Exploring Darkness Through Light:

on combining lensing and galaxy maps

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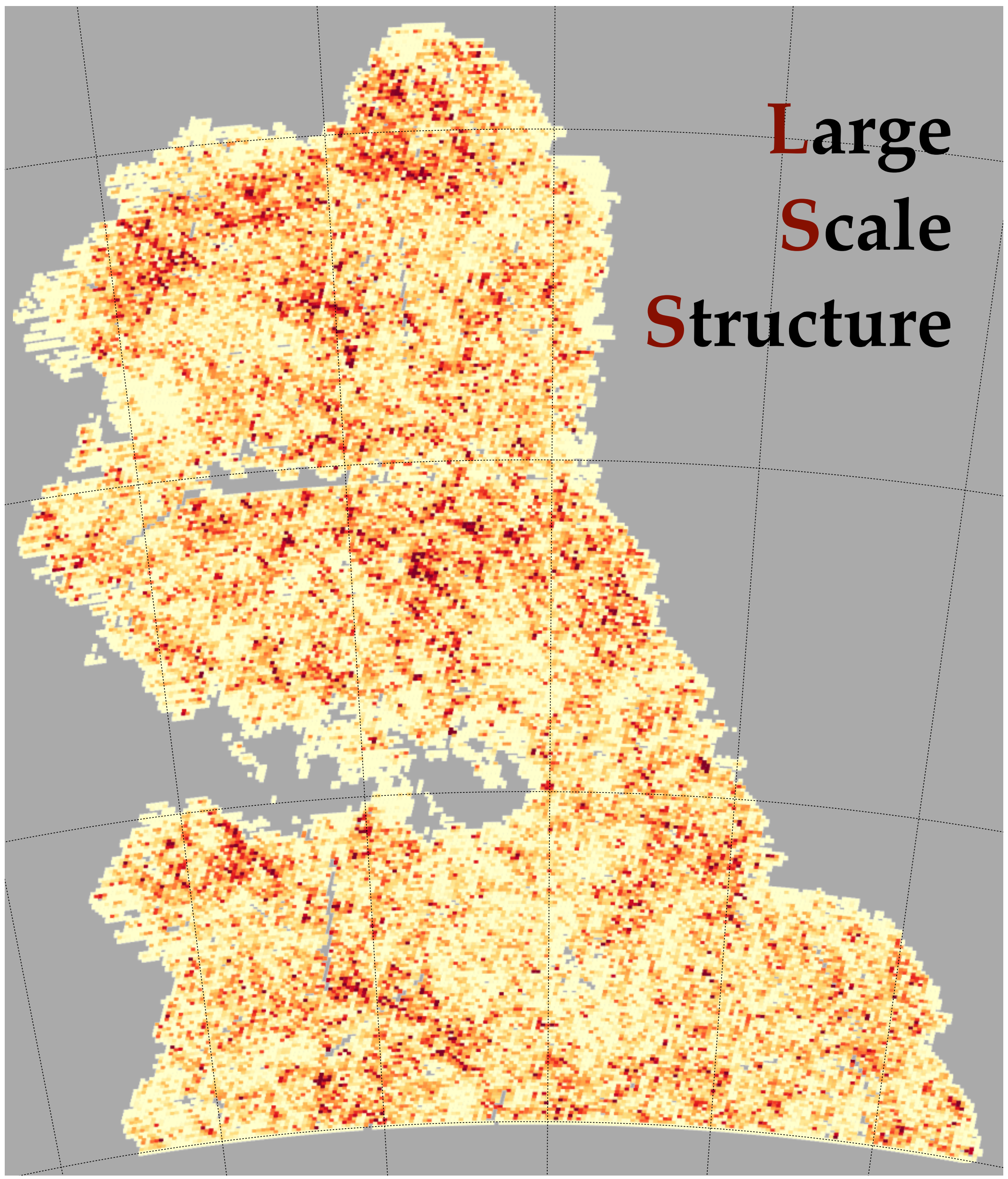
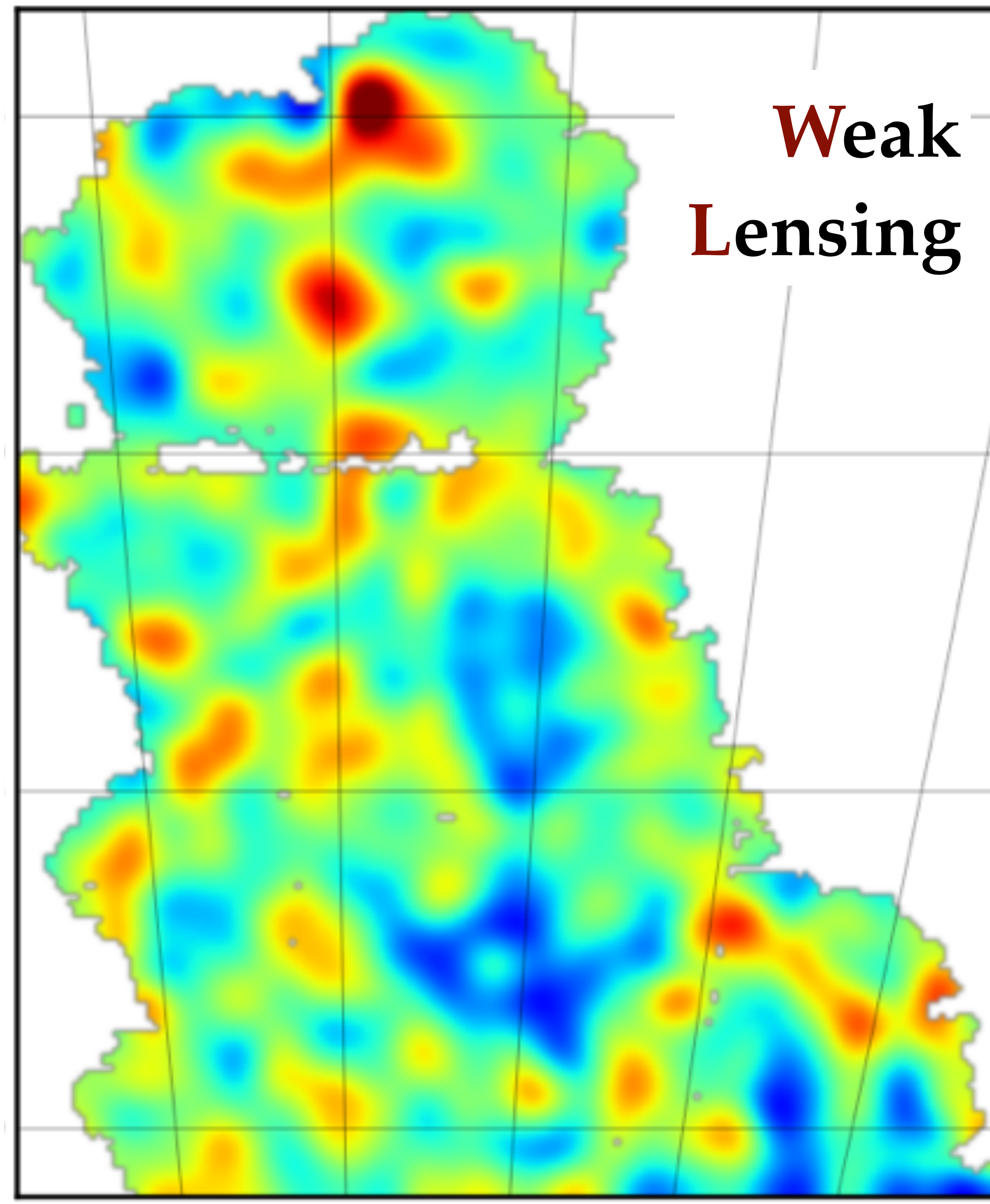
Two Cosmological Maps



