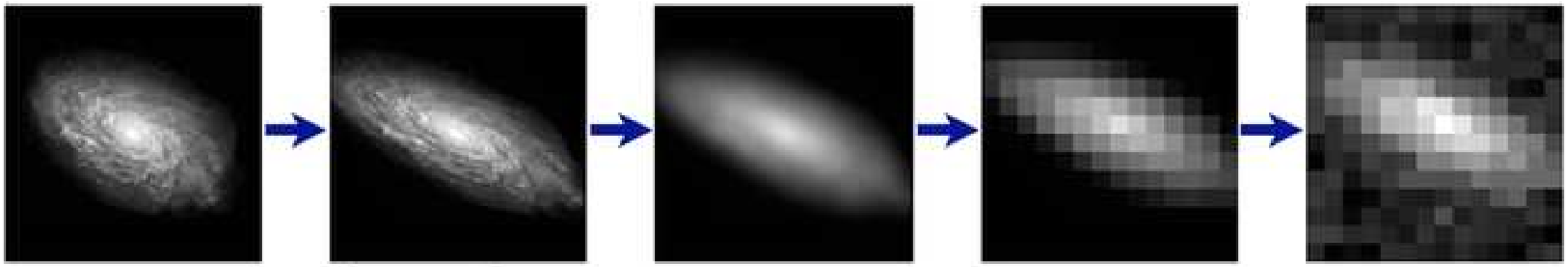
Linear scale "breakings"



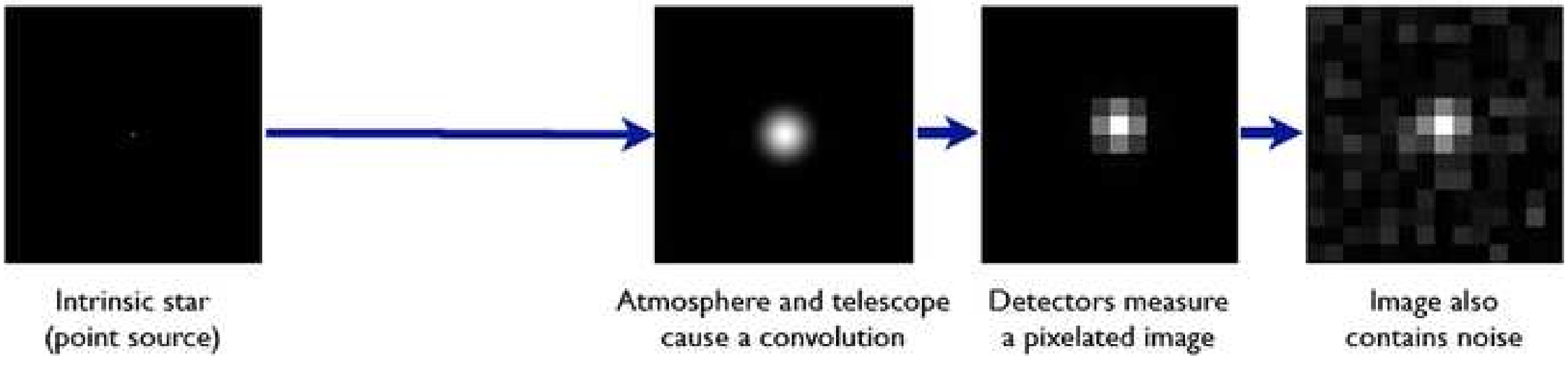
DES Weak lensing

The Forward Process.

Galaxies: Intrinsic galaxy shapes to measured image:

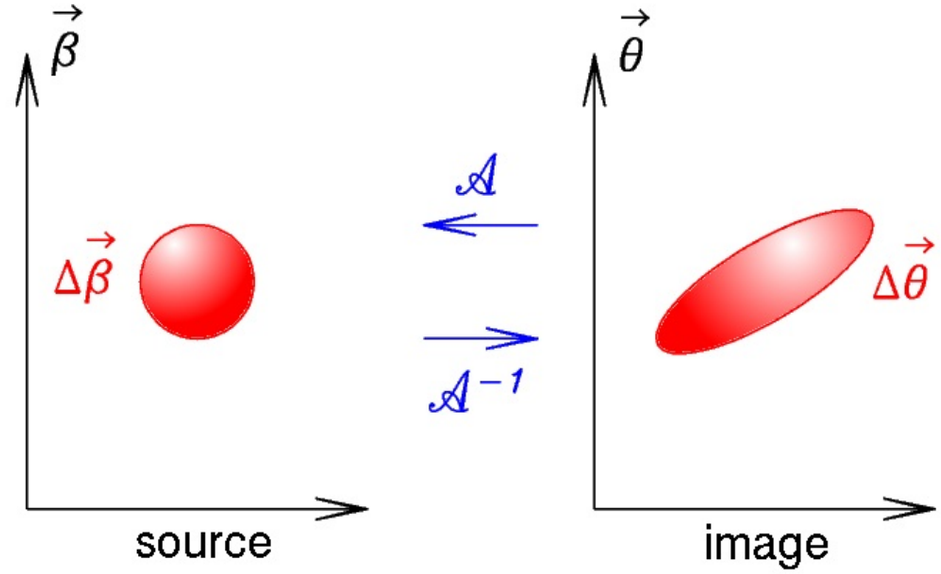


Stars: Point sources to star images:



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

From measurements to mass maps



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

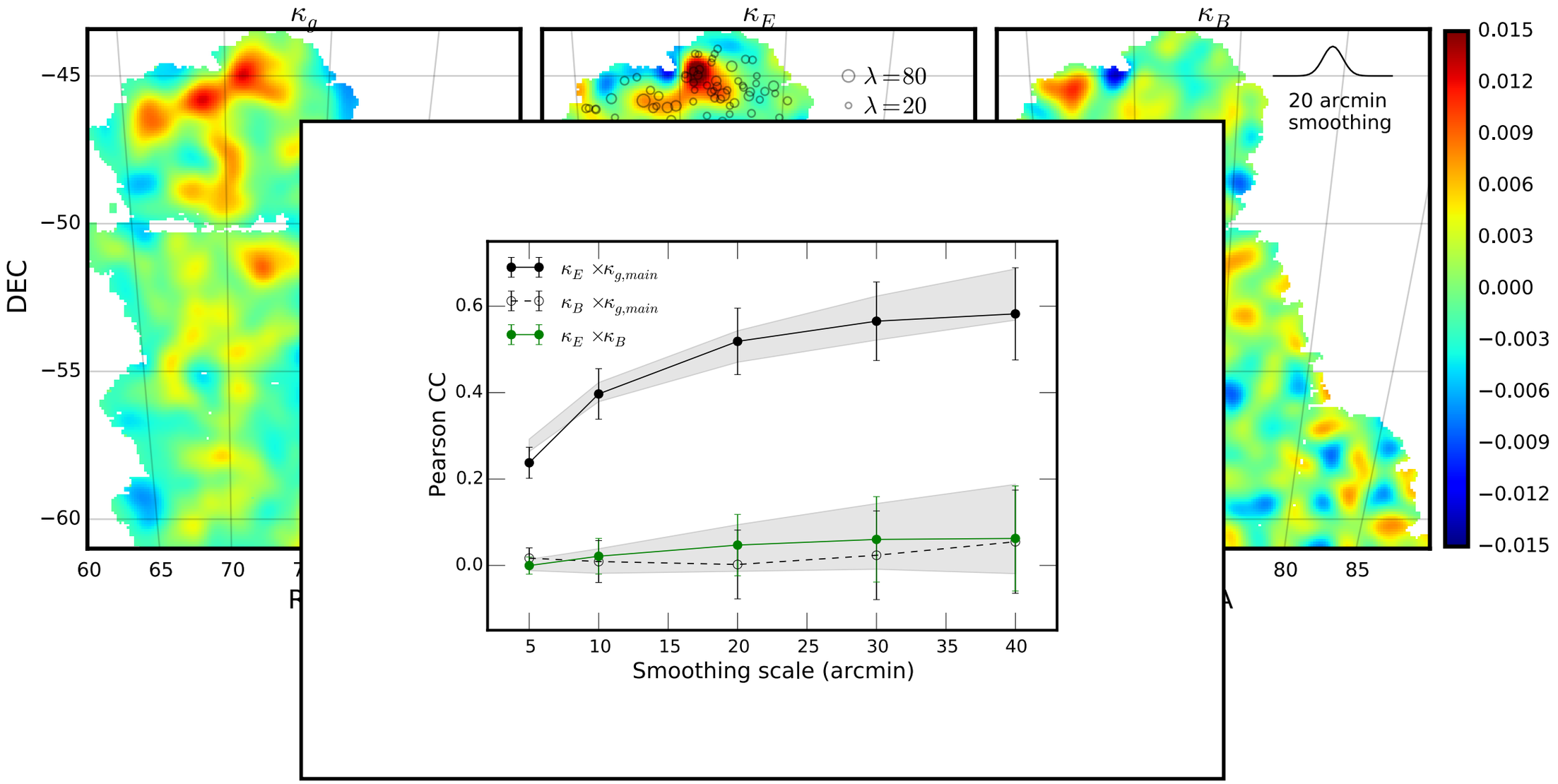
It gets simpler in Fourier space: $\hat{\kappa}_l = D_l^* \hat{\gamma}_l,$ Kaiser & Squires, 93

