Efficient simulations for the coming galaxy surveys

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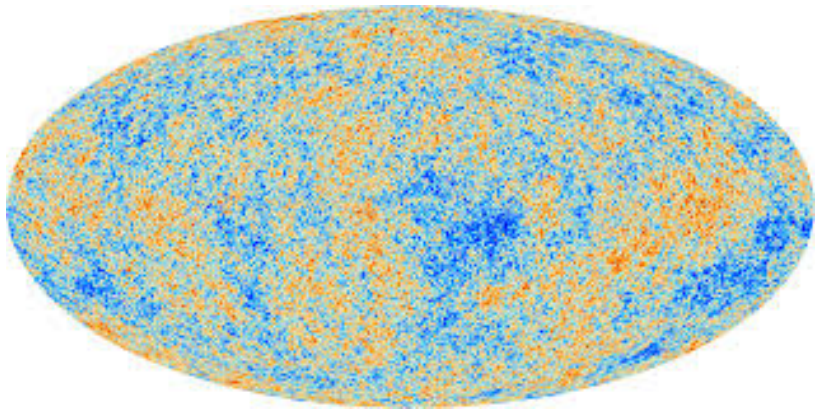
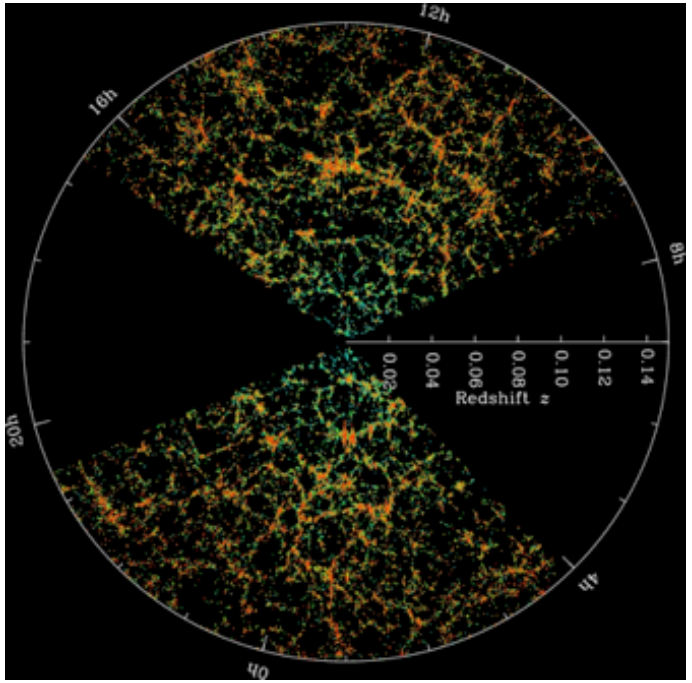
The ΛCDM model

Large-scale homogeneity and isotropy



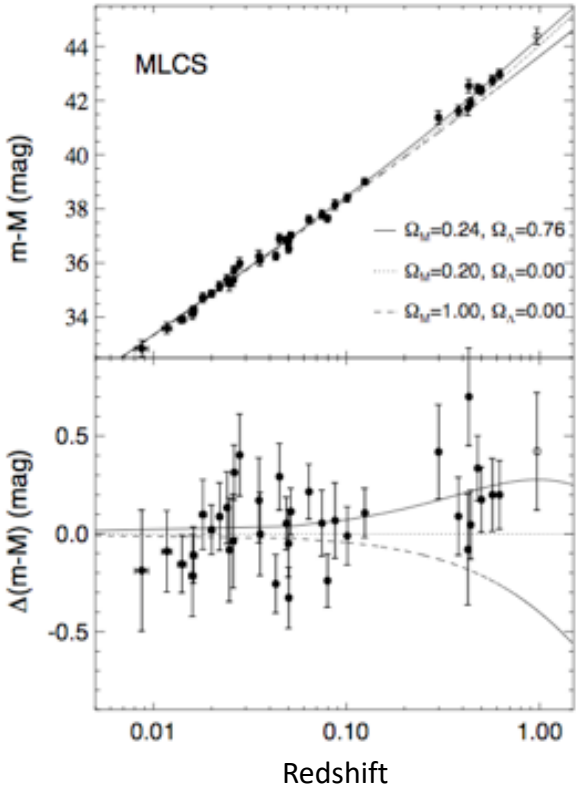
Planck

Gravitational instability



SDSS

Expansion



Riess et al. 1998

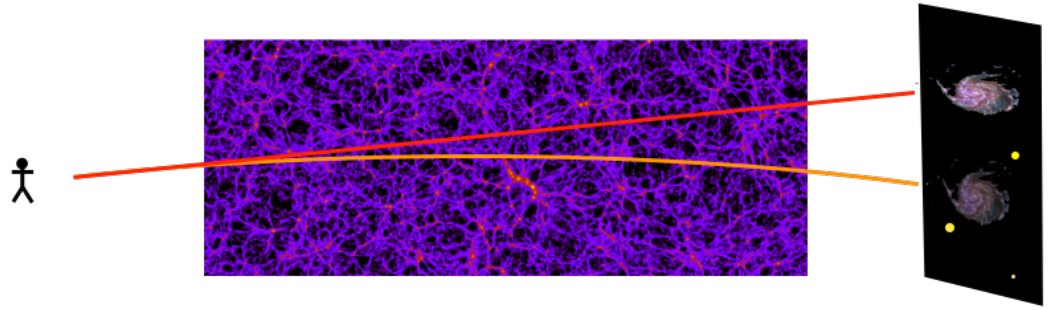
The cosmic pie

Cosmology: theory + observations + simulations

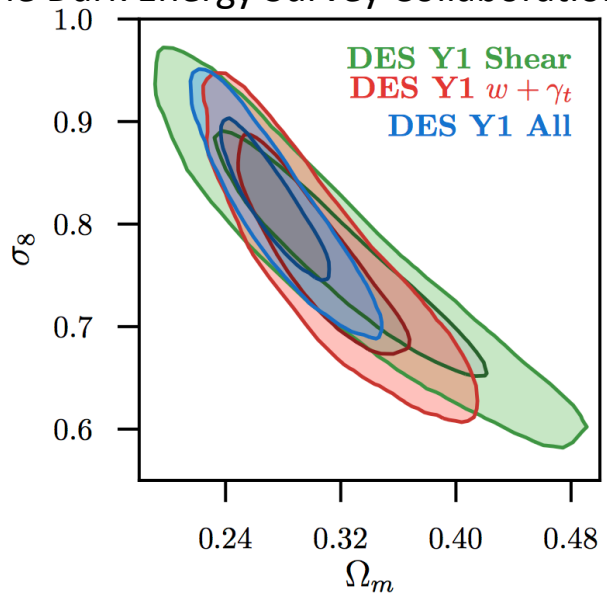
THEORY
- General relativity
- Copernican principle
- Standard model of particle physics

MODELS
- ΛCDM
- Inflation

PREDICTIONS
- Expansion rate
- Structure formation



The Dark Energy Survey Collaboration 2017



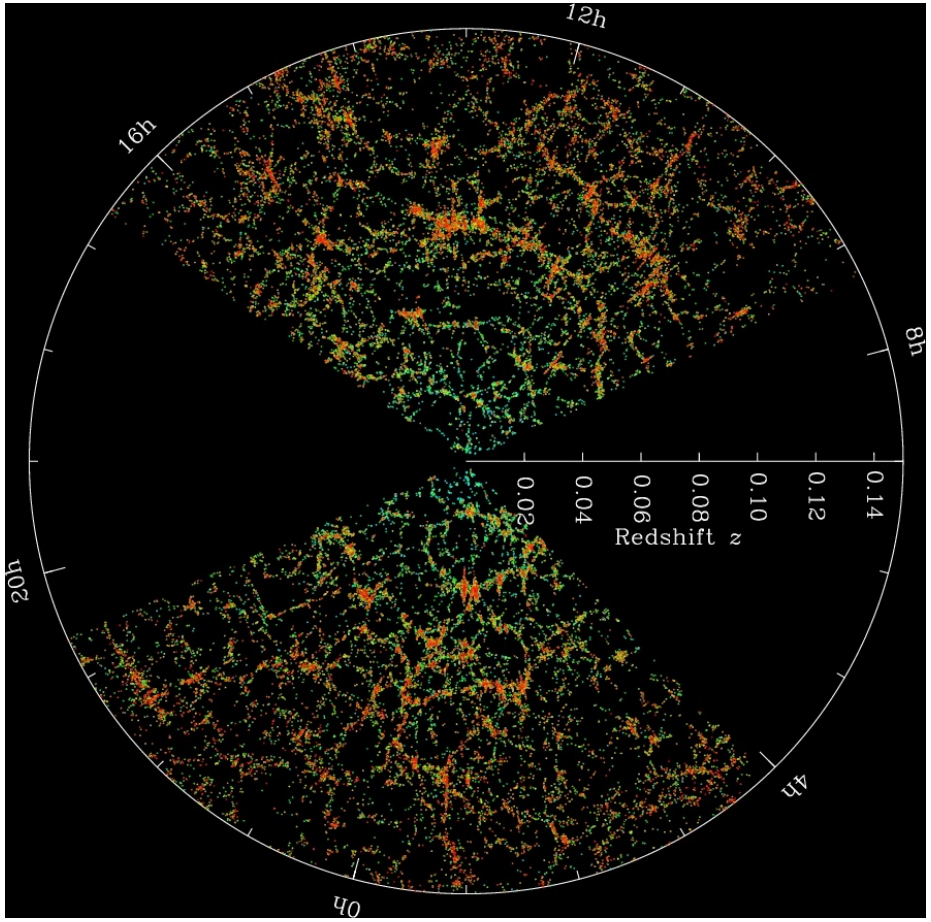
GALAXY SURVEYS

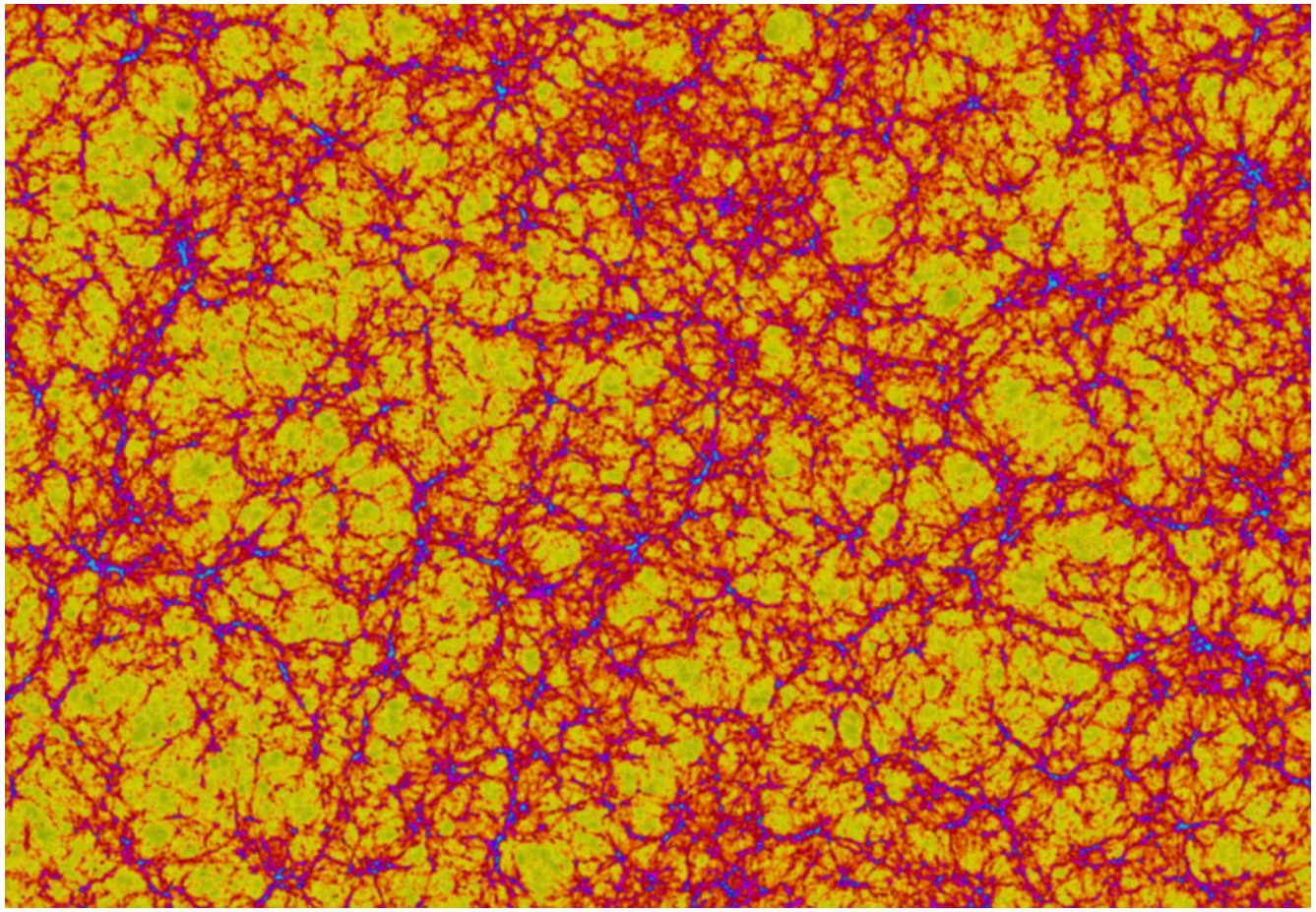
euclid

WFIRST

OBSERVATIONS
- Galaxy distribution
- Image distortion by weak gravitational lensing
- Supernovae
- Clusters of galaxies
- Cosmic microwave background

