Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Fast Generation of Covariance Matrices for Weak Lensing

Sgier, Réfrégier, Amara, Nicola 2018 (1801.05745)

Raphaël Sgier
Institute for Particle Physics and Astrophysics

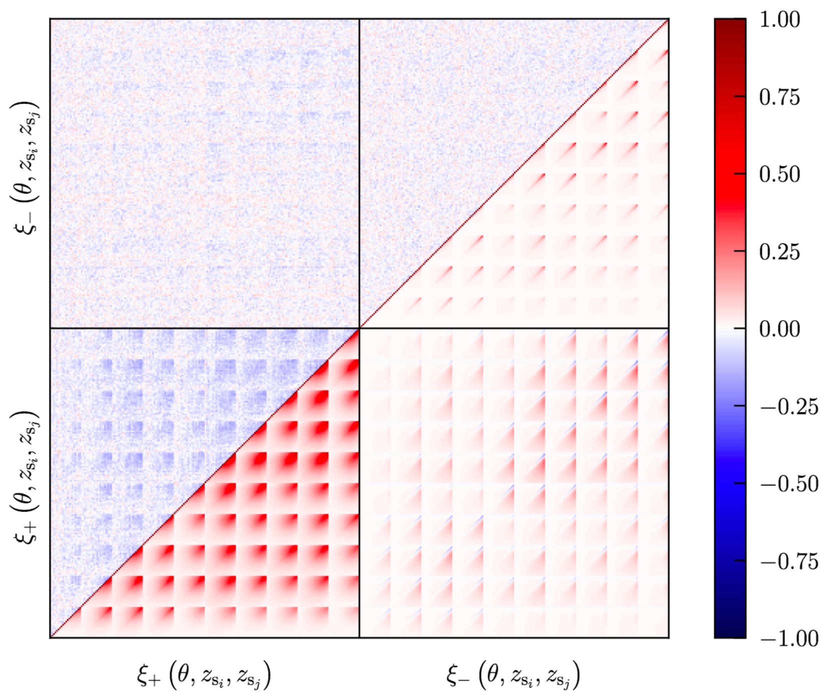
Swiss Cosmology Days 2018

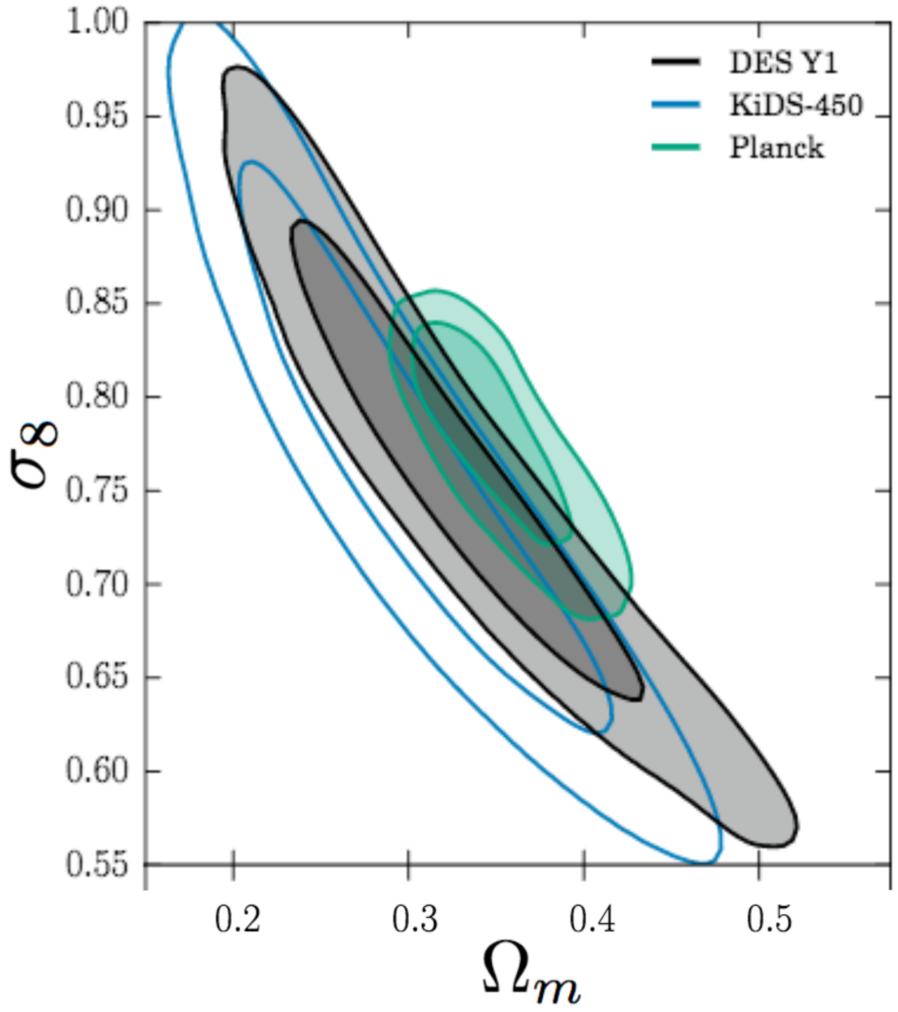
Motivation

- Interpretation of LSS data.

$$\mathcal{L}(D|\theta) \propto e^{-\frac{1}{2}(X^{\rm D}-X^{\rm M})^{\rm T}{\rm cov}^{-1}(X^{\rm D}-X^{\rm M})}$$

- large ensemble of N-Body simulations needed for a well-converged covariance matrix.





DES collaboration 2017 (1708.0153)

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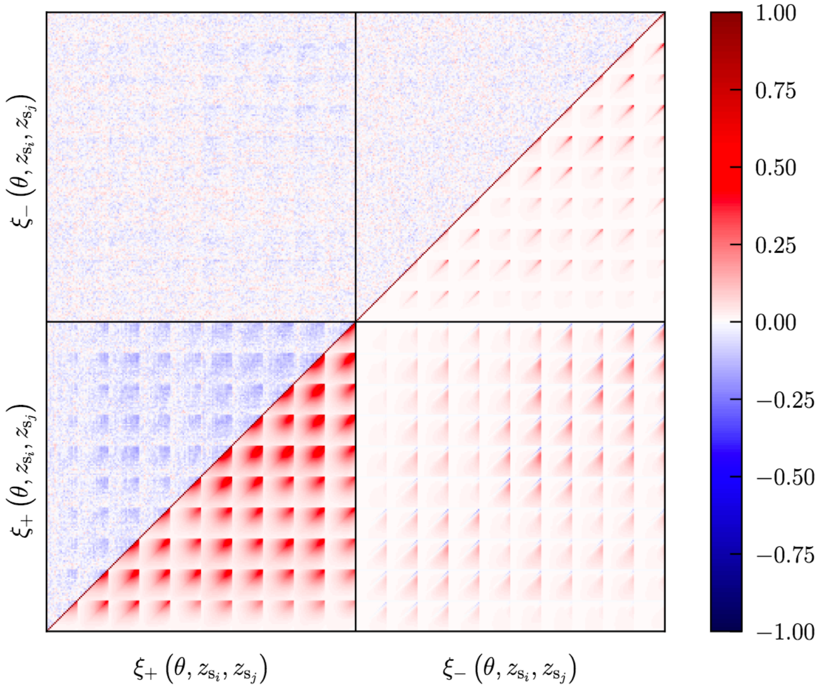
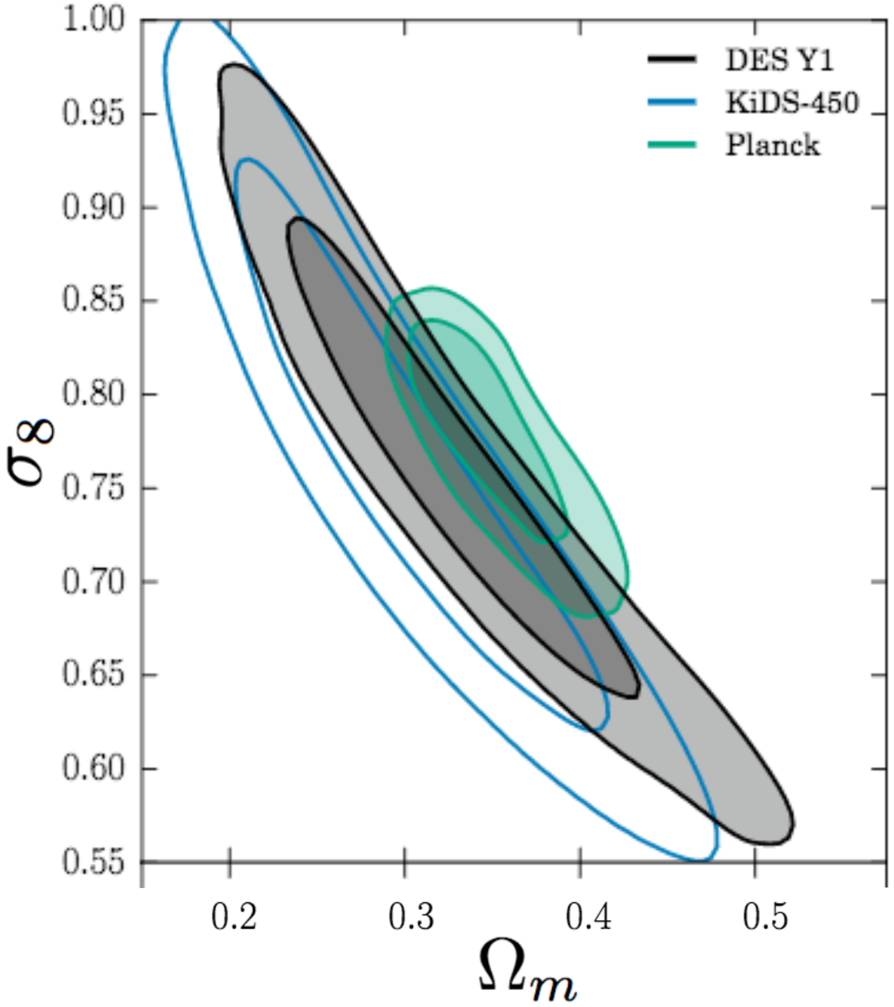
↓