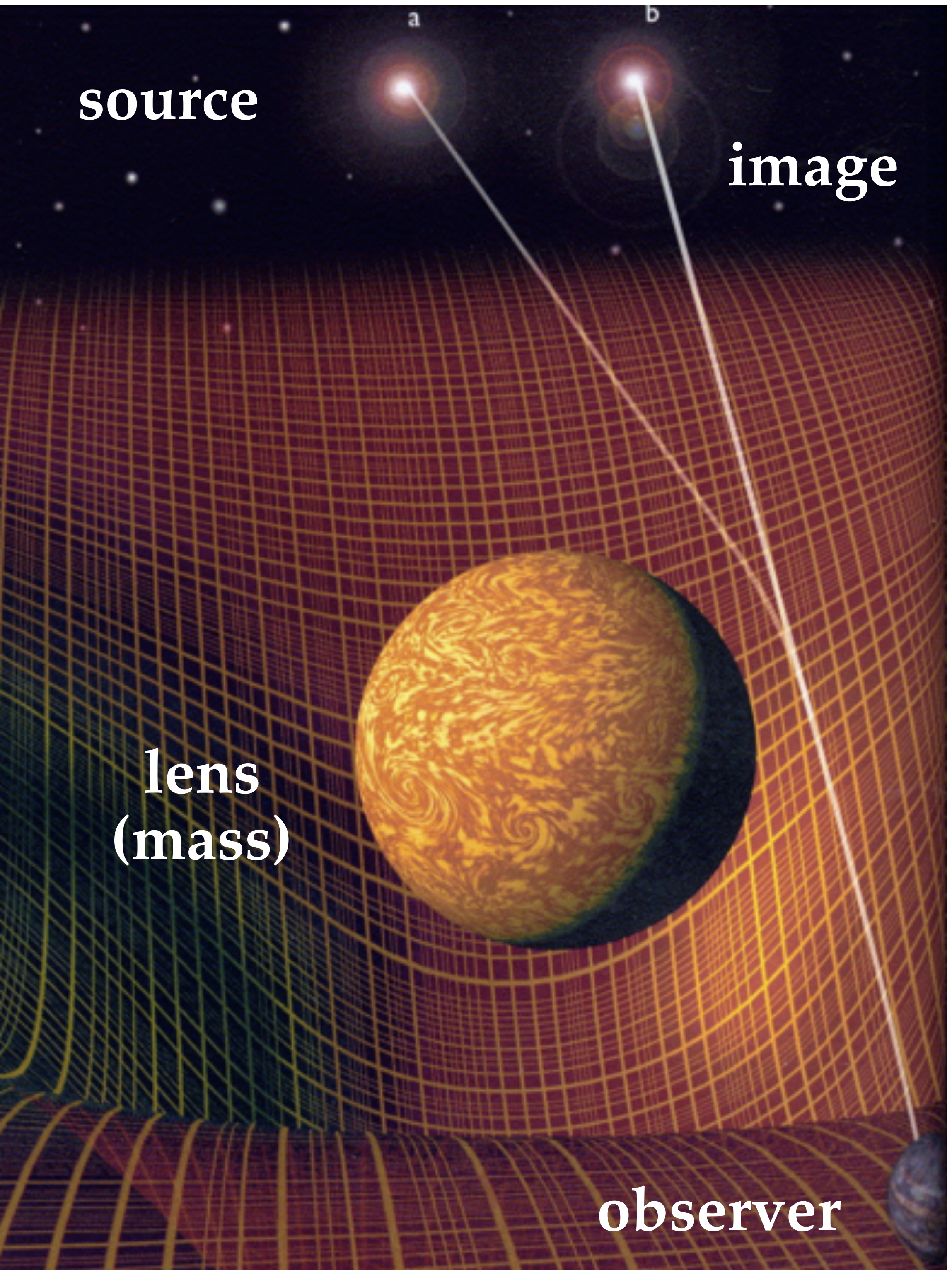


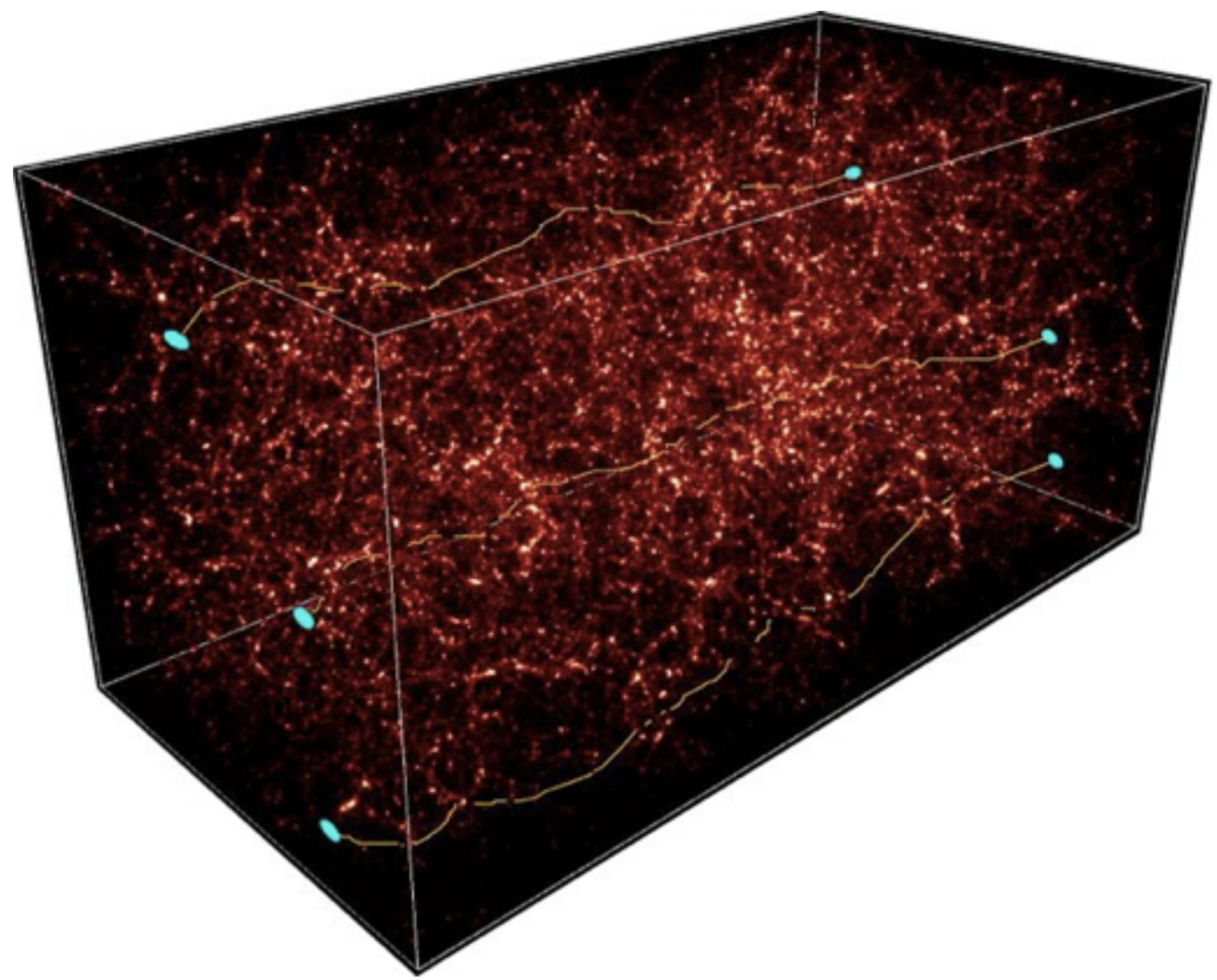
This talk is based on…

- **The COSMOS Density Field: A Reconstruction Using Both Weak Lensing and Galaxy Distributions (Amara et al. 2012)**
  - *MNRAS, 424, 553 (2012), arXiv: 1205.1064*
- **A New Method to Measure Galaxy Bias by Combining the Density and Weak Lensing Fields (Pujol et al. 2016)**
  - *Submitted, arXiv:1505.05885*
- **Galaxy Bias from the DES Science Verification Data: Combining Galaxy Density Maps and Weak Lensing Maps (Chang et al. 2016)**
  - *Submitted, arXiv:1601.00405*

DARK ENERGY SURVEY

Weak Gravitational Lensing





Convergence vs. Shear

DM overdensity

Convergence
= projected over-density

$$\kappa(\boldsymbol{\theta}, p_s) = \int_0^\infty d\chi \, q(\chi, p_s) \delta(\boldsymbol{\theta}, \chi)$$