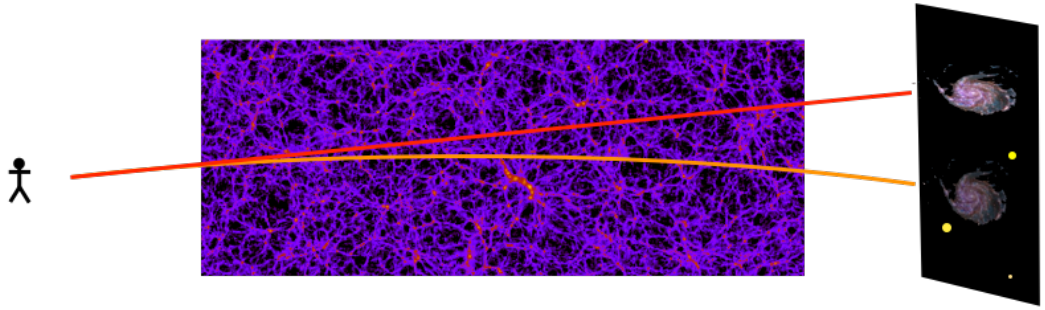
Reproducing observations with simulations





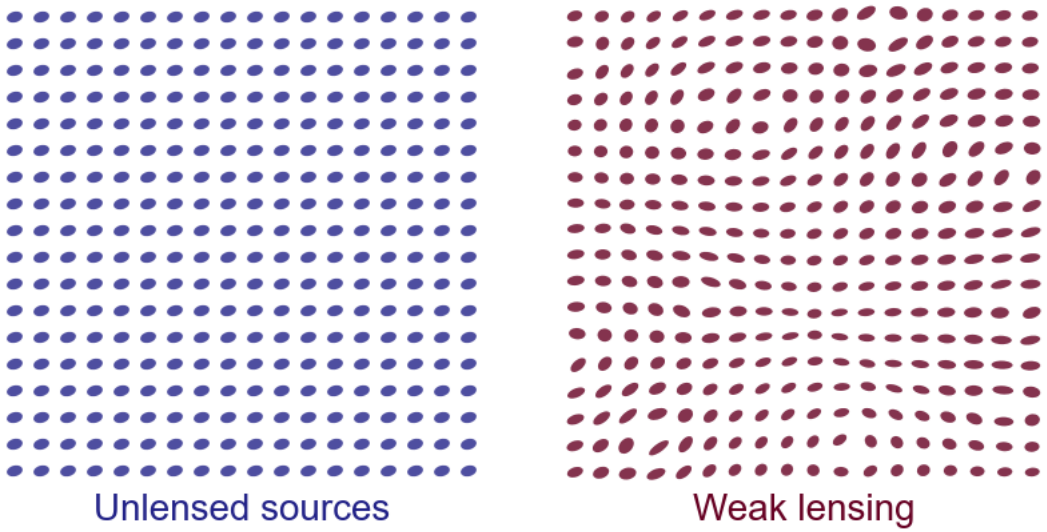
Credit: M. Blanton and SDSS

Strong gravitational lensing

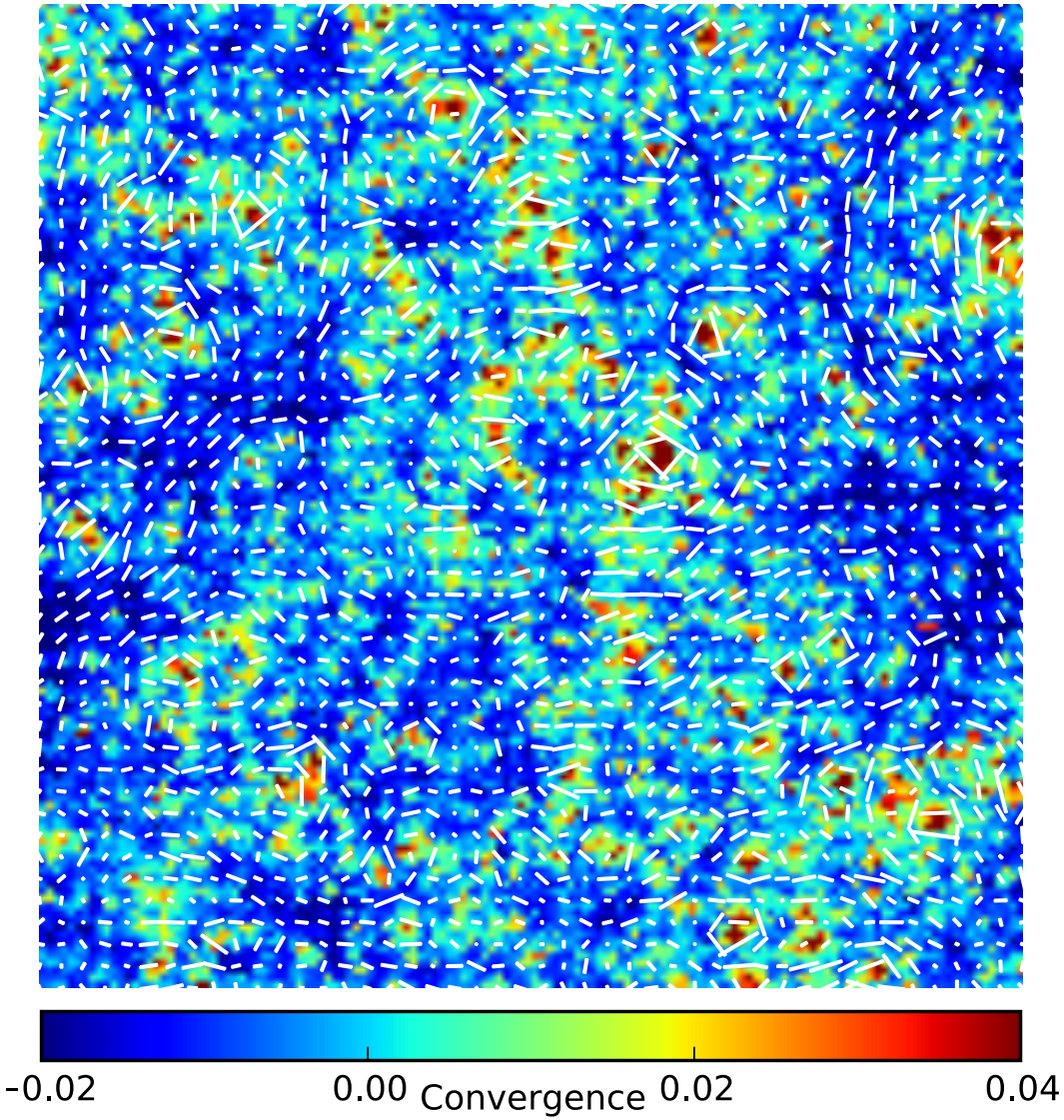


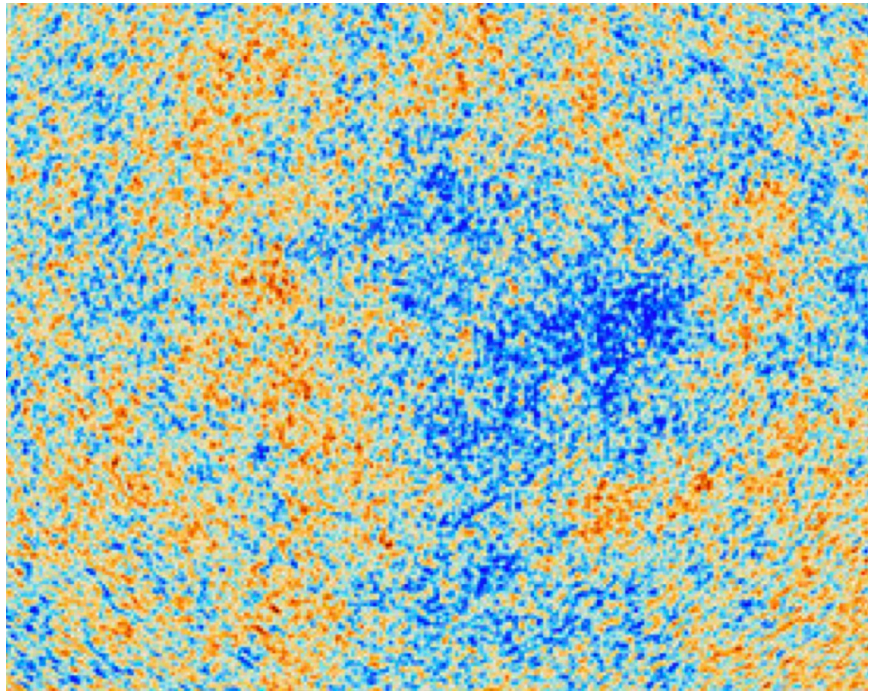
Credit: NASA / ESA / J. Lotz / STScI

Weak gravitational lensing



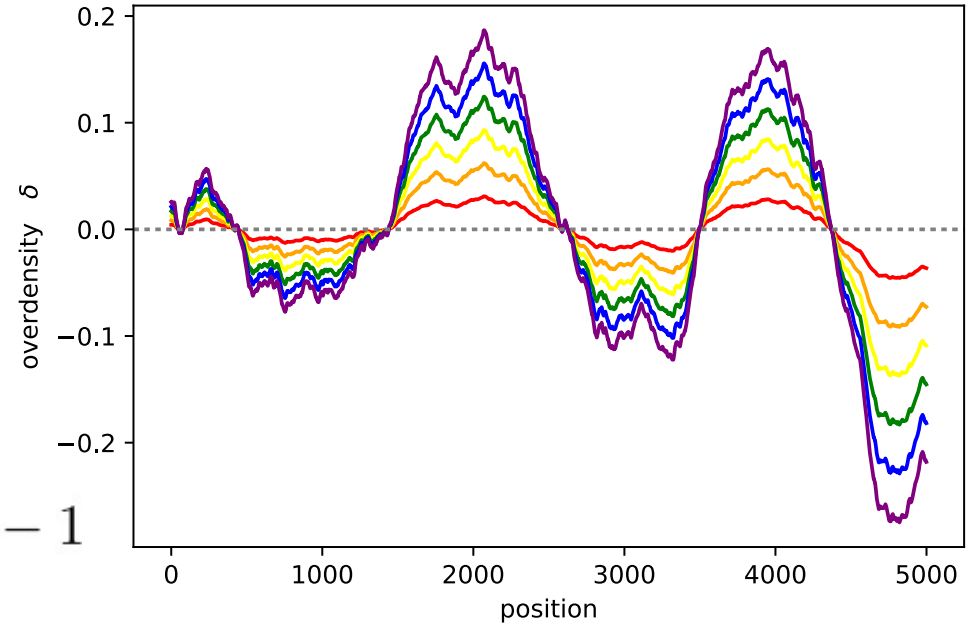
Credit: Chieh-An Lin



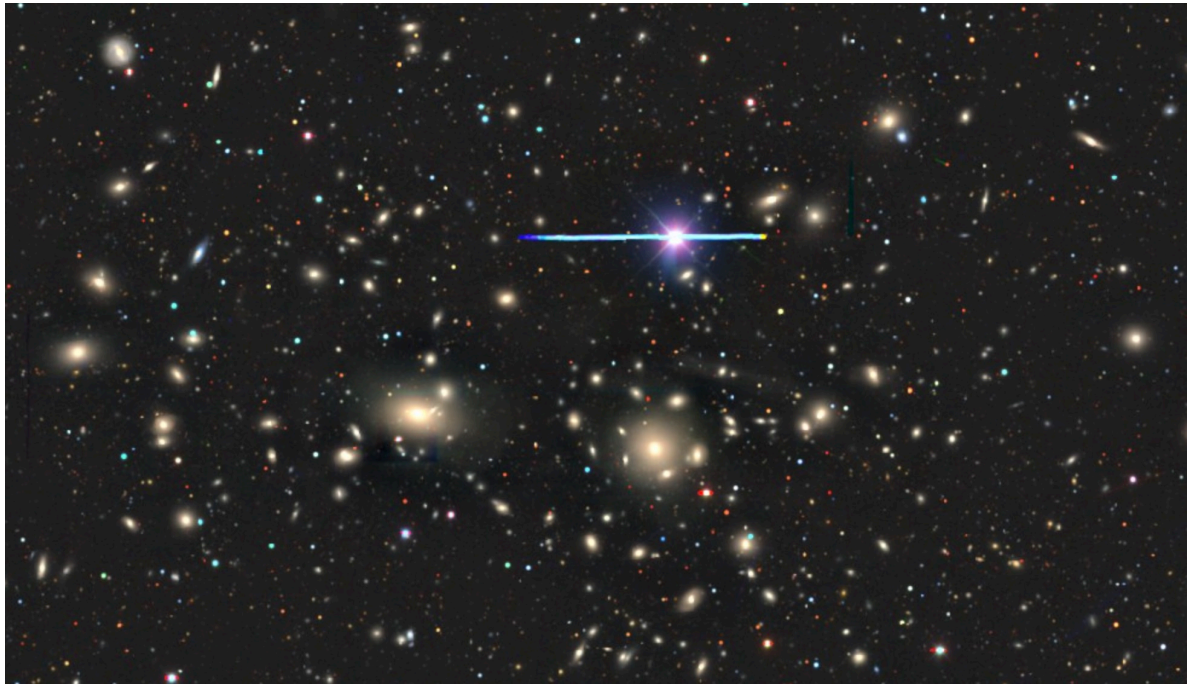


Credit: ESA and the Planck collaboration

The (non-)linear growth of structure



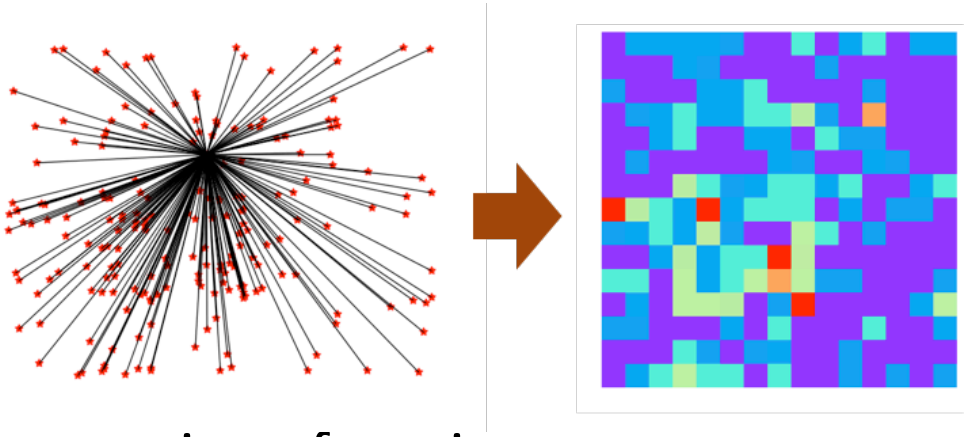
$$\delta = \frac{\rho}{\bar{\rho}} - 1$$



