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The Nordic Institute for Theoretical Physics

Probing Galaxy-Halo Connections:
Insights from DES Y3 Galaxy-Galaxy Lensing

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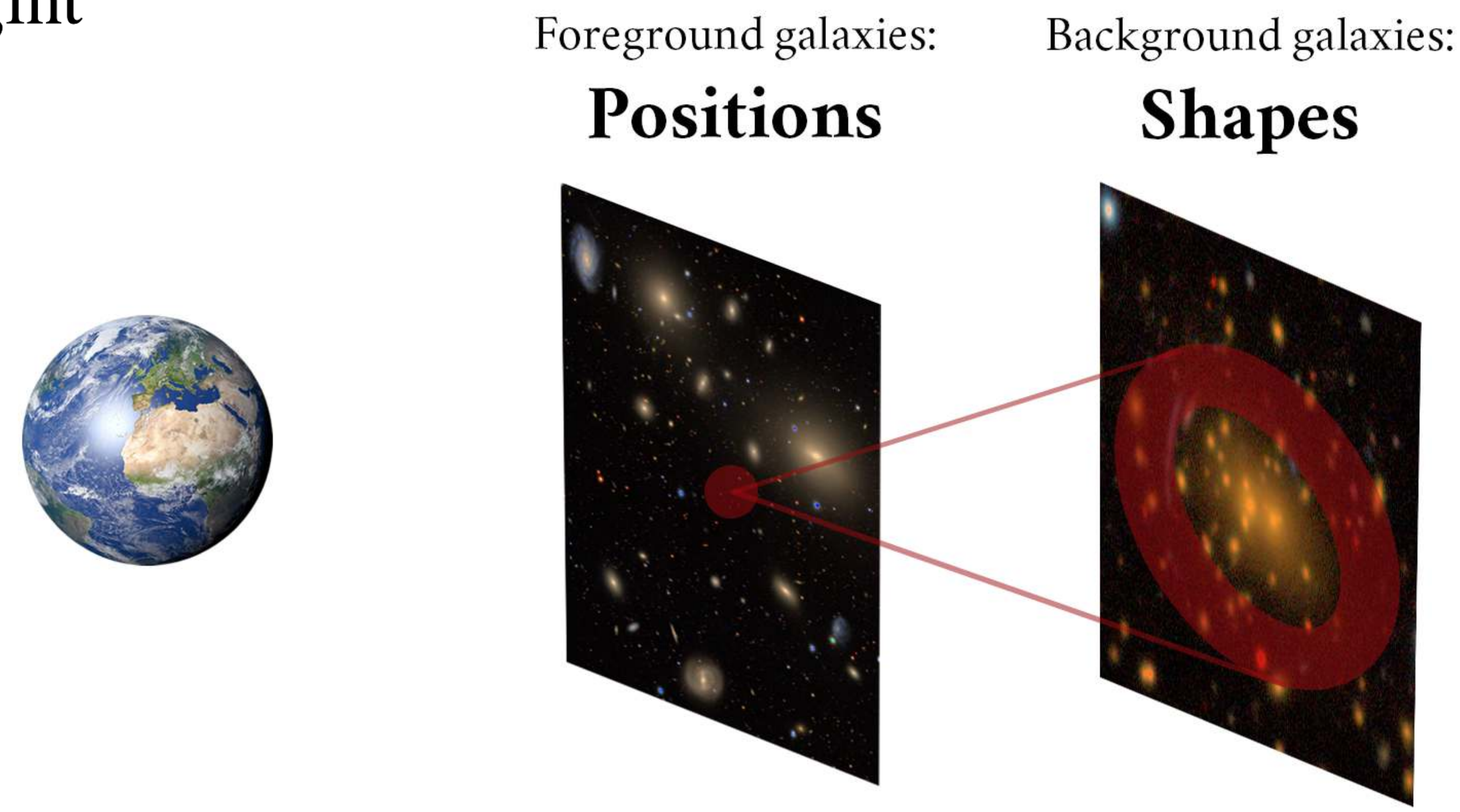
Galaxy-galaxy lensing: *Measuring the mean tangential shear*

We cross-correlate the tangential component of the ellipticity of source galaxies with the position of lens galaxies, averaging over many lens-source pairs as a function of angular separation between them:

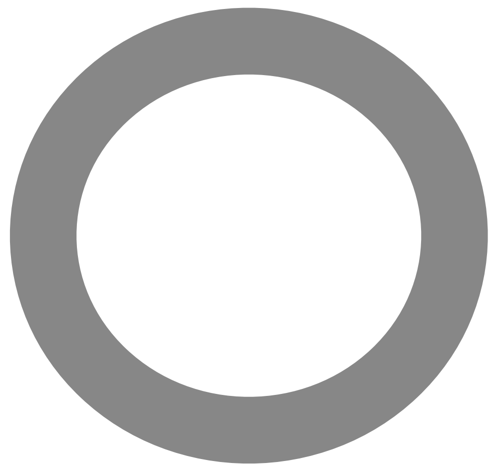
$$e^{\text{obs}} \approx \gamma + e^{\text{int}}$$



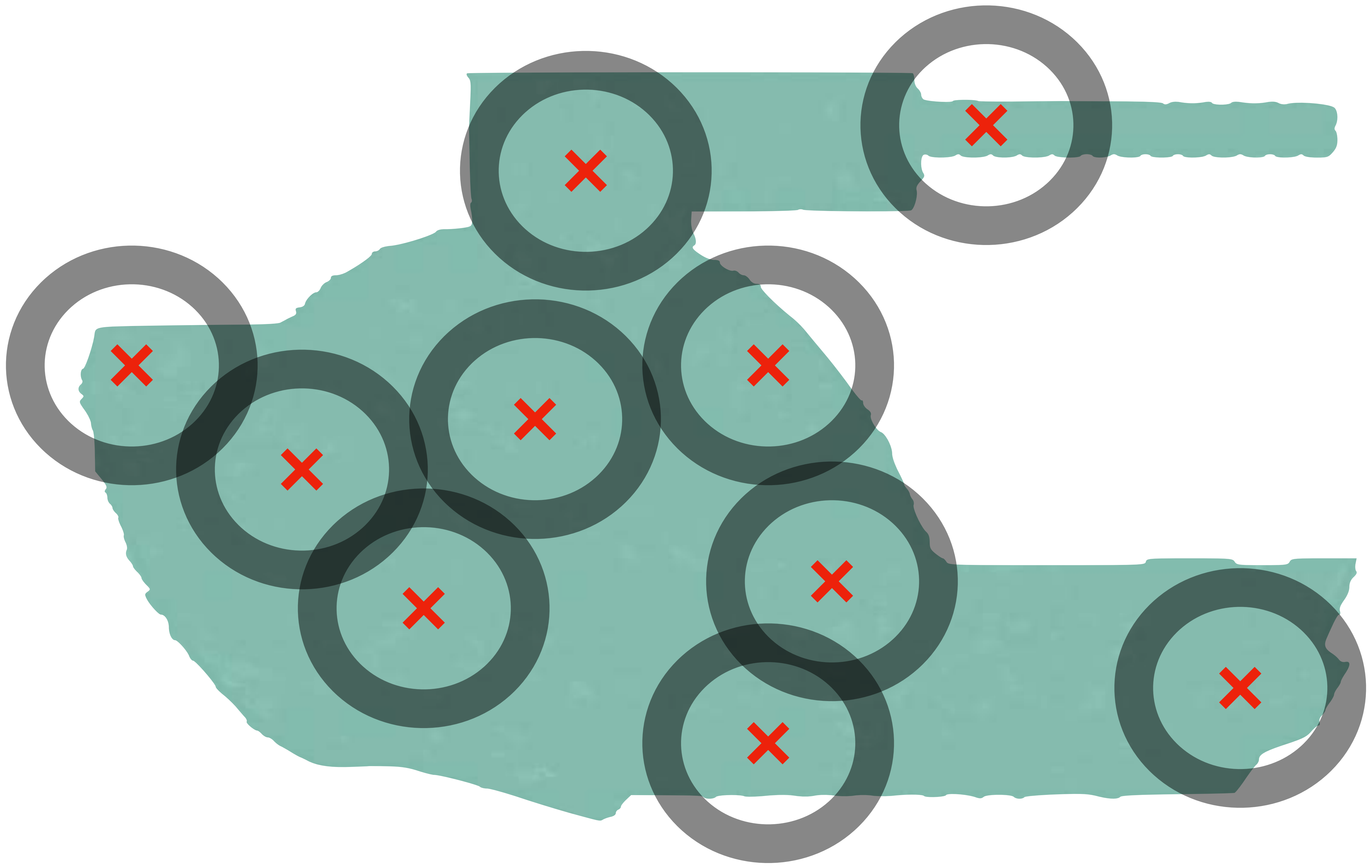
$$\gamma_t(\theta) = \frac{\sum_{LS} w_{LS}\, e_{t,LS}(\theta)}{\sum_{LS} w_{LS}(\theta)}$$

Measuring the tangential shear

Lens galaxy

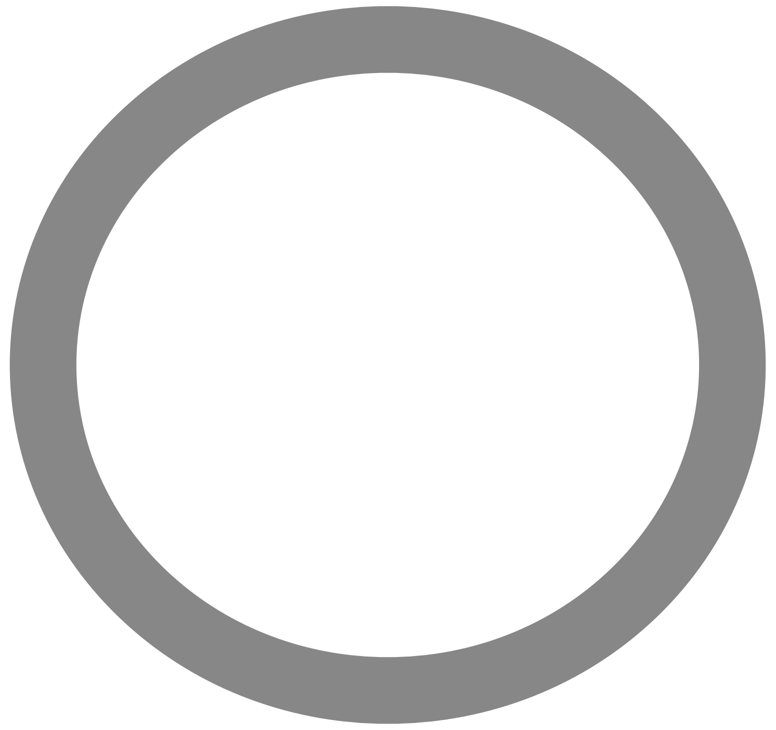


Source annulus at a given theta angular distance from the lens galaxy.

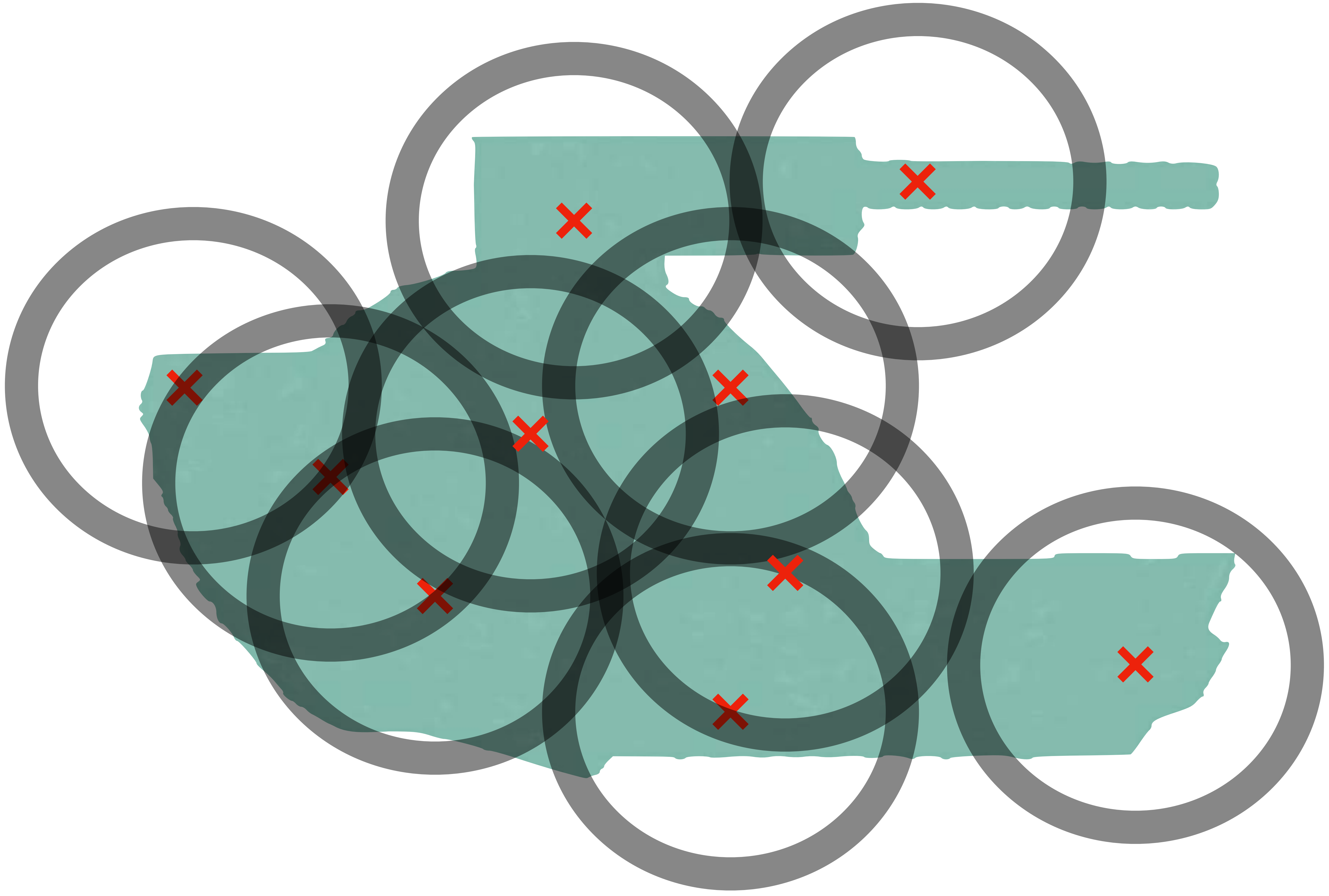


Measuring the tangential shear

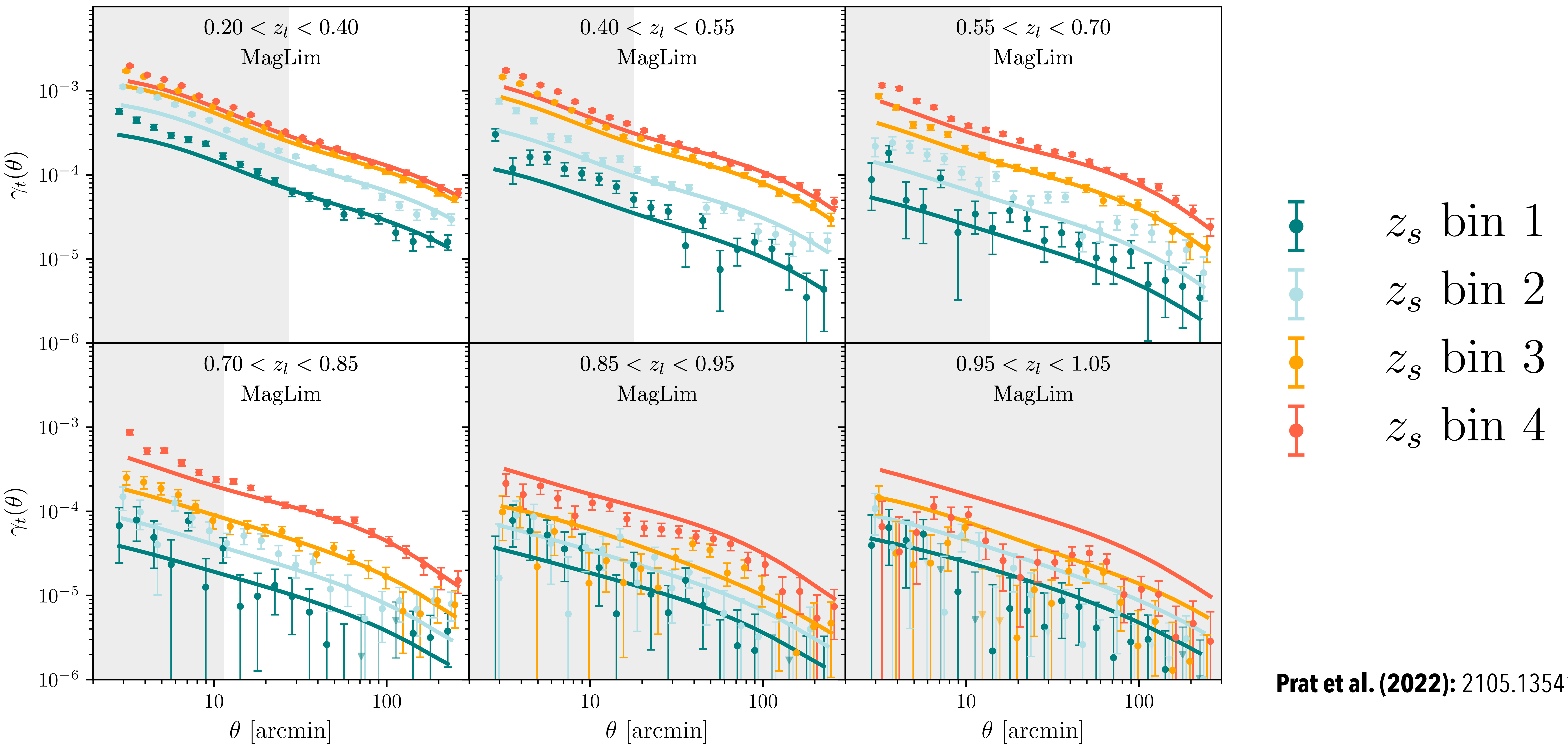
Lens galaxy



Source annulus at a given theta angular distance from the lens galaxy.



