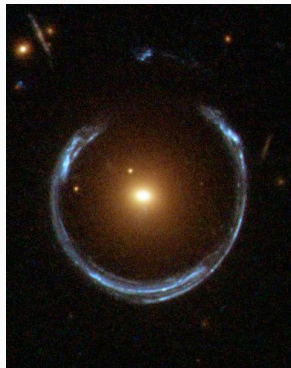


Cosmology with strong lensing images

Julien Larena

Particles, Astroparticles and Cosmology: Theory
Laboratoire Univers et Particules de Montpellier
Université de Montpellier



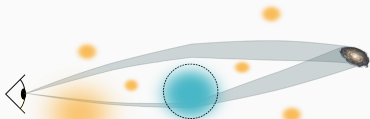
GDR Cophy, June 2026, Clermont-Ferrand

1 June 2026

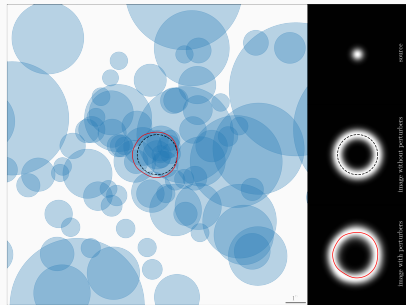
Einstein rings to measure weak lensing

Strong lensing in a clumpy Universe

Line-of-sight haloes perturb strong lensing images



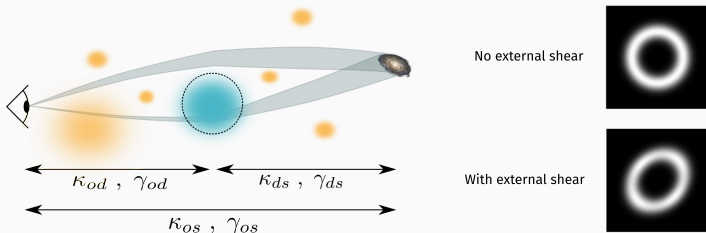
- Population effects
- Noise in strong lensing (e.g. TDCOSMO)
- New window for cosmic shear [Birrer et al, 2016]



Weak lensing of strong lensing

- Diffuse lenses along LOS or dense ones far away: LSS.
- Distortions due to individual lenses **constant over beam**:
- Tidal collective LOS effects:

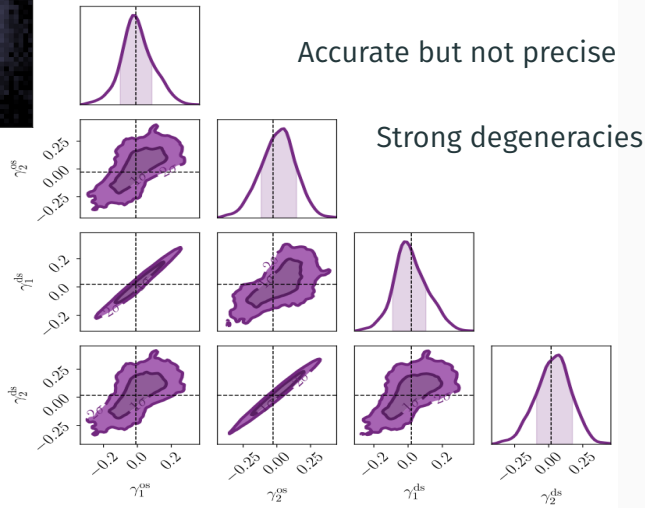
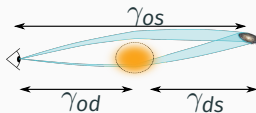
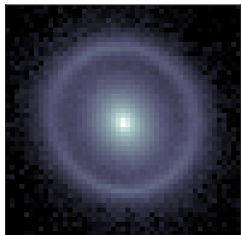
$$\Gamma_{ij} = \kappa_{ij} \mathbf{1} + \begin{pmatrix} \text{Re}(\gamma_{ij}) & \text{Im}(\gamma_{ij}) \\ \text{Im}(\gamma_{ij}) & -\text{Re}(\gamma_{ij}) \end{pmatrix}$$



Measuring γ_{ij} : info on LSS.
Is it doable?

