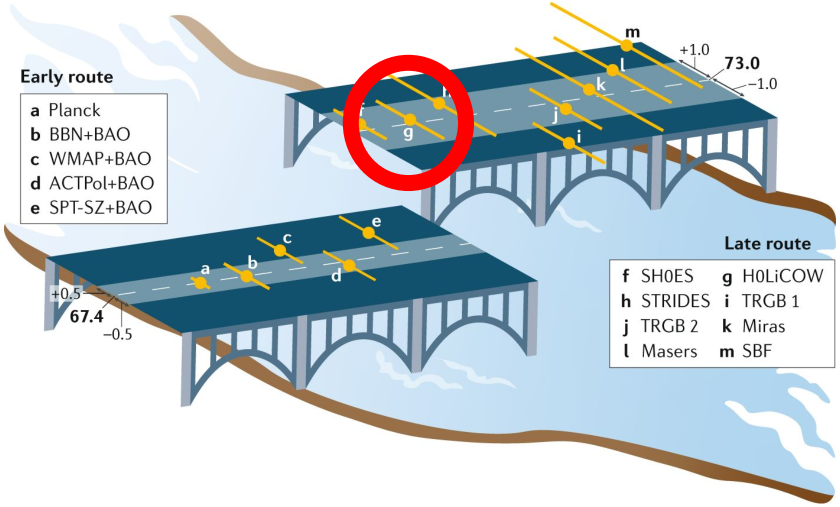
The Impact of Line-of-sight structures on Measuring H0 with Strong Lensing Time-delays

Time-Domain Cosmology with Strong Gravitational Lensing
2021/01, Tokyo

Nan Li (NAOC), Christoph Becker (Durham), Simon Dye (Nottingham)

Motivations

- The H0 tension is at **4+** sigma.
- Strong lensing time delays is an **independent** method for measuring H0.
- The impact of **external convergence** is a key issue in this approach.
- There will be **~1000** strong lensing time delay Systems in the era of LSST.



Is the assumption *"constant external convergence"* accurate enough?

Mass Sheet Degeneracy

$$t(\vec{\theta}, \vec{\beta}) = \frac{D_{\Delta t}}{c} \phi(\vec{\theta}, \vec{\beta})$$

$$D_{\Delta t} \equiv (1 + z_{\rm d}) \frac{D_{\rm d} D_{\rm s}}{D_{\rm ds}}$$

$$\phi(\vec{\theta}, \vec{\beta}) \equiv \left[\frac{(\vec{\theta} - \vec{\beta})^2}{2} - \psi(\vec{\theta}) \right]$$

$$\psi_\lambda(\vec{\theta}) = \lambda \psi(\vec{\theta}) + \frac{1-\lambda}{2} \vec{\theta}^2$$

$$\kappa_\lambda(\vec{\theta}) = \lambda \kappa(\vec{\theta}) + (1 - \lambda)$$

$$\vec{\beta} = \vec{\theta} - \vec{\alpha}(\vec{\theta})$$

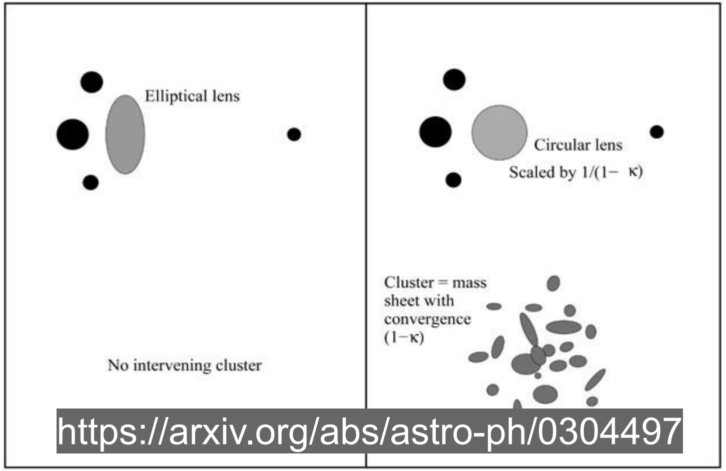
$$\vec{\beta} \rightarrow \lambda \vec{\beta}$$

