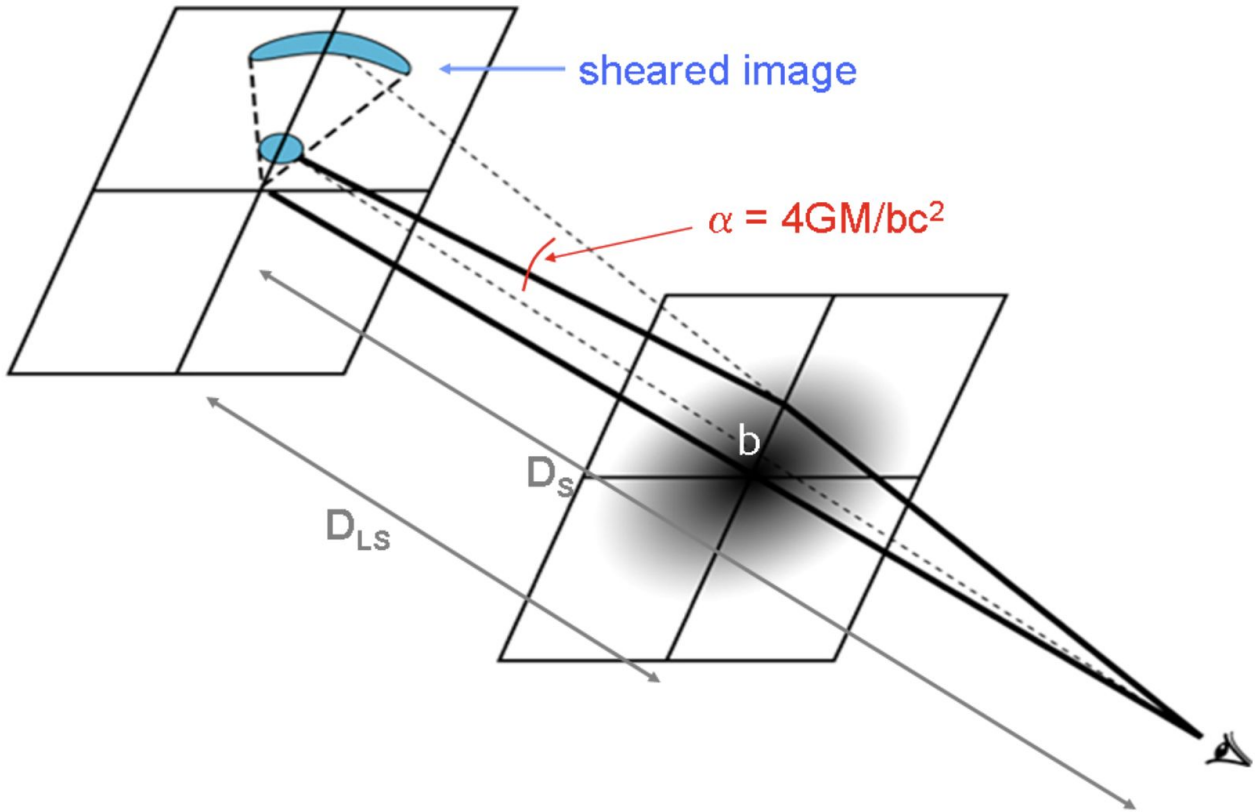
Vernon Wetzell
vwetzell@sas.upenn.edu

Shear Determination

Tackling Bias for the Billion-Galaxy Era

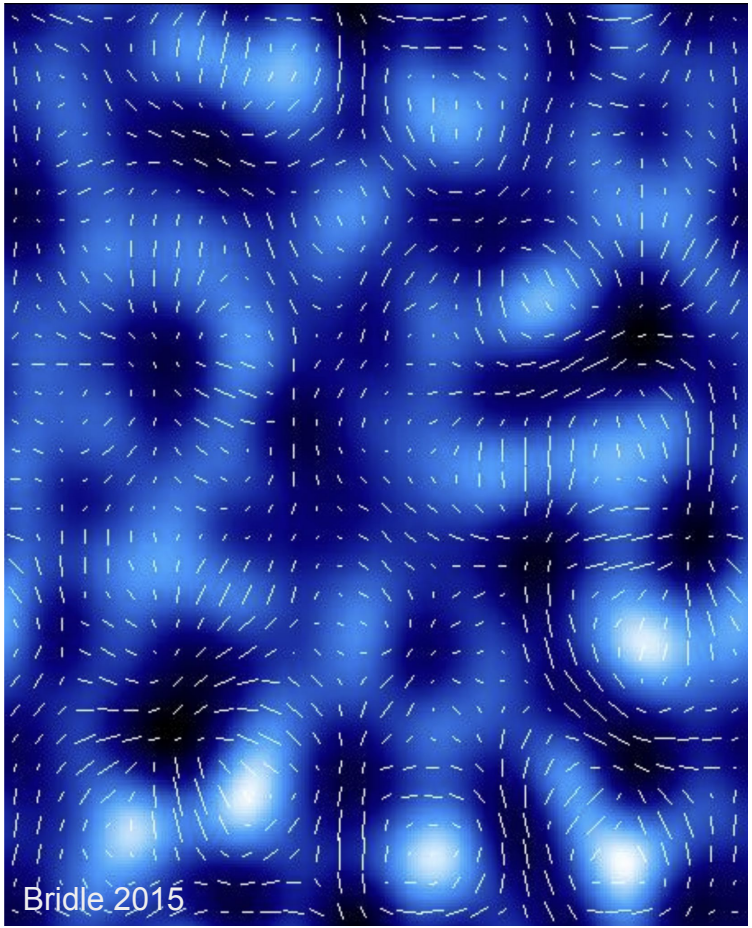
Background generated with Gemini

Weak Lensing



LSST Science Collaboration et al. 2009

Shear Field



2-point Correlation Function

Mass Maps, 3-point Functions, etc.