Tidal regime: Degeneracies

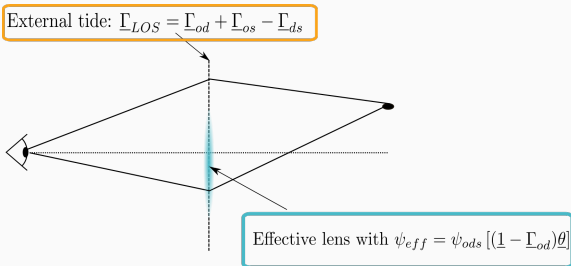
[Hogg, Fleury, JL, Martinelli, MNRAS 2023]



- Equivalent lens equation:

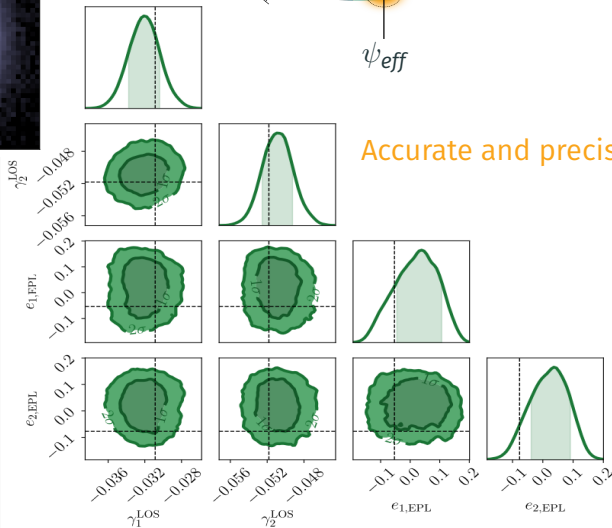
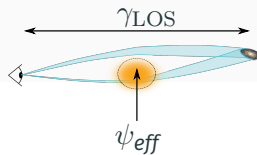
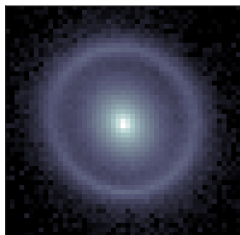
$$\tilde{\beta} = (\mathbf{1} - \Gamma_{LOS}) \theta - \nabla_{\theta} \psi_{eff}$$

- From 3+9 to 6 parameters.



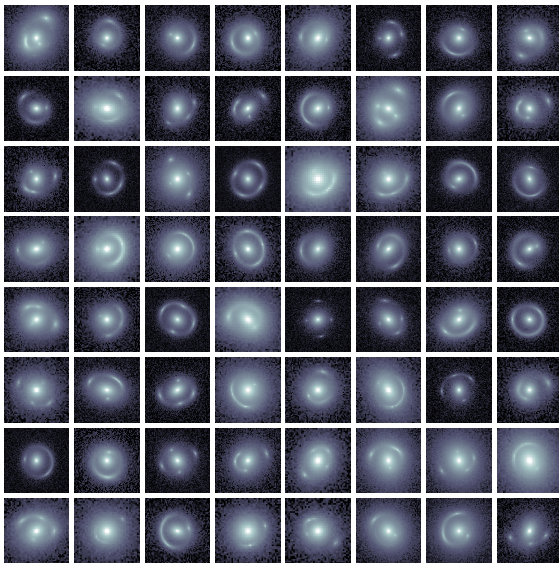
Tidal regime: Minimal lens model

[Hogg, Fleury, JL, Martinelli, MNRAS 2023]



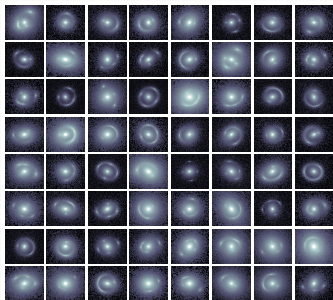
Is LOS shear measurable?

Can we measure $\gamma_{LOS} = \gamma_{od} + \gamma_{os} - \gamma_{ds}$?



