A Forecast of tomographic cross-correlation of CSST cosmic shear and ALiCPT CMB lensing

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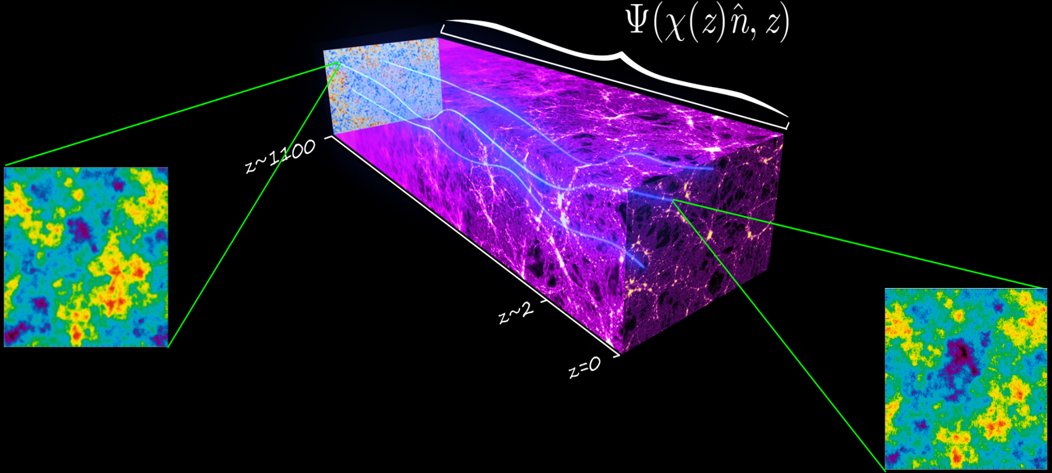
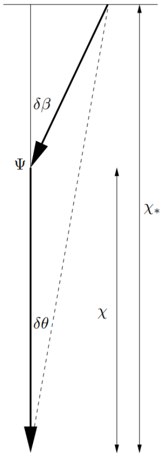

$\Psi(\chi(z)\hat{n}, z)$
z~1100
z~2
z=0

Gravitational lens



Coforming Newtonian Gauge:

$$\mathrm{d}s^2 = a^2(t)[(1+2\Psi_\mathrm{N})\mathrm{d}t^2 - (1+2\Phi_\mathrm{N})\mathrm{d}\vec{x}^2]$$

Deflection angle:

$$\boldsymbol{\alpha} = -\frac{2}{c^2}\int_0^{z_*}\frac{c\mathrm{d}z}{H(z)}\frac{\chi_* - \chi}{\chi_*\chi}\boldsymbol{\nabla}_{\boldsymbol{\theta}}\Psi(\boldsymbol{\theta}, z)$$

Jacobian matrix:

$$A_{ij} = \frac{\partial\boldsymbol{\beta}}{\partial\boldsymbol{\theta}} = \delta_{ij} + \frac{\partial\alpha_j}{\partial\theta_i} = \begin{bmatrix} 1-\kappa-\gamma_1 & -\gamma_2 \\ -\gamma_2 & 1-\kappa+\gamma_1 \end{bmatrix}$$

κ:convergence, isotropic magnification ;
γ:shear, anisotropic stretching

CMB Lensing

Lensing effect:

$$\tilde{\Theta}(\boldsymbol{\theta}) = \Theta(\boldsymbol{\theta} + \boldsymbol{\alpha}(\boldsymbol{\theta})) = \Theta(\boldsymbol{\theta}) + \nabla^i \psi \nabla_i \Theta(\boldsymbol{\theta}) + \mathcal{O}(\psi^2)$$

Where $\boldsymbol{\alpha}(\boldsymbol{\theta}) = \nabla \psi(\boldsymbol{\theta})$,and flat sky with plane wave mode:

$$\Theta(\boldsymbol{\theta}) = \int \frac{\mathrm{d}^2 \ell}{(2\pi)^2} \Theta(\boldsymbol{\ell}) e^{i\boldsymbol{\ell}\cdot\boldsymbol{\theta}}, \psi(\boldsymbol{\theta}) = \int \frac{\mathrm{d}^2 L}{(2\pi)^2} \psi(\boldsymbol{L}) e^{i\boldsymbol{L}\cdot\boldsymbol{\theta}}$$

$$\tilde{\Theta}(\boldsymbol{\ell}) \approx \Theta(\boldsymbol{\ell}) - \int \frac{\mathrm{d}^2 \ell'}{(2\pi)^2} \Theta(\boldsymbol{\ell})[\boldsymbol{\ell} \cdot (\boldsymbol{\ell} - \boldsymbol{\ell}')] \psi(\boldsymbol{\ell} - \boldsymbol{\ell}')$$

