UNIONS: The impact of systematic errors on weak-lensing peak counts

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Work done with Virginia Ajani, Martin Kilbinger, Valeria Pettorino, Samuel Farrens, Jean-Luc Starck, Raphaël Gavazzi, Michael J. Hudson
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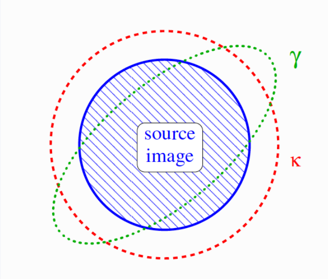
CONTENT

Introduction

WEAK LENSING



- Deformation:
  - convergence κ: isotropic magnification,
  - shear $\gamma \equiv \gamma_1 + i\gamma_2$: anisotropic stretching,
- Weak lensing: $\kappa << 1$; $|\gamma| << 1$

Reduce shear

$$g = \frac{\gamma}{1-\kappa}$$

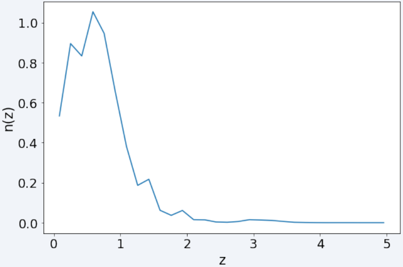
CFIS DATA

- Part of UNIONS (Ultra-violet Near-Infrared Optical Northern Survey)
- Homogeneous and multi-wavelength
- Northern hemisphere: 2017-2025
- Catalogue: P3: $34.7° \times 17.7°$
- Provided by Guinot, et al. (2022)

MassiveNuS simulations

- Done by Liu et al. (2018)
- Massive neutrinos simulations
- Dark matter only
- 3 cosmological parameters are varying: $\sum M_\nu$, Ω_m, A_s
- 101 cosmologies, 10,000 realisations
- Fixed z: 0.5, 1, 1.5, 2, 2.5
- Resolution: 0.4 arcmin/pixel, size: 512×512 pixels
- Fiducial cosmology: $M_\nu = 0.1, \Omega_\mathrm{m} = 0.3, A_\mathrm{s} = 2.1 \times 10^{-9}$
- Theoretical peak counts model - Ajani et al. (2020)

Effective redshift distribution



- Mean redshift: $z = 0.65$
- Linear interpolation
- Hypothesis: uniform distribution

$$\kappa_{z=0.65} = \kappa_{z=0.5}\lambda + \kappa_{z=1}(1-\lambda)$$

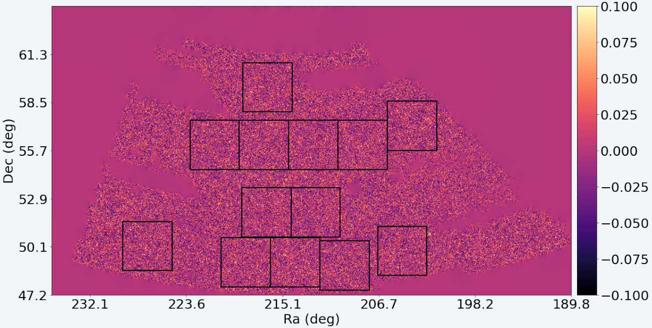
$$\bar{z} = \int n(z) z \mathrm{d}z = \int [\delta(z-0.5)\lambda + \delta(z-1)(1-\lambda)] z \mathrm{d}z$$

$$= 0.5\lambda + 1(1-\lambda) = 0.65,$$

$\Rightarrow$ Convergence map at $z = 0.65$ with $\lambda = 0.7$

Weak lensing peak counts

- Statistics higher than second order
- Sensitive to cosmology and non-Gaussianities
- Local maxima: pixel whose eight neighbors are smaller
- KS93 algorithm *(Kaiser and Squires, 1993)*: shear ⇒ convergence