Wide-Field Lensing Mass Maps from DES Science Verification Data

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

Convergence maps reconstructed from

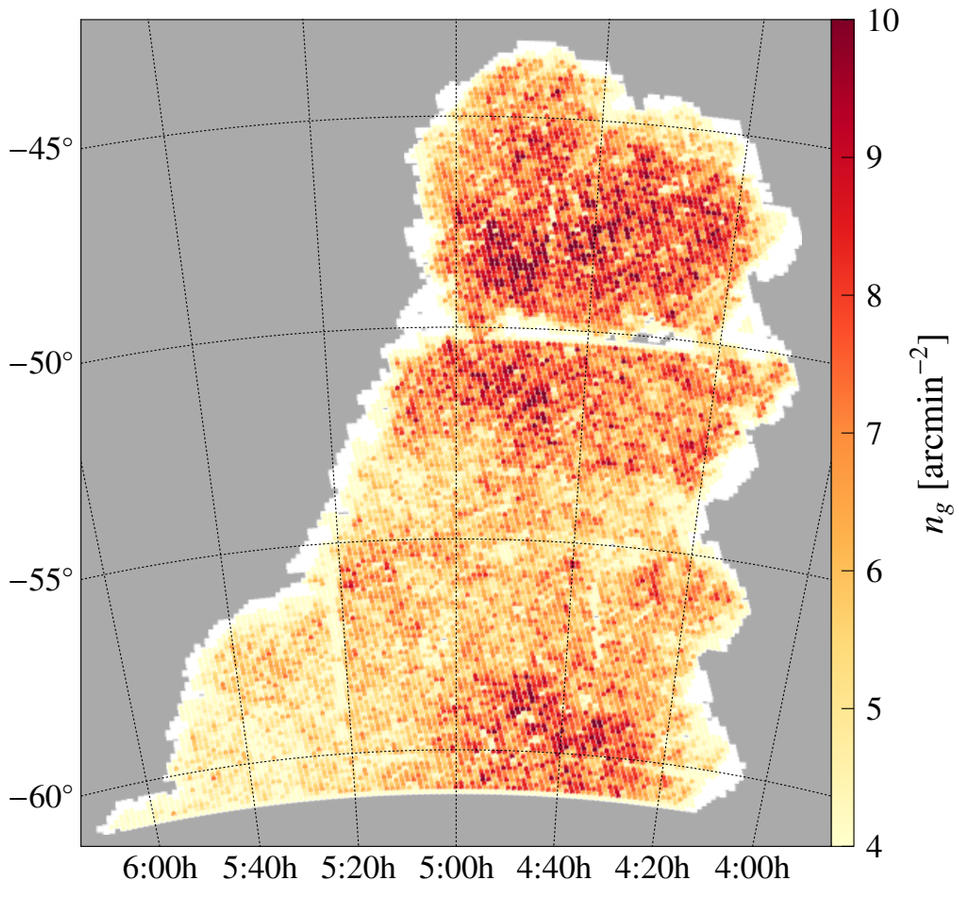
Galaxy catalog | Shear E-modes | Shear B-modes

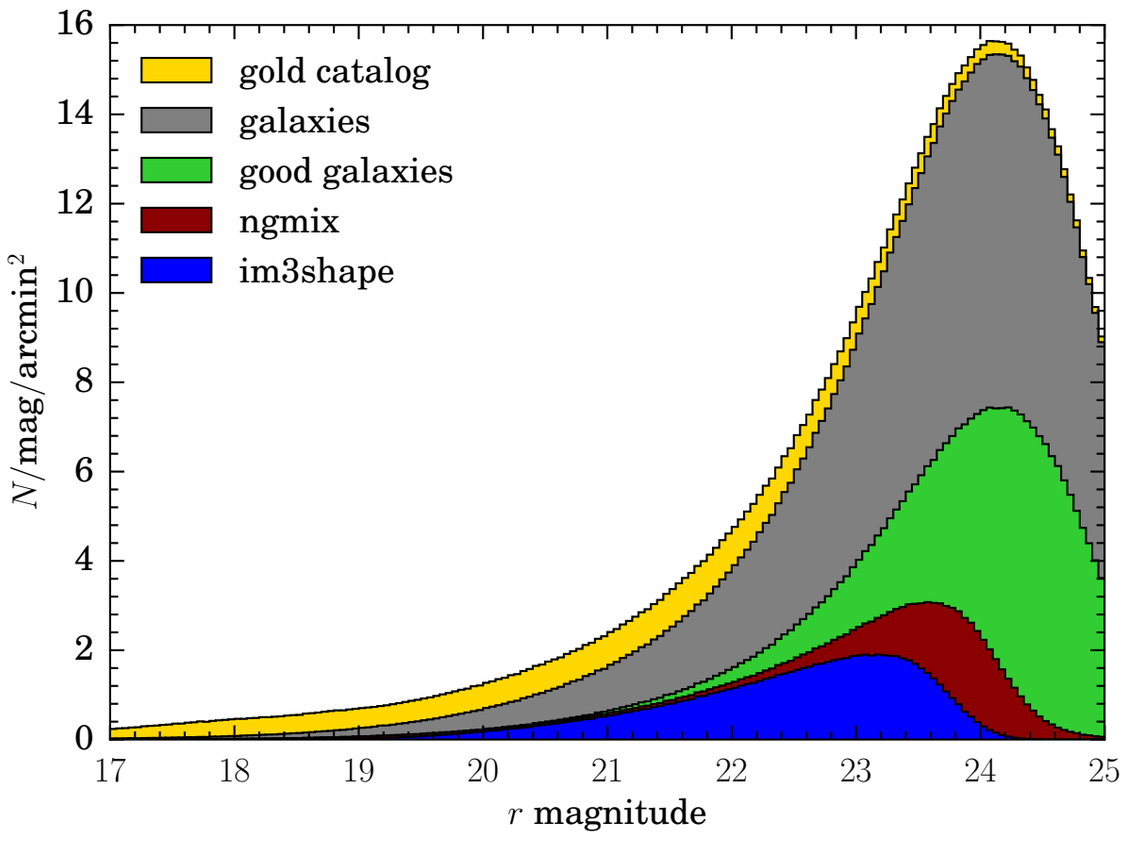


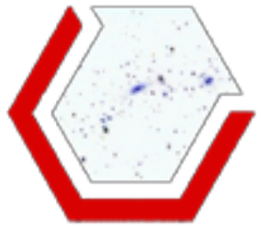
Weak lensing

Becker et al.,1507.05598
Abbott et al., 1507.05552
Jarvis et al., 1507.05603
Bonnet et al., 1507.05909