Galaxy-galaxy lensing DES Y3: *tangential shear*



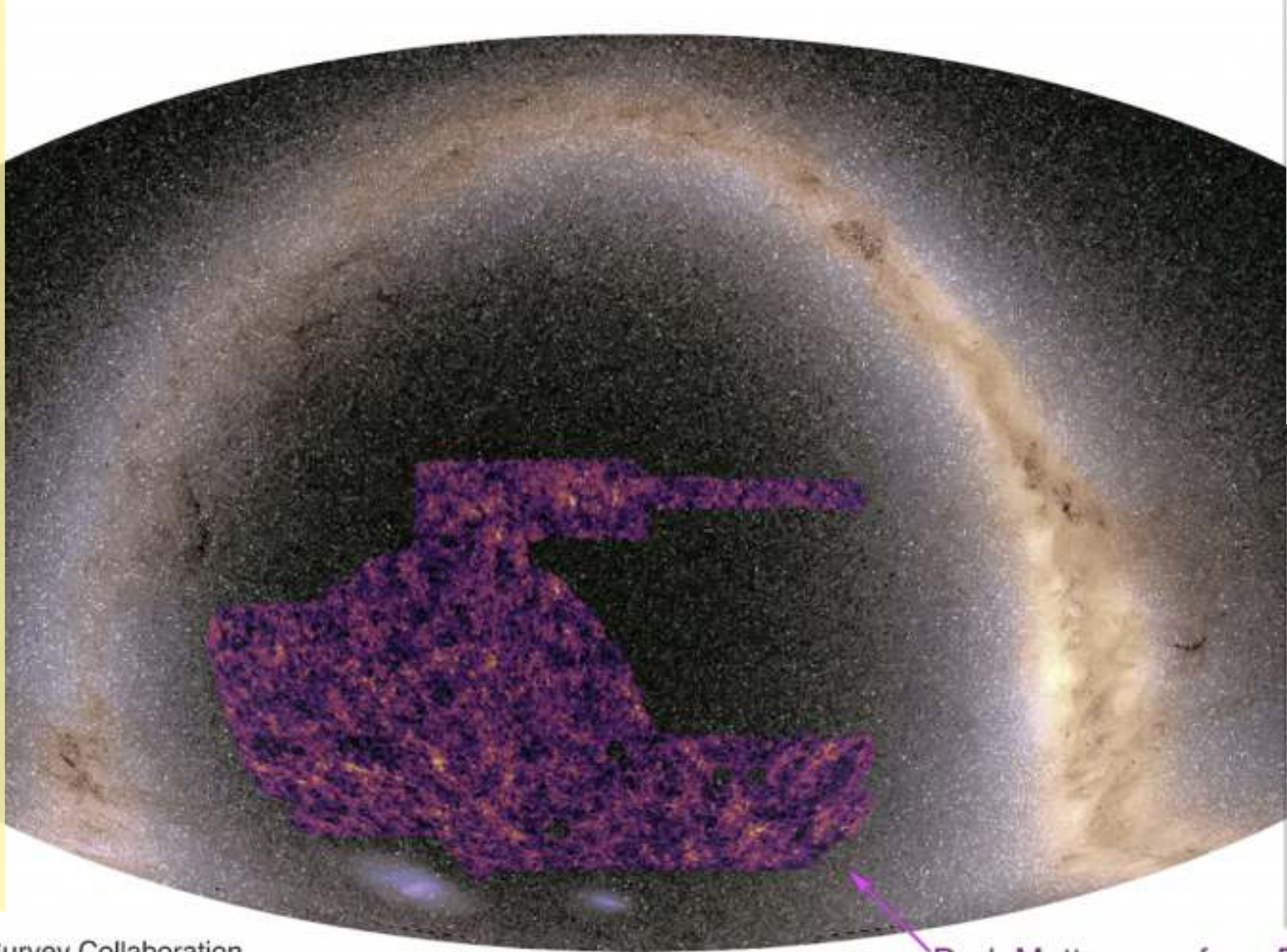
Prat et al. (2022): 2105.13541

(Limitations of) *Galaxy-galaxy lensing for DES Y3 3x2pt cosmology*

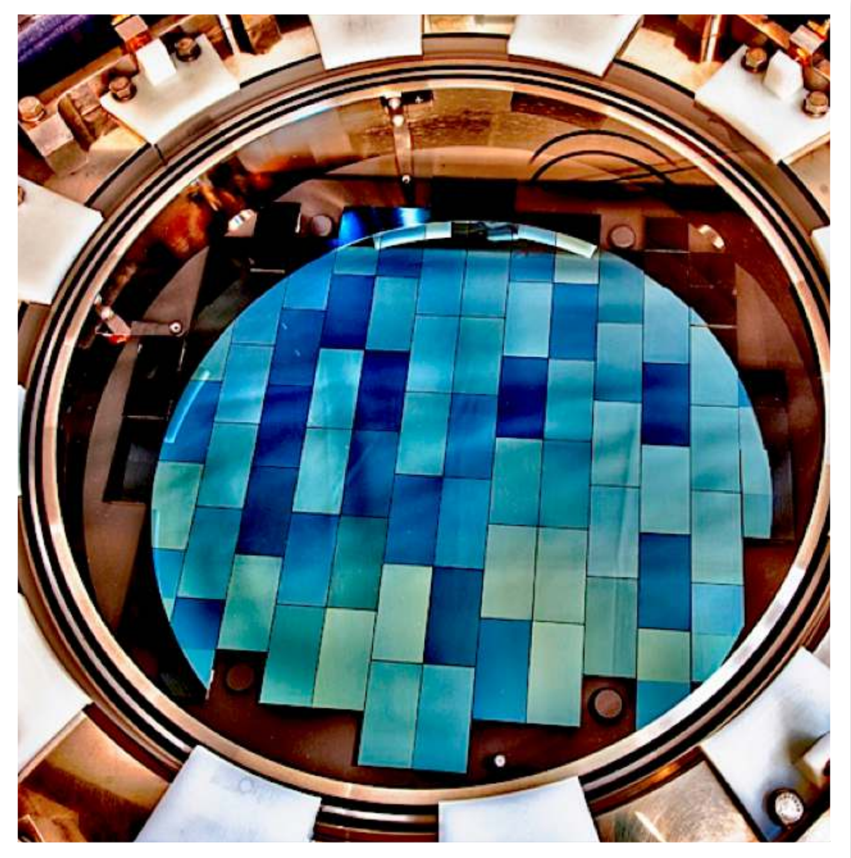
Judit Prat, Jonathan Blazek, Carles Sánchez, Isaac Tutusaus, Shivam Pandey, Elisabeth Krause, Michael Troxel and other DES colleagues

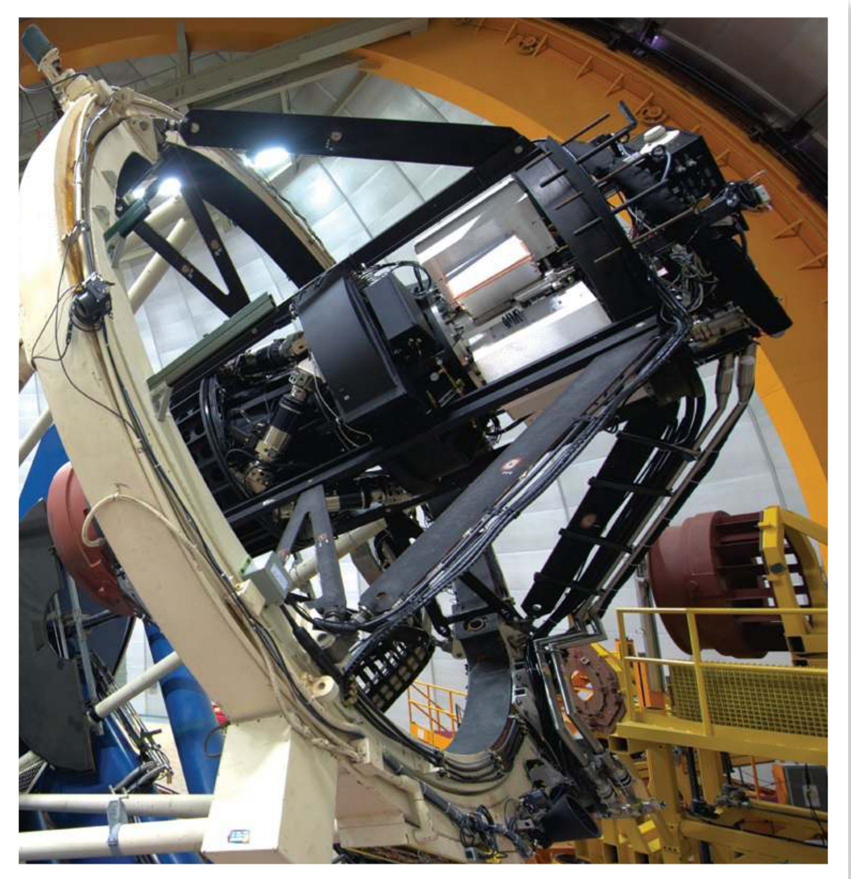
The Dark Energy Survey: *a photometric lensing survey*

- 570 Megapixel camera for the Blanco 4m telescope in Chile.
- Full survey 2013-2019 (Y3 2013-16).
- Wide field: 5000 sq. deg. in 5 bands. ~23 magnitude.
- DES Y3: Positions and shapes of > 100M galaxies.



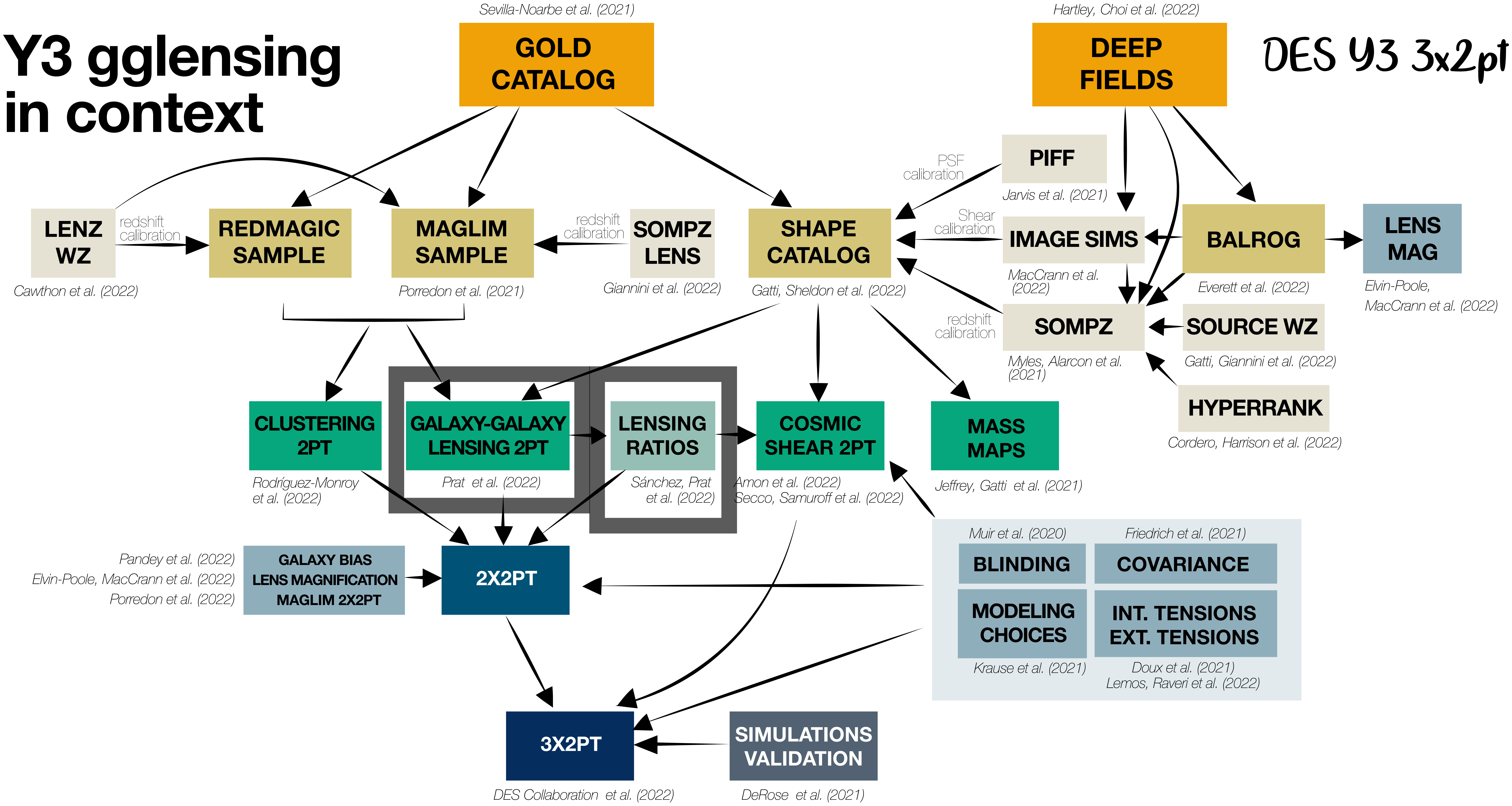
N. Jeffrey; Dark Energy Survey Collaboration



