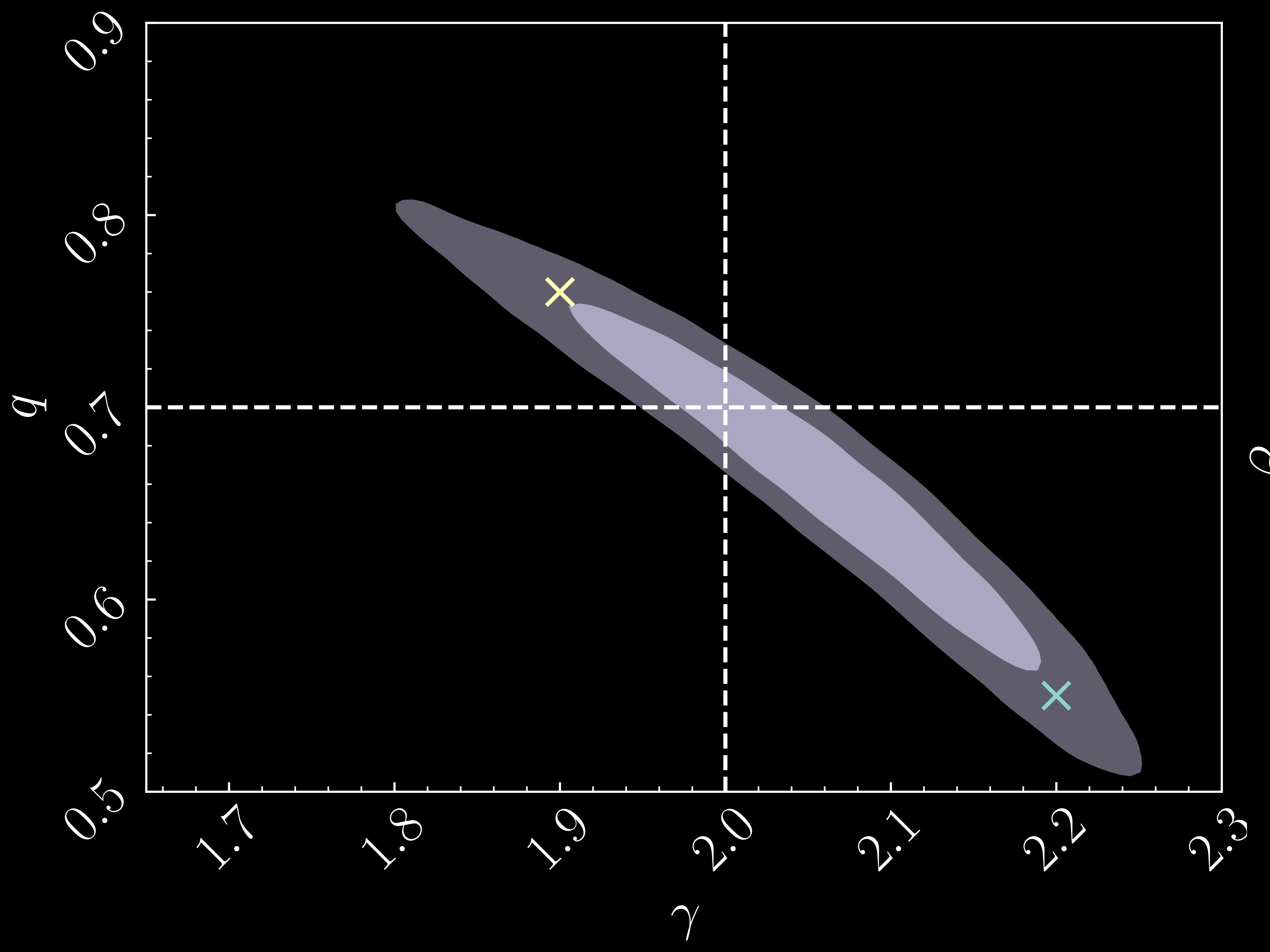
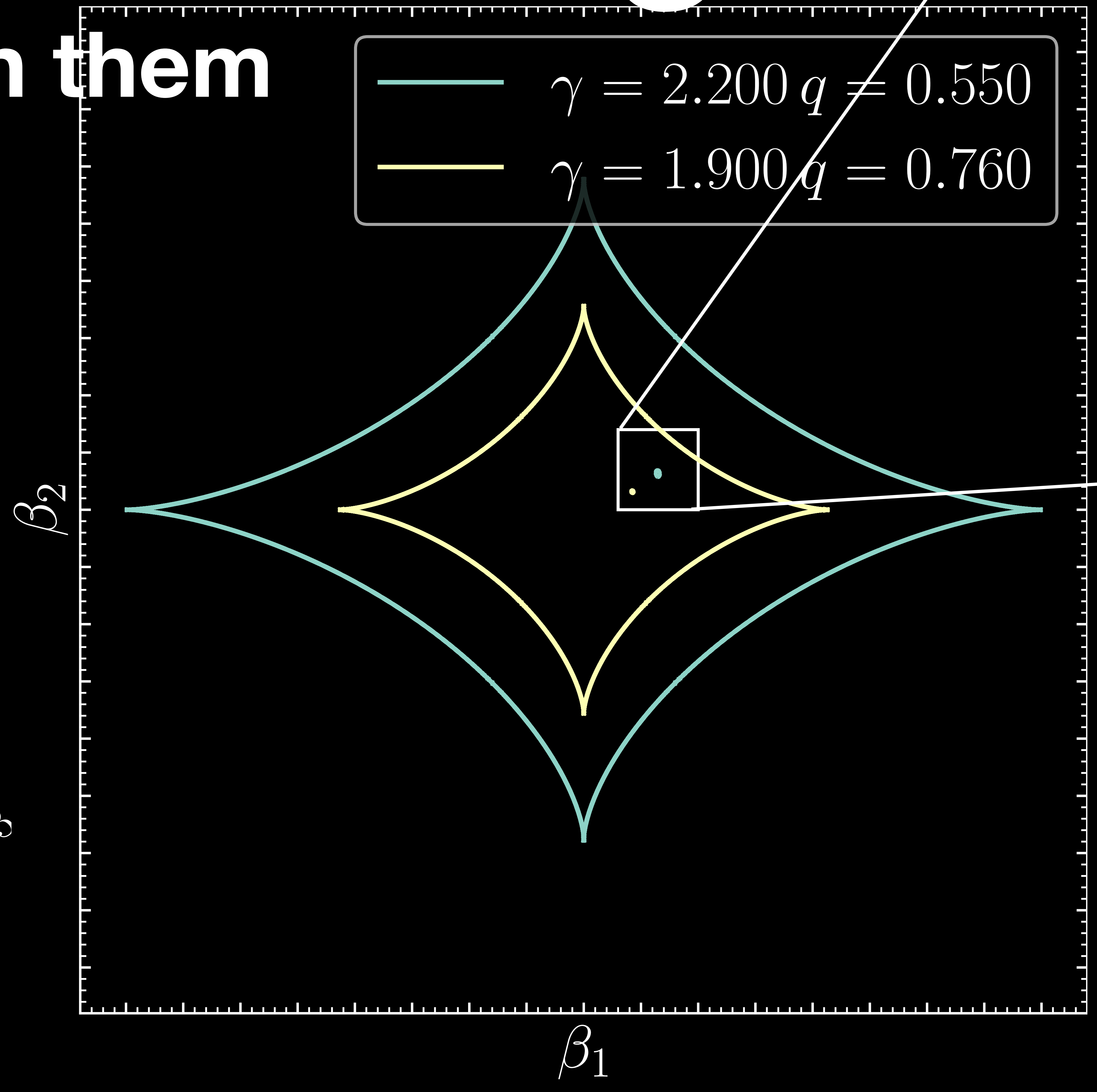
