Redshift Evolution of Lensing Galaxy Density Slopes

Via Cosmological independent Distance Ratios in the Era of LSST

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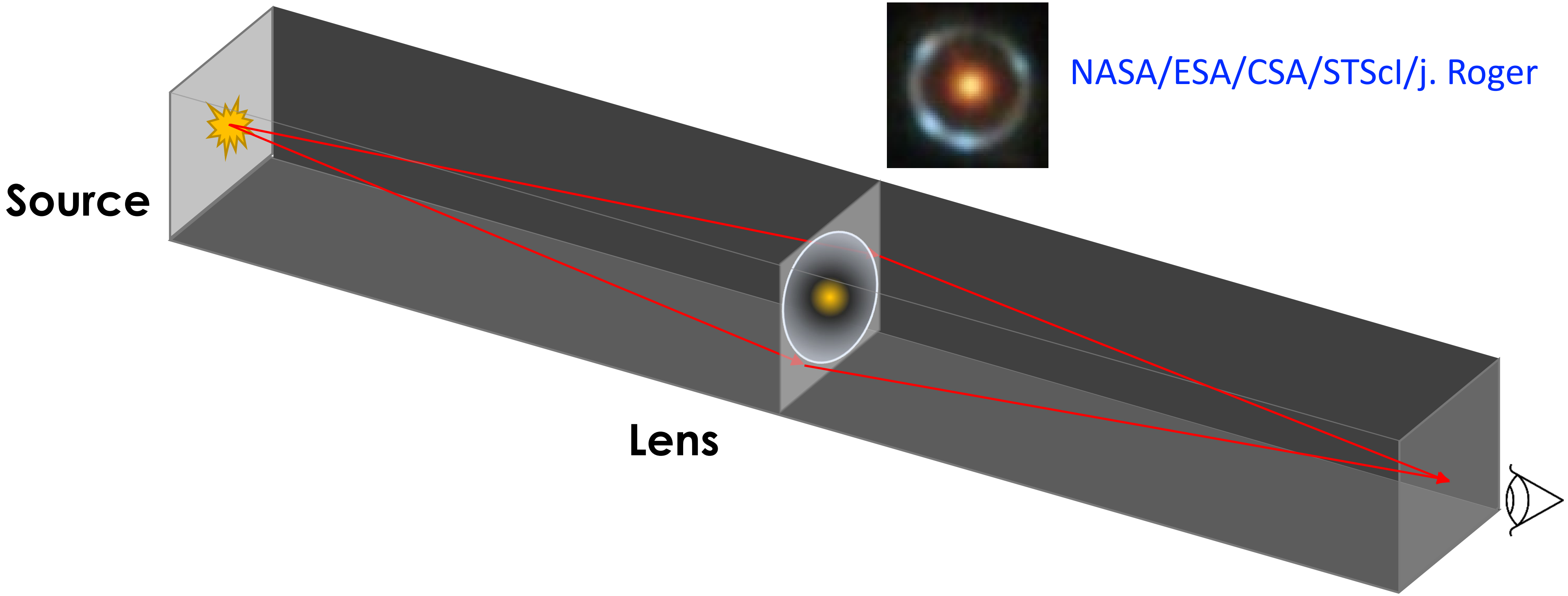
NCBJ

CAMK PAN

Strong Gravitational lensing



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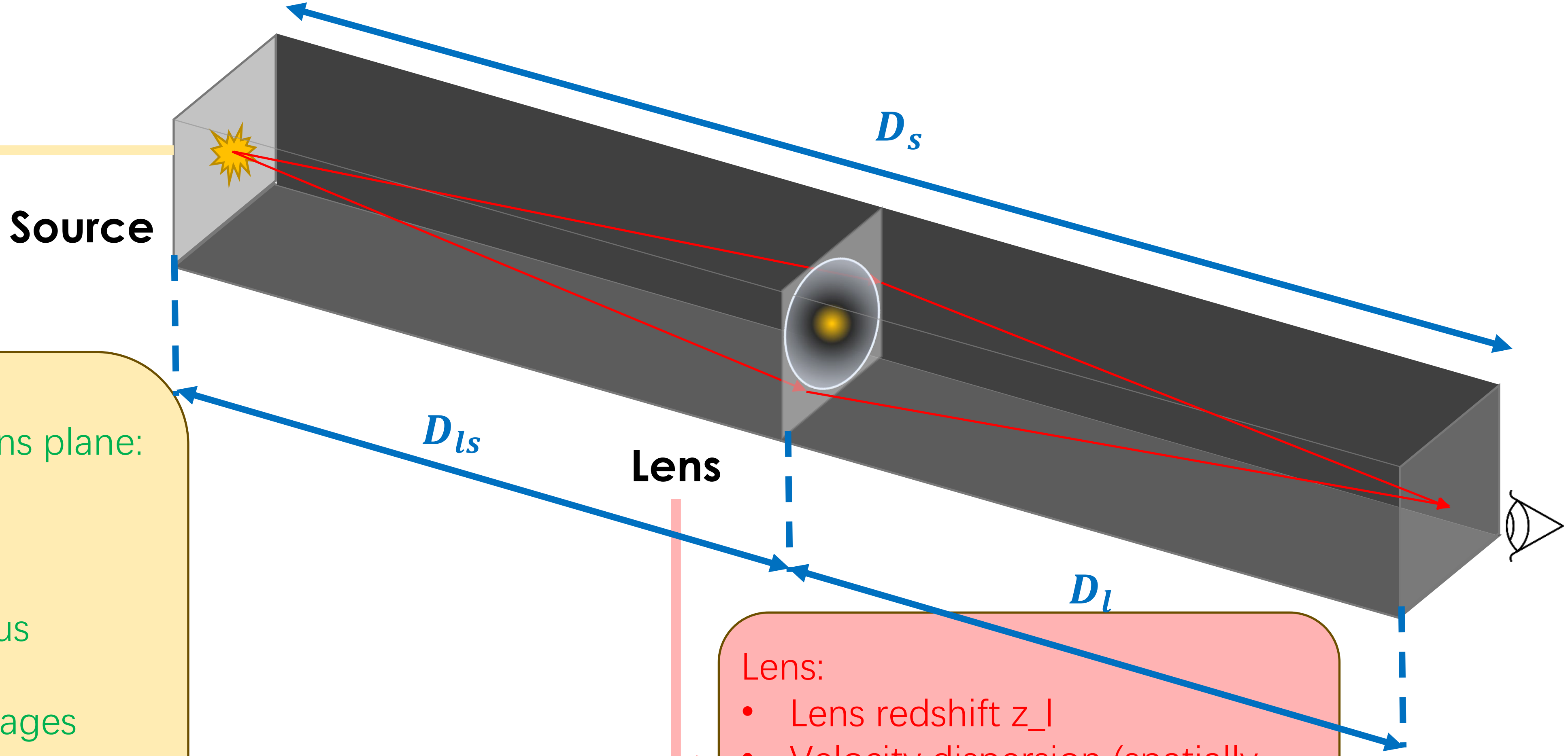


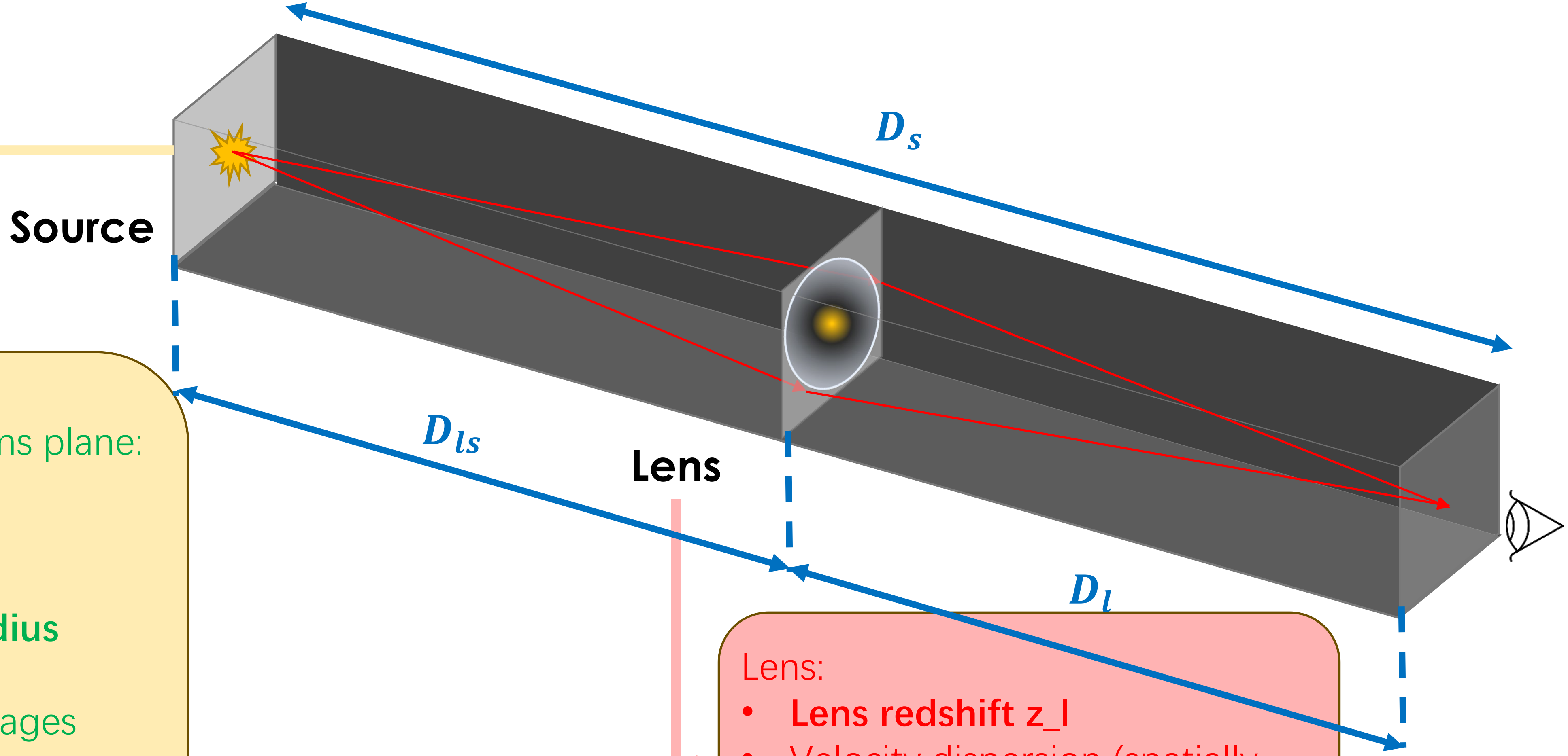
Source Images on the lens plane:

