Quasi-2D Shear Correlation

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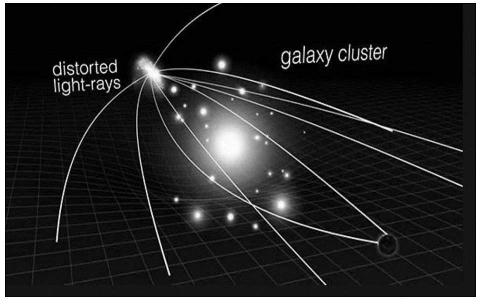
PART ONE

Methodology

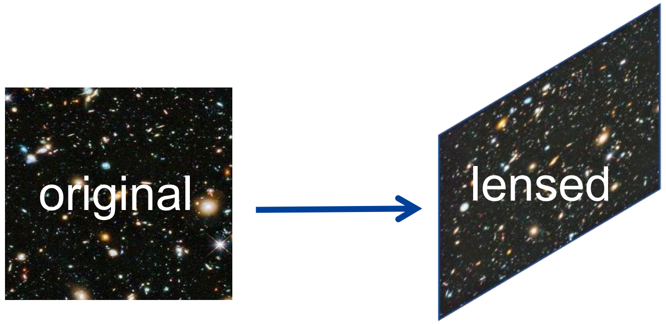
Introduction

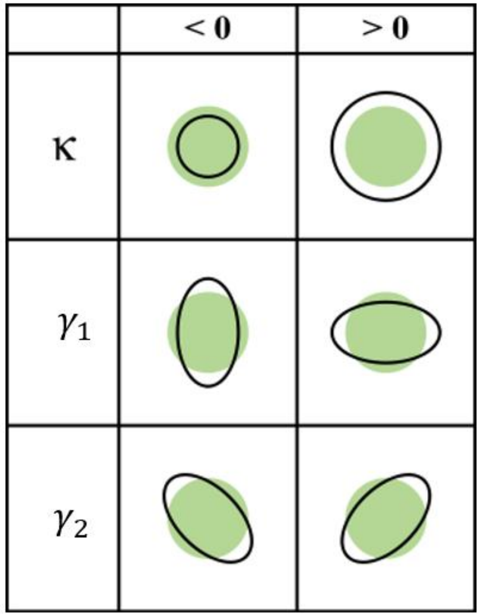
- **Shear** refers to the distortion of the background source image caused by the bending of the light path as it passes through a mass distribution.
- Weak lensing is sensitive to the matter fluctuations (σ_8) and the matter density (Ω_m).

$$\vec{x}_S = \begin{pmatrix} x_S \\ y_S \end{pmatrix} = \begin{pmatrix} 1-\kappa-\gamma_1 & -\gamma_2 \\ -\gamma_2 & 1-\kappa+\gamma_1 \end{pmatrix} \begin{pmatrix} x_I \\ y_I \end{pmatrix} = \overleftrightarrow{A} \cdot \vec{x}_I$$

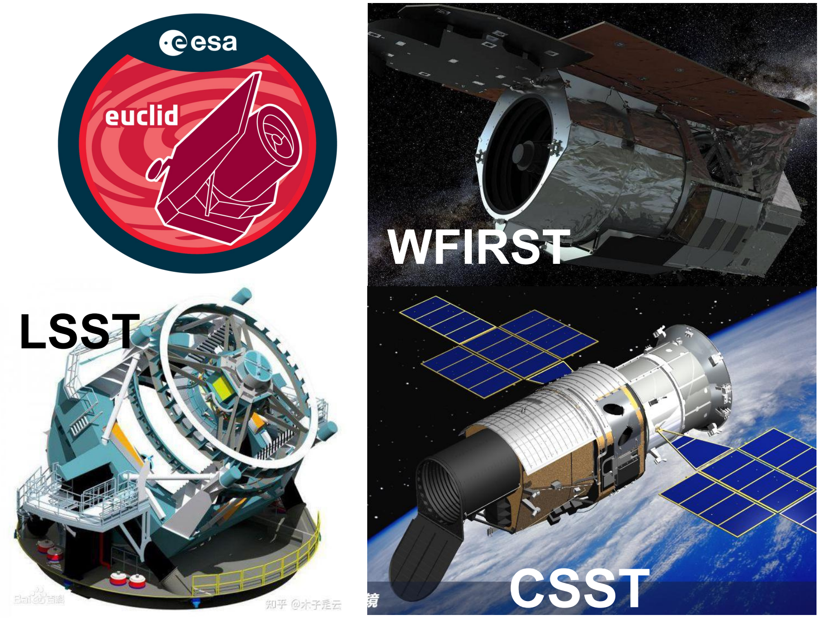


Reduced shear: $g_i=\gamma_i/(1-\kappa)$





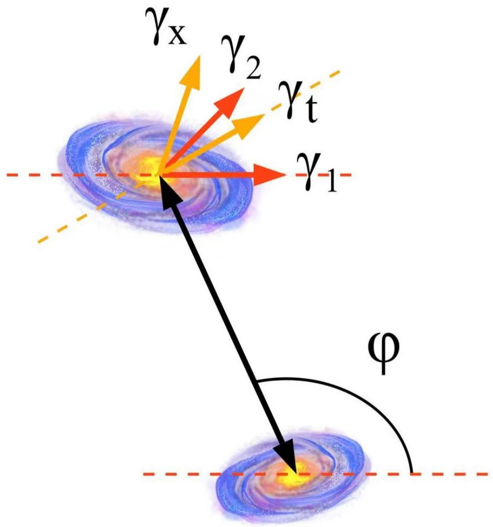
Nowadays: DES, HSC, KiDs, ...
Future:



Shear-shear correlation

- Shear-shear correlation is to measure the correlation between shear signals at two given positions separated by a certain distance.

$$\xi_\pm = \xi_{\gamma_t\gamma_t} \pm \xi_{\gamma_\times\gamma_\times}$$



Model

$$\xi_\pm^{ij}(\theta) = \int_0^\infty \frac{d\ell}{2\pi}\, \ell\, C^{ij}(\ell)\, J_\nu(\ell\theta),$$

$$C^{ij}(\ell) = \int_0^\infty dz\, \frac{W^i(z)W^j(z)}{\chi(z)^2} P_\delta\left(\frac{\ell}{\chi(z)}, z\right)$$