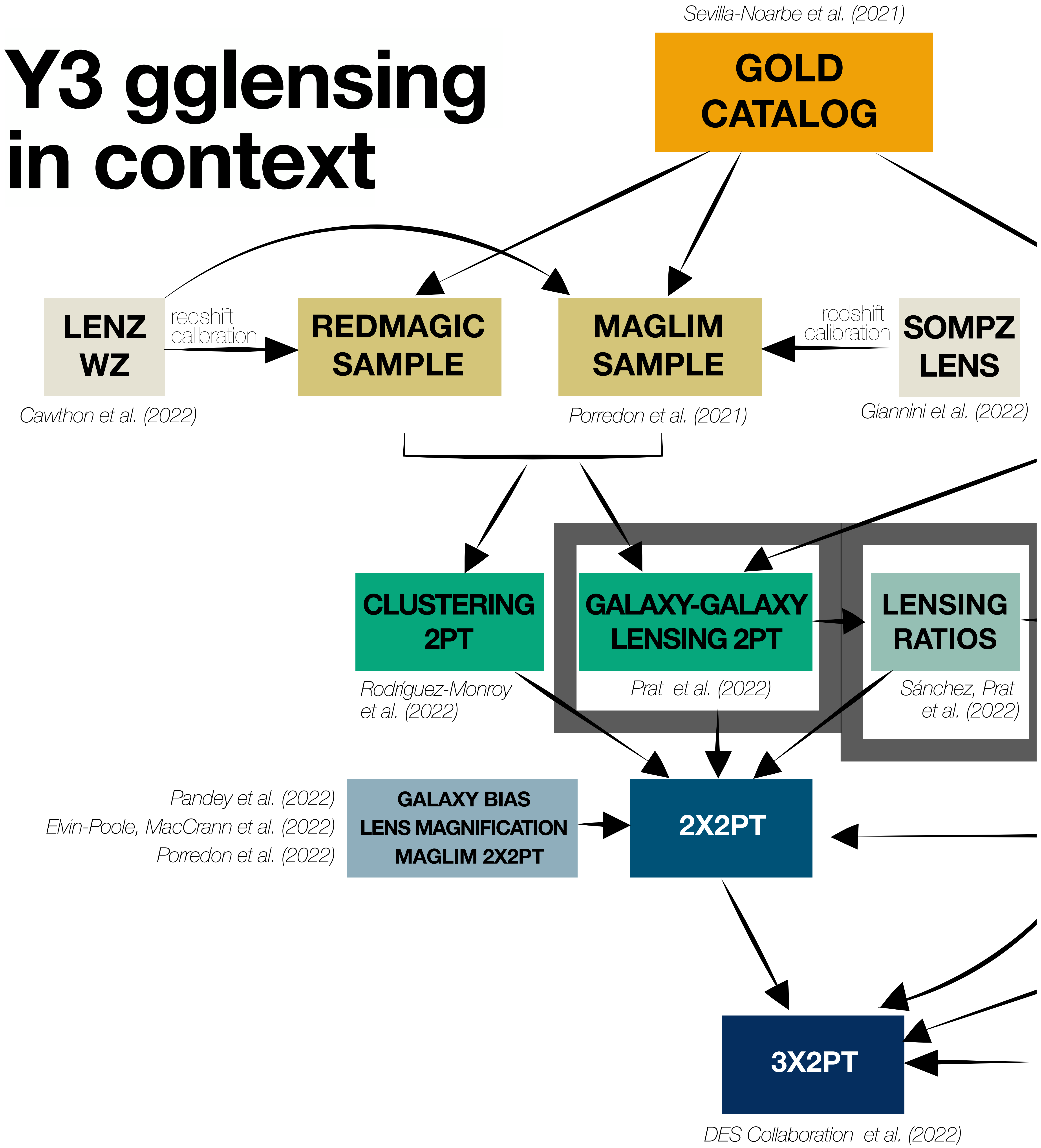


Y3 gglensing in context

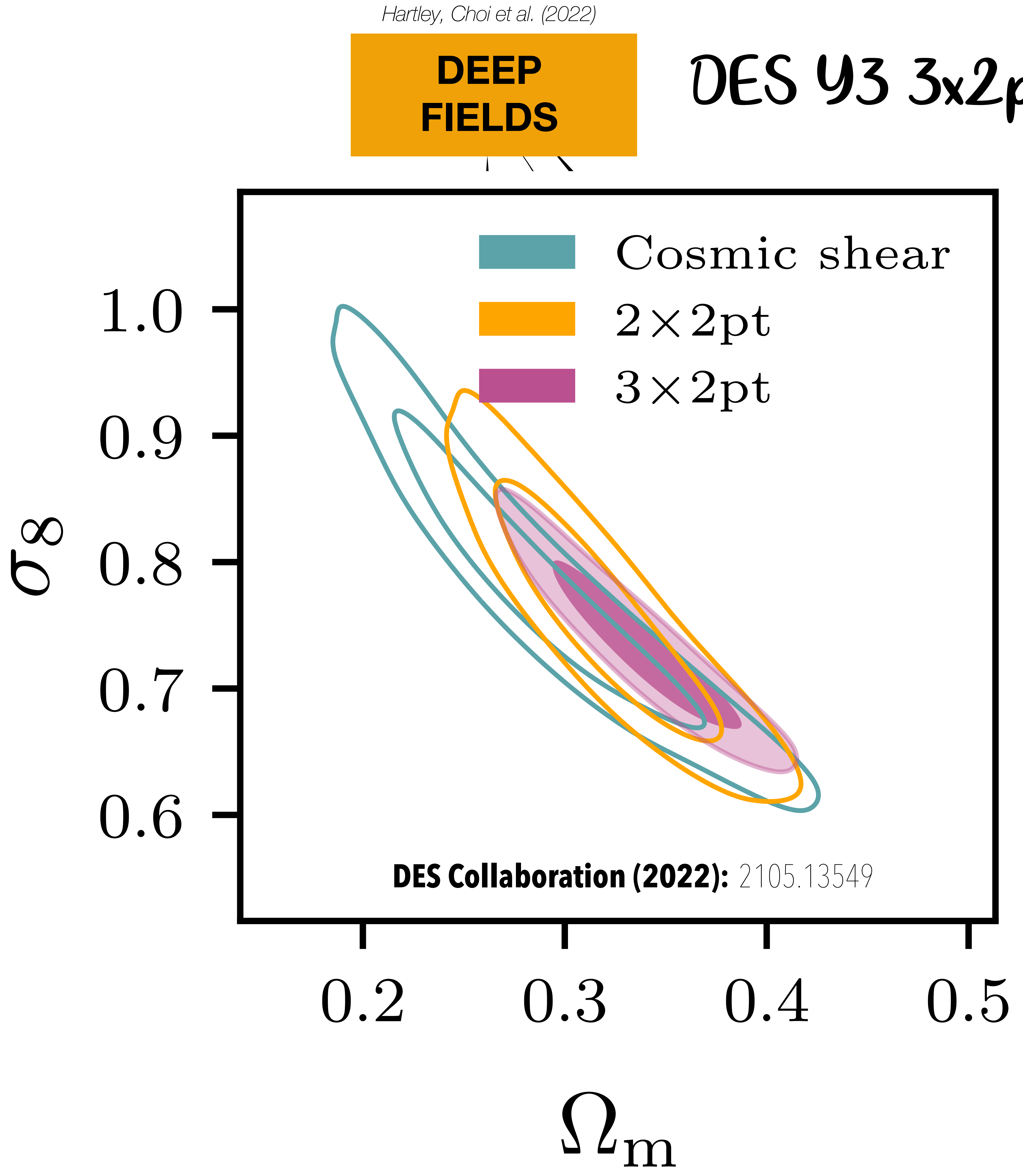
DES Y3 3x2pt



Y3 gglensing in context



DES Y3 3x2pt



DES Y3 3x2pt: *Galaxy samples for cosmology*

redMaGiC lens sample

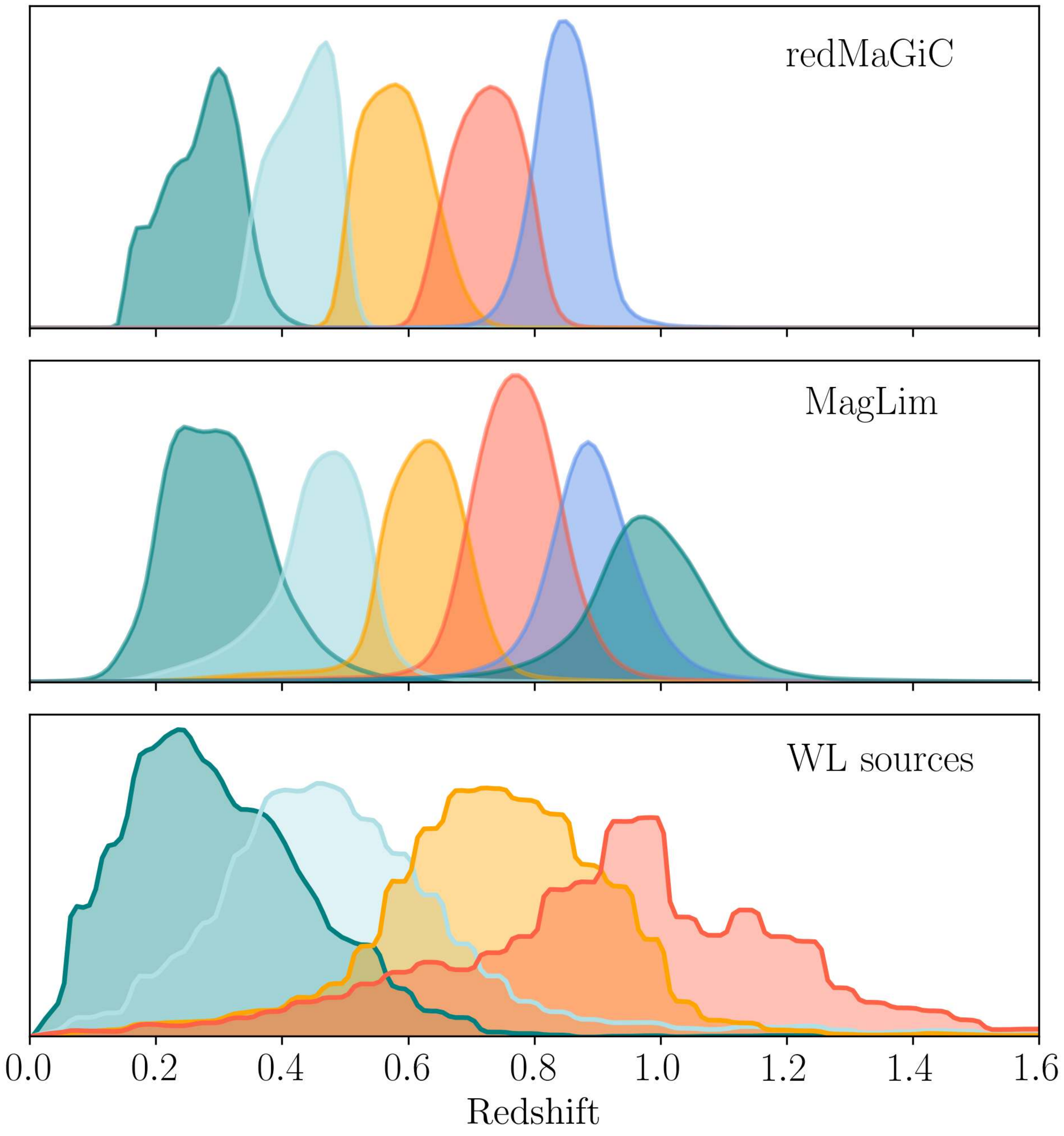
Redshift bin	N^i_{gal}	n^i_{gal}	b^i	α^i
$0.15 < z < 0.35$	330243	0.022141	1.74 ± 0.12	1.31
$0.35 < z < 0.50$	571551	0.038319	1.82 ± 0.11	-0.52
$0.50 < z < 0.65$	872611	0.058504	1.92 ± 0.11	0.34
$0.65 < z < 0.80$	442302	0.029654	2.15 ± 0.12	2.25
$0.80 < z < 0.90$	377329	0.025298	2.32 ± 0.14	1.97

MagLim lens sample

Redshift bin	N^i_{gal}	n^i_{gal}	b^i	α^i
$0.20 < z < 0.40$	2236473	0.1499	1.49 ± 0.10	1.21
$0.40 < z < 0.55$	1599500	0.1072	1.69 ± 0.11	1.15
$0.55 < z < 0.70$	1627413	0.1091	1.90 ± 0.12	1.88
$0.70 < z < 0.85$	2175184	0.1458	1.79 ± 0.13	1.97
$0.85 < z < 0.95$	1583686	0.1062	–	1.78
$0.95 < z < 1.05$	1494250	0.1002	–	2.48

Metacalibration source sample

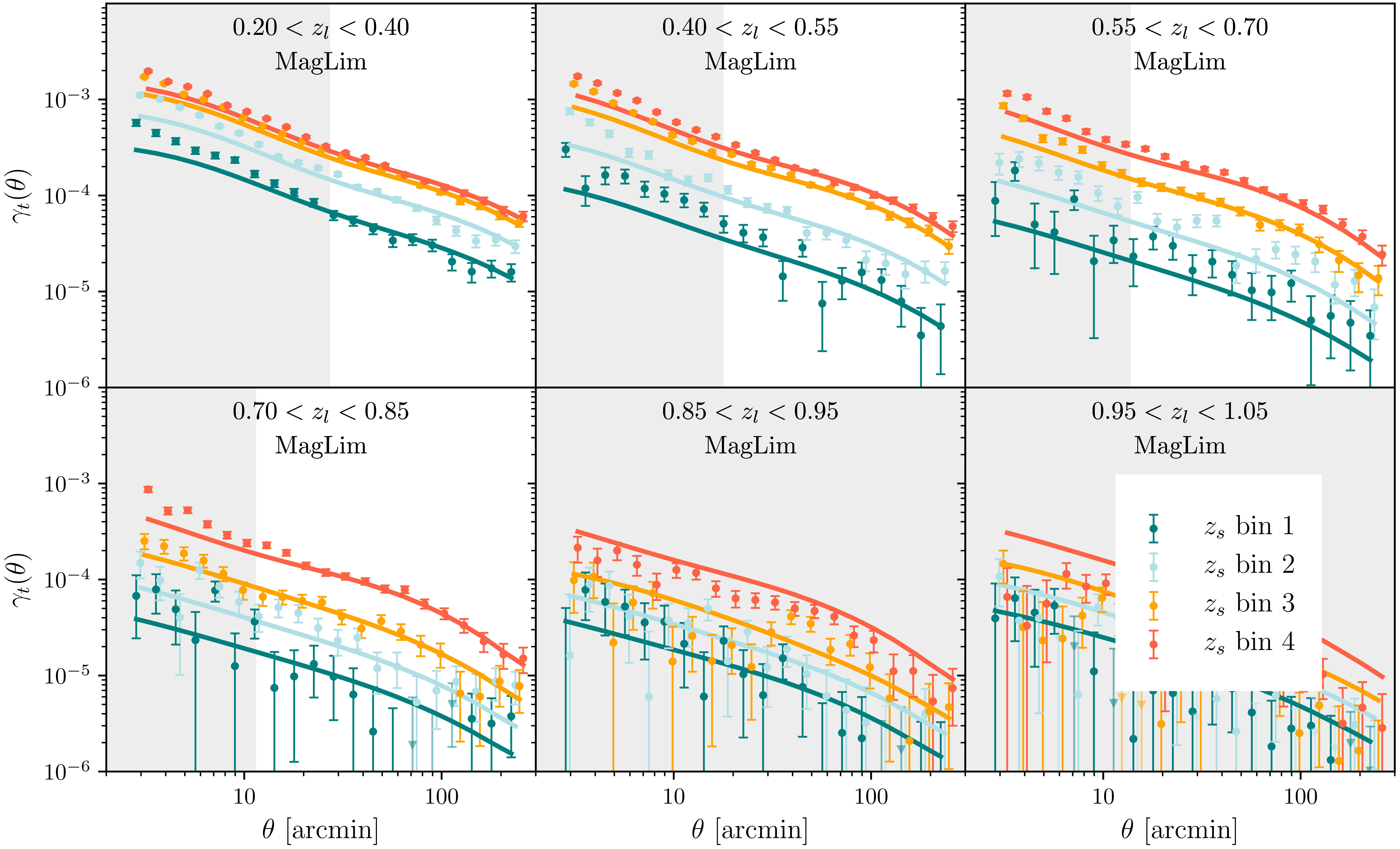
Redshift bin	N^j_{gal}	n^j_{gal}	σ^j_ϵ	α^j
1	24940465	1.476	0.243	0.335
2	25280405	1.479	0.262	0.685
3	24891859	1.484	0.259	0.993
4	25091297	1.461	0.301	1.458



Galaxy-galaxy lensing DES Y3: *tangential shear*

- REDMAGIC S/N:
  i. **Total:**120.
  ii. **After scale cuts** (>6Mpc/h): 55
  iii. **With PM marg:** 28

- MAGLIM S/N:
  i. **Total:**148.
  ii. **After scale cuts** (>6Mpc/h): 67
  iii. **With PM marg:** 32



Tangential shear modeling: Point-mass marginalization

The tangential shear is non-local, i.e. at each angular scale, the tangential shear has information down to all scales below it.

$$\gamma_t(\theta) = \frac{\Delta\Sigma(\theta)}{\Sigma_{\rm crit}}$$

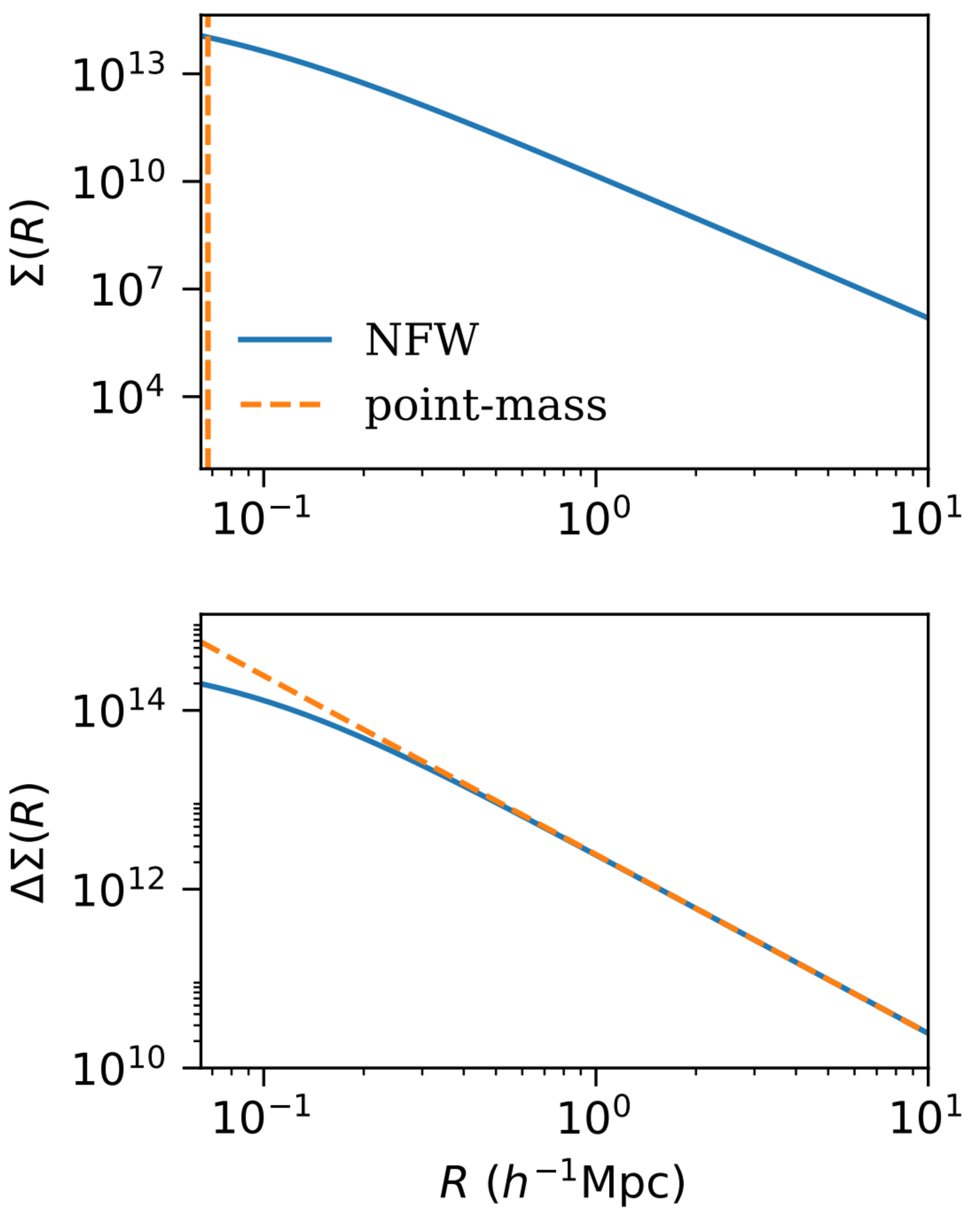
Non-local Lens property: $\Delta\Sigma(\theta) = \bar{\Sigma}(<\theta) - \Sigma(\theta)$

Surface mass density

Geometrical factor: $\Sigma^{-1}_{\rm crit}(z_{\rm l}, z_{\rm s}) = \frac{4\pi G}{c^2}\frac{D_{ls}\,D_l}{D_s}$

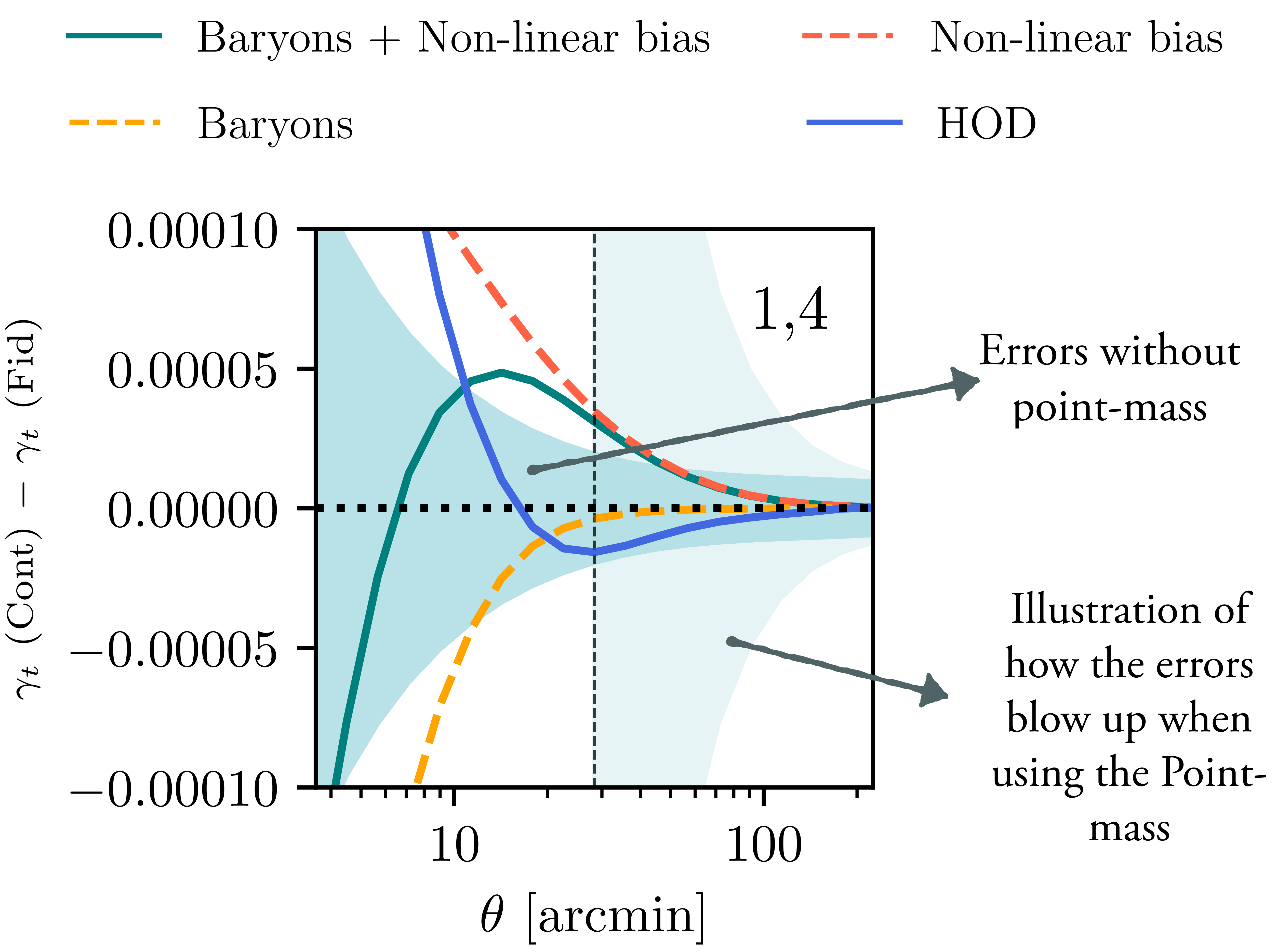
Then, we marginalize over a point mass to remove the small scale information which we can't model:

$$\gamma_t^{ij}(\theta) = \gamma_{t,\rm model}^{ij}(\theta) + \frac{A^{ij}}{\theta^2}$$



Tangential shear modeling: How did we define scale cuts?

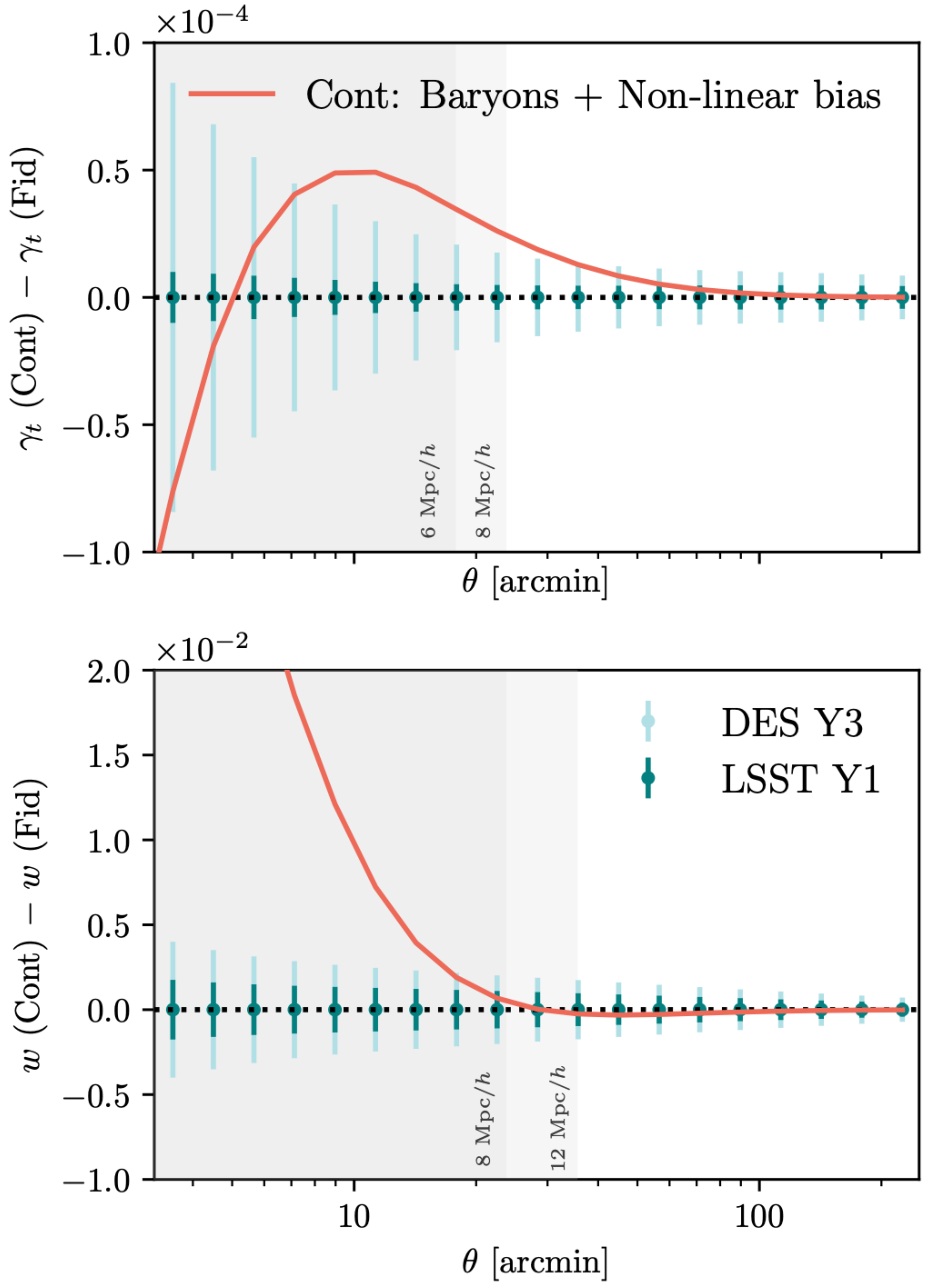
- We contaminate our fiducial model with effects we are not included.
- **Criteria:** No more than 0.3 sigma effect in the S_8-Ω_m plane.
- **Limiting factor:** Non-linear galaxy bias using perturbation theory (*Pandey et. al 2020, 2008.05991)* and baryonic contamination (from OWLS hydrodynamical simulation) to the power spectrum.
- **Result:** Scales > 6 Mpc/h for galaxy-galaxy lensing and >8 Mpc/h for galaxy clustering.