Coma cluster. Credit: DECaLS, NOAO/AURA/NSF

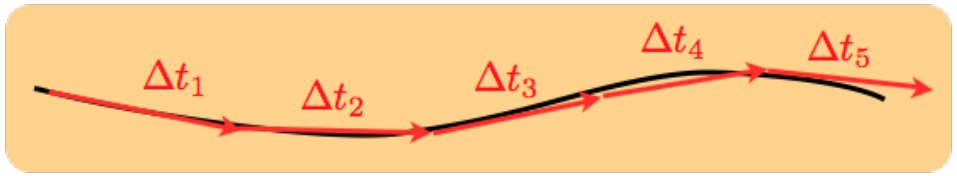
N-body simulations

1. Sample discretely the phase space by point-like particles
2. Estimate forces

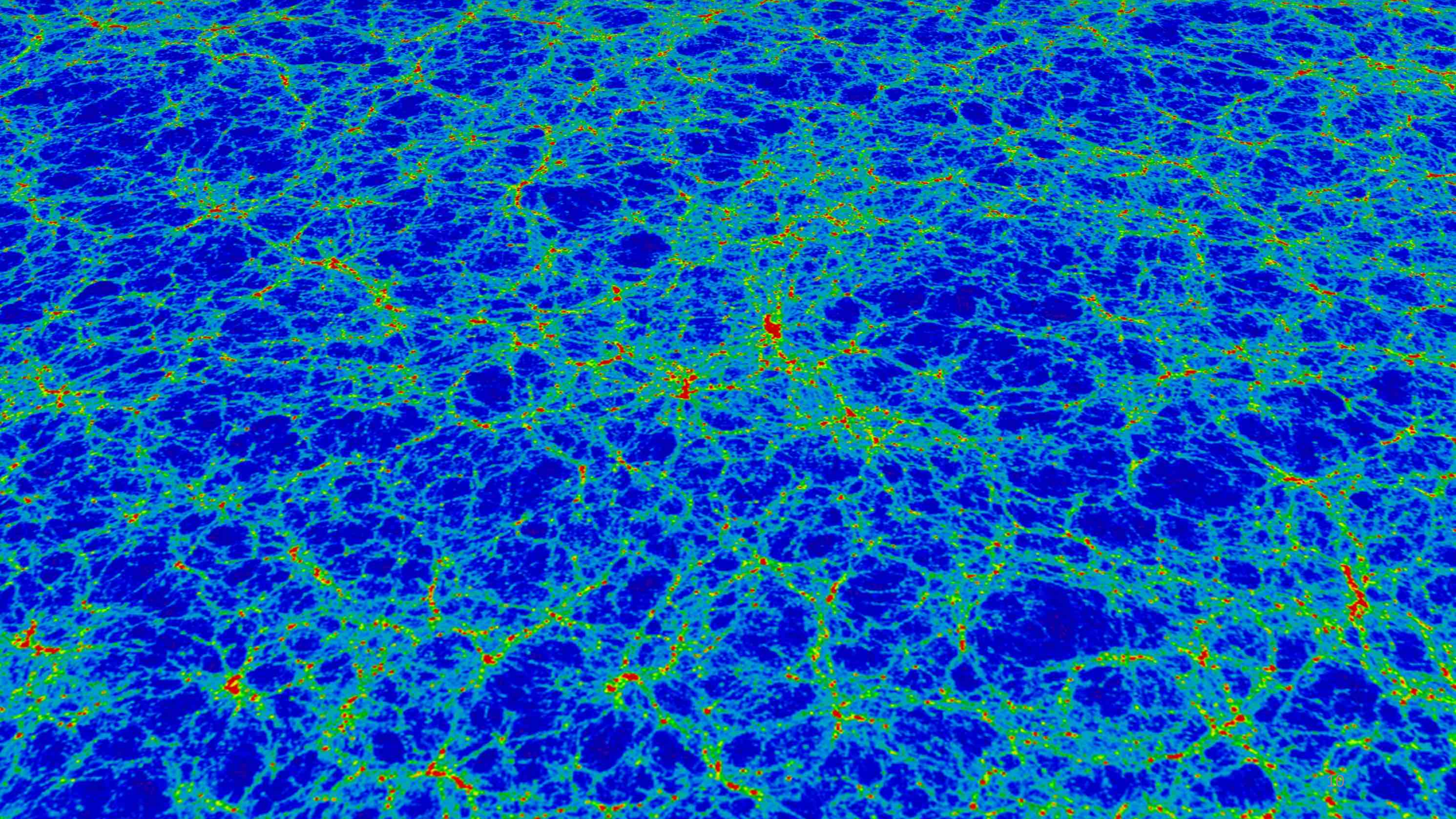


+ FFT

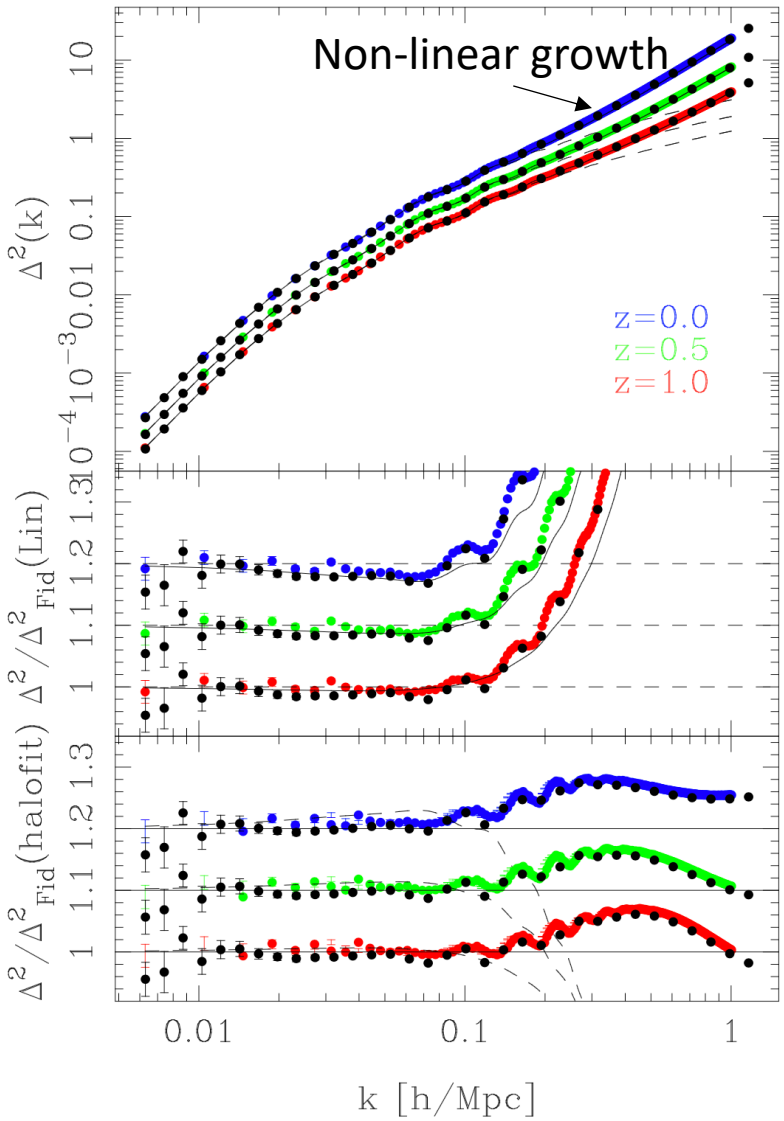
3. Integrate equation of motion



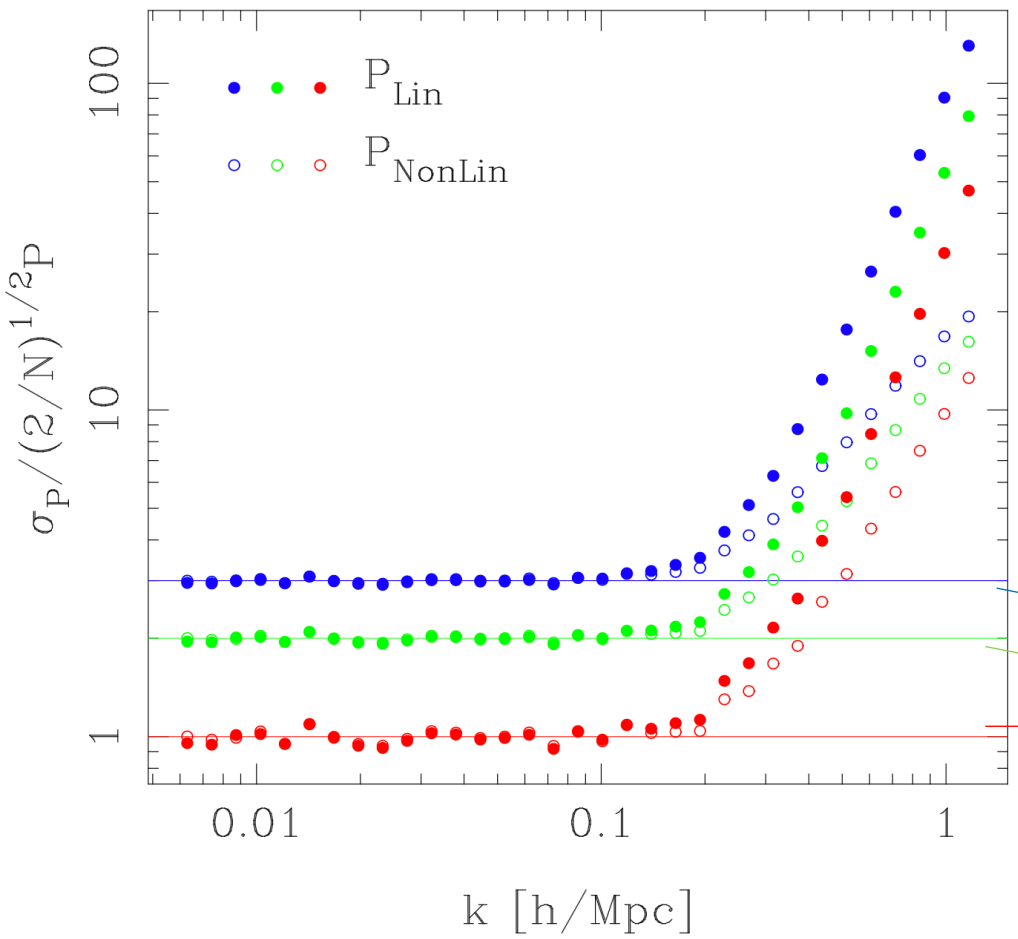
- Have large computational requirements



Power spectrum predictions from simulations



Variance of the power spectrum



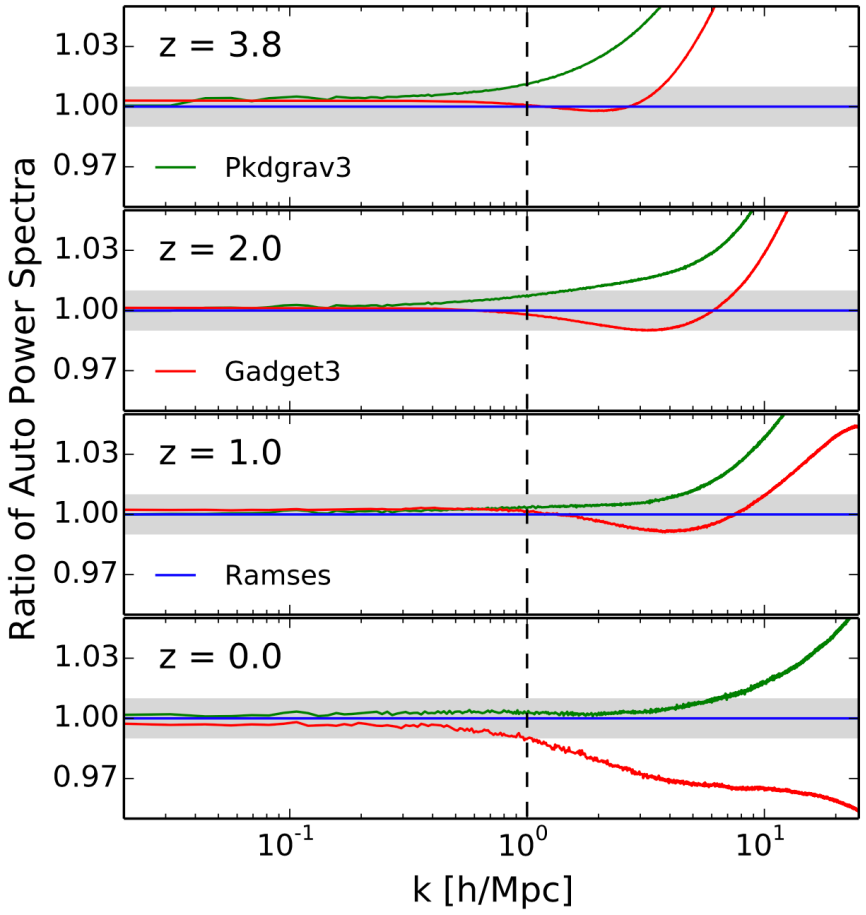
For a Gaussian field:

$$\frac{\sigma}{P} = \sqrt{\frac{2}{N-1}}$$

Smith et al. 2014

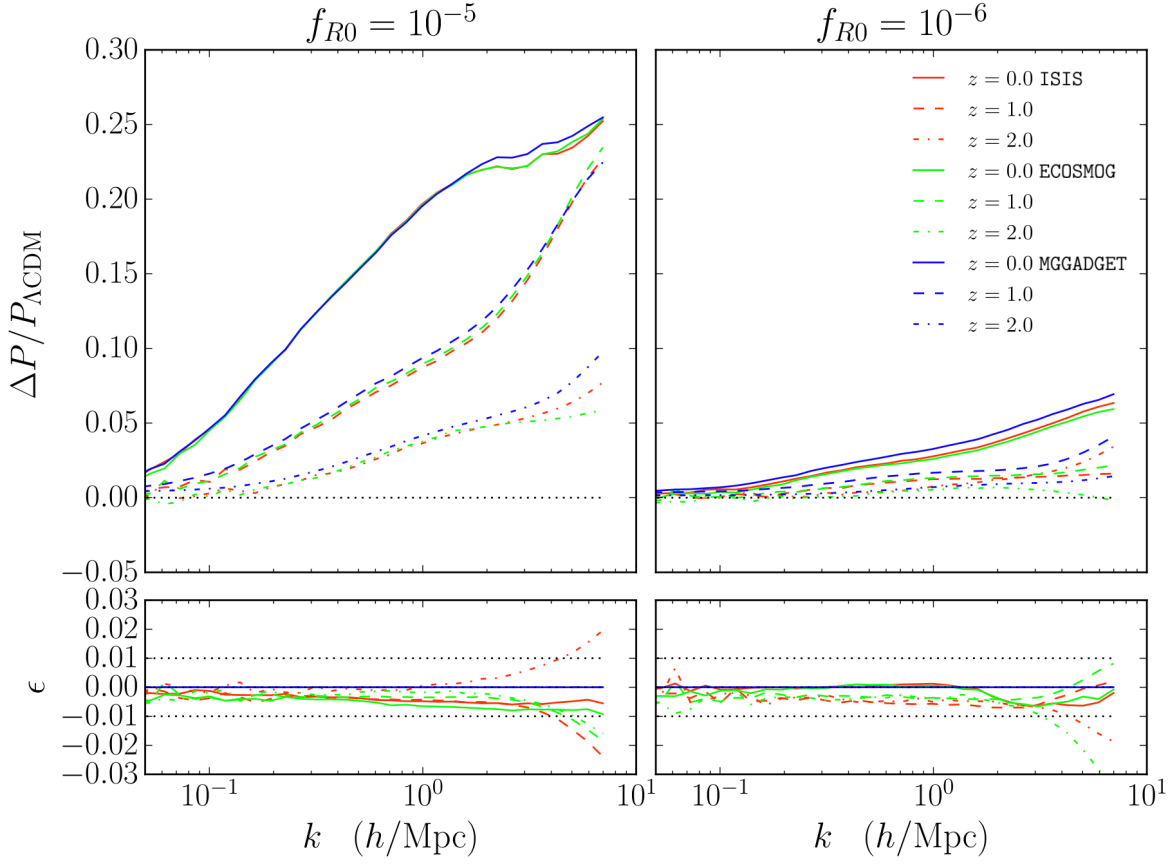
Challenges in numerical simulations

Code comparison



Schneider et al. 2016

Modified gravity theories

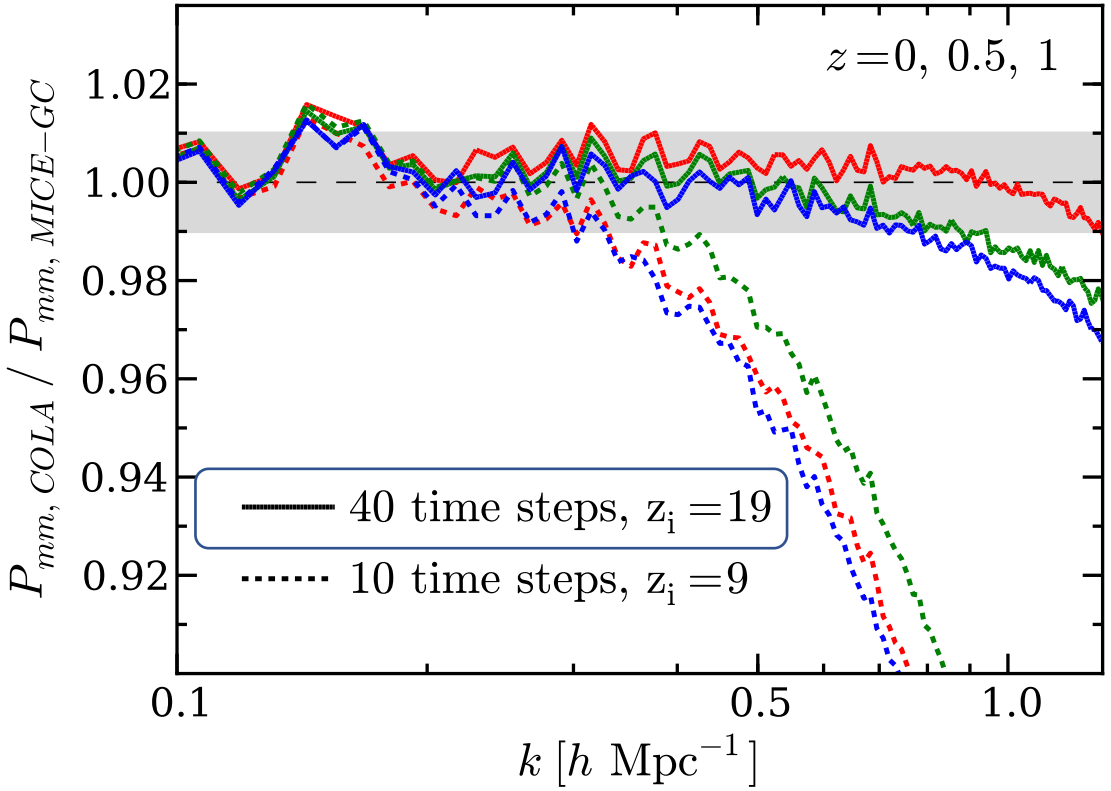


Whinther et al. 2015

+ neutrinos
+ baryonic effects
+ …

We want cheaper simulations!

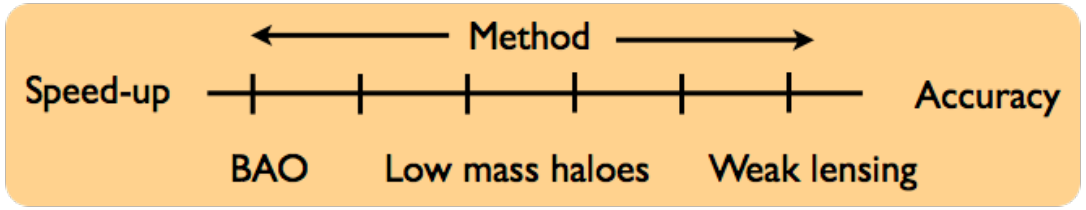
Matter power spectrum



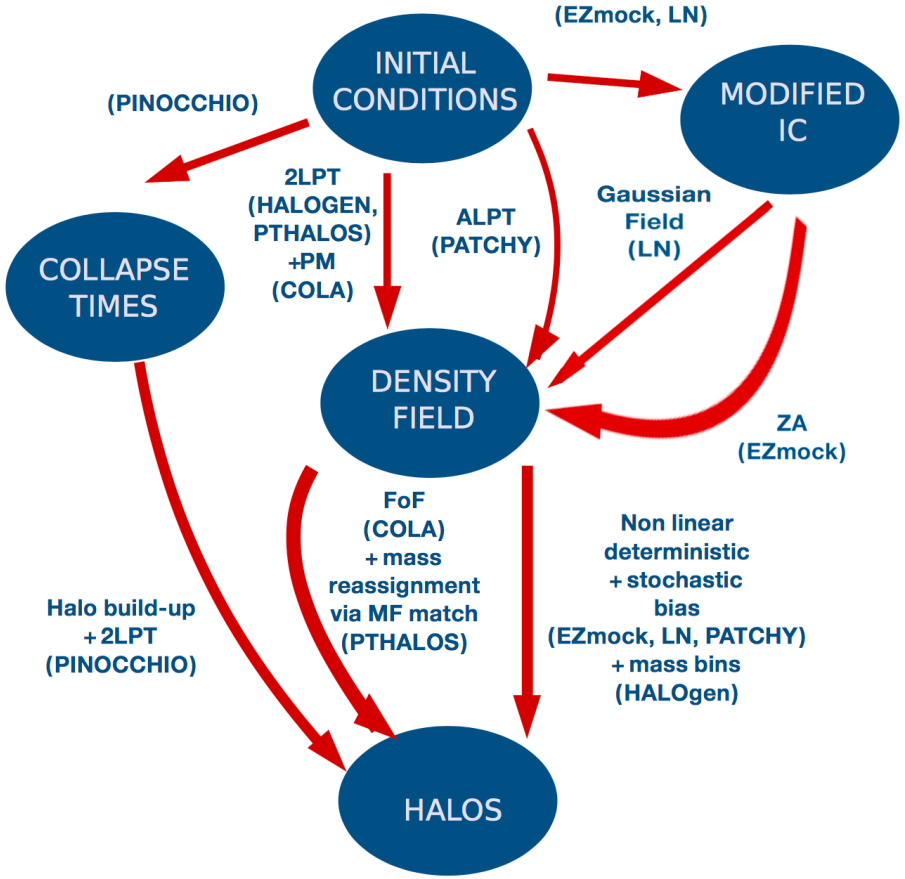
Izard et al. 2016

The sweet spot for approximate methods

- Avoid solving the most expensive part of a numerical simulation
- Run instead a cheap evolution of the density field
- Identify collapsed regions (dark matter halos)