Mode-coupling:

$$\langle \tilde{\Theta}(\boldsymbol{\ell}_1) \tilde{\Theta}^*(\boldsymbol{\ell}_2) \rangle \neq 0, \quad \text{for} \quad \boldsymbol{\ell}_1 \neq \boldsymbol{\ell}_2$$

CMB Lensing noise level

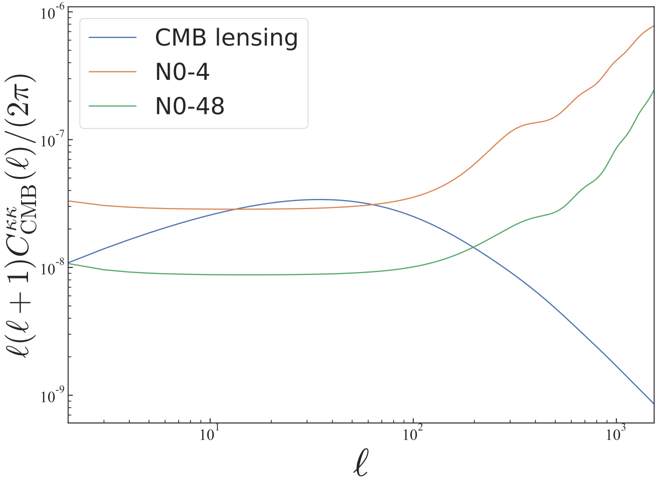
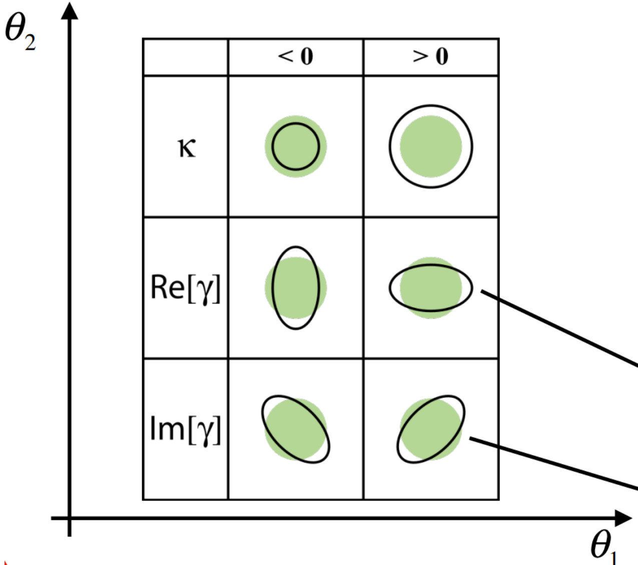


Figure: Power spectrum of CMB lensing potential and reconstruction noise with N0-4 and N0-48

Weak lensing effect



$$\kappa = \psi_{,11} + \psi_{,22}$$

$$\gamma_1 = \psi_{,11} - \psi_{,22}$$

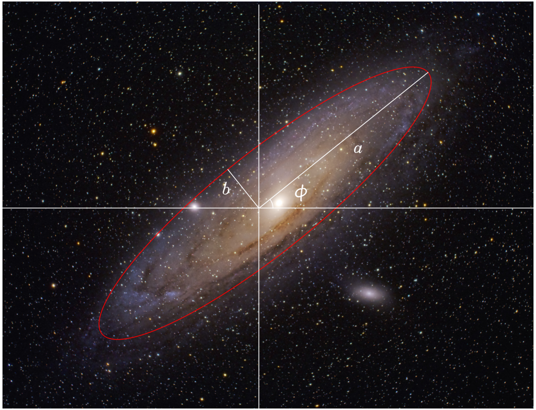
$$\gamma_2 = \psi_{,12}$$

e.g.