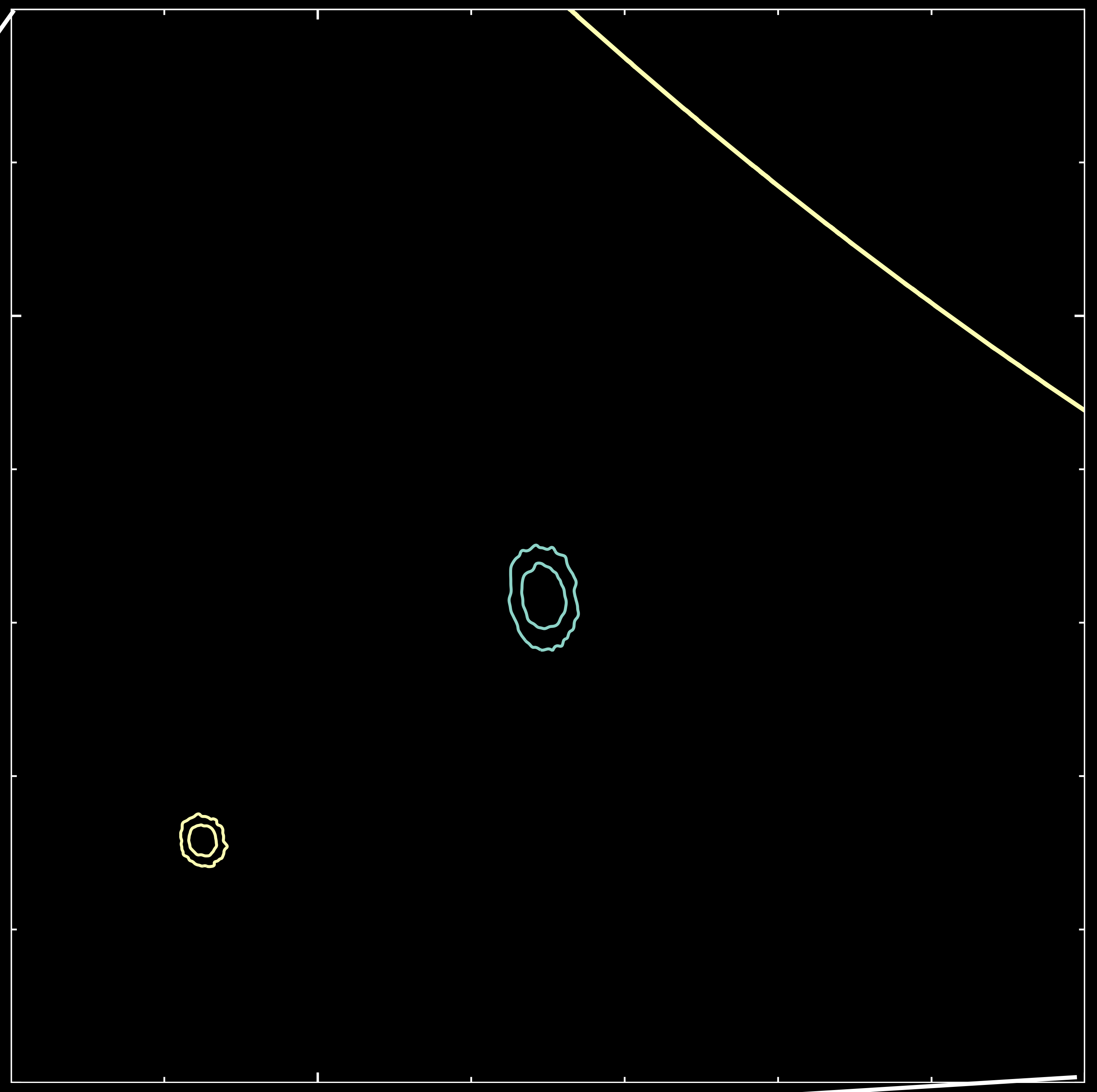
Selection effects in time-delay lensing