- Source redshift z_s
- Spectrum
- Images' separations
- Effective Einstein radius
- Flux
- Flux ratio between images
- Time-delays
- ……

Lens:

- Lens redshift z_l
- Velocity dispersion (spatially-resolved stellar kinematics)
- ……

Strong Gravitational lensing



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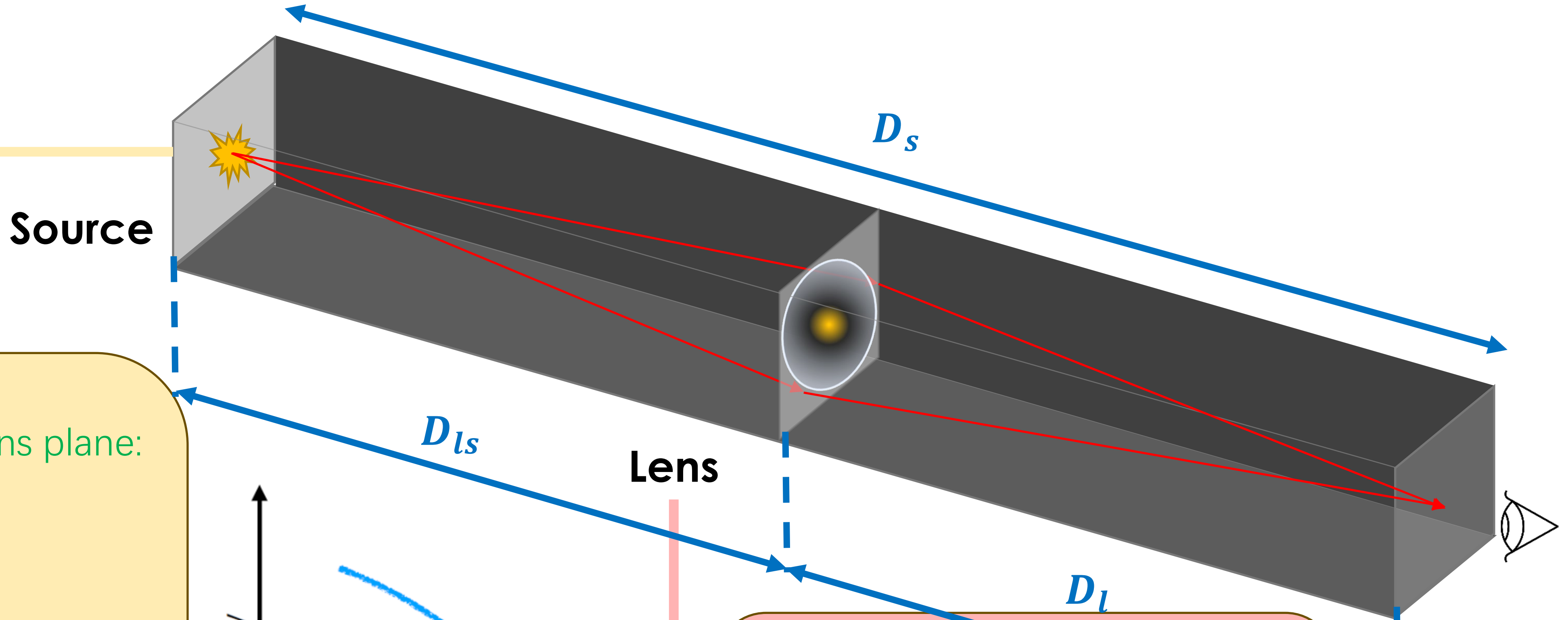

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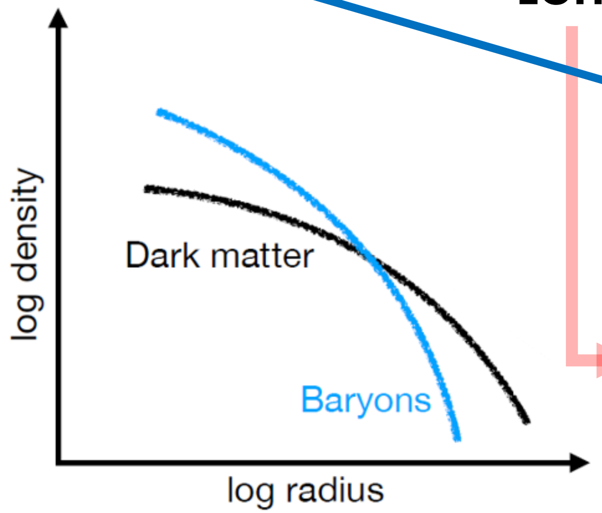