Computational Power ⚡ Resolution





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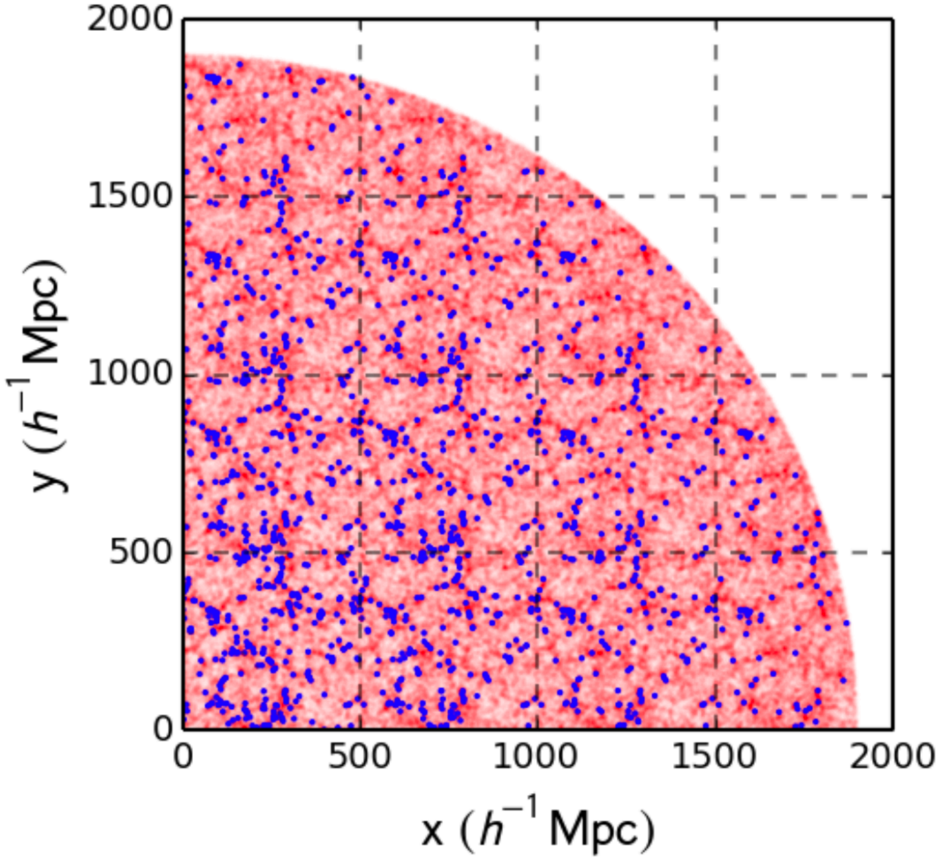
N-Body Simulations

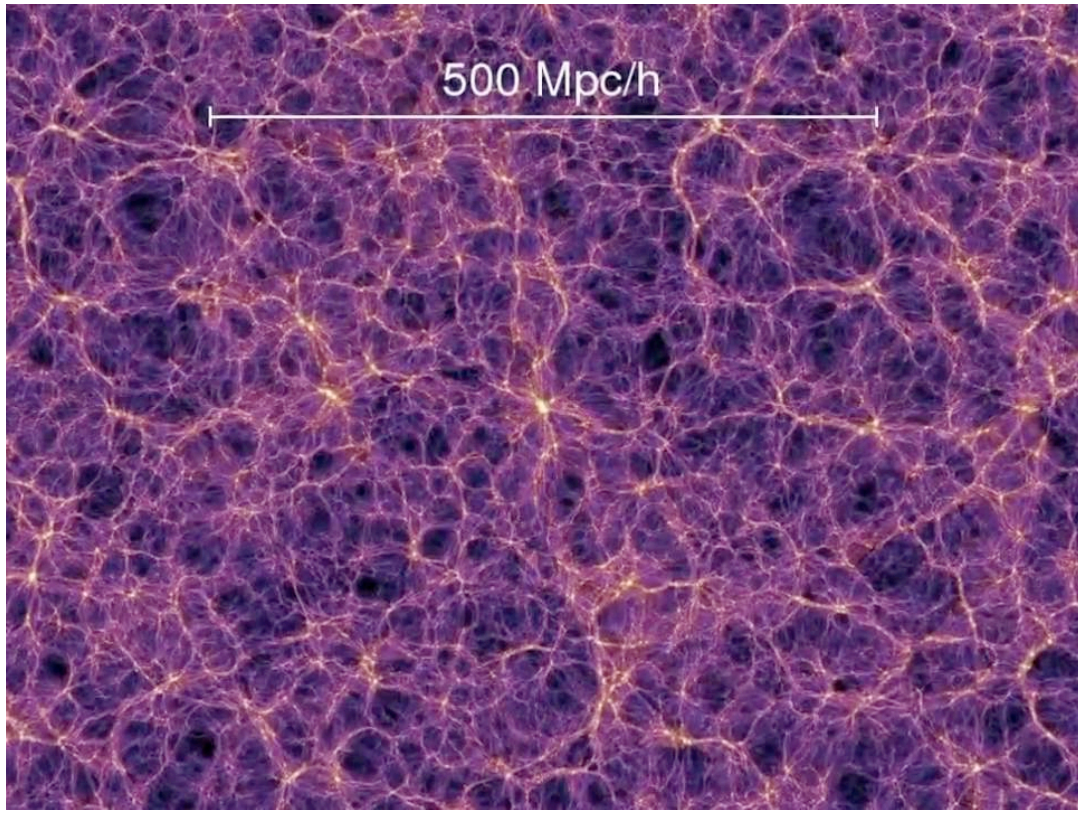
Mass resolution: $$m = \frac{V}{N} \cdot \rho_{\mathrm{crit}} \cdot \Omega_{\mathrm{m}}$$



L-PICOLA Simulation code

Howlett et al. 2015 (1506.03737)

$$N = 2160^3 \quad V = 500\,\mathrm{Mpc}/h$$



Millennium Simulation (MPA Garching)

N-Body Simulations

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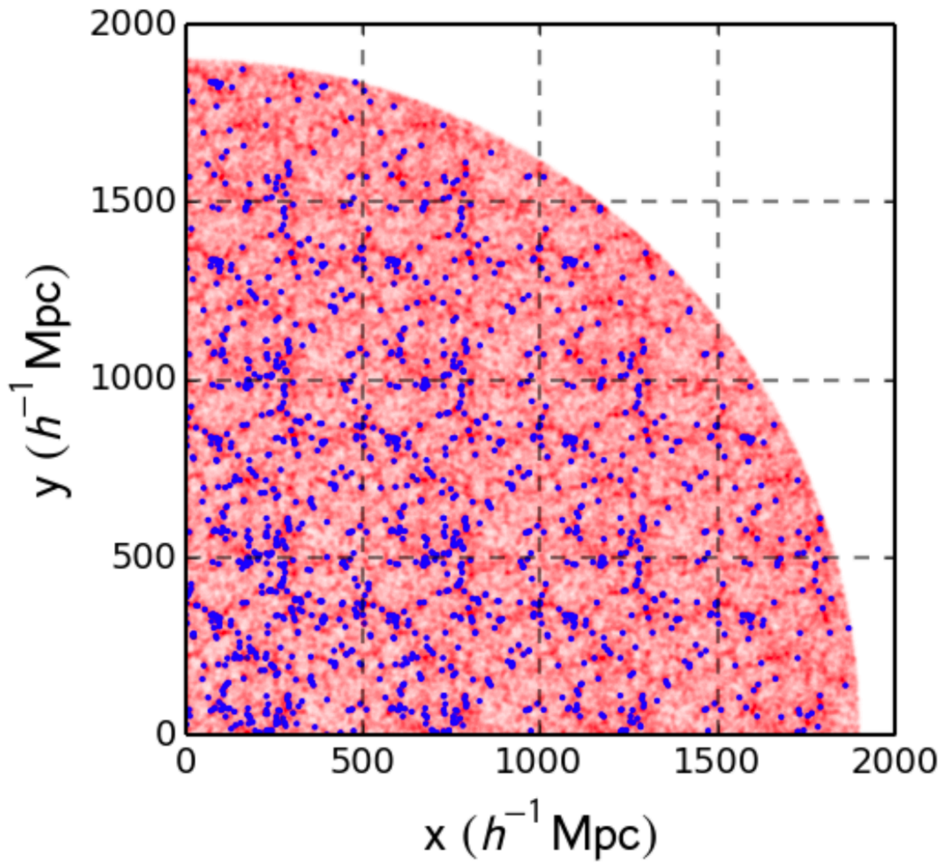
→ we use large V to avoid replications and avoid dealing with SSC.



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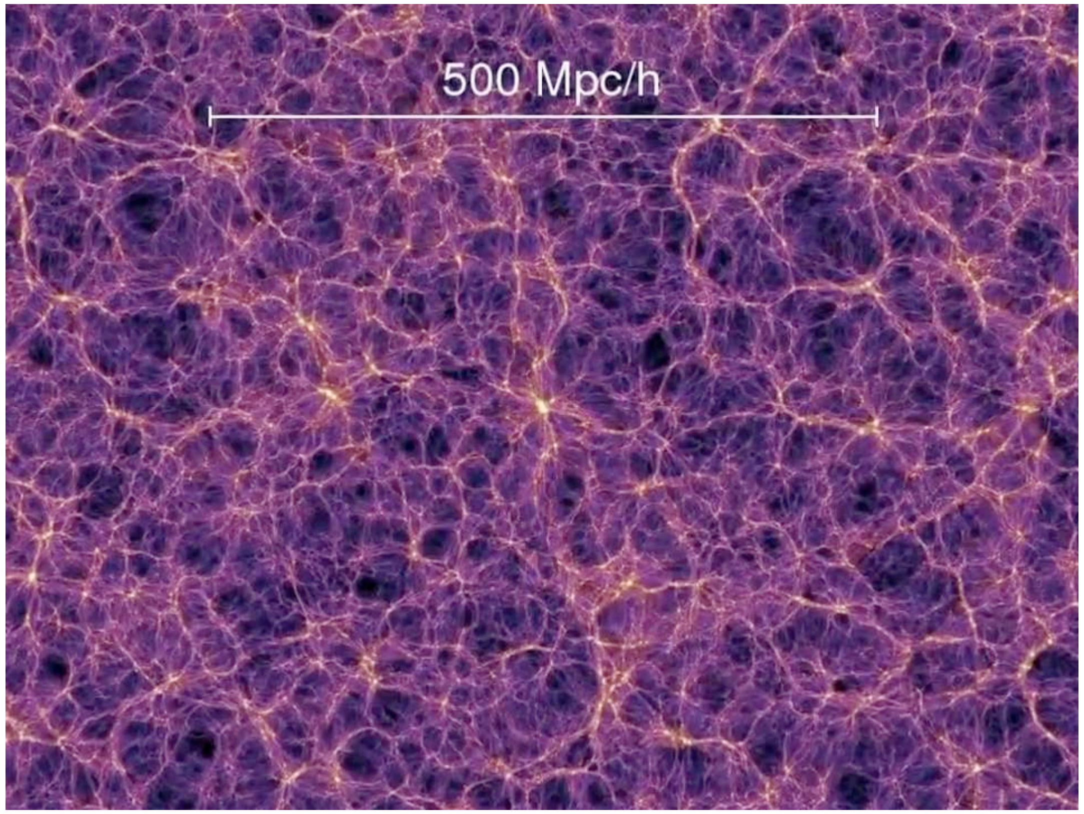