And how to deal with them







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$$\mathrm{P}(p \mid d) \propto \mathrm{P}(p)\mathrm{P}(d \mid p)$$

Where can the prior choice affect H_0?

- Lens density profile
- Lens azimuthal structure
- Lens 3D structure (for stellar dynamics)
- Source flux, size, position

The correct prior

$P_g(\psi_g) :=$ Foreground galaxy distribution

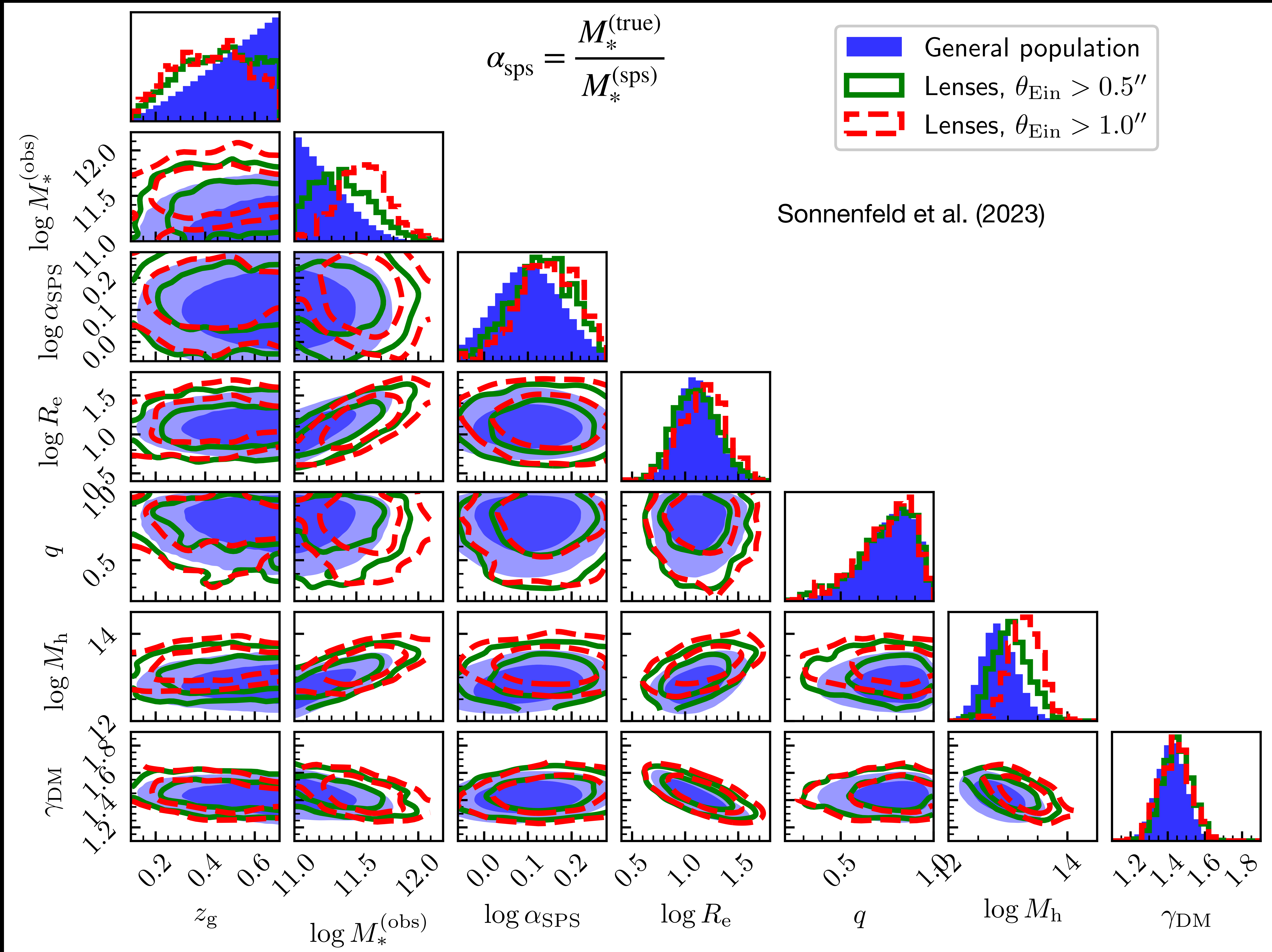
$P_s(\psi_s) :=$ Background source distribution