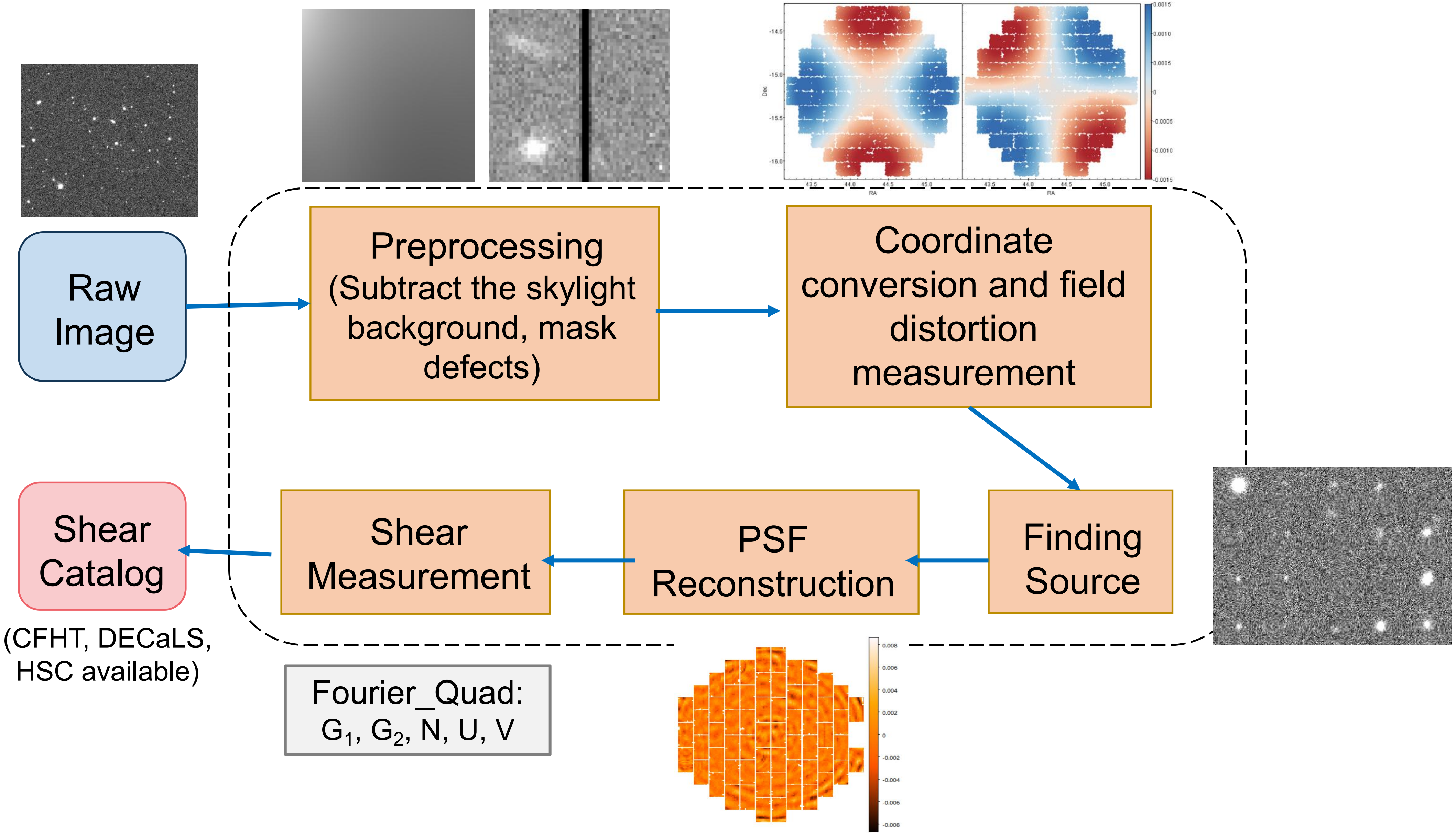
$$W^i(z) = W^i_{\rm G}(z) + W^i_{\rm I}(z)$$

$$W^i_{\rm G}(z) = \frac{3}{2}\Omega_m \frac{H_0^2}{c^2}\frac{\chi(z)}{a(z)} \int_z^\infty dz' n^i(z') \frac{\chi(z') - \chi(z)}{\chi(z')}$$

$$W^i_{\rm I}(z) = -\frac{A_{\rm IA} C_1 \rho_c \Omega_{\rm m}}{D(z)} n^i(z)$$

- Possible systematics: intrinsic alignment, baryon effect, errors of photometric redshift ...
  - Baryonic Correction Model (BCM; Schneider & Teyssier (2015))
    - $M_c = 1.2 \times 10^{14} M_\odot /h$ and $\eta_b = 0.5$
  - Nonlinear Alignment Model (NLA; Bridle & King (2007)) (free A_{IA}) $\xi_\pm = \xi_{GG\pm} + \xi_{II\pm} + \xi_{GI\pm}$

Pipeline



Raw Image
Preprocessing (Subtract the skylight background, mask defects)
Coordinate conversion and field distortion measurement
Finding Source
PSF Reconstruction
Shear Measurement
Shear Catalog
(CFHT, DECaLS, HSC available)
Fourier_Quad: G_1, G_2, N, U, V

Fourier_Quad Method

Shear Estimators

$$G_1 = -\frac{1}{2}\int d^2\vec{k}\,(k_x^2 - k_y^2)\,T(\vec{k})M(\vec{k})$$

$$G_2 = -\int d^2\vec{k} k_x k_y T(\vec{k})M(\vec{k})$$

$$N = \int d^2\vec{k}\left[k^2 - \frac{\beta^2}{2}k^4\right]T(\vec{k})M(\vec{k})$$

$$M(\vec{k}) = \left|\widetilde{f}^S(\vec{k})\right|^2 - F^S - \left|\widetilde{f}^B(\vec{k})\right|^2 + F^B$$

$$T(\vec{k}) = \left|\widetilde{W}_\beta(\vec{k})\right|^2 / \left|\widetilde{W}_{PSF}(\vec{k})\right|^2$$

The ensemble averages of the shear estimators give

$$\frac{\langle G_1\rangle}{\langle N\rangle} = g_1 + O(g_{1,2}^3),$$

$$\frac{\langle G_2\rangle}{\langle N\rangle} = g_2 + O(g_{1,2}^3)$$

Unbiased, recovering the shear values to the second order in accuracy.