$$\psi(\theta_1, \theta_2) = \theta_1^{\ 2} + \frac{1}{2}\theta_2^{\ 2}$$

$$\psi \sim \theta_1 \bullet \theta_2 \Rightarrow \gamma_2$$

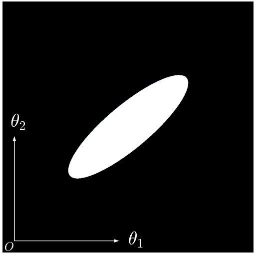
Shape of galaxies



Galaxy ellpiticity:

$$\varepsilon_s = \frac{a-b}{a+b}\exp(2i\phi) = \varepsilon_{s1} + i\varepsilon_{s2}$$

Shape of galaxies



Centroid:

$$\bar{\theta}_i = \int \mathrm{d}\theta \theta_i q_I(I(\boldsymbol{\theta}))$$

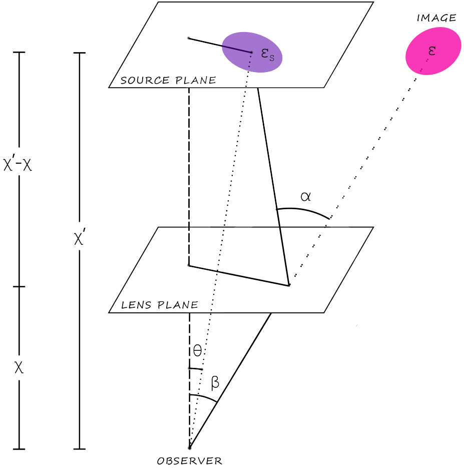
Surface brightness quadrupole (e.g. Blandford et al. 1991).

$$Q_{ij} = \int \mathrm{d}^2\theta q_I(I(\boldsymbol{\theta}))(\theta_i - \bar{\theta}_i)(\theta_j - \bar{\theta}_j)$$

Ellipticity (Bonnet Mellier 1995) :

$$\varepsilon = \frac{Q_{11} - Q_{22} + 2iQ_{12}}{Q_{11} + Q_{22} + 2\sqrt{\det(Q)}}$$

Weak lensing effect on galaxies



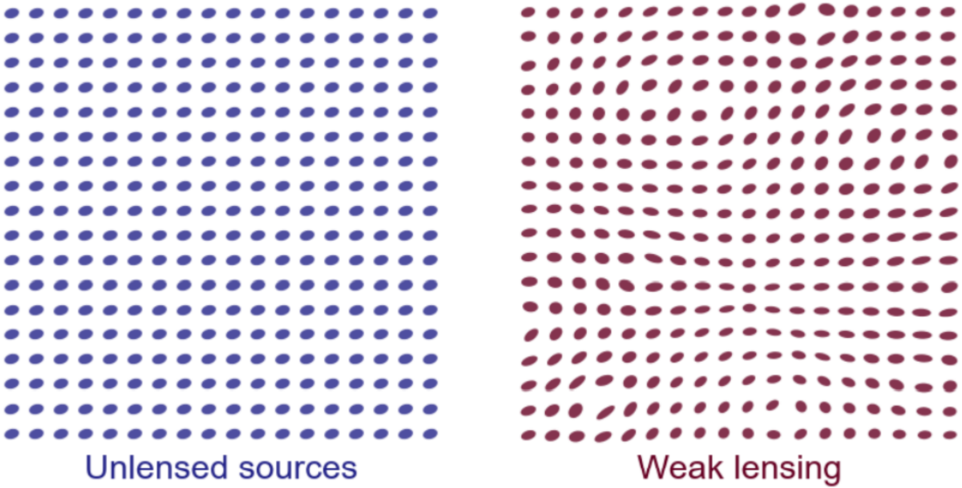
$$\tilde{Q}_{ij} = \frac{\int d^2\beta I_s(\boldsymbol{\beta})(\beta_i - \bar{\beta}_i)(\beta_j - \bar{\beta}_j)}{\int d^2\beta I_s(\boldsymbol{\beta})}$$

Weak lensing effect:

$$Q = A^{-1}\tilde{Q}A^{-1}$$

$$\Rightarrow \varepsilon = \varepsilon_s + \gamma + \mathcal{O}\left[\left(\frac{\gamma}{1-\kappa}\right)^2\right]$$

