The weak lensing of strong lensing
A new cosmological probe

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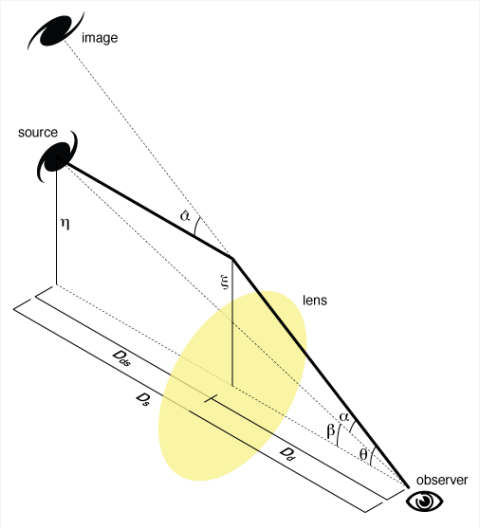
- Today I will present a proof-of-concept that the LOS shear is measureable, using simulated strong lensing images

Measuring line-of-sight shear with Einstein rings: a proof of concept, N. B. Hogg et al., MNRAS, 520, 4, April 2023. arXiv:2210.07210

Gravitational lensing

Massive objects distort local spacetime, curving the geodesics.



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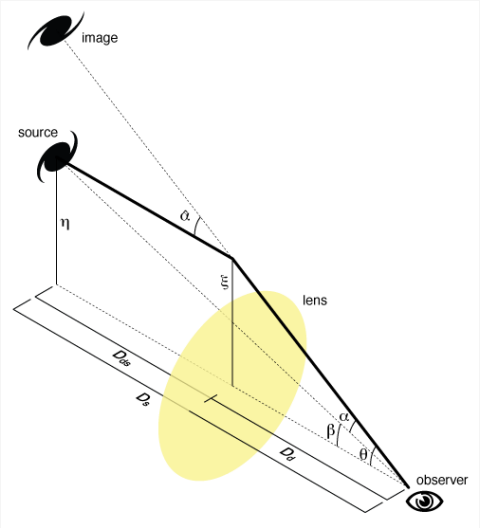
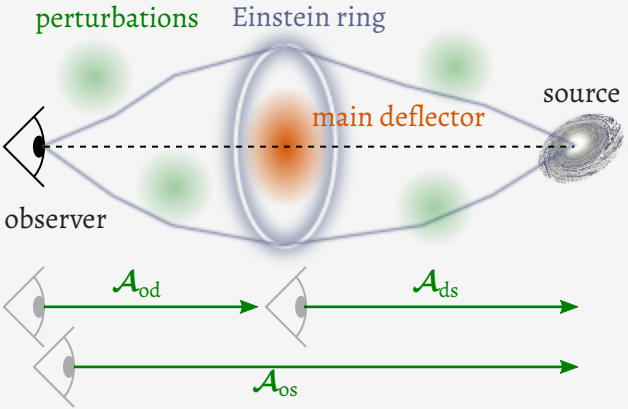
$$\boldsymbol{\beta} = \boldsymbol{\theta} - \boldsymbol{\alpha}(\boldsymbol{\theta}). \qquad (1)$$



Line-of-sight shear



Line-of-sight shear

The amplification matrices act on the lens equation,

$$\boldsymbol{\beta} = \boldsymbol{\mathcal{A}}_{\mathrm{os}}\boldsymbol{\theta} - \boldsymbol{\mathcal{A}}_{\mathrm{ds}}\boldsymbol{\alpha}(\boldsymbol{\mathcal{A}}_{\mathrm{od}}\boldsymbol{\theta}) \tag{2}$$