Shear
= primary WL observable

$$\langle \boldsymbol{\varepsilon} \rangle \approx \boldsymbol{\gamma}$$

The Kaiser-Squires (KS 1993) method:

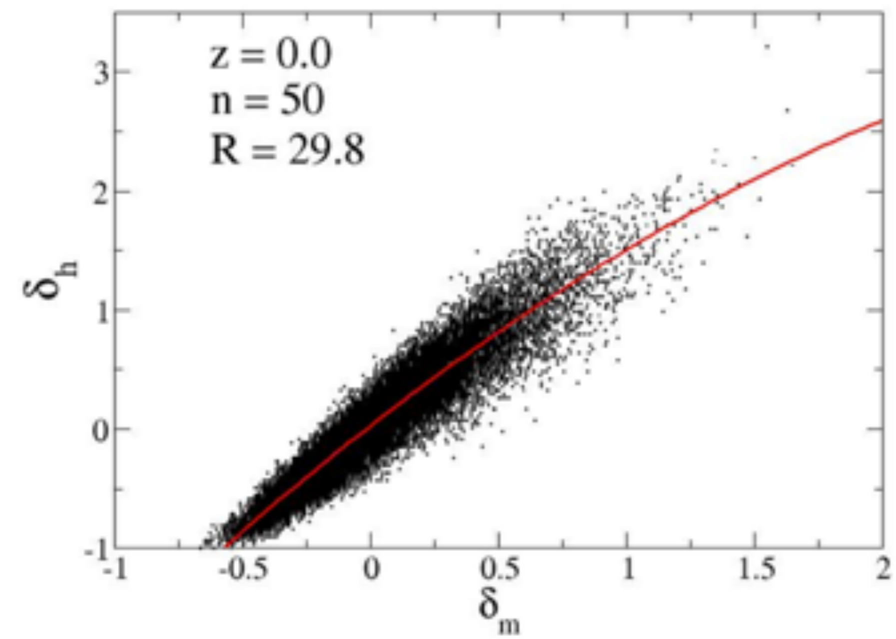
$$\tilde{\kappa}(\boldsymbol{\ell}) - \tilde{\kappa_0} = D^*(\boldsymbol{\ell})\tilde{\gamma}(\boldsymbol{\ell}); \;\; \tilde{\gamma}(\boldsymbol{\ell}) - \tilde{\gamma_0} = D(\boldsymbol{\ell})\tilde{\kappa}(\boldsymbol{\ell})$$

$$D(\boldsymbol{\ell}) = \frac{\ell_1^2 - \ell_2^2 + i2\ell_1\ell_2}{|\boldsymbol{\ell}|^2}$$

DARK ENERGY SURVEY

Local Galaxy Bias

Manera & Gaztanaga (2009)



- The local bias prescription connects galaxy to dark matter **locally**

$$\delta_g = b_0 + b_1\delta + b_2\delta^2 + \ldots$$
$$\delta = \mu_0 + \mu_1\delta_g + \mu_2\delta_g^2 + \ldots$$

- At large scales the linear local bias approaches the **Kaiser bias**

$$\xi_g(r) = b_K^2(r)\xi(r)$$
$$\omega_g(\theta) = b_K^2(\theta)\omega(\theta)$$

DARK ENERGY SURVEY

Building a Convergence Template

DM overdensity

Convergence
= projected over-density

$$\kappa(\boldsymbol{\theta}, p_s) = \int_0^\infty d\chi \, q(\chi, p_s) \delta(\boldsymbol{\theta}, \chi)$$

galaxy overdensity

Template
(Linear constant bias)

$$\kappa_g(\boldsymbol{\theta}, p_s) = \int_0^\infty d\chi \, q(\chi, p_s) \delta_g(\boldsymbol{\theta}, \chi)$$

$\delta_g = b\delta$ →

$$b = \frac{\langle \kappa_g \kappa_g \rangle}{\langle \kappa_g \kappa \rangle} = \frac{\langle \kappa_g \kappa \rangle}{\langle \kappa \kappa \rangle}$$

DARK ENERGY
SURVEY

Building a Convergence Template

Convergence
= projected over-density

$$\kappa(\boldsymbol{\theta}, p_s) = \int_0^\infty d\chi \, q(\chi, p_s)\delta(\boldsymbol{\theta}, \chi)$$

radial selection function

Template
(Linear evolving bias)

$$\kappa'_g(\boldsymbol{\theta}, \phi', p_s) = \int_0^\infty d\chi \, q(\chi, p_s)\phi'(\chi)\delta_g(\boldsymbol{\theta}, \chi)$$

$$\delta_g(\chi) = b(\chi)\delta(\chi)$$

$$b = \frac{1}{f_1}\frac{\langle \kappa'_g \kappa'_g \rangle}{\langle \kappa'_g \kappa \rangle} = \frac{1}{f_2}\frac{\langle \kappa'_g \kappa \rangle}{\langle \kappa \kappa \rangle}$$

DARK ENERGY
SURVEY

Building a Convergence Template

Convergence
= projected over-density

$$\kappa(\boldsymbol{\theta}, p_s) = \int_0^\infty d\chi\, q(\chi, p_s)\delta(\boldsymbol{\theta}, \chi)$$