Weak lensing effect on galaxies



Ellpiticity noise ε_s

$$\varepsilon = \varepsilon_s + \gamma$$

Distribution of instrinsic ellpiticity (Bartelmann & Narayan, 1995):

$$p(\varepsilon_s) = \frac{\exp(-|\varepsilon_s|^2/\sigma_\varepsilon^2)}{\pi\sigma_\varepsilon^2[1 - \exp(-1/\sigma_\varepsilon^2)]}$$

$\sigma_\varepsilon \approx 0.2$(e.g. Miralda-Escudé 1991b; Tyson & Seitzer 1988)

$$\langle\varepsilon\rangle \approx \gamma, \quad e^{4i\varphi}\langle\varepsilon\varepsilon\rangle(\vartheta) = e^{4i\varphi}\langle\gamma\gamma\rangle(\vartheta) = \xi_-(\vartheta), \quad \langle\varepsilon\varepsilon^*\rangle(\vartheta) = \langle\gamma\gamma^*\rangle(\vartheta) = \xi_+(\vartheta)$$

In harmonic space:

$$\langle\gamma(\boldsymbol{\ell}')\gamma^*(\boldsymbol{\ell})\rangle = (2\pi)^2\delta_D(\boldsymbol{\ell}' - \boldsymbol{\ell})(C_\ell^{\gamma\gamma} + N_\ell)$$

Where:

$$N_\ell = \frac{4\pi f_{\rm sky}}{N_g}\sigma_\varepsilon^2$$

Theoretical C_ℓ

E/B mode of cosmic shear:$\gamma_E(\boldsymbol{\ell}) = \kappa(\boldsymbol{\ell}); \quad \gamma_B(\boldsymbol{\ell}) = 0$
corss-correlation C_ℓ's:

$$C_i^{\kappa_{\rm CMB}\gamma_E}(\ell) = \int_0^{z_*} \frac{c\mathrm{d}z}{H(z)} \frac{q_{\rm CMB}(z) q_i(z)}{\chi^2} P_\delta(k = \frac{\ell + 1/2}{\chi}, z)$$

Lensing efficiency:

$$q_i(z) = \frac{3\Omega_{m0}}{2} \frac{H_0^2}{c^2} (1+z)\chi(z) \int_z^{z_*} n_i(z') \frac{\chi(z') - \chi(z)}{\chi(z')} \mathrm{d}z'$$

CMB lensing kernel:

$$q_{\rm CMB}(z) = \frac{3\Omega_{m0}}{2c} \frac{H_0^2}{H(z)} (1+z)\chi(z)$$

Systematic error

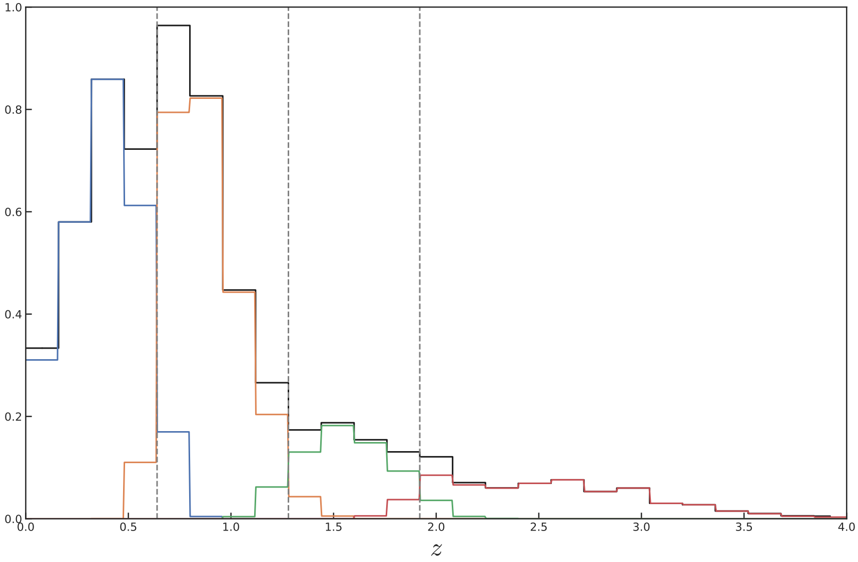
1. Intrinsic Alignment (e.g. Hand et al., 2013):

$$q_{\mathrm{IA},i}(z) = -A_0 \left(\frac{L}{L_0}\right)^{\beta} \left(\frac{1+z}{1+z_0}\right)^{\eta} \frac{C_1 \rho_{m,0}}{D(z)} n_i(z)$$