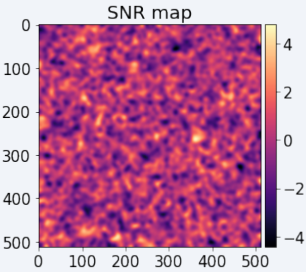


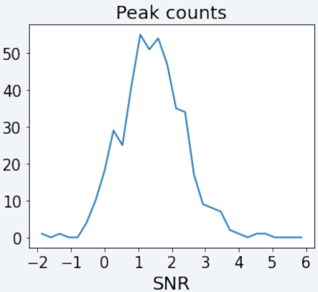
Peak counts

- Smooth with a Gaussian kernel: 2 arcminutes
- Divide by the noise: SNR map
- Compute peak counts with *lenspack* python package
- Noise: Gaussian random field: $\sigma^2_{\text{pix}} = \frac{\langle \sigma^2_{\text{e}} \rangle}{2 n_{\text{gal}} A_{\text{pix}}}$

CFIS data

$\sigma_{\text{e}} = 0.44,\ n_{\text{gal}} = 7$ galaxies/arcmin^2, $A_{\text{pix}} = 0.4^2$ arcmin^2/px^2





Parameter inference - MCMC

- Model peak function with `MassiveNuS` simulations
- Interpolated to an arbitrary cosmological parameter vector (M_ν, Ω_m, A_s): Gaussian process
- Covariance: computed at the mass-less model
- Data: peaks are the mean over 13 mask-free patches
- Likelihood: multivariate Gaussian
- Prior of the parameters:
  - $\sum M_\nu : [0.06 - 0.62]$
  - $\Omega_m : [0.18 - 0.42]$
  - A_s: $[1.29 - 2.91] \times 10^{-9}$
- 1D and 2D marginalised posteriors of the distribution
- 68% and 95.5% credible region

Local shear calibration

Metacalibration

$$g_i^{\text{obs}} = \sum_{j=1}^{2} R_{ij} g_j^{\text{true}} + c_i$$

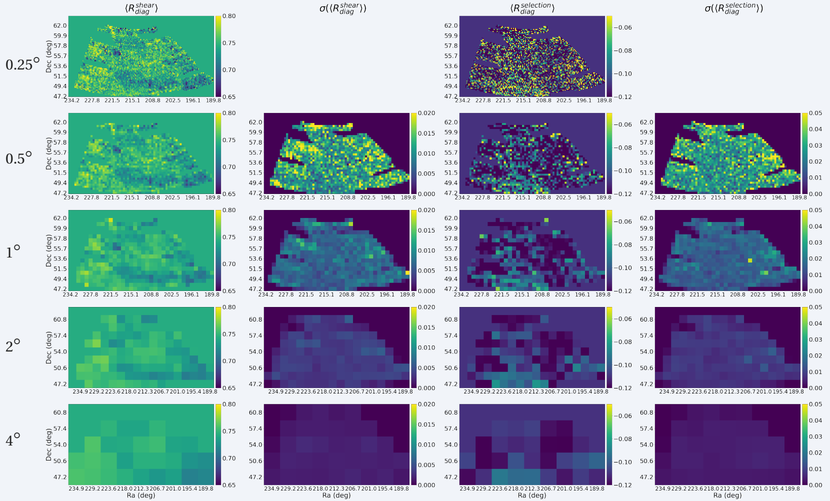
$$\text{tr}(R) = 2(1+m)$$

- R: response matrix
- c: additive shear bias
- m: multiplicative shear bias
- $R = \langle R^{\text{shear}} \rangle + \langle R^{\text{selection}} \rangle$
- Local calibration on $0.25, 0.5, 1, 2, 4$ square degree