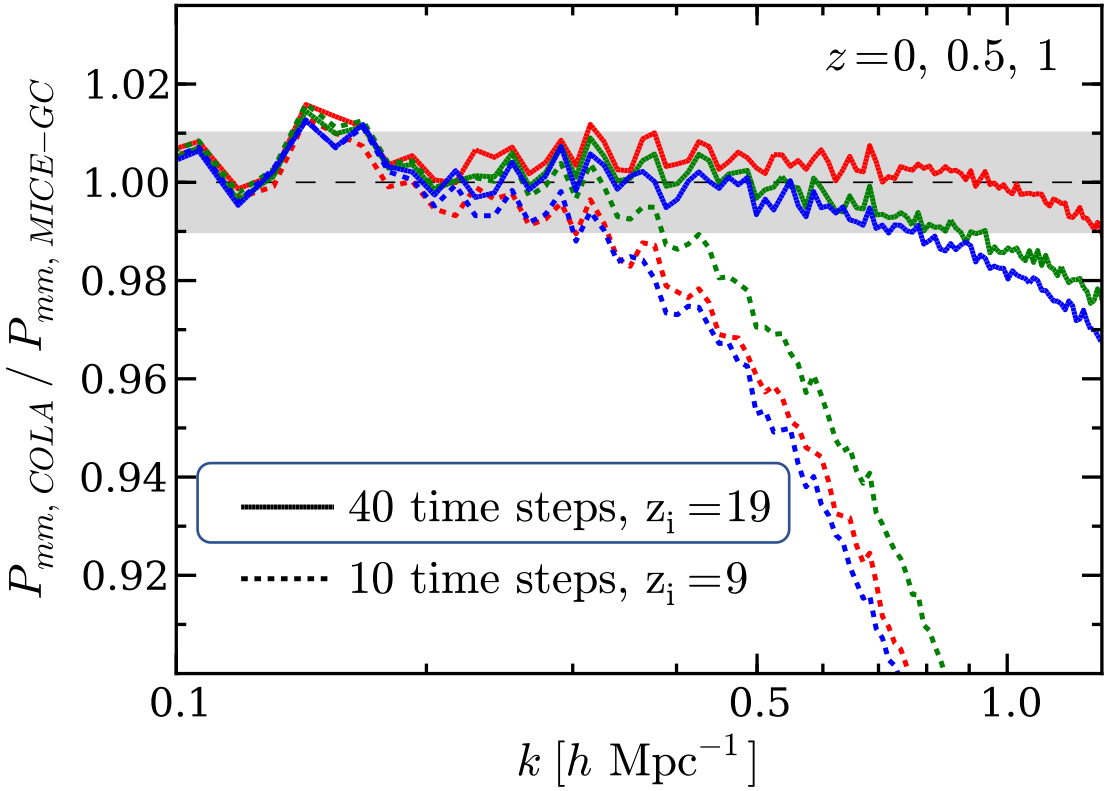


Log-normal
PTHalos
HALOgen
EZmocks
PATCHY
PeakPatch
PINOCCHIO
COLA (ICE-COLA)



Optimal set-up for weak lensing covariances

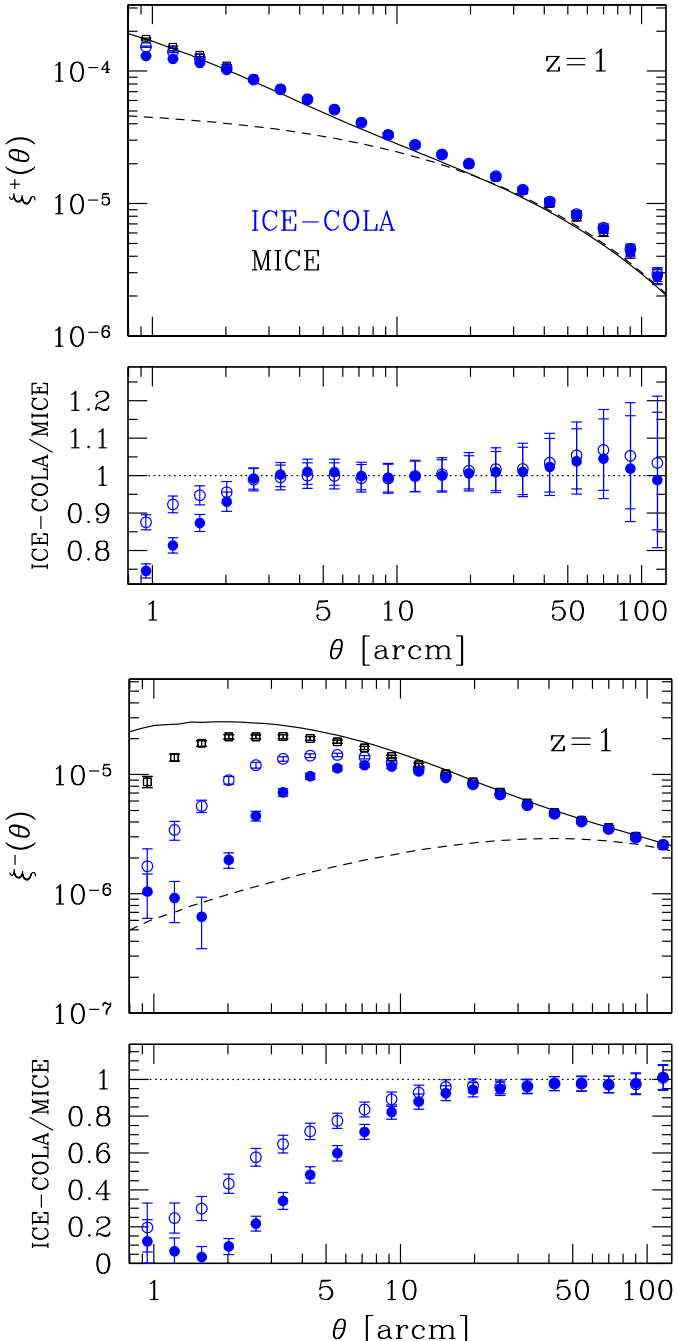
Matter power spectrum



Izard et al 2016

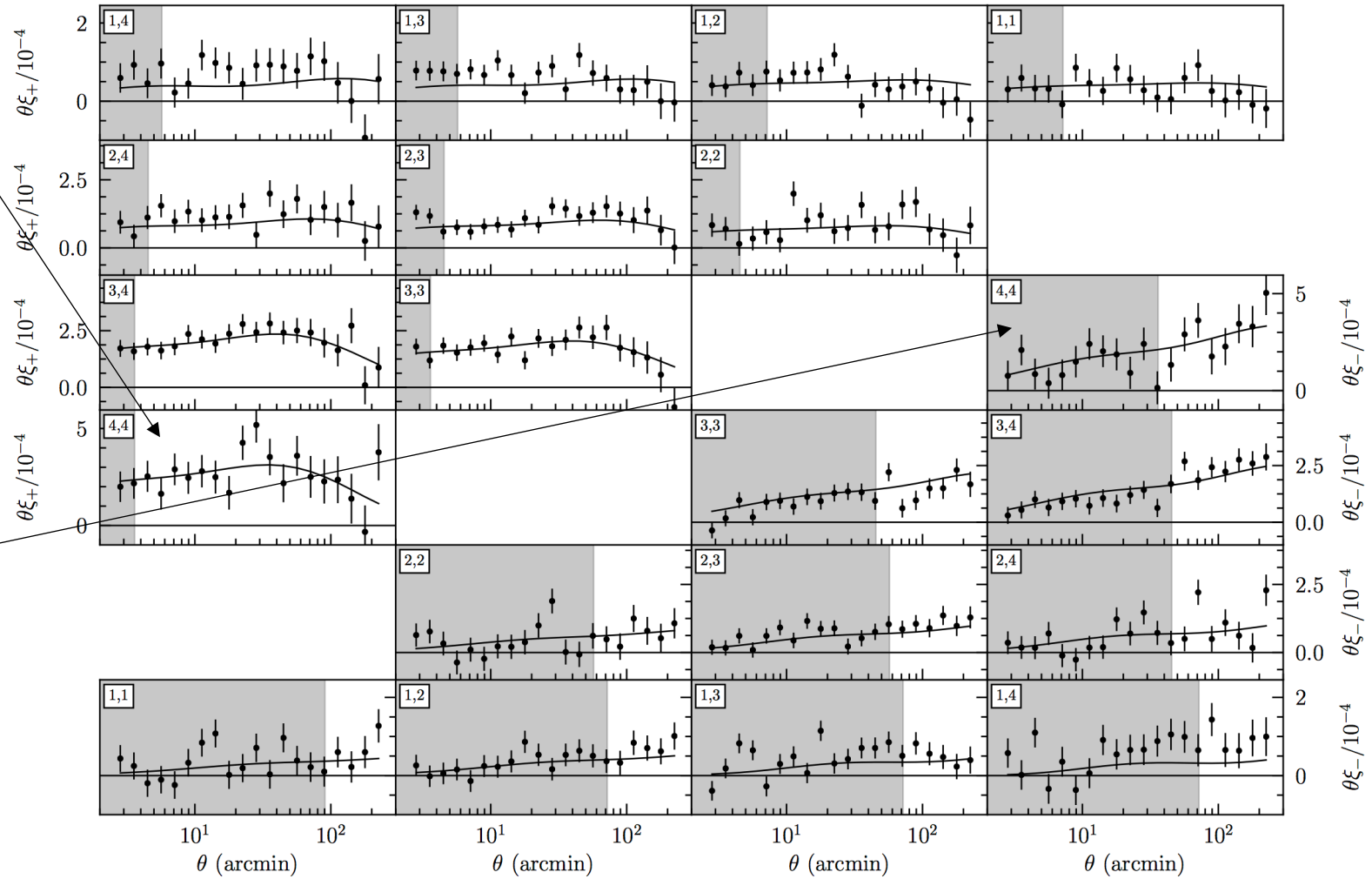
- 2048^3 particles run on 1024 cores in <1h (2.7 Tb memory)
- Matter power spectrum: 1% agreement up to k ~ 1 h/Mpc
- Mass function: 5% accuracy

