Weak lensing mocks using approximate methods

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Computational challenges in Euclid

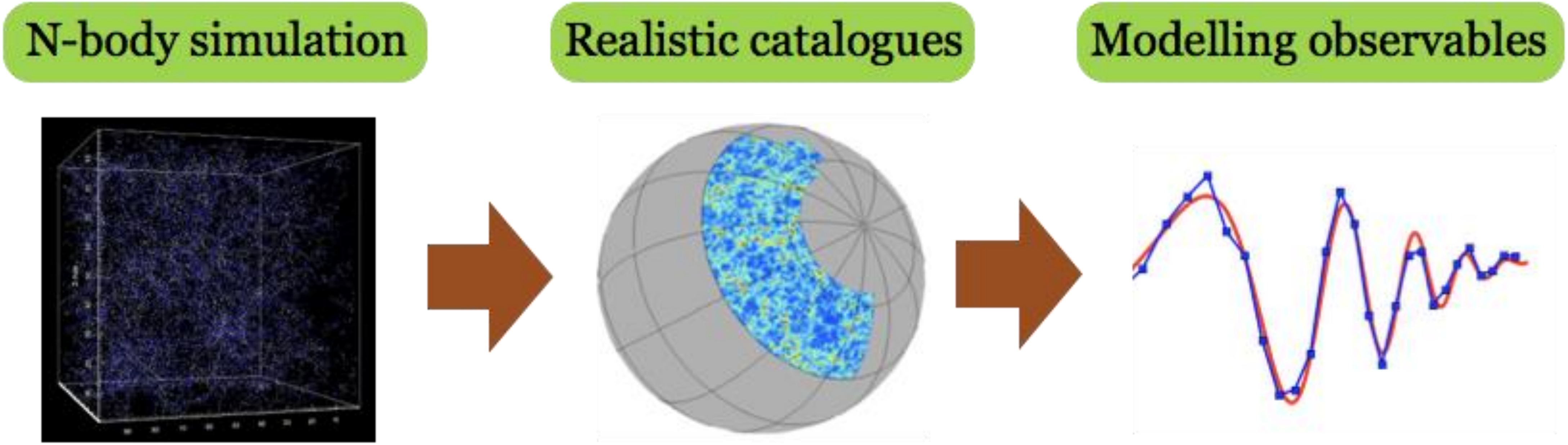
- **Systematic effects** will dominate the error budget for weak lensing measurements in Euclid (shape measurements, photometric errors, selection function, theoretical predictions…).
- These can be better understood using **mock galaxy catalogues**.
- Standard N-body simulations demand **large computational resources** (cpu+storage).
- We need **efficient techniques** to produce high-level data catalogues.

The need for approximate methods

- **Problem**
  - Estimate **covariance matrices** for weak lensing and clustering
  - Provide **mock catalogues** to calibrate and validate analysis pipelines
- **Requirements**
  - Sample large volumes (tens of Gpc^3)
  - Produce massive ensembles of realizations ($>10^3$)
  - Explore different cosmologies or gravitational models
- **Solution**
  - Identify the **optimal balance** between accuracy and speed-up for this problem
  - Develop **fast methods** that allow generating the required number of realizations

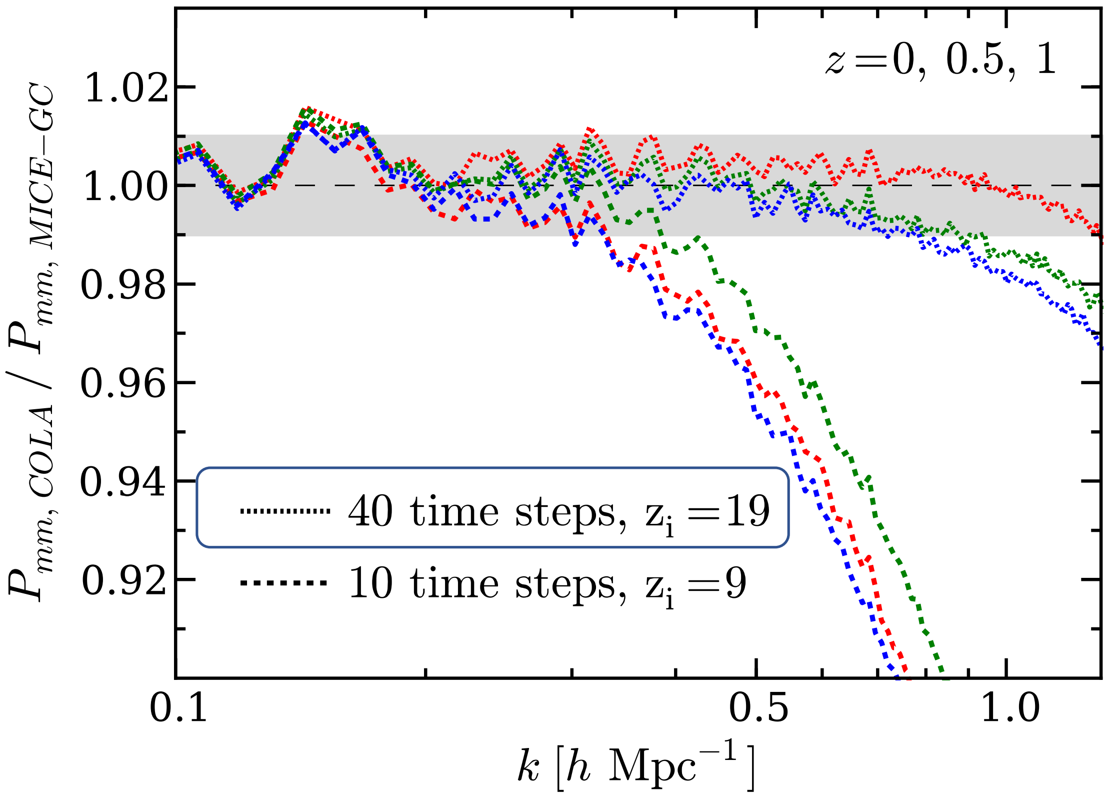
Galaxy catalog pipeline

- The COLA method (Tassev et al 2013): incorporates a theoretical description of the evolution of the matter density field in a numerical cosmological simulation.
- Speed-up thanks to using a cheaper and faster numerical integration.
- Parallel COLA (Koda et al. 2015)