Millennium Simulation (MPA Garching)

L-PICOLA

N-Body code

- ⊕ recovers non-linear regime
- ⊖ computationally expensive

Lagrangian Perturbation Theory

- ⊕ exact results on large scales
- ⊖ PT breaks down at k_{NL}

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COLA

Tassev, Zaldarriaga,
Eisenstein 2013 (1301.0322)

calculate large scales exactly with 2LPT

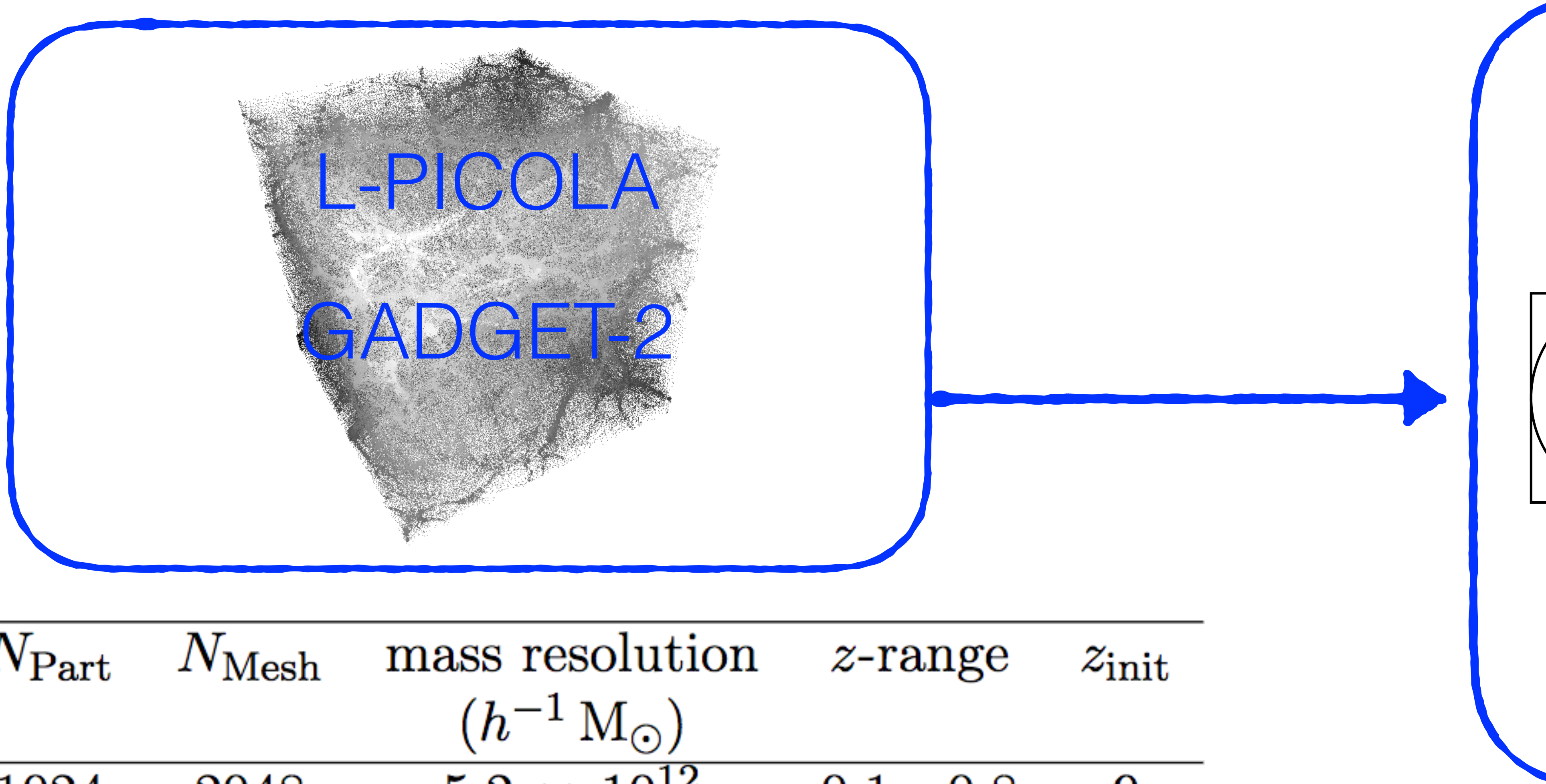
PM-code solves small scales

L-PICOLA

Howlett et al. 2015 (1506.03737)

Can we use L-PICOLA to efficiently and accurately generate covariance matrices for weak lensing?

Simulations and Lightcone



$L_{\rm Box}$ (h^{-1} Mpc)	$N_{\rm Part}$	$N_{\rm Mesh}$	mass resolution (h^{-1} M$_\odot$)	z-range	$z_{\rm init}$
4200	1024	2048	5.2×10^{12}	0.1 - 0.8	9
6300	1024	2048	1.8×10^{13}	0.8 - 1.5	9

$$h = 0.7\,,\ \Omega_{\rm m} = 0.276\,,\ \Omega_{\rm b} = 0.045\,,\ n_s = 0.961\,,\ \sigma_8 = 0.811$$

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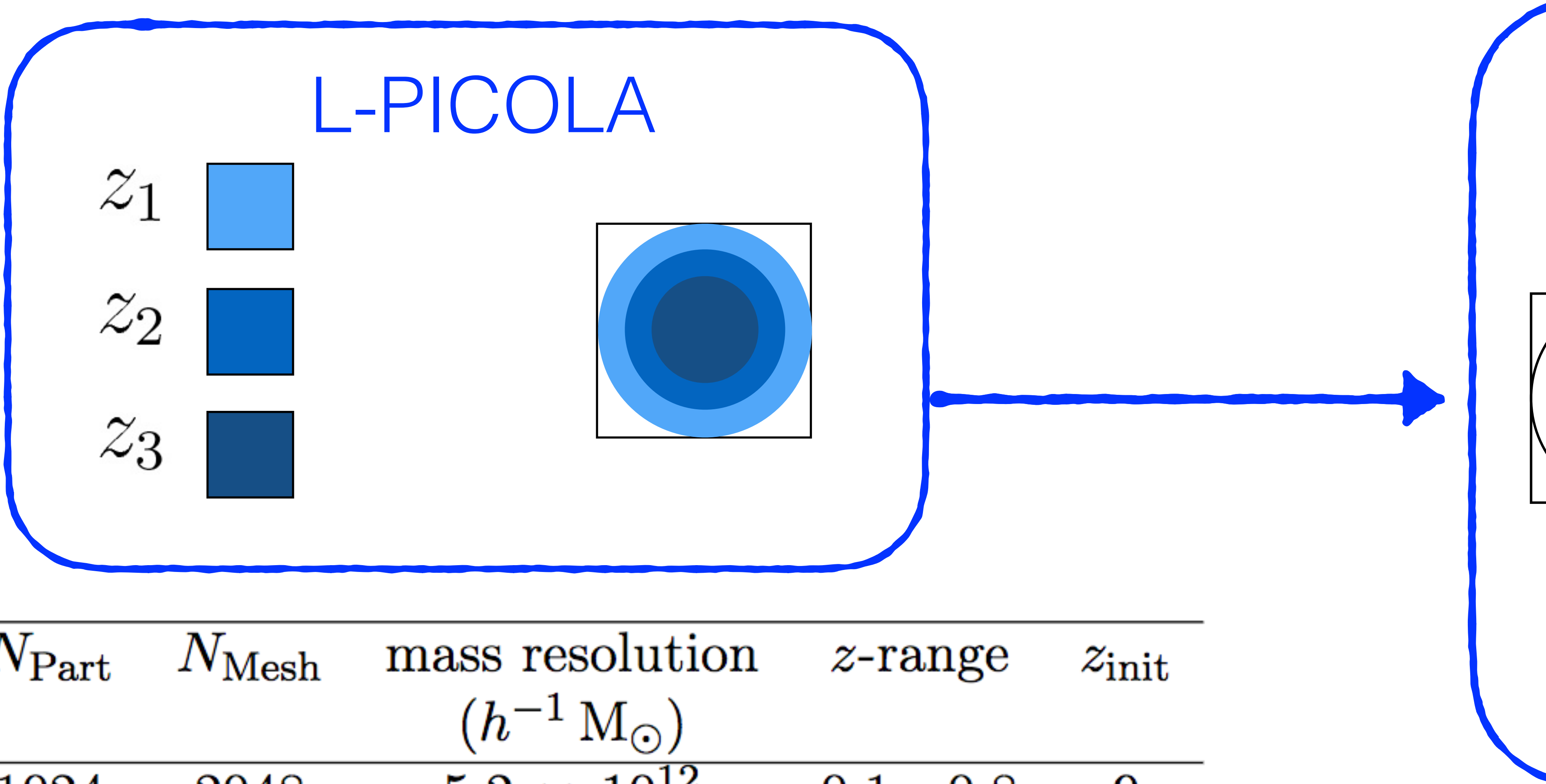