$$\boxed{P_{SL}(\psi_g, \psi_s) \propto P_g(\psi_g) P_s(\psi_s) P_{sel}(\psi_g, \psi_s)}$$

$P_{sel}(\psi_g, \psi_s) :=$ Selection probability

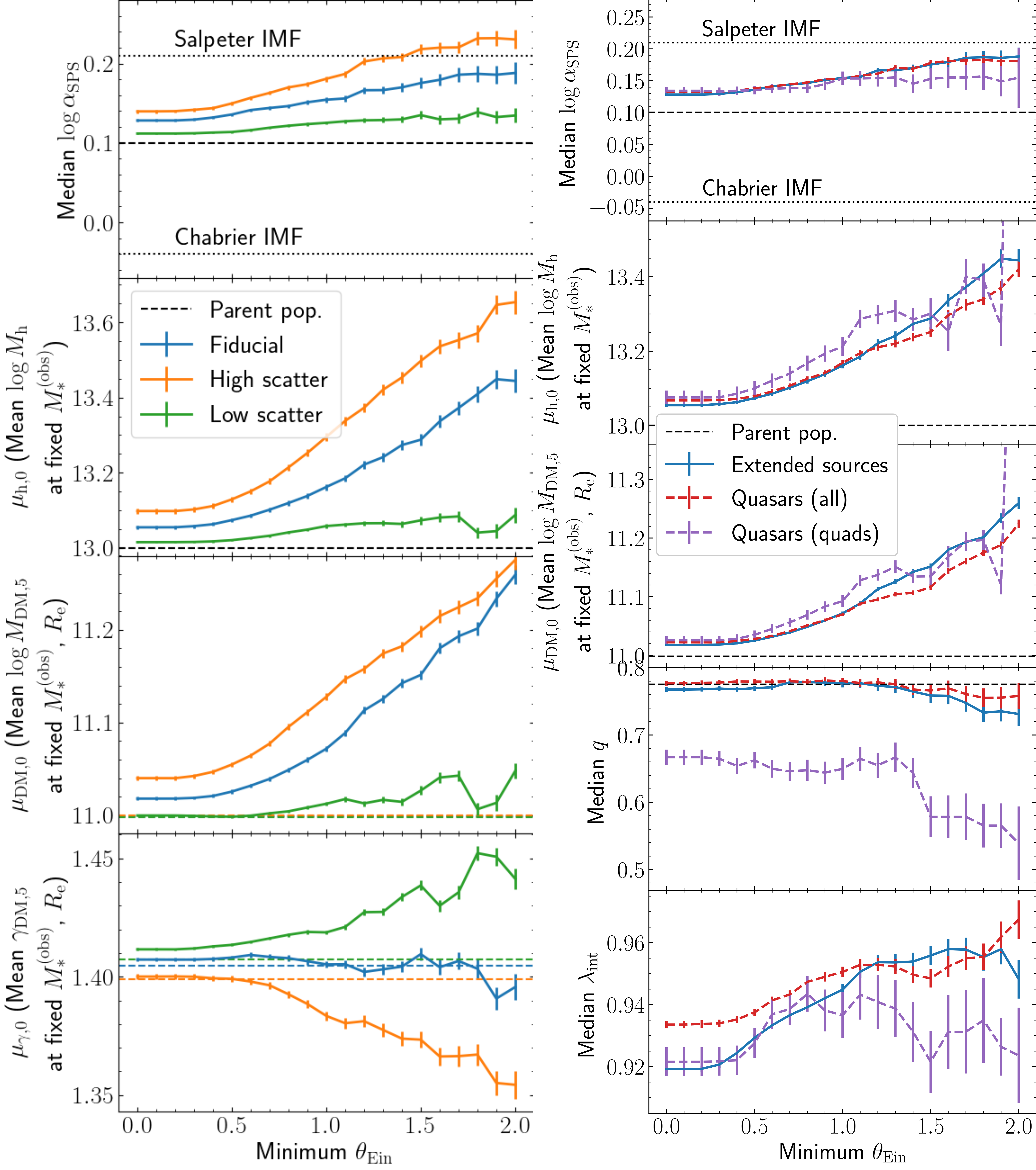
Galaxies vs. lenses (simulations)

- Lens definition: at least two peaks in the lensed source surface brightness, each detected with S/N>10



What determines the bias:

- Intrinsic scatter
- Completeness in Einstein radius



Galaxies vs. SLACS lenses

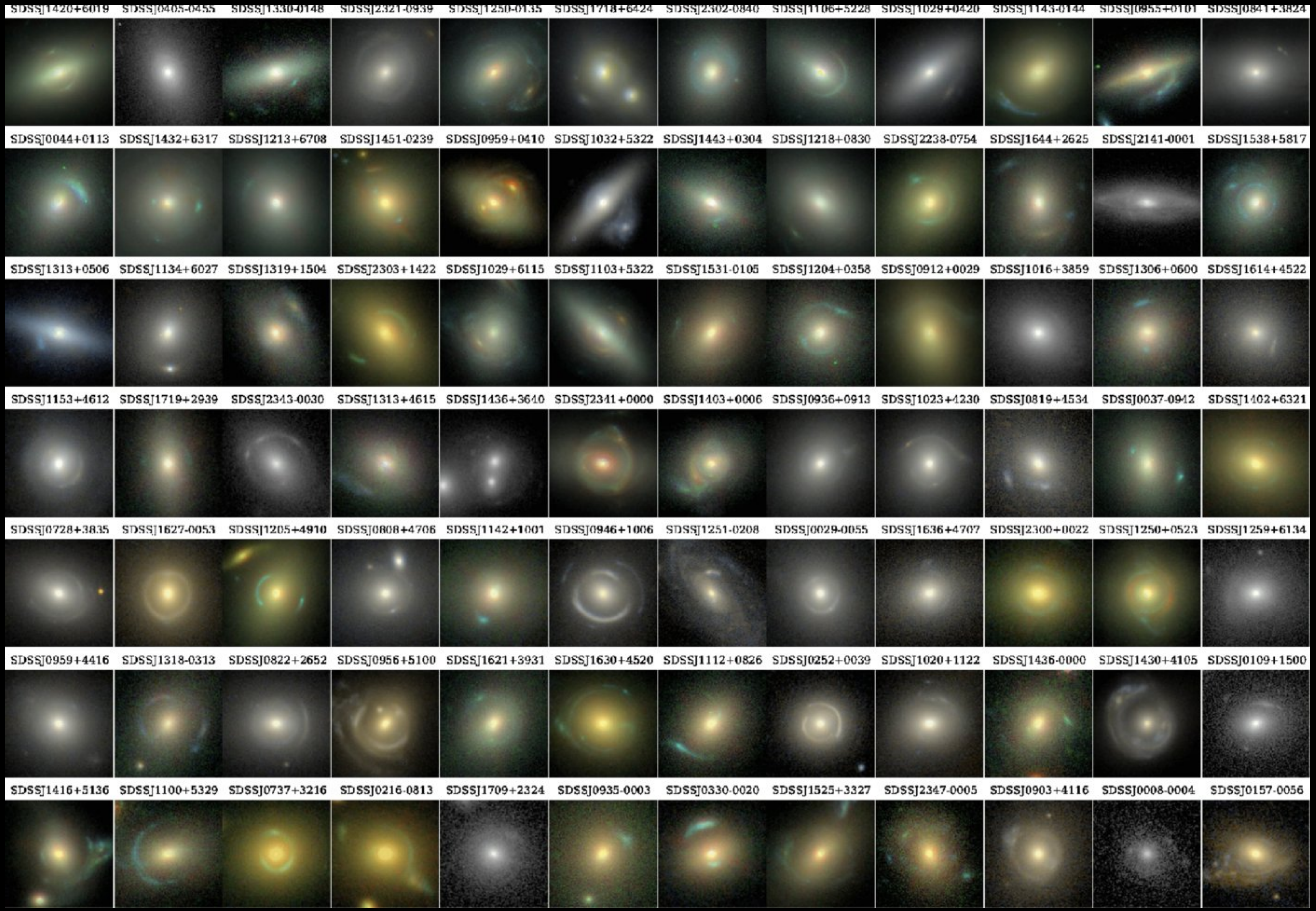
1. Pre-select galaxies in SDSS main and LRG spectroscopic sample

2. Search for emission lines at higher redshift than the source

3. Follow-up with HST the candidates with the highest <u>predicted</u> Einstein radius,

$$\theta_{\rm E}^{\rm (est)} = 4\pi \left(\frac{\sigma_v^{\rm obs}}{c} \right)^2 \frac{D_{\rm ds}}{D_{\rm s}}$$