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







Weak lensing

Becker et al.,1507.05598
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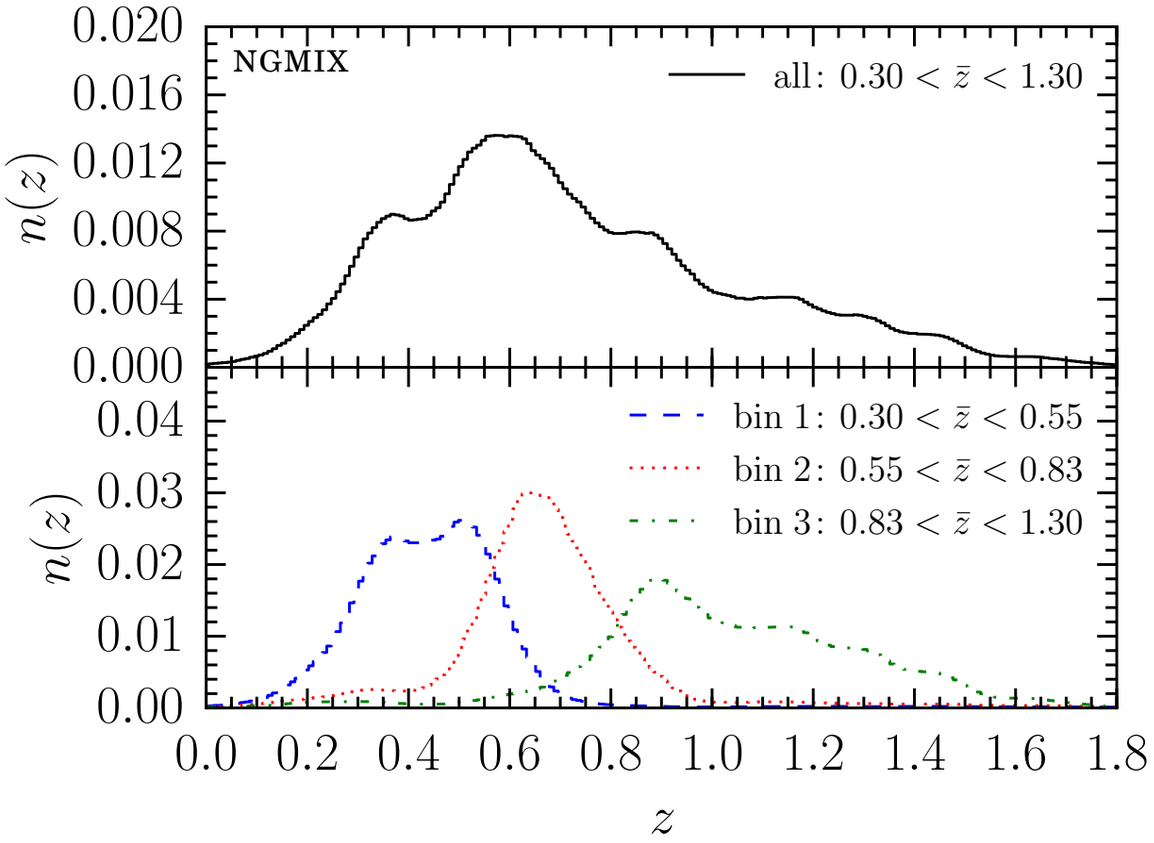
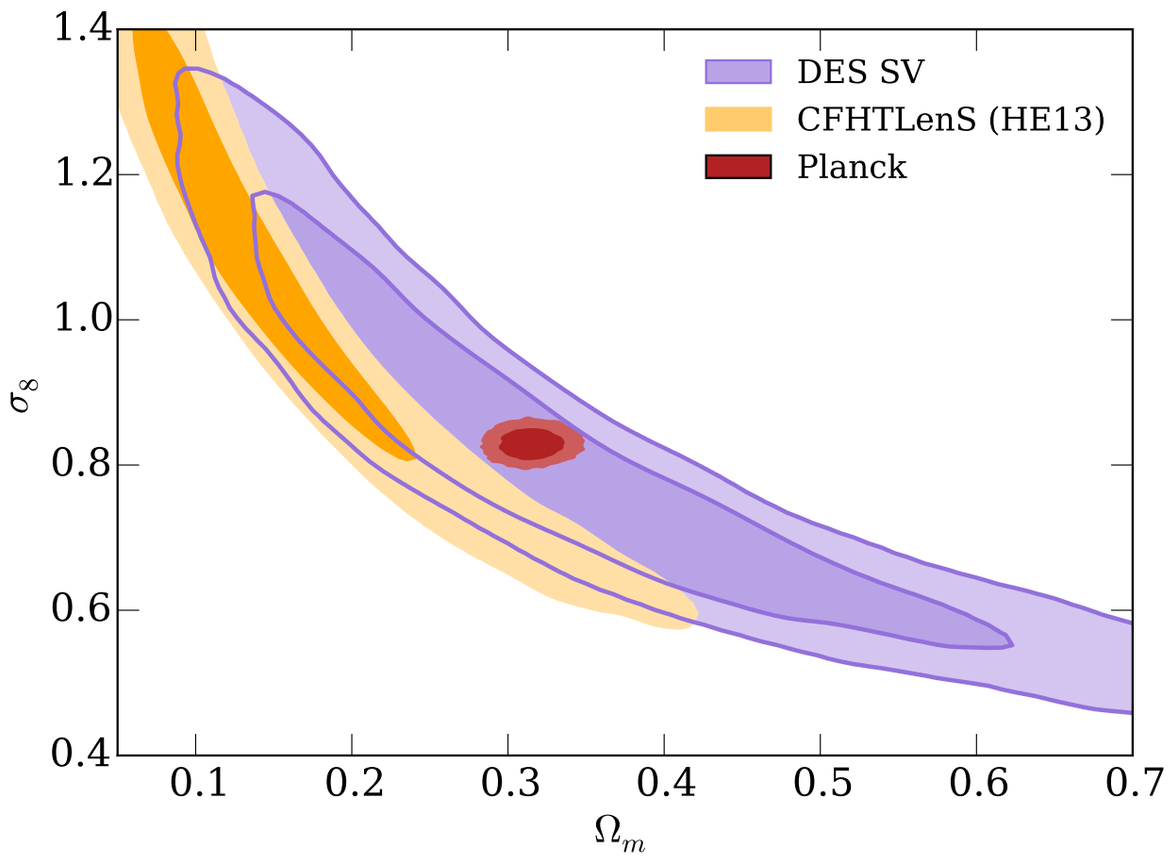
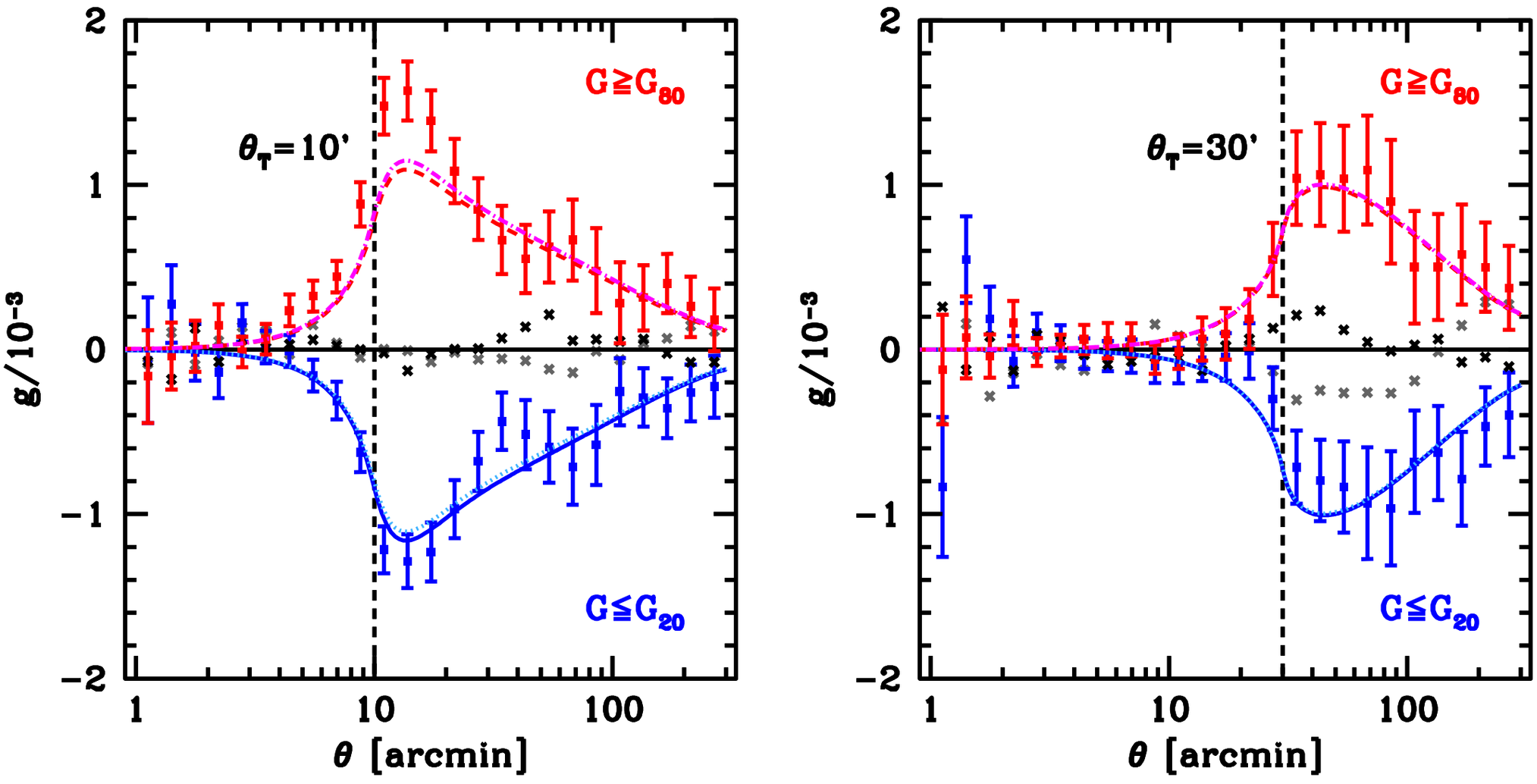
SV cosmology results