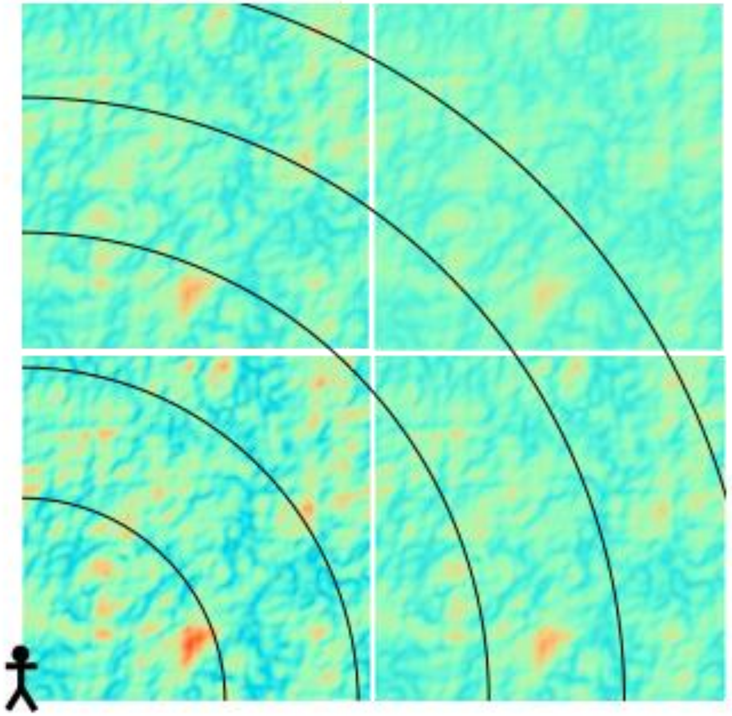
Optimal set-up for weak lensing covariances

Matter power spectrum

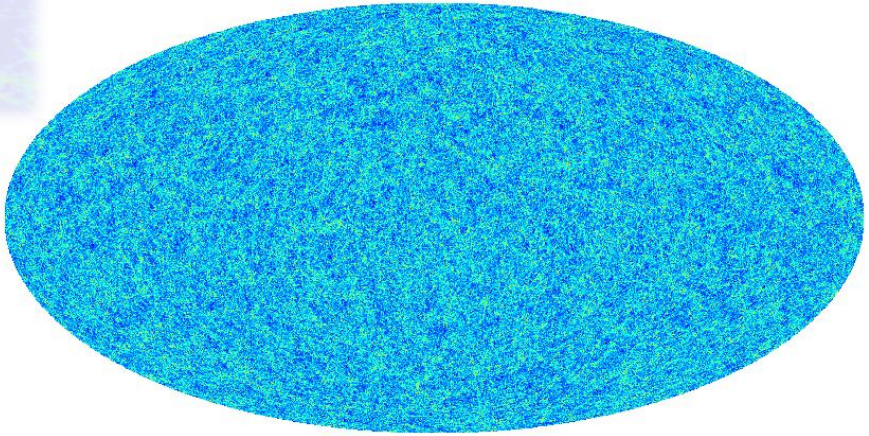


- 2048^3 particles run on 1024 cores in <1h (2.7 Tb memory)
- Matter power spectrum: 1% agreement up to k ~ 1 h/Mpc
- Mass function: 5% accuracy

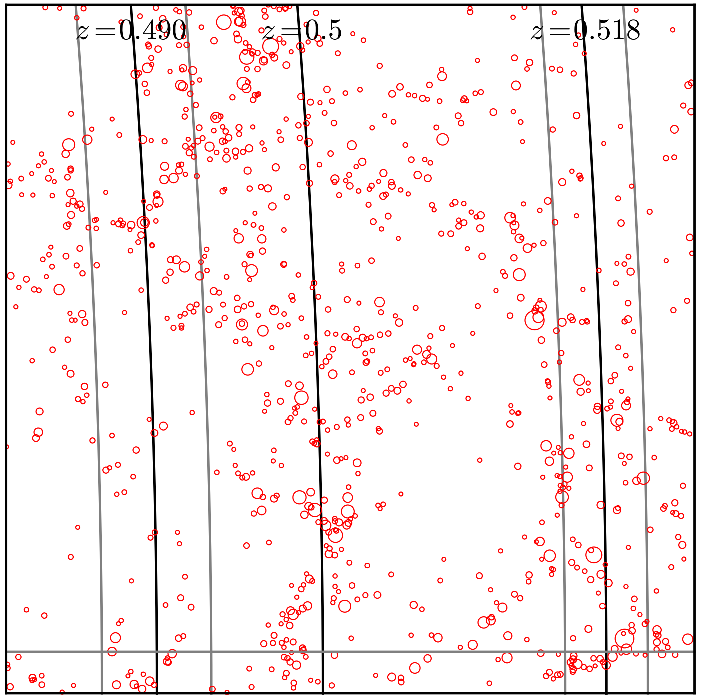
Light cone geometry



On-the-fly



2D projected matter map
Healpix discretization
(265x50M pixels)



Halo catalog

Weak lensing pipeline

SIMULATION

2048^3 particles
Lbox = 1536 Mpc/h
$m_p = 3\text{x}10^{10}\ M_{sun}$

z. ≤ 1.4
All sky
2 box replicas (64 total)

1024 cores
~2h / run
~300 realizations

On-the-fly →

Projected matter density field (2D, Healpix format)

Weak lensing pipeline

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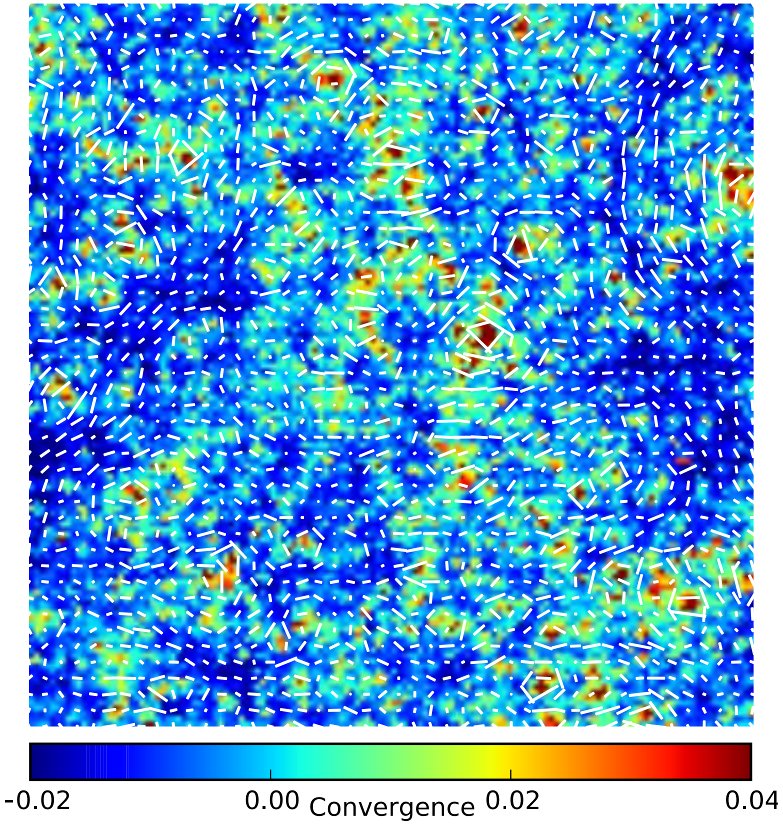


Projected matter density field (2D, Healpix format)