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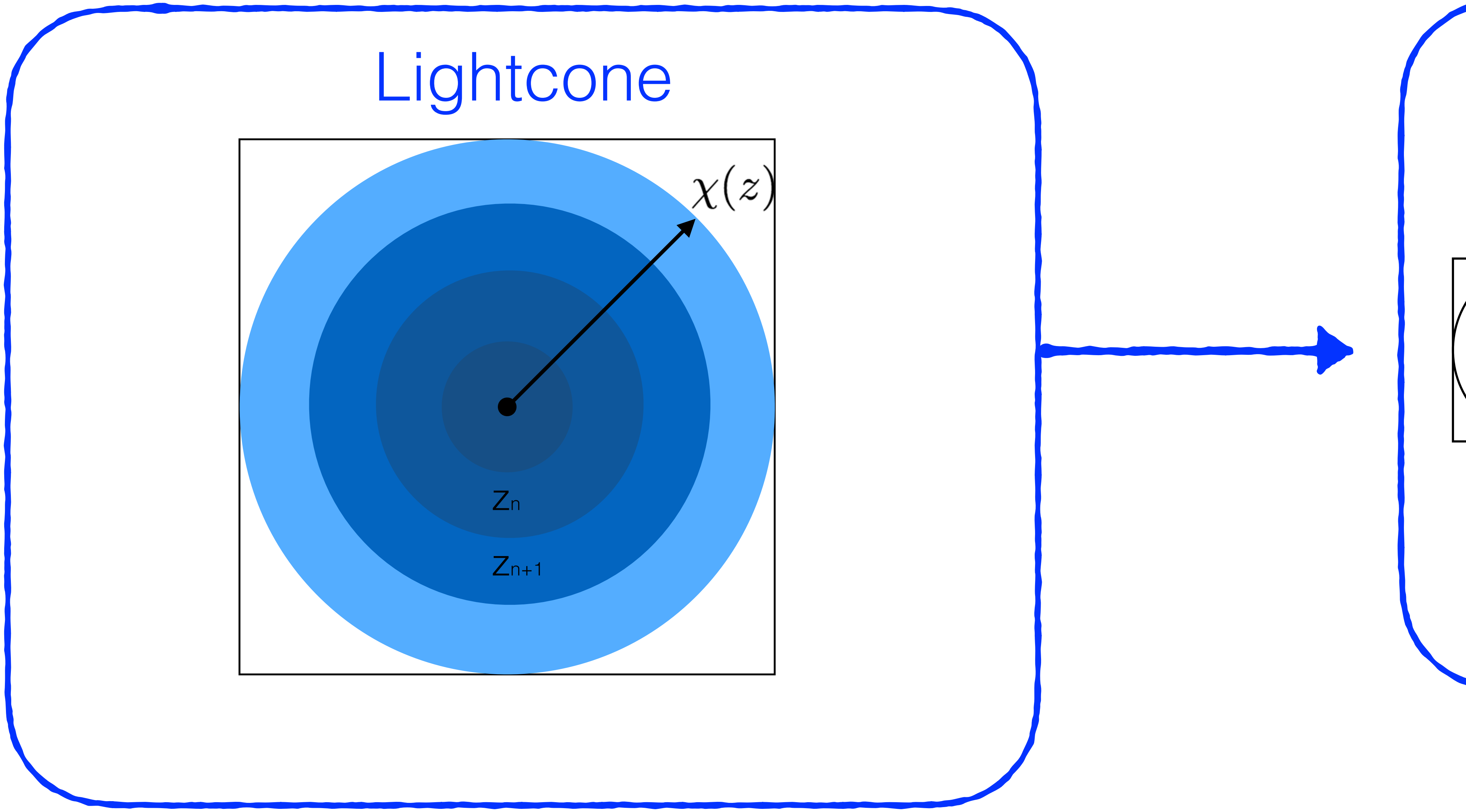
- 1 GADGET-2 and L-PICOLA sims in snapshot mode
- 150 L-PICOLA sims in lightcone mode

Simulations and Lightcone

MICE

MICE Simulation
based on GADGET-2



Lightcone

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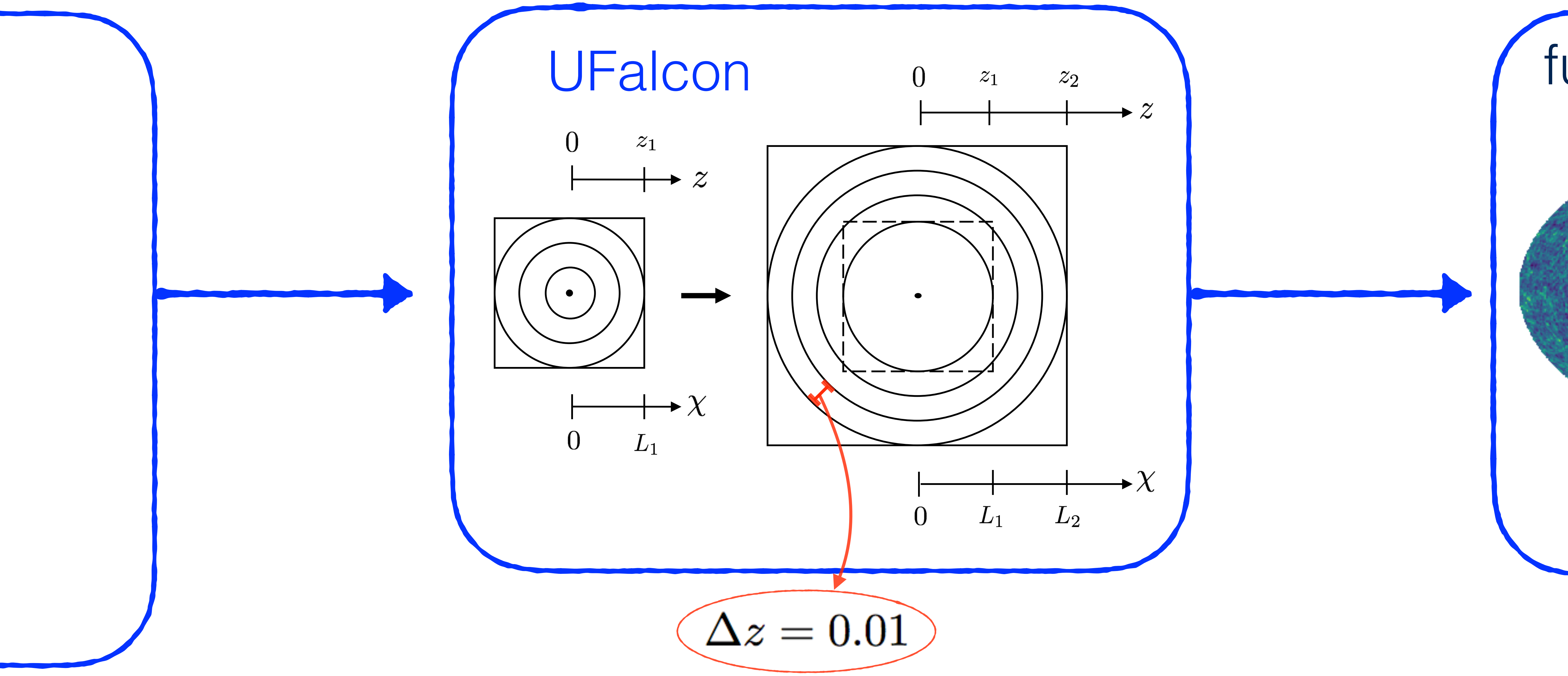

- Use Born-Approximation for the convergence map:

$$\kappa(\theta_{\mathrm{pix}}) \approx \frac{3}{2}\Omega_m \sum_b W_b \frac{H_0}{c}\left[\frac{N_{\mathrm{pix}}}{4\pi}\frac{V_{\mathrm{sim}}}{N_{\mathrm{part}}^{\mathrm{sim}}}\left(\frac{H_0}{c}\right)^2 \frac{n_p(\theta_{\mathrm{pix}},\Delta\chi_b)}{\mathcal{D}^2(z_b)} - \left(\frac{c}{H_0}\Delta\mathcal{D}_b\right)\right]$$

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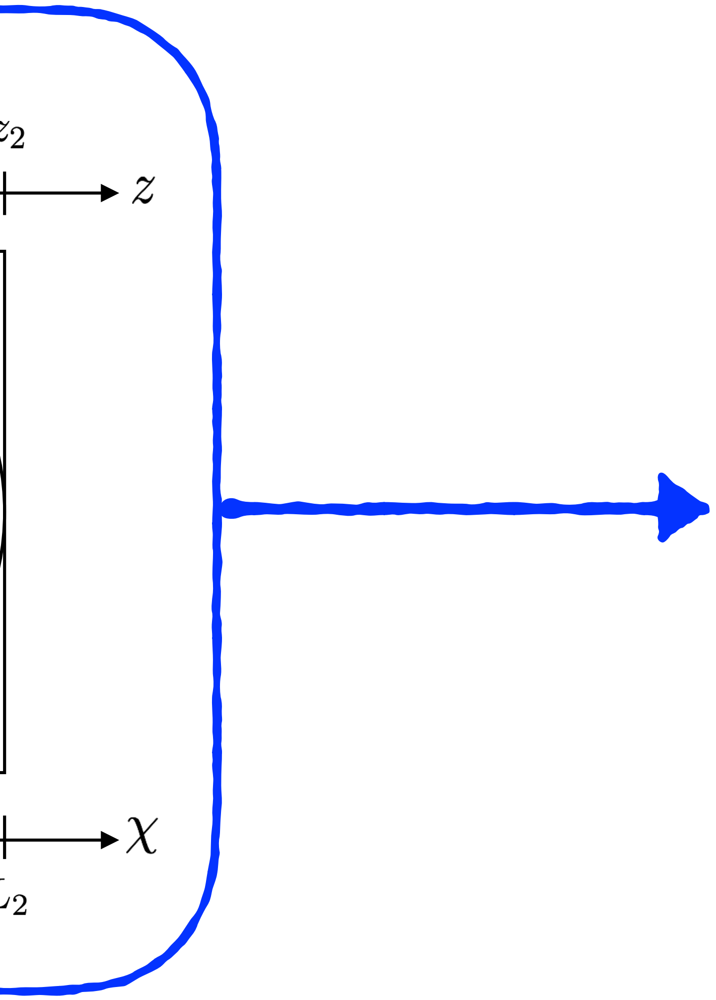
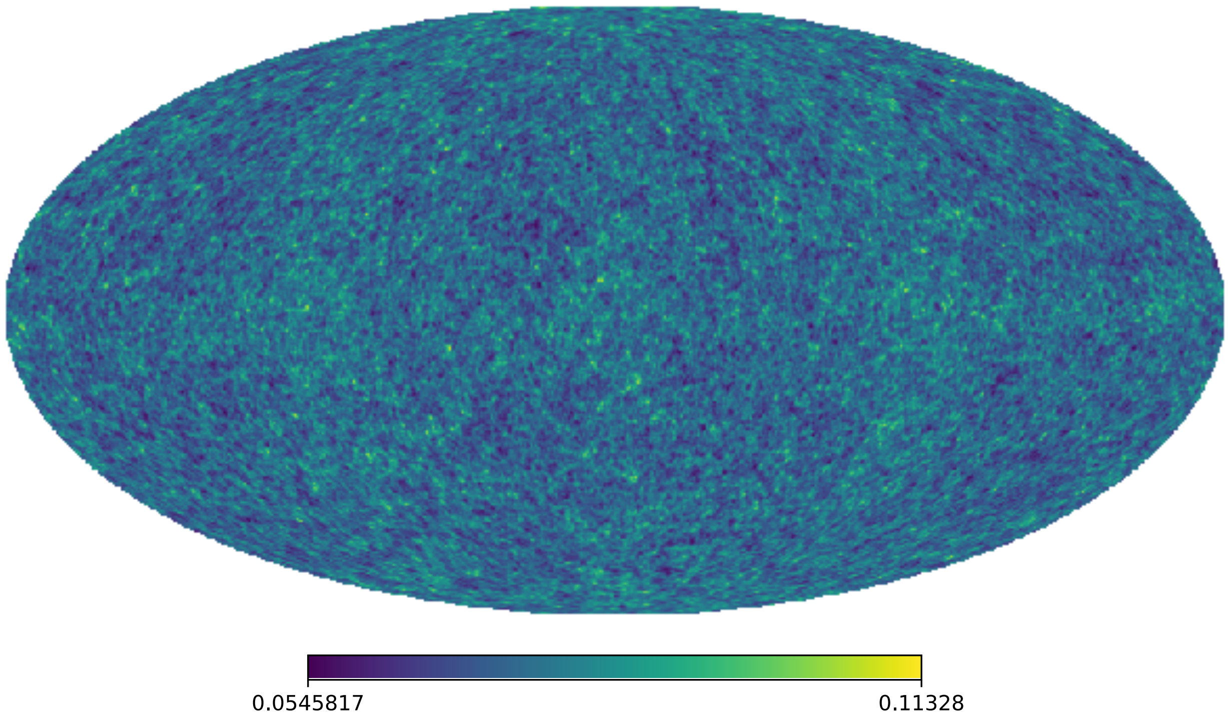
Simulations and Lightcone