Forecasted scale cuts for LSST Y1

- In a recent analysis we conclude that if we use linear galaxy bias we will need **8 Mpc/h cuts if using point-mass marginalization** for LSST Y1 for the tangential shear, but **40 Mpc/h if not using PM marginalization**.

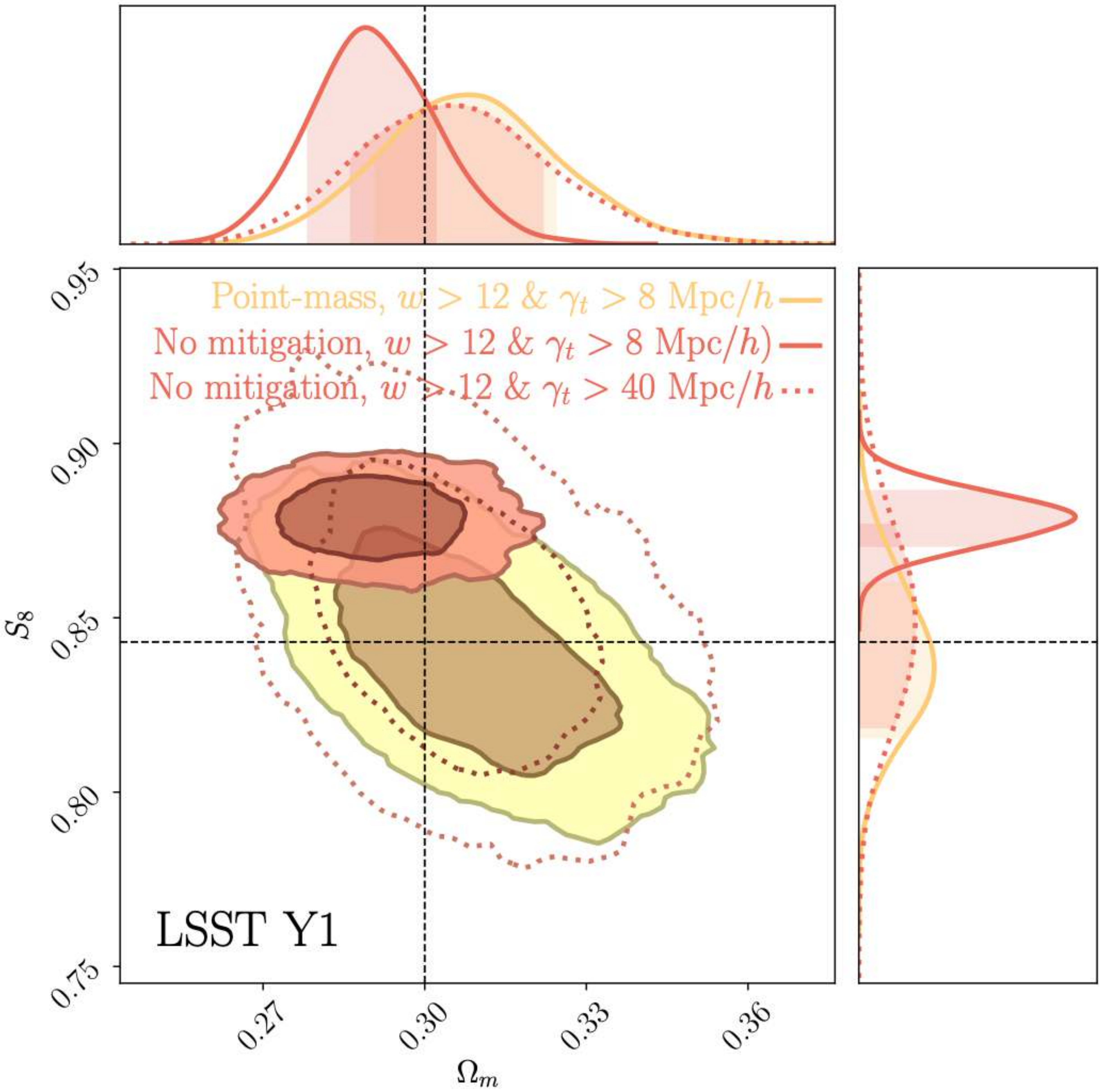
Prat, Zacharegkas et al. (2023): 2212.03734



Is applying point-mass better than using larger-scale cuts?

- In a recent analysis we conclude that using a marginalization scheme yields ~1.3 more constraining power on the S_8 parameter assuming a LSST Y1 simulated scenario than just applying larger scale cuts.

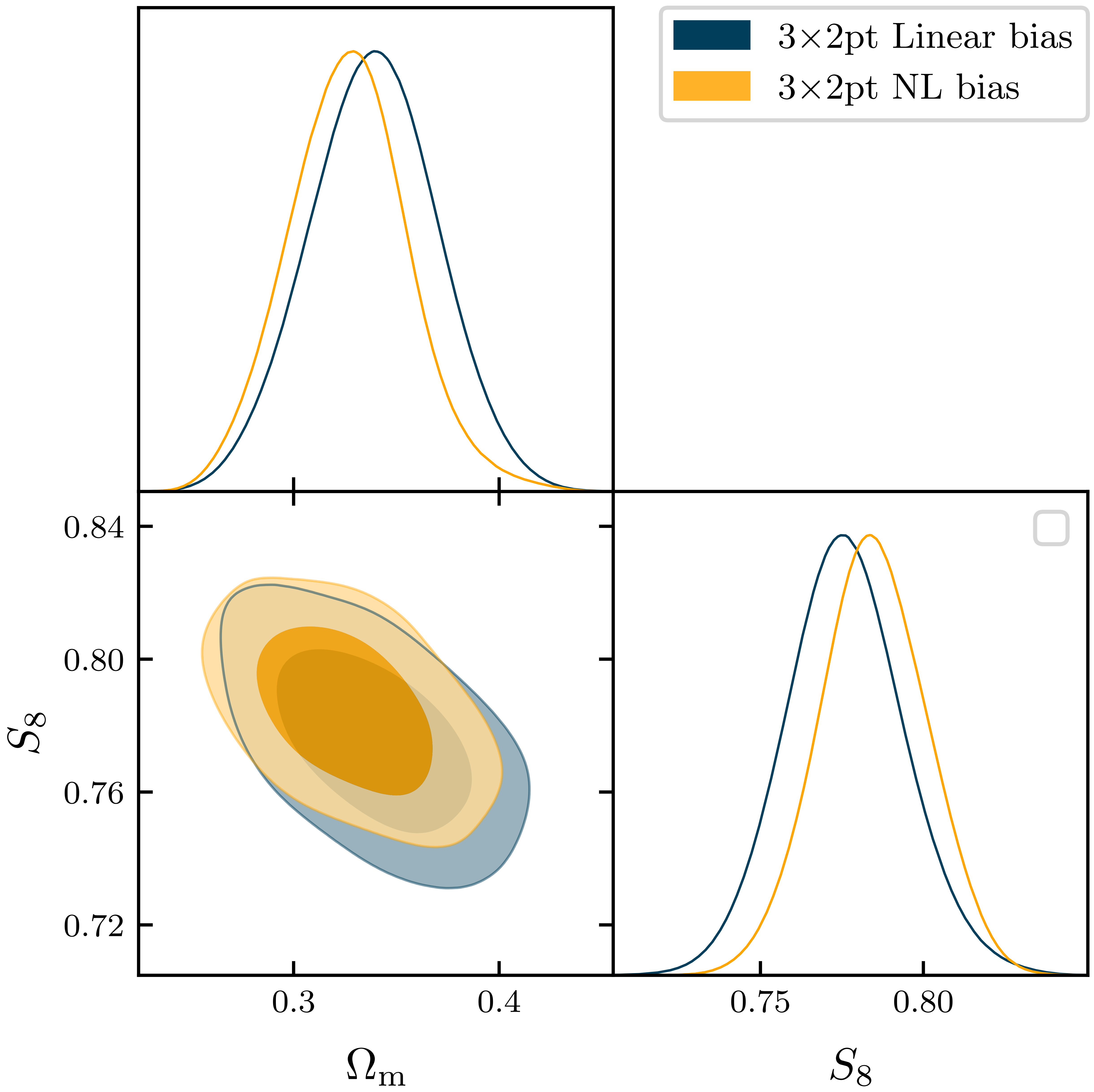
Prat, Zacharegkas et al. (2023): 2212.03734



DES Collaboration (2022): Phys. Rev. D 105, 023520

How much do we improve with non-linear galaxy bias?

- In Y3 for 3x2pt:
  - S_8: 0%
  - Ω_m: 11.11%
  - σ_8: 4.55%

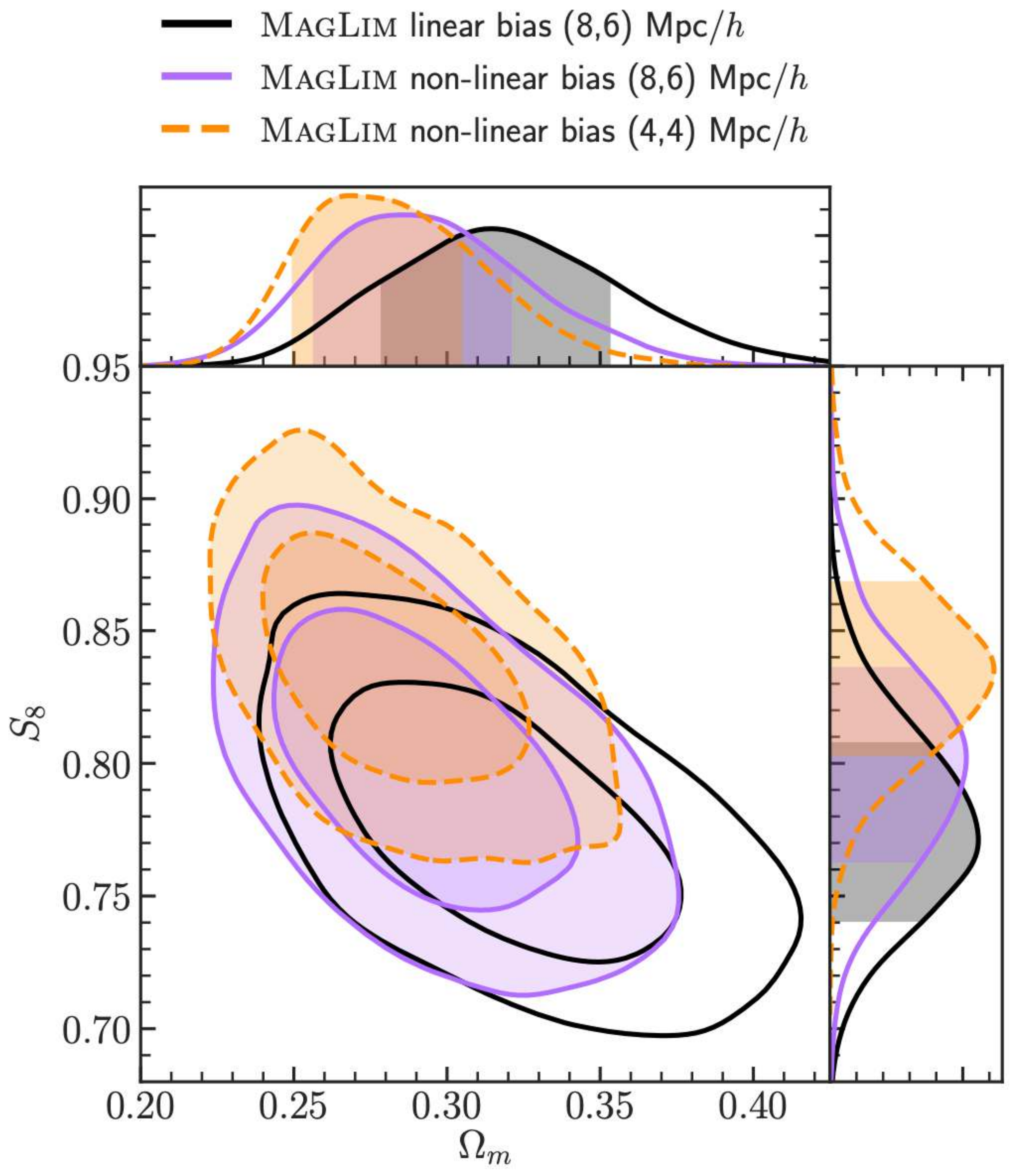


Porredon et al. (2022): Phys. Rev. D 106, 103530

How much do we improve with non-linear galaxy bias?

- In Y3 for 2x2pt:
  - S_8: 2.94%
  - Ω_m: 26.67%
  - σ_8: 0.73%

- So mostly we improve on Ω_m.



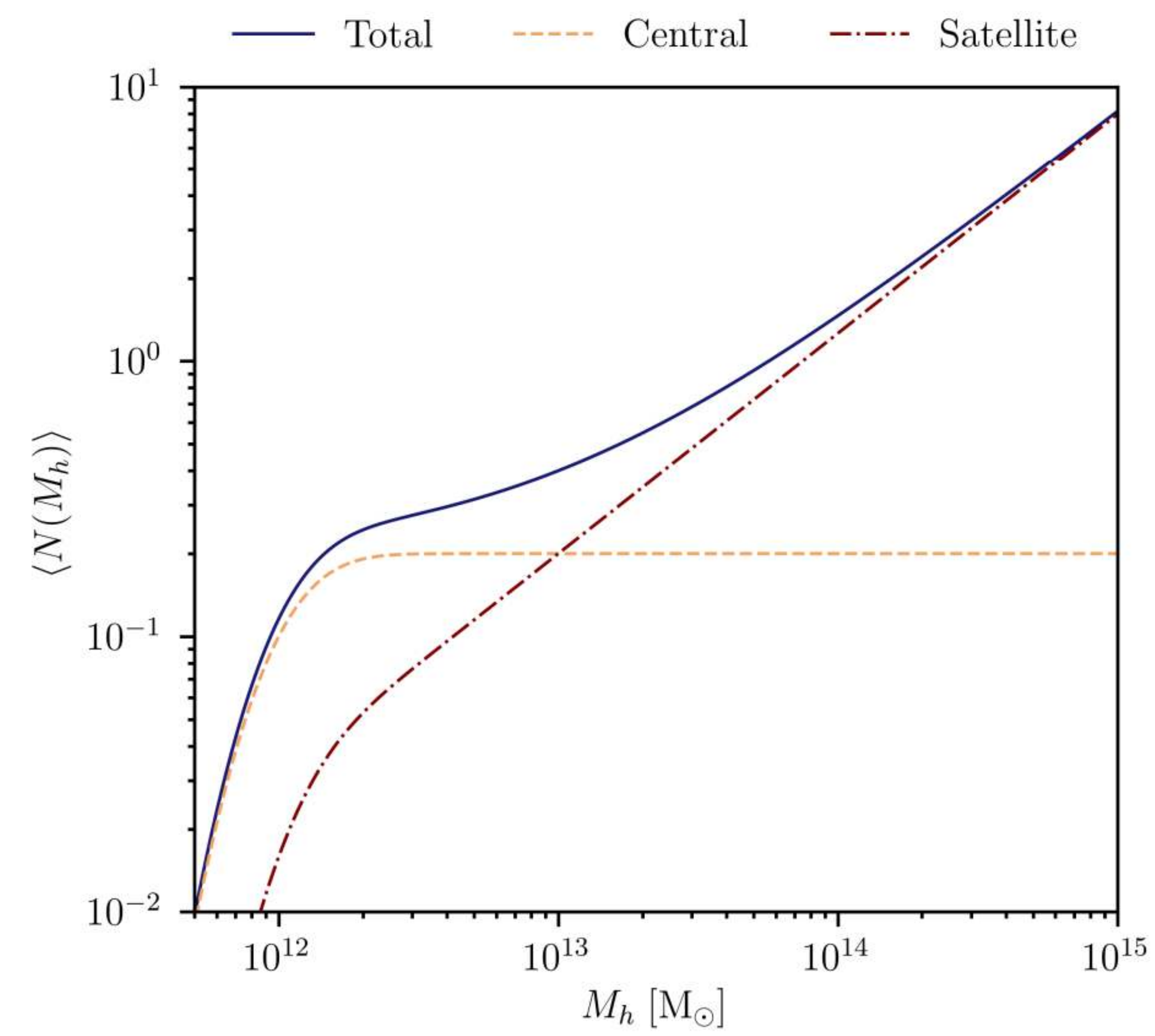
Extension to small scales for galaxy-galaxy lensing DES Y3: *cosmology samples*

Georgios Zacharegkas, Chihway Chang, Judit Prat, Shivam Pandey, and other DES colleagues

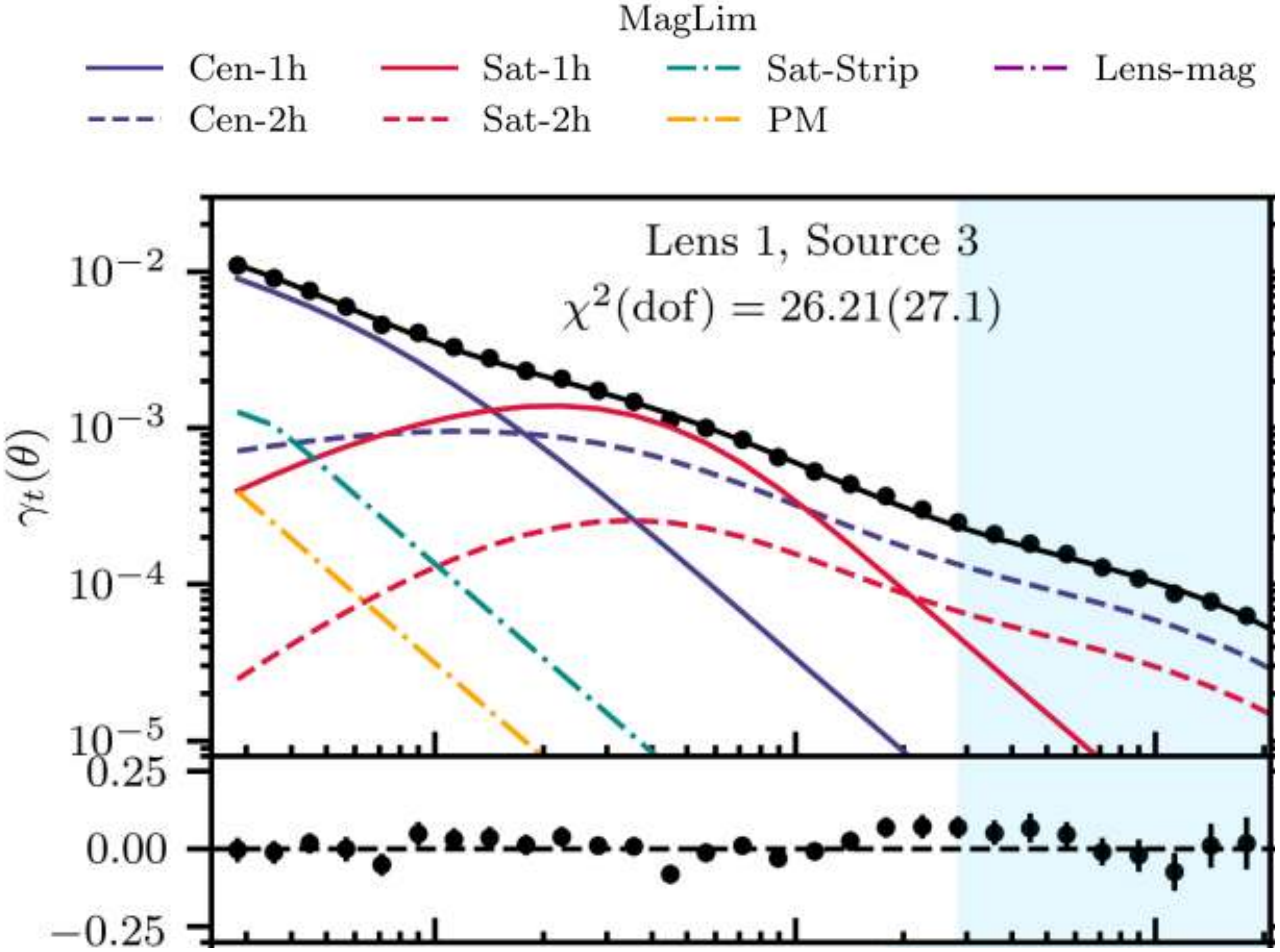
Georgios Zacharegkas,
Postdoc at Argonne National Laboratory, previous graduate student at UChicago

Halo Occupation Model (HOD): *to model small scales*

We extend the galaxy-galaxy lensing signal in the DES Y3 cosmology analysis to the highly nonlinear scales (~100 kpc) *at fixed cosmology*. We fit a 5-parameter HOD model.