ApJ, 834, 8 (2017)

Fourier_Quad Method

Shear Estimators

$$G_1 = -\frac{1}{2}\int d^2\vec{k}\left(k_x^2 - k_y^2\right)T(\vec{k})M(\vec{k})$$

$$G_2 = -\int d^2\vec{k}k_xk_yT(\vec{k})M(\vec{k})$$

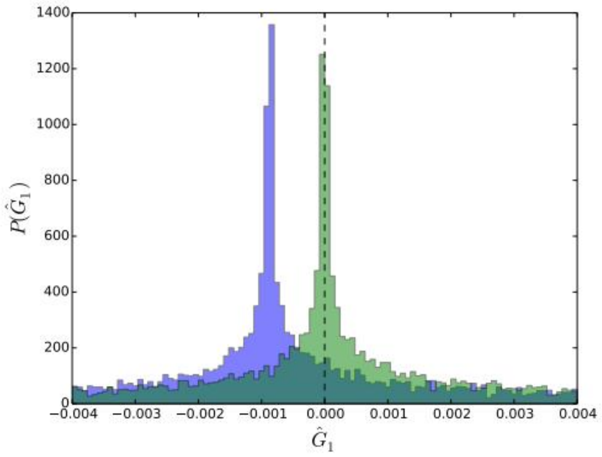
$$N = \int d^2\vec{k}\left[k^2 - \frac{\beta^2}{2}k^4\right]T(\vec{k})M(\vec{k})$$

$$U = -\frac{1}{2}\beta^2\int d^2\vec{k}\left(k_x^4 - 6k_x^2k_y^2 + k_y^4\right)T(\vec{k})M(\vec{k})$$

$$V = -2\beta^2\int d^2\vec{k}\left(k_x^3k_y - k_xk_y^3\right)T(\vec{k})M(\vec{k})$$

$$M(\vec{k}) = \left|\tilde{f}^S(\vec{k})\right|^2 - F^S - \left|\tilde{f}^B(\vec{k})\right|^2 + F^B$$

$$T(\vec{k}) = \left|\widetilde{W}_\beta(\vec{k})\right|^2 / \left|\widetilde{W}_{PSF}(\vec{k})\right|^2$$



The relation between the shear estimates of lensed galaxy image and those of unlensed galaxy is

$$G_i = G_i^S + g_iB_i$$

$$B_i = \begin{cases} N + U & i = 1 \\ N - U & i = 2 \end{cases}$$

ApJ, 834, 8 (2017)

PDF-SYM Method for shear

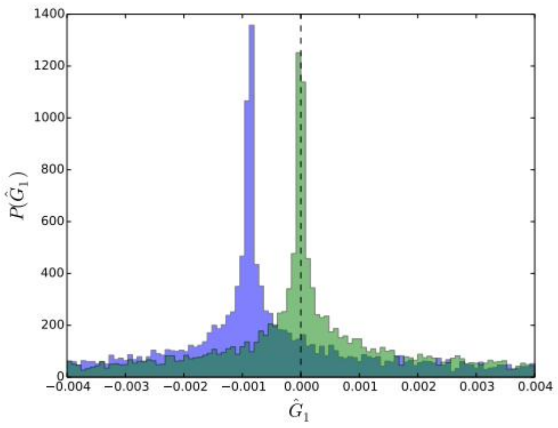
(Probability Distribution Function Symmetrization)

Averaging	PDF-SYM
Unbiased. Affected by outlier.	Unbiased, optimal. Accuracy approach the Cramér-Rao bound.

The PDF-SYM method is similar to **finding the median**.

- Use $\hat{g}_i$ to modify the shear estimators

$$\hat{G}_i = G_i - \hat{g}_i B_i = G_i^S + (g_i - \hat{g}_i) B_i.$$

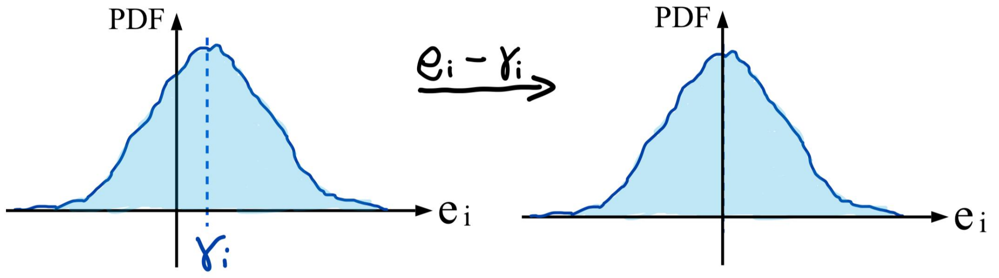


For recovering shear, $\hat{g}_i = g_i$ can best symmetrize $P(\hat{G}_i)$.

$$\chi^2 = \frac{1}{2} \sum_{i>0} \frac{(n_i - n_{-i})^2}{n_i + n_{-i}}$$

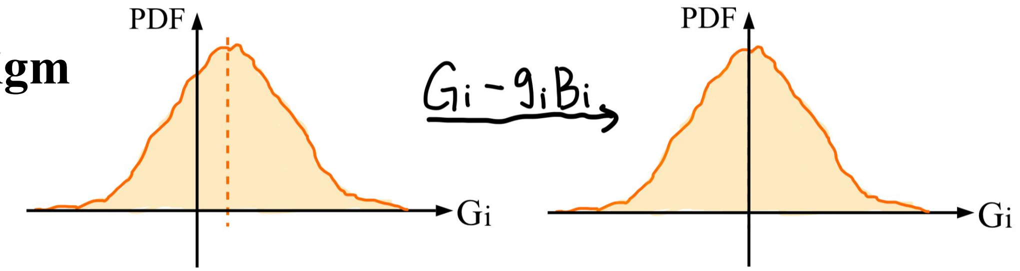
- **Ellipticity**

$$e_i = e_i^S + \gamma_i$$



- **Fourier_Quad paradigm**

$$G_i = G_i^S + g_i B_i$$



PDF-SYM Method for shear-shear correlation

(Probability Distribution Function Symmetrization)