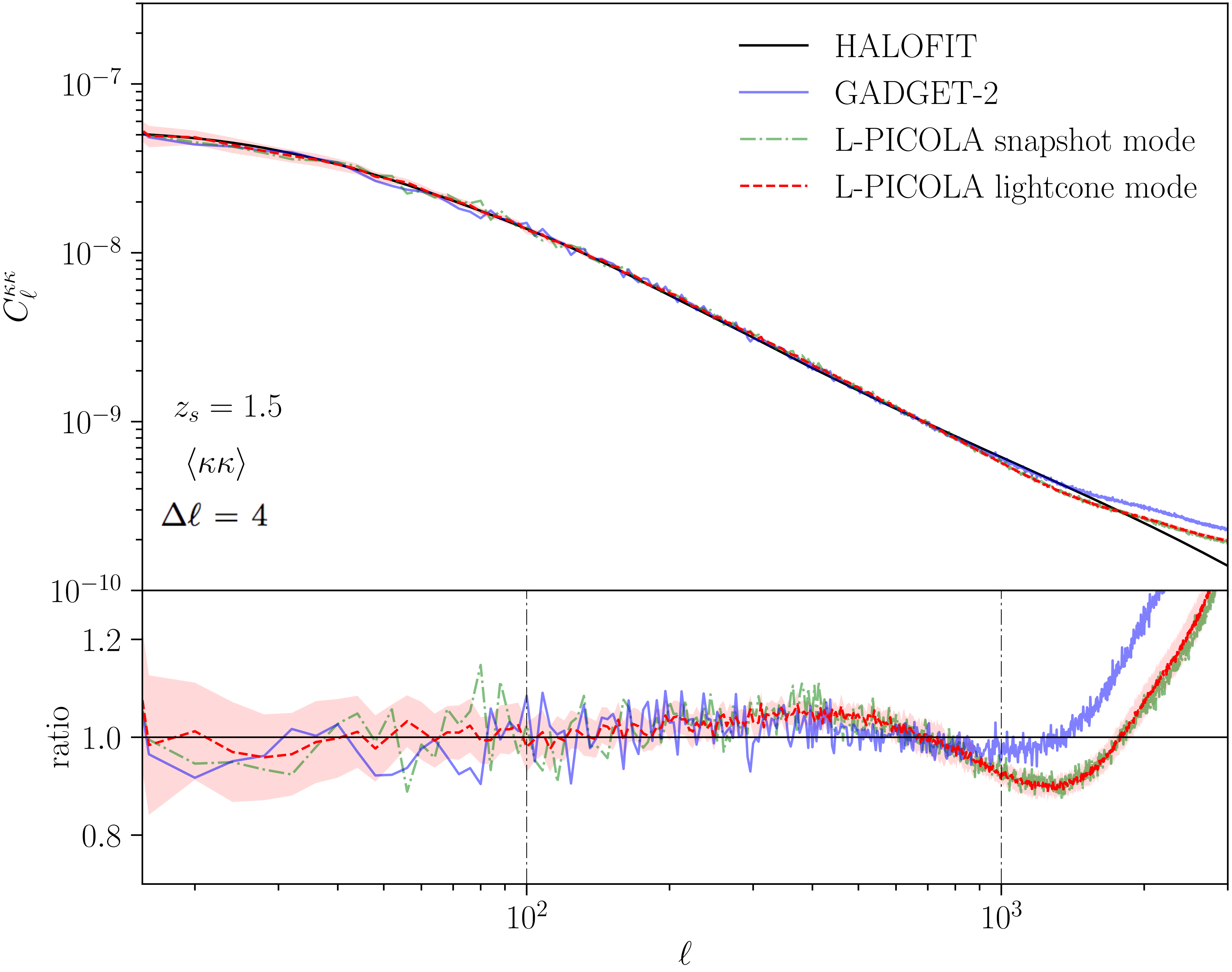


full-sky convergence map



- Walltime: ~2h for simulation + ~1h for lightcone
- both parts parallelized on Cluster

Power Spectrum



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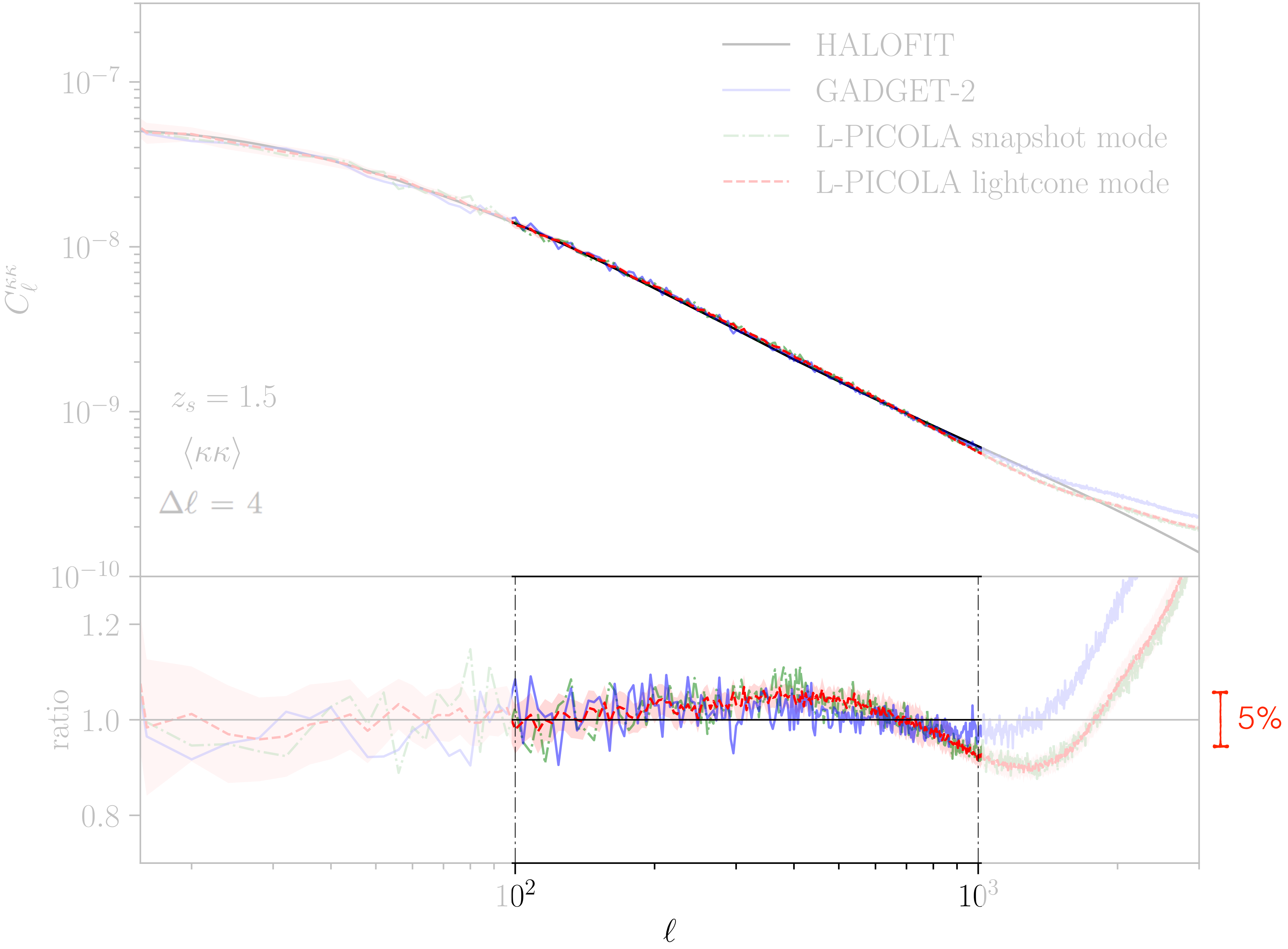
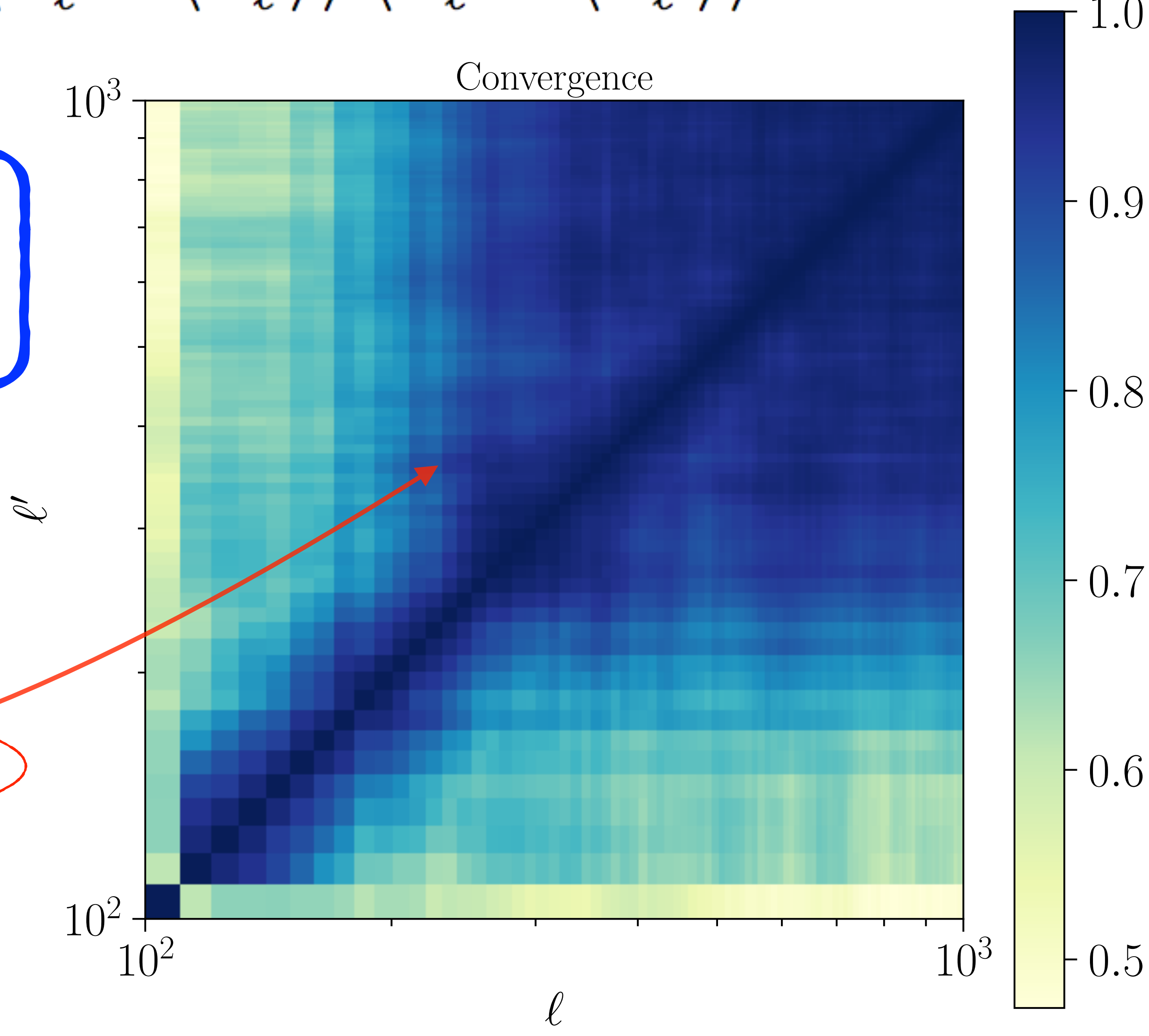