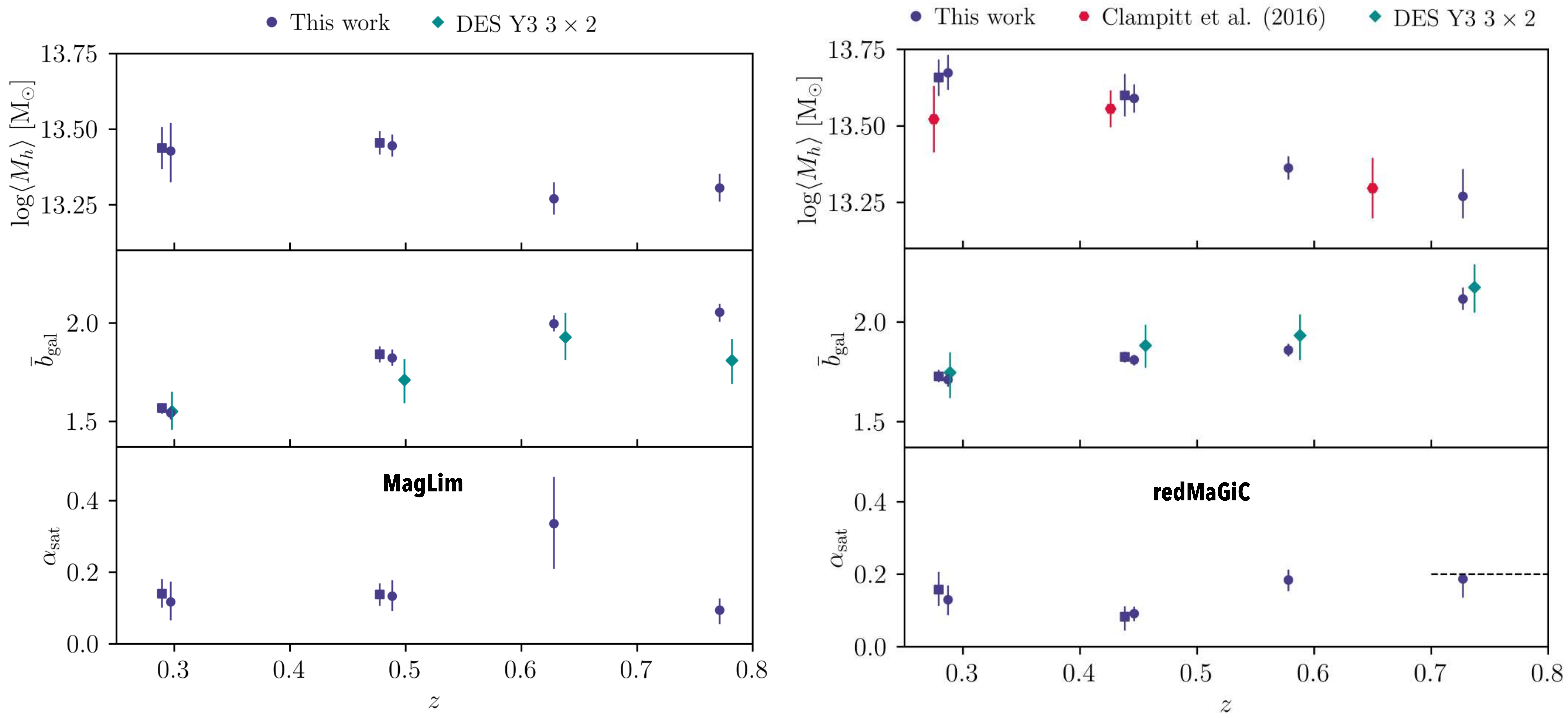


Zacharegkas, Chang, Prat et al. (2022): *arXiv: 2106.08438*



Zacharegkas, Chang, Prat et al. (2022): *arXiv: 2106.08438*

Galaxy-matter connection results



Lessons learned and future prospects

- **We are pushing the limits of the current HOD prescriptions.** Using this model we were able to obtain good fits to the measurements over all angular scales and for all redshift bins we considered, but two out of twelve bin combinations show a best-fit χ^2 per degree-of-freedom ~ 2, which could motivate additional modeling developments for the future, or indicate some residual systematic effect that is not well understood. *This is only with galaxy-galaxy lensing.*

- **Moving forward:** Georgios Zacharegkas and Chihway Chang are leading an analysis to extend this framework for stellar mass samples, and jointly fit galaxy clustering and galaxy-galaxy lensing. *Keep an eye for it!*

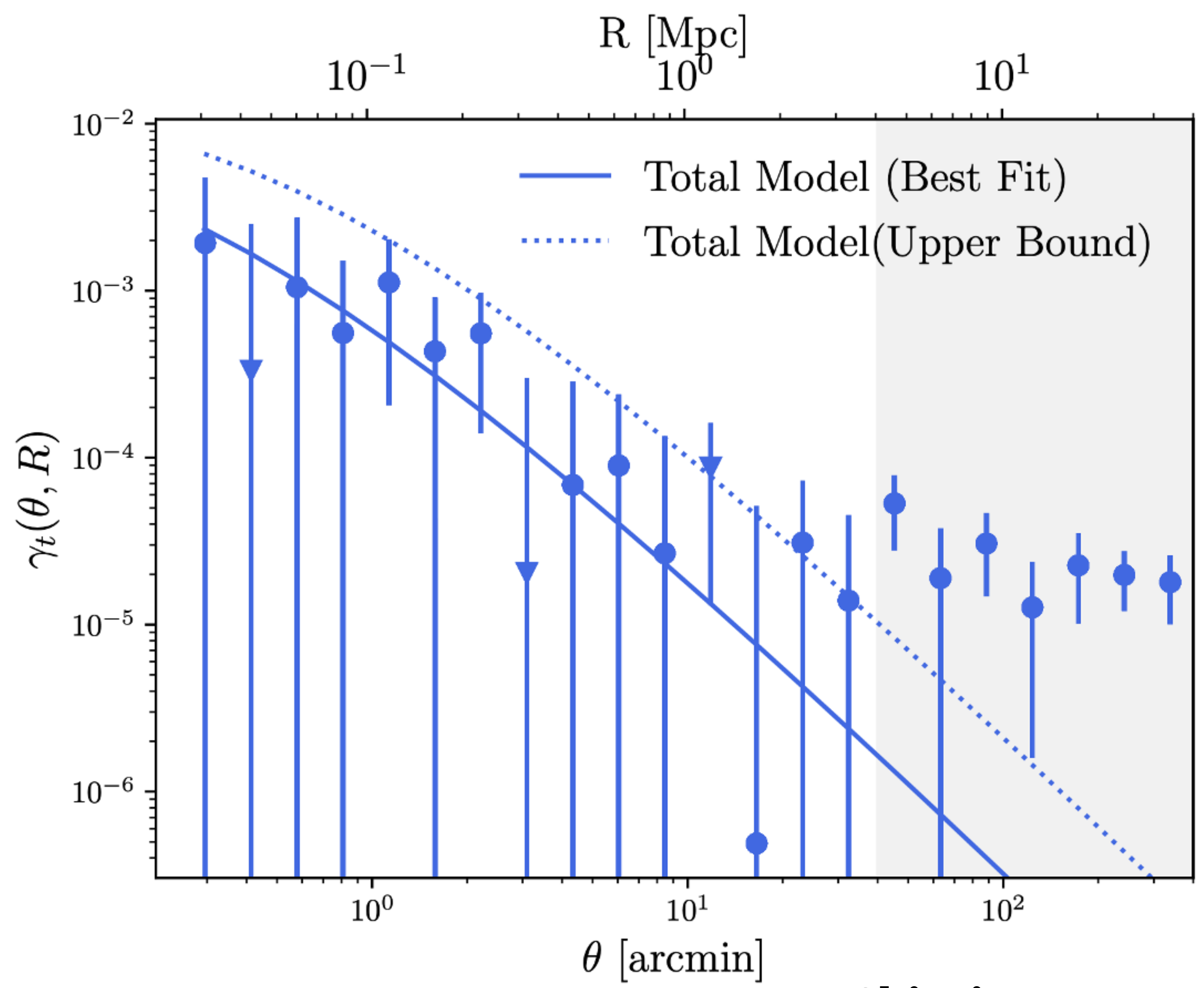
Extension to small scales for galaxy-galaxy lensing DES Y3: *LSBG samples*

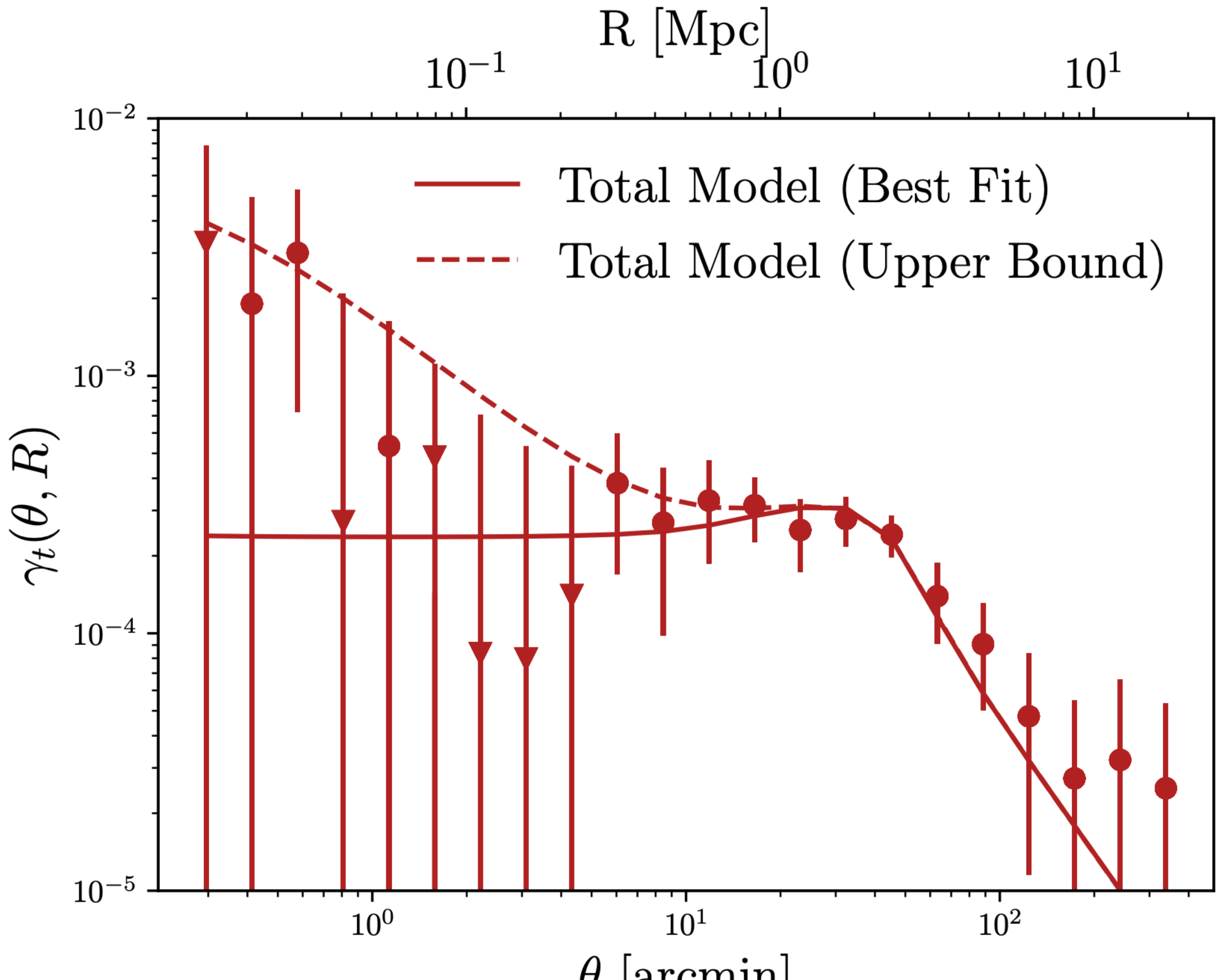
Nathalie Chicoine, Judit Prat, Georgios Zacharegkas, Chihway Chang, and other DES colleagues

Nathalie Chicoine,
PhD student at University of Pittsburg, previous undergraduate at UChicago

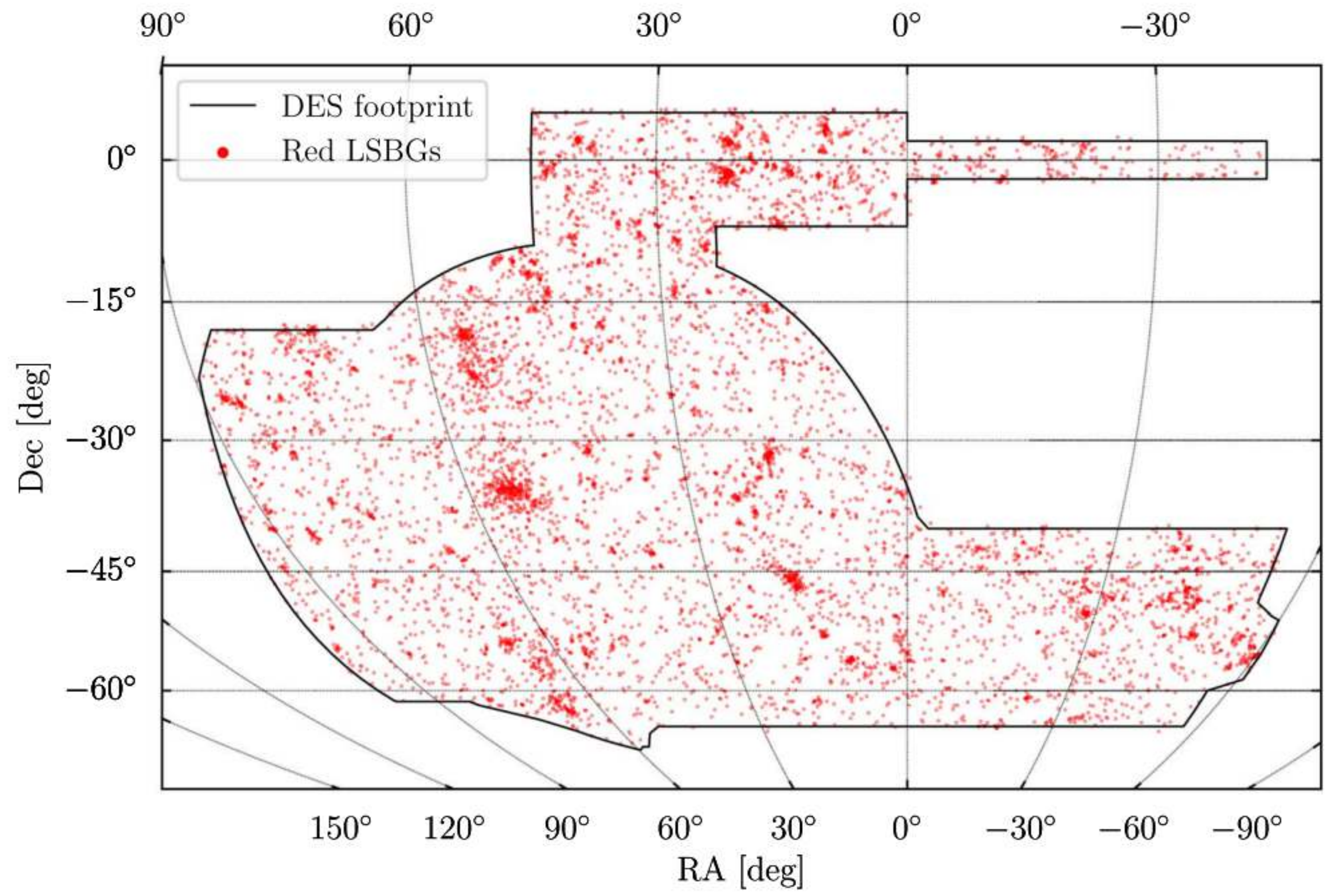
Lensing around low-surface brightness galaxies (LSBGs)

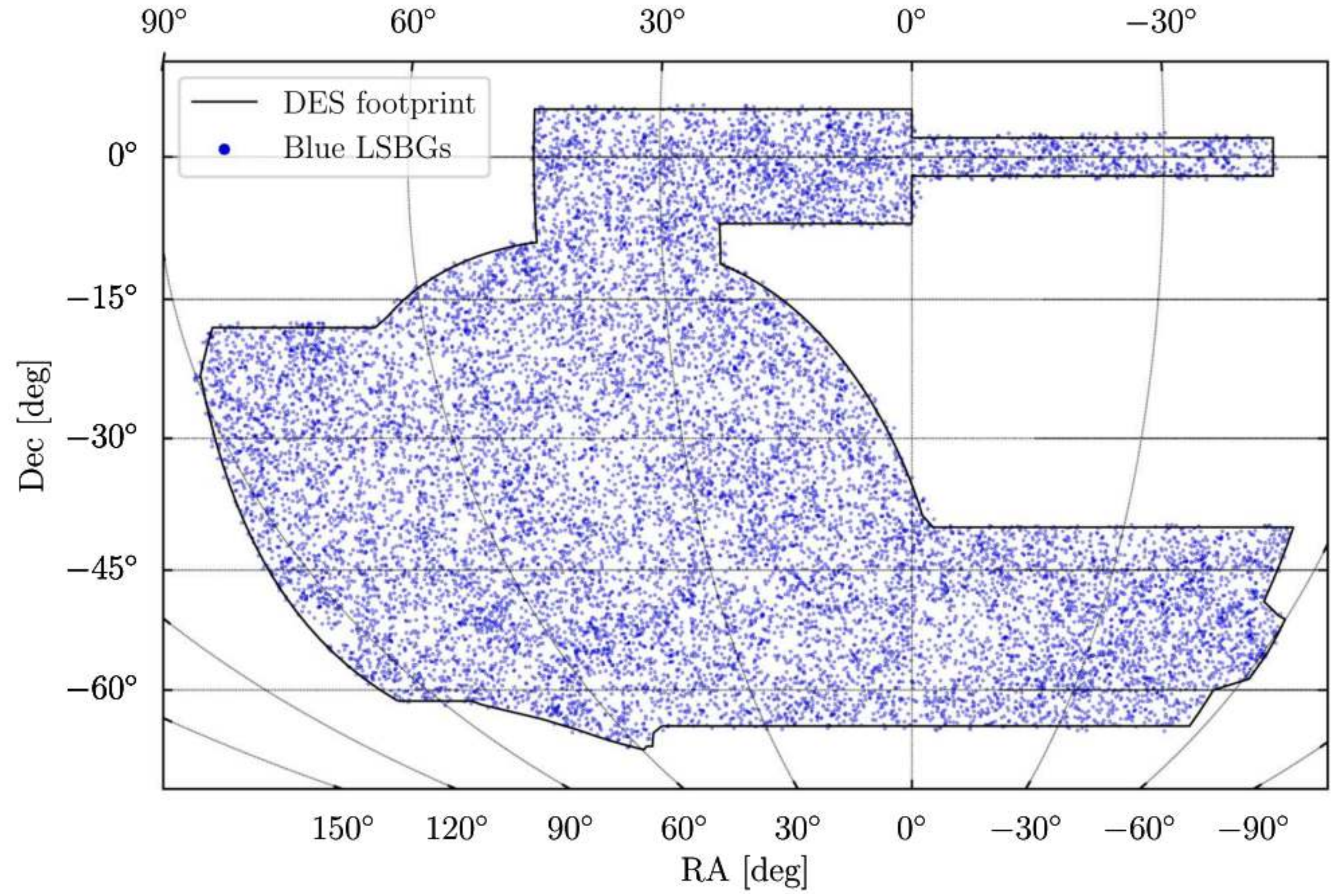
- We performed a weak lensing study around ~24000 LSBGs galaxies using DES Y3 data.
- We fit a simple NFW profile model.