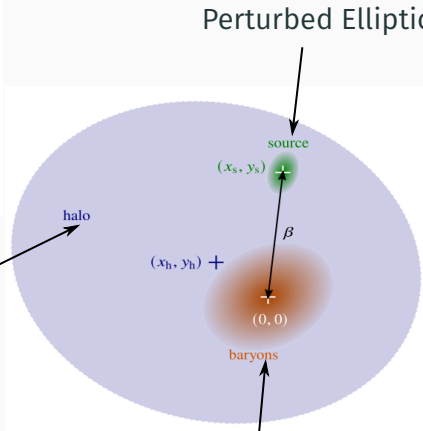
A catalogue of mock images

[Hogg, Fleury, JL, Martinelli, MNRAS 2023]



Elliptical NFW

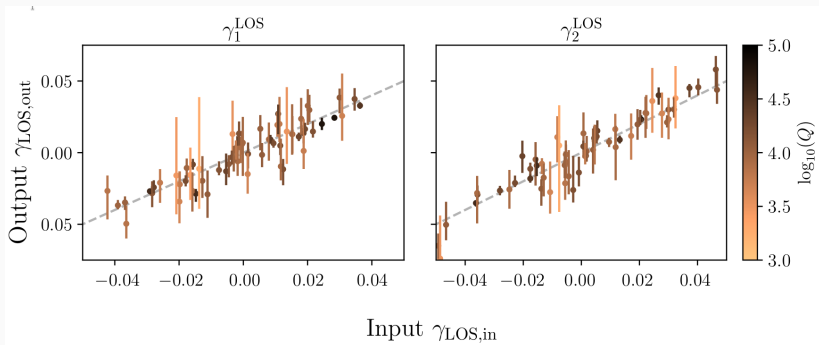
halo



Elliptical Sérsic

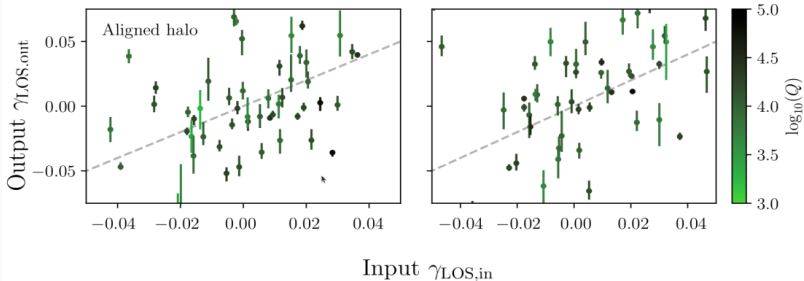
Results: LOS shear is measurable

[Hogg, Fleury, JL, Martinelli, MNRAS 2023]

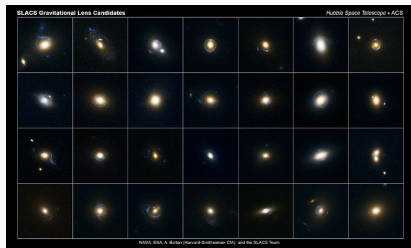
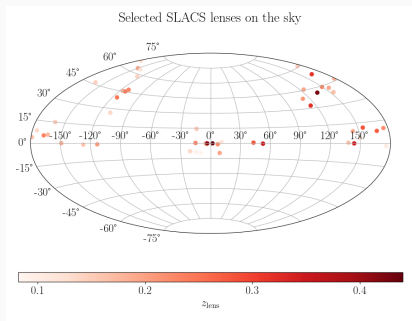


Beware oversimplifying the lens model

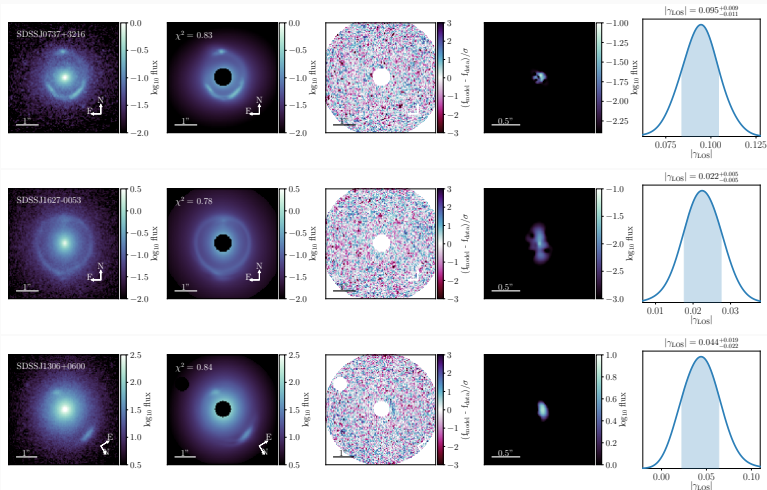
[Hogg, Fleury, JL, Martinelli, MNRAS 2023]