- Use $\hat{g}_i$ to modify the shear estimators

$$\hat{G}_i = G_i - \hat{g}_i B_i = G_i^{\mathrm{S}} + (g_i - \hat{g}_i) B_i.$$

- The modified PDF:

$$P(\hat{G}_i, \hat{G}'_i) + P(-\hat{G}_i, -\hat{G}'_i) - P(-\hat{G}_i, \hat{G}'_i) - P(\hat{G}_i, -\hat{G}'_i)$$
$$\approx \int dB \int dB' (\langle g_i g'_i \rangle + \hat{\xi}) B B' \partial_{\hat{G}_i} \partial_{\hat{G}'_i} P_{\mathrm{S}}. \quad (12)$$

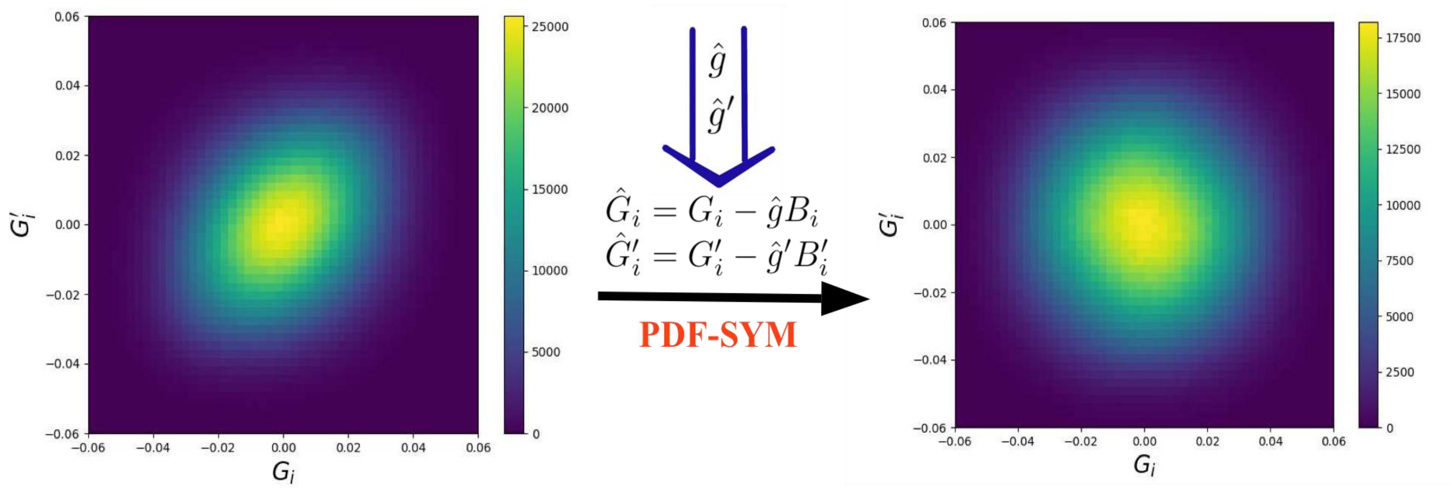
$$\langle \hat{g}\hat{g}' \rangle = \hat{\xi}$$

If $\hat{\xi} > 0$,
$\hat{g} = \hat{g}' = |\hat{\xi}|^{\frac{1}{2}}$ or $-|\hat{\xi}|^{\frac{1}{2}}$

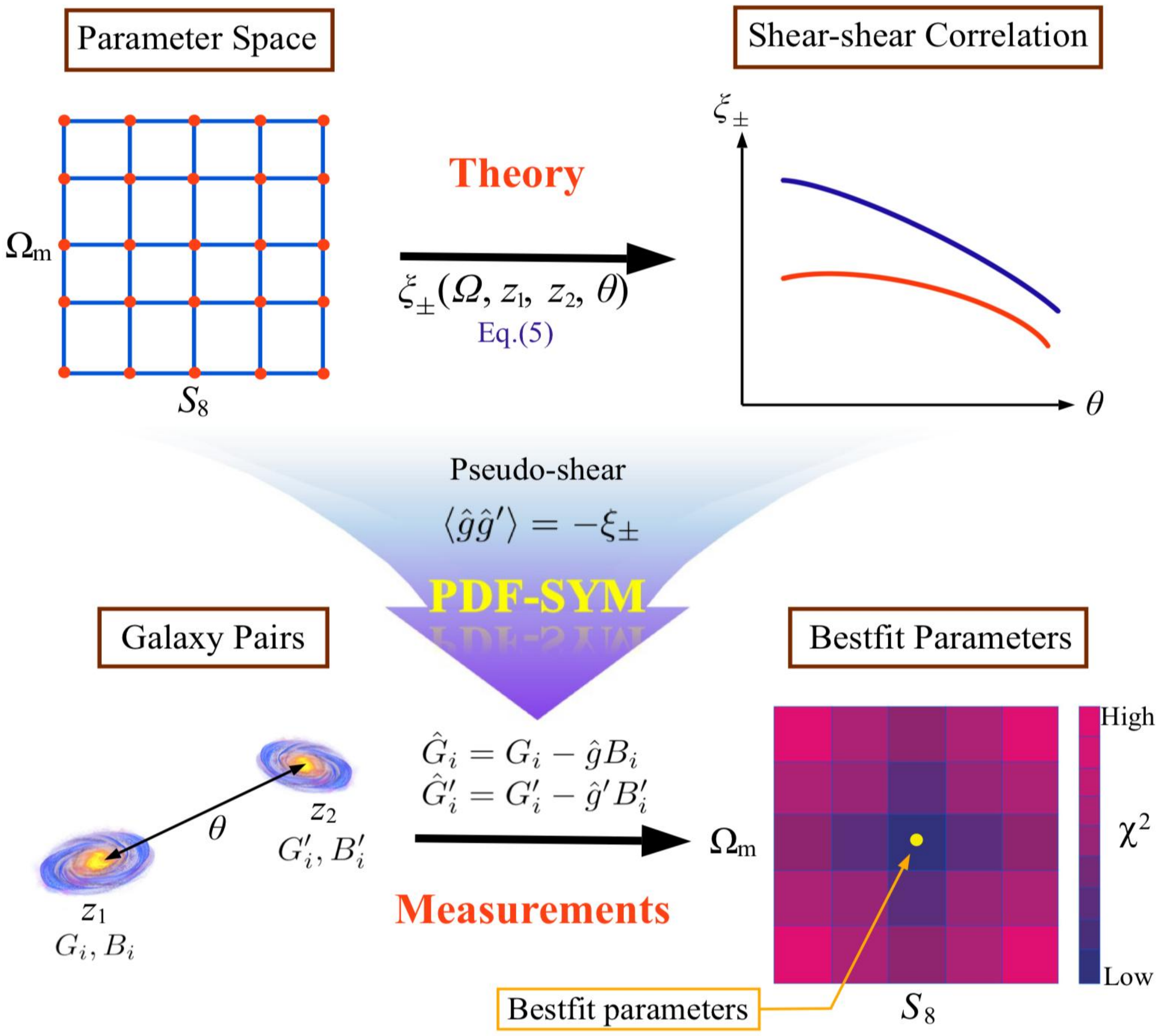
If $\hat{\xi} < 0$,
$\hat{g} = -\hat{g}' = |\hat{\xi}|^{\frac{1}{2}}$ or $-|\hat{\xi}|^{\frac{1}{2}}$