Chicoine, Prat et al. (2024): 2407.19081

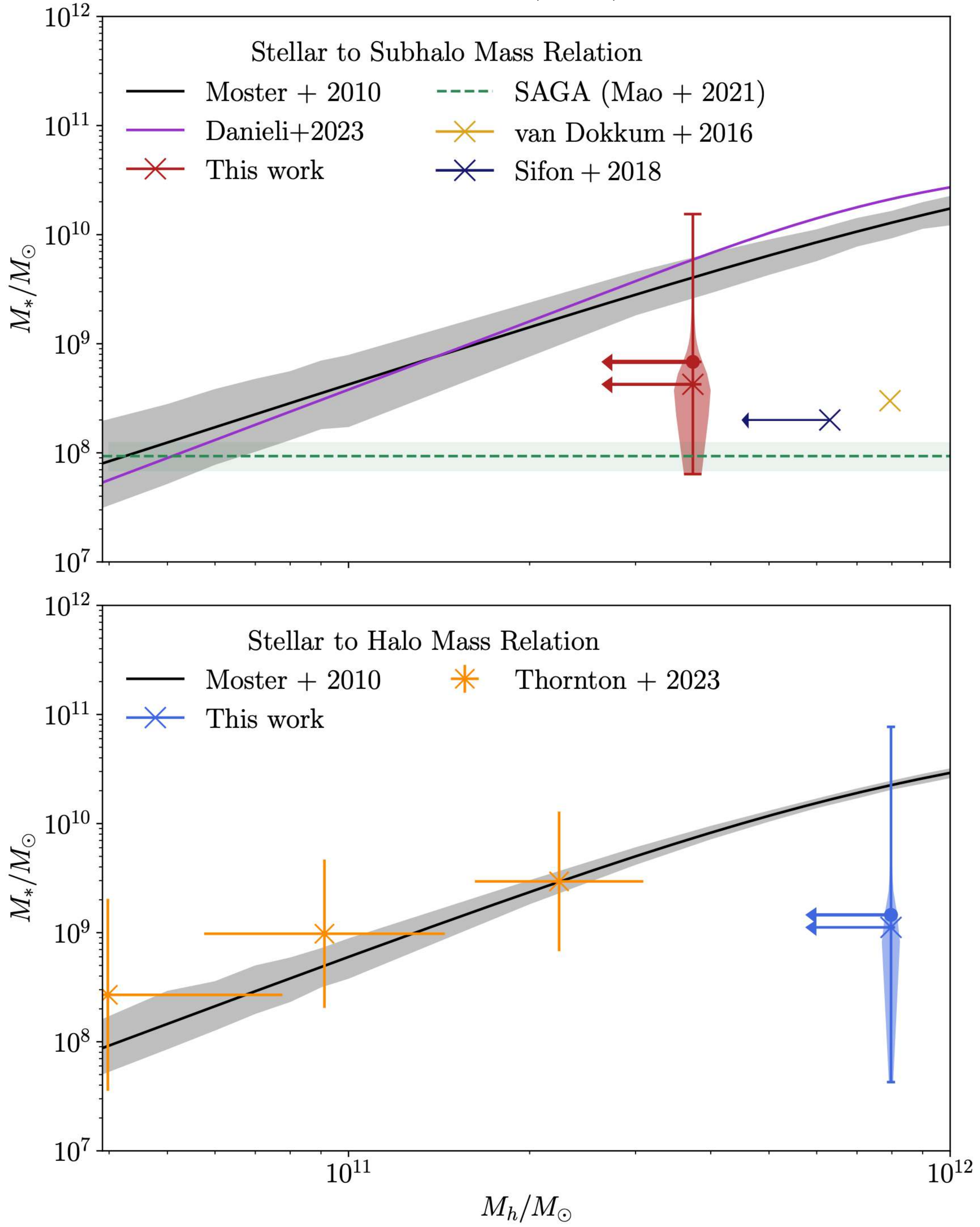




Stellar-to-(sub)halo relation for LSBGs

- We measured the halo mass of such galaxies for the first time.
- Stellar-to-halo mass relation at small masses and for satellite galaxies.
- We find that 28% of the red and 16% of the blue LSBG galaxies meet these conditions and can be classified as UDGs.
- The DES Y6 LSBG catalog may include upwards of 45,000 galaxies and assuming 8gal/arcmin^2 for the source catalog, t**he lensing signal would grow by a factor of~ 2.6**, improving the precision of the LSBG mass constraints.

Chicoine, Prat et al. (2024): 2407.19081



Conclusions and future directions

- We are still using linear galaxy bias for headline collaboration results. Scale cuts and mitigation of dependence on small scales are one of the largest limiting factors of current analyses and they will become even worse in Stage IV surveys unless we improve the modeling.
- People are still reluctant to use informative priors. One reason is that they might not be valid when using them on extended cosmology models or that they have cosmology dependence. *How can we move forward on this front?*
- We need more work connecting real data analysis with advances on knowledge from simulations.
- We used HOD to advance the knowledge on galaxy-matter connection for the cosmology samples and are pushing the boundaries of weak lensing analyses around low-mass halos. *How can we best fold this kind of knowledge in simulation generation or in other pieces of analyses?*

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Mock Barcelona

October 2024

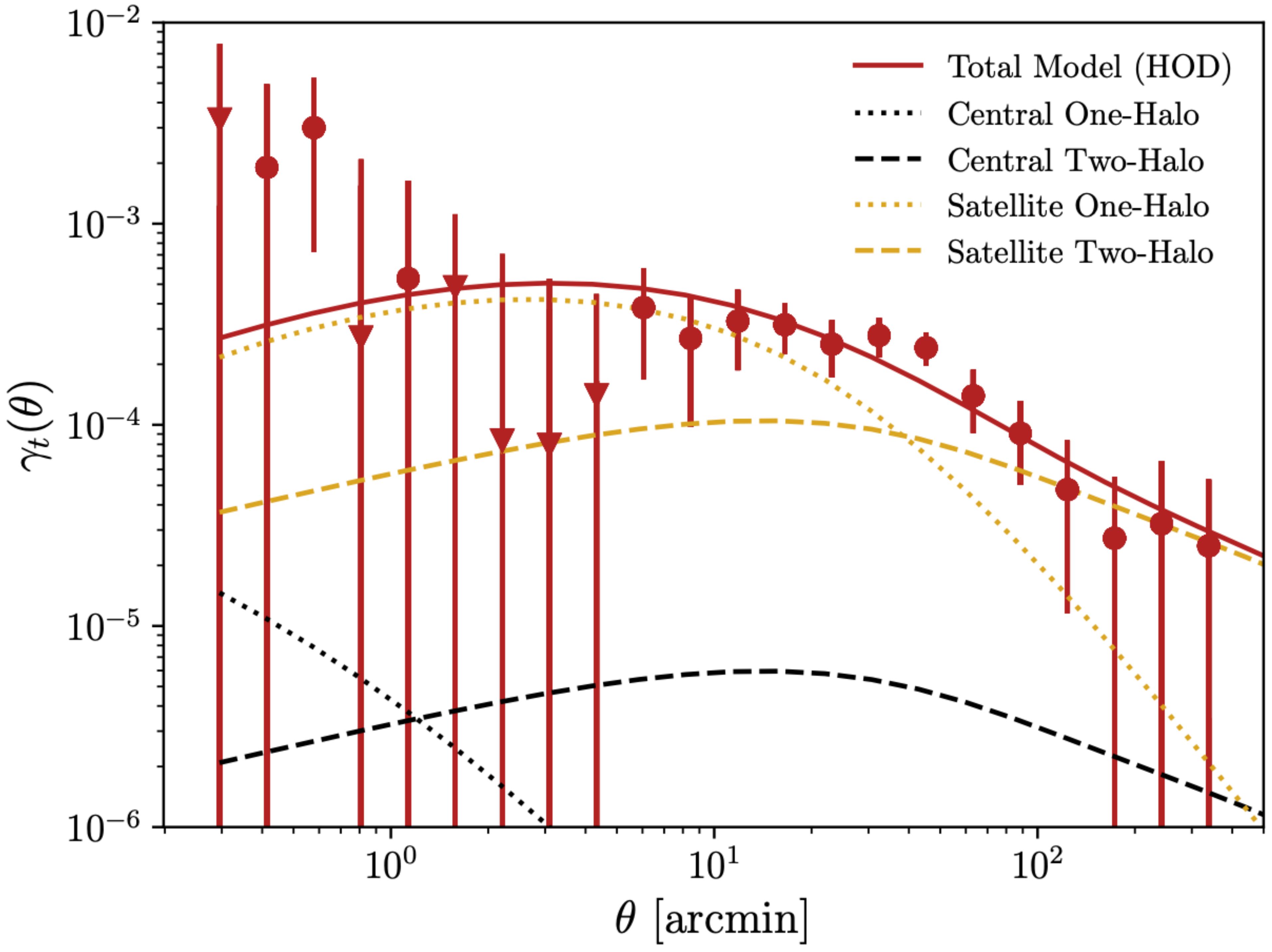


Figure C1. HOD model fit to the red LSBG tangential shear measurements, adopting the model from Zacharegkas et al. (2022). The central one-halo and two-halo terms are subdominant and do not contribute significantly to the model. We find that the best-fit model requires a high satellite fraction of 0.94 ± 0.2 and a host halo mass of $\log(M_{\mathrm{host}}/M_{\odot}) = 13.1 \pm 0.2$. Note that the triangle markers indicate a negative shear measurement.

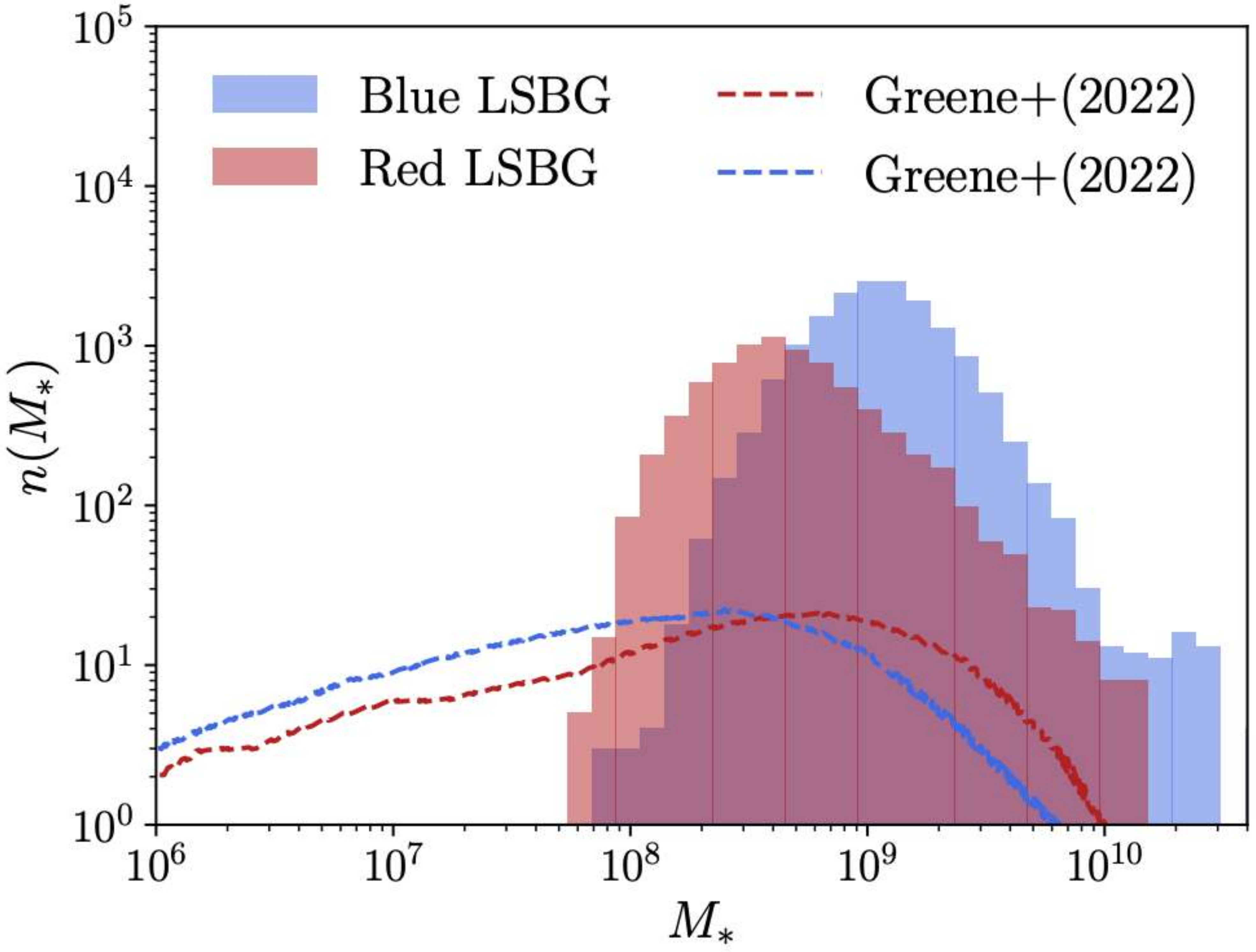
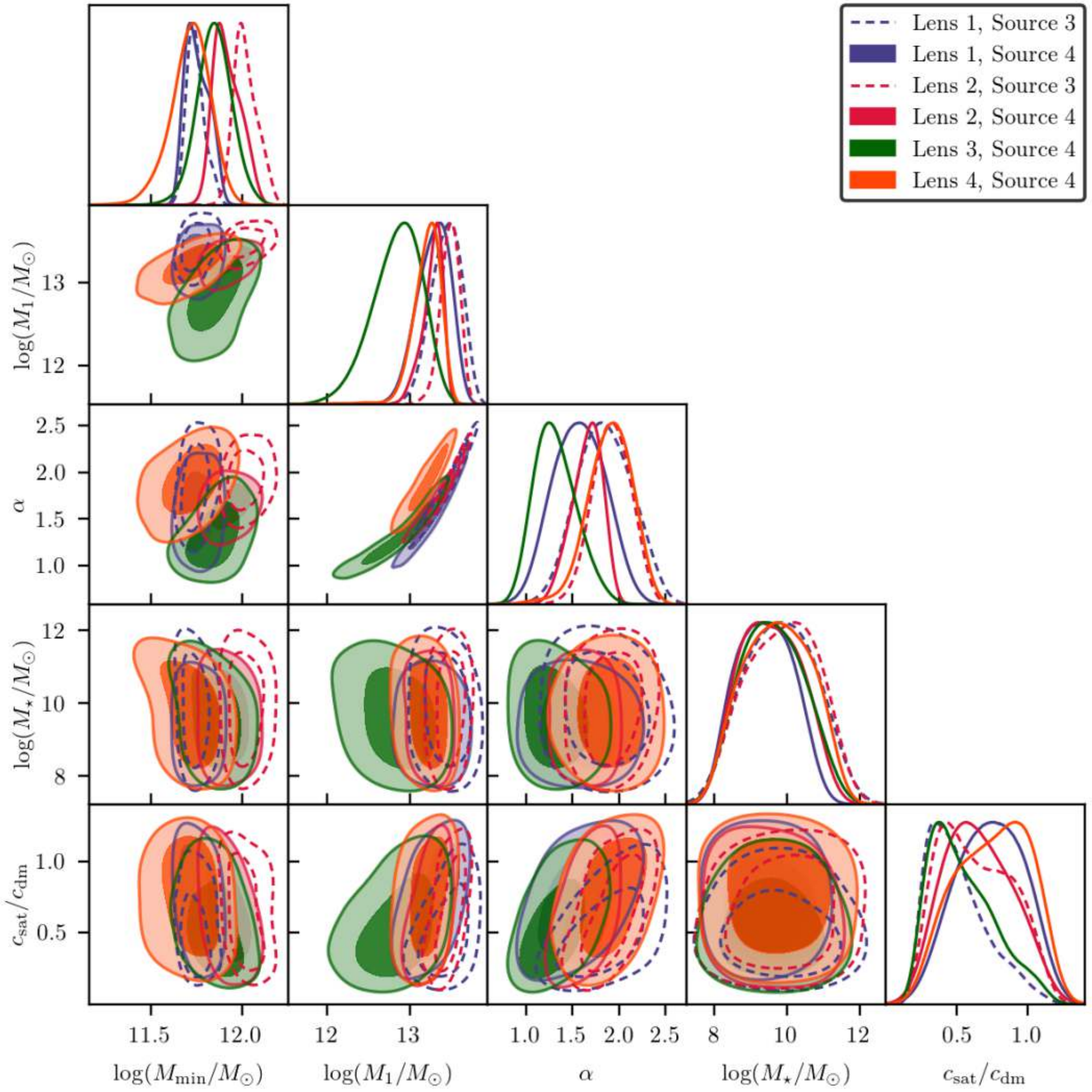
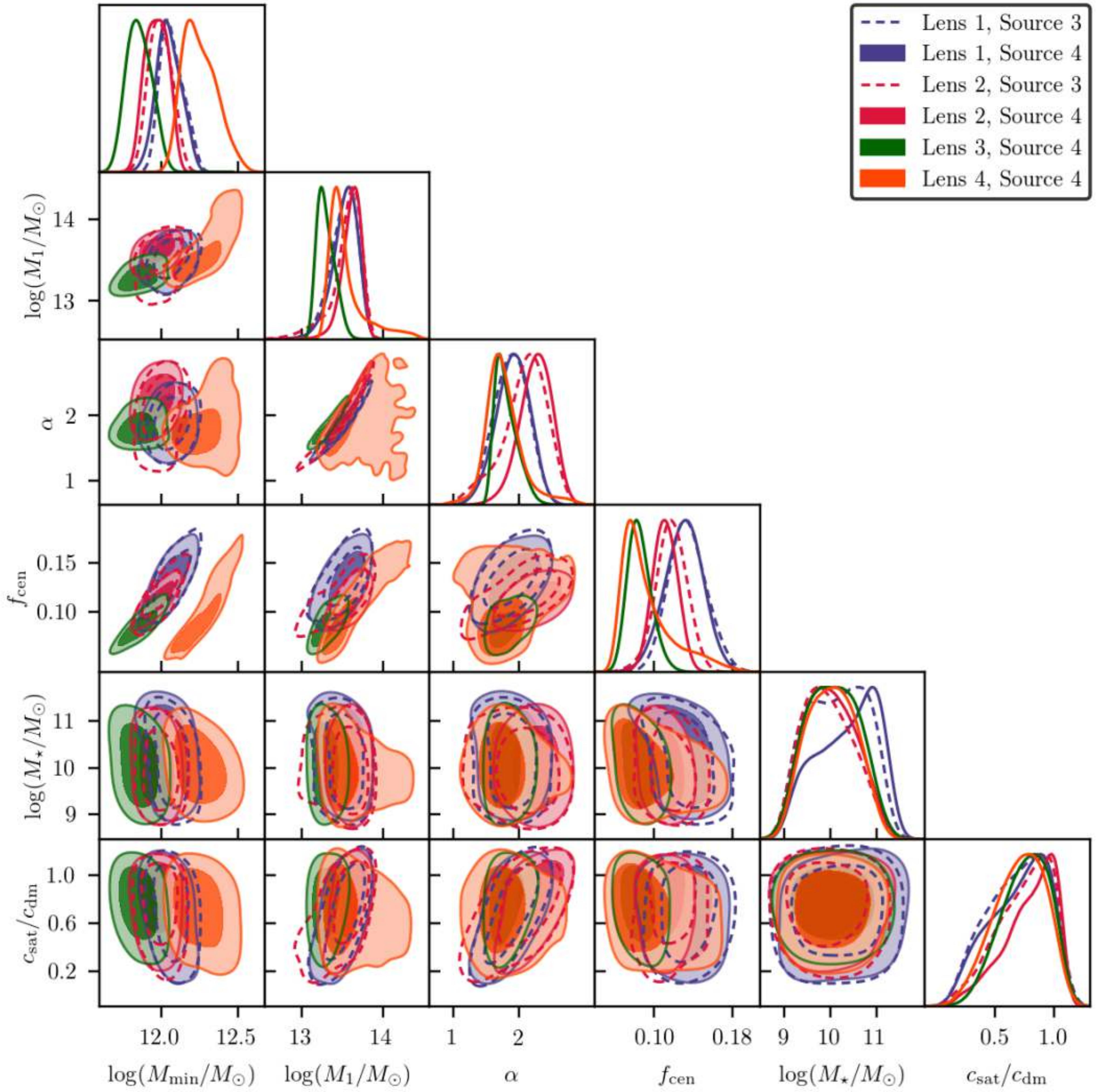


Figure 7. Comparison between the red and blue LSBG stellar mass distributions, generated with the Bell et al. (2003) CMLR, and the results from the HSC LSBG red and blue stellar mass distributions from Greene et al. (2022), represented by the dashed lines. Note that the Greene et al. (2022) distribution has a larger low-mass tail, possibly due to the increased depth of the HSC data, and utilizes the Into & Portinari (2013) CMLR.