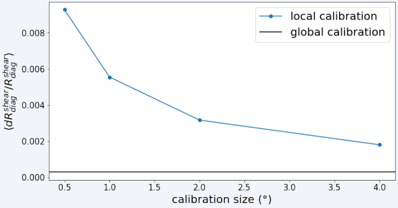
Usefull notations

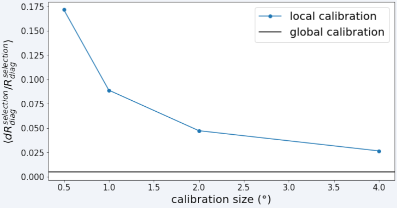
$$R_{\text{diag}} = (R_{11} + R_{22})/2$$
$$R_{\text{off-diag}} = (R_{12} + R_{21})/2$$

R_{SHEAR} AND $R_{\text{SELECTION}}$



Parameters - Conclusion





- Standard deviation and errors: low
- Calibration on small size is working
- Spread around the mean value
- Calibration on smaller size: more fluctuations
- Need to know which size is the more accurate

Impact of systematics on cosmological parameters

SYSTEMATICS AND UNCERTAINTIES STUDIED

- Local calibration ⇒ not detailed here
- Local calibration & Residual multiplicative shear bias
- Redshift uncertainty
- Baryonic feedback
- Intrinsic alignment & cluster member dilution

⇒ Combining all of them

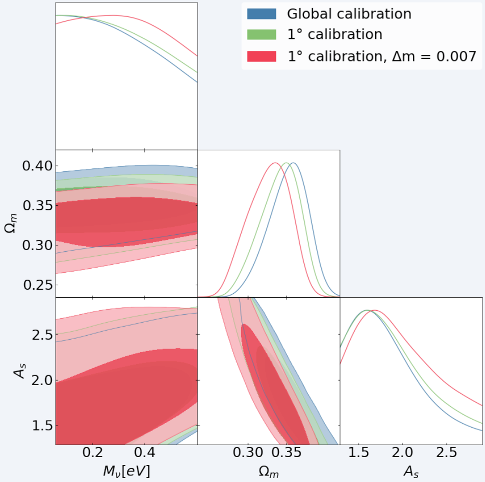
Ideal model

$z = 0.65$, no baryonic correction, global calibration, $-2 <$ SNR < 6

Residual multiplicative shear bias

- Metacalibration not perfect
- $\Delta m = m^{\mathrm{metacal}} - m^{\mathrm{true}}$
- Estimated with simulations
- $\Delta m = 0$: metacalibration perfect
- $\Delta m = 0.007$: Guinot et al. (2022)
- Add Δm to the response matrix in the local case

RESIDUAL MULTIPLICATIVE SHEAR BIAS



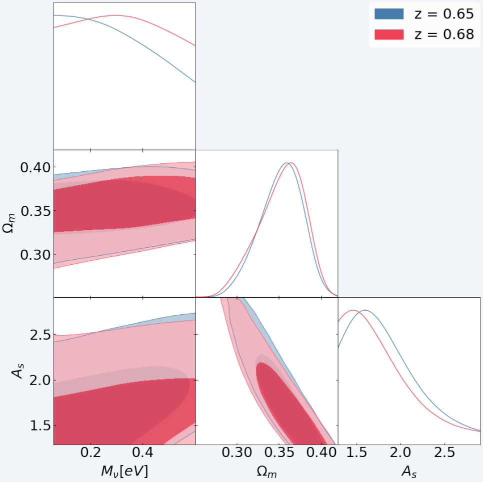
- Ω_m shifts of -0.024 (i.e. -0.5σ)
- Local calibration and Δm have an impact

$\Rightarrow$ Need to know Δm

Parameters

- $z = 0.65$
- No baryonic correction
- Calibration on $1^{\circ 2}$
- $\Delta m = 0, \Delta m = 0.007$
- $-2 <$ SNR < 6