For recovering shear-shear correlation, $\hat{\xi} = -\langle g_i g'_i \rangle$ can best symmetrize $P(\hat{G}_i, \hat{G}'_i)$.

$$\chi^2 = \frac{1}{2} \sum_{i,j>0} \frac{(n_{i,j} + n_{-i,-j} - n_{-i,j} - n_{i,-j})^2}{n_{i,j} + n_{-i,-j} + n_{-i,j} + n_{i,-j}}$$



Quasi-2D Analysis



Steps:

1. Calculate the theorectical auto-correlation funcions of γ_t, $\gamma_\times$ with different parameters.
2. Find two galaxies and use the theory to modify the shear estimators.
3. Calculate the χ^2 and find the minimun in parameter space.

Quasi-2D:

1. The redshift of each galxy is **used**.
2. There is just **one** bin on redshift.

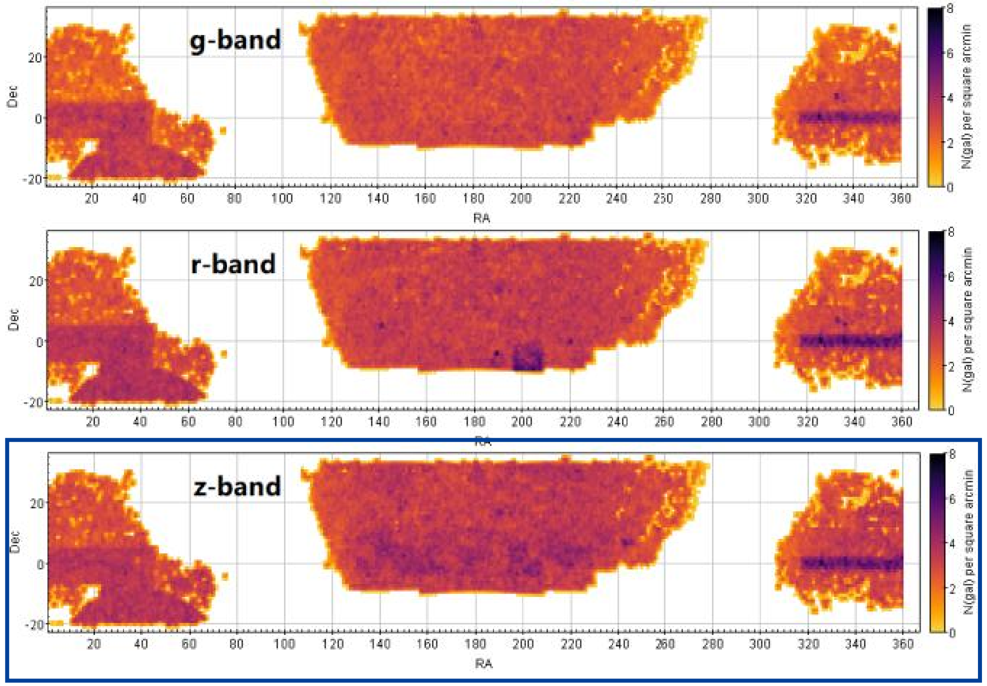
- **Jackknife approach** to estimate the covariance matrix of parameters (N_{JK}=200)