Covariance Matrix

Covariance matrix for scales $10^2 < \ell < 10^3$ using 150 UFalcon maps: $\mathrm{cov}(\ell, \ell') = \langle C^q_\ell - \langle C^q_\ell \rangle \rangle \langle C^q_{\ell'} - \langle C^q_{\ell'} \rangle \rangle$

$$\boxed{\mathrm{corr}(\ell, \ell') = \frac{\mathrm{cov}(\ell, \ell')}{\sqrt{\mathrm{cov}(\ell, \ell)\mathrm{cov}(\ell', \ell')}}}$$



stronger mode-coupling

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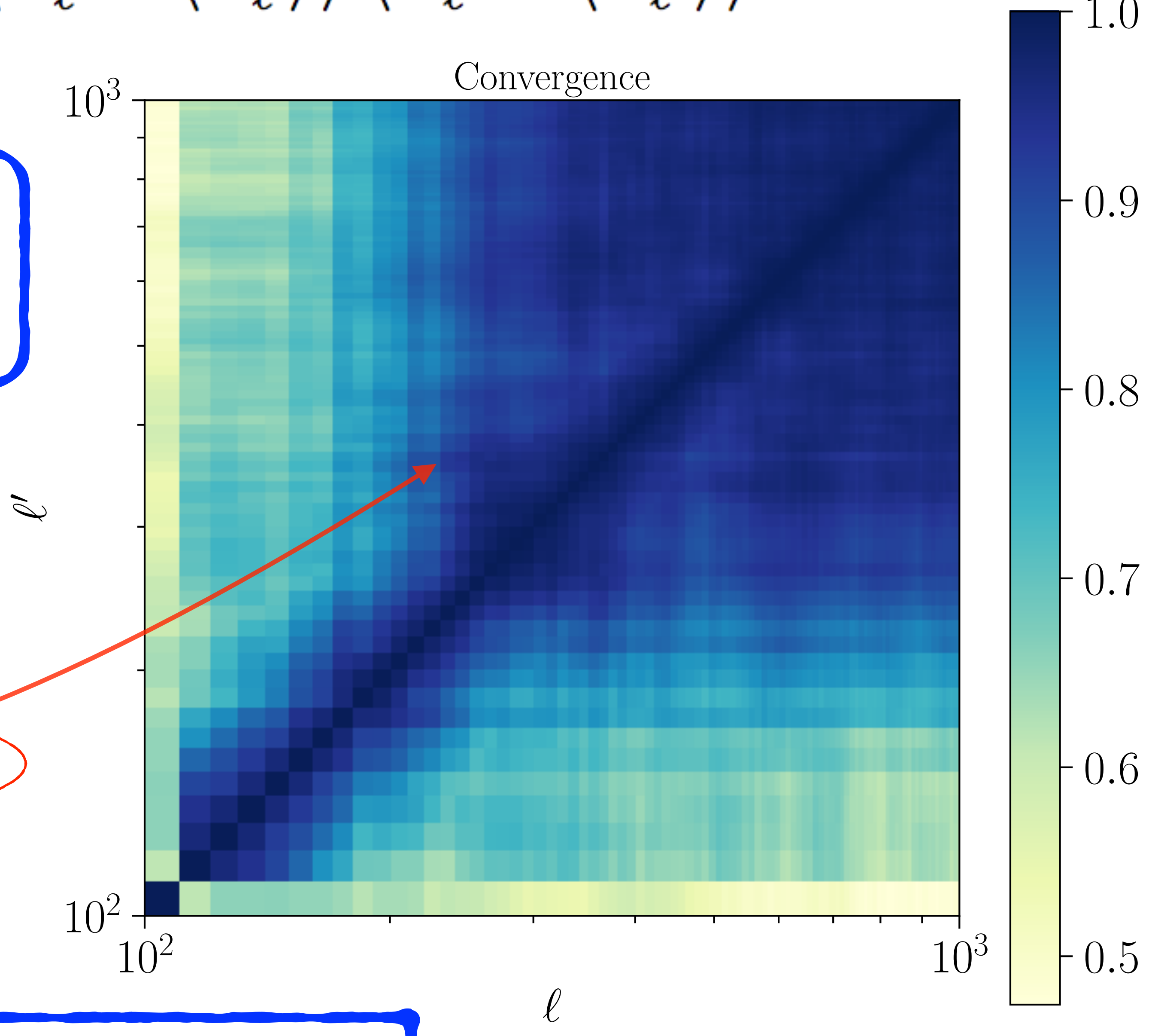
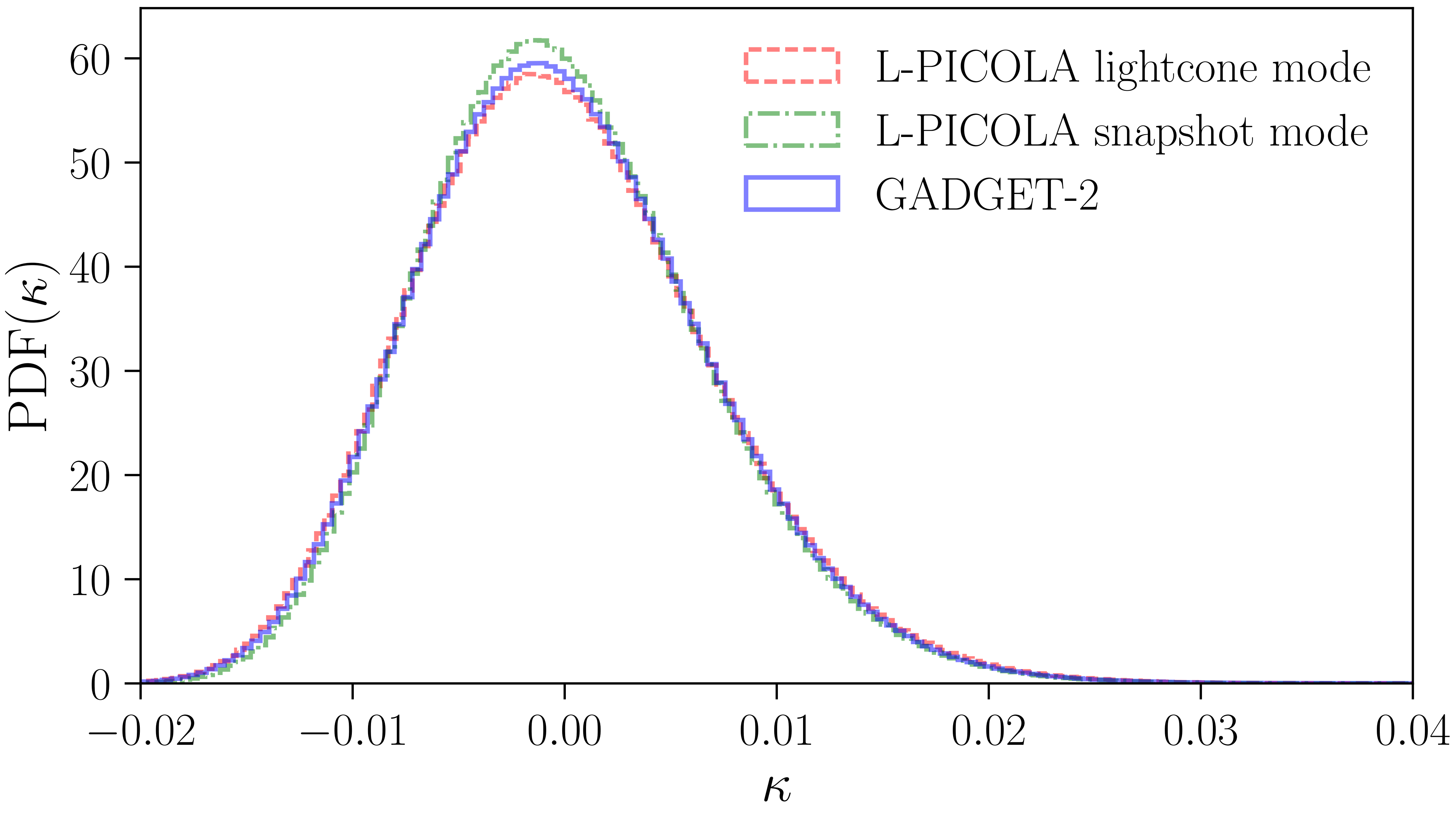


stronger mode-coupling

→ accurate enough for weak lensing?