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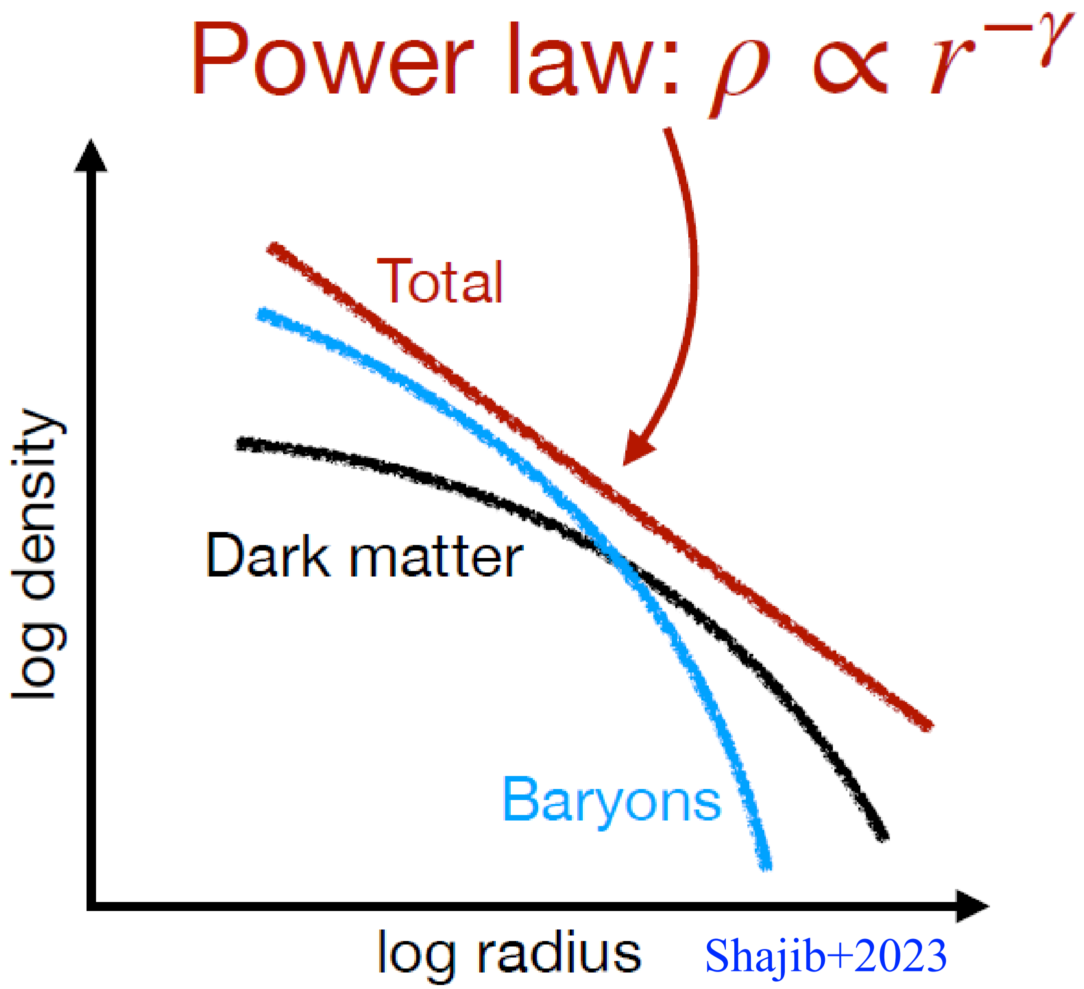
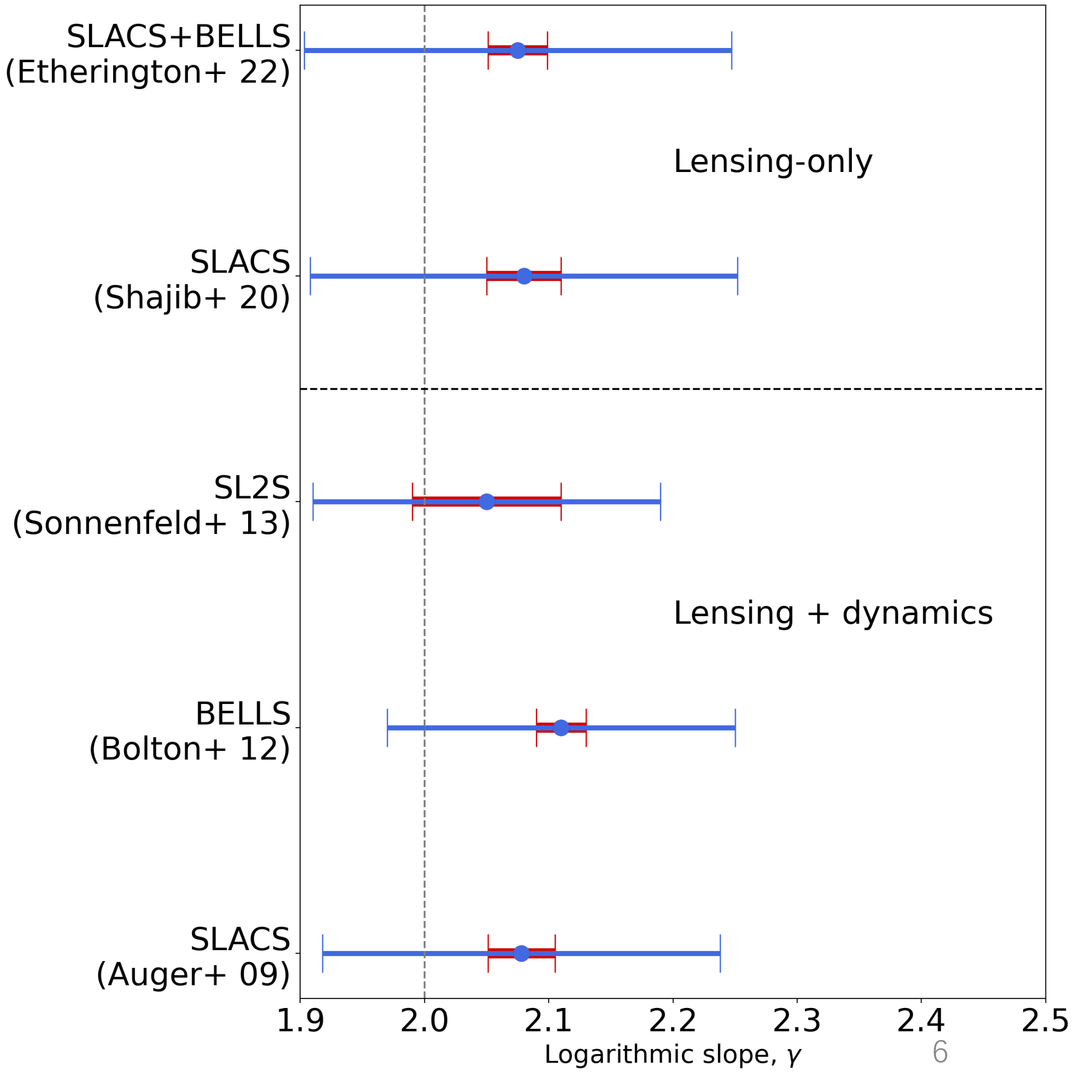
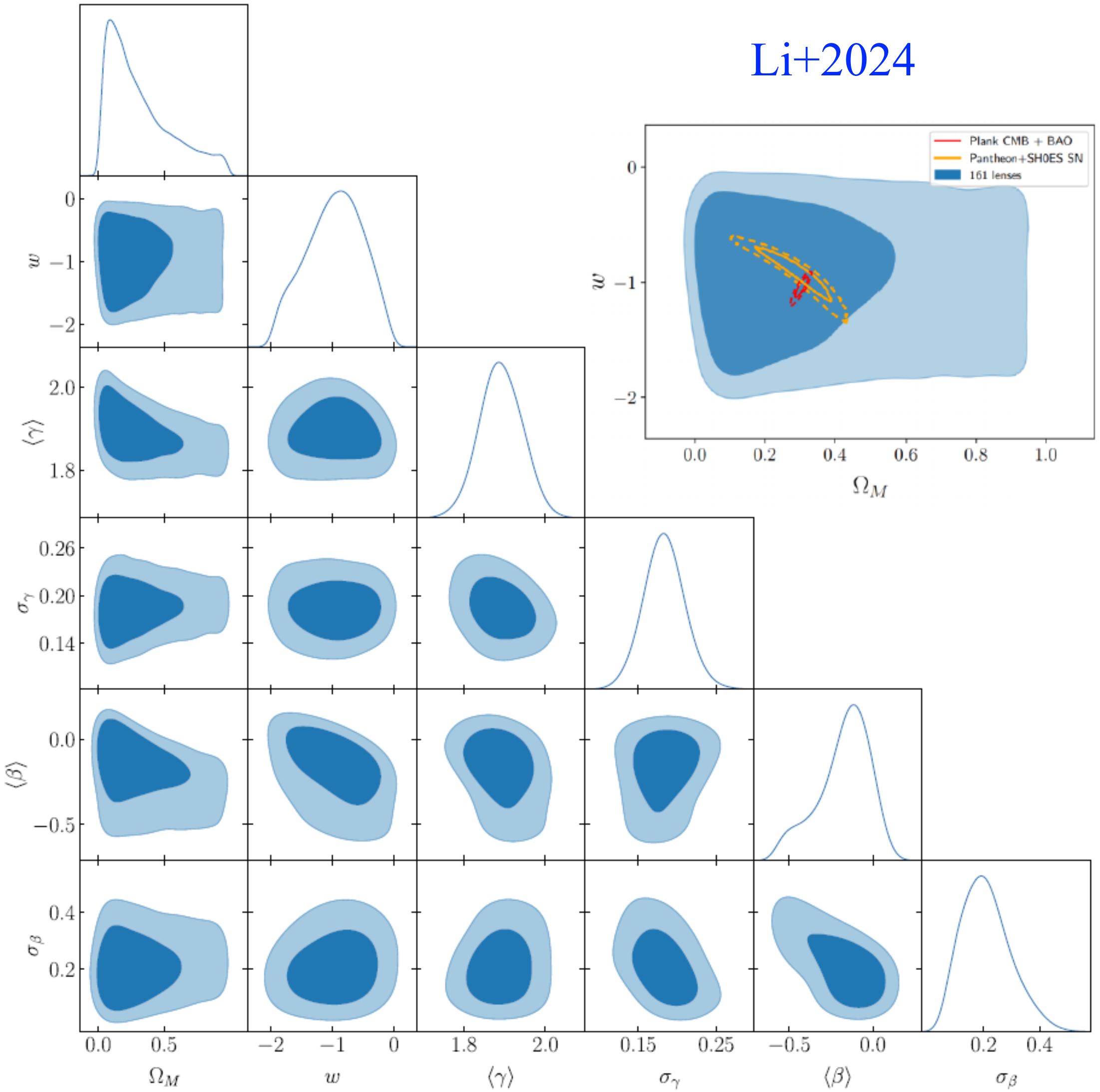
Bulge-Halo conspiracy