4. Keep lenses with clear multiple images



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Astronomy & Astrophysics

The SLACS strong lens sample, debiased

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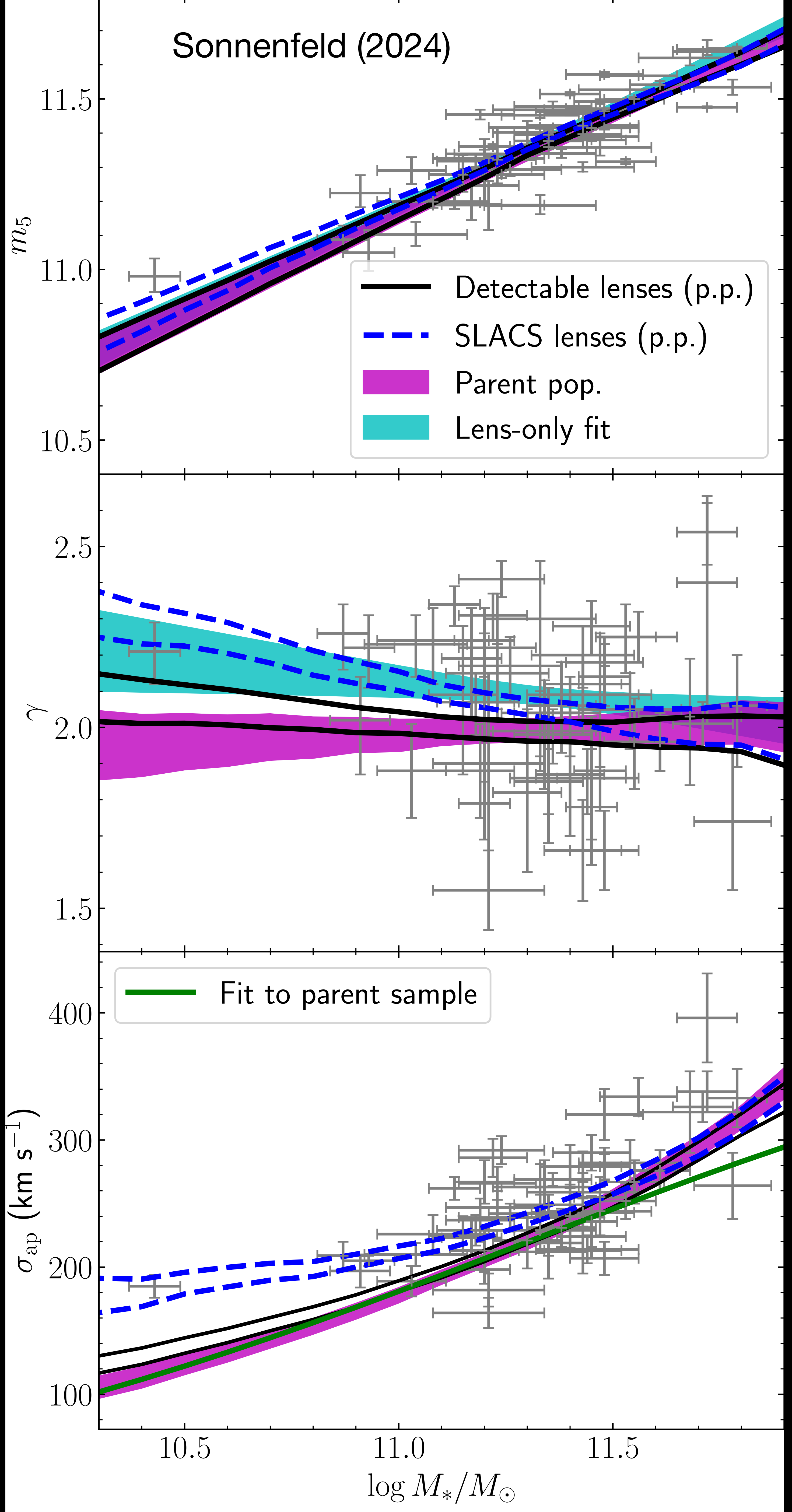
$$\mathrm{P}_{\mathrm{SL}}(\psi_{\mathrm{g}}, \psi_{\mathrm{s}}) \propto \mathrm{P}_{\mathrm{g}}(\psi_{\mathrm{g}})\mathrm{P}_{\mathrm{s}}(\psi_{\mathrm{s}})\mathrm{P}_{\mathrm{sel}}(\psi_{\mathrm{g}}, \psi_{\mathrm{s}})$$

- Model: power-law density profile $\rho(r) \propto r^{-\gamma'}$
- Data: Einstein radius, velocity dispersion
- Lensing + dynamics (spherical Jeans eq.)
- <u>Result: γ was overestimated by 0.1</u>