Cosmological Parameters

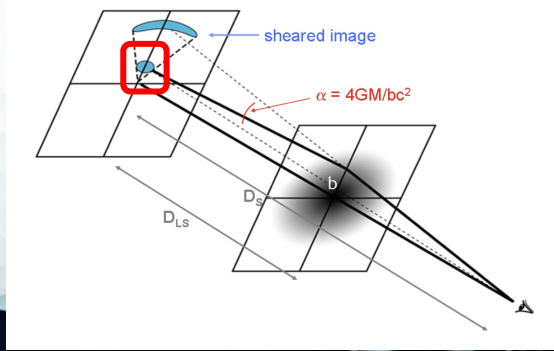
Ω_m: Matter Density

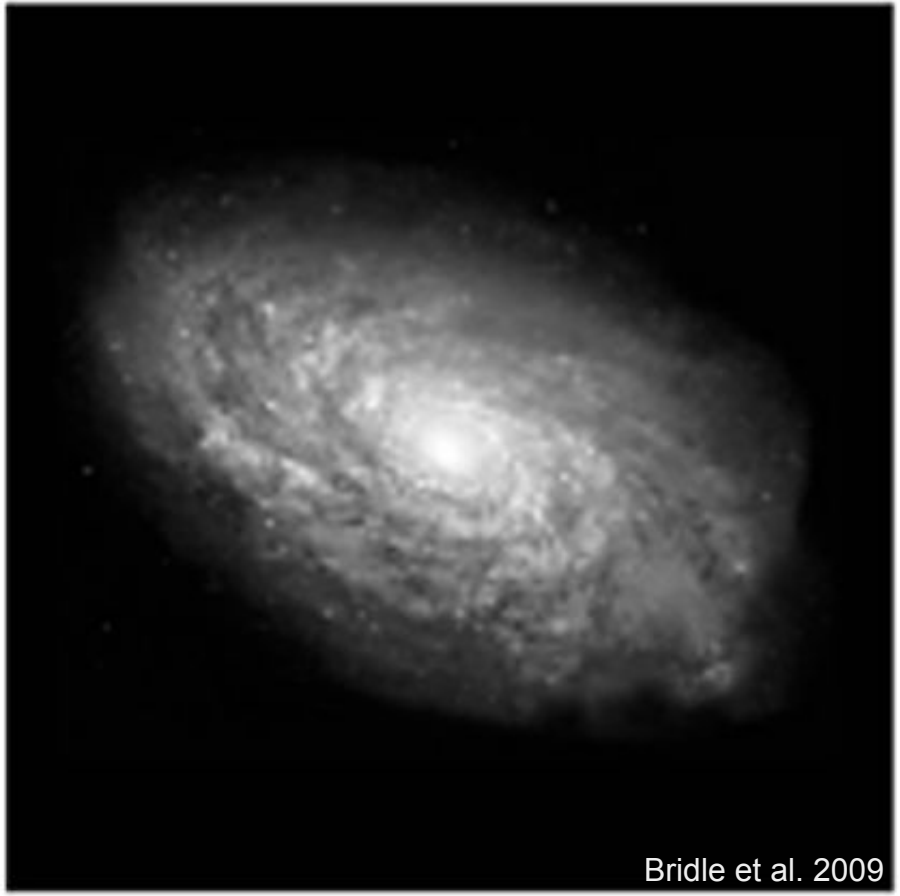
σ_8: Matter Fluctuations

$S_8 = \sigma_8(\Omega_m/0.3)^{0.5}$

Shear Measurement Challenges

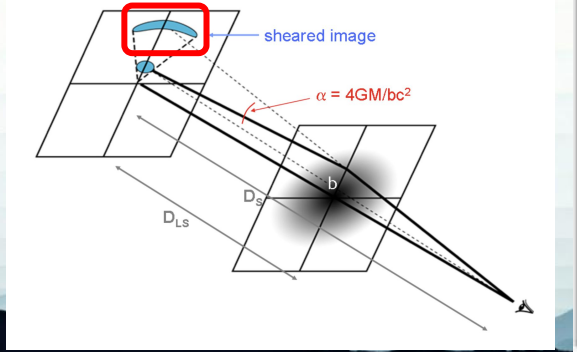
- Unknown source

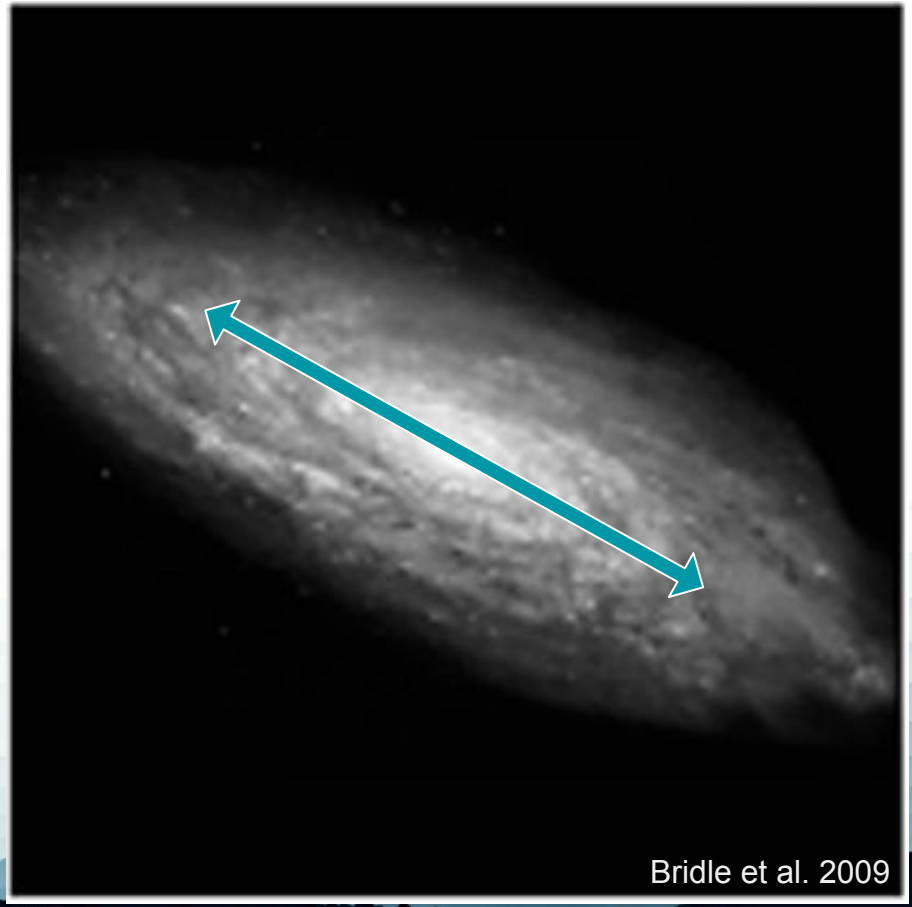




Shear Measurement Challenges

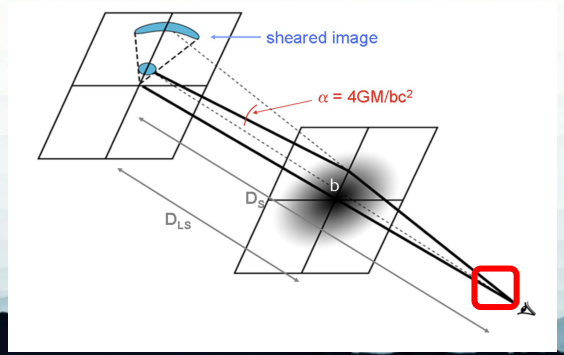