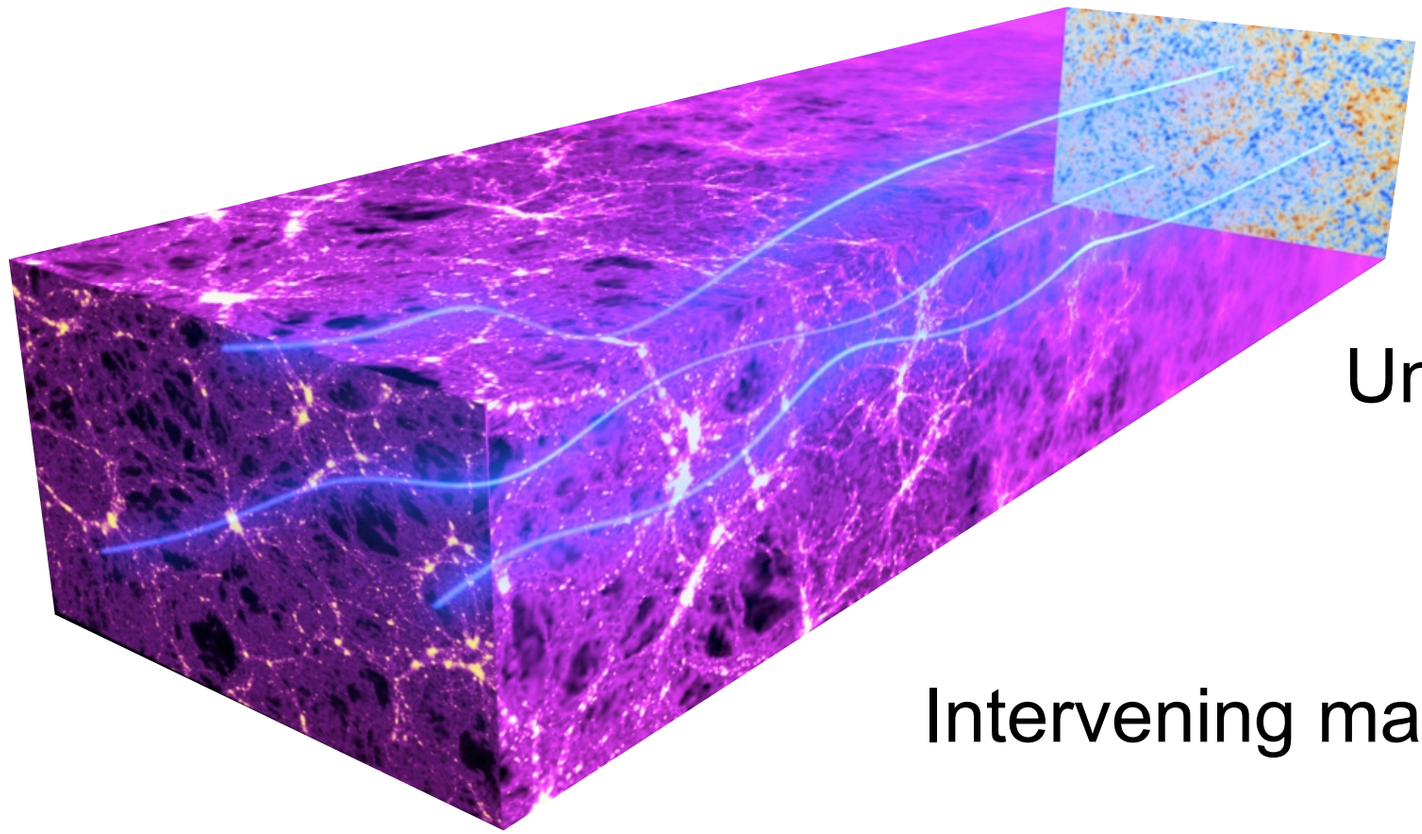
Weak lensing by galaxy troughs

Gruen et al., MNRAS 2016



CMB lensing from South Pole Telescope and Planck

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



Unlensed CMB

Intervening matter

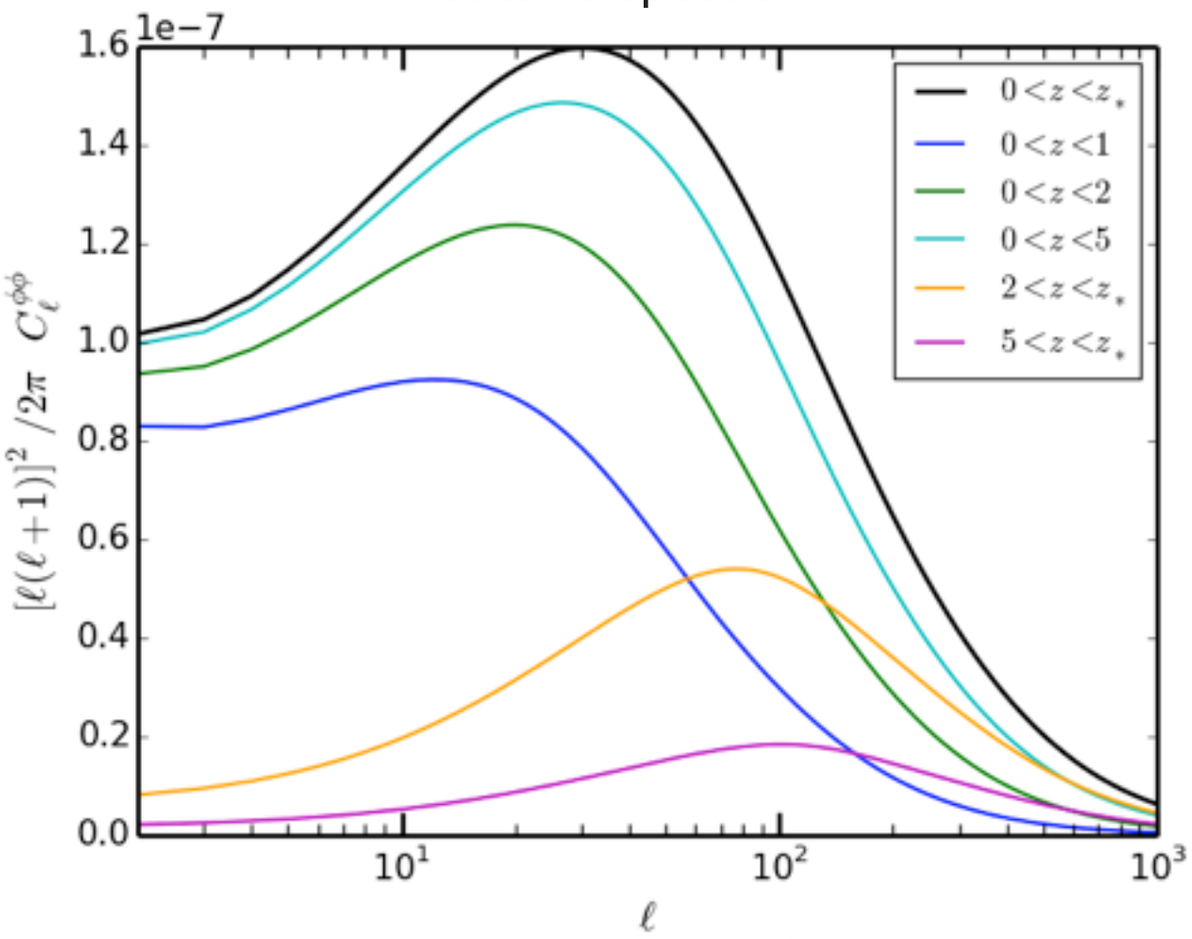
Observed CMB is lensed

CMB lensing from South Pole Telescope and Planck

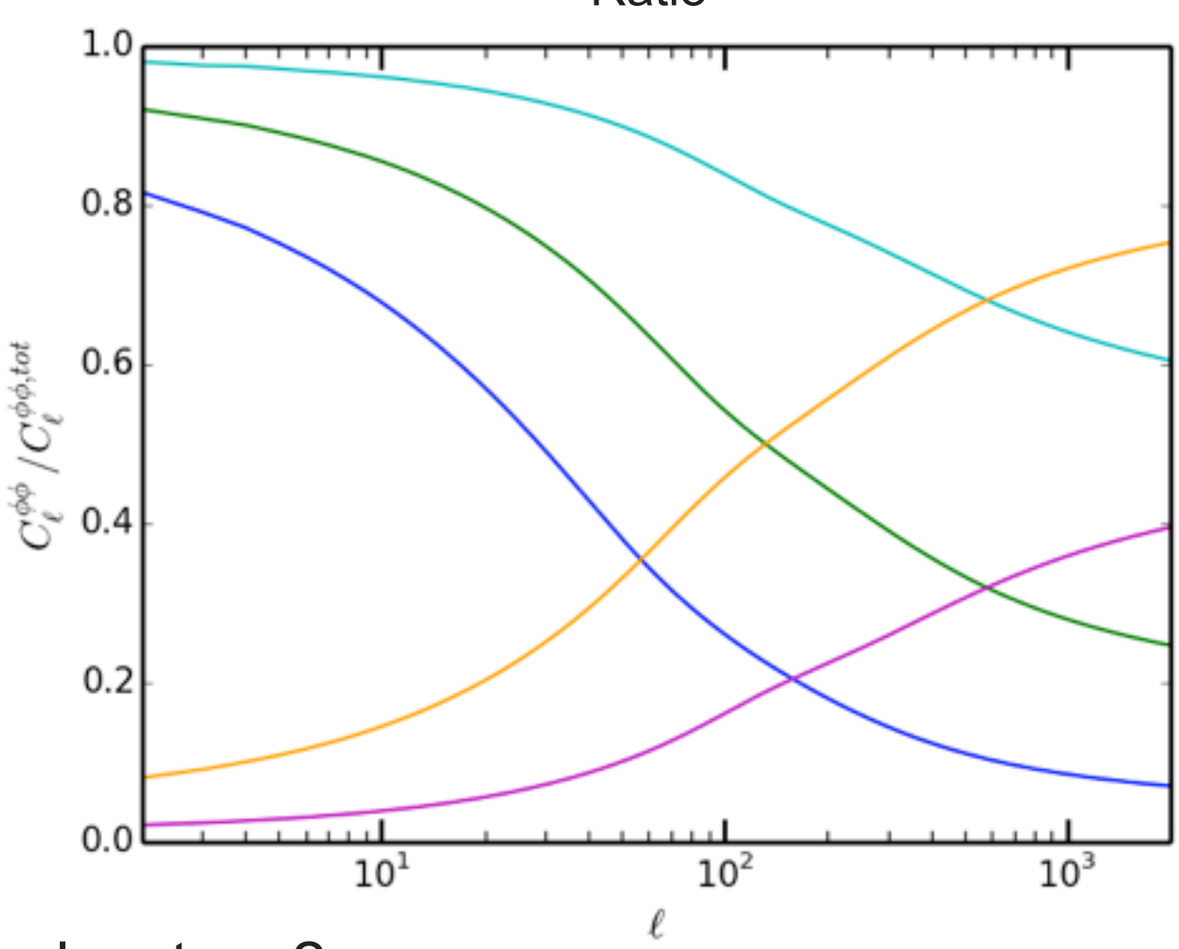
CMB lensing potential is an unbiased tracer of all the matter distribution up to z~1100