More complicated models

$$\kappa_{g,1} = \int_0^\infty d\chi\, q(\chi, p_s)\delta_g(\boldsymbol{\theta}, \chi)$$

$$\kappa_{g,2} = \int_0^\infty d\chi\, q(\chi, p_s)\delta_g^2(\boldsymbol{\theta}, \chi)$$

$$\kappa = \mu_1\kappa_{g,1} + \mu_2\kappa_{g,2}$$

→ **Build up a 3D bias map** → **Build up a 3D Dark Matter map**

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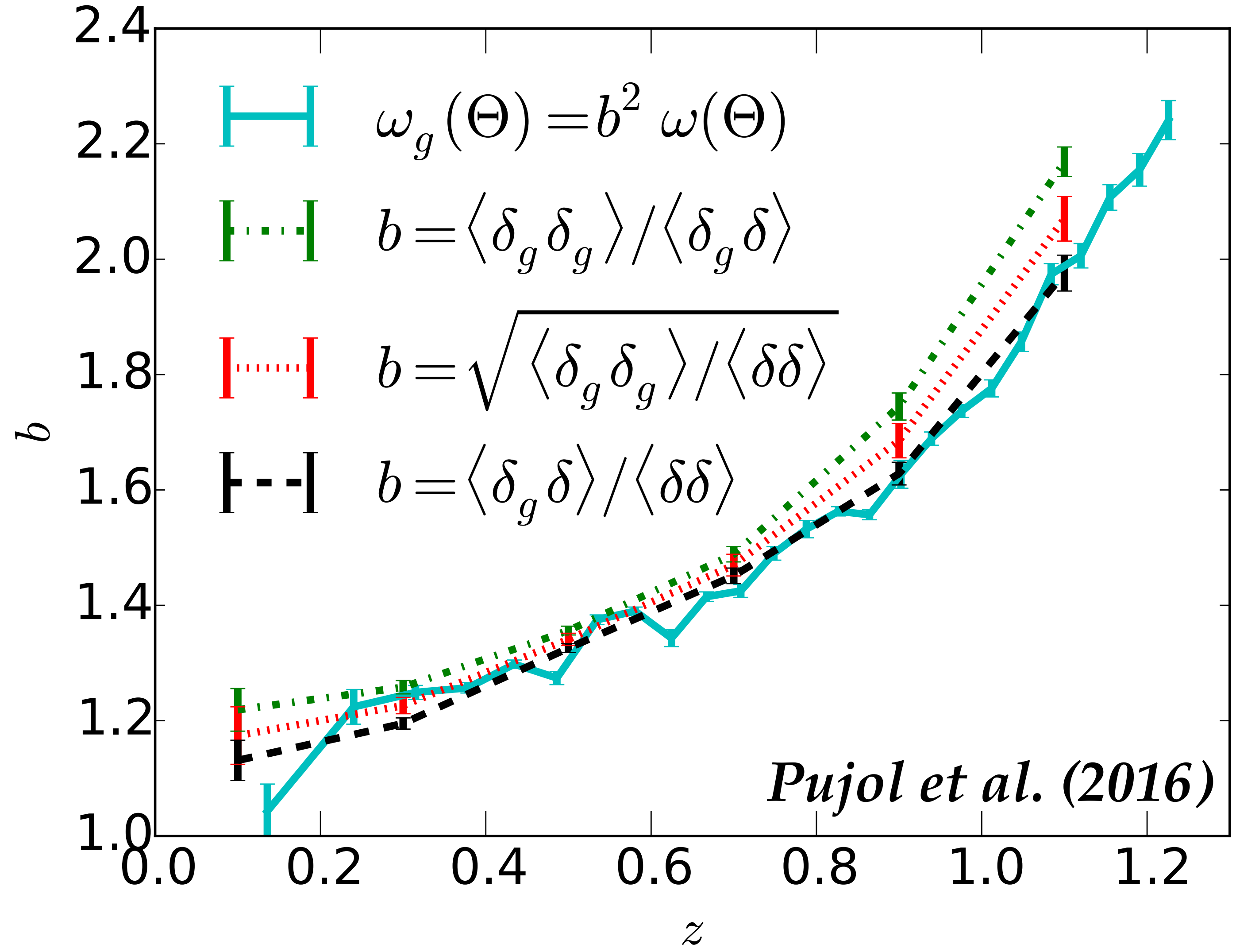
Building a Convergence Template

In the linear-evolving case, we have tested the method to **~% accuracy**.

The discrepancy with **Kaiser bias** comes from stochasticity and the discrete nature of galaxies.



The Dark Energy Survey

Practical Considerations:

- Shape noise
- KS conversion and masks
- Photometric redshift (photo-z's)
- Galaxy sample

$$b = \frac{1}{f}\frac{\langle\gamma'_{\alpha,g}\gamma'_{\alpha,g}\rangle - \langle\gamma'^{N}_{\alpha,g}\gamma'^{N}_{\alpha,g}\rangle}{\langle\gamma'_{\alpha,g}\gamma'_{\alpha}\rangle - \langle\gamma'^{N}_{\alpha,g}\gamma'^{N}_{\alpha}\rangle},\ \alpha = 1,2$$