- Unknown source
- Unknown shear





Shear Measurement Challenges

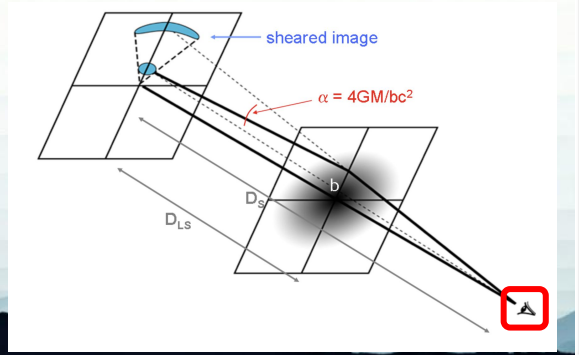
- Unknown source
- Unknown shear
- Complicated PSF

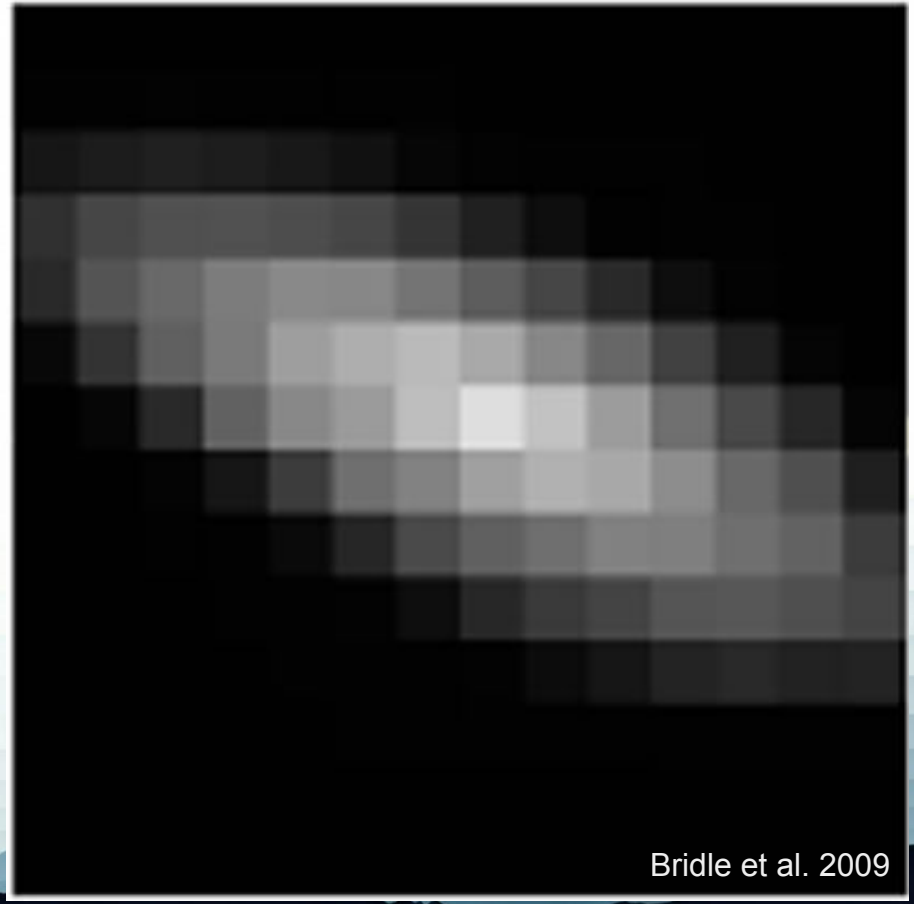



Bridle et al. 2009

Shear Measurement Challenges

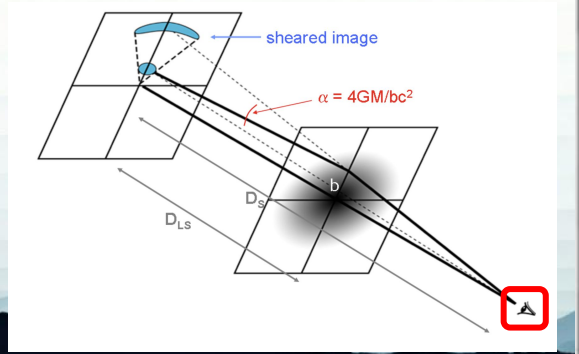
- Unknown source
- Unknown shear
- Complicated PSF
- Pixelated Image