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

Absolute spectrum



Ratio



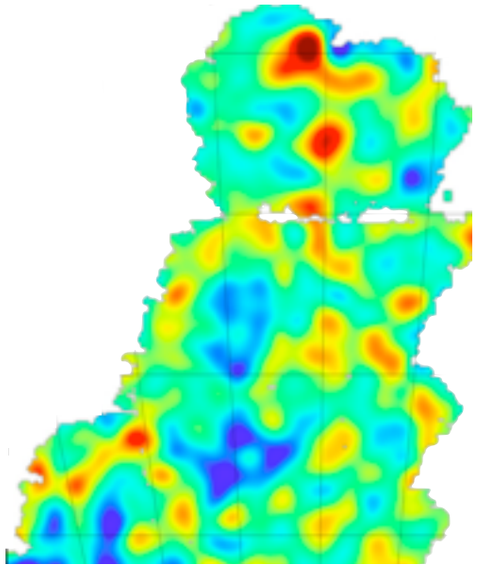
CMB Lensing kernel is wide and peaks at z ~2

DES will enable CMB lensing tomography

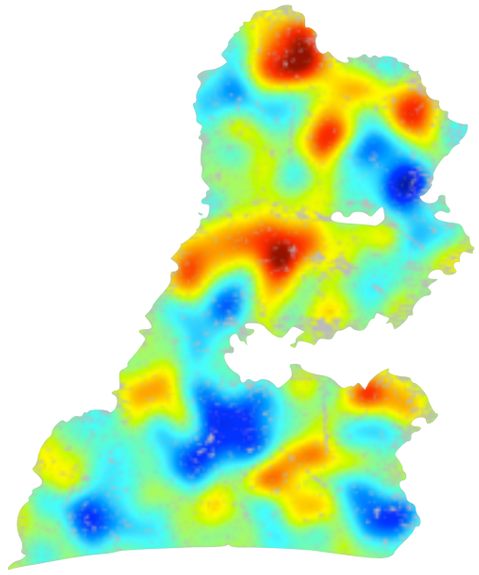
CMB lensing from South Pole Telescope and Planck

Same structure seen by different techniques

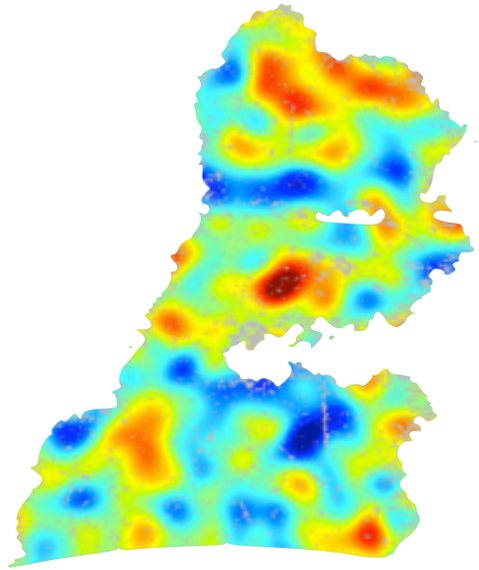
Cosmic shear
(données DES-SV)



DES-galaxies



CMB lensing
(SPT data)