→ **Test with simulations**

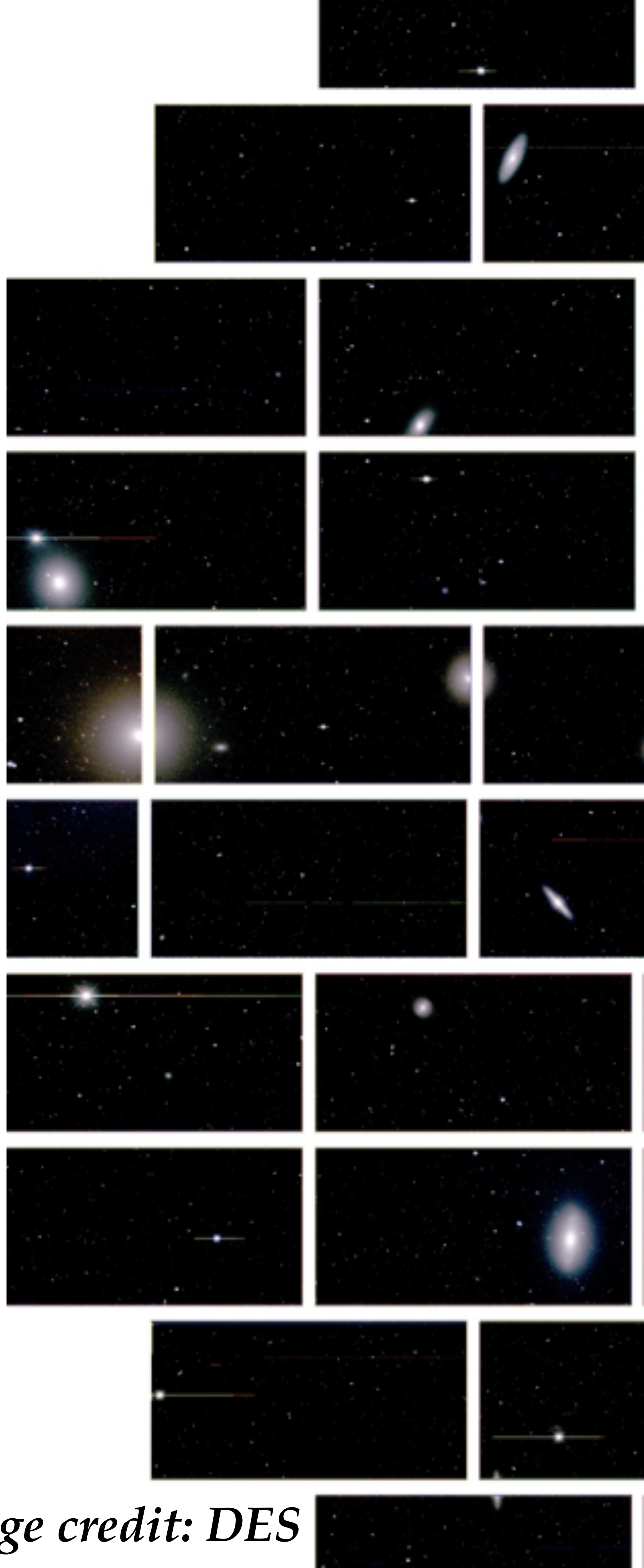
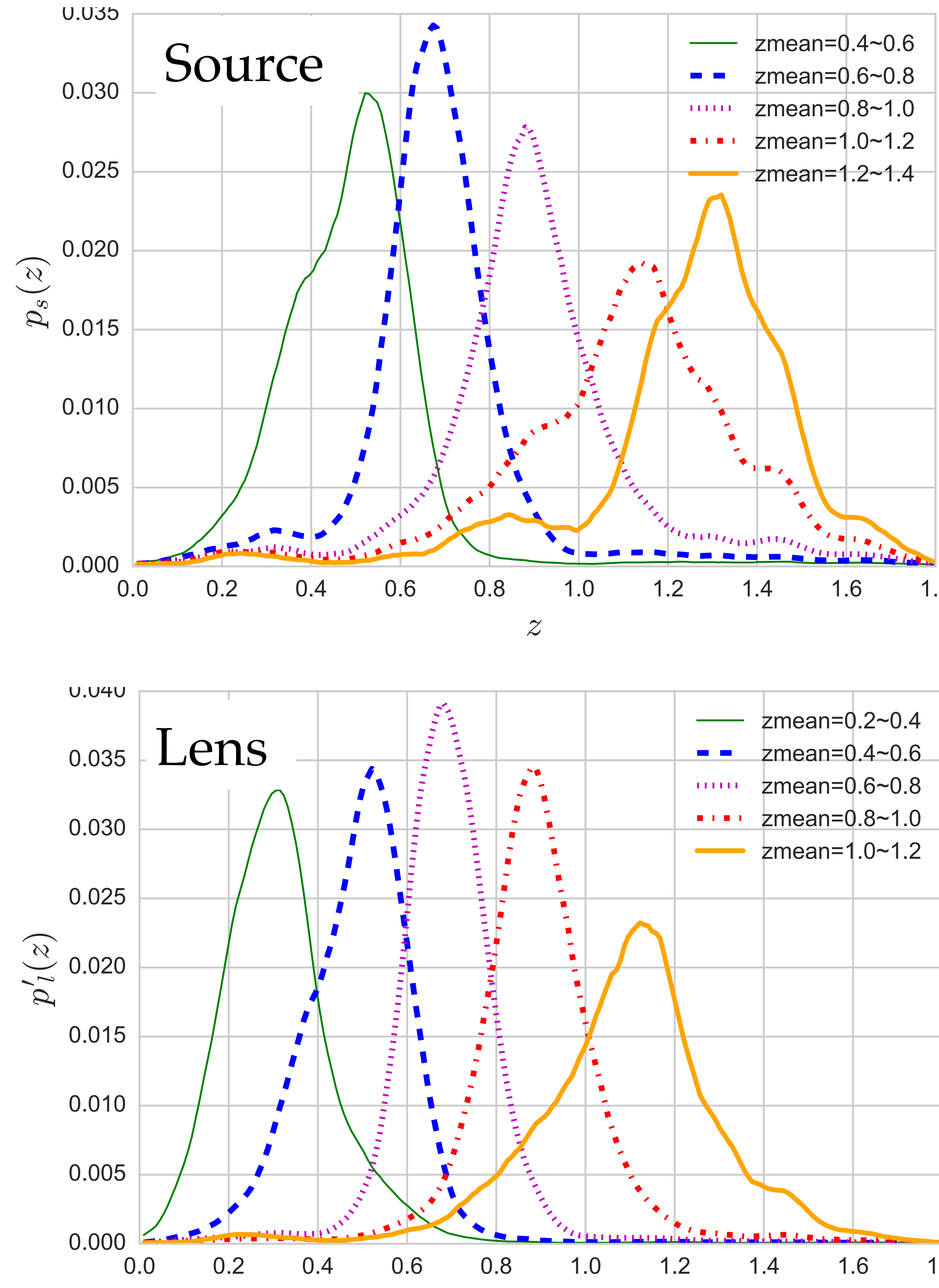