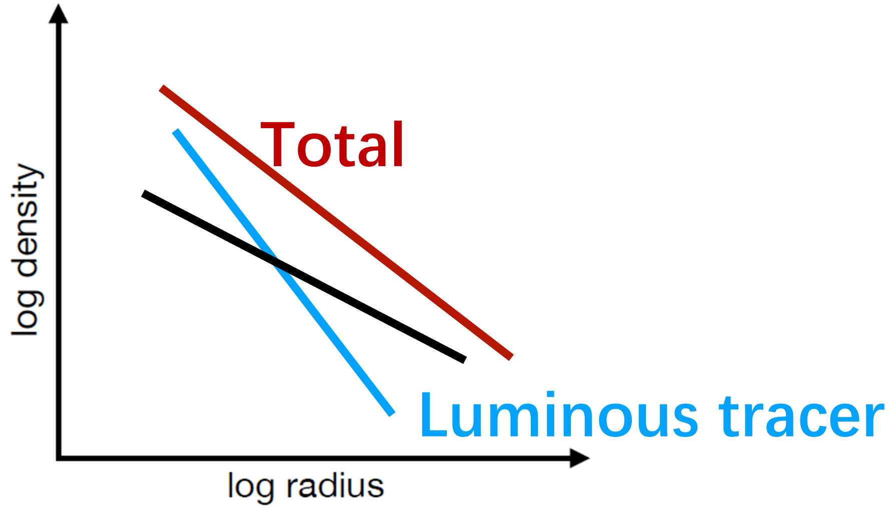




Cosmology from Strong lensing Populations



Li+2024



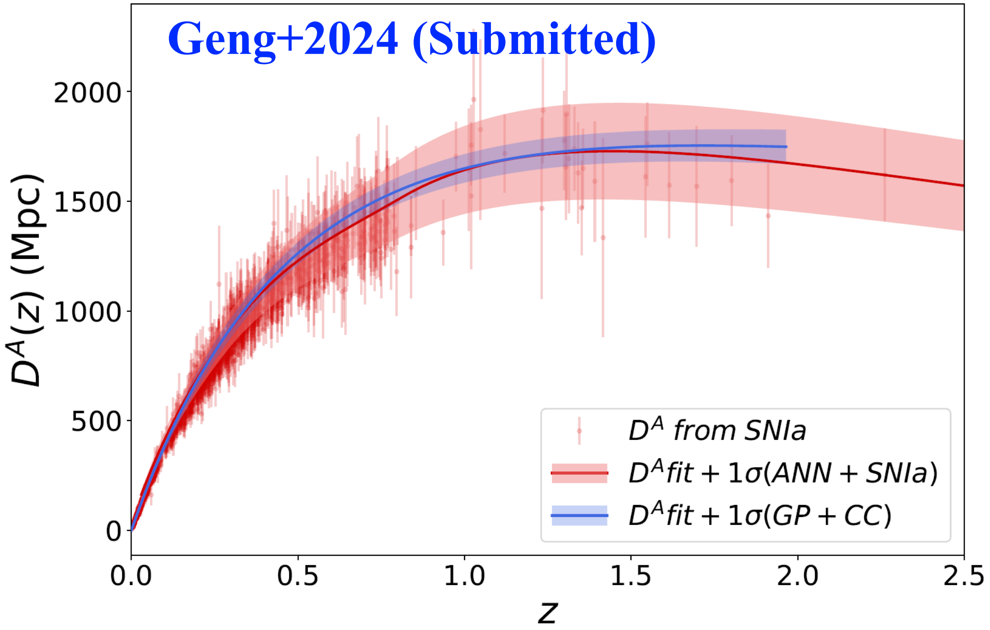
Extended Power-law Model

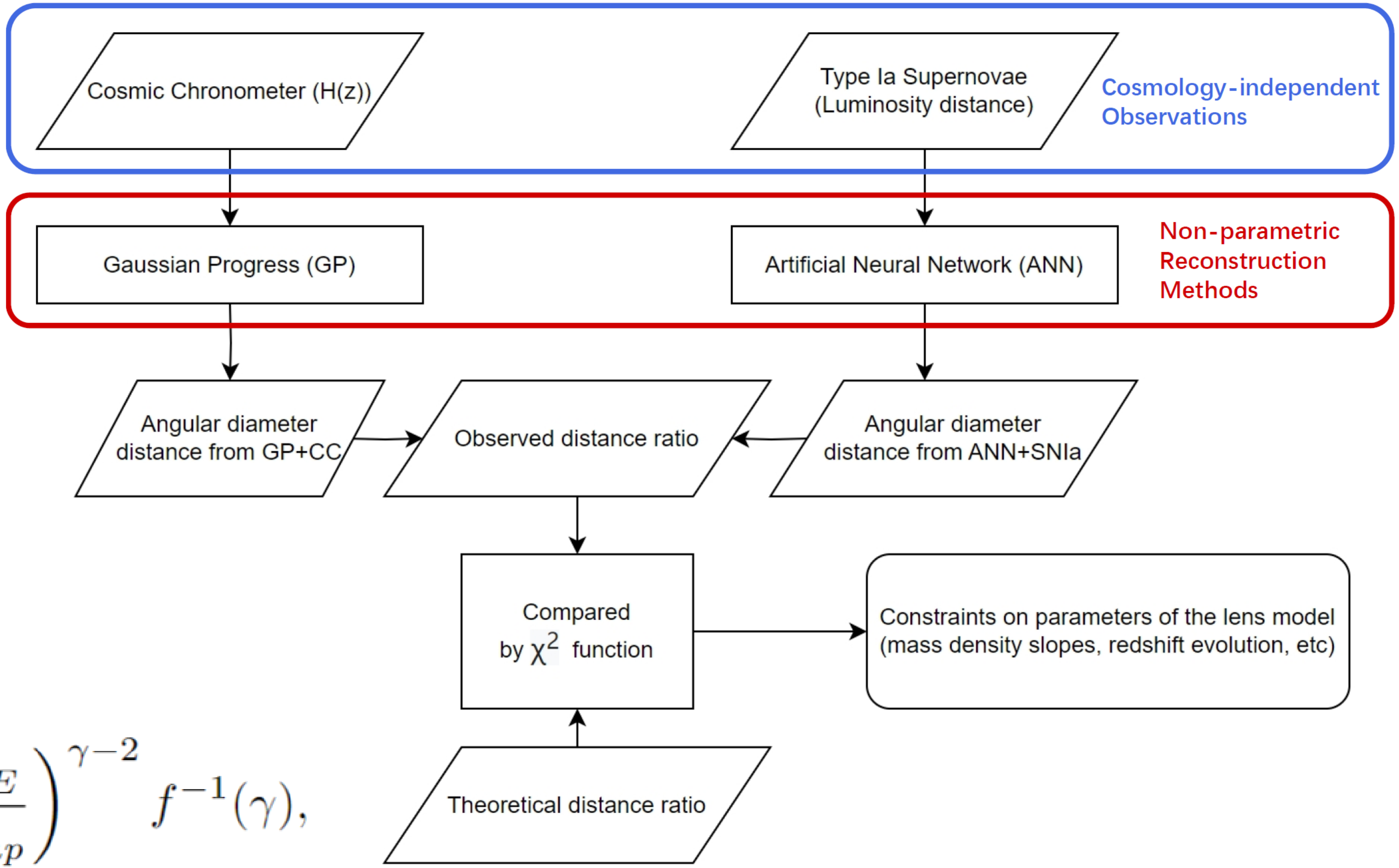
$$\rho_L(r) = \rho_L r^{-\delta}$$

$$\rho_{tot}(r) = \rho_{tot} r^{-\gamma}$$

$$\beta(r) = 1 - \frac{\langle\sigma_\theta^2\rangle}{\langle\sigma_r^2\rangle},$$