1-Point Distribution

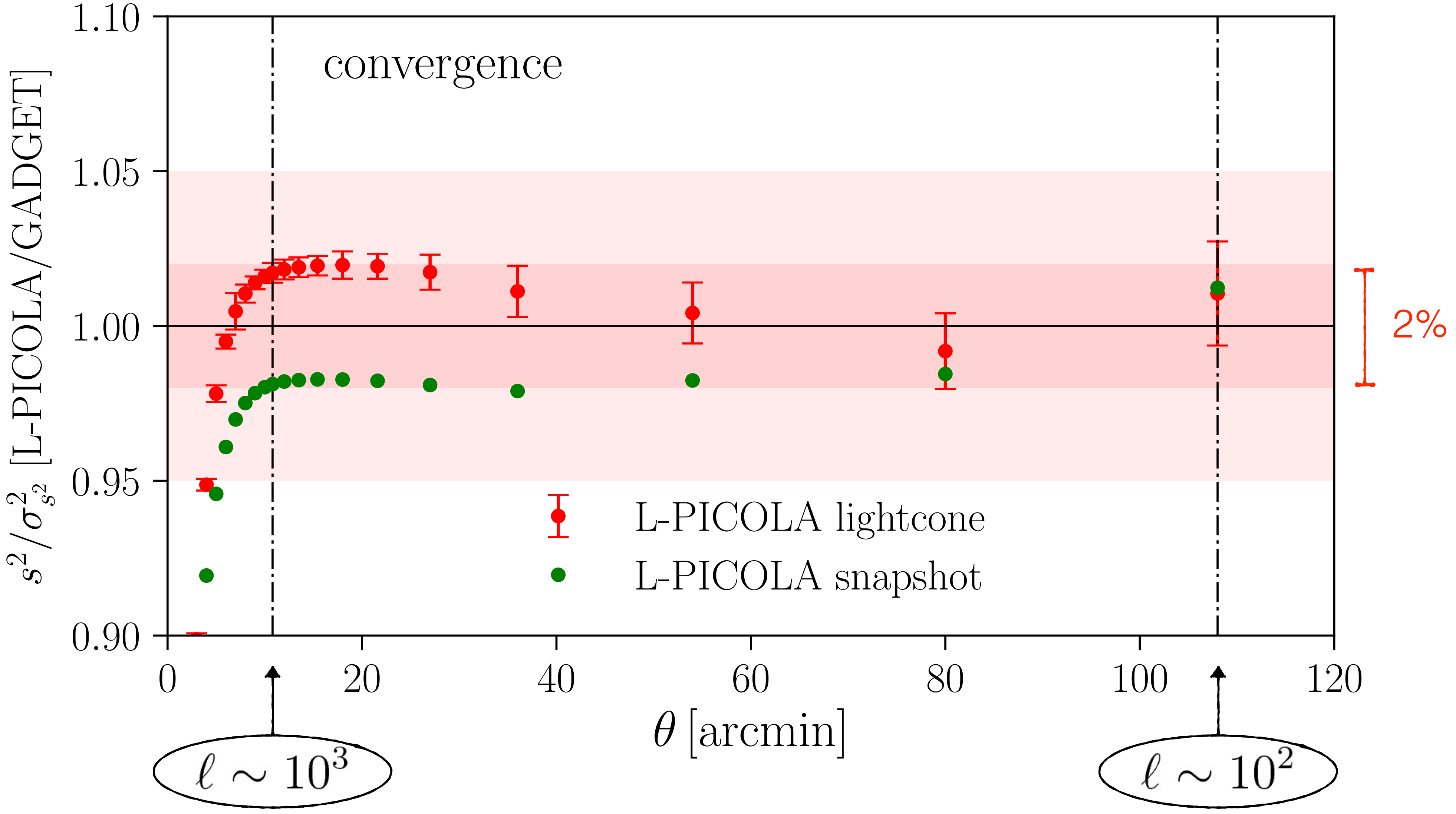


1-Point Distribution

Variance of sample variance as a measure of non-Gaussianity.

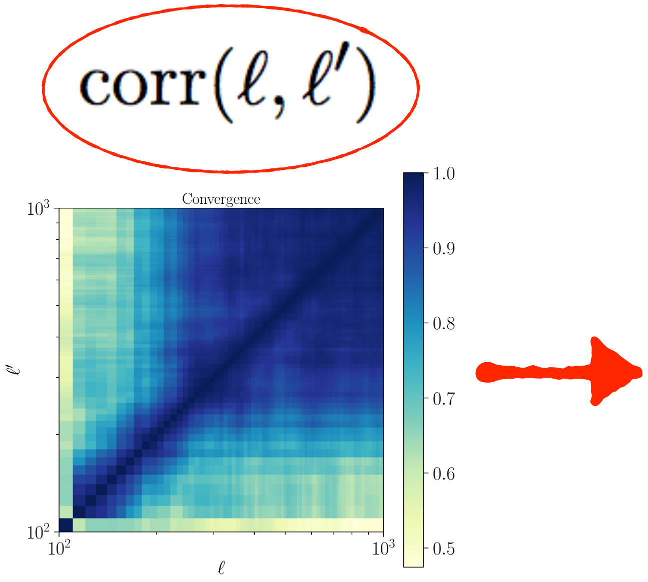
$$s^2 = \frac{1}{N}\sum_{i=1}^{N}(q_i - \bar{q}) \quad , \quad \sigma^2_{s^2} = \frac{(N-1)^2}{N^3}\mu_4 - \frac{(N-1)(N-3)}{N^3}\mu_2^2 \sim \boxed{\frac{1}{N}(\mu_4 - \mu_2^2)}$$

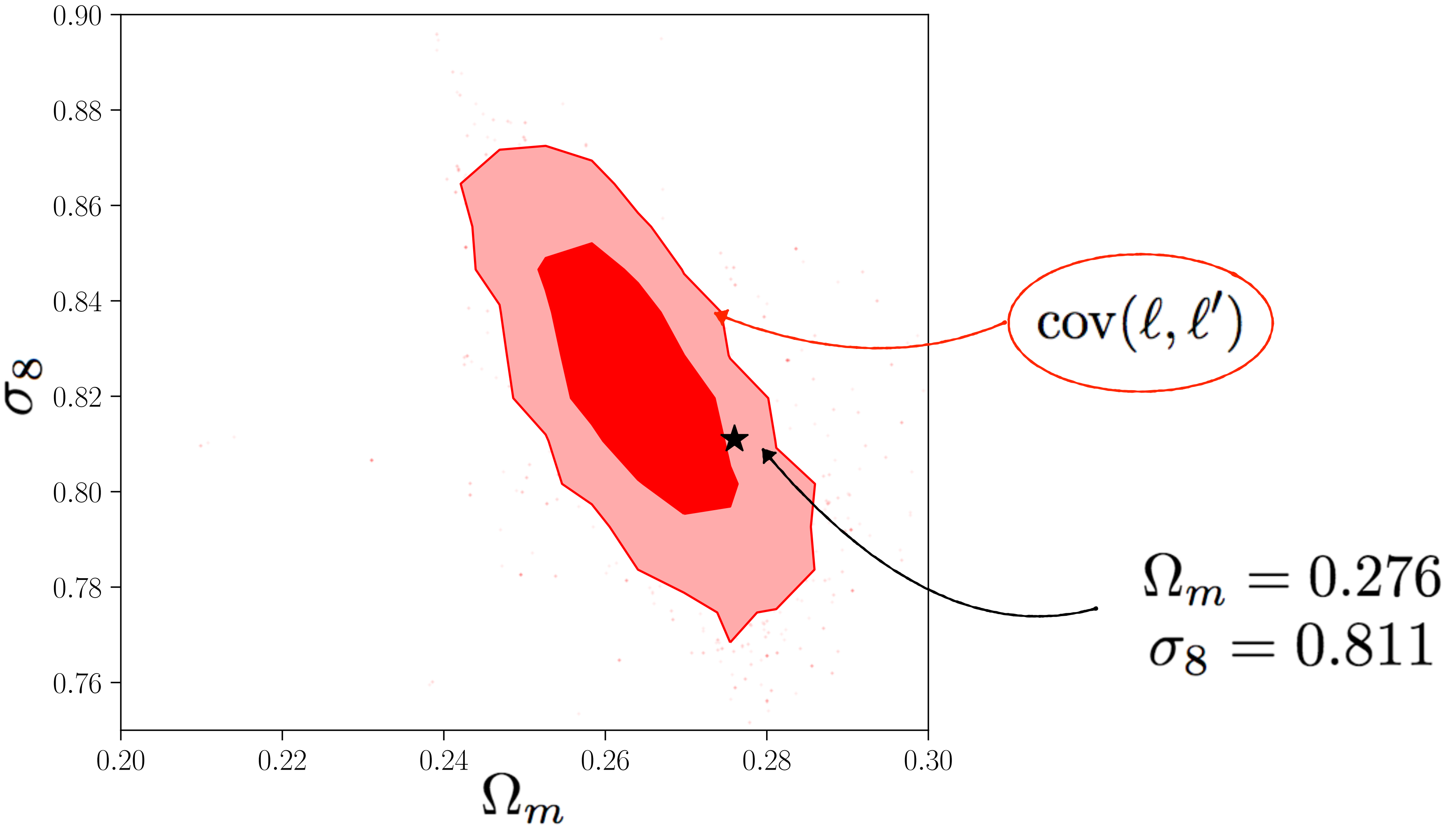
$q_i = \kappa_i$



Parameter Constraints

- Sample Ω_m and σ_8 with a Monte Carlo Markov Chain (MCMC) on scales $10^2 < \ell < 10^3$.
- Flat priors: $0.05 < \Omega_m < 0.9$, $0.2 < \sigma_8 < 1.6$