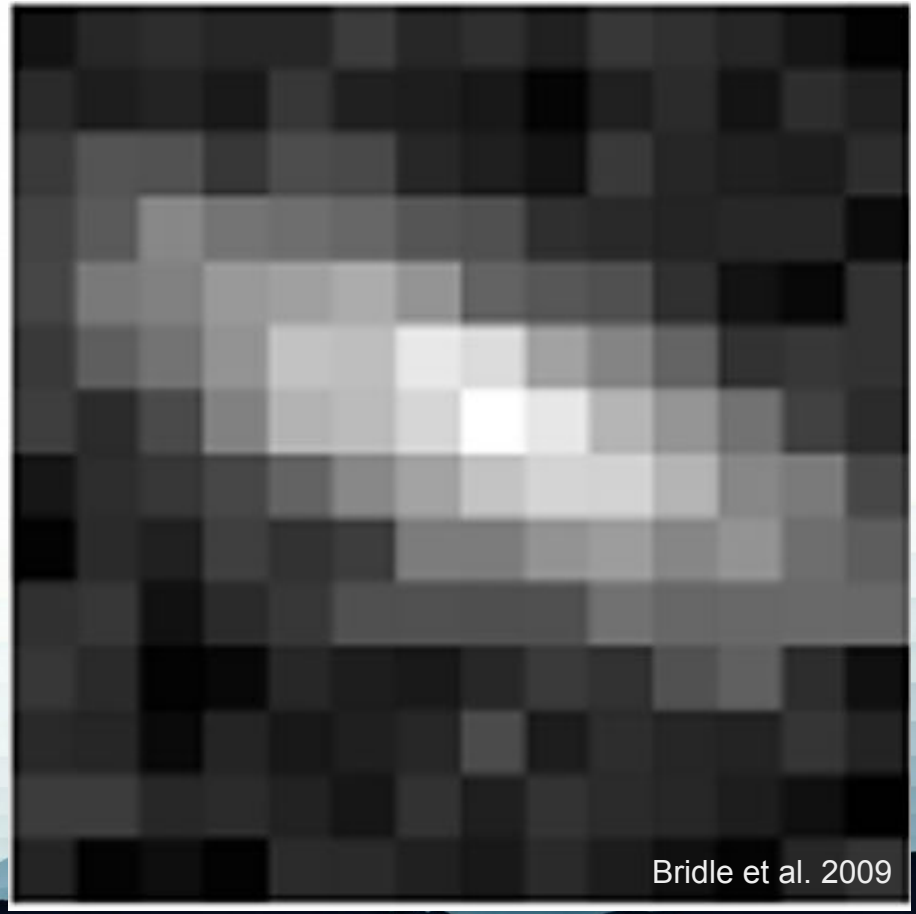




Shear Measurement Challenges

- Unknown source
- Unknown shear
- Complicated PSF
- Pixelated Image
- Noise





Shear

$$g_{Observed} = c + (1 + m) g_{True}$$

Additive bias

- Diagnosed with data
- Internally calibrated

Multiplicative bias

- Degenerate with cosmology
- Calibrated with image simulations

Shear

$$g_{Observed} = c + (1 + m) g_{True}$$

Additive bias limit

$$|c| < 10^{-4}$$

Multiplicative bias limit

$$|m| < 0.003$$

Calibrating Bias

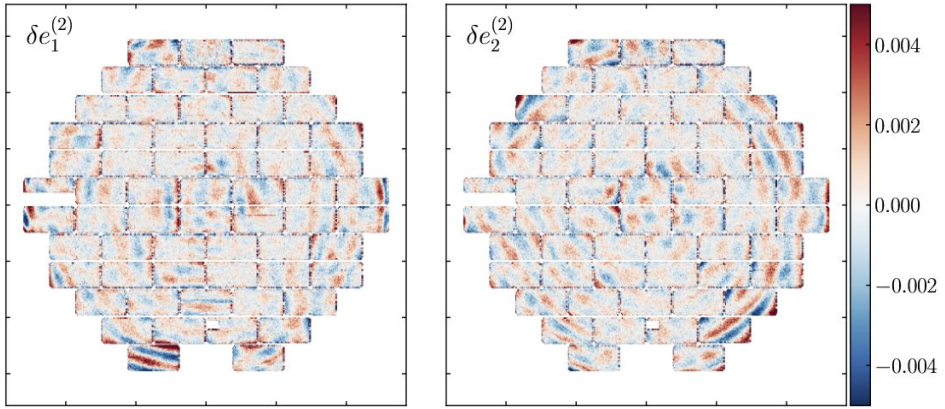
Algorithm specific

- Detection and selection

Algorithm independent

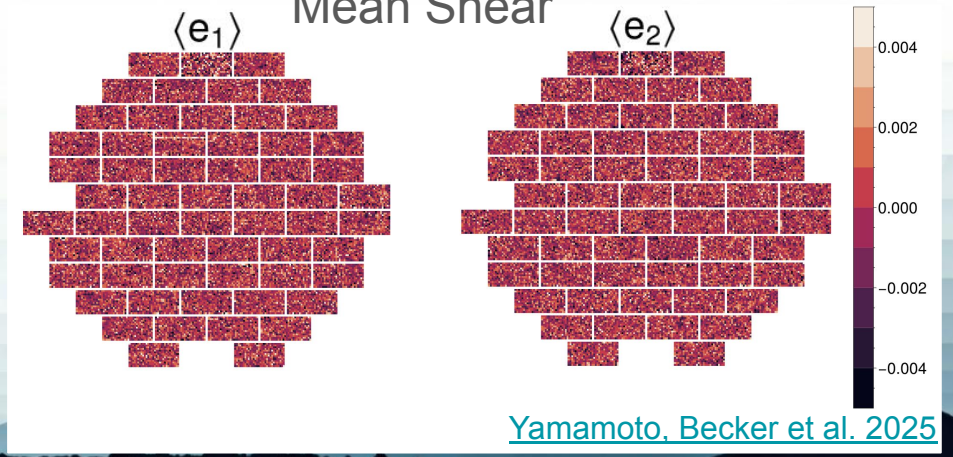
- Astrometry, photometry, and PSF modeling

