Cosmic Shear Simulations for Higher-Order Statistics

Juan Mena-Fernández[1]

On behalf of the HOS topical team of DESC

[1]Laboratoire de Physique Subatomique et de Cosmologie (LPSC)

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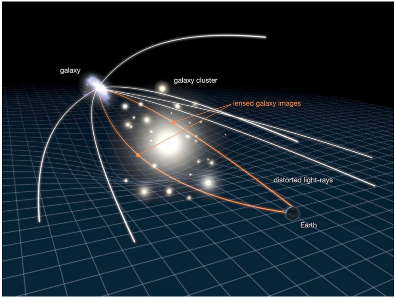
Outline

1. Weak lensing and HOS
2. Construction of the lightcones
3. Tests
4. Conclusions

Weak gravitational lensing

Weak gravitational lensing **distorts the images of background objects** due to the presence of a foreground matter distribution.



Credits: NASA/ESA

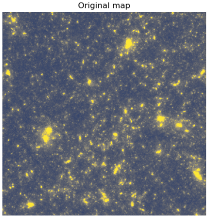
Three lensing regimes:

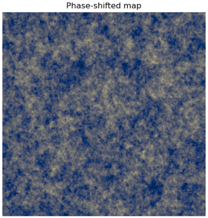
- Cluster lensing. The foreground object is a cluster. Distortions of $\sim$10%.
- Galaxy-galaxy lensing. The foreground object is a galaxy. Distortions of $\sim$1%.
- **Cosmic shear**. Caused by **large-scale structure (LSS)**. Distortions of $\sim$0.1-1%.

Cosmic shear is traditionally analyzed using two-point functions...

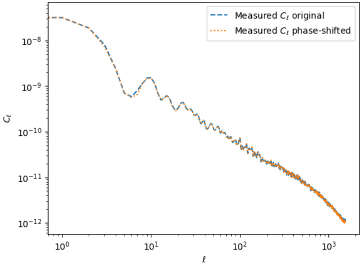
Why higher-order statistics?

1. Two-point functions do not give us information about non-Gaussian features.





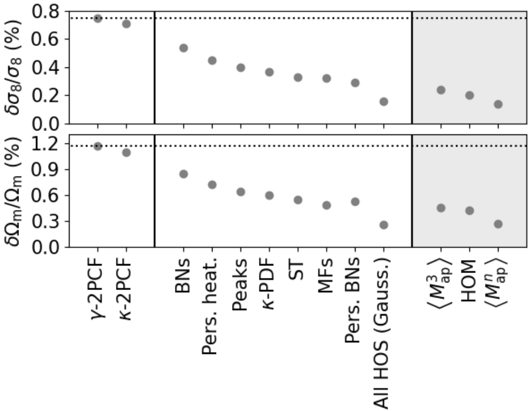
$\longrightarrow$



Different structures but same C_ℓ!

Why higher-order statistics?

2. Two-point functions + HOS = better constraints on cosmological parameters.



Credits: *Euclid* preparation XXVIII - A&A 675, A120 (2023)

Motivation and context

- HOS are a **powerful tool for cosmology**.
- However, they usually lack theoretical predictions.
- Therefore, **we rely on simulations**, which are