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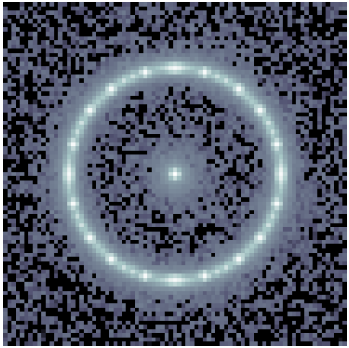
and are defined as

$$\boldsymbol{\mathcal{A}}_{ab} = \mathbf{1} - \boldsymbol{\Gamma}_{ab}\,, \quad \boldsymbol{\Gamma}_{ab} = \begin{bmatrix} \kappa_{ab} + \mathrm{Re}\,(\gamma_{ab}) & \mathrm{Im}\,(\gamma_{ab}) - \omega_{ab} \\ \mathrm{Im}\,(\gamma_{ab}) + \omega_{ab} & \kappa_{ab} - \mathrm{Re}\,(\gamma_{ab}) \end{bmatrix}, \tag{3}$$

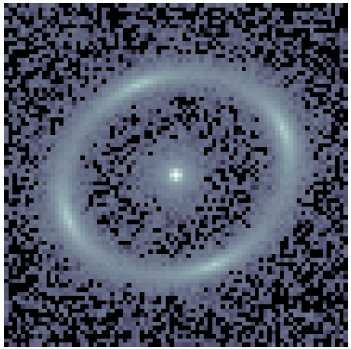
where κ_{ab} is the convergence, γ_{ab} the shear and ω_{ab} the rotation of the image.

Visualising shear



No shear: Einstein ring is circular (unlike a galaxy).

Visualising shear



With shear: Einstein ring is elliptical (all shape distortion is cosmological, not intrinsic).

Problem

⚠ Shear parameters are degenerate with lens model parameters.

Solution: minimal lens model

Multiply by the combination $\boldsymbol{\mathcal{A}}_{\rm od}\boldsymbol{\mathcal{A}}_{\rm ds}^{-1}$, creating the "minimal model",

$$\tilde{\boldsymbol{\beta}} = \boldsymbol{\mathcal{A}}_{\rm LOS}\boldsymbol{\theta} - \boldsymbol{\mathcal{A}}_{\rm od}\boldsymbol{\alpha}(\boldsymbol{\mathcal{A}}_{\rm od}\boldsymbol{\theta}), \tag{4}$$

where $\boldsymbol{\mathcal{A}}_{\rm LOS} = \boldsymbol{\mathcal{A}}_{\rm od}\boldsymbol{\mathcal{A}}_{\rm ds}^{-1}\boldsymbol{\mathcal{A}}_{\rm os}$.

Fleury et al. (2021)

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where $\mathcal{A}_{\rm LOS} = \mathcal{A}_{\rm od}\mathcal{A}_{\rm ds}^{-1}\mathcal{A}_{\rm os}$. It is thus the **line-of-sight (LOS) shear**,

$$\gamma_{\rm LOS} = \gamma_{\rm od} + \gamma_{\rm os} - \gamma_{\rm ds}, \tag{5}$$

which is expected to be measurable.

Fleury et al. (2021)

Does the minimal LOS model evade degeneracies?

- I implemented the LOS formalism in the `lenstronomy` software

`lenstronomy/LineOfSight`

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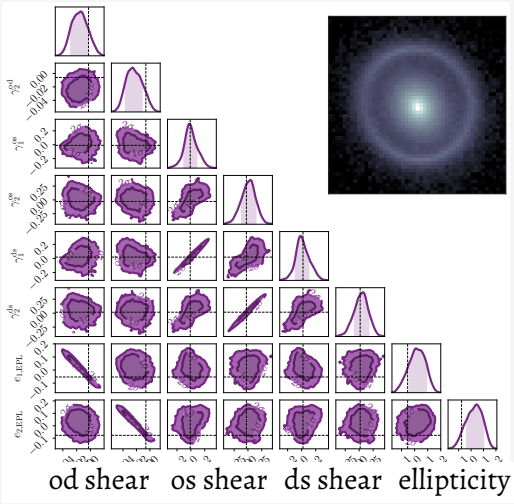
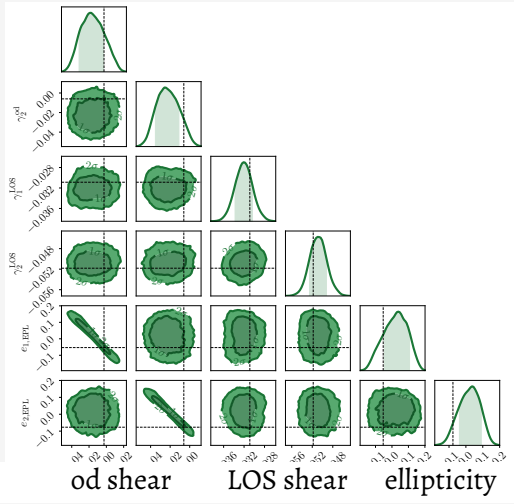
- I implemented the LOS formalism in the `lenstronomy` software
- This allowed us to create and fit mock images with LOS shear included, to look for degeneracies
- If the formalism works as expected, we can create more complex mocks to see if the LOS shear is systematically measureable