$$\lambda = 1 - \kappa_{\rm ext}$$

$$D_{\Delta t} = \frac{D_{\Delta t}^{\rm model}}{\lambda}$$

$$H_0 \propto D_{\Delta t}^{-1}$$

$$H_0 = \lambda H_0^{\rm model}$$

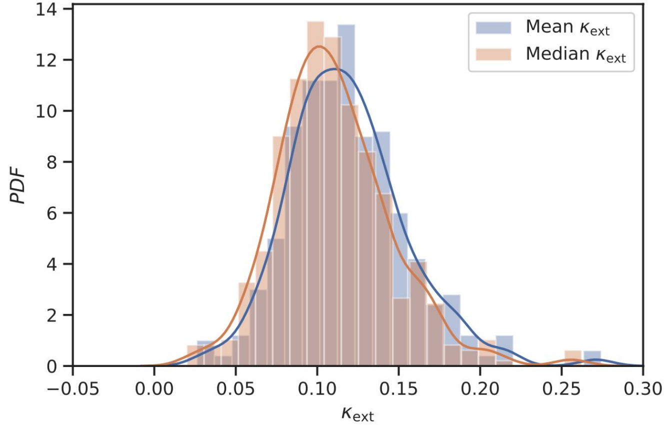


https://arxiv.org/abs/astro-ph/0304497

Simulations

Lens Population:

- BCGs of galaxy groups from CosmoDC2[1] with zlens = 0.5 ± 0.01
- Lightcones from CosmoDC2 (20” X 20”)
- SIE Model {VelDisp, Ellipticity, Orientation}



Source Population:

- zsrc = 2.0
- Point Source

Number of Simulations:

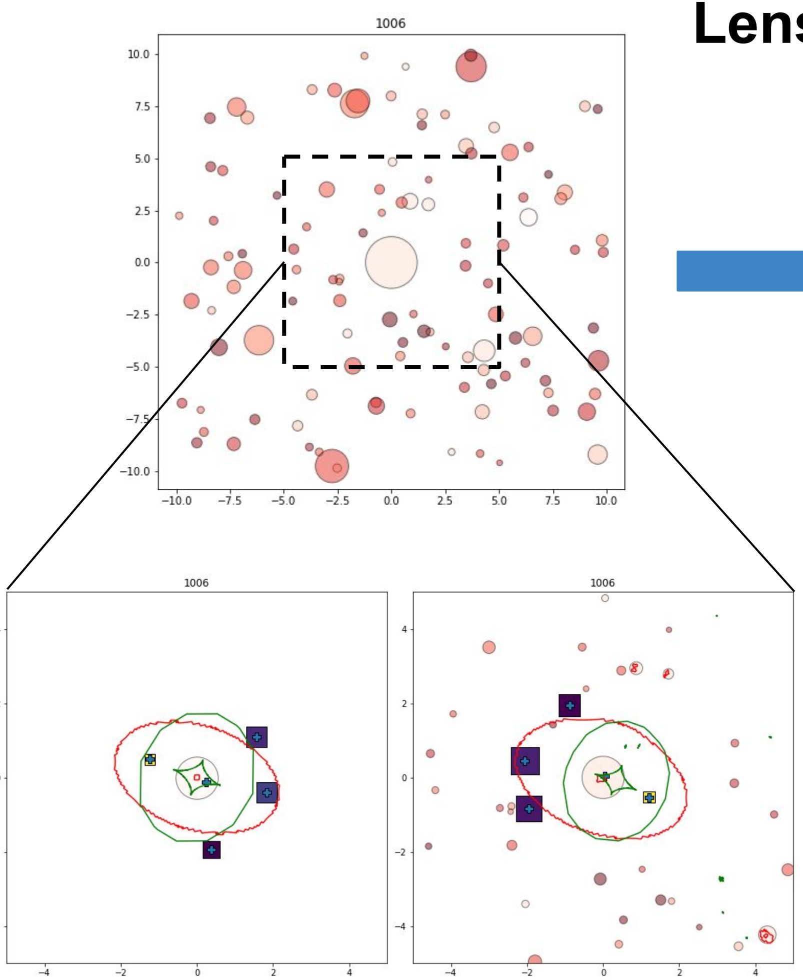
- Kext:~400 Quads
- L.O.S:~400 Quads
- Kext is the median value of the effective convergence of the fully raytraced convergence map, L.O.S includes all halos along the line of sight.