Source redshift distribution

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

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

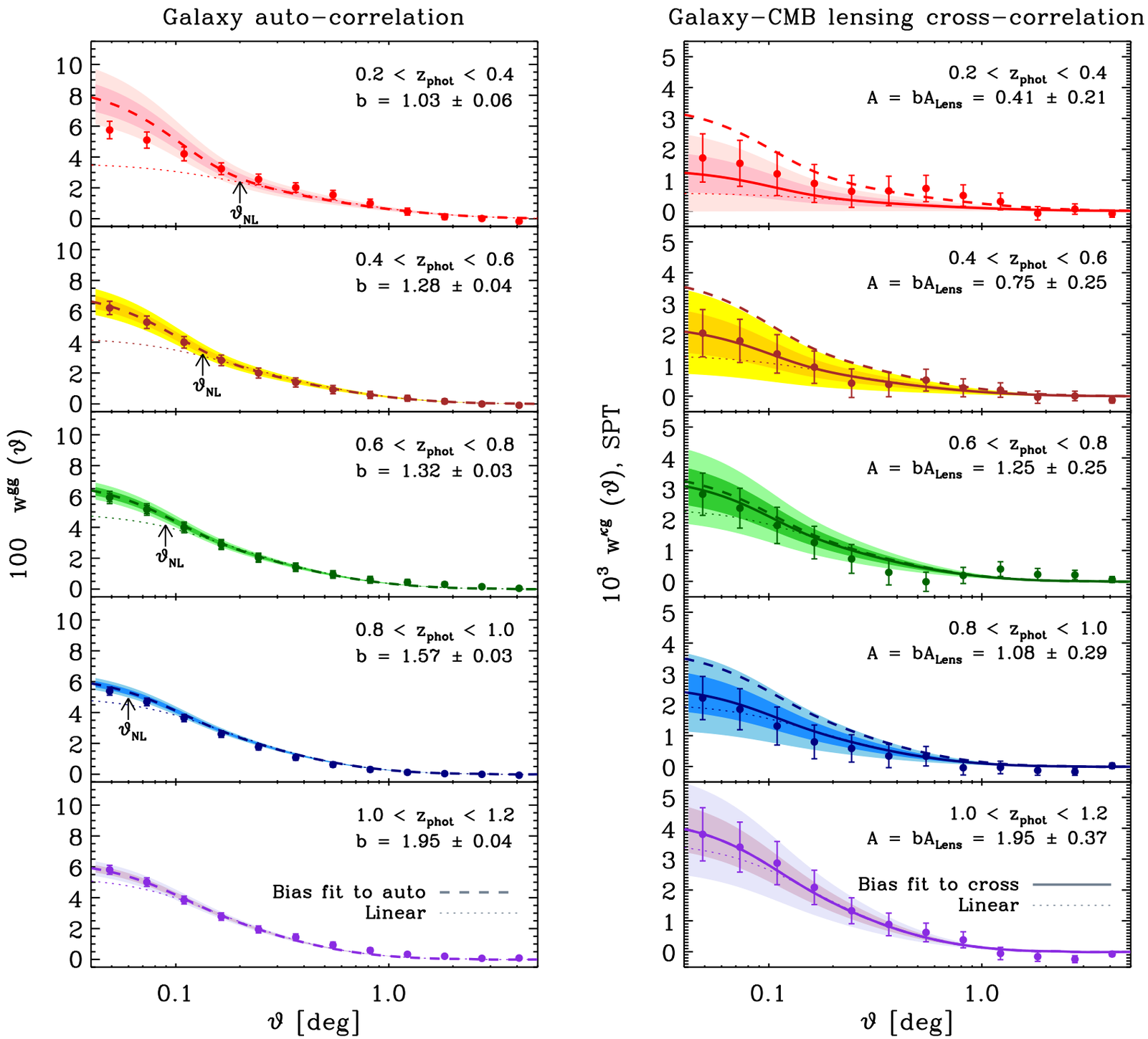
bias

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

matter density contrast

CMB lensing tomography

Giannantonio et al., 1507.05551



CMB lensing tomography

Giannantonio et al., 1507.05551

Linear growth function

$$C_\ell^{gg} = \frac{2}{\pi}\int_0^\infty dk\, k^2\, P(k)\, W_\ell^g(k)\, W_\ell^g(k)$$

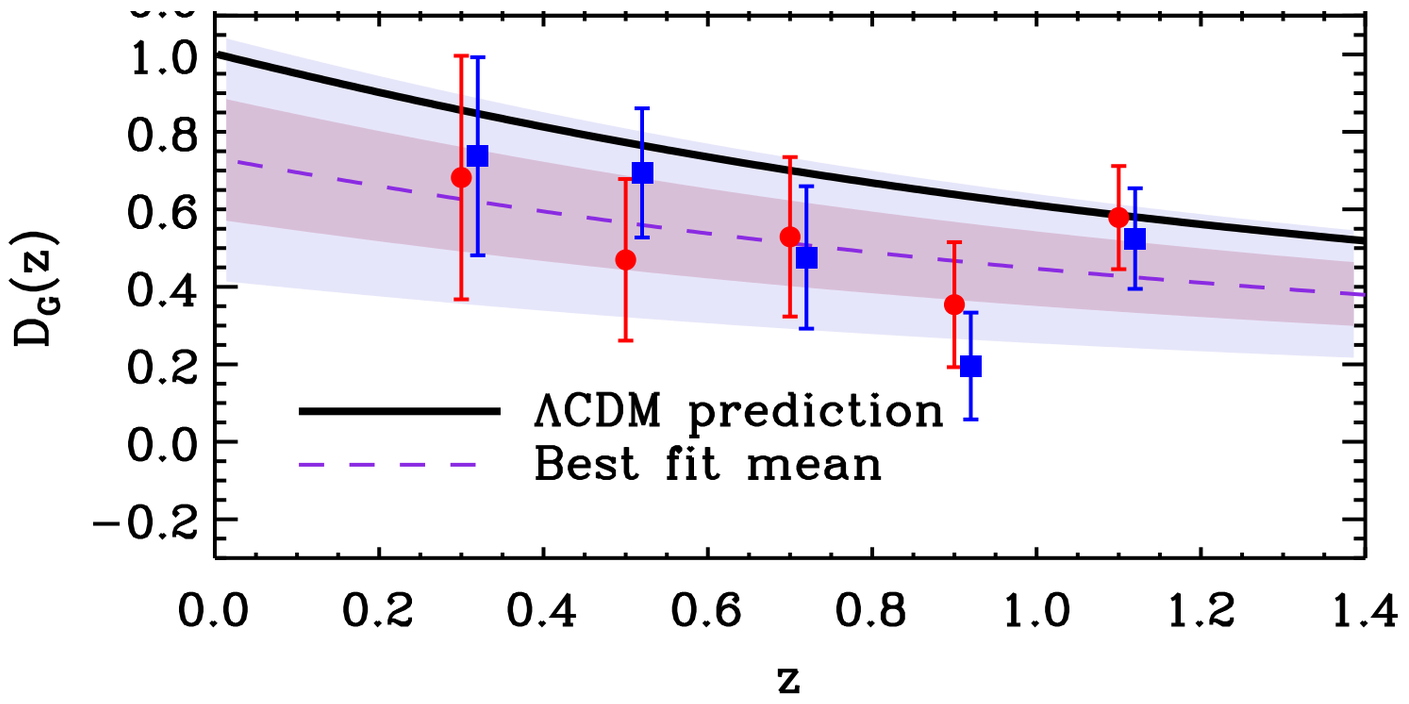
$$C_\ell^{\kappa g} = \frac{2}{\pi}\int_0^\infty dk\, k^2\, P(k)\, W_\ell^\kappa(k)\, W_\ell^g(k)\,,$$

$$W_\ell^g(k) = \int_0^\infty dz\, b(z)\frac{dn}{dz}(z)\, D(z)\, j_\ell[k\chi(z)]$$

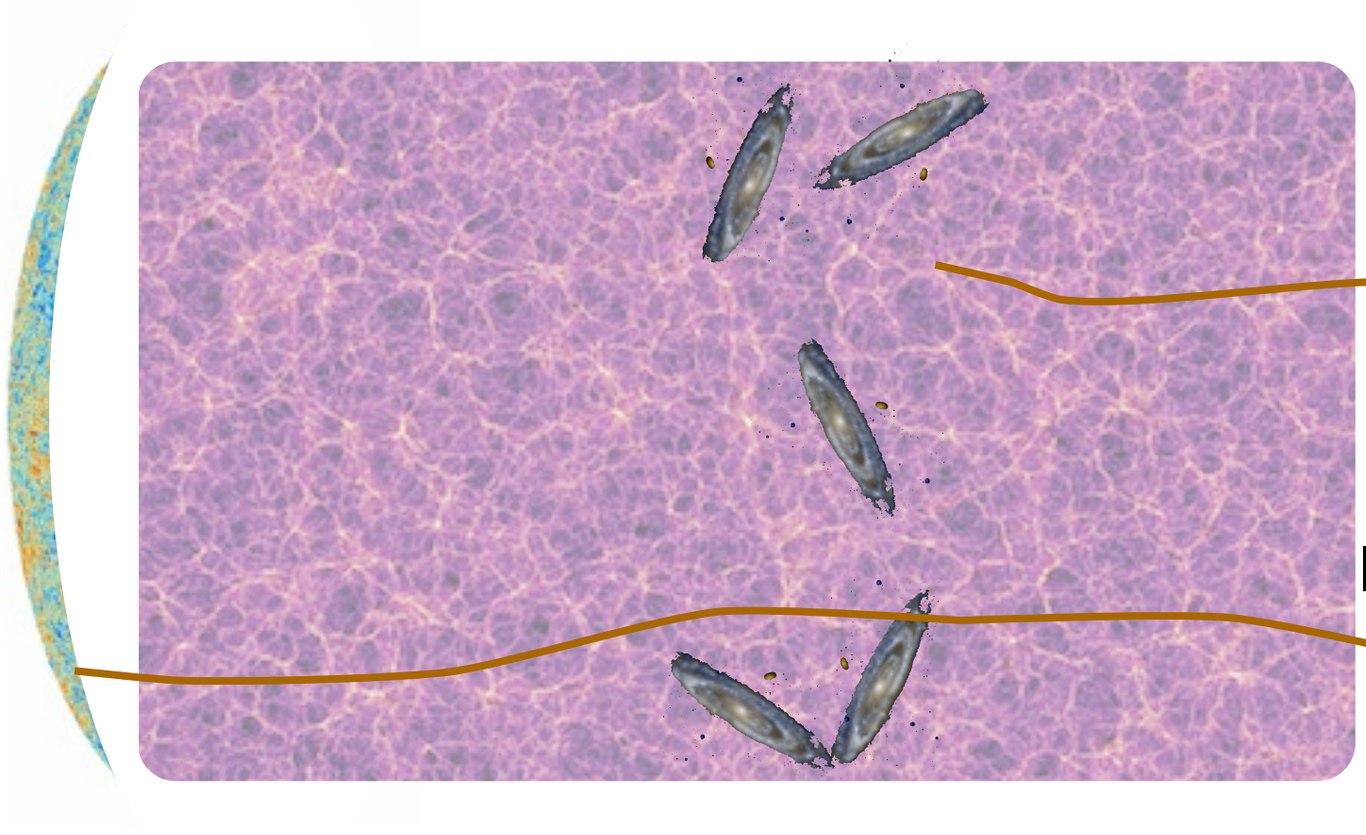
$$W_\ell^\kappa(k) = \frac{3\Omega_m H_0^2}{2}\int_0^\infty dz\, \frac{\chi_* - \chi}{\chi_*\chi}(z)\, D(z)\, j_\ell[k\chi(z)]\,,$$