`lenstronomy/LineOfSight`

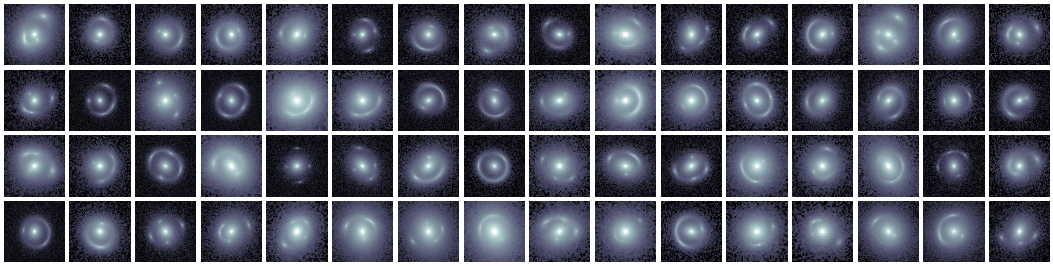
Does the minimal LOS model evade degeneracies? Yes





The minimal LOS model evades degeneracies in a simple lens.
What happens when we consider more realistic (complicated) lenses?

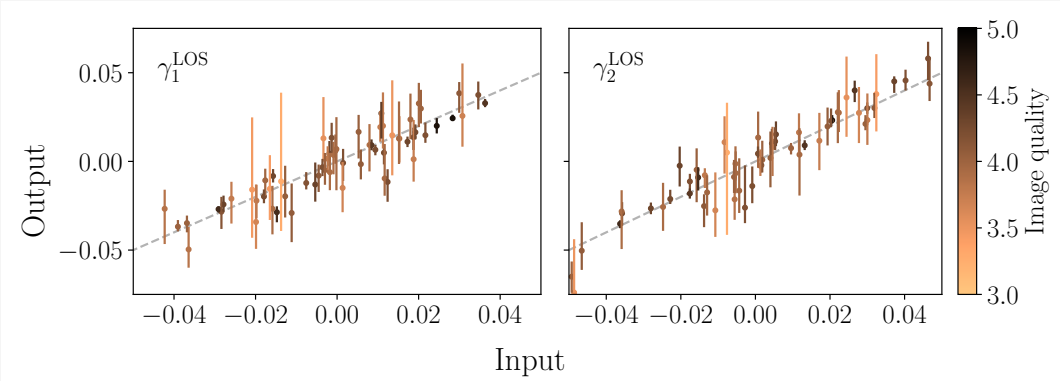
Mock images



Our 64 HST-like mock images comprised of randomly offset elliptical baryonic and dark matter components plus elliptical Sérsic profiles for the lens and source light.

analosis

Results (construct with full model, fit with minimal model)



$\chi^2 = 1.0$; average precision of 1%; no outliers $> 2\sigma$

Hogg et al. (2023)

The LOS shear is well-recovered from complex lenses,
provided the lens mass is modelled correctly.

Coming soon…

- Detect LOS shear in HST (SLACS) and JWST (COSMOS-Web) lenses.

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- Investigate beyond shear effects (flexion).

Thanks!

2210.07210

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