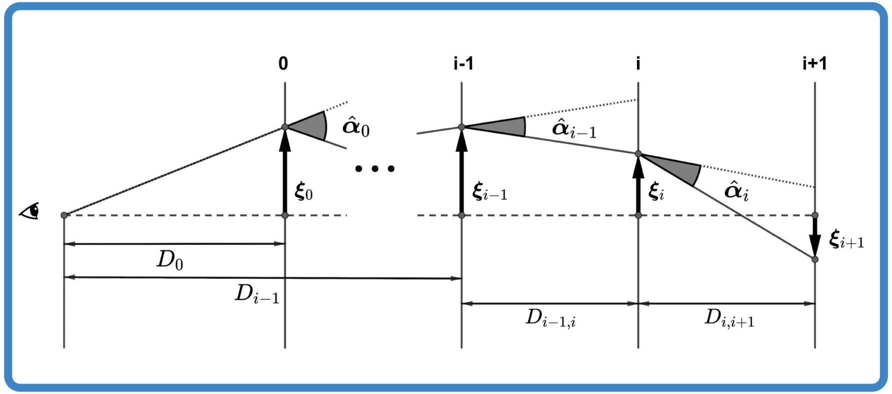
Mock catalog:

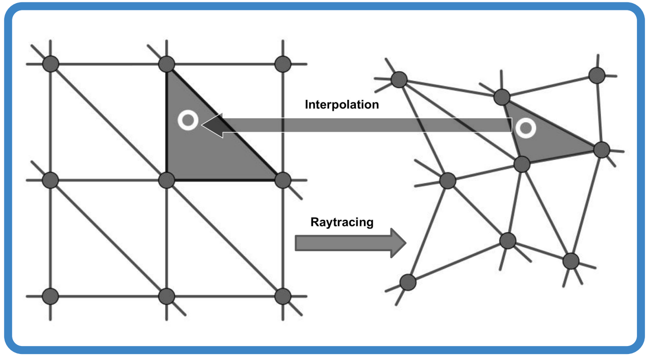
- {ximg[4], yimg[4], delays[4], mags[4]}
- ~800 such mock systems