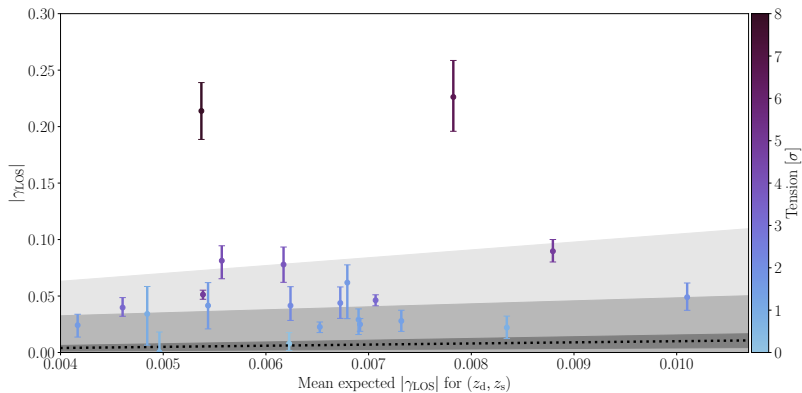


- Sloan Lens ACS
- Spectro identified in SDSS, followed up with HST
- Subset of 50 "nice" images
- Standard lens modelling: Elliptical Power Law

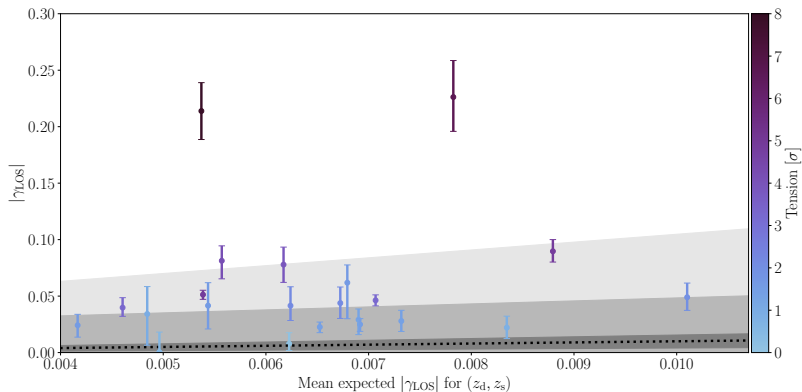


- 45 out of 50 good fits with good constraints on γ_{LOS} .





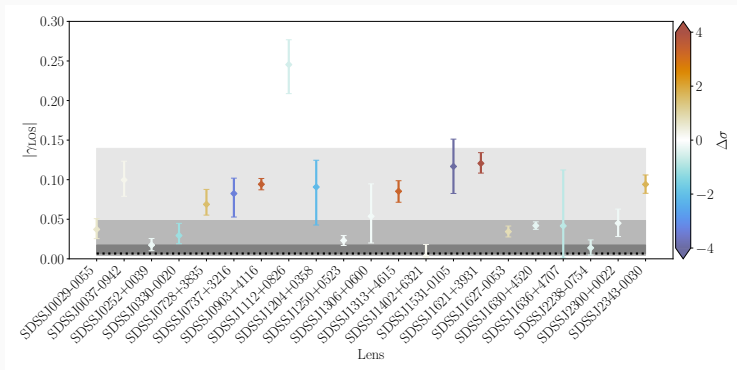
- Very high compared to LSS LOS lensing expected from simulations.



- Systematic LOS/WL bias.
- No correlation between LOS shear and : PSF, filter, flux and SNR, lens and source redshifts

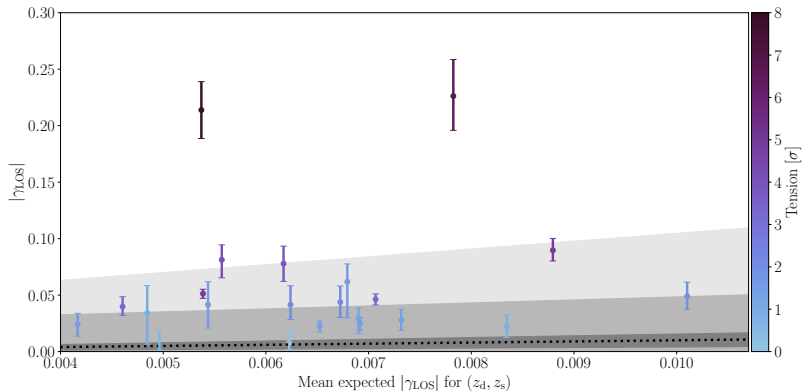
What about lens model?