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Astronomy & Astrophysics

Caustic area biases and how to deal with them

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ABSTRACT

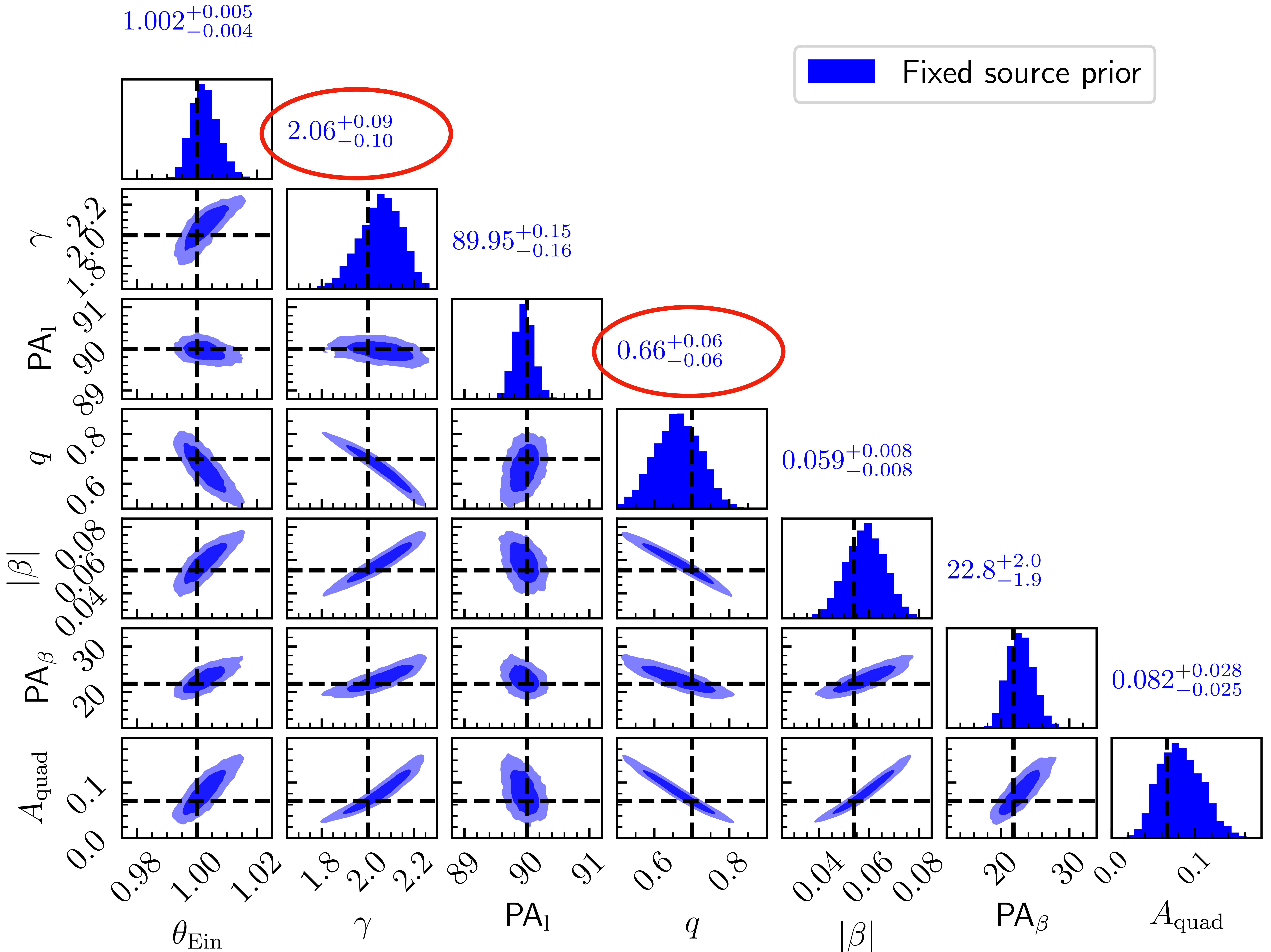
Quadruply imaged strongly lensed point sources (quads) are routinely used for measurements of the expansion rate of the Universe with time delays. It has recently been suggested that any quad lens is subject to a Malmquist-like bias that causes the inferred area enclosed within the tangential caustic to be systematically underestimated, and that such a bias might translate into a corresponding bias on the expansion parameter. In this work we extended that analysis by also considering the effect of Eddington bias. We find that the sign and amplitude of the combined bias depend on the functional form of the caustic area distribution of the lens population and on the noise associated with the caustic area estimation process. Based on simulations, we estimate that the corresponding impact on H_0 is of the order of a percent or smaller. If the likelihood of the lensing data is known, then the bias can be accounted for when modelling the lens population. However, ignoring the criteria used to select a quad might lead to a bias at the lens modelling stage that causes the inferred caustic area to be overestimated. Such a bias disappears for lens models that are well constrained by the data.

Thought experiment

- I have a quad lens, with perfectly measured image positions.
- I know that the true mass distribution is an elliptical power-law.
- I fit an elliptical power-law to the four image positions.
- I choose the following priors:

$$\theta_{\mathrm{E}} \sim \mathrm{U}(0, 3''); \quad \gamma \sim \mathrm{U}(1, 3); \quad q \sim (0.2, 1); \quad \boldsymbol{\beta} \sim \mathrm{U}(-3'', 3'') \otimes \mathrm{U}(-3'', 3'')$$

- Do I recover the truth?



$1.002^{+0.005}_{-0.004}$
$2.06^{+0.09}_{-0.10}$
$89.95^{+0.15}_{-0.16}$
$0.66^{+0.06}_{-0.06}$
$0.059^{+0.008}_{-0.008}$
$22.8^{+2.0}_{-1.9}$
$0.082^{+0.028}_{-0.025}$
Fixed source prior
γ
$\mathrm{PA_l}$
q
$|\beta|$
PA_β
A_quad
θ_Ein

What's going on?