[1] https://portal.nersc.gov/project/lsst/cosmoDC2/_README.html

Lensing Ray-tracing through Lightcones

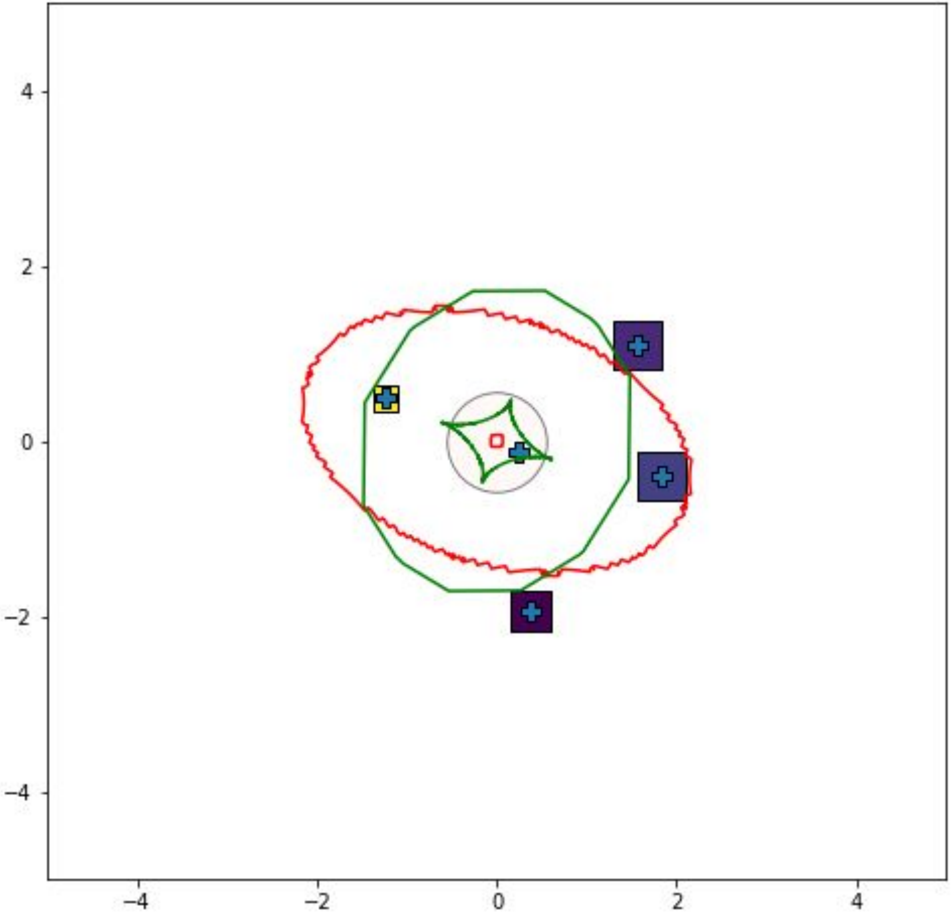


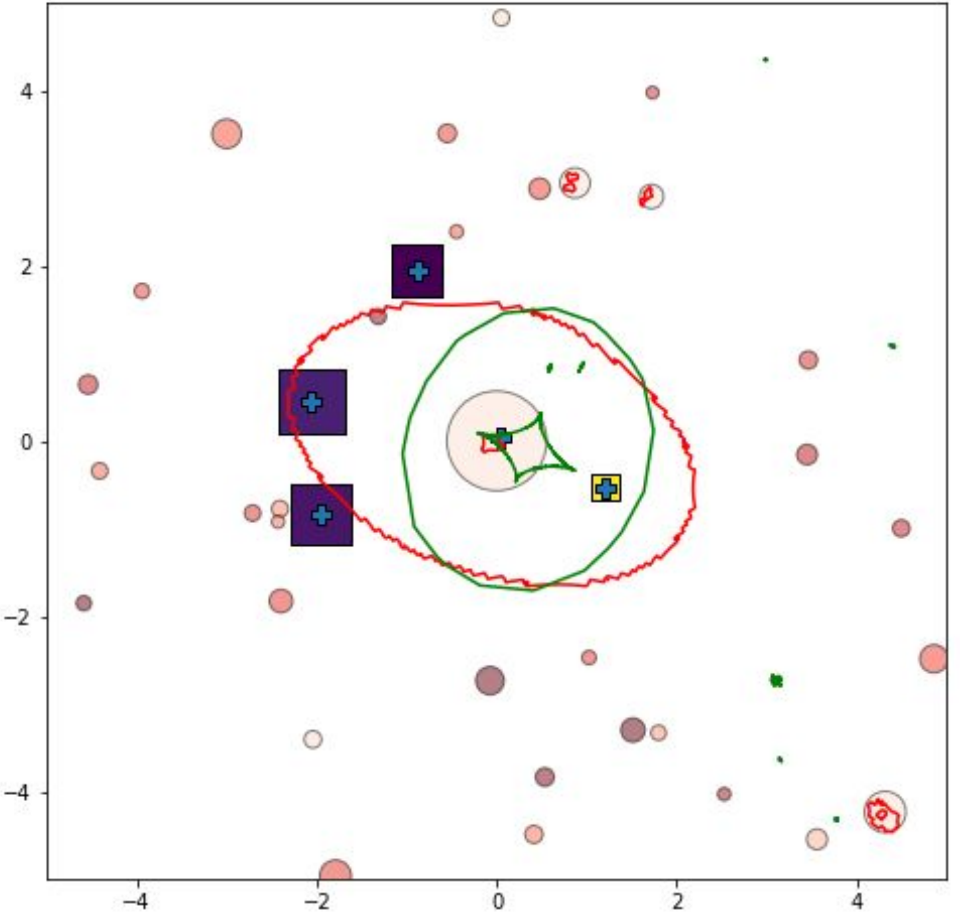




Li+ 2020, arXiv:2006.08540

Examples of Mock Lenses with L.O.S. Galaxies





Modeling Mock Lenses Using Lenstronomy

Lenstronomy: https://github.com/sibirrer/lenstronomy

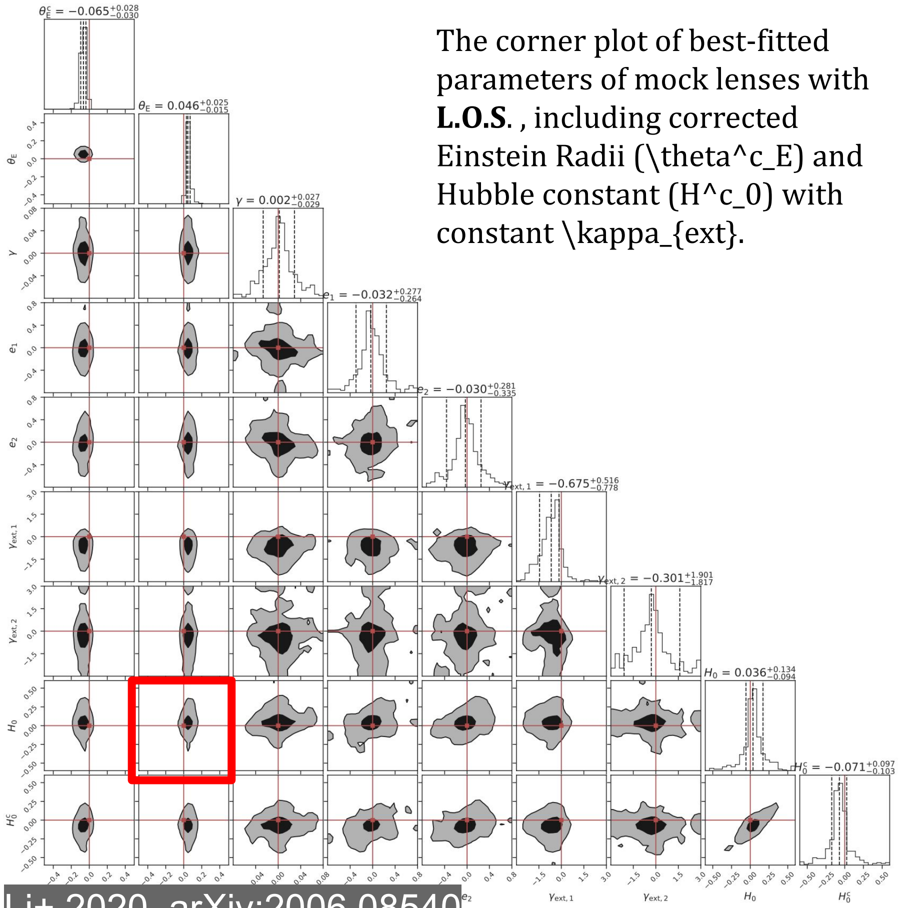
Lens Models:
- Singular Elliptical Power Law + External Shear
- xlens, ylens, b, e, gamma, lens_pa, gamma_ext_1, gamma_ext_2
- xsrc, ysrc
- H0

Lenstronomy:
- PSO method, 200 particles, 500 iterations
- optimization
    - xlens, ylens
    - b, e, gamma, lens_pa
    - gamma_ext_1, gamma_ext_2

	Parameter	Prior