[Hogg, Johnson, Shajib, JL, arxiv:2501.16292]



- Simplest (octupolar) deformation of lens model not working [Etherington, MNRAS 2024]
- Most gains come from larger error bars

Measuring LOS shear on SLACS lenses



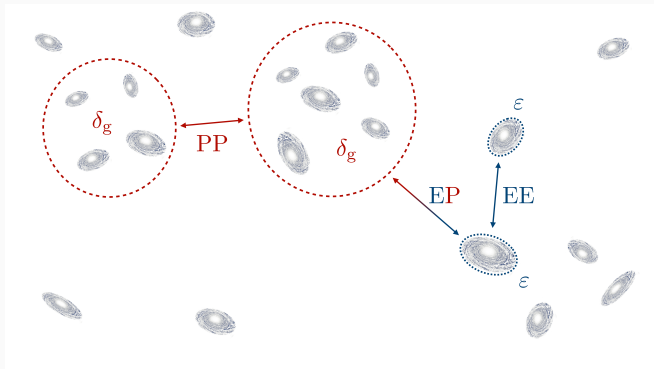
- Strongly lensed LOS are biased sample of LOS?
- Lens environment?
- **Lens modelling too simplistic.**

Cosmology with LOS shear

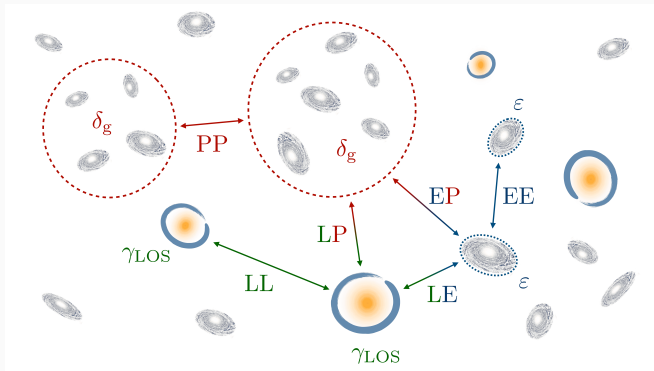
3×2 pt correlation

[Fleury, Johnson, Duboscq, Hogg, JL, arxiv:2603.03441]

- Standard 3×2 pt: PP, PE, EE



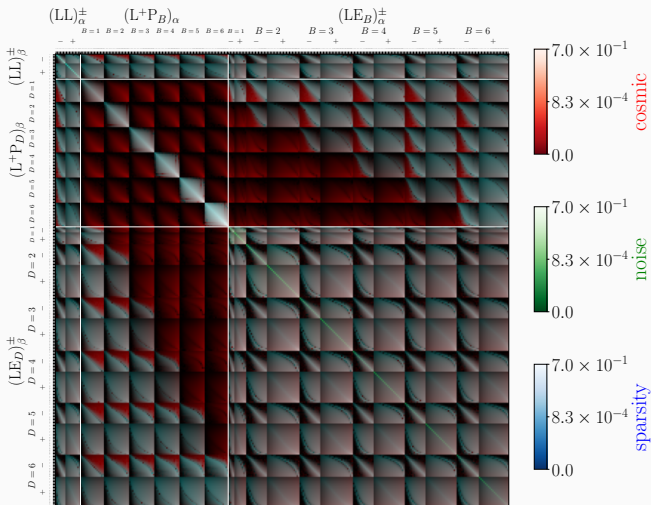
- Adding γ_{LOS} : 6×2 pt
- Euclid will image $\simeq 1.7 \times 10^5$ strong lensing events.



Forecast: Covariance matrix

[Fleury, Johnson, Duboscq, Hogg, JL, arxiv:2603.03441]