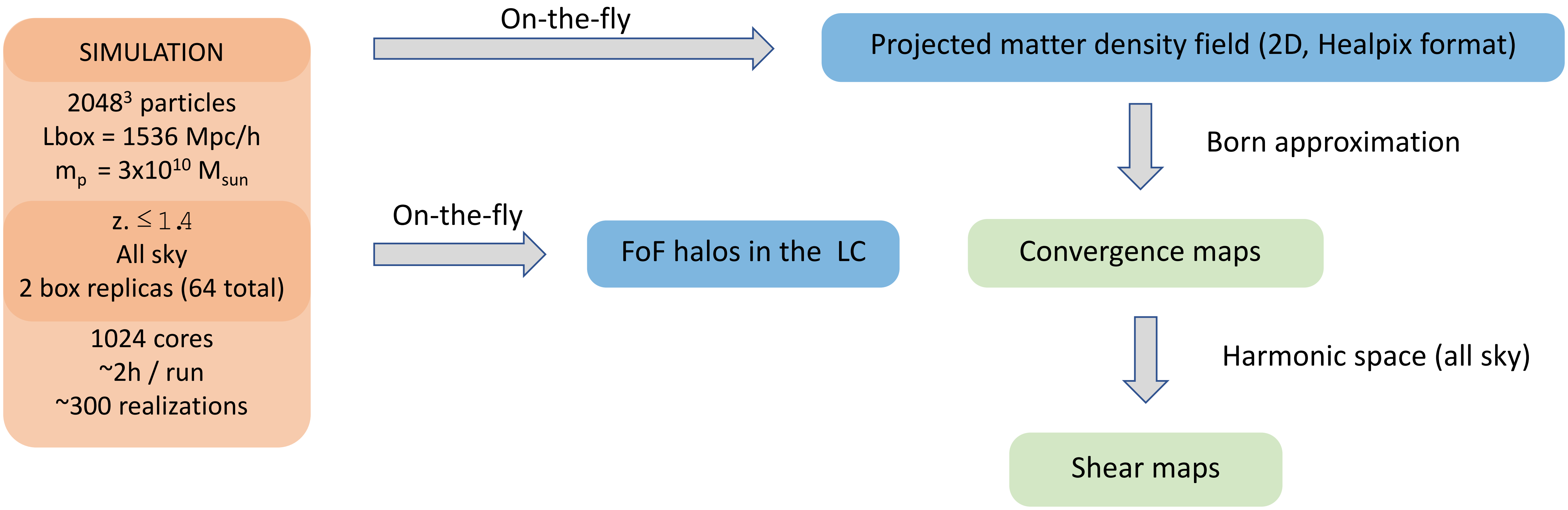
↓ Born approximation

Convergence maps

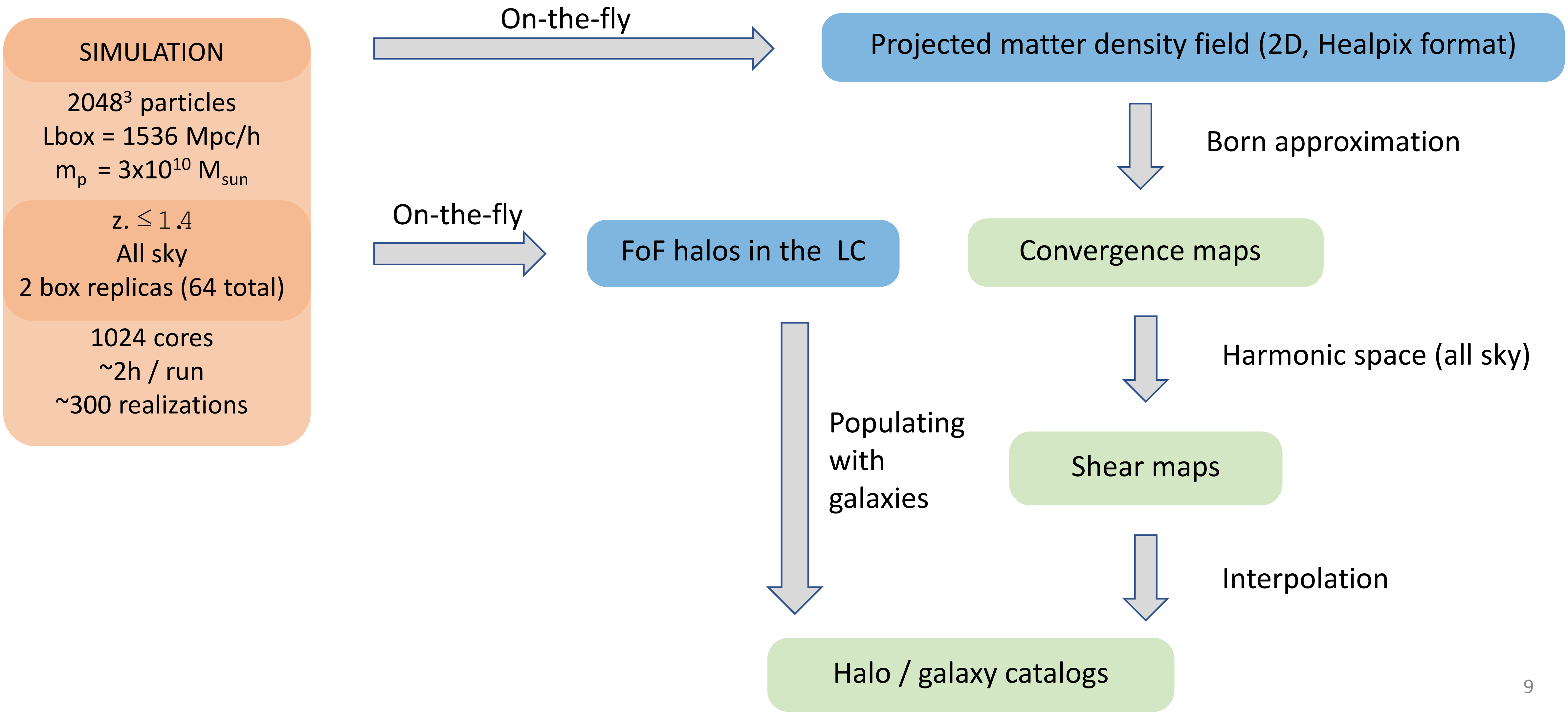
↓ Harmonic space (all sky)