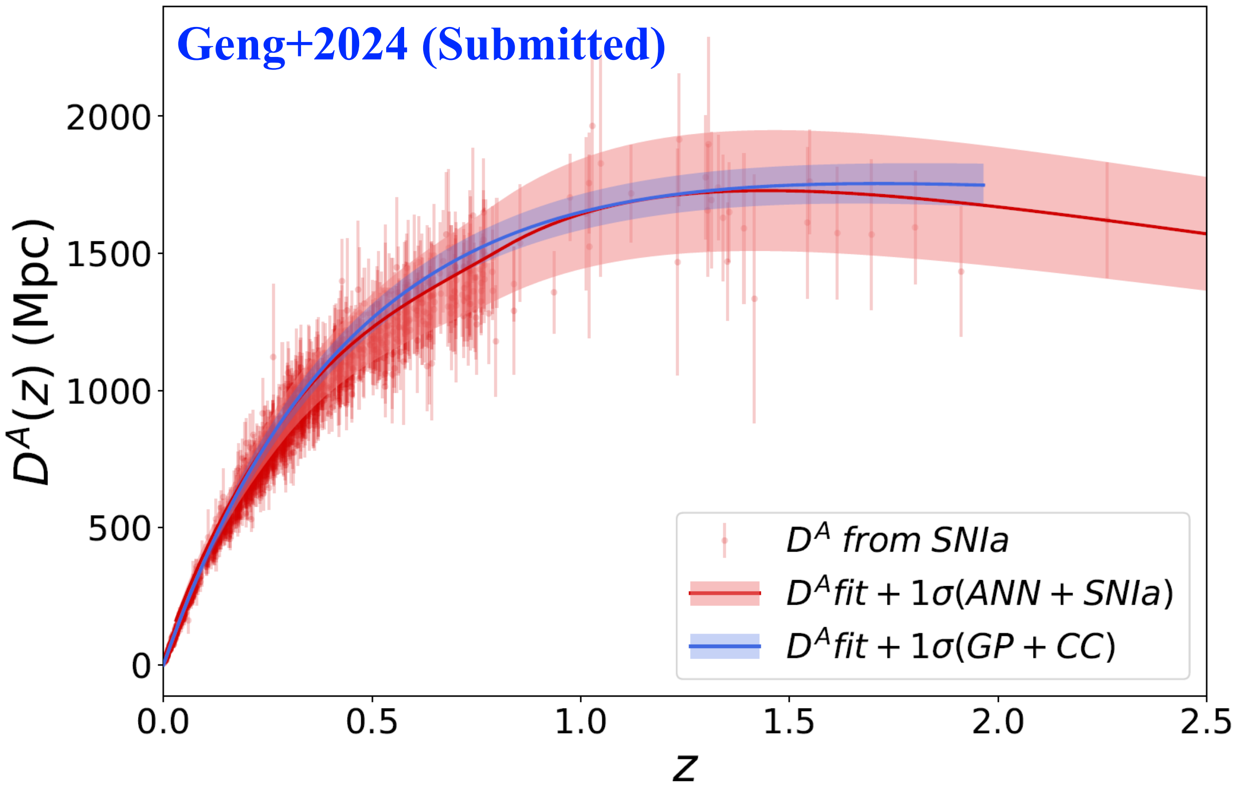
Cosmology model-independent distance ratio





$$\mathcal{D}^{th}(\vartheta_{free};\vartheta_{given}) = \frac{D_{ls}}{D_s} = \frac{c^2}{4\pi}\frac{\theta_E}{\sigma_{ap}^2}\left(\frac{\theta_E}{\theta_{ap}}\right)^{\gamma-2} f^{-1}(\gamma),$$

Non-parametric Reconstruction



Gaussian Process (GP)

Assuming both the available data and the points we aim to reconstruct follow Gaussian distributions.

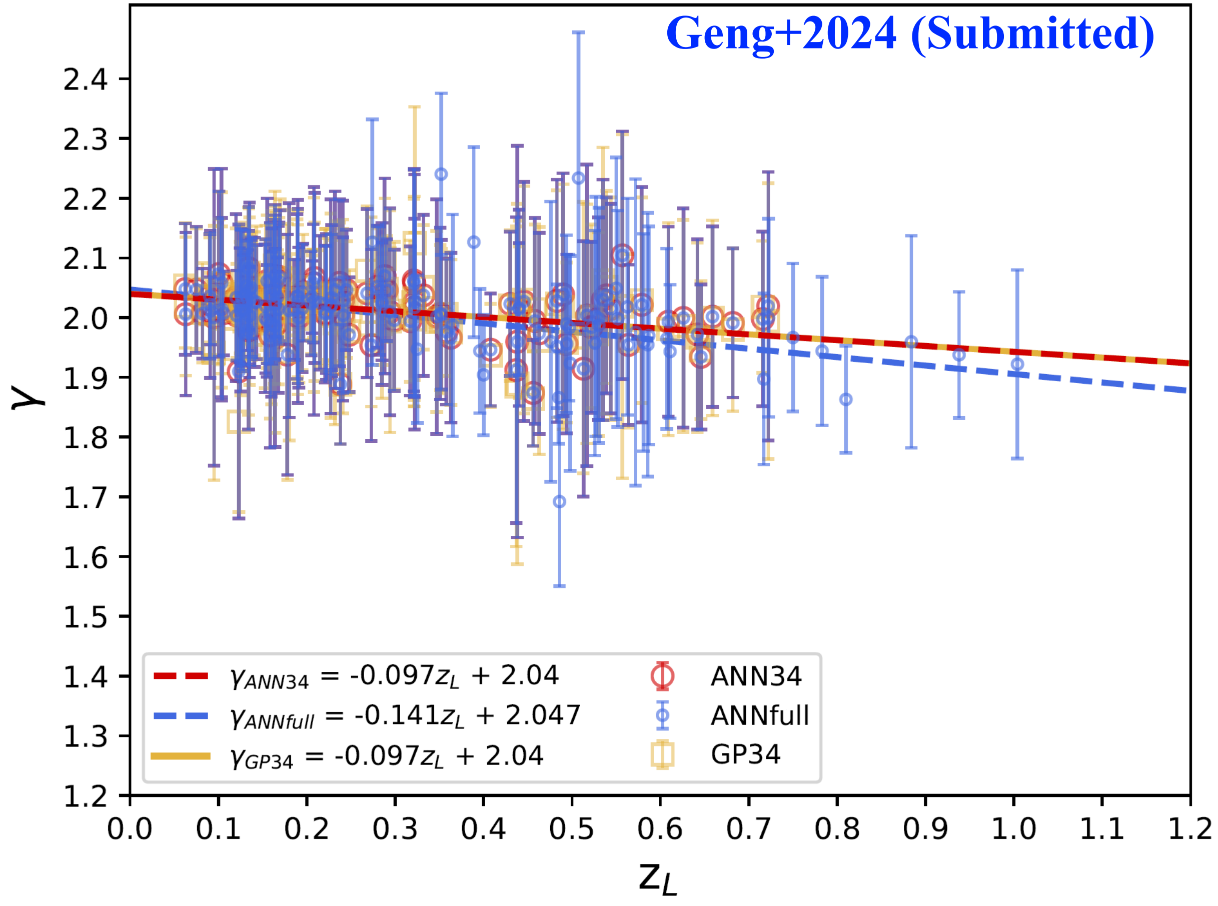
$$\begin{bmatrix} \mathbf{y} \\ \mathbf{f} \end{bmatrix} \sim \mathcal{N}\left(\begin{bmatrix} \mu(Z) \\ \mu(Z') \end{bmatrix}, \begin{bmatrix} K(Z,Z) & K(Z,Z') \\ K(Z',Z) & K(Z',Z') \end{bmatrix} \right)$$

Artificial Neural Network (ANN)

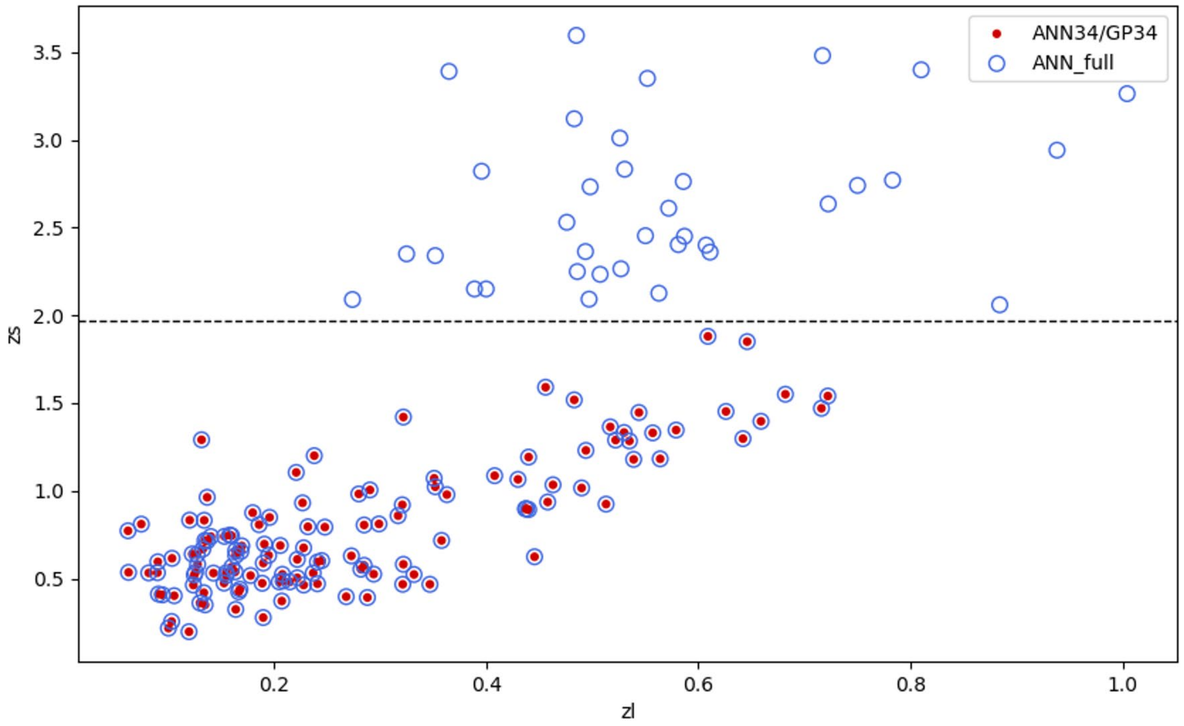
- 3-layer
- 20 neurons in each layer
- learning rate was set to 0.001