$\Omega_m = 0.276$
$\sigma_8 = 0.811$

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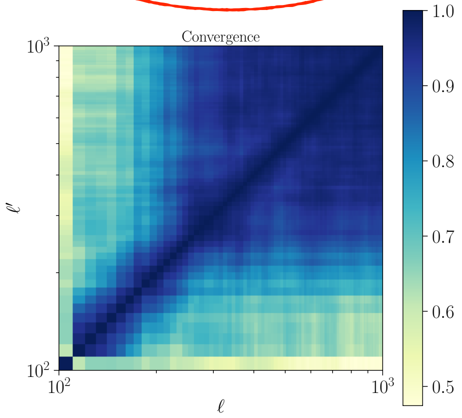
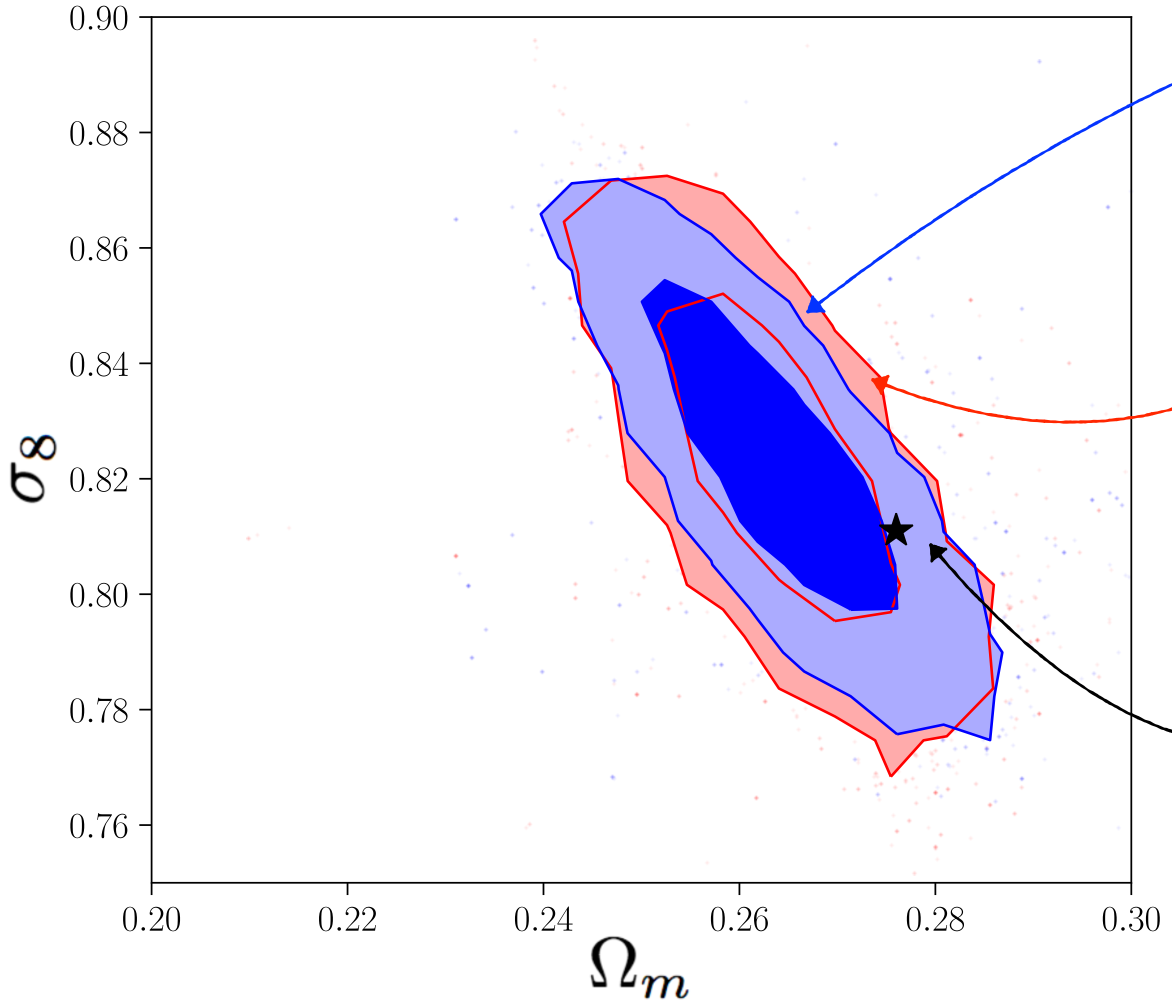
$\mathrm{corr}(\ell, \ell')$





$\widetilde{\mathrm{cov}}(\ell, \ell') \equiv f(\ell) f(\ell') \mathrm{cov}(\ell, \ell')$

$f(\ell) = C_\ell^{\mathrm{GADGET-2}} / C_\ell^{\mathrm{L-PICOLA}}$

$\mathrm{cov}(\ell, \ell')$

$\Omega_m = 0.276$
$\sigma_8 = 0.811$

Conclusion

Summary:

- UFalcon applied to L-PICOLA: Fast way to generate full-sky weak lensing maps up to $z_s = 1.5$ (**2-3h walltime**).
- 5% agreement between L-PICOLA and GADGET-2 power spectra.
- 2% agreement between $s^2/\sigma_{s^2}^2$ based on L-PICOLA and GADGET-2 maps.
- Obtained constraints in the $\Omega_\mathrm{m} - \sigma_8$ plane are robust to changes on percent level for optimistic survey configuration.
- Survey specific masks applicable.

Outlook:

- UFalcon: include further probes.
- Application of pipeline to models beyond $\Lambda\mathrm{CDM}$.

Thank you!

Backup Slides

Simulations and Lightcone

N-Body code

- ⊕ recovers non-linear regime
- ⊖ computationally expensive

Lagrangian Perturbation Theory

- ⊕ exact results on large scales
- ⊖ PT breaks down at $k_{\rm NL}$

COLA

calculate large scales exactly with 2LPT

N-Body code (PM) solves small scales

several orders of magnitude faster than GADGET-2

$$\partial_t^2 \mathbf{x}_{\rm res} = -\nabla\Phi - \partial_t^2 \mathbf{x}_{\rm LPT} \quad \text{with} \quad \mathbf{x}_{\rm res} = \mathbf{x} - \mathbf{x}_{\rm LPT}$$

discretize in PM-code

use exact 2LPT expression

Checks Performed

1) Compare maps using L-PICOLA to GADGET-2:

- spherical harmonic power spectrum $C_\ell^{\kappa\kappa}$
- probability distribution function (PDF)
- higher order moments

2) Compute covariance matrix using
150 L-PICOLA maps.

3) Infer cosmological parameter constraints
in the $\Omega_{\rm m} - \sigma_8$ - plane.

Mass Maps

$$\delta(\theta_{\rm pix}) \approx \sum_b \left[\frac{N_{\rm pix}}{4\pi} \frac{V_{\rm sim}}{N_{\rm part}^{\rm sim}} \left(\frac{H_0}{c} \right)^2 \frac{n_p(\theta_{\rm pix}, \Delta\chi_b)}{\mathcal{D}^2(z_b)} - \left(\frac{c}{H_0} \Delta\mathcal{D}_b \right) \right] / \sum_b \left(\frac{c}{H_0} \Delta\mathcal{D}_b \right)$$

$$\kappa(\theta_{\rm pix}) \approx \frac{3}{2} \Omega_m \sum_b W_b \frac{H_0}{c} \left[\frac{N_{\rm pix}}{4\pi} \frac{V_{\rm sim}}{N_{\rm part}^{\rm sim}} \left(\frac{H_0}{c} \right)^2 \frac{n_p(\theta_{\rm pix}, \Delta\chi_b)}{\mathcal{D}^2(z_b)} - \left(\frac{c}{H_0} \Delta\mathcal{D}_b \right) \right]$$

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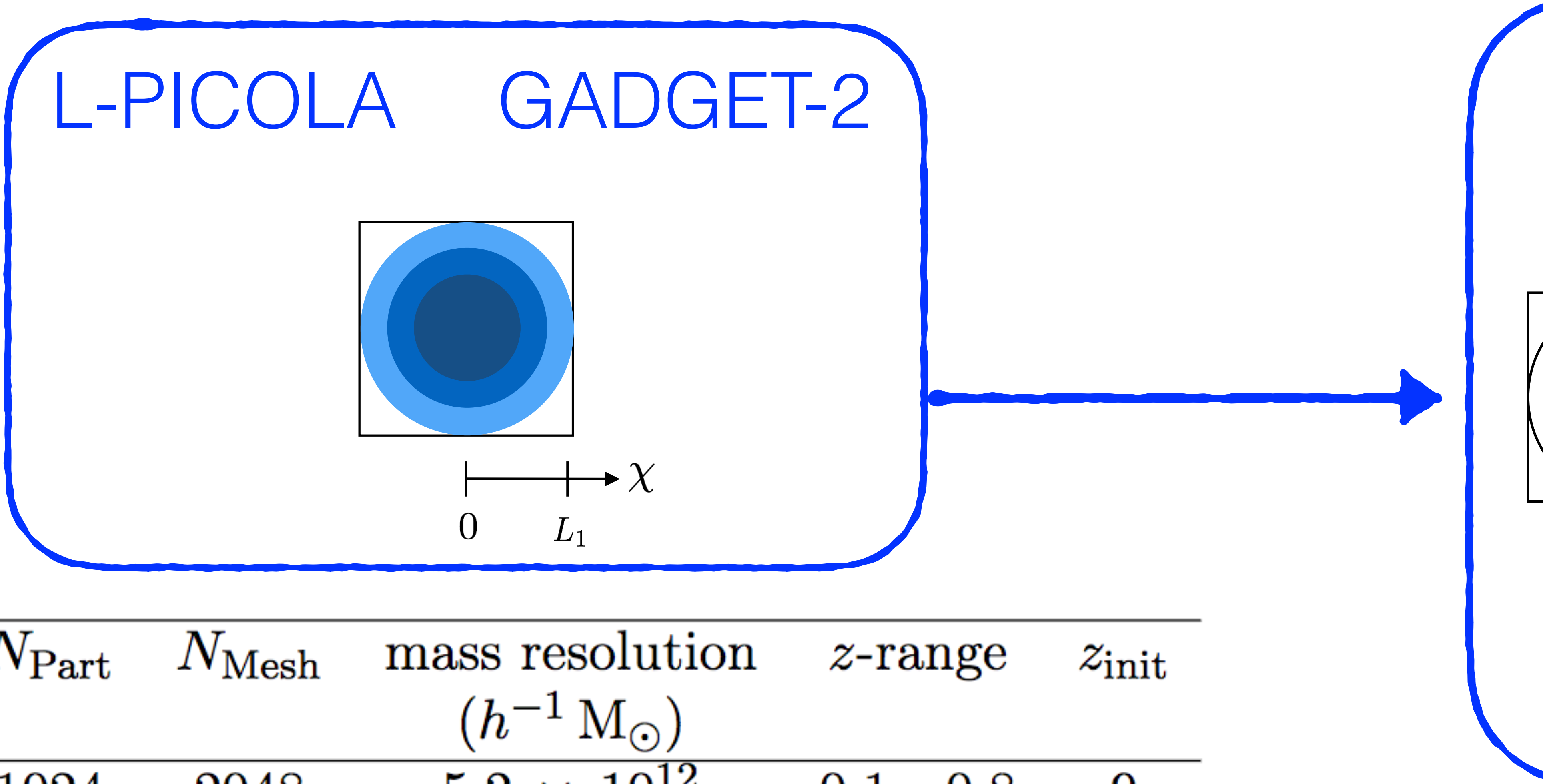

L-PICOLA GADGET-2

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