Model constraints		
Multiple image pos.	RA, DEC (arcsec)	$\mathcal{N}(\theta_{\rm sim}, 0.01)$
Flux-ratios	$\Delta F_{1-2,1-3,1-4}$	$\mathcal{N}(F_{\rm sim}, 0.01)$
Time delays	$\Delta t_{1-2,1-3,1-4}$ (days)	$\mathcal{N}(\Delta t_{\rm sim}, 0.01)$
Model component		
Lens, SEPL	θ_E (arcsec)	$\mathcal{U}(0.01, 10)$
Lens, SEPL	γ	$\mathcal{U}(1.7, 2.3)$
Lens, SEPL	$e_{1,2}$	$\mathcal{U}(-0.5, 0.5)$
Lens, SEPL	$\theta_{1,2}$ (arcsec)	$\mathcal{U}(-10, 10)$
External shear	$\gamma_{\rm ext,1}$	$\mathcal{U}(0.0, 0.5)$
External shear angle	$\theta_{\gamma,\rm ext}$ (rad)	$\mathcal{U}(-\pi, \pi)$
Source, Point	$\beta_{1,2}$ (arcsec)	$\mathcal{U}(-10, 10)$
Hubble-Lemaitre constant	H_0 (km/s/Mpc)	$\mathcal{U}(20, 120)$