Simulations



ICE-COLA provides enough accuracy to model current weak lensing experiments

Observations

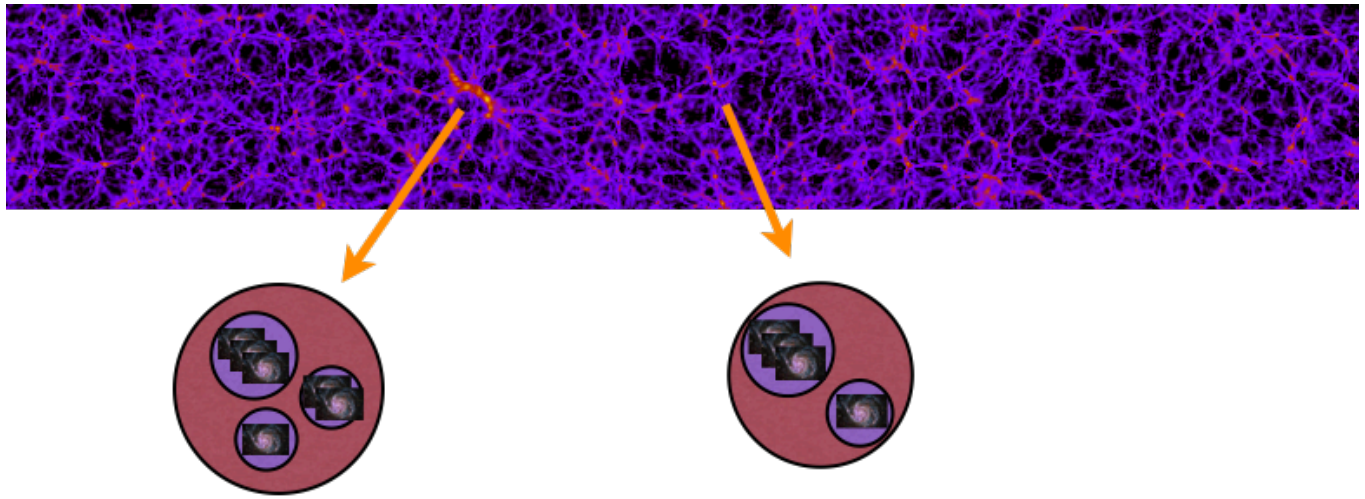


DES Y1 Results, Troxel et al 2017

Modeling the galaxy distribution

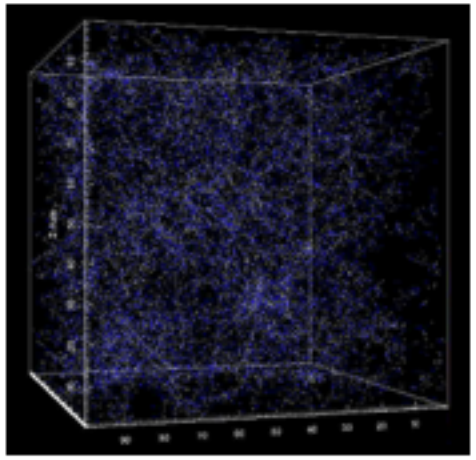
The dominant force on large enough scales is gravity

- Matter evolves and forms collapsed objects, halos.
- Filaments form bridges connecting them
- Galaxies are born in halos