PSF Errors



Schutt et al. 2025

Mean Shear



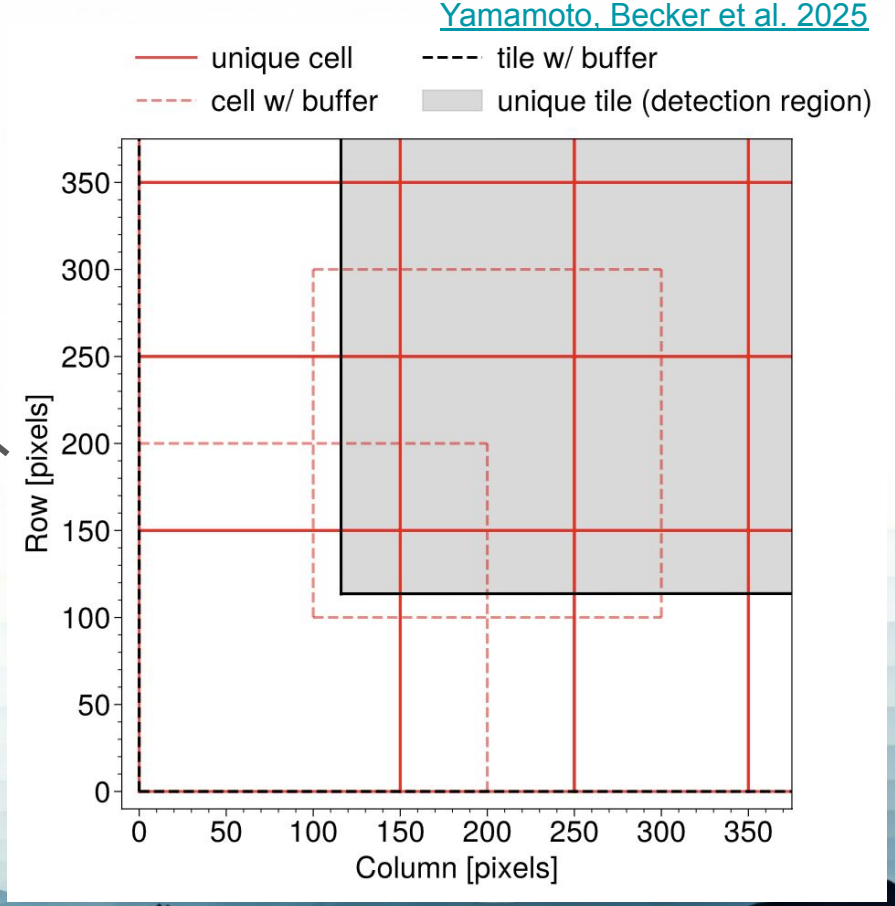
Yamamoto, Becker et al. 2025

Background generated with Gemini

Calibrating Bias

TBD for LSST DESC

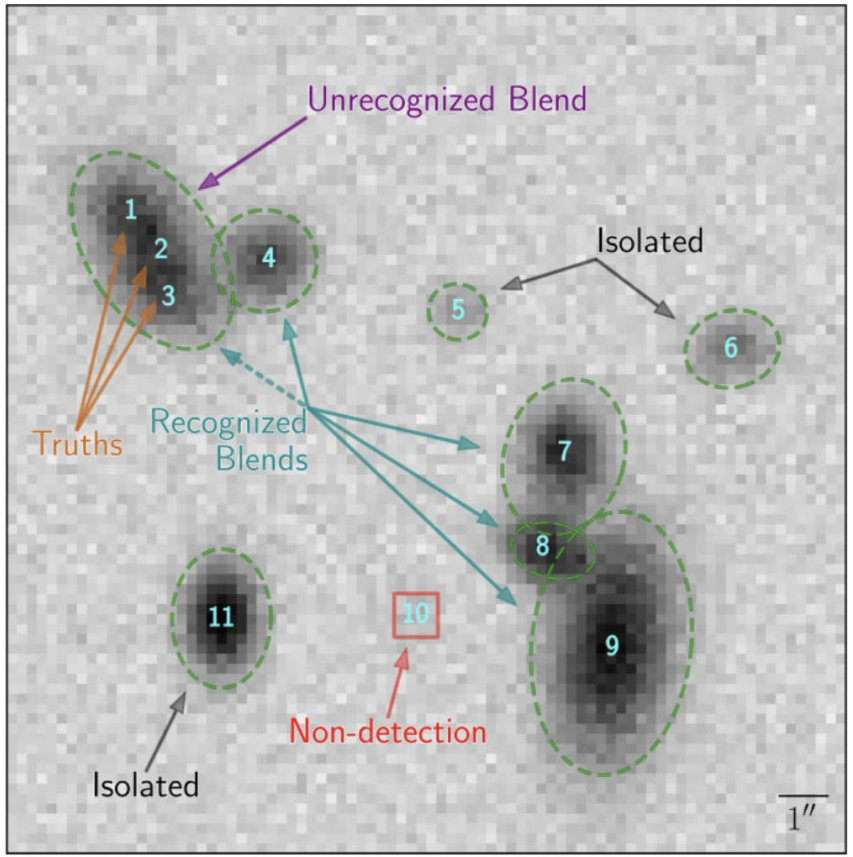
- Exposure coaddition
- Exposure masking
- Image simulations
- Deblending