Redshift uncertainty



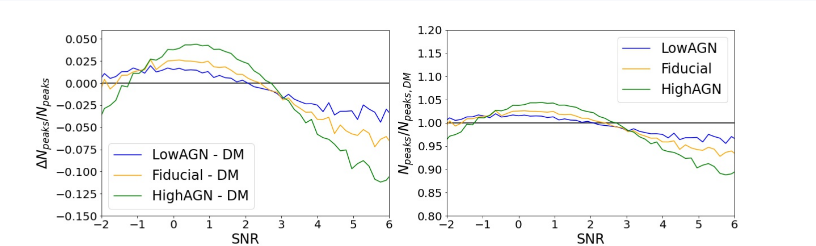
- Close redshift
- Close constraints
- $z = 0.65$ to $z = 0.68$: Ω_m shifts of $+0.001$ (i.e. $+0.02\sigma$)

Parameters

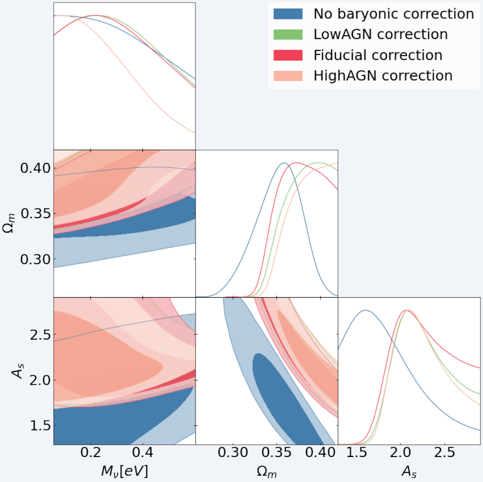
- $z = 0.65, z = 0.68$
- No baryonic correction
- Global calibration
- $-2 < \text{SNR} < 6$

BARYONIC FEEDBACK - METHOD

- Baryonic process: difficult to model
- Coulton et al. (2020): study BAHAMAS simulation ⇒ 3 strength of baryonic feedback
- LowAGN < fiducial < HighAGN
- Fractional difference with their data (left)
- Obtain the baryonic correction (right)
- Multiply our data: mimic the baryonic feedback



BARYONIC FEEDBACK

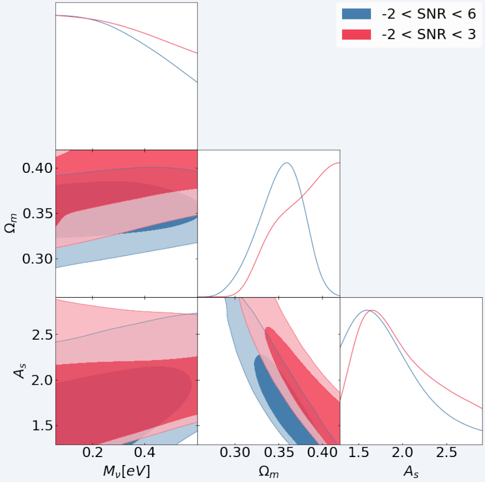


- Less peaks ⇒ Ω_m higher to compensate
- No correction to LowAGN correction: Ω_m shifts of $+0.027$ (i.e. $+0.5\sigma$)

Parameters

- $z = 0.65$
- Baryonic correction
- Global calibration
- $-2 <$ SNR < 6

Intrinsic alignment & cluster member dilution

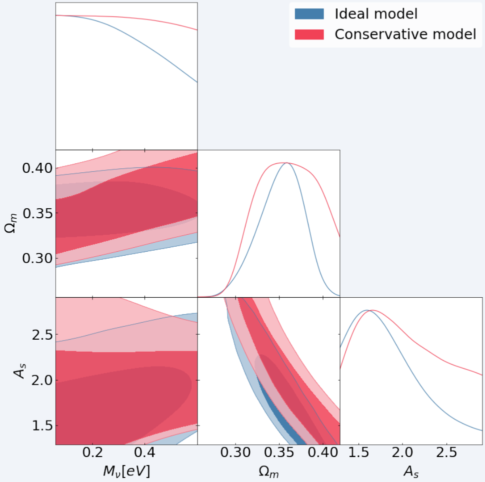


- Cut high SNR ⇒ cut part of the effects
- All range to cut range: Ω_m shifts of $+0.027$ (i.e. $+0.5\sigma$)