Shear maps

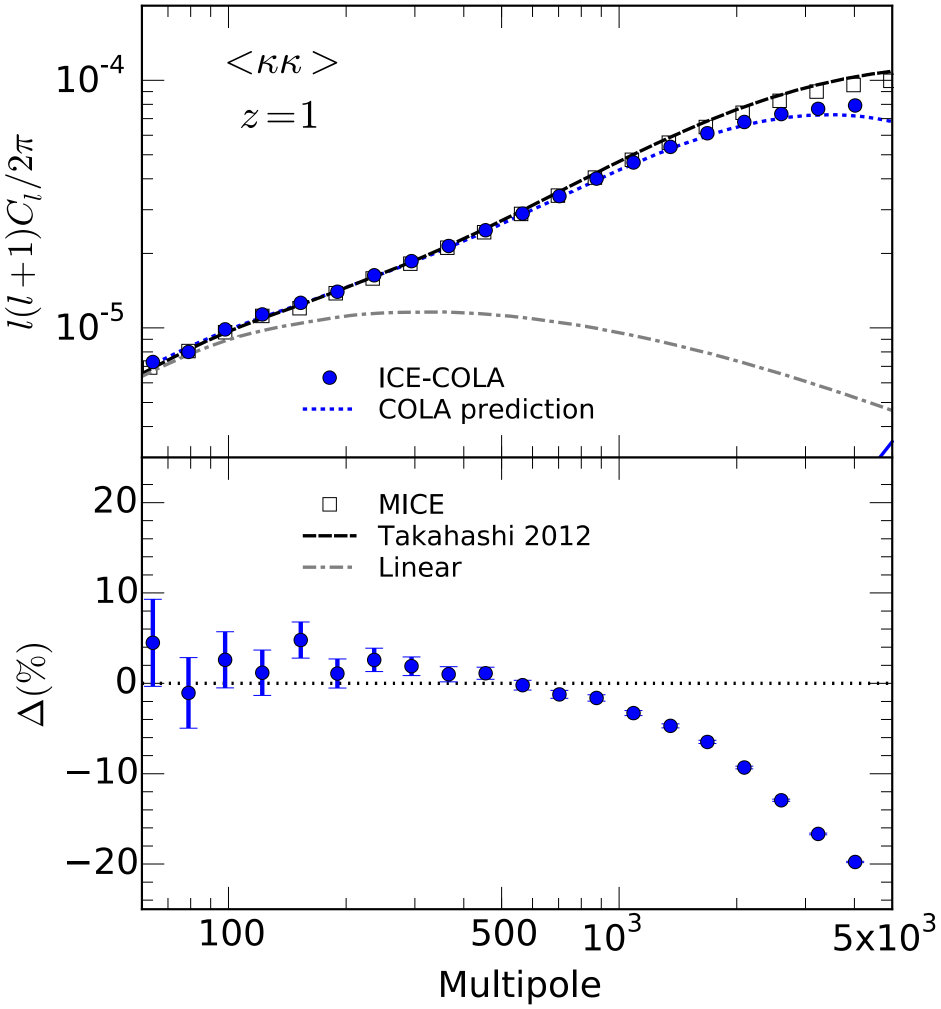
Weak lensing pipeline



Weak lensing pipeline

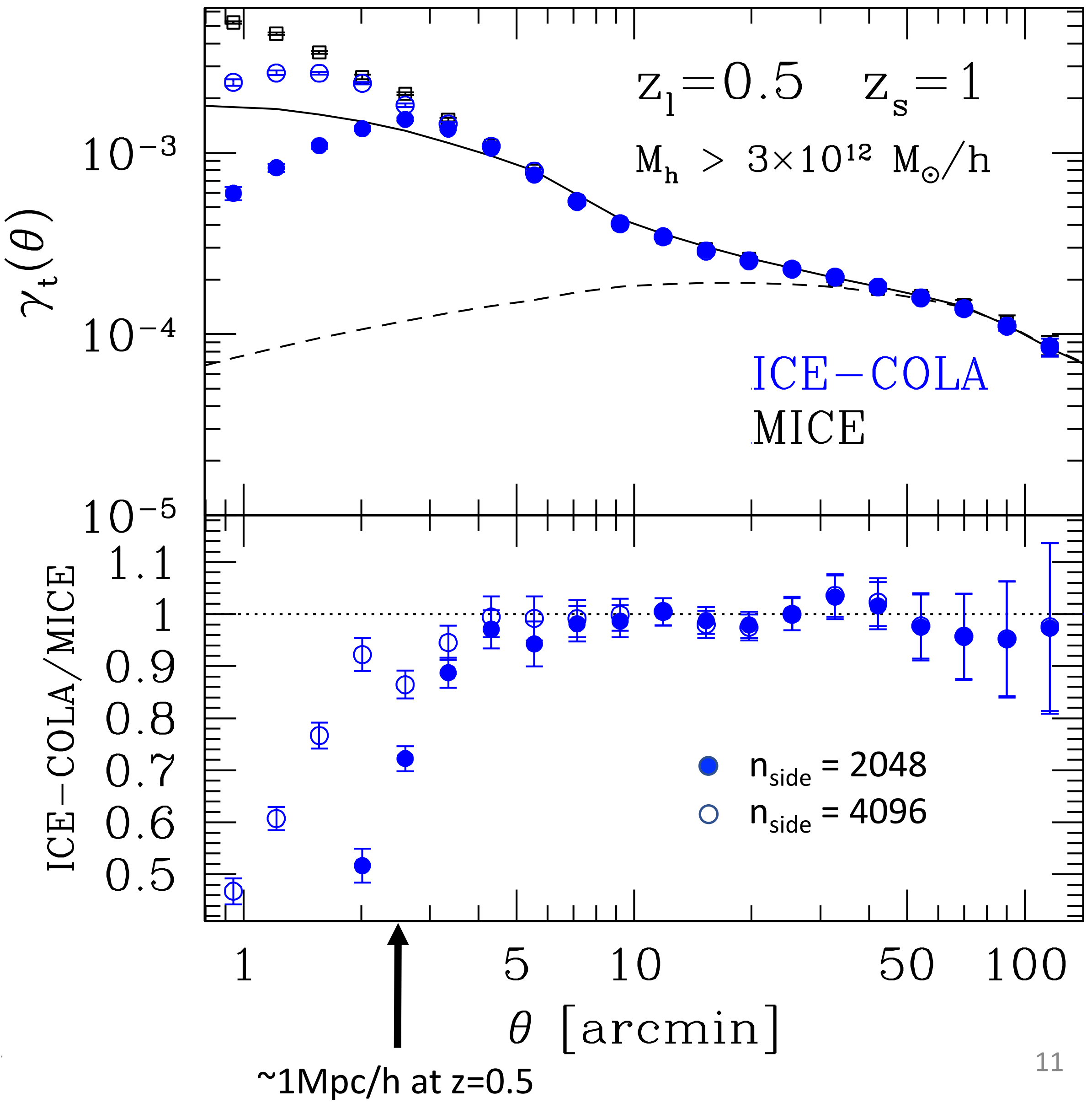


Convergence power spectrum

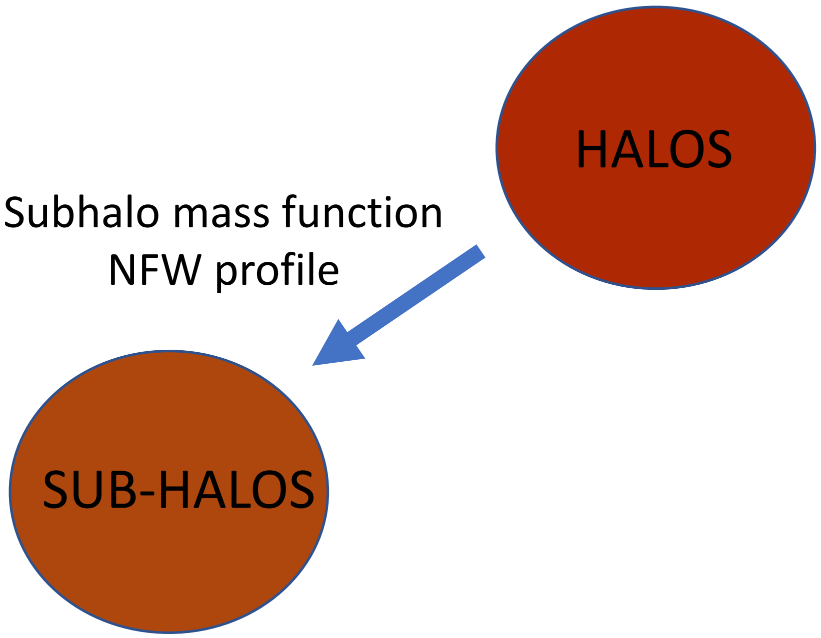