Li+ 2020, arXiv:2006.08540

Results



The corner plot of best-fitted parameters of mock lenses with **L.O.S.** , including corrected Einstein Radii (\theta^c_E) and Hubble constant (H^c_0) with constant \kappa_{ext}.

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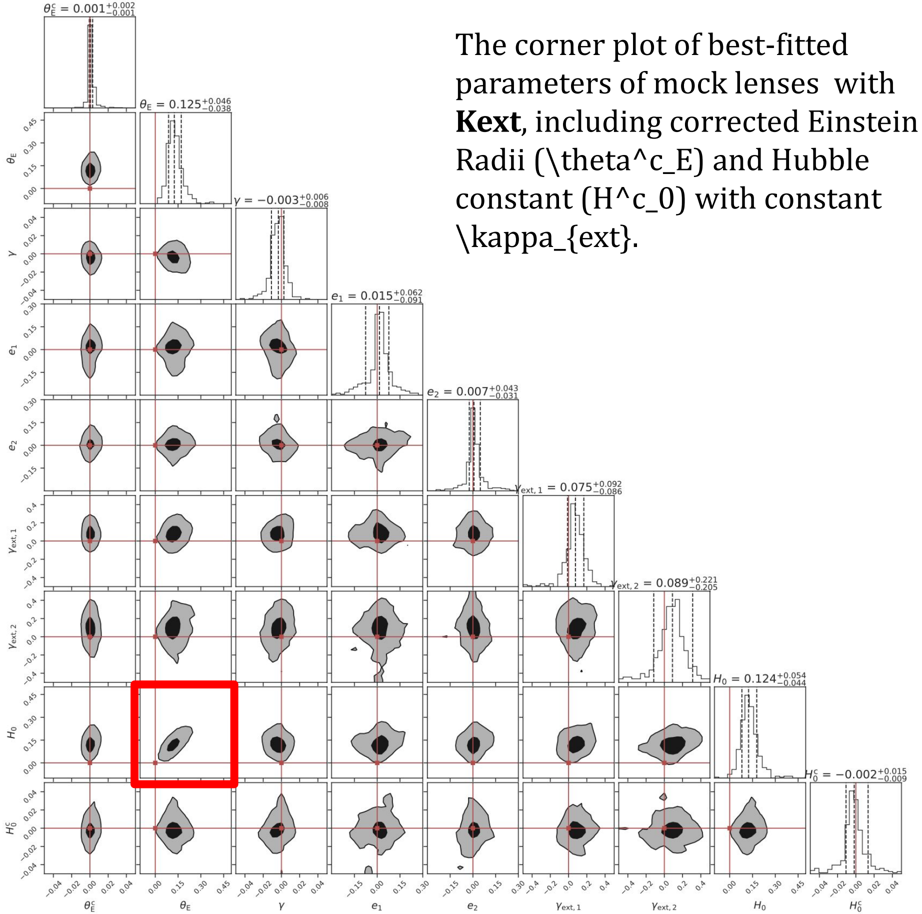