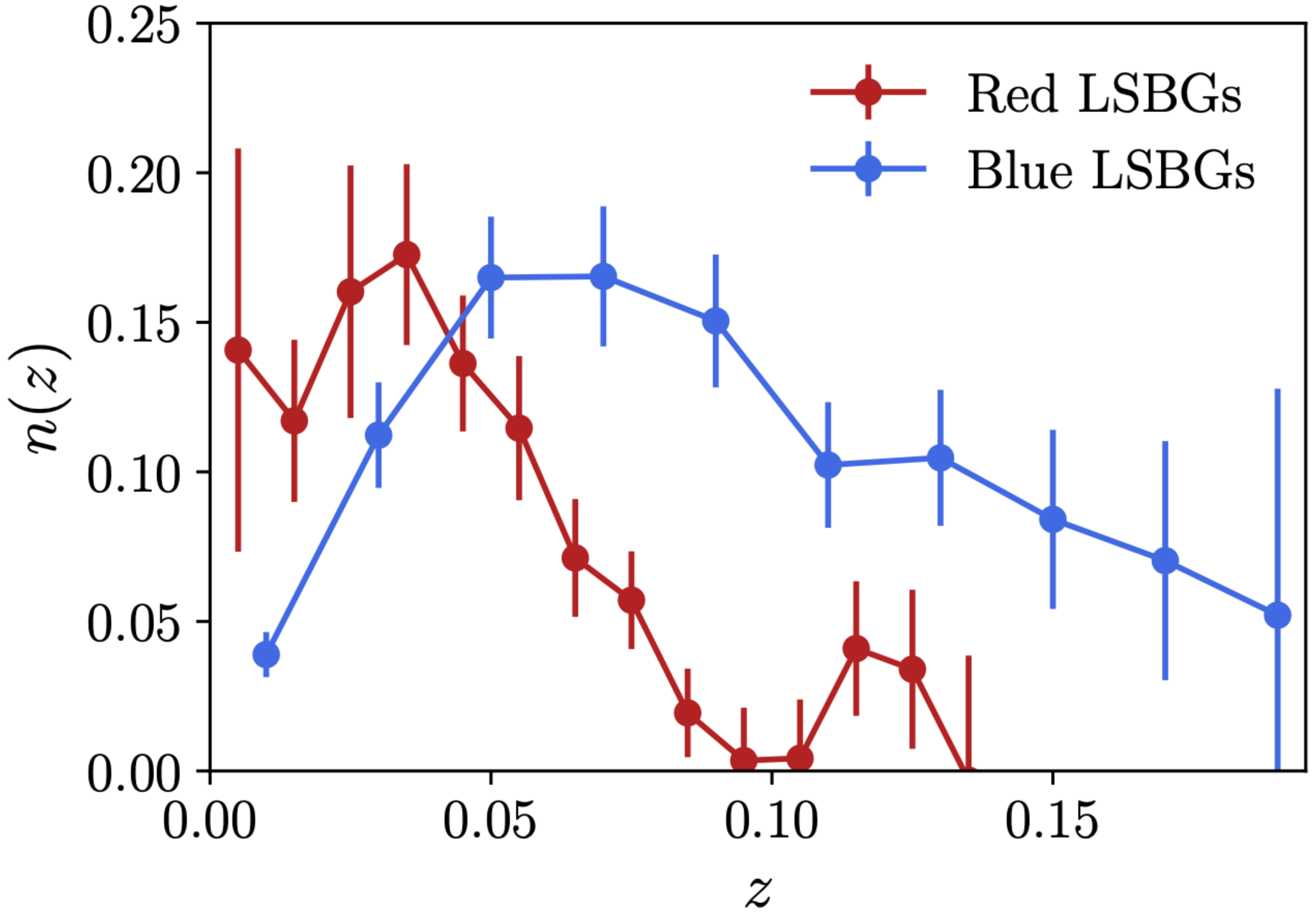

Lens 1, Source 3
Lens 1, Source 4
Lens 2, Source 3
Lens 2, Source 4
Lens 3, Source 4
Lens 4, Source 4
$\log(M_{\rm min}/M_\odot)$
$\log(M_1/M_\odot)$
α
$\log(M_\star/M_\odot)$
$c_{\rm sat}/c_{\rm dm}$

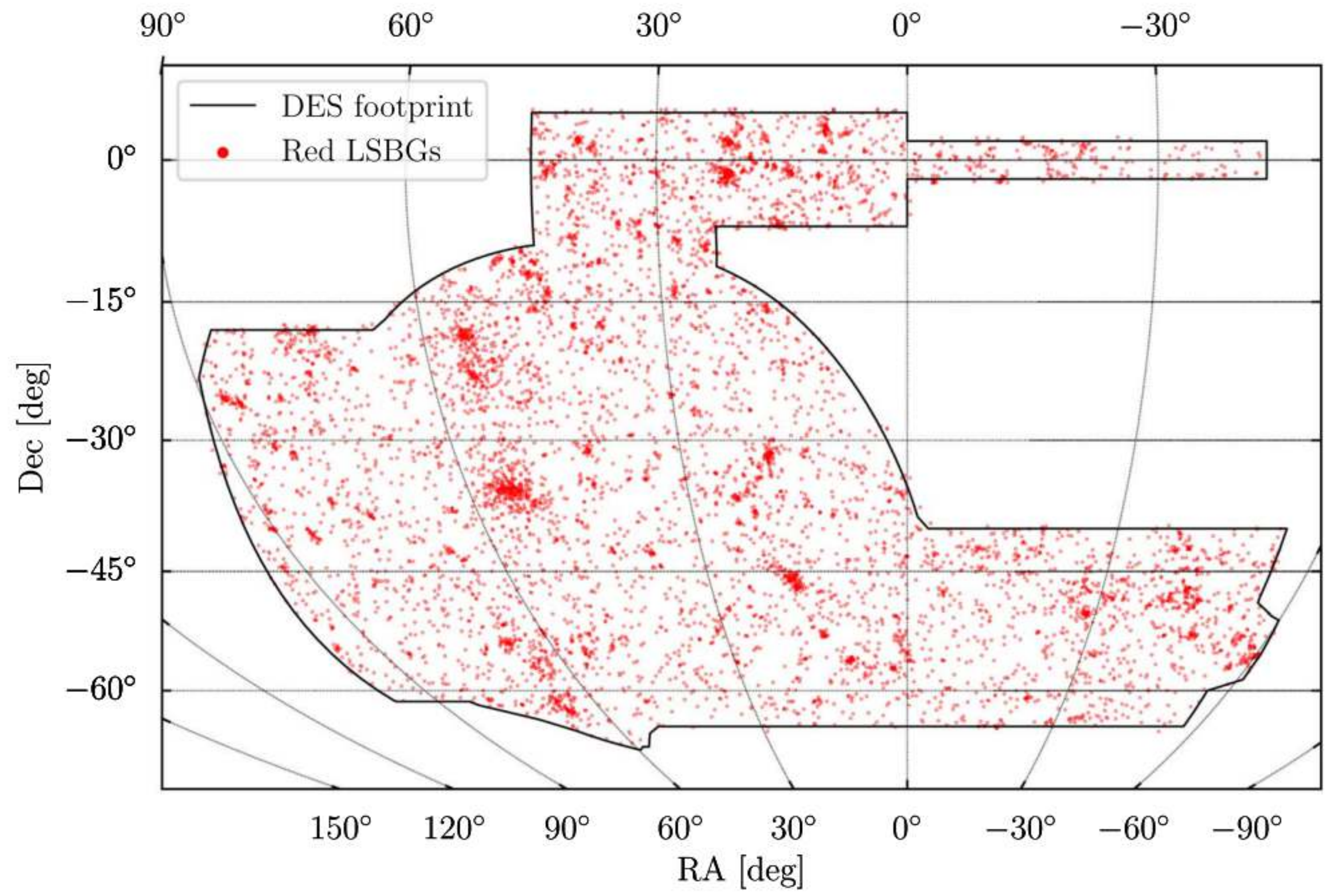

Lens 1, Source 3
Lens 1, Source 4
Lens 2, Source 3
Lens 2, Source 4
Lens 3, Source 4
Lens 4, Source 4
$\log(M_{\rm min}/M_\odot)$
$\log(M_1/M_\odot)$
α
$f_{\rm cen}$
$\log(M_\star/M_\odot)$
$c_{\rm sat}/c_{\rm dm}$

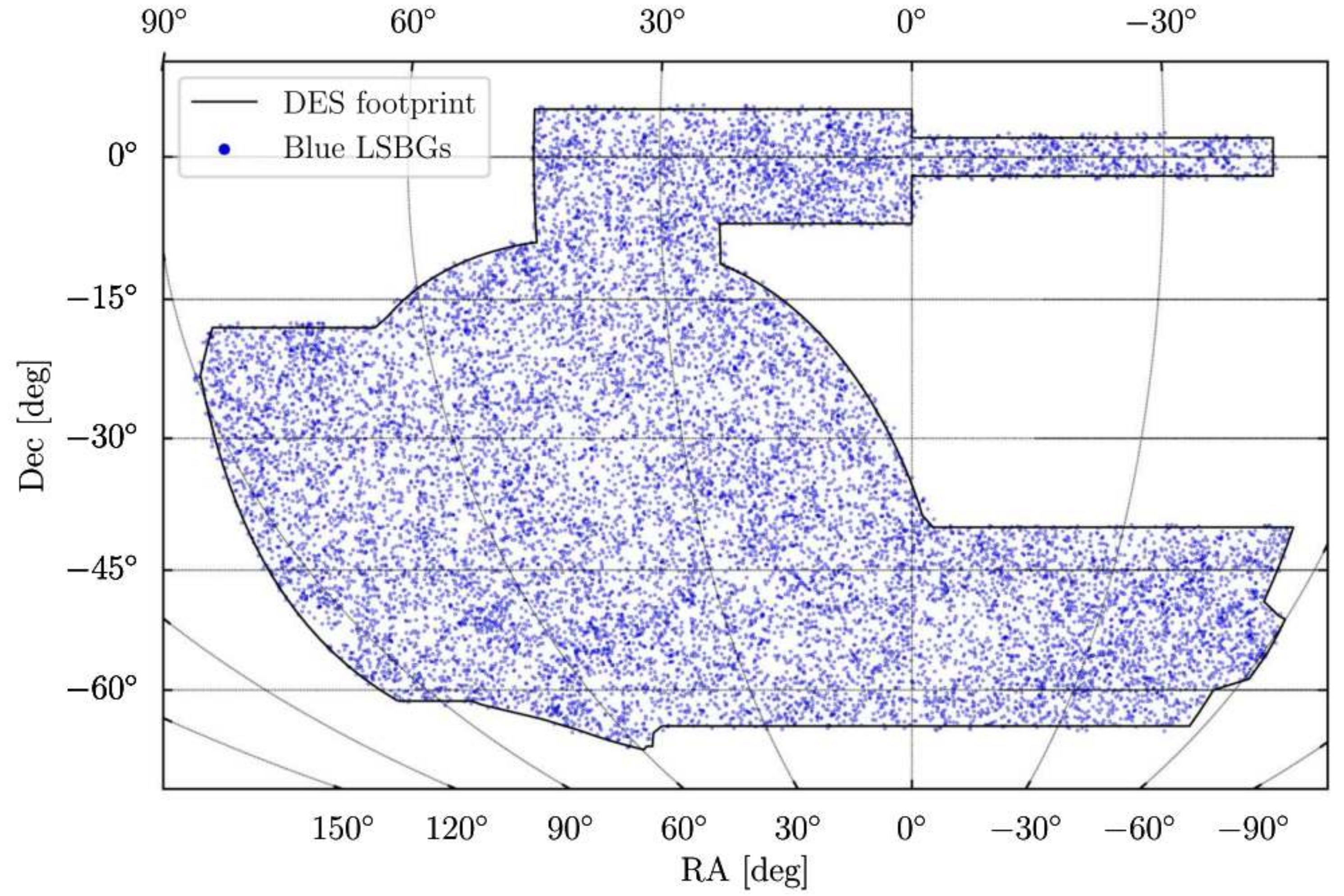
Lensing around low-surface brightness galaxies (LSBGs)

- We performed a weak lensing study around ~24000 LSBGs galaxies using DES Y3 data.
- We cross-correlate the positions of the LSBG catalog with the positions of the all-sky 2MPZ catalog which contains ~10^6 galaxies. It has median redshift of $z \sim 0.1$, a maximum redshift of $z \sim 0.4$, and a precision of $\sigma z \sim 0.015$.

Chicoine, Prat et al. (2024): 2407.19081







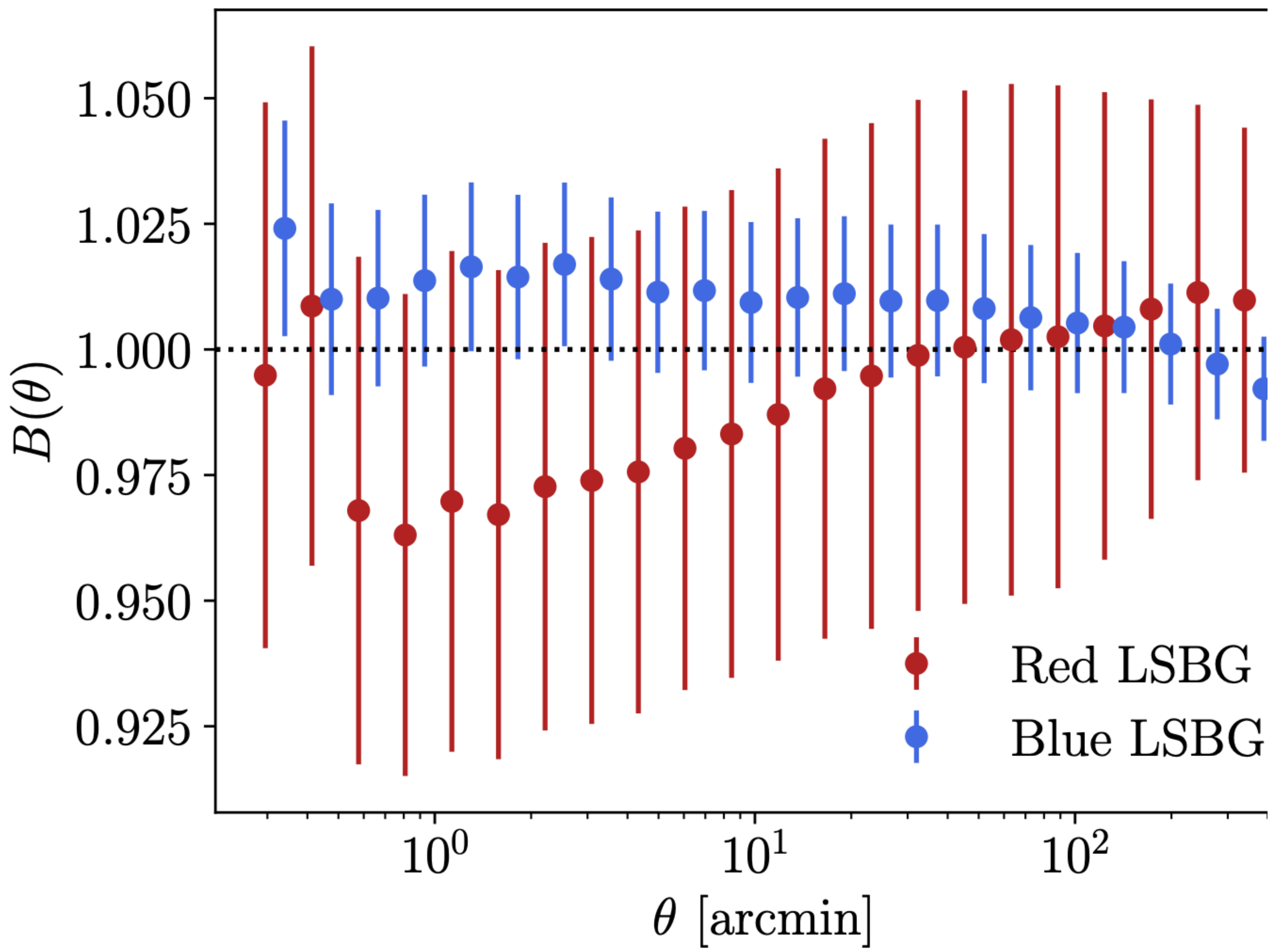


Figure A3. Boost factor measurements for the red and blue LSBG sa
with an offset in θ to improve visibility. The errorbars come from the
knife covariance. The boost factor measurements are highly correlate
consistent with unity for both red and blue galaxies. The increased
variation between the red galaxy positions in the DES footprint heighte
boost factor covariance measurements, leading to larger errorbars.