Single density slope constraints

Individual constraining



LSD: 5
SL2S: 26
SLACS: 57
S4TM: 38
BELLS:21
BELLS GALLERY: 14



Extended power-law density slope

$$\rho_L(r) = \rho_L r^{-\delta}$$

$$\rho_{tot}(r) = \rho_{tot} r^{-\gamma}$$

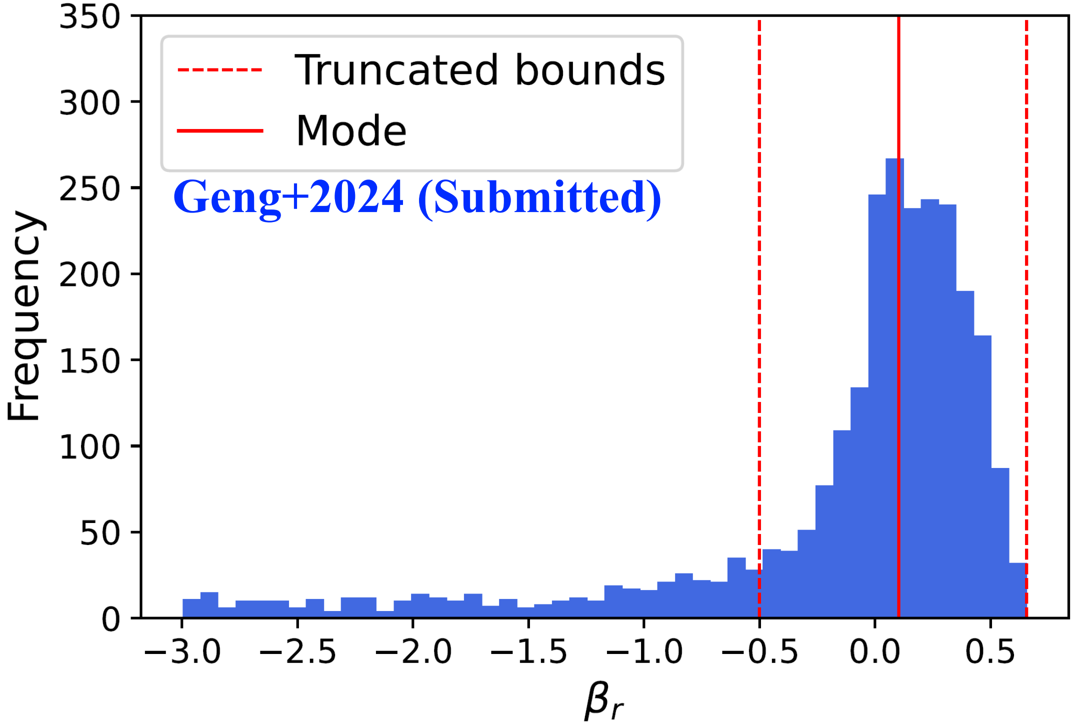
$$\beta(r) = 1 - \frac{\langle \sigma_\theta^2 \rangle}{\langle \sigma_r^2 \rangle},$$

Zhu+2023

- Data from MaNGA survey (SDSS Data release 17)
- ~ 10,000 galaxies
- Observations based on integral field unit (IFU)
- Axisymmetric Jeans Anisotropic Modeling (JAM) method
- Visual quality > 0 (2597 galaxies)

Triangular Prior

Tri(-0.5, 0.656, mode=0.102)

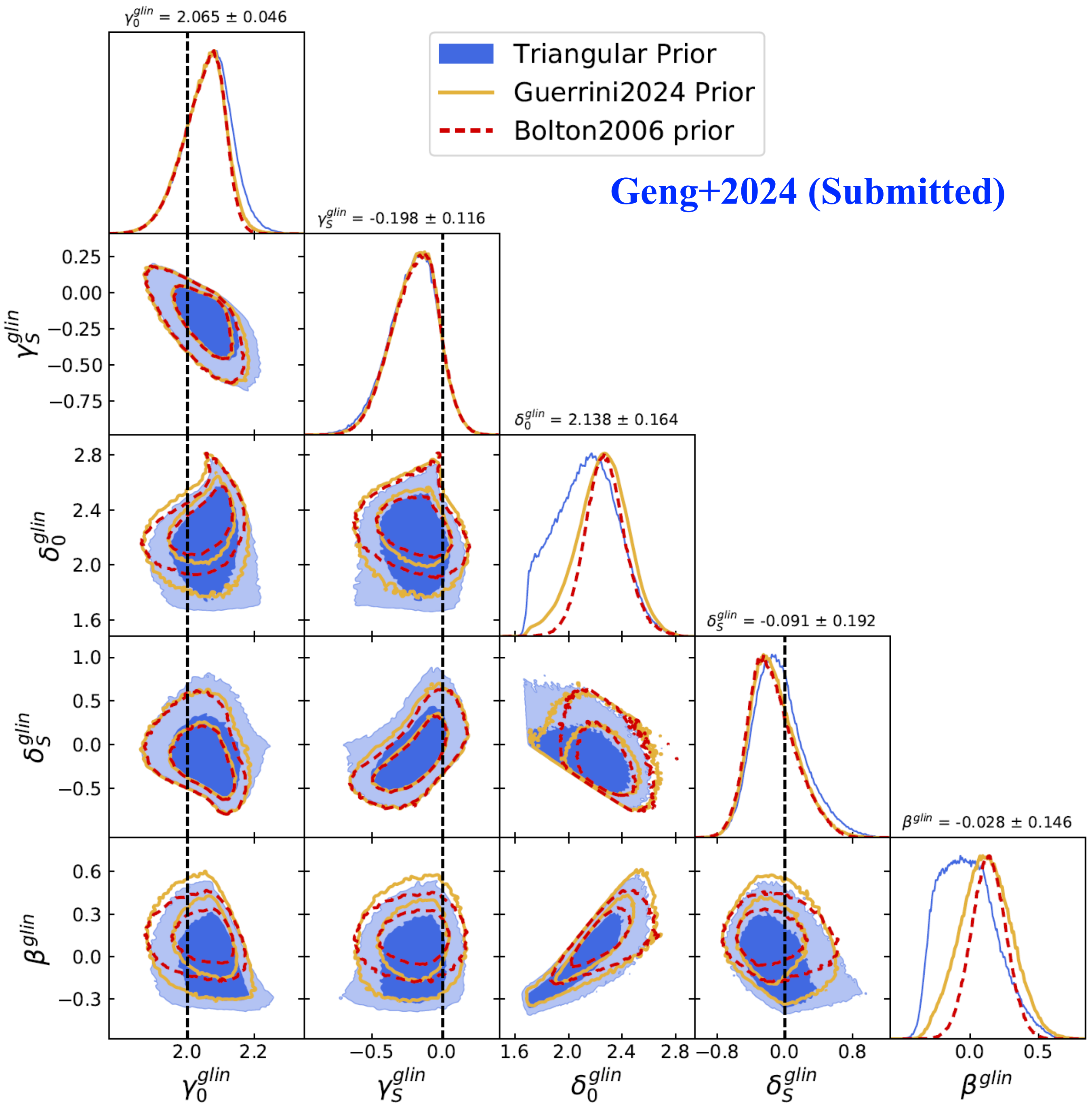


Redshift Evolution

$$\gamma^{EPL} = \gamma_0^{lin} + \gamma_s^{lin} \times z_l$$
$$\delta^{EPL} = \delta_0^{lin} + \delta_s^{lin} \times z_l$$