Parameters

- $z = 0.65$
- No baryonic correction
- Global calibration
- $-2 < \text{SNR} < 6$ and $-2 < \text{SNR} < 3$

Combining all systematics effects



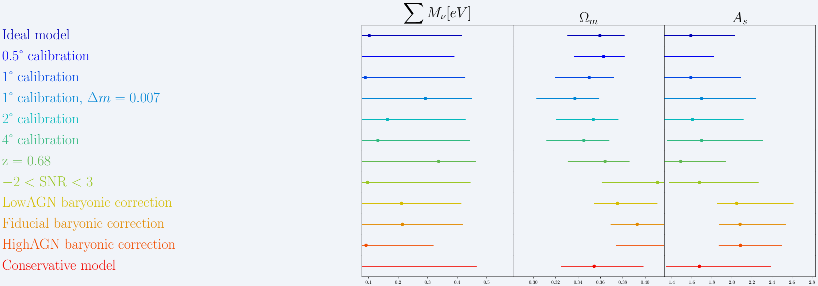
- Ideal to conservative: Ω_m shifts by $+0.008$ (i.e. $+0.2\sigma$)

Parameters

- $z = 0.65$
- Fiducial baryonic correction
- Local calibration $1^{\circ 2}$
- $\Delta m = 0.007$
- $-2 < \text{SNR} < 3$

Conclusion

Conclusion


Ideal model
0.5° calibration
1° calibration
1° calibration, $\Delta m = 0.007$
2° calibration
4° calibration
z = 0.68
$-2 < \mathrm{SNR} < 3$
LowAGN baryonic correction
Fiducial baryonic correction
HighAGN baryonic correction
Conservative model
$\sum M_\nu [eV]$
Ω_m
A_s
0.1 0.2 0.3 0.4 0.5
0.30 0.32 0.34 0.36 0.38 0.40
1.4 1.6 1.8 2.0 2.2 2.4 2.6 2.8

Conclusion

- Most important systematics:
  - Local calibration & Δ_m
  - Baryonic correction
  - Cluster member dilution & intrinsic alignment
- Better knowledge of the redshift to check the actual Δz or do tomographic analyses
- Use of hydrodynamical simulations
- Model the cluster member dilution & intrinsic alignment

$\Rightarrow$ here: starting point for future analyses with larger catalogue

Want to now more?

Paper on arXiv! `https://arxiv.org/abs/2204.06280`

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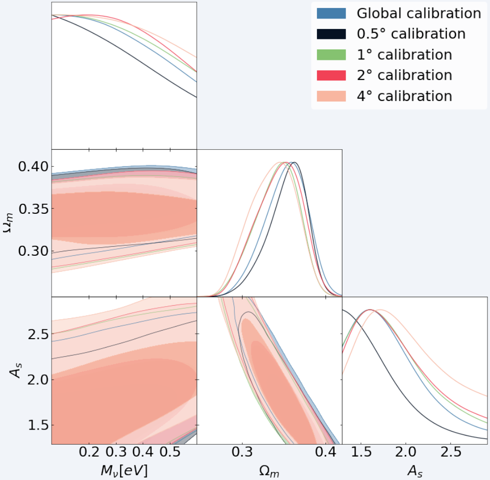
Local calibration

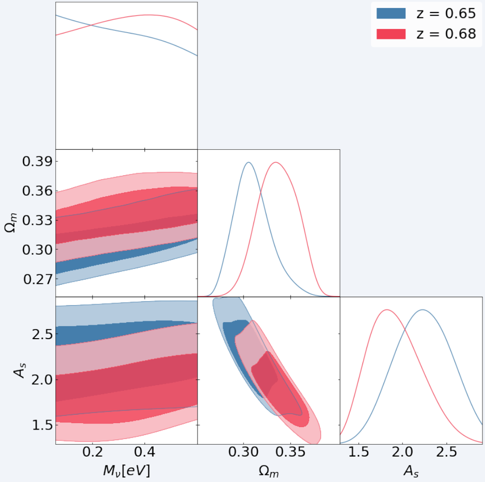


- No systematic variation
- Local to global on 4 square degree: Ω_m shifts by -0.015 (i.e. -0.3σ)