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

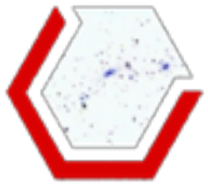
$$\left(\hat{D}_G\right)_i \equiv \left\langle \frac{\left(C_\ell^{\kappa g}\right)^i_{\rm obs}}{\left(\not{C}_\ell^{\kappa g}\right)^i_{\rm the}} \sqrt{\frac{\left(\not{C}_\ell^{gg}\right)^i_{\rm the}}{\left(C_\ell^{gg}\right)^i_{\rm obs}}} \right\rangle_\ell .$$



CMB lensing and Cosmic shear



sheared galaxies



DES

lensed CMB

Planck

SPT

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

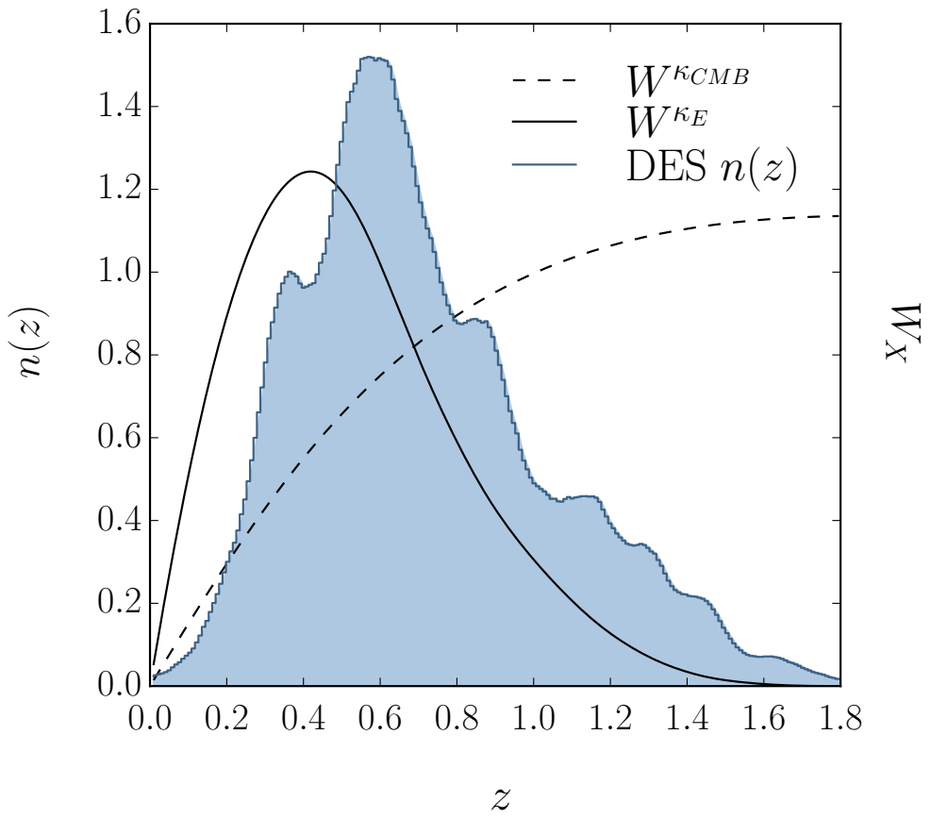
$$W_{\mathrm{GWL}}\left[\chi(z)\right] = \frac{3H_0^2\Omega_{\mathrm{m}}}{2c^2}\frac{\chi}{a(\chi)}\int_{\chi}^{\chi_{\mathrm{hor}}} d\chi' n(\chi')\frac{\chi'-\chi}{\chi'}, \qquad W_{\mathrm{CMBWL}}\left[\chi(z)\right] = \frac{3H_0^2\Omega_{\mathrm{m}}}{2c^2}\frac{\chi}{a(\chi)}\frac{\chi_*-\chi}{\chi_*},$$