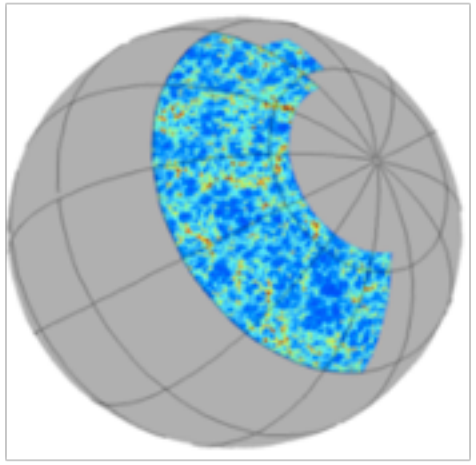


Efficient generation simulated galaxy catalogs

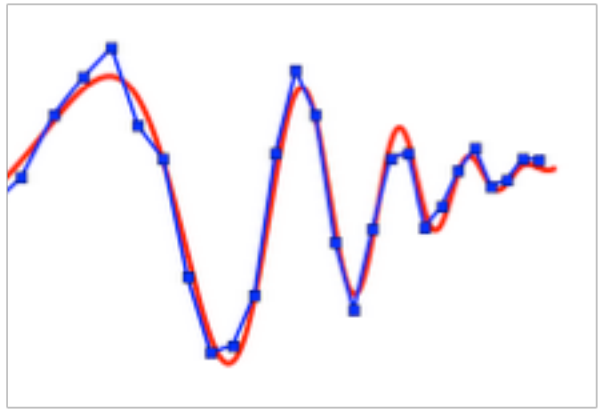
N-body simulation



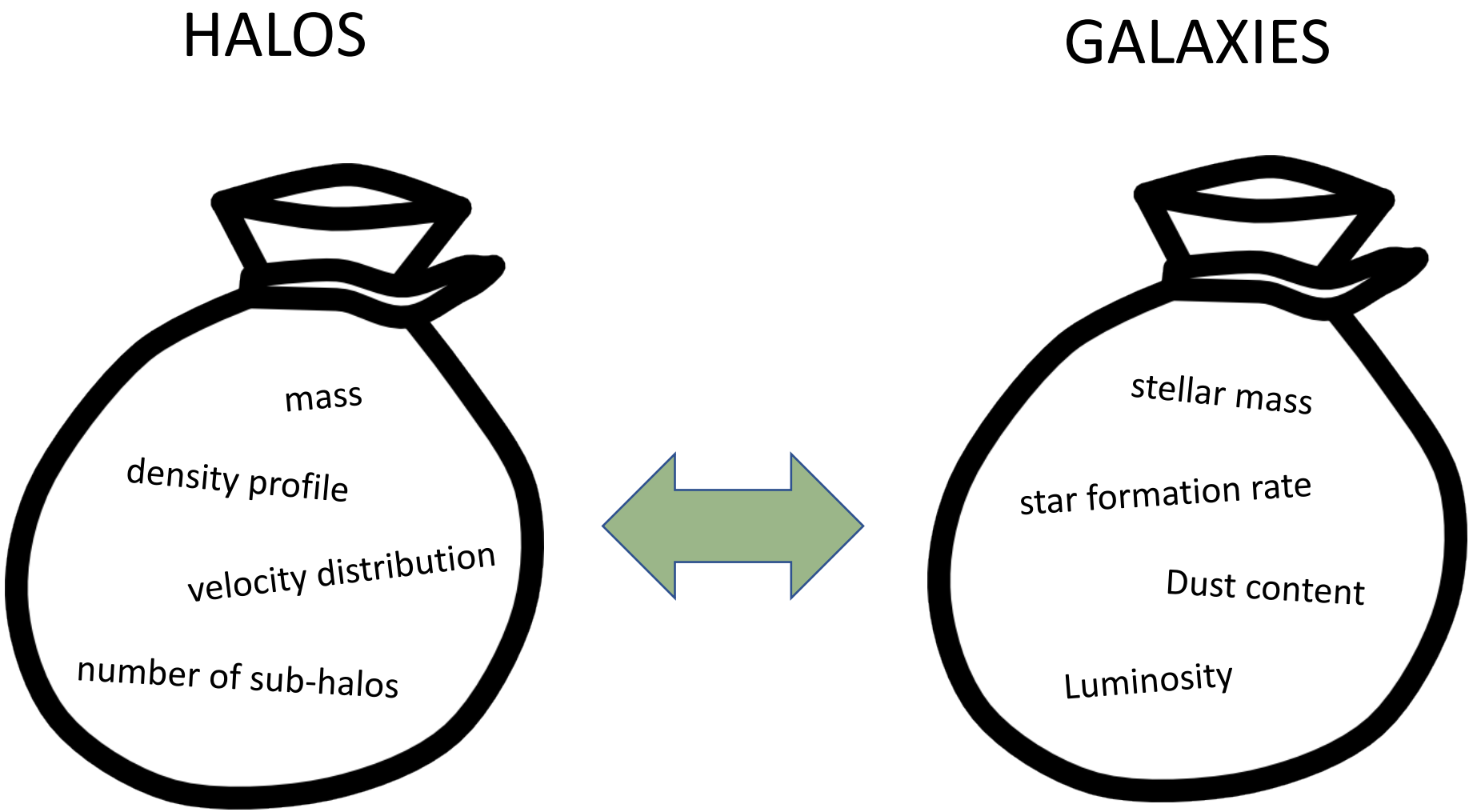
Realistic catalogues



Modelling observables

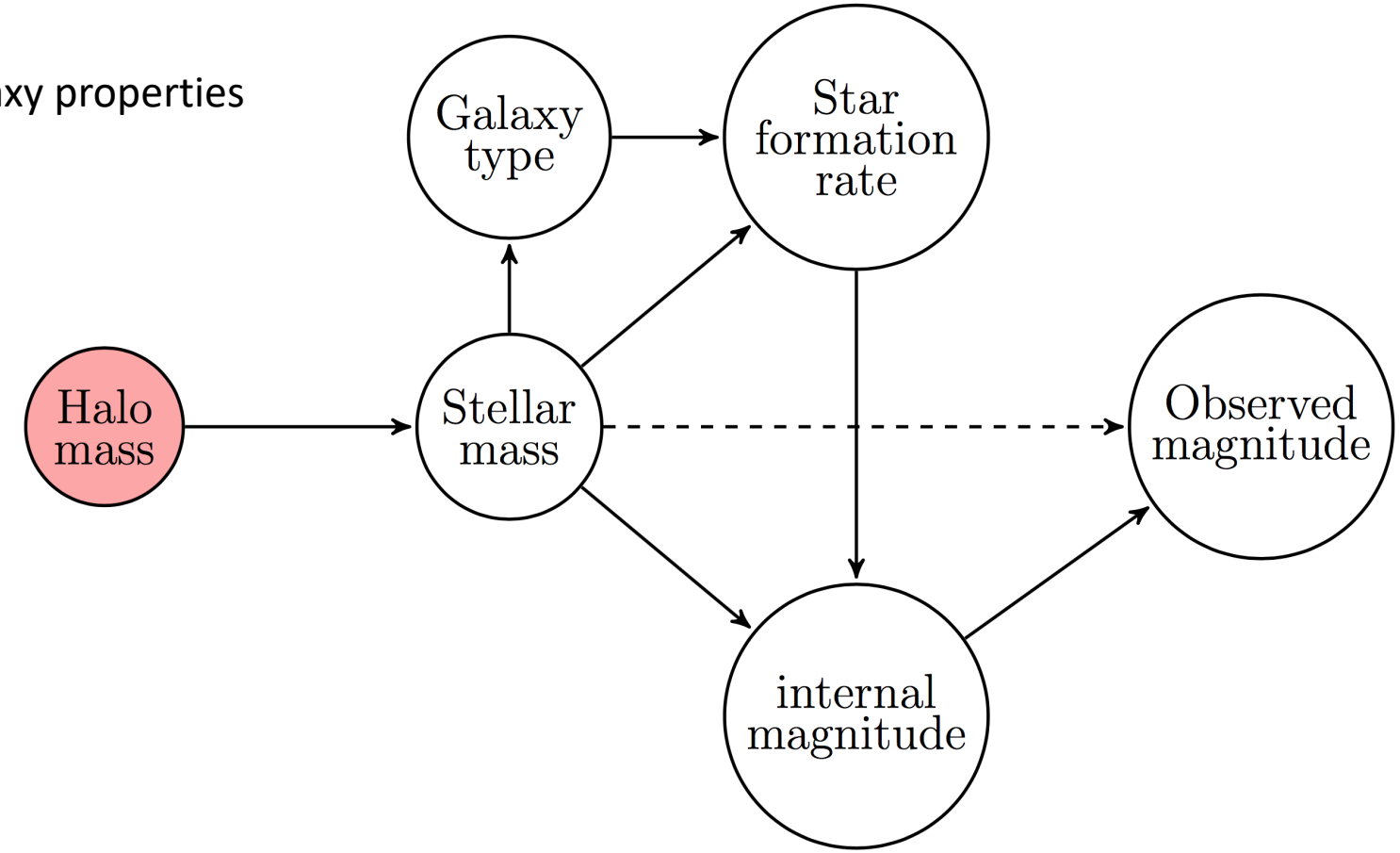


From halos to galaxies

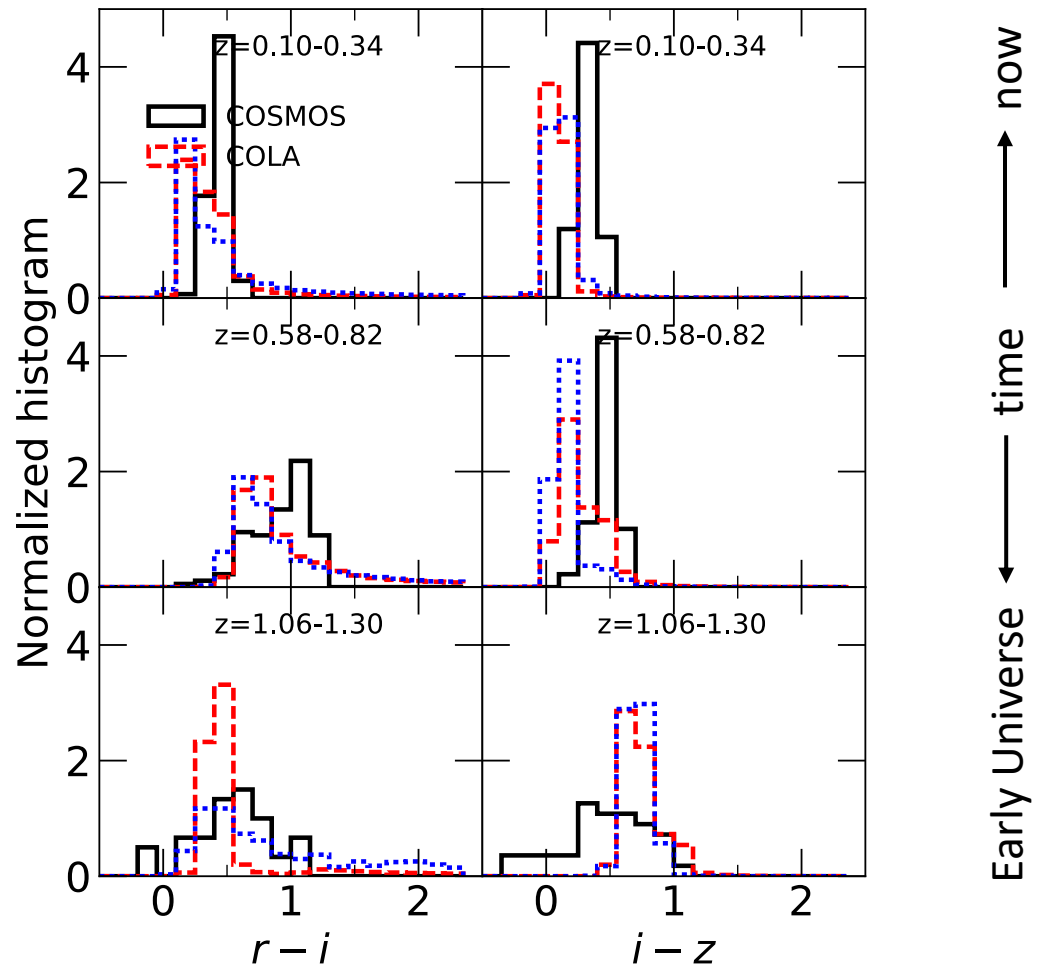


Galaxy model

Ghost software (Bull 2017):