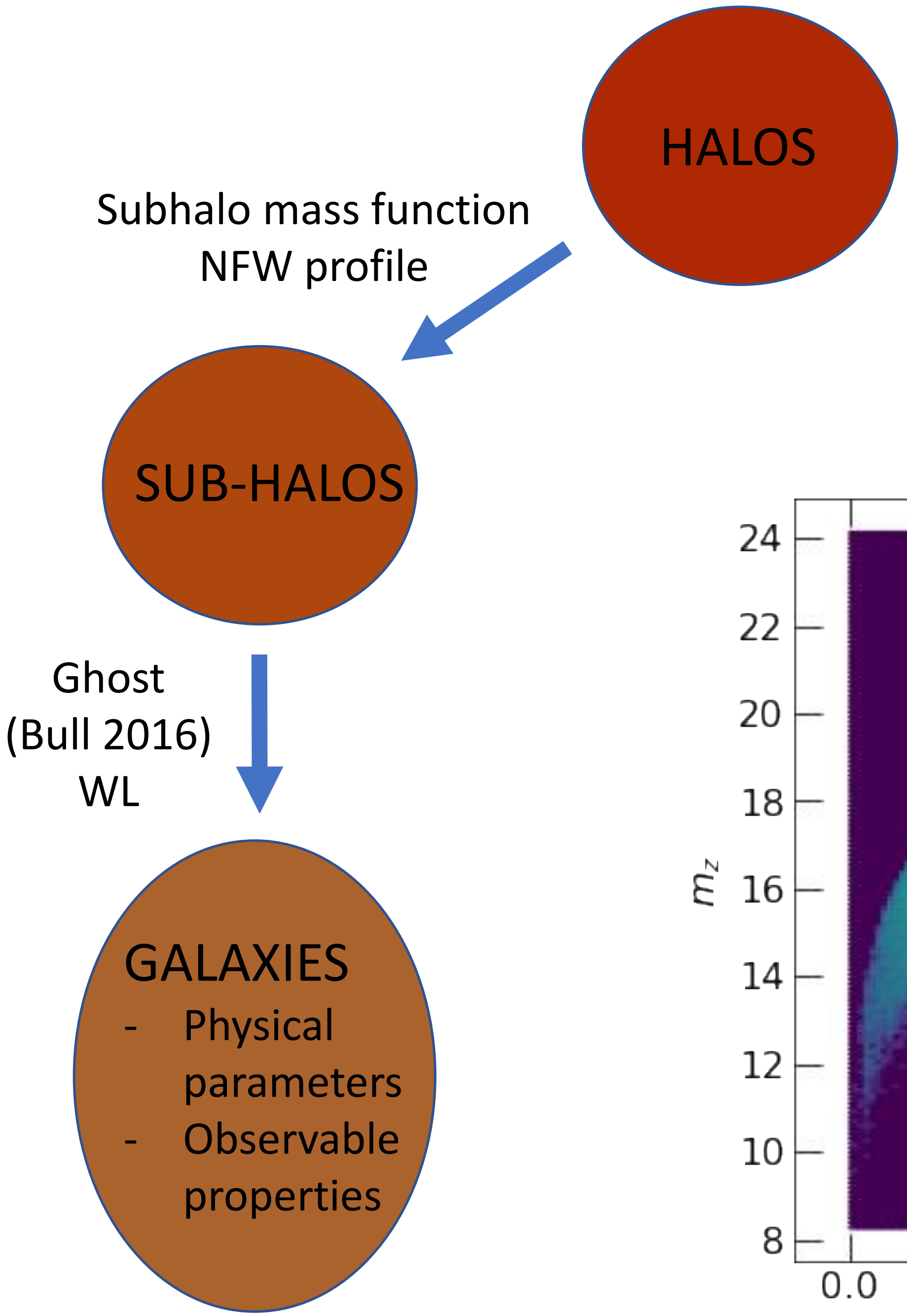
Tangential shear

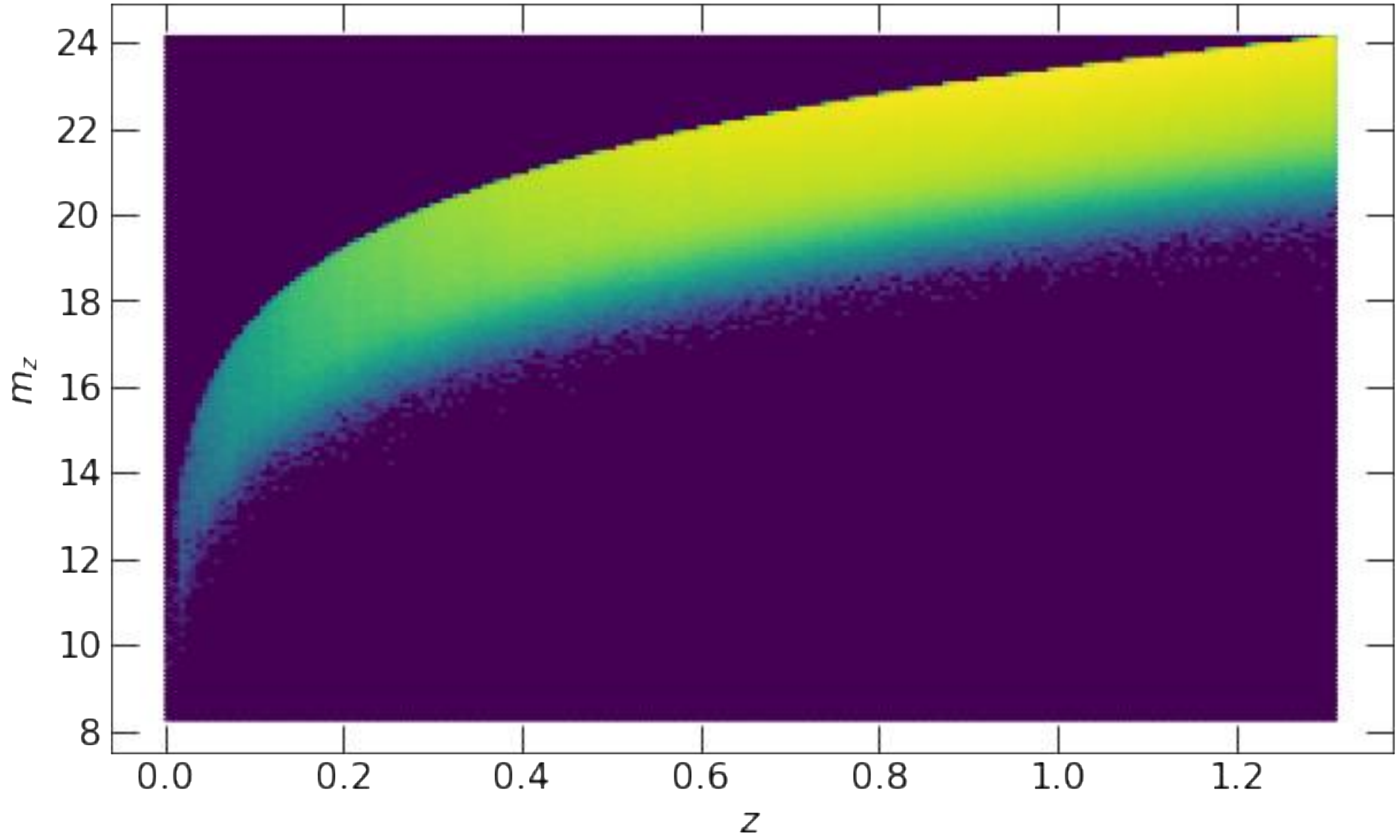
Correlation between the orientation of galaxy shapes in the background and the distribution of foreground galaxies