Blends

- Galaxies in projection
- Current algorithms assume isolated galaxies

Nourbakhsh et al. 2022



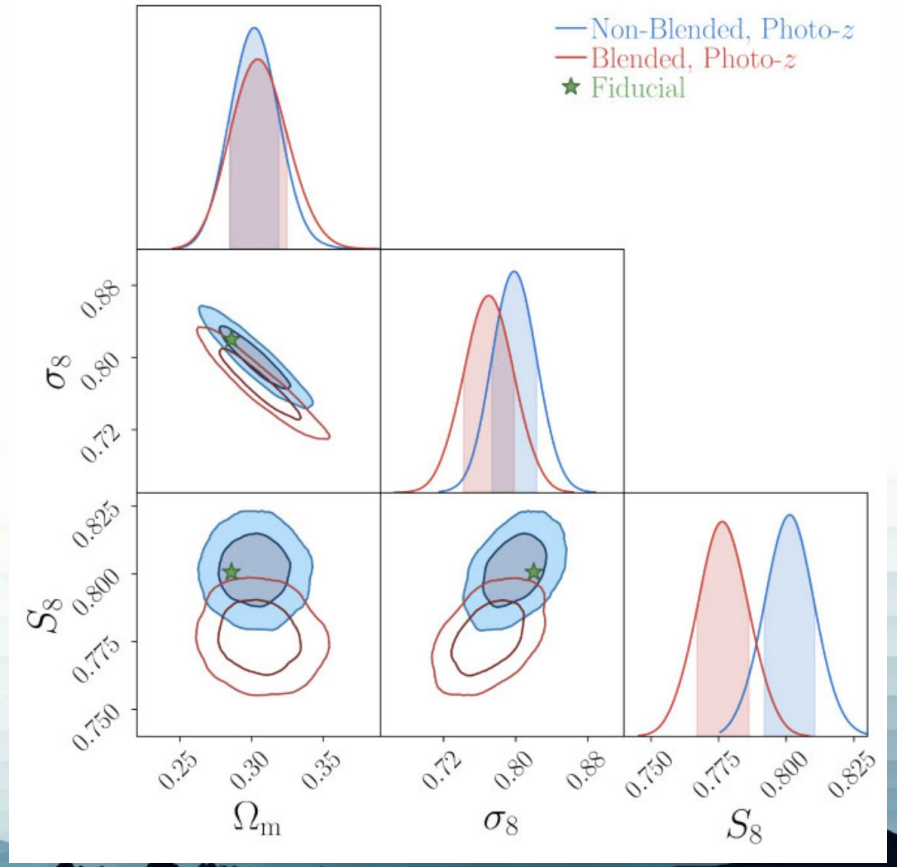
Background generated with Gemini

Blends

- Galaxies in projection
- Current algorithms assume isolated galaxies

Blends cause
$|m| \gtrsim 0.01$

Nourbakhsh et al. 2022



What are the current algorithms?

Bayesian Fourier Domain (BFD)

An accurate and practical method for inference of weak gravitational lensing from galaxy images

Gary M. Bernstein,[1★] Robert Armstrong,[2] Christina Krawiec[1] and Marisa C. March[1]
[1]*Department of Physics and Astronomy, University of Pennsylvania, 209 S. 33rd St, Philadelphia, PA 19104, USA*
[2]*Department of Astrophysical Sciences, Princeton University, Princeton, NJ 08544, USA*

AnaCal

Analytical Weak Lensing Shear Inference for Precision Cosmology

Xiangchong Li[1★], Rachel Mandelbaum[1], The LSST Dark Energy Science Collaboration
[1] *Department of Physics, McWilliams Center for Cosmology, Carnegie Mellon University, Pittsburgh, PA 15213, USA*

Metadetection

Mitigating Shear-dependent Object Detection Biases with Metacalibration

Erin S. Sheldon[1], Matthew R. Becker[2], Niall MacCrann[3,4], and Michael Jarvis[5]
[1] Brookhaven National Laboratory, Bldg 510, Upton, New York 11973, USA
[2] High Energy Physics Division, Argonne National Laboratory, Lemont, IL 60439, USA
[3] Center for Cosmology and Astro-Particle Physics, The Ohio State University, Columbus, OH 43210, USA
[4] Department of Physics, The Ohio State University, Columbus, OH 43210, USA
[5] Department of Physics and Astronomy, University of Pennsylvania, Philadelphia, PA 19104, USA

Shear Measurements

Shear

Shear Dependent Galaxy Shape

$$\mathbf{g} = \mathcal{R}^{-1} \boldsymbol{e}$$

Response

$$\mathcal{R}_{ij} = \left. \frac{\partial e_i}{\partial g_j} \right|_{\mathbf{g}=0}$$

Bayesian Fourier Domain (BFD)

- Fourier Moments: $\boldsymbol{M}$
- Calibrated with deep field galaxies
- Per galaxy response

Deep field galaxies

$$P(\mathbf{g}|\boldsymbol{M}) \propto P\left(\boldsymbol{M}|\boldsymbol{M}(\boldsymbol{g},\boldsymbol{G})\right) P(\boldsymbol{G}) P(\boldsymbol{g})$$

$$P(\mathbf{g}|\boldsymbol{M}) = P + \boldsymbol{Q}\cdot\boldsymbol{g} + \frac{1}{2}\boldsymbol{g}\cdot\boldsymbol{R}\cdot\boldsymbol{g}$$

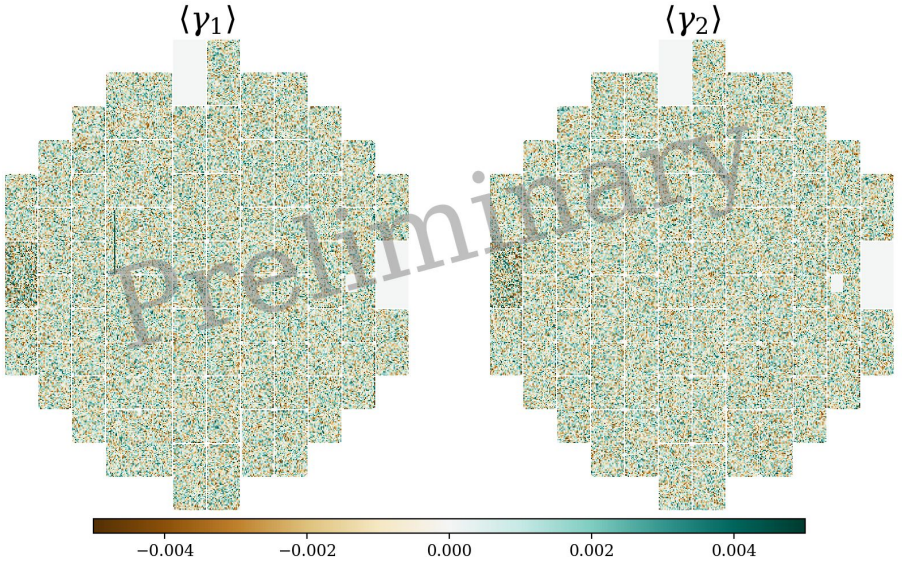
$$\boldsymbol{g} = \hat{\boldsymbol{R}}^{-1}\hat{\boldsymbol{Q}}$$