Enables a fast modeling of galaxy properties



Galaxy colors in the simulated catalogs



now ← time ← Early Universe

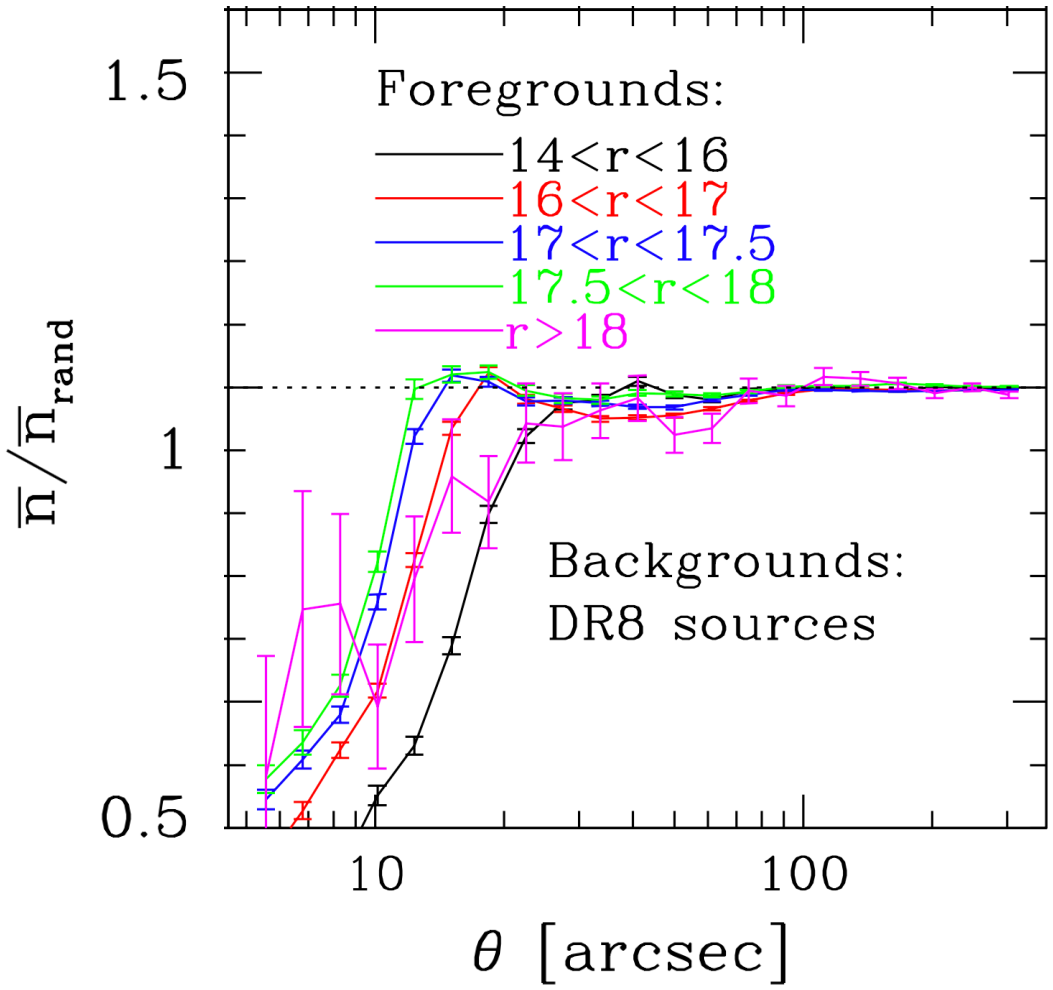
bluer ← color → redder

Observational systematics

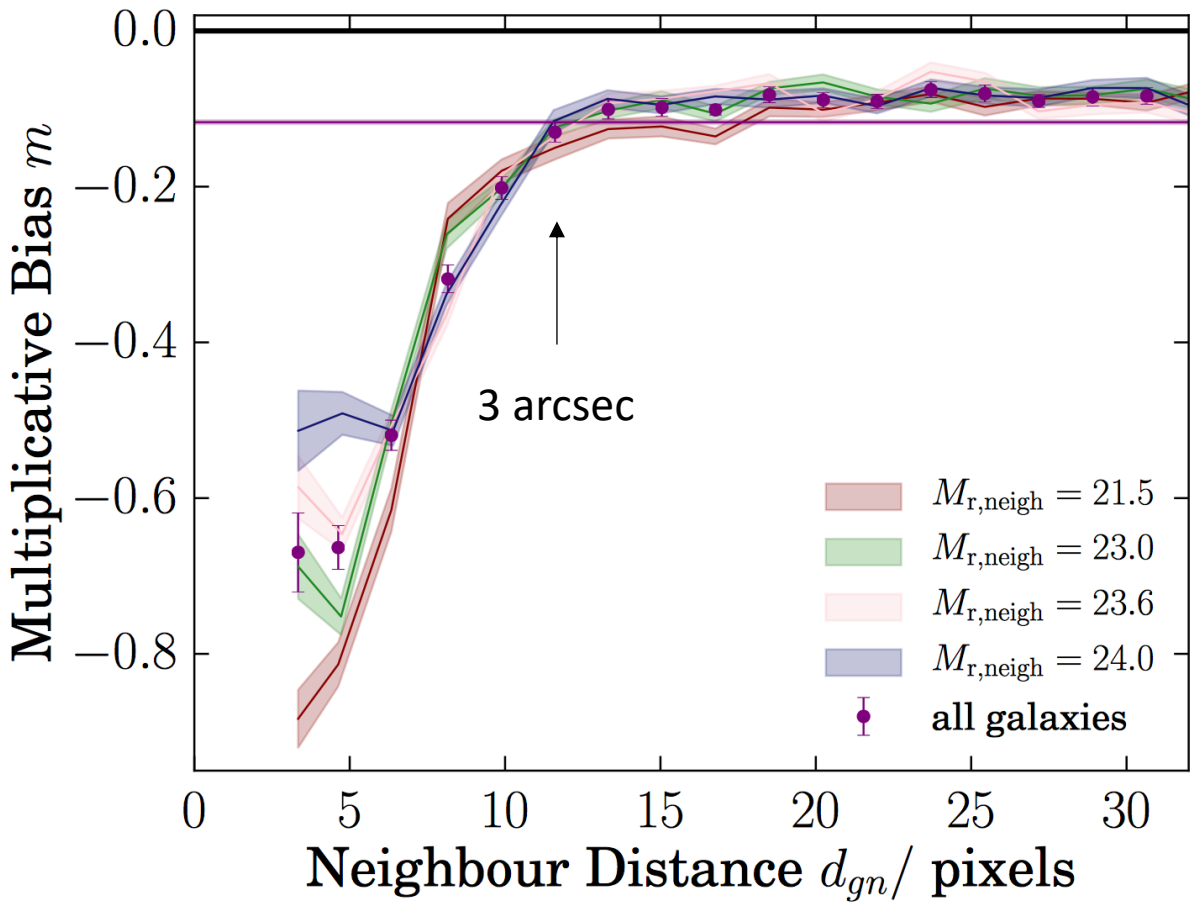
Credit: DECaLS, NOAO/AURA/NSF

Neighbor bias

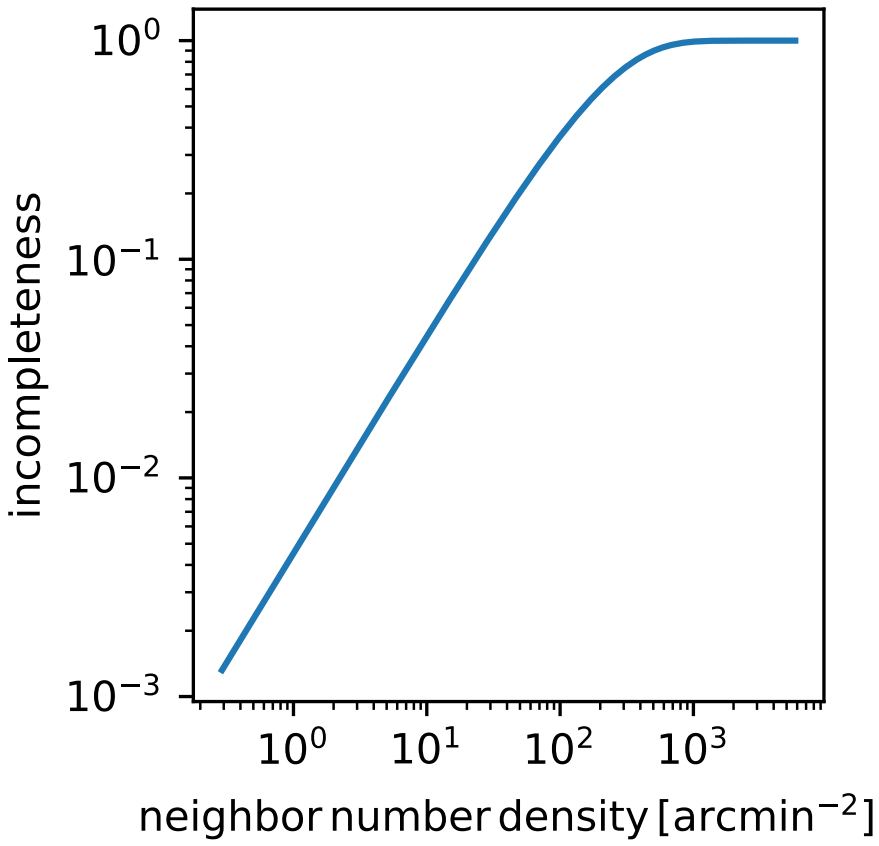
SDSS DR8, Aihara et al. 2011

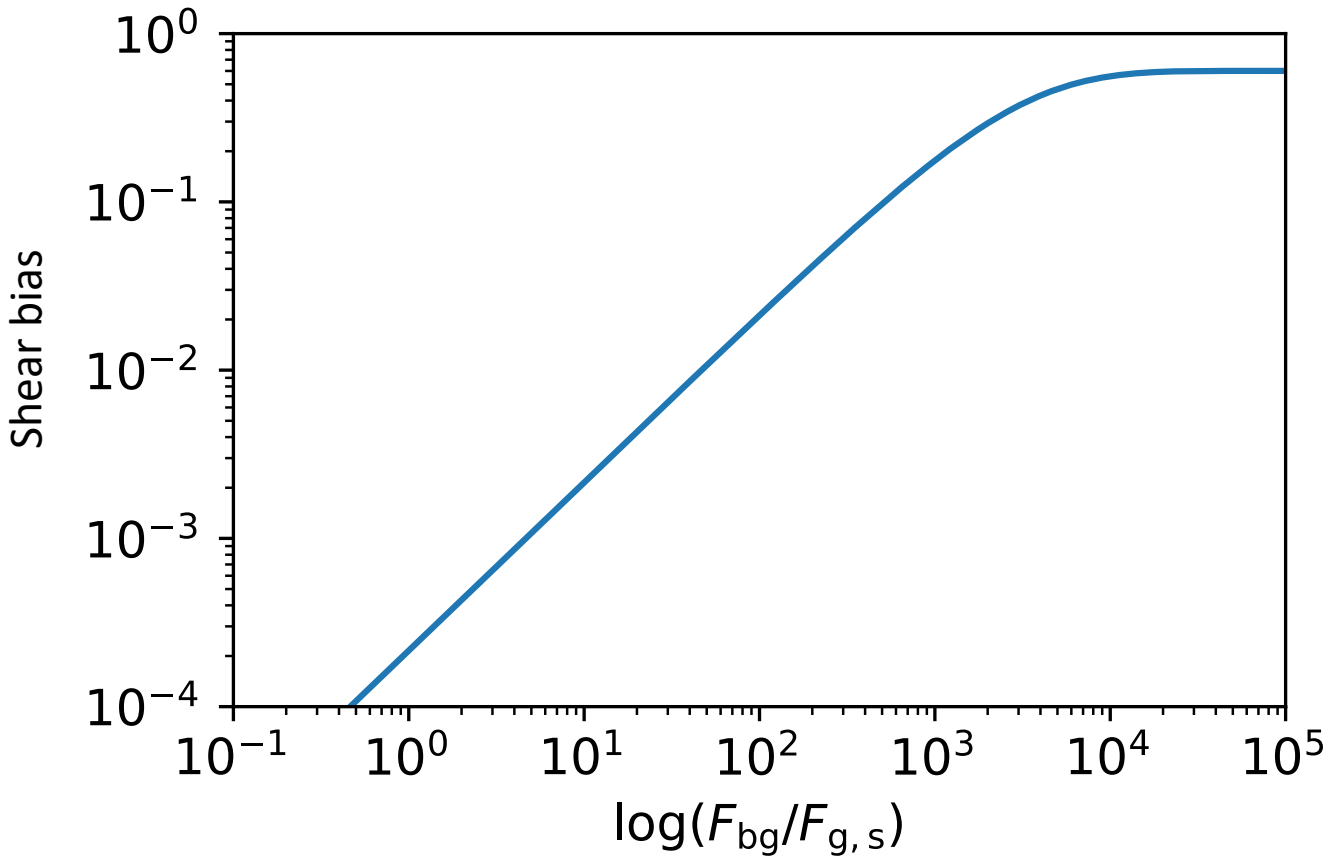