Parameters

- $z = 0.65$
- No baryonic correction
- Calibration on different size
- $-2 <$ SNR < 6

REDSHIFT UNCERTAINTY - SIMULATIONS ONLY

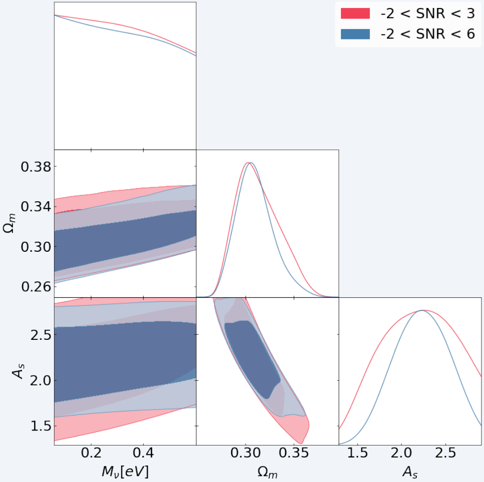


- $z = 0.65$ to $z = 0.68$: Ω_m shifts of $+0.026$ (i.e. $+0.7\sigma$)

Parameters

- data vector: mean fiducial at $z = 0.65, z = 0.68$
- model: simulations at $z = 0.65$

IA and boost factor - Simulations only

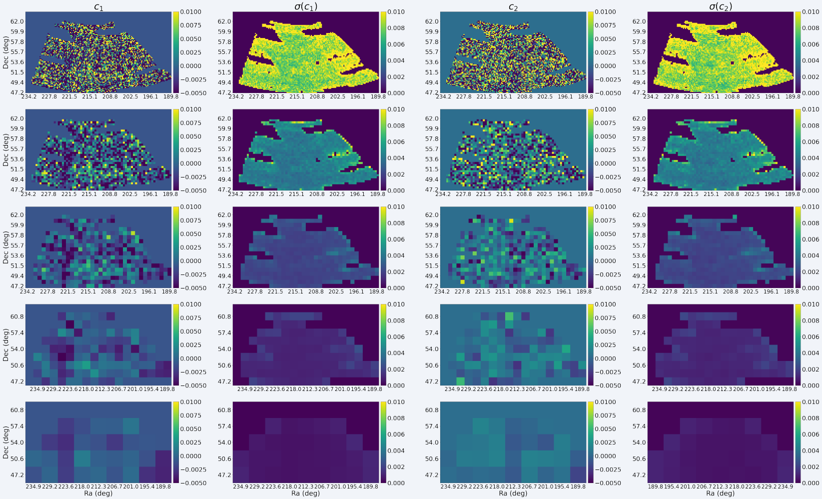


- Reduce range: constraints larger
- Less information

Parameters

- data vector: $-2 < SNR < 6$ and $-2 < SNR < 3$
- model: $-2 < SNR < 6$

Parameters - Additive bias



METACALIBRATION

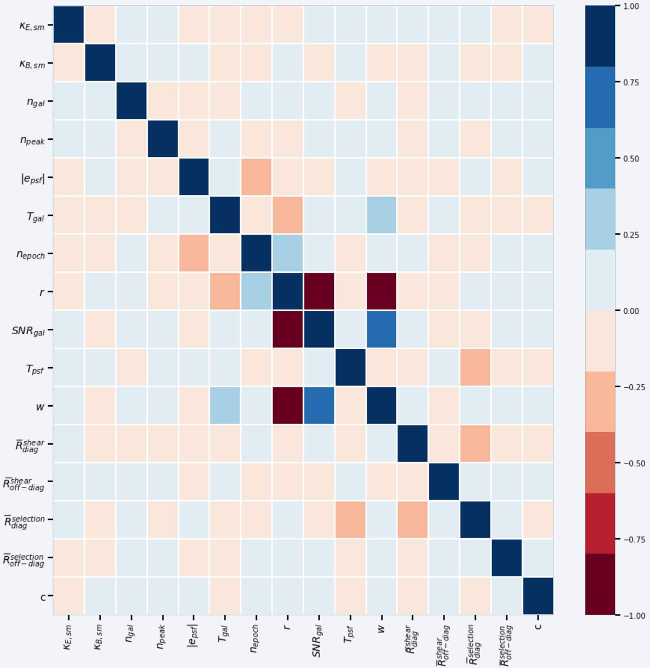
Link between observed and true shear

$$g_i^{\text{obs}} = \sum_{j=1}^{2} R_{ij} g_j^{\text{true}} + c_i \tag{1}$$

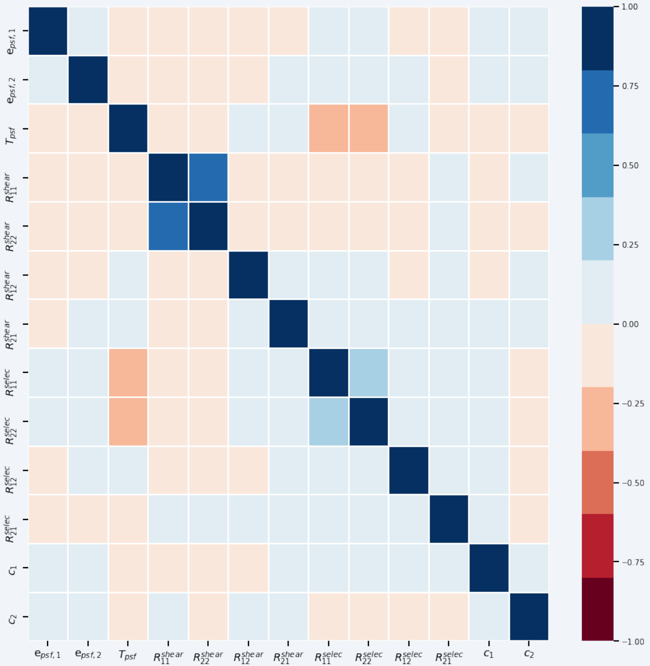