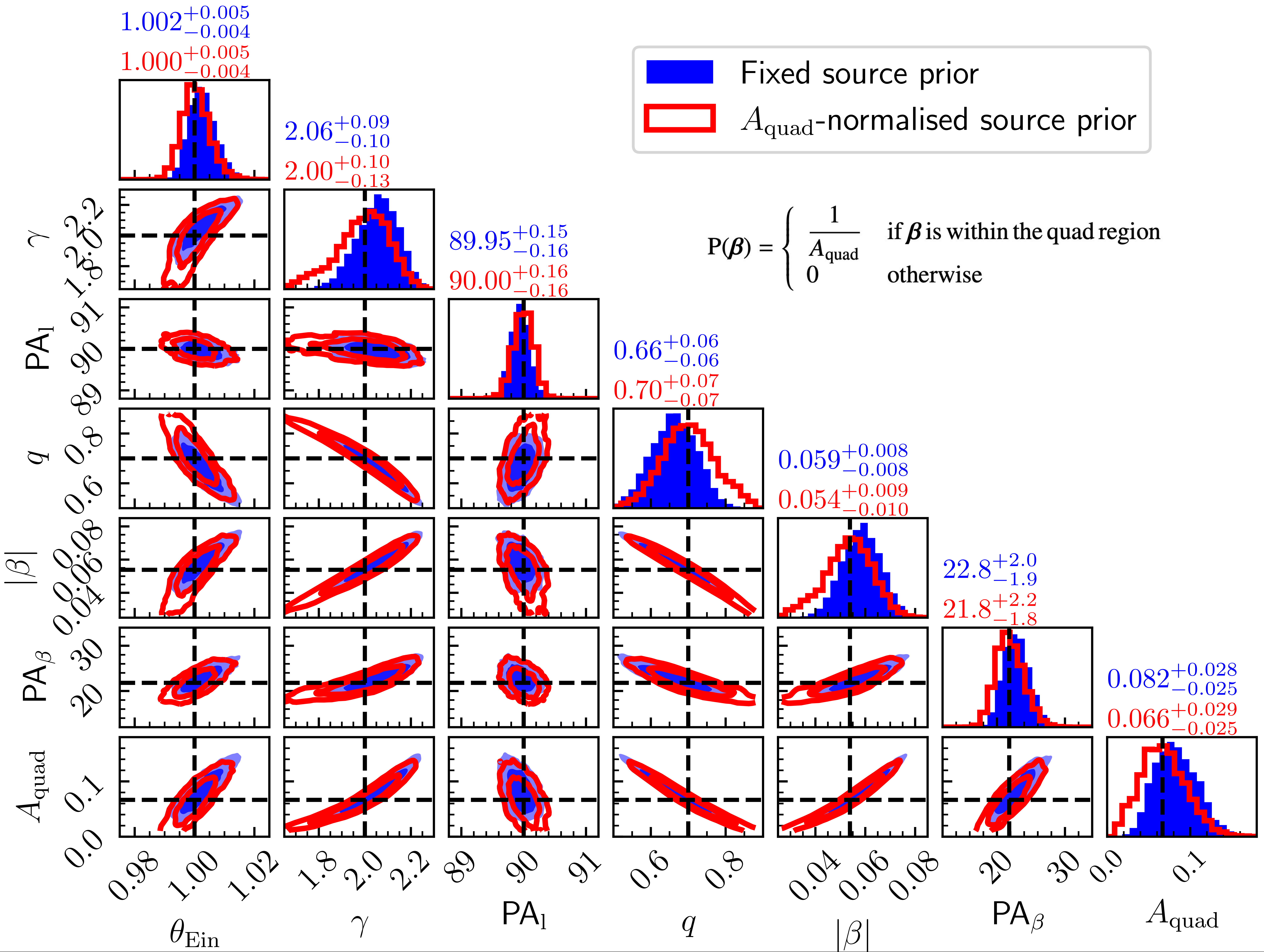
The correct prior

$\mathrm{P_g}(\psi_\mathrm{g}) :=$ Foreground galaxy distribution

$\mathrm{P_s}(\psi_\mathrm{s}) :=$ Background source distribution

$$\boxed{\mathrm{P_{SL}}(\psi_\mathrm{g}, \psi_\mathrm{s}) \propto \mathrm{P_g}(\psi_\mathrm{g})\mathrm{P_s}(\psi_\mathrm{s})\mathrm{P_{sel}}(\psi_\mathrm{g}, \psi_\mathrm{s})}$$

$$\mathrm{P_{sel}}(\psi_\mathrm{g}, \boldsymbol{\beta}) = \begin{cases} 1 & \text{if quad} \\ 0 & \text{otherwise} \end{cases}$$



Fixed source prior
$A_{\rm quad}$-normalised source prior
$P(\boldsymbol{\beta}) = \begin{cases} \frac{1}{A_{\rm quad}} & \text{if } \boldsymbol{\beta} \text{ is within the quad region} \\ 0 & \text{otherwise} \end{cases}$
$1.002^{+0.005}_{-0.004}$
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$21.8^{+2.2}_{-1.8}$
$0.082^{+0.028}_{-0.025}$
$0.066^{+0.029}_{-0.025}$
$\theta_{\rm Ein}$
γ
$\rm PA_l$
q
$|\beta|$
$\rm PA_\beta$
$A_{\rm quad}$

Take-home points

- If somebody gives you a lens, ask where he/she got it from!
- Strong lensing selection is an issue of priors.
- The sneakiest prior is the one you don’t think about.
- Conjugate-point analyses with fixed priors on the source position always prefer the solution with the largest caustic area.
- What about with extended sources?