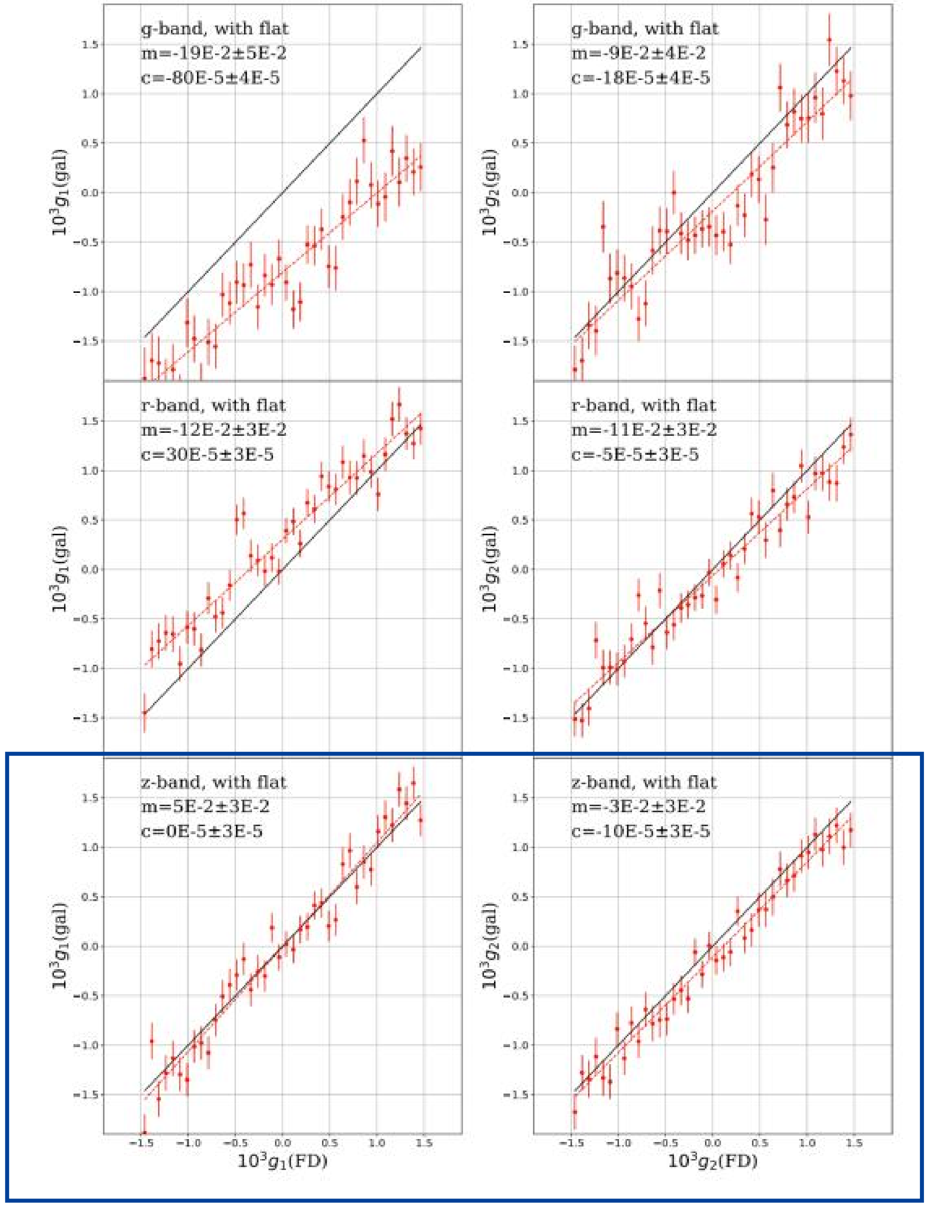
PART TWO

Data and Results

DECam Legacy Survey (DECaLS)

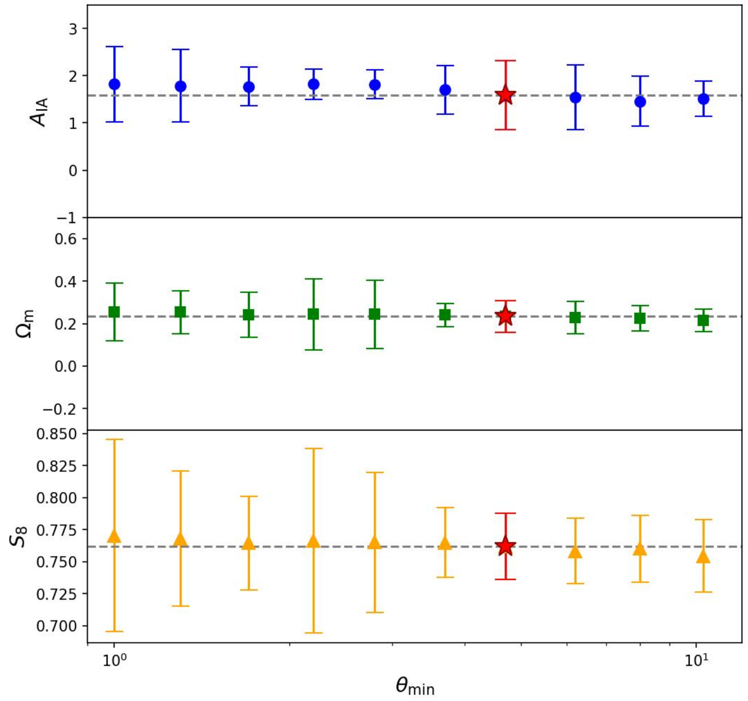
- DECaLS is one of the three public projects in Dark Energy Spectroscopic Instrument (DESI) Legacy Imaging Surveys (Dey et al. 2019)
- Area: about 10000 deg^2
- Band: g, r, z band, containing 15420/15162/16501 exposures.
- Only z-band data used in this work.





Results

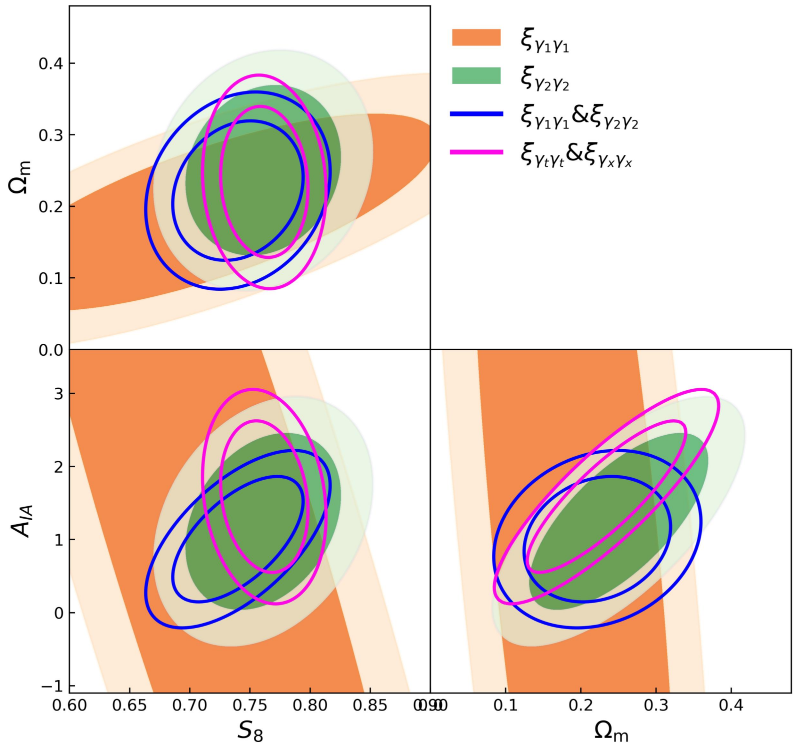
Baseline results: γ_t, $\gamma_\times$



Angular range: 4.7-180 arcmin

$$S_8 = 0.762 \pm 0.026$$
$$\Omega_m = 0.234 \pm 0.075$$
$$A_{IA} = 1.59 \pm 0.73.$$