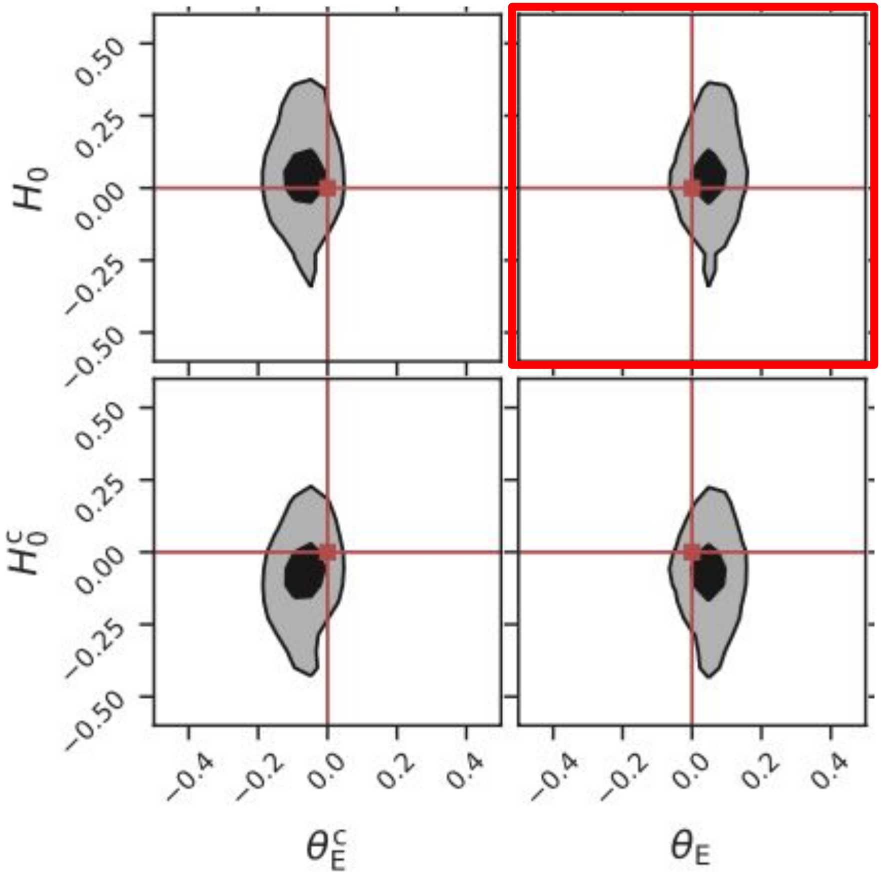
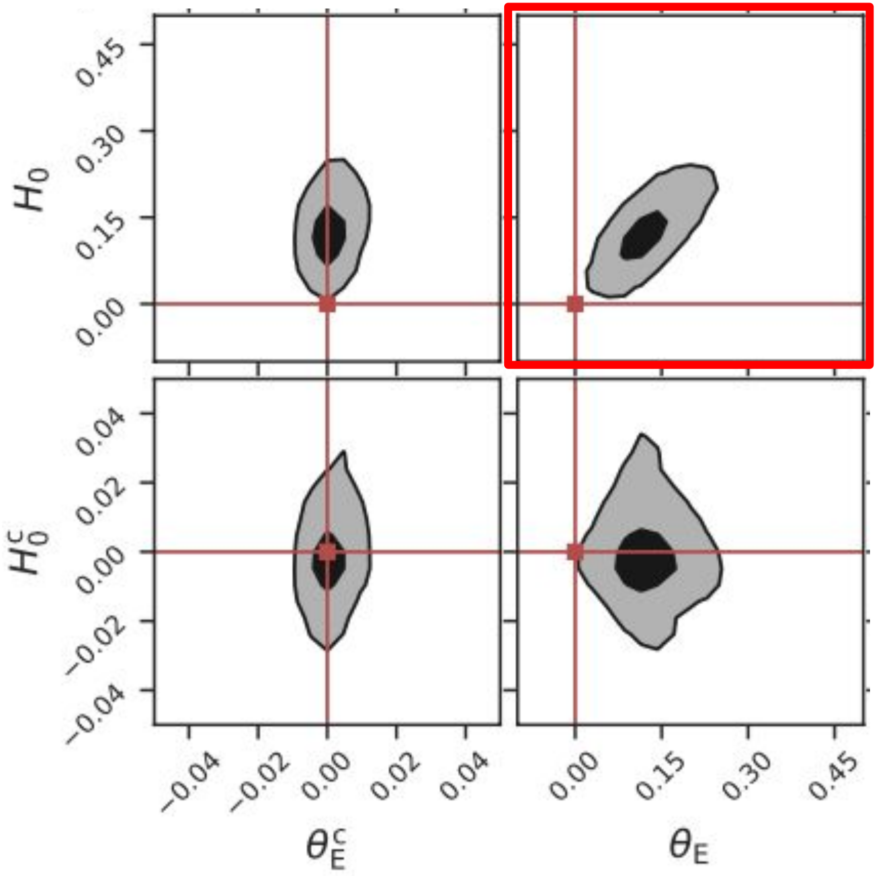


The corner plot of best-fitted parameters of mock lenses with **Kext**, including corrected Einstein Radii (\theta^c_E) and Hubble constant (H^c_0) with constant \kappa_{ext}.