HALOS


HALOS
Subhalo mass function
NFW profile
SUB-HALOS


HALOS
Subhalo mass function
NFW profile
SUB-HALOS
Ghost
(Bull 2016)
WL
GALAXIES
- Physical parameters
- Observable properties


m_z
24
22
20
18
16
14
12
10
8
0.0
0.2
0.4
0.6
0.8
1.0
1.2
z

HALOS

Subhalo mass function
NFW profile

SUB-HALOS

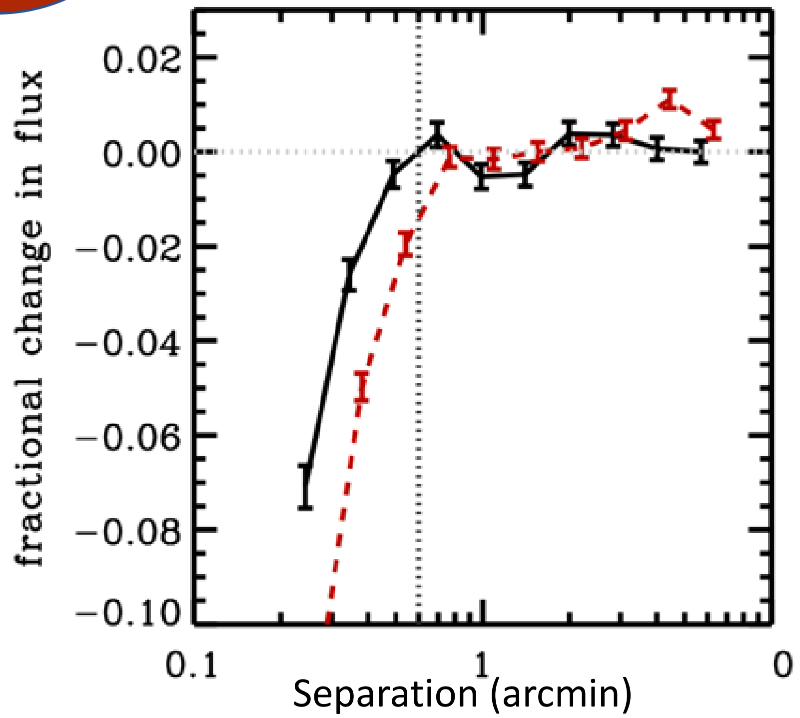
Ghost
(Bull 2016)
WL

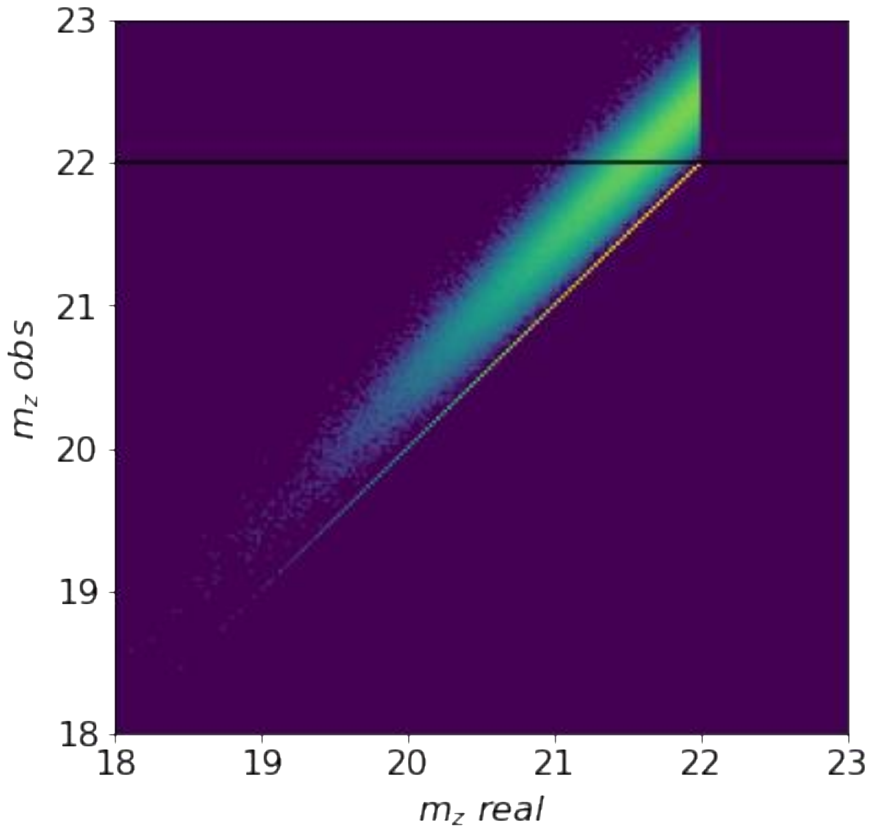
GALAXIES
- Physical parameters
- Observable properties