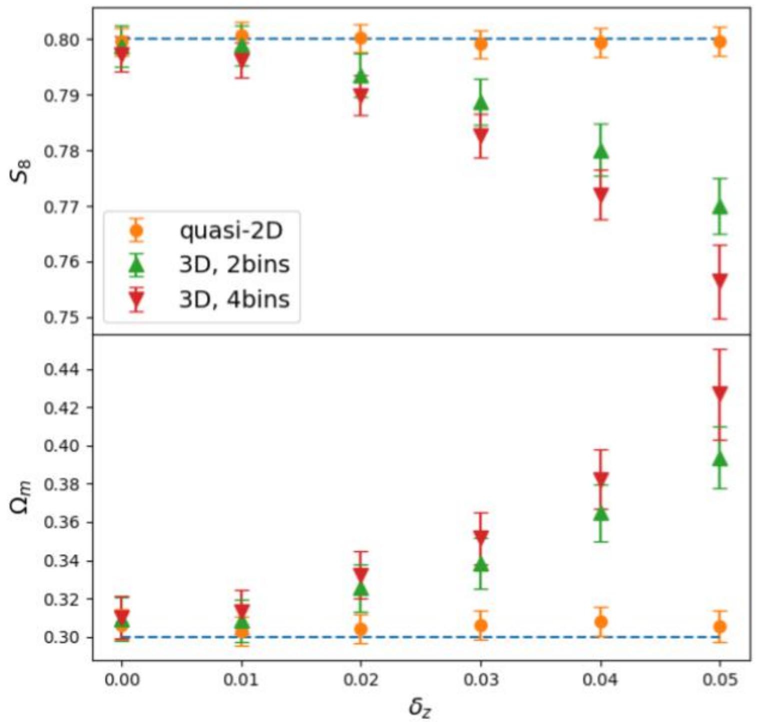
Consistency of γ_1, γ_2



$$\xi_{\gamma_1\gamma_1} = \xi_{\gamma_2\gamma_2} = \frac{\xi_+}{2}.$$

The results using different shear components are consistent, but the errors from γ_1 is quite large.

Photo-z



Quasi-2D lensing: It has a tolerance for photo-z errors.

3D lensing: It need some extra modification on photo-z

2D Analysis

The estimators of total shear-shear correlations:

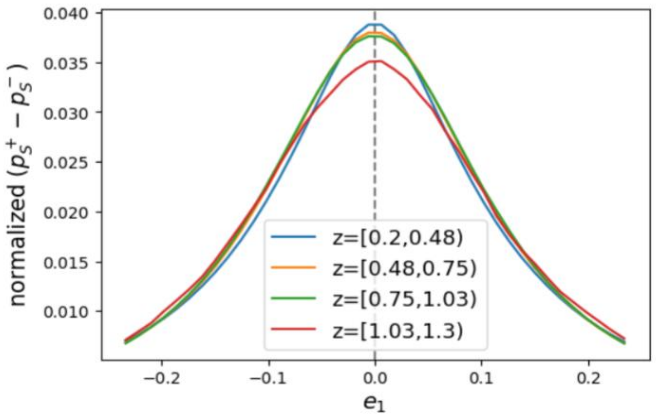
$$\langle \hat{g}\hat{g}' \rangle = -\frac{\int dz \int dz' w(z,z') \langle g(z) g'(z') \rangle}{\int dz \int dz' w(z,z')},$$

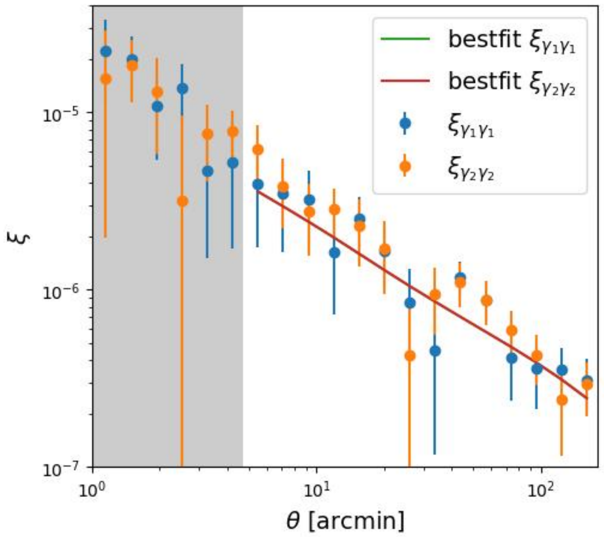
in which $w(z,z')$ is the weight given by the PDF shape:

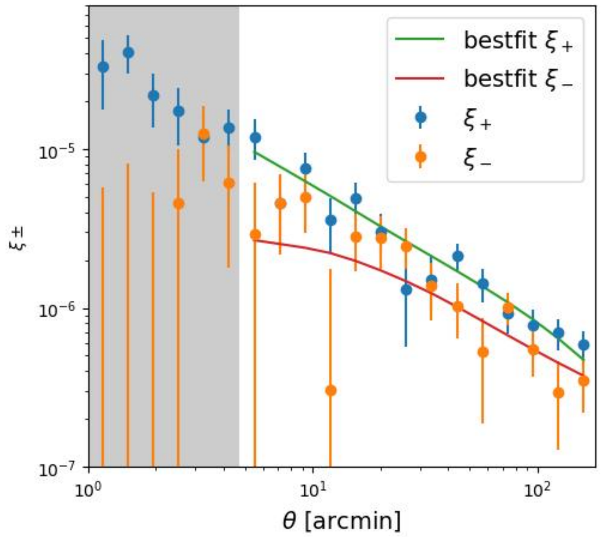
$$w(z,z') = P_S^+(0,0,z,z') - P_S^-(0,0,z,z').$$

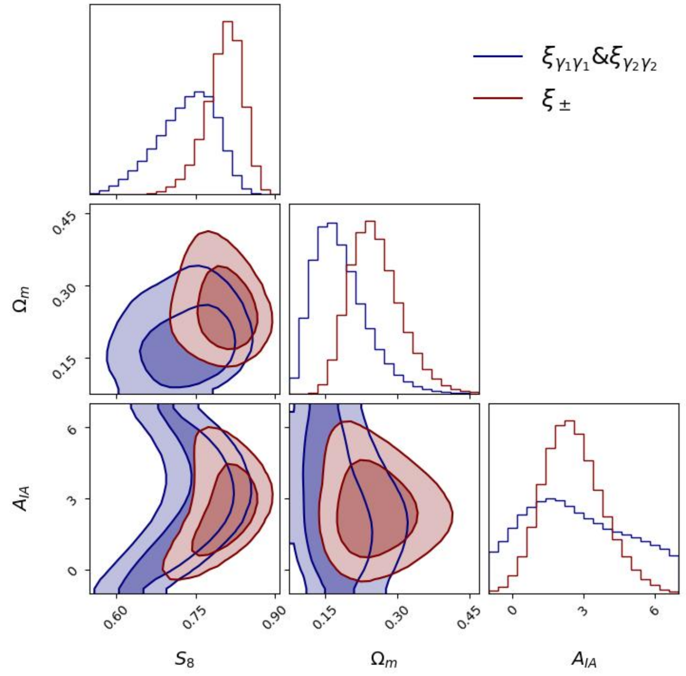
In practice, we find that as a good approximation, we can factorize $w(z,z')$ as:

$$w(z,z') \approx [p_S^+(0,z) - p_S^-(0,z)][p_S^+(0,z') - p_S^-(0,z')]$$





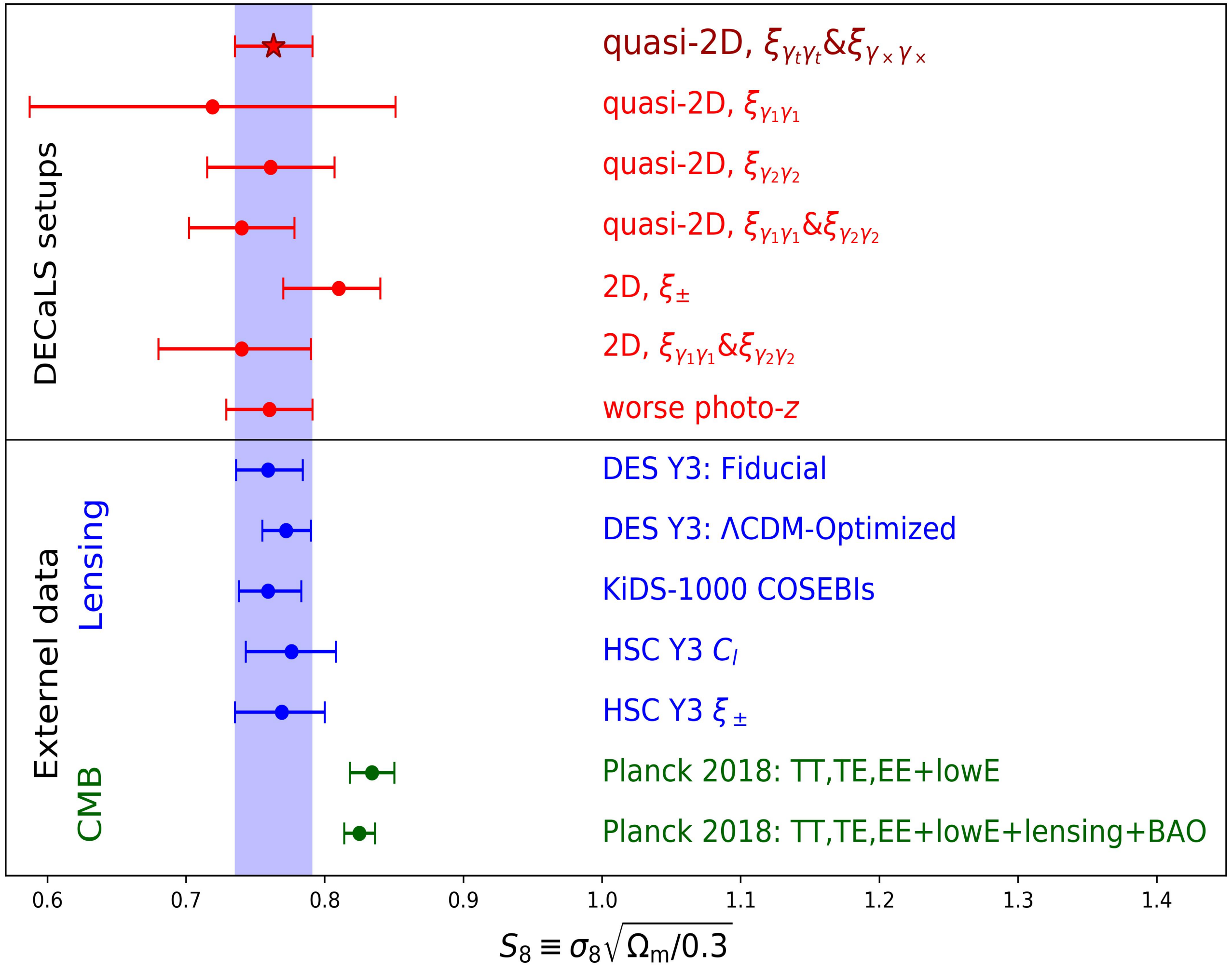




Summary

- We provide a new method, PDF-SYM method, to constrain cosmological parameters using quasi-2D shear correlations.
- Quasi-2D means that we use the redshift for each galaxy but do not divide bins on it.
- Our method has a tolerence for photo-z errors, and the results are robust in different consistency tests.

Setups	S_8	Ω_m	A_{IA}
Quasi-2D $\xi_{\gamma_t\gamma_t}\&\xi_{\gamma_\times\gamma_\times}$	**0.762 ± 0.026**	**0.23 ± 0.07**	**1.59 ± 0.73**
Quasi-2D $\xi_{\gamma_1\gamma_1}$	0.719 ± 0.132	0.19 ± 0.10	1.05 ± 6.43
Quasi-2D $\xi_{\gamma_2\gamma_2}$	0.761 ± 0.046	0.25 ± 0.08	1.25 ± 0.85
Quasi-2D $\xi_{\gamma_1\gamma_1}\&\xi_{\gamma_2\gamma_2}$	0.740 ± 0.038	0.22 ± 0.07	1.00 ± 0.60
Worse photo-z	0.761 ± 0.031	0.24 ± 0.06	2.37 ± 1.04
2D $\xi_\pm$	$0.81^{+0.03}_{-0.04}$	$0.25^{+0.06}_{-0.05}$	$2.47^{+1.35}_{-1.16}$
2D $\xi_{\gamma_1\gamma_1}\&\xi_{\gamma_2\gamma_2}$	$0.74^{+0.05}_{-0.06}$	$0.17^{+0.06}_{-0.05}$	$2.50^{+2.67}_{-2.01}$



Our S_8 are consistent with those from other lensing surveys, but has more than 2σ-tension compared with Planck predictions.

THANKS FOR WATCHING