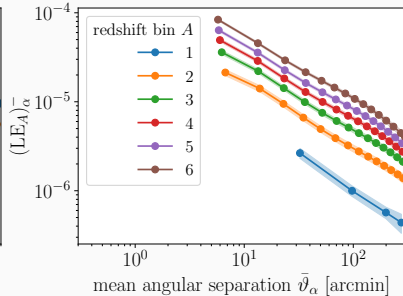
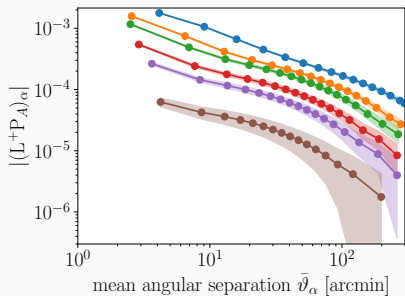
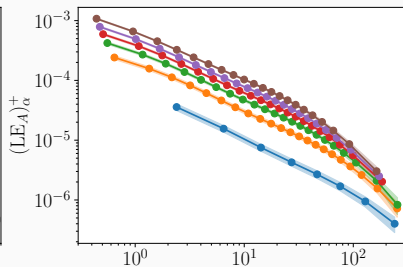
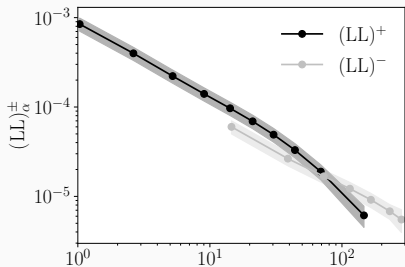
- $N_{\text{lens}} = 10^5$ ($\simeq 60\%$ of Euclid sample); $\Delta\gamma_{\text{LOS}} \simeq 0.05$



Forecast: Correlation functions

[Fleury, Johnson, Duboscq, Hogg, JL, arxiv:2603.03441]

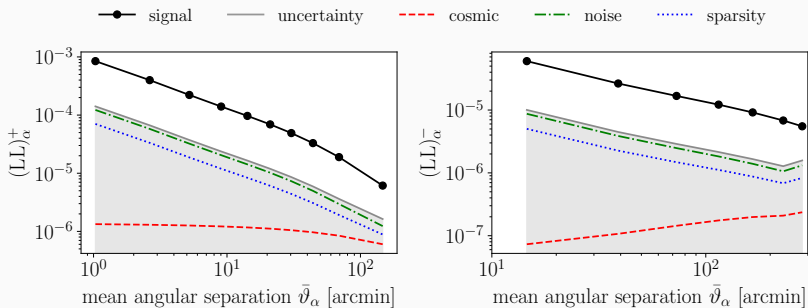
- $N_{\text{lens}} = 10^5$; $\Delta\gamma_{\text{LOS}} \simeq 0.05$

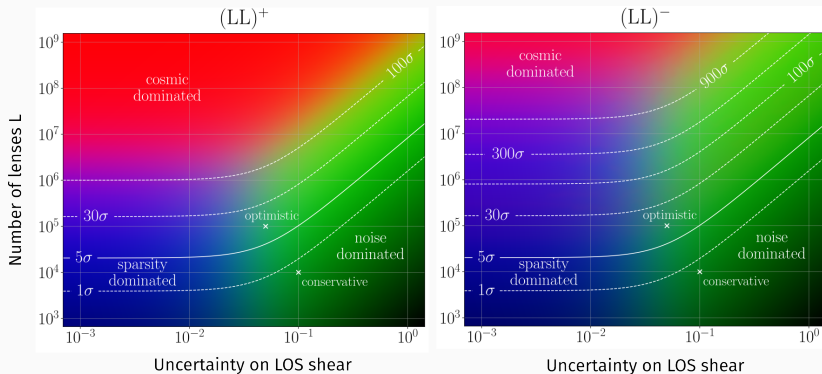


Forecast: LL noise breakdown

[Fleury, Johnson, Duboscq, Hogg, JL, arxiv:2603.03441]