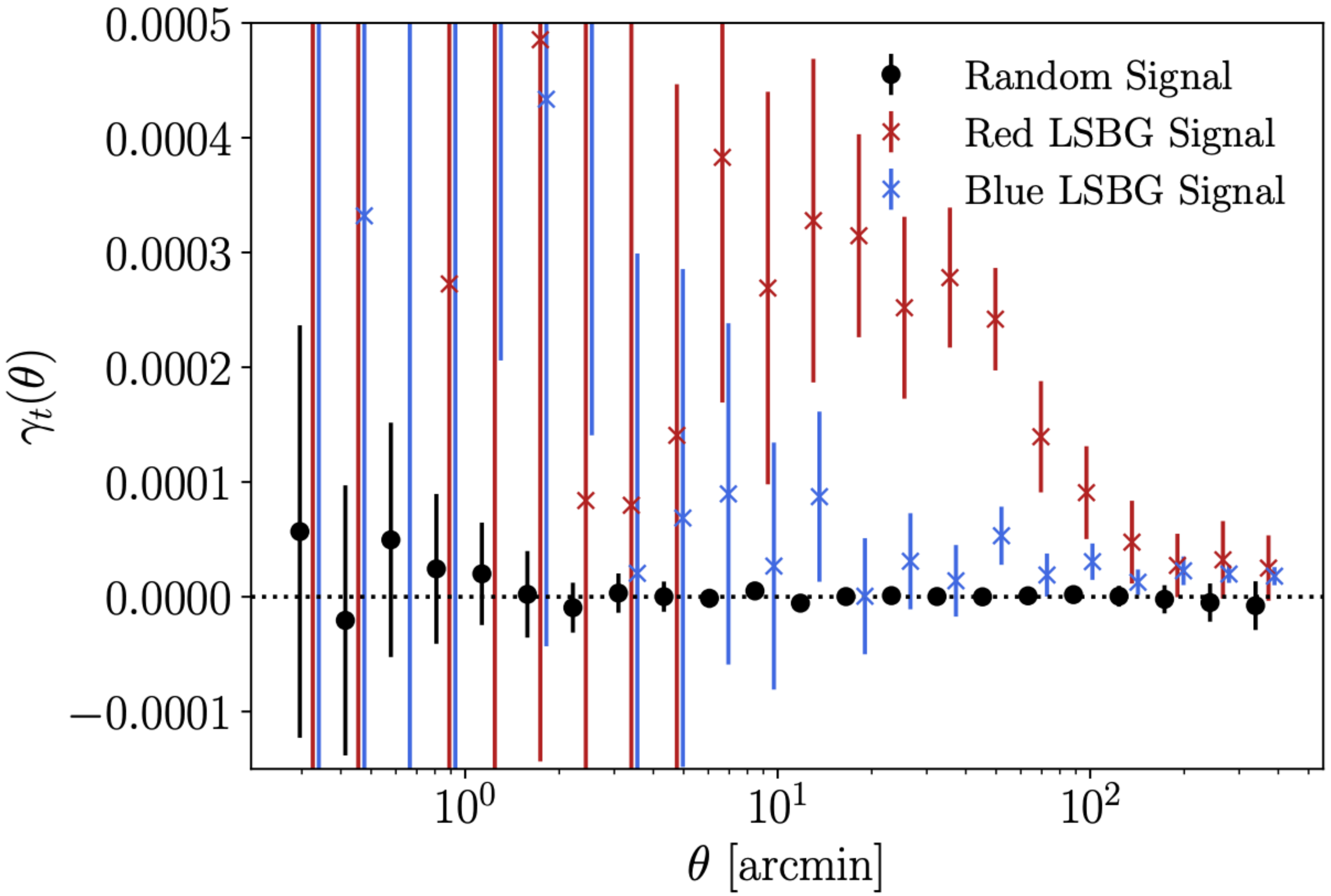


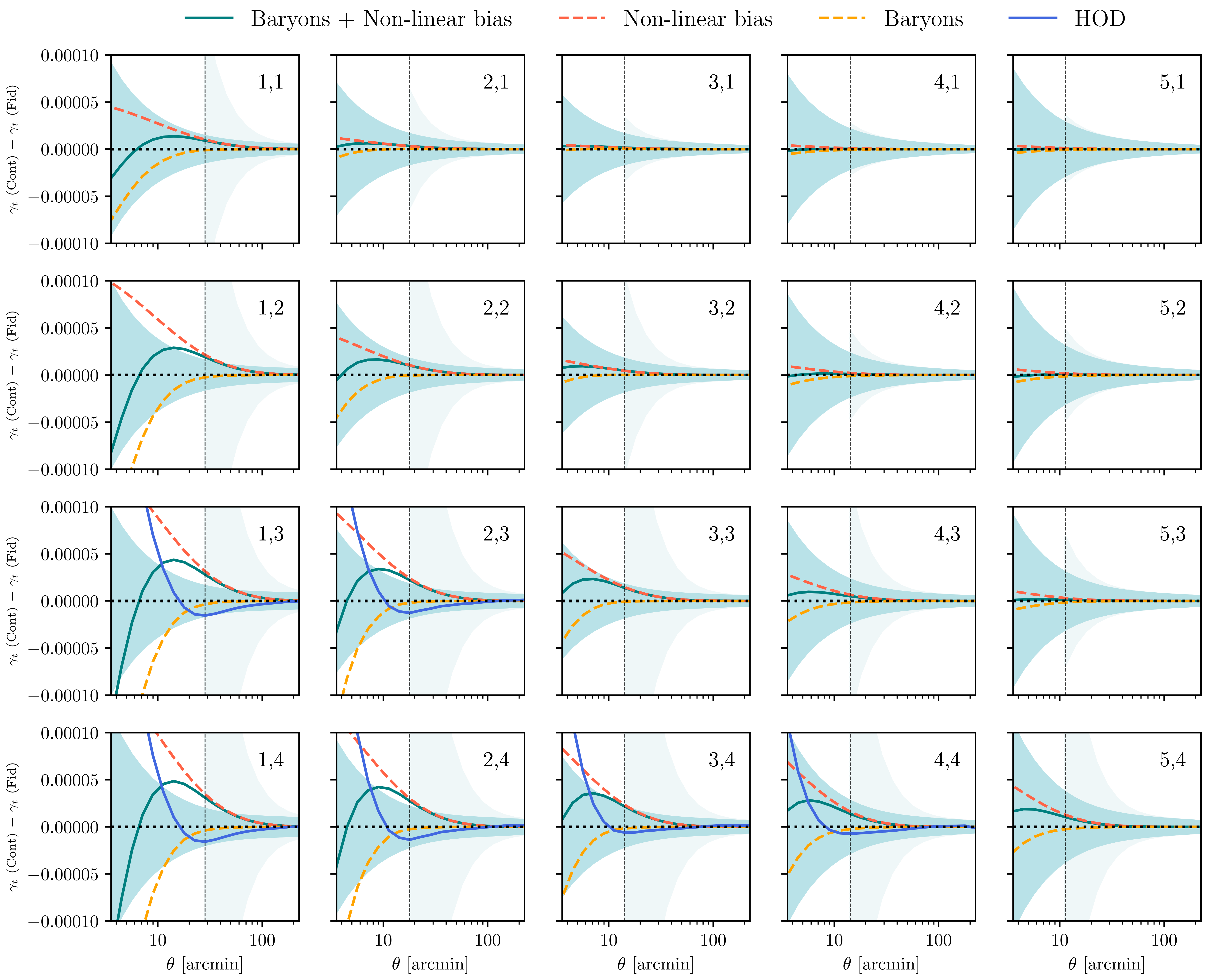
Figure A2. Tangential shear measurements around the random point sample, divided into 22 angular bins, compared to the red and blue LSBG lensing signals. All shape catalog redshift bins are combined. The shear measurements do not produce a significant signal, with a $\chi^2_{\rm null}$ of 3.21/22.

MacCrann et al. (2019): 1903.07101

Tangential shear modeling: Point-mass marginalization

- Given our scale cuts (6Mpc/h), we cannot choose an informative prior, since the point-mass at these scales also encapsulates information coming from the 2-halo regime. Thus we choose an infinite prior which is applied directly to the inverse covariance analytically.

- To illustrate the impact of the point-mass to the uncertainties, we use a finite point-mass of $5 \times 10^{13}\ M_\odot$ to obtain a covariance and plot here the uncertainties.



Ultra diffuse galaxies

UDGS

- UDGs are typically defined as galaxies with a physical radius of (Reff (g) > 1.5kpc) and a central surface brightness of μ0 (g) > 24.0 mag arcsec−2.
- We find that 28% of the red and 16% of the blue LSBG galaxies meet these conditions and can be classified as UDGs.

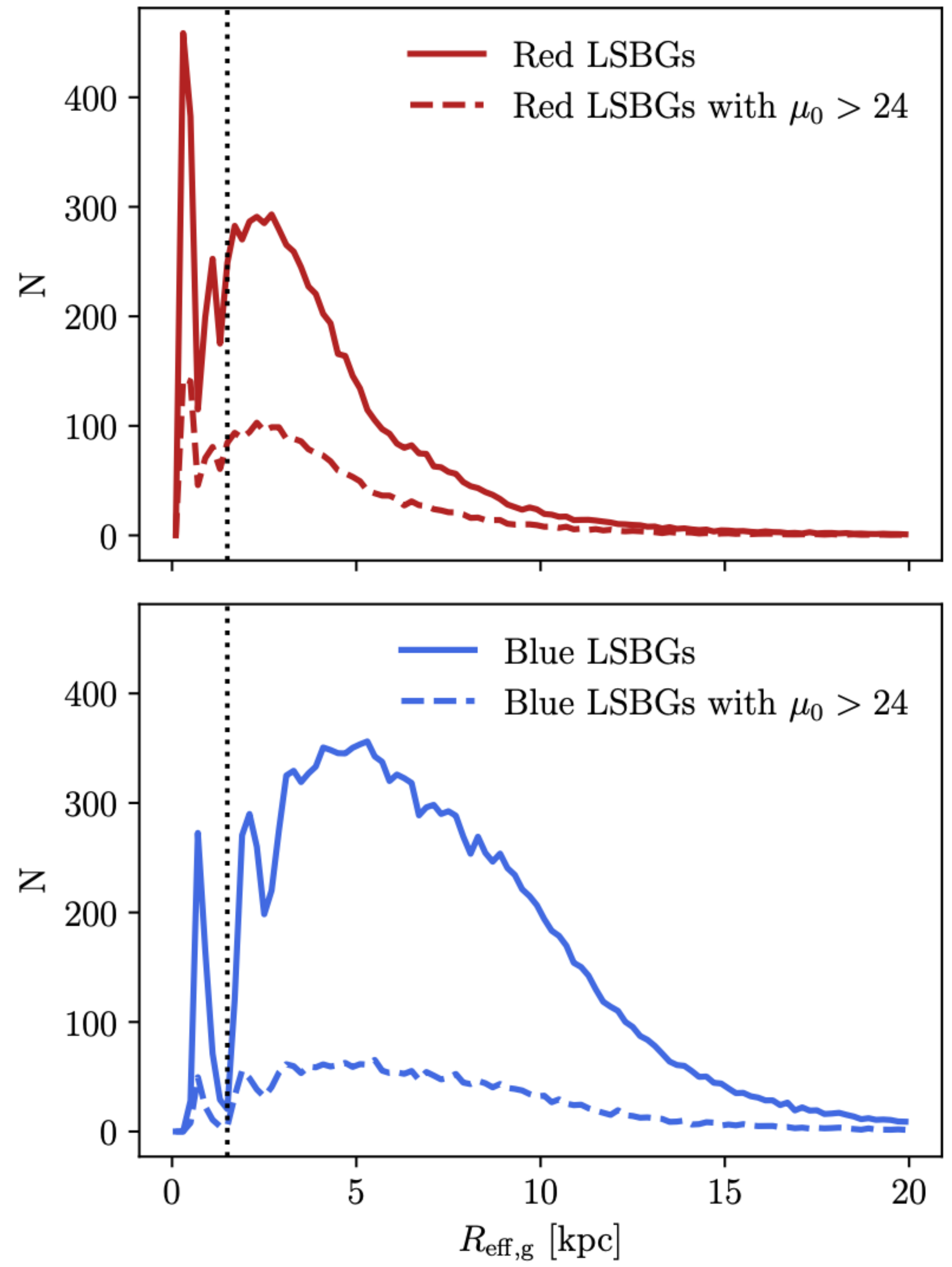
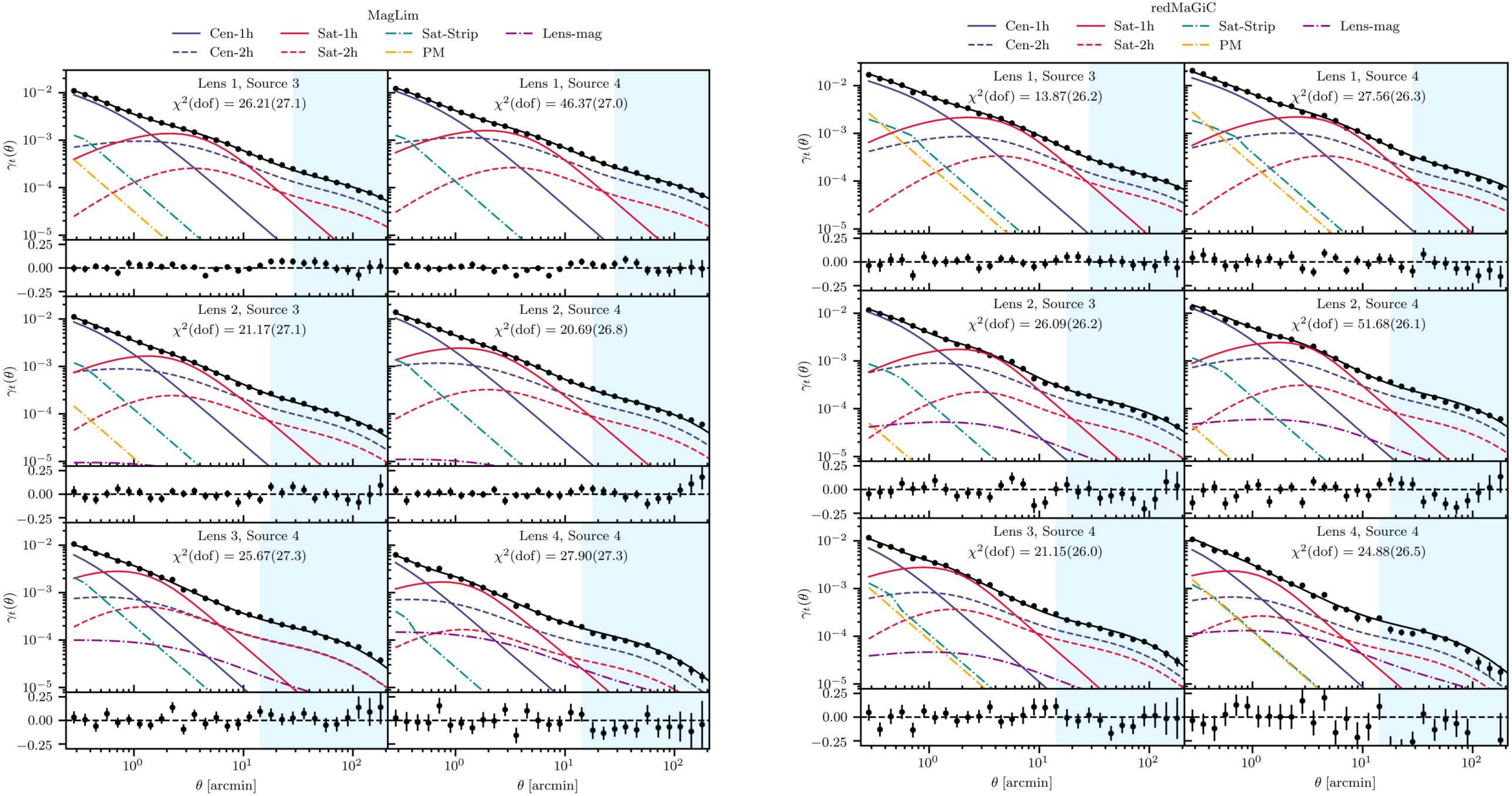
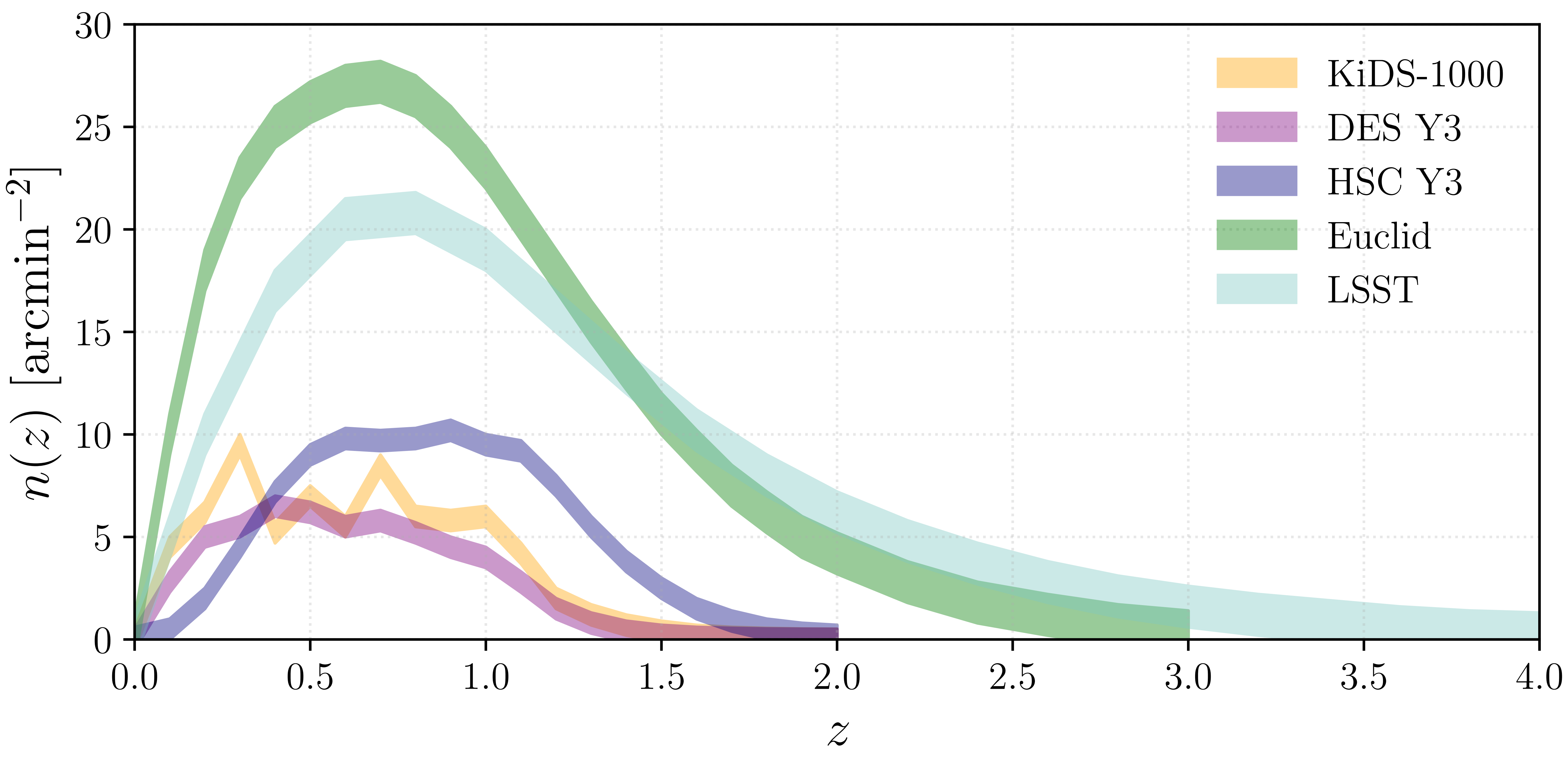


Figure D1. Physical size distribution for the red and blue LSBG samples. The dashed lines show the galaxies that meet the central surface brightness qualifications for an UDG. The black vertical dashed lines indicate the physical size cutoff for red and blue UDGs.


MagLim
Cen-1h
Sat-1h
Sat-Strip
Lens-mag
Cen-2h
Sat-2h
PM
Lens 1, Source 3
χ^2(dof) = 26.21(27.1)
Lens 1, Source 4
χ^2(dof) = 46.37(27.0)
Lens 2, Source 3
χ^2(dof) = 21.17(27.1)
Lens 2, Source 4
χ^2(dof) = 20.69(26.8)
Lens 3, Source 4
χ^2(dof) = 25.67(27.3)
Lens 4, Source 4
χ^2(dof) = 27.90(27.3)
$\gamma_t(\theta)$
θ [arcmin]
redMaGiC
Lens 1, Source 3
χ^2(dof) = 13.87(26.2)
Lens 1, Source 4
χ^2(dof) = 27.56(26.3)
Lens 2, Source 3
χ^2(dof) = 26.09(26.2)
Lens 2, Source 4
χ^2(dof) = 51.68(26.1)
Lens 3, Source 4
χ^2(dof) = 21.15(26.0)
Lens 4, Source 4
χ^2(dof) = 24.88(26.5)

What's coming?

Exciting times ahead!



	Survey	Area (deg^2)	Source density [arcmin^{-2}]	Redshift range	Observing Status
Stage III	DES Y3	4,143	5.59	0.2 - 1.3	Completed
	KiDS-1000	773	6.17	0.1 - 1.2	Completed
	HSC Y3	416	15	0.3 - 1.5	Ongoing
Stage IV	Euclid	14,000	~27	0 - 2+	Ongoing
	LSST	18,000	~27	0 - 3+	Future (2024+)
	Roman	2,000	~50	0 - 3+	Future (2027+)