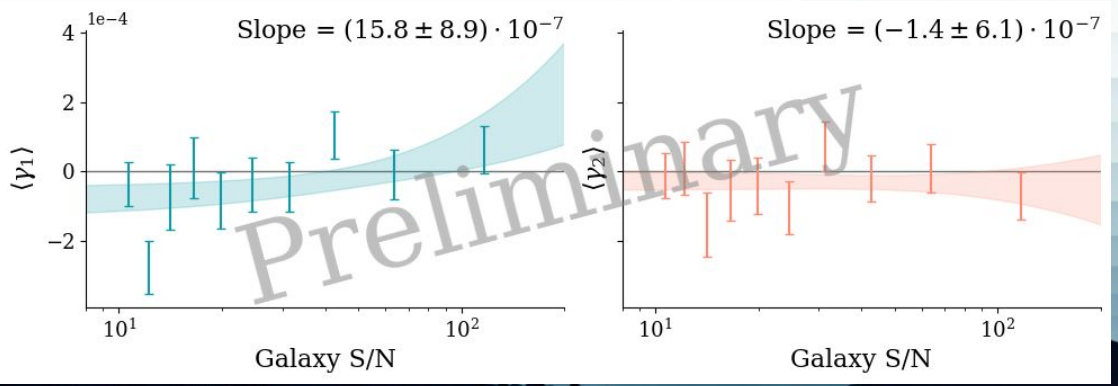
Background generated with Gemini

DES Y6 BFD Catalog

Gatti, Wetzell et al.

- Shear catalog exists
- Null tests in progress
- Image simulations now





Background generated with Gemini

AnaCal

- Fourier shapelets: $\boldsymbol{v}$
- Analytic calibration from images
- Uses average response

Analytic

$$\tilde{\mathcal{R}}_{ij} = \frac{\partial e_i}{\partial g_j} = \sum_k \frac{\partial e_i}{\partial v_k} \frac{\partial v_k}{\partial g_j}$$

$$\langle \mathcal{R} \rangle = \langle \tilde{\mathcal{R}} \rangle - \left\langle \text{Noise Correction} \right\rangle$$

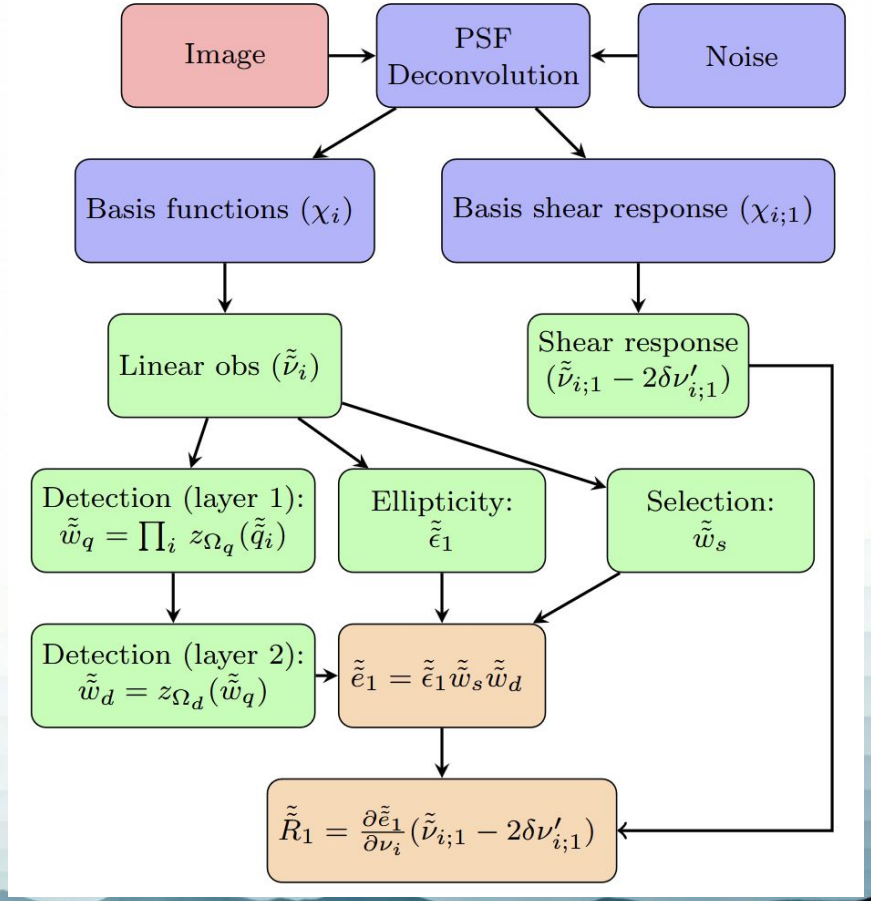
$$\langle \mathbf{g} \rangle \approx \langle \mathcal{R} \rangle^{-1} \langle \boldsymbol{e} \rangle$$

Background generated with Gemini

AnaCal

- Fourier shapelets: $\boldsymbol{v}$
- Analytic calibration from images
- Uses average response

Li & Mandelbaum et al. 2024



Metadetection

- Real space Gaussian fit
- Numerical calibration from artificially sheared images
- Uses average response

Sheared catalogs

$$\langle \mathcal{R}_{ij} \rangle = \frac{\langle e_i^+ \rangle - \langle e_i^- \rangle}{\Delta g_j}$$

Added shear

$$\langle \mathbf{g} \rangle \approx \langle \mathcal{R} \rangle^{-1} \langle \boldsymbol{e} \rangle$$