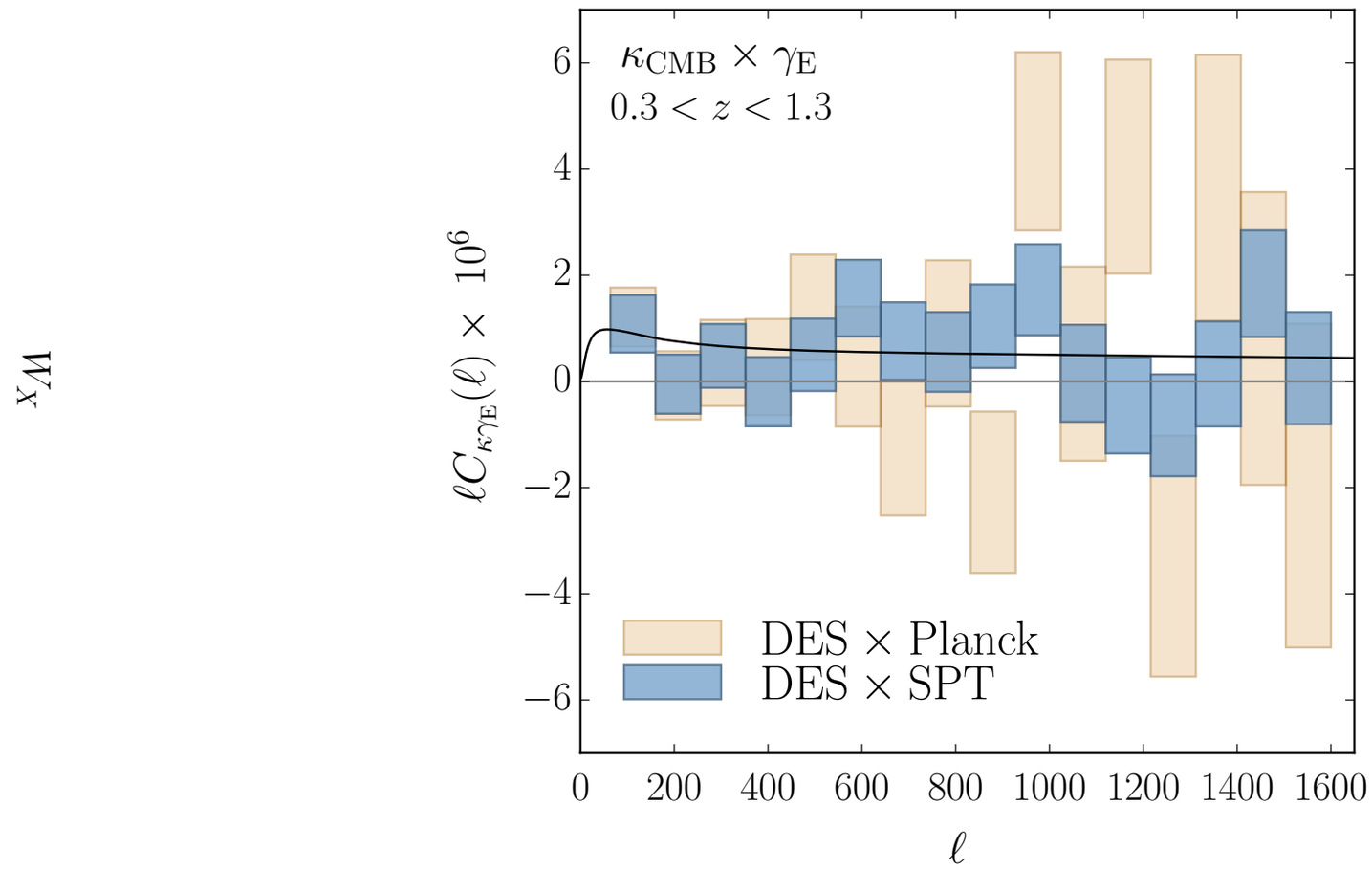
CMB lensing x DES shear

Kirk et al., 1512.04535

Cross-correlation of gravitational lensing from DES Science Verification with SPT and Planck lensing

D. Kirk[1],[*] Y. Omori[2],[†] A. Benoit-Lévy[1], R. Cawthon[3,4], C. Chang[5], P. Larsen[6], G. Holder[2],

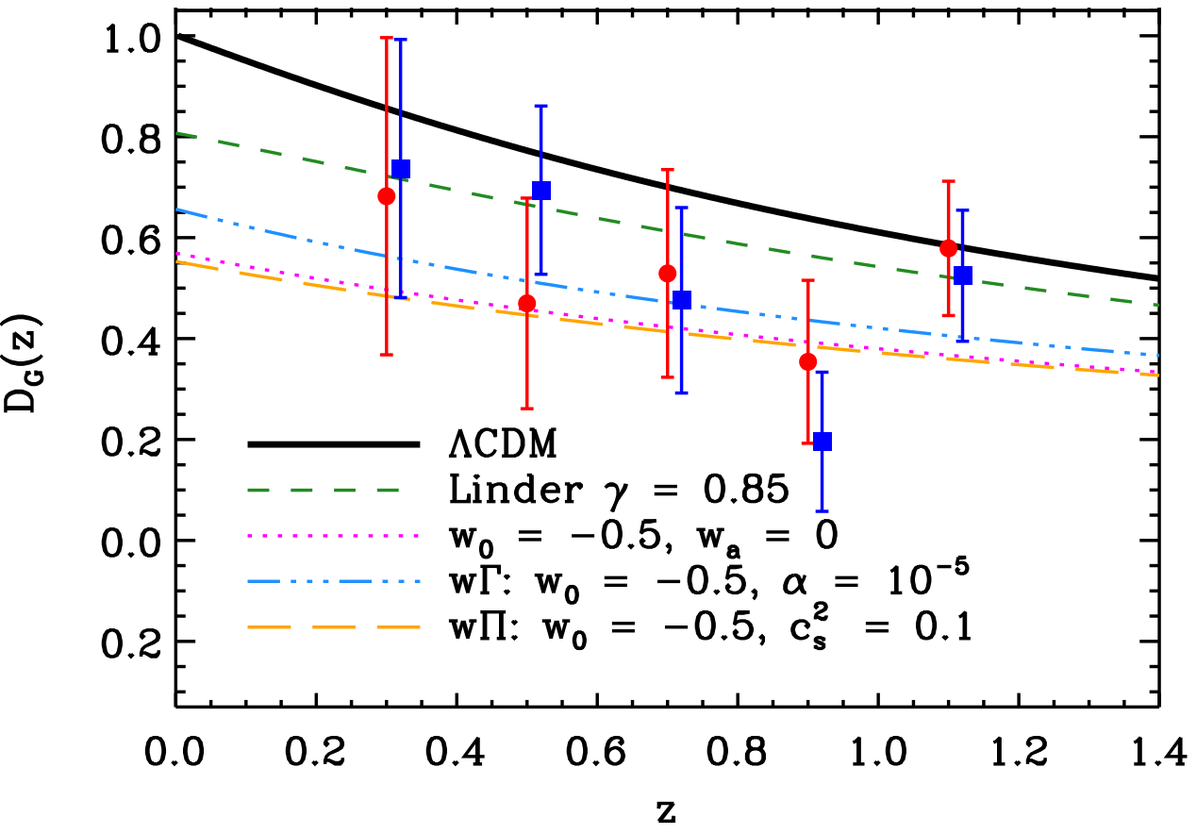




Redshift Range	$0.3 < z < 1.3$	
$\kappa_{\rm CMB}\gamma_{\rm E}$	A	χ^2/d.o.f.
`ngmix` × SPT	$0.88^{+0.30}_{-0.30}$	0.93
`ngmix` × *Planck*	$0.86^{+0.39}_{-0.39}$	1.52

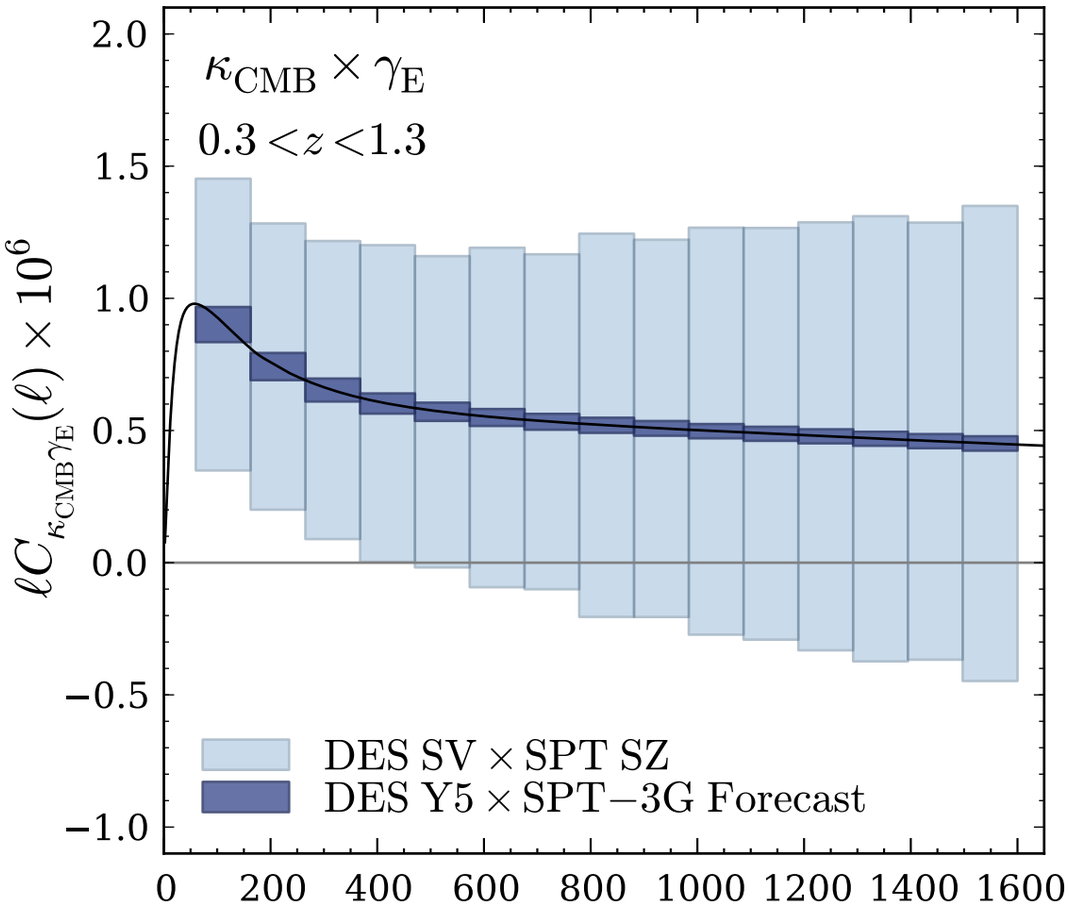
CMB lensing x DES: prospects

galaxy - CMB lensing



Giannantonio et al., 1507.05551

galaxy lensing - CMB lensing



Kirk et al., 1512.04535

Conclusion (I)

SV analysis is finished, now public at

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

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

Y2-3 data is being produced