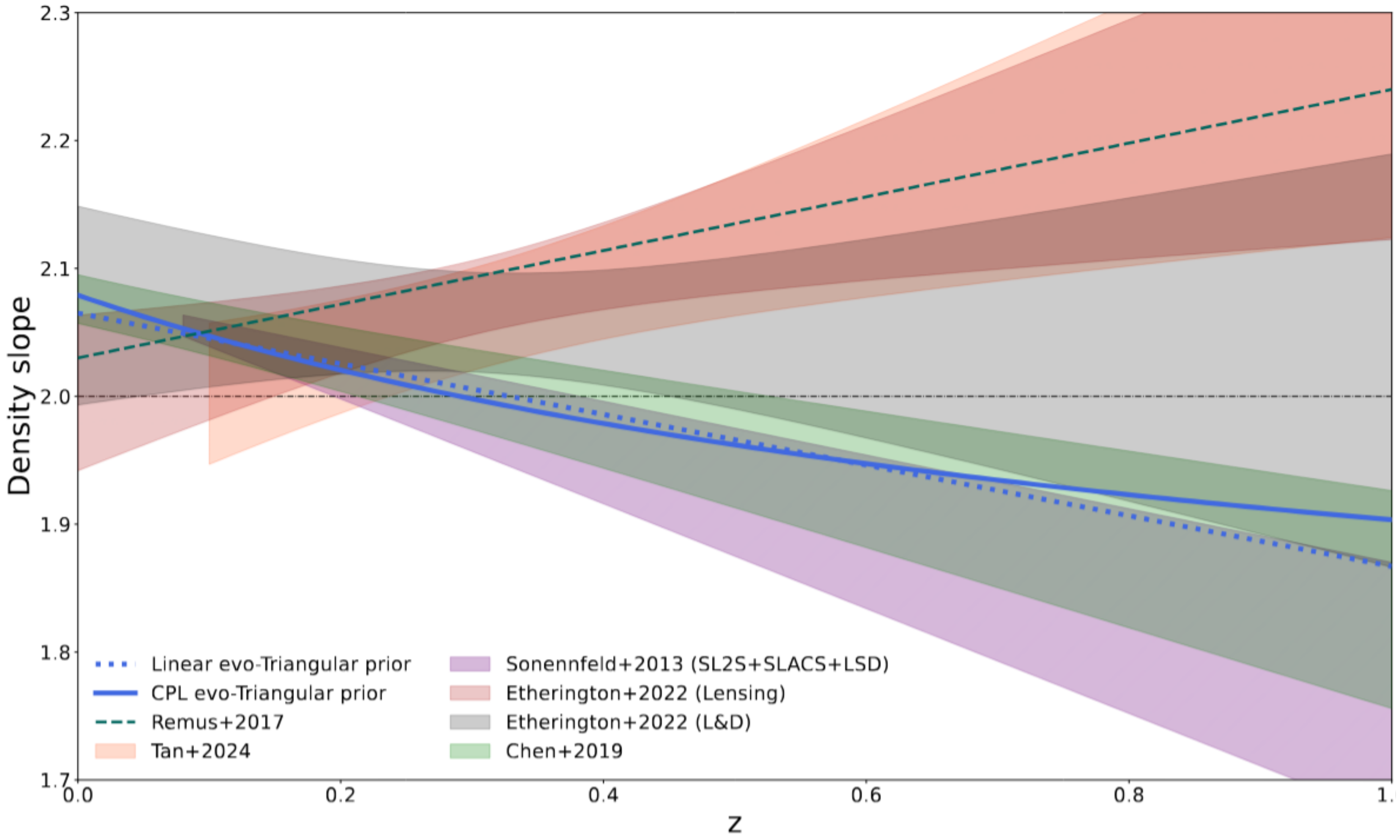
Linear evolution + Triangular prior
Tri(-0.5, 0.656, mode=0.102)

$$\gamma_0^{\mathrm{glin}} = 2.065 \pm 0.046$$
$$\gamma_s^{\mathrm{glin}} = -0.20 \pm 0.12$$
$$\delta_0^{\mathrm{glin}} = 2.14 \pm 0.16$$
$$\delta_s^{\mathrm{glin}} = -0.09 \pm 0.19$$