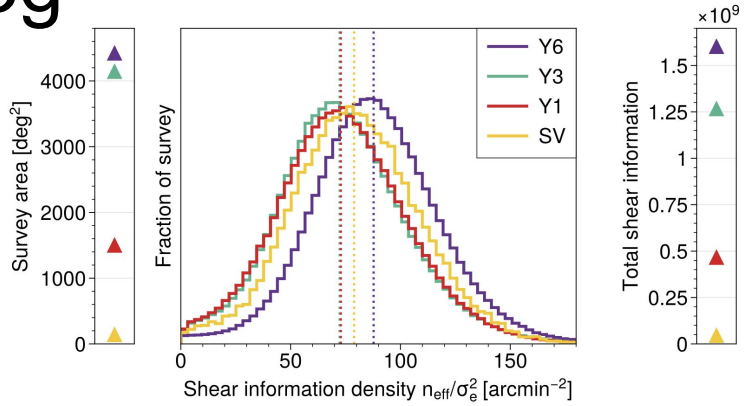
Background generated with Gemini

DES Y6 Metadetection Catalog

arXiv:2501.05665

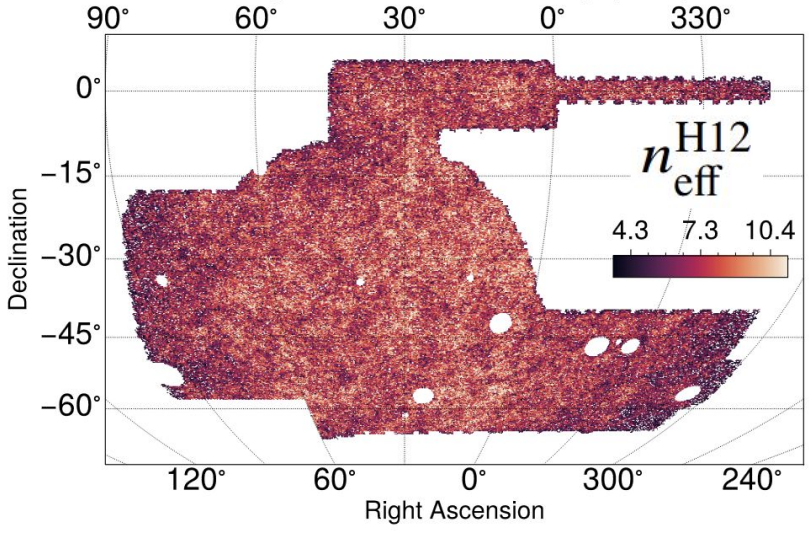
Dark Energy Survey Year 6 Results: Cell-based Coadds and Metadetection Weak Lensing Shape Catalog

M. Yamamoto,[1,2]* M. R. Becker,[3] E. S. Sheldon,[4] M. Jarvis,[5] R. A. Gruendl,[6,7] F. Menanteau,[6,7] E. S. Rykoff,[8,9] S. Mau,[8,9,10] T. Schutt,[8,9,10] M. Gatti,[11,12] M. A. Troxel,[1] A. Amon,[2] D. Anbajagane,[11,12] G. M. Bernstein,[5] D. Gruen,[13,14] E. Huff,[15] M. Tabbutt,[16] A. Tong,[1,5] B. Yanny,[17] & Y6KP+Builders (Dark Energy Survey Collaboration)



Configuration	m_1 [10^{-3}]	c_2 [10^{-4}]
fiducial	$+3.4 \pm 6.1$	$+1.0 \pm 2.6$

Year	$n_{\rm eff}^{\rm C13}$, $n_{\rm eff}^{\rm H12}$	$\sigma_{\rm e}^{\rm C13}$, $\sigma_{\rm e}^{\rm H12}$
Y6	7.97, 8.22	0.270, 0.289
Y3	5.32, 5.59	0.255, 0.261

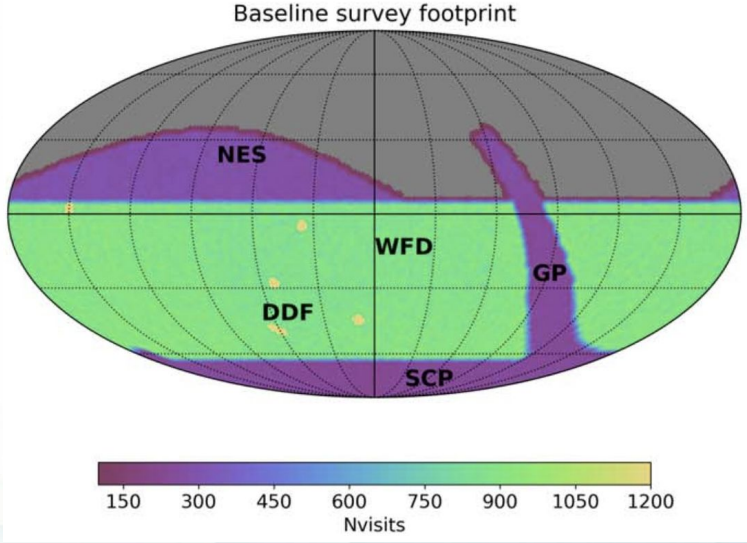


Background generated with Gemini

Preparing for LSST DESC and 2 Billion Galaxies

DES Y6 Metadetection	LSST DESC Y10
4422 deg^2	~18,000 deg^2
~50 visits	~825 visits
151,922,791 galaxies	~2 billion galaxies
8.22 galaxies / arcmin^2	27.74 galaxies / arcmin^2

Bianco et al. 2022



Summary

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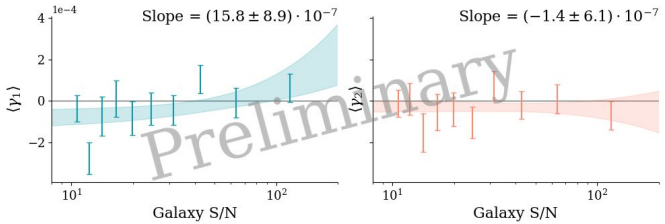
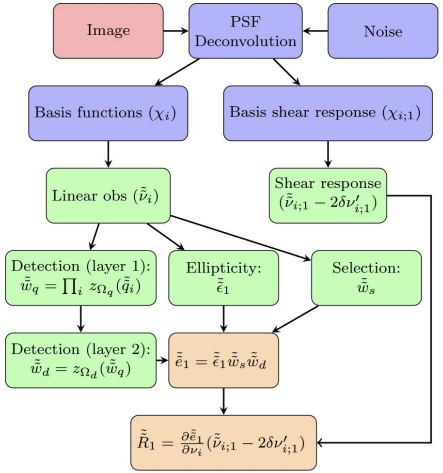
BFD

DES Y6 Catalog in prep.



AnaCal

HSC Catalog in prep.



Metadetection

DES Y6 Catalog Complete
Cosmology on the way