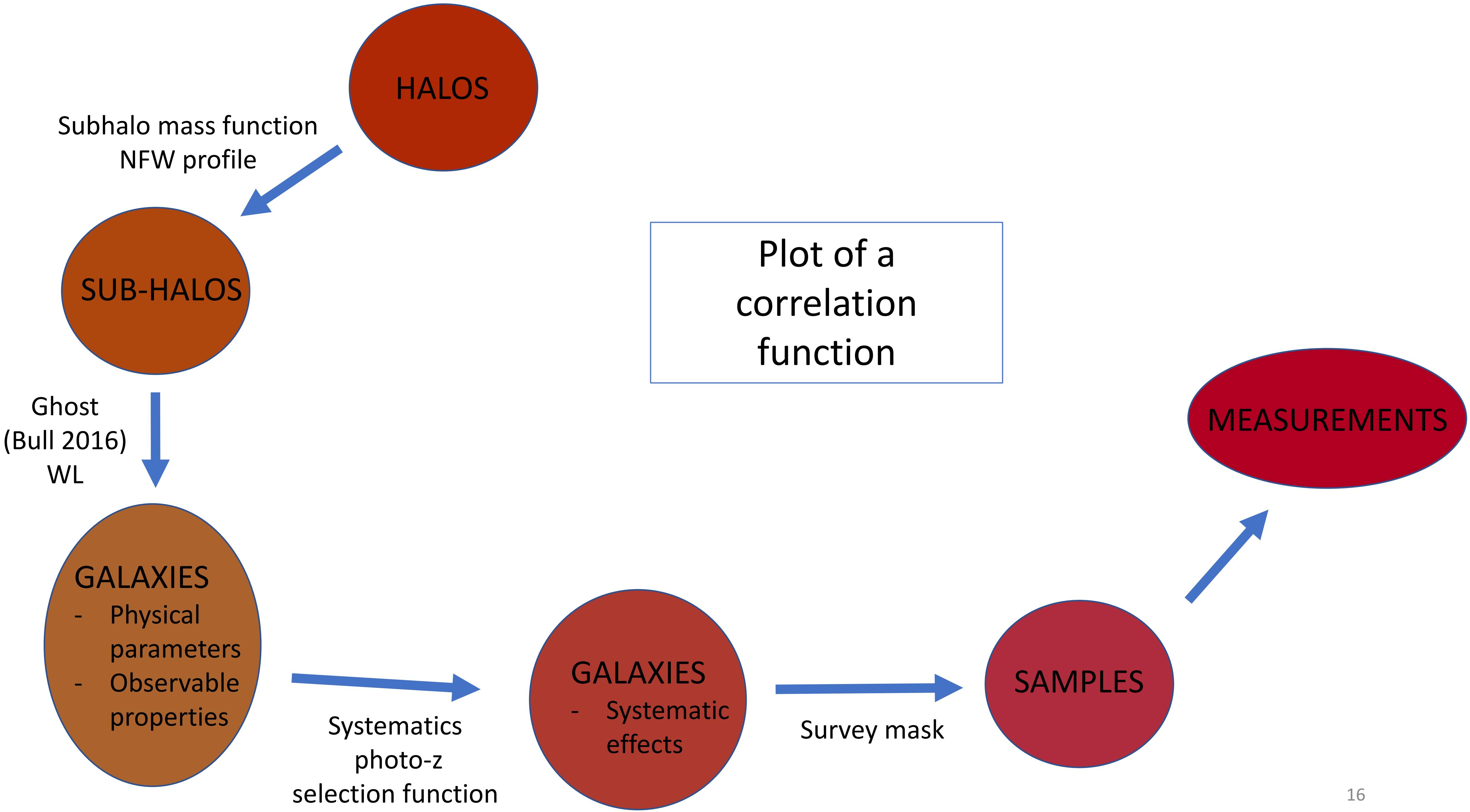
Systematics
photo-z
selection function

GALAXIES
- Systematic effects

Huff & Graves (2014),
SDSS DR7 (Blanton 2005)



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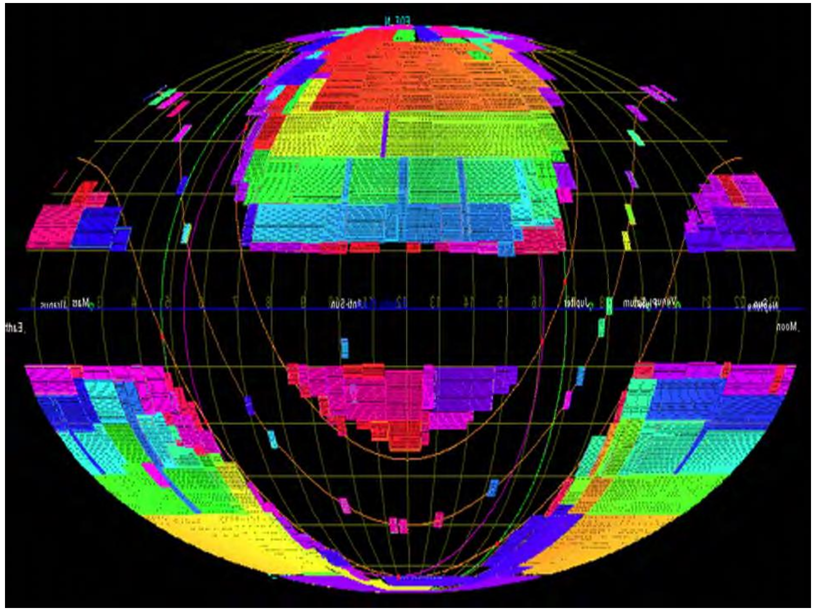
GALAXIES
- Systematic effects
Survey mask
SAMPLES
MEASUREMENTS
Plot of a correlation function

Modeling systematic effects on WL

- **Cosmic shear** measurements are affected by:
  - Shape uncertainties
  - Photometric redshift errors
  - Survey selection function
- These may vary across the sky and in a coherent way, affecting both the signal and the covariance matrix
- We model the conditional probability

$$P(\gamma_{obs}, z_{obs}, detection|\gamma_{true}, z_{true}, \theta)$$



Euclid footprint (Euclid Consortium)

Covariance matrices

- Provisional results

Plot of a
covariance matrix

Feedback!

What are the priorities and concerns in Euclid for observational systematics in covariance estimation?