$$g_j^{\text{true}} = \sum_{i=1}^{2} R_{ij}^{-1} g_i^{\text{obs}} - \sum_{i=1}^{2} R_{ij}^{-1} c_i. \tag{2}$$

R matrix

$$R_{ij}^{\text{shear}} = \frac{g_i^{\text{obs,+}} - g_i^{\text{obs,-}}}{2\Delta g_j}, \qquad \langle R_{ij}^{\text{selection}} \rangle = \frac{\langle g_i^{\text{obs,0,M+}} \rangle - \langle g_i^{\text{obs,0,M-}} \rangle}{2\Delta g_j}, \tag{3}$$



$\kappa_{E,sm}$
$\kappa_{B,sm}$
n_{gal}
n_{peak}
$|e_{psf}|$
T_{gal}
n_{epoch}
r
SNR_{gal}
T_{psf}
w
$\bar{R}^{shear}_{diag}$
$\bar{R}^{shear}_{off-diag}$
$\bar{R}^{selection}_{diag}$
$\bar{R}^{selection}_{off-diag}$
c
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00



$e_{psf,1}$
$e_{psf,2}$
T_{psf}
R_{11}^{shear}
R_{22}^{shear}
R_{12}^{shear}
R_{21}^{shear}
R_{11}^{selec}
R_{22}^{selec}
R_{12}^{selec}
R_{21}^{selec}
c_1
c_2
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00