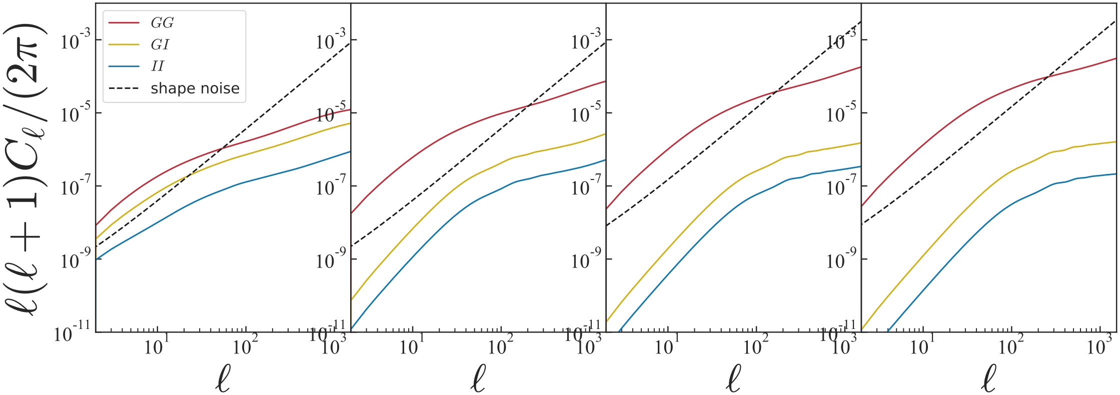
2. Photo-z error

$$p(z^P|z) = \frac{1}{\sqrt{2\pi}\sigma_z(1+z)} \exp[-\frac{(z - z^P - \Delta_z^i)^2}{2(\sigma_z(1+z))^2}]$$

Photo-z



Noise level



Cross-correlation algorithm

$$\kappa_{\mathrm{CMB}}(\boldsymbol{\ell}) = \zeta_1(\boldsymbol{\ell})(C^{\kappa\kappa}_{\mathrm{CMB}}(\ell))^{1/2}$$
$$G(\boldsymbol{\ell}) = \zeta_1(\boldsymbol{\ell})\frac{C^{G\kappa}_{\ell}}{(C^{\kappa\kappa}_{\mathrm{CMB}}(\ell))^{1/2}} + \zeta_2(\boldsymbol{\ell})\left[C^{GG}_{\ell} - \frac{(C^{G\kappa}_{\ell})^2}{C^{\kappa\kappa}_{\mathrm{CMB}}(\ell)}\right]^{1/2}$$

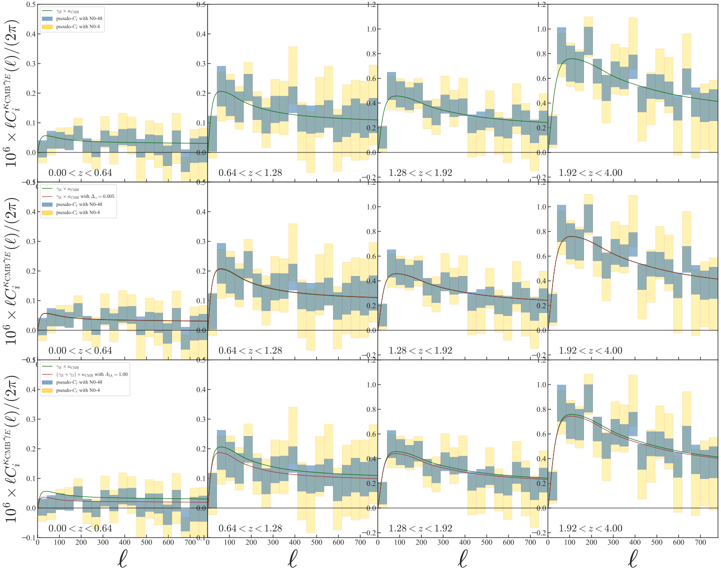
$\zeta_{1,2}$ are two complex numbers drawn from a Gaussian distribution with unit variance (Kamionkowski et al.1997).