Image credit: DES

DARK ENERGY SURVEY

Data and Analysis

- Construct **3D grid** for source and lenses
- n(z) for each bin from **SkyNet**

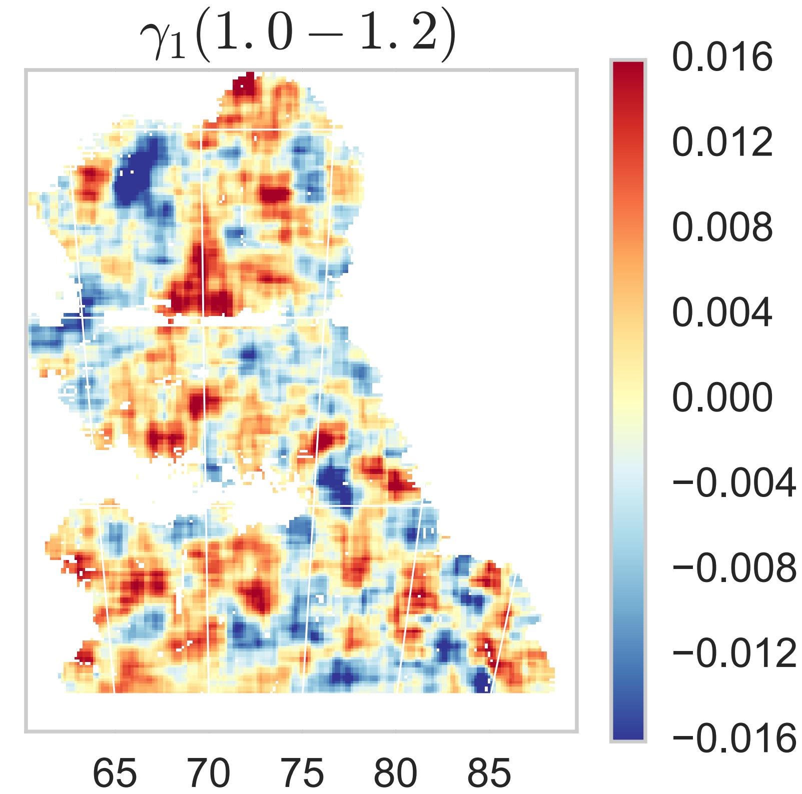


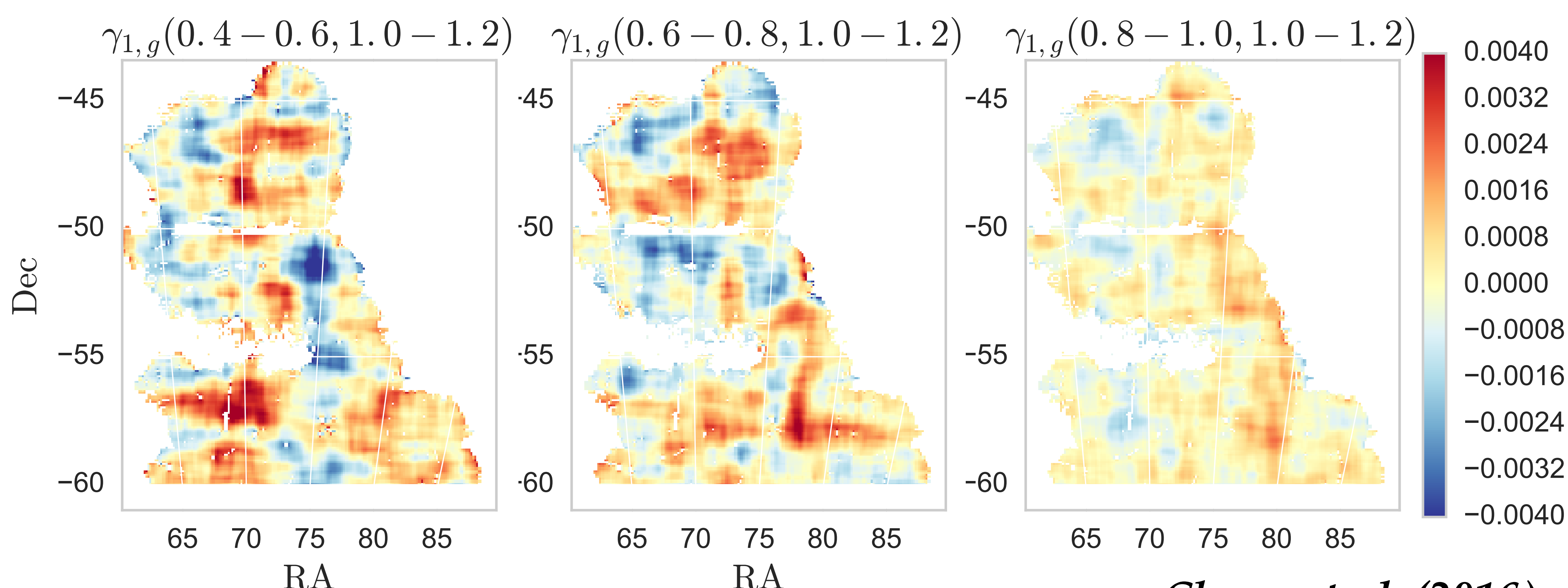
Chang et al. (2016)