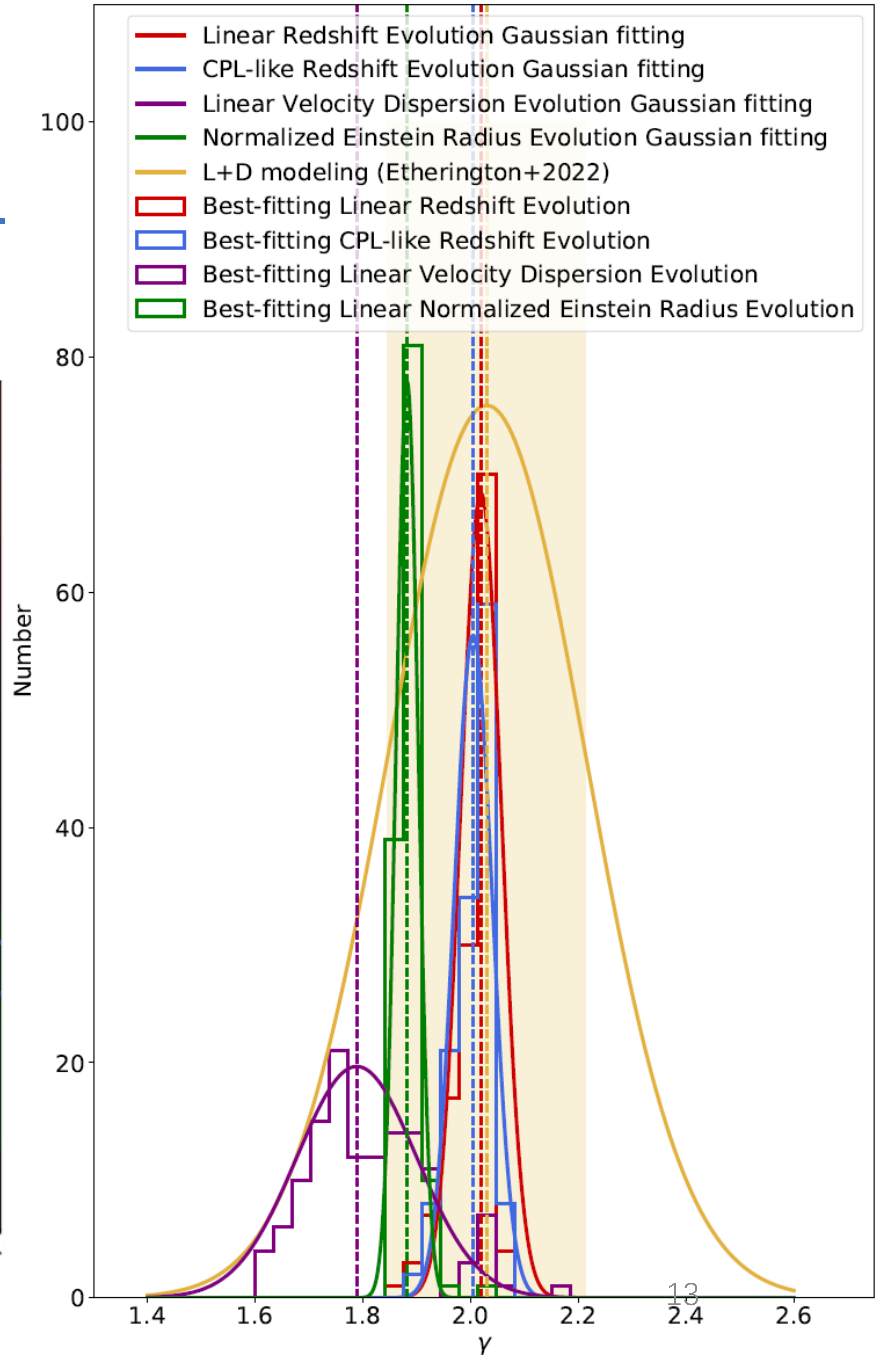


Results

Consist well with Lensing+Dynamics works



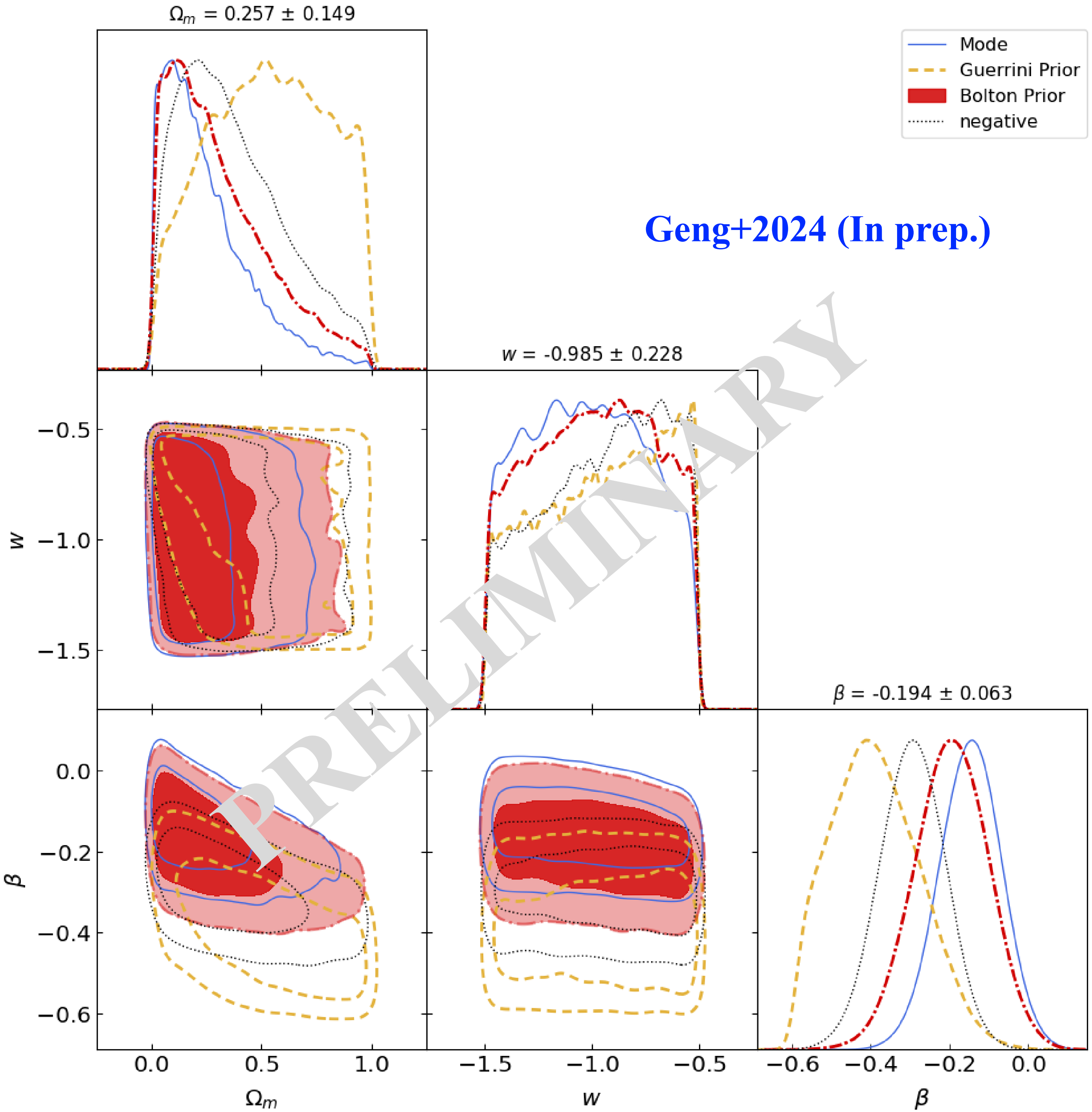
Geng+2024 (Submitted)



Results

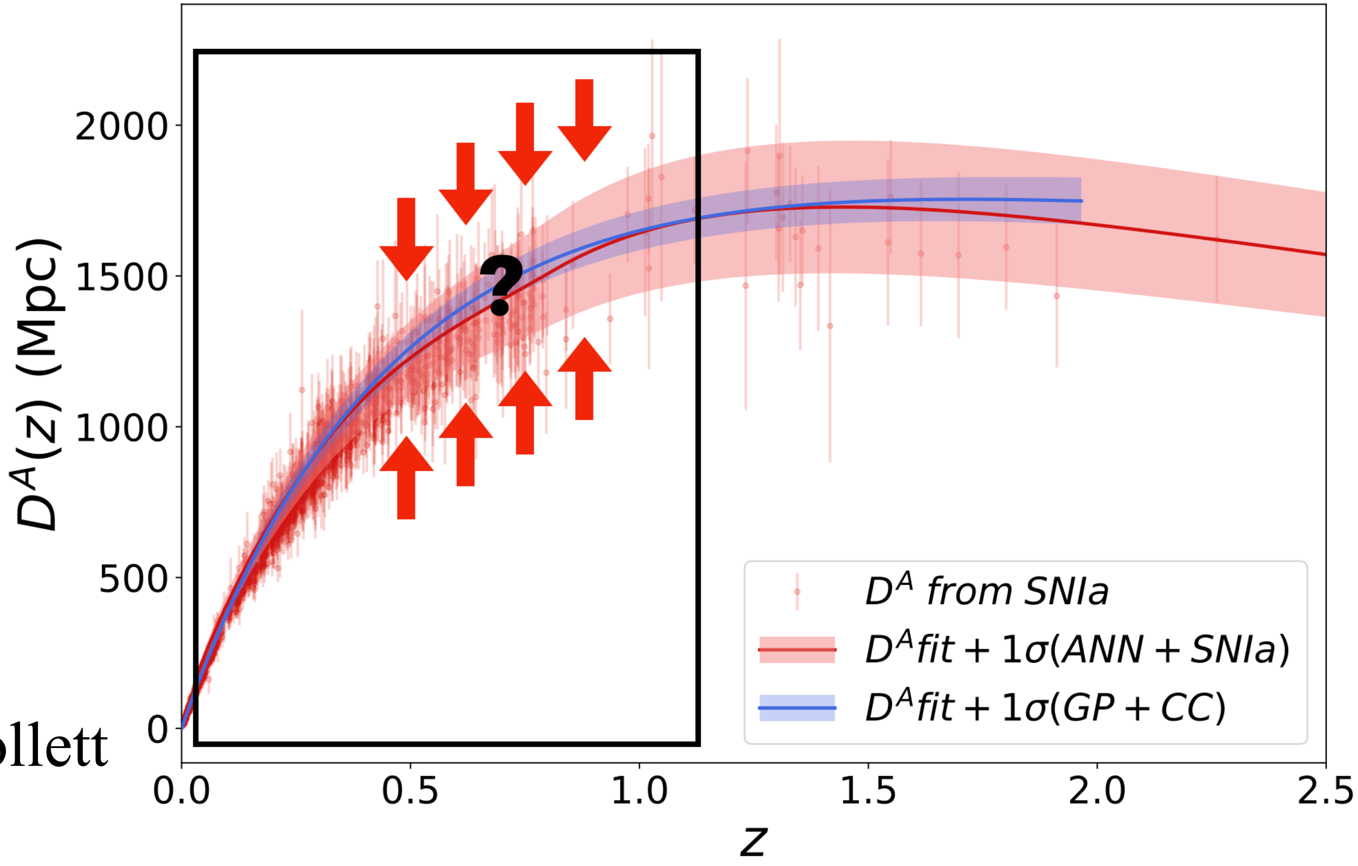
$$\beta_{mode} = \mathrm{Tri}((-0.5, 0.656, \mathrm{mode} = 0.102)$$
$$\beta_{Guerrini} = 0.2 \pm 0.22$$
$$\beta_{Bolton} = 0.18 \pm 0.13$$
$$\beta_{neg} = -0.1 \pm 0.1$$

$$\Omega_m = 0.257 \pm 0.149$$
$$w = -0.985 \pm 0.228$$



What do we expect from LSST?

Type Ia Supernova
LSST : ~1,000 **x100** SNIa up to z~1.2
LSST+Roman: up to z~3
(Petrecca+2024)



Strong Gravitational Lenses
LSST:
~120,000 galaxy–galaxy strong lenses (Collett 2015)
+Spectroscopy follow-ups

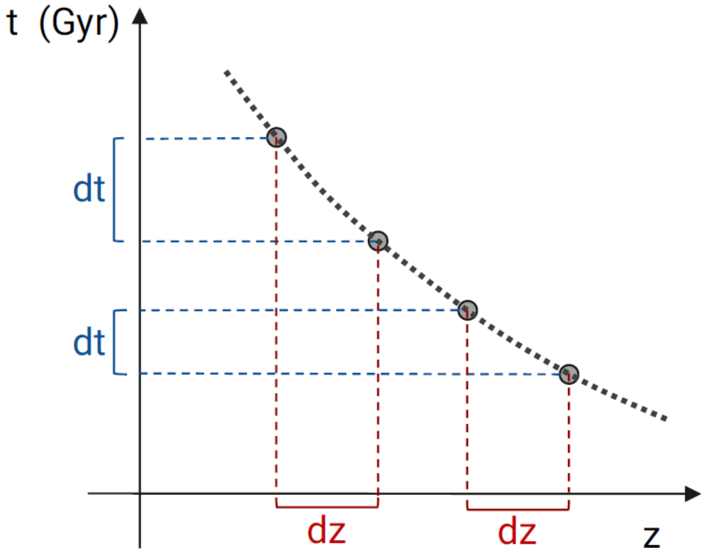
Summary and Perspective

- New cosmology-independent approach for reconstructing the distance ratios of SGL systems to constrain the mass-density slope
- Finding total mass density slope evolution follows $\gamma = 2.065(\pm 0.046) - 0.20(\pm 0.12) \times z$
- Confirming the validity of Extended Power-Law (EPL) model at population level
- Emphasizing the importance of large-scale optical surveys like LSST and spectroscopic follow-ups.

Thank you for your attention!

Back-up slides

Cosmic Chronometers



Tomasetti et al. 2023

spectroscopic redshift

$$H(z) = \frac{\dot{a}}{a} = -\frac{1}{1+z}\frac{dz}{dt}$$

Jimenez & Loeb (2002)

can be traced with "chronometers"

$$D4000 = A(\mathrm{SFH}, Z/\mathrm{Z}_{\odot}) \cdot \mathrm{age} + B.$$

$$H(z) = -\frac{1}{1+z} A(\mathrm{SFH}, Z/\mathrm{Z}_{\odot}) \frac{\mathrm{d}z}{\mathrm{d}D4000}$$