$$\gamma(\boldsymbol{\ell}) = \left(\frac{\ell_1^2 - \ell_2^2 + 2i\ell_1\ell_2}{|\boldsymbol{\ell}|^2}\right)G(\boldsymbol{\ell}) = G(\boldsymbol{\ell})e^{2i\beta}$$

pseudo-C_ℓ measurement:

$$\langle\kappa_{\mathrm{CMB}}(\boldsymbol{\ell})\gamma^*_{\mathrm{E,i}}(\boldsymbol{\ell}')\rangle = (2\pi)^2\delta_D(\boldsymbol{\ell} - \boldsymbol{\ell}')C_i^{\kappa_{\mathrm{CMB}}\gamma_E}(\ell)$$

pseudo-C_ℓ

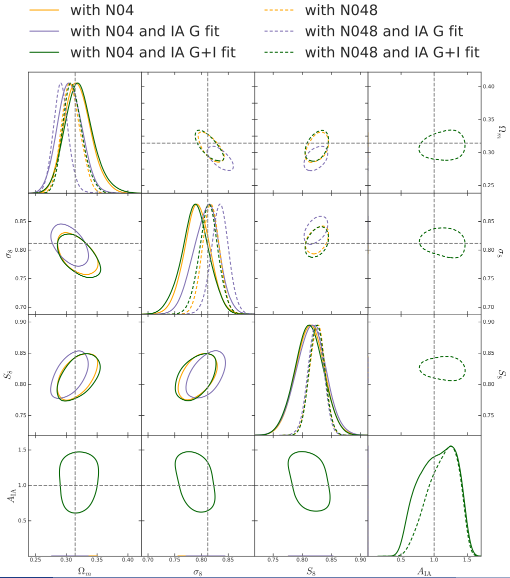


$\gamma_E \times \kappa_{\mathrm{CMB}}$
pseudo-C_ℓ with N0-48
pseudo-C_ℓ with N0-4
$\gamma_E \times \kappa_{\mathrm{CMB}}$ with $\Delta_z = 0.005$
$(\gamma_E + \gamma_I) \times \kappa_{\mathrm{CMB}}$ with $A_{\mathrm{IA}} = 1.00$
$10^6 \times \ell C_i^{\kappa_{\mathrm{CMB}}\gamma_E}(\ell)/(2\pi)$
$0.00 < z < 0.64$
$0.64 < z < 1.28$
$1.28 < z < 1.92$
$1.92 < z < 4.00$
ℓ

Prior

Parameters	Fiducial value	Prior
Ω_m	0.314	$U(0.05, 0.7)$
h	0.67	fixed
Ω_b	0.049	fixed
σ_8	0.811	$U(0.3, 1.3)$
n_s	0.96	fixed
A_{IA}	1.0	$U(0.5, 1.5)$
Δ_z^1	0.005	fixed
Δ_z^2	0.005	fixed
Δ_z^3	0.005	fixed
Δ_z^4	0.005	fixed
σ_z	0.05	fixed

Cosmological constrain



Cosmological constrain

Parameter 68% limits	with N04	N04 IA G fit	N04 IA G+I fit
$\boldsymbol{\Omega_m}$	$0.319^{+0.019}_{-0.023}$	0.306 ± 0.020	$0.321^{+0.020}_{-0.025}$
$\boldsymbol{\sigma_8}$	0.792 ± 0.024	$0.808^{+0.026}_{-0.022}$	0.788 ± 0.025
$\boldsymbol{S_8}$	0.813 ± 0.024	0.815 ± 0.025	0.812 ± 0.024
$\boldsymbol{A_{\mathrm{IA}}}$	/	/	$1.05^{+0.34}_{-0.23}$
$\boldsymbol{\alpha}$	0.45	0.47	0.45

Parameter 68% limits	with N048	N048 IA G fit	N048 IA G+I fit
$\boldsymbol{\Omega_m}$	$0.308^{+0.014}_{-0.016}$	$0.291^{+0.011}_{-0.013}$	$0.311^{+0.013}_{-0.017}$
$\boldsymbol{\sigma_8}$	0.817 ± 0.016	0.834 ± 0.016	0.813 ± 0.018
$\boldsymbol{S_8}$	0.825 ± 0.013	0.823 ± 0.013	0.825 ± 0.013
$\boldsymbol{A_{\mathrm{IA}}}$	/	/	$1.13^{+0.27}_{-0.18}$
$\boldsymbol{\alpha}$	0.40	0.45	0.44

Appreciate your Criticism