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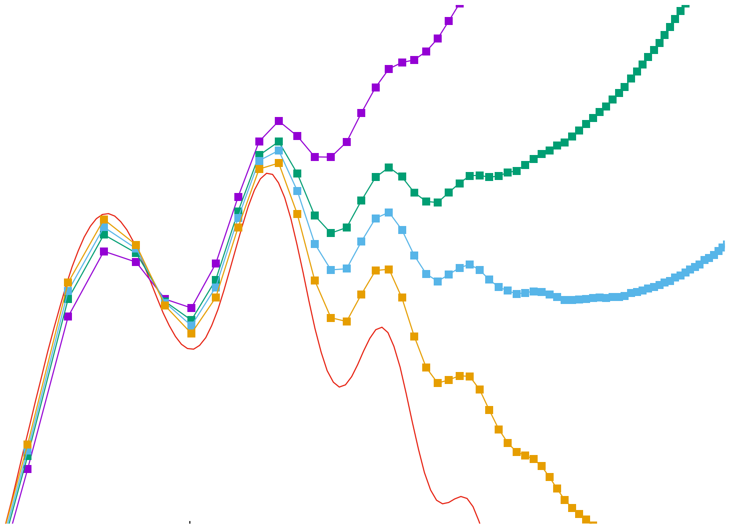
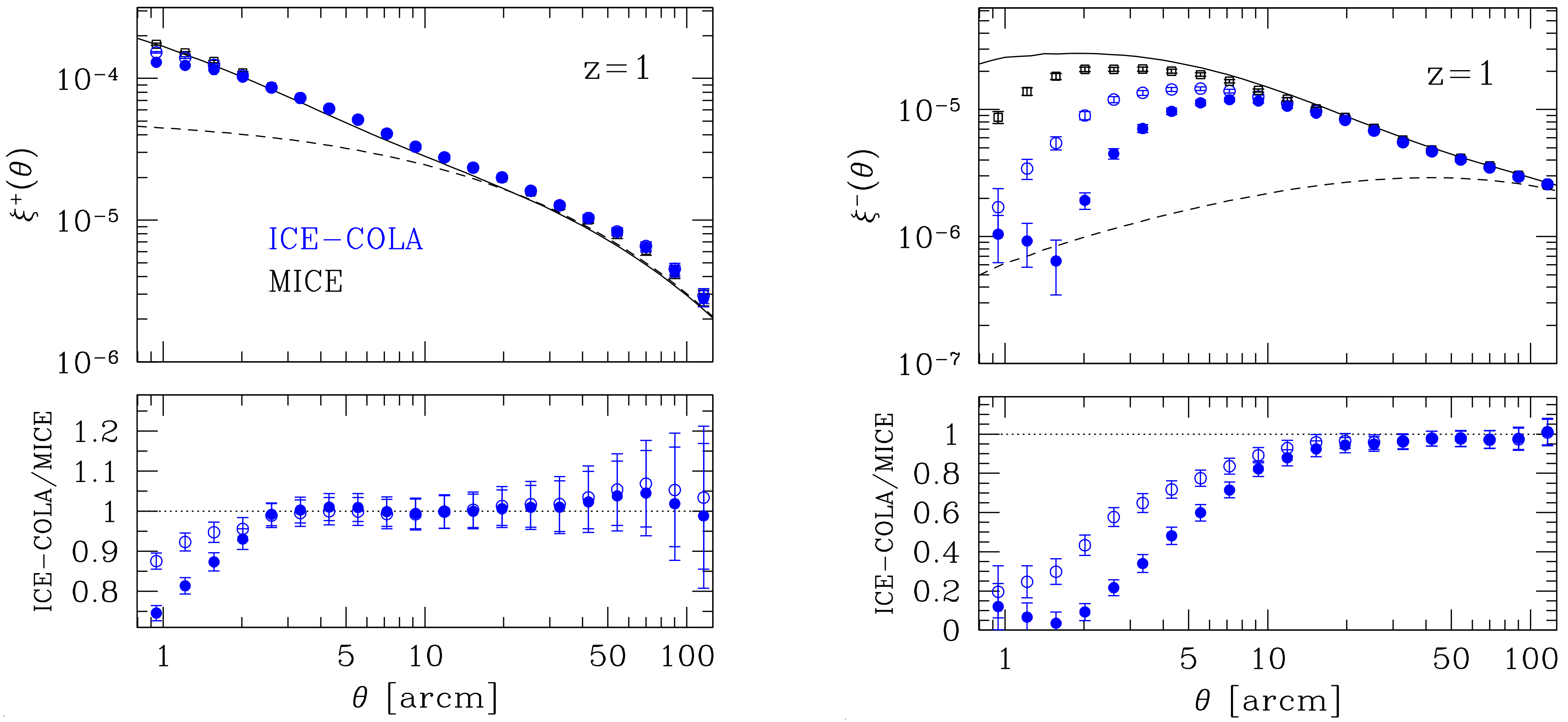


Shear correlation functions

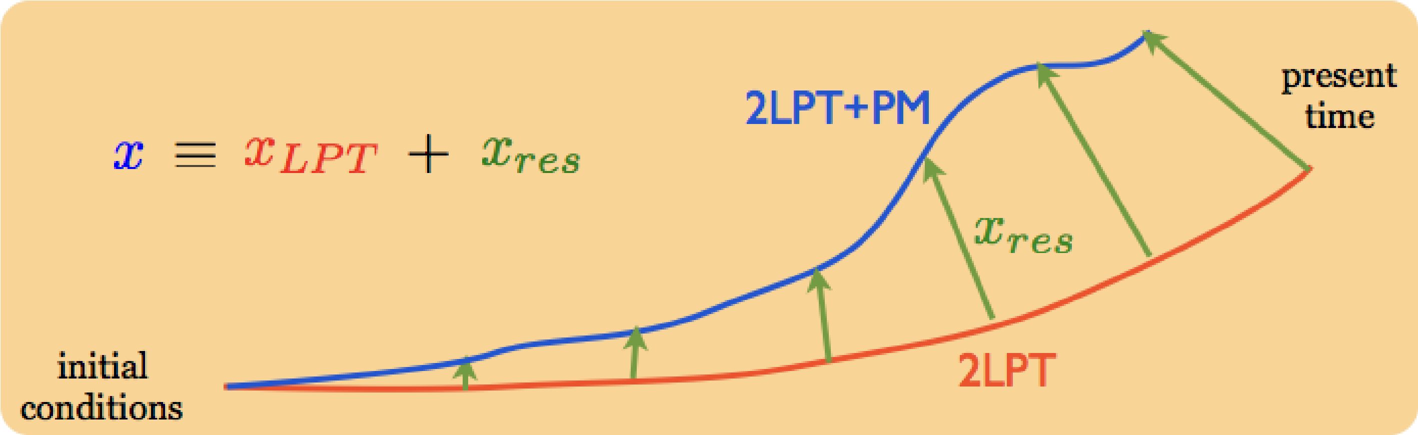


The COLA method

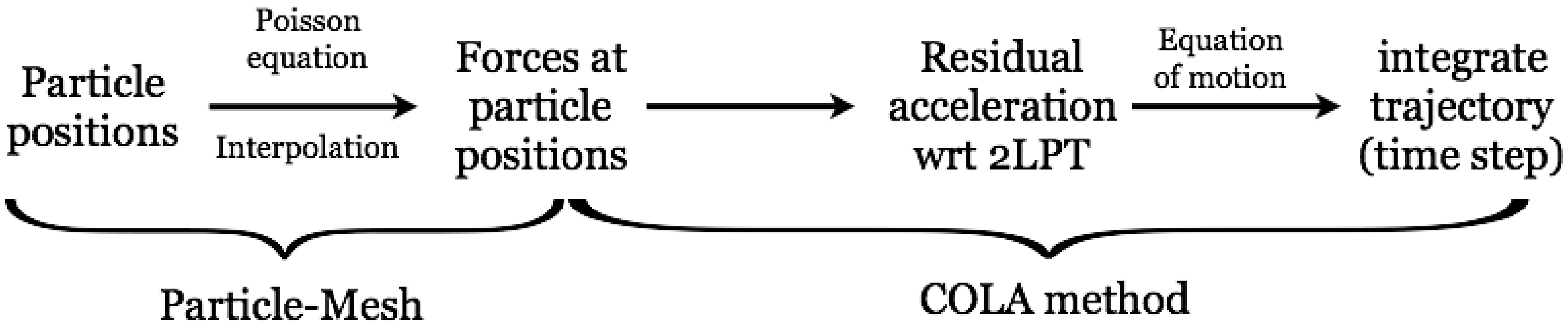
COmoving Lagrangian Acceleration (Tassev et al. 2013):

Use Perturbation Theory for an approximated guess of the solution

Add residual displacements with a cheap numerical N-body solver



$$\partial_t^2 \boldsymbol{x}_{\rm res}(t) = -\nabla\Phi(t) - \partial_t^2 \boldsymbol{x}_{\rm LPT}(t),$$



Comparison with other approximate methods

PROS

- ✓ Large scale dynamics is exact
- ✓ Accuracy at small scales is adjustable
- ✓ 2-3 orders of magnitude faster than conventional N-body simulations

CONS

- ❖ Large memory consumption
- ❖ Not as fast as fast methods using biasing prescriptions