Results

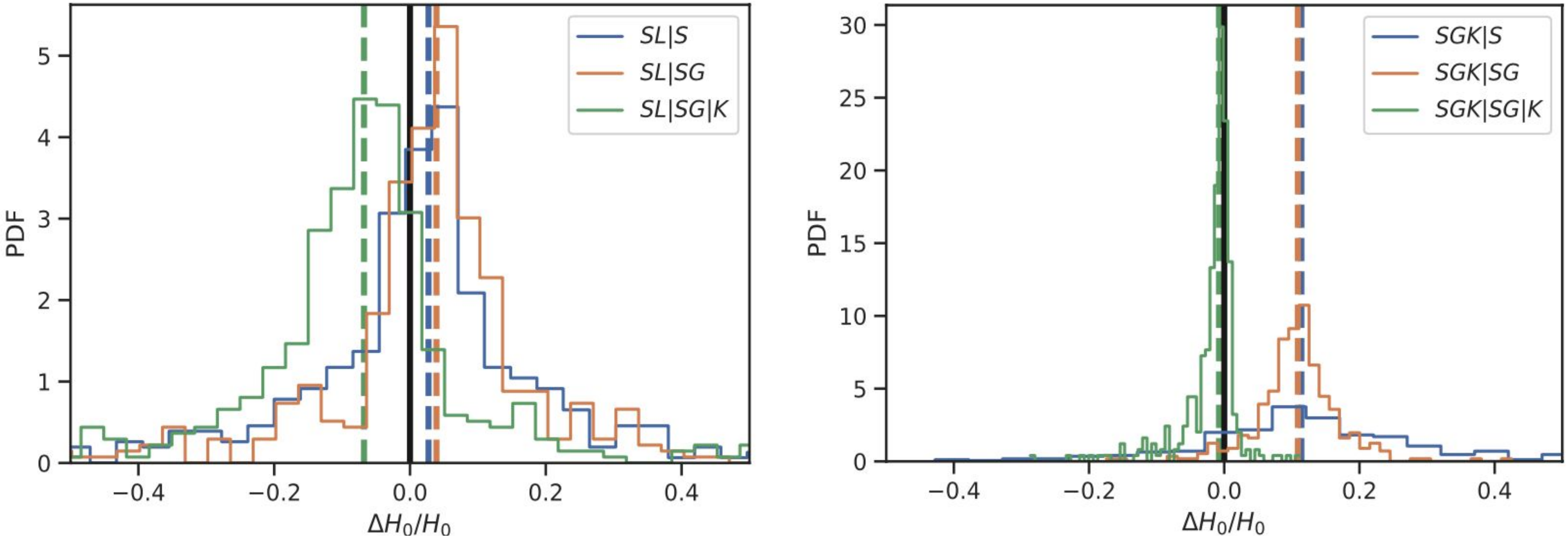




Mocks with L.O.S.

Mocks with Kext

Results



PDFs of the fractional differences between measured H0 and the true value. Blue histograms show the PDF of fractional differences with single SEPL mass model only; orange histograms show the PDF of fractional errors with the mass model of SEPL + external shear; green histograms show the corrected fractional differences of the orange histograms with constant \kappa_{ext} correction. Back vertical solid line stands for the value of zero. Blue, orange, and green vertical dashed lines stand for the median of each PDF.

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Summary

1. Strong lensing time delay is an independent approach to study H0 tension. External convergence is critical.
2. The assumption of constant external convergence is not accurate enough, which is ~3 times larger than the impacts of the L.O.S in the systems in our work.
3. More sophisticated models of the L.O.S. is needed when modeling SLTD systems.
4. Alternatively, comperical models for correcting the biases might be useful too.