DES Y1 (IM3SHAPE), Samuroff et al. 2018

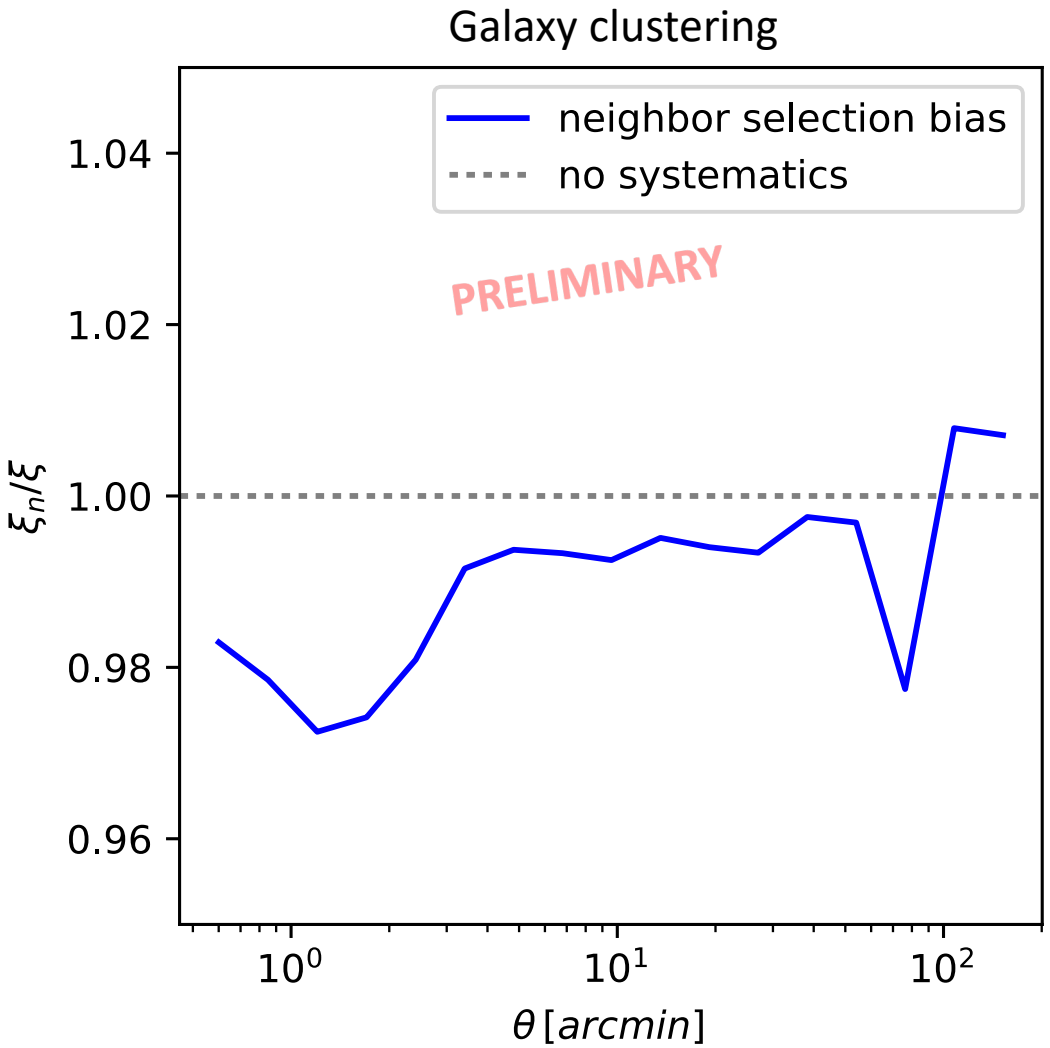


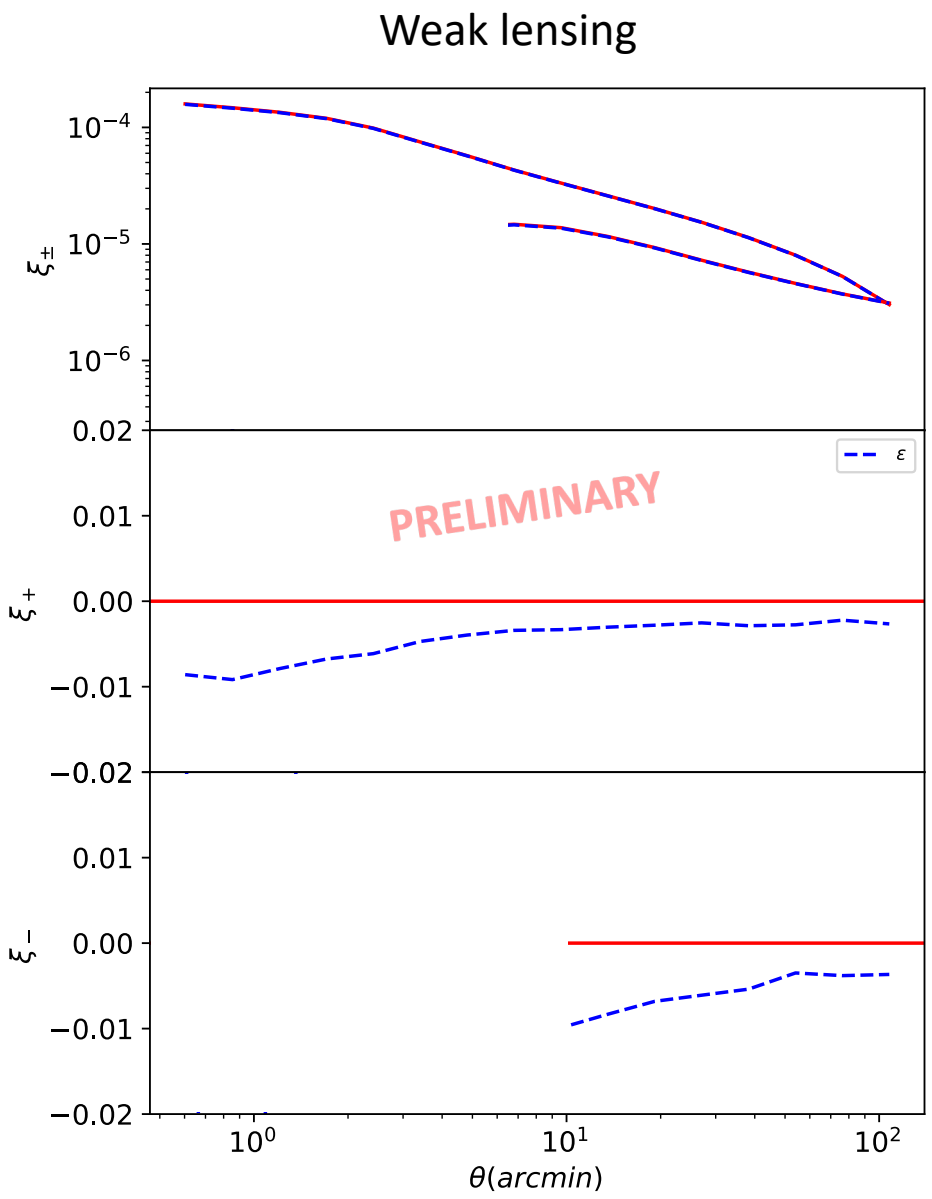
Model for the neighbor bias





Impact on observables





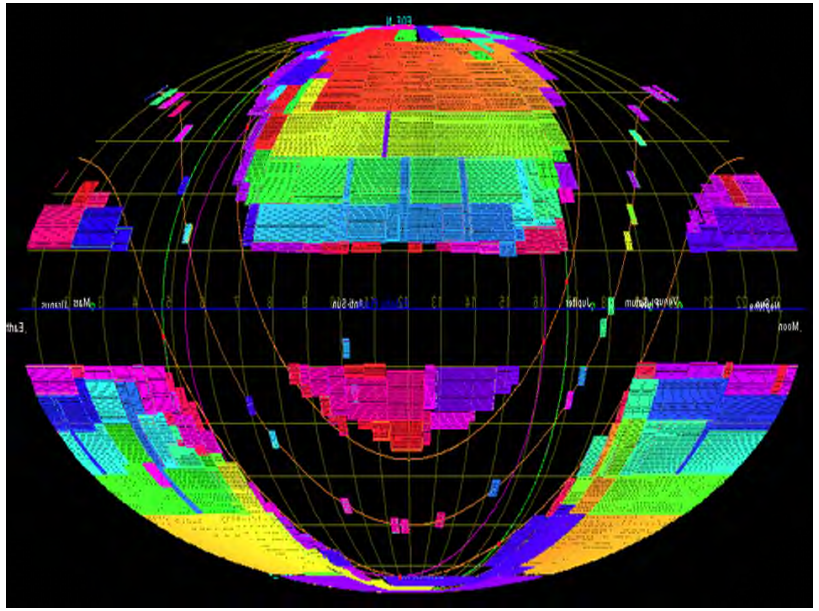
Thanks!

Backup slides

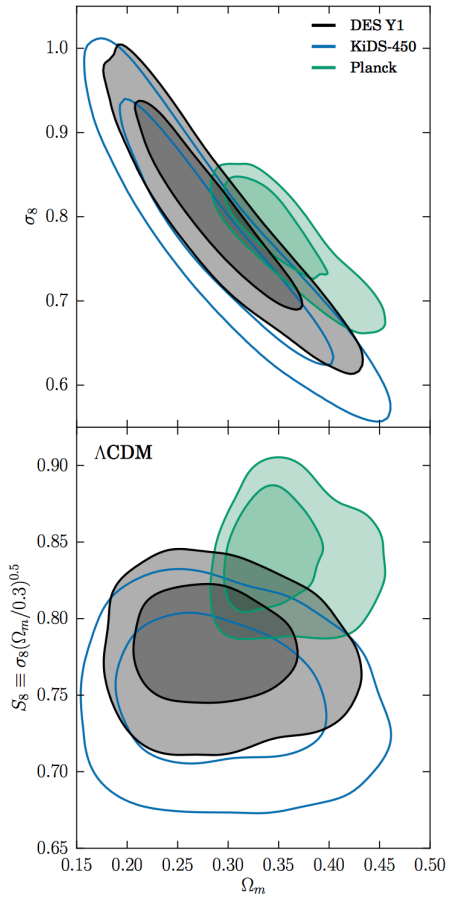
Modeling systematic effects on WL

- **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)



DES Y1 Results, Troxel et al 2017