DARK ENERGY SURVEY

Data and Analysis

- Make γ_i and $\gamma_{i,g}$ maps on the **3D grid**
- **Cross-correlate** and account for full n(z)





Chang et al. (2016)

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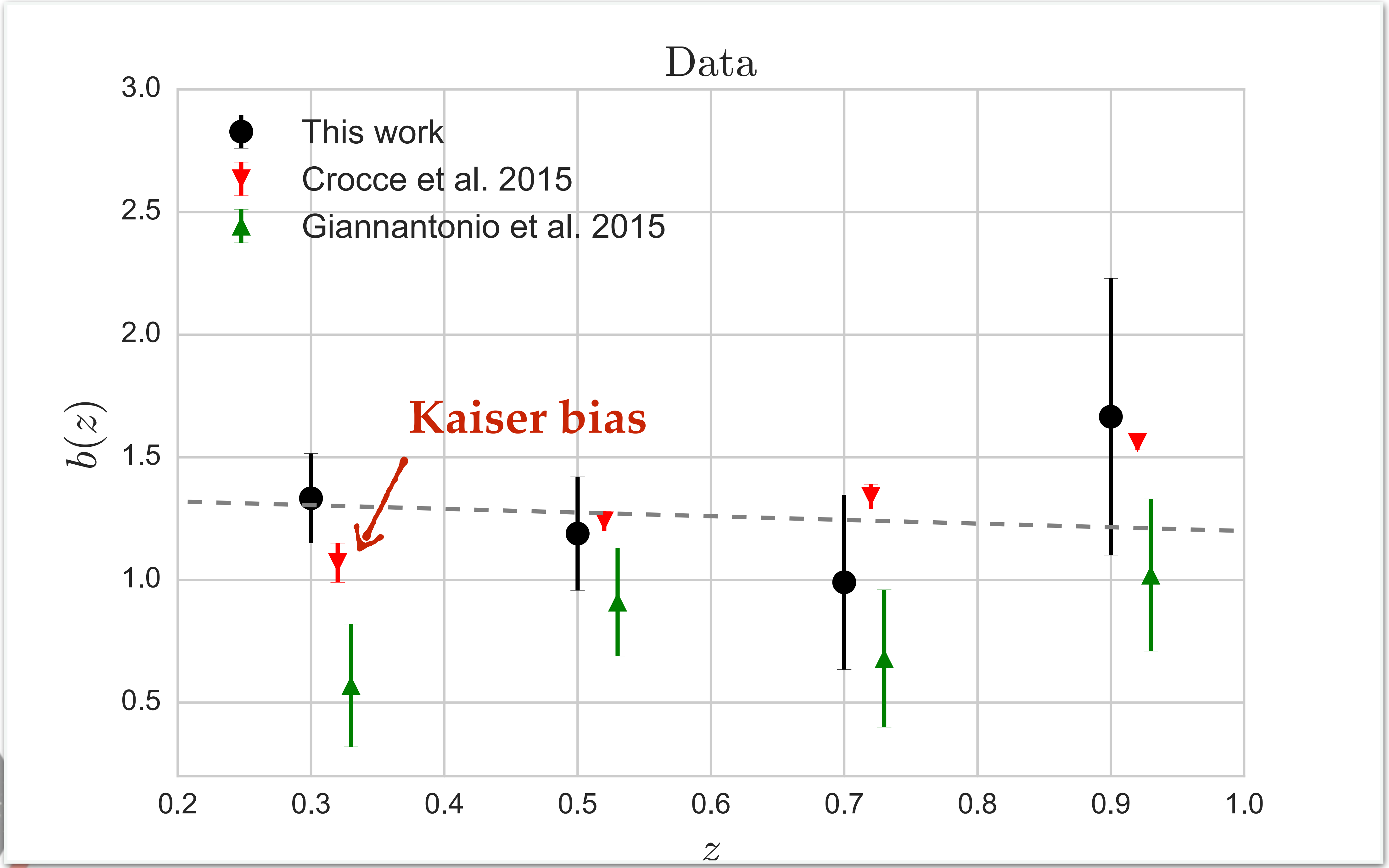
Results



Chang et al. (2016)

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Summary and Outlook

- Combining **Weak Lensing** and **Large-Scale Structure** makes a lot of sense!
- The main challenge is to understand the relation between Dark Matter and galaxies — i.e. the **galaxy bias**.
- For **DES SV**, we constrain the linear evolving galaxy bias using WL and LSS maps.
- Our methodology can be extended to **more complicated galaxy bias models** for future larger data sets.

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