- $N_{\text{lens}} = 10^5$; $\Delta\gamma_{\text{LOS}} \simeq 0.05$



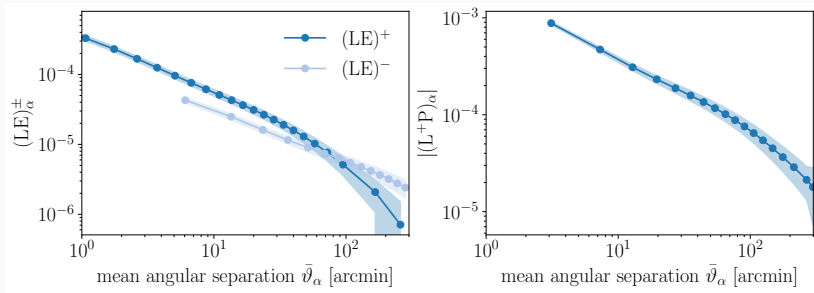


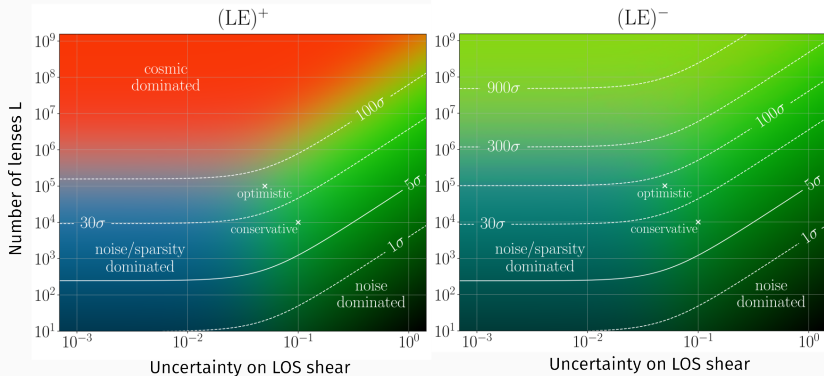
- Improving σ_{LOS} not crucial: **sparsity floor**
- 5σ detection no matter σ_{LOS} .

Forecast: A pessimistic case

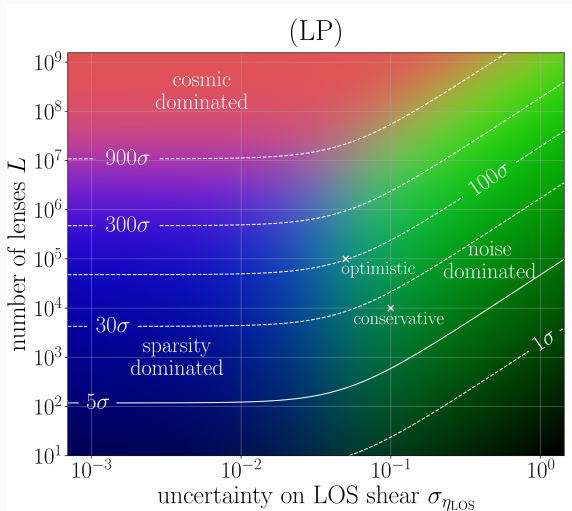
[Fleury, Johnson, Duboscq, Hogg, JL, arxiv:2603.03441]

- $N_{\text{lens}} = 10^4$; $\Delta\gamma_{\text{LOS}} \simeq 0.1$.
- No detection of LL .





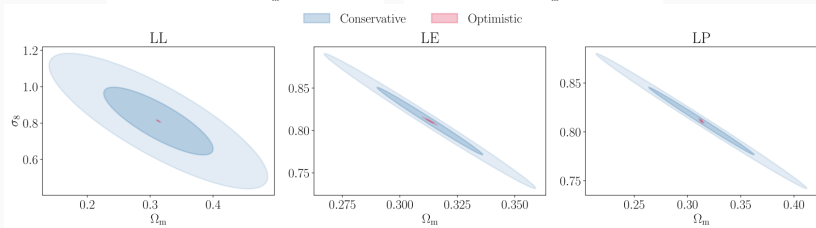
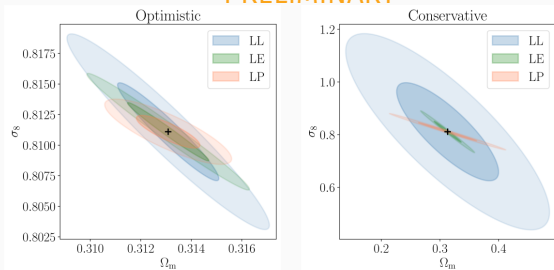
- 5σ detection even with 300 lenses if $\sigma_{LOS} \simeq 0.05$.



- 5 σ detection even with 200 lenses if $\sigma_{\text{LOS}} \simeq 0.05$.

Forecast: Cosmological constraints

PRELIMINARY



Conclusion

Conclusion and outlook

- Einstein rings can be used as probe for LSS.
- Supplement cosmic shear and galaxy number counts in 6×2 pt.
- Preliminary **Fisher forecast** for cosmological parameters **very promising**.
- Challenges remain to measure γ_{LOS} :
 - Line-of-sight typicality
 - **Lens modelling**
 - Automation of shear measurements: getting ready for 10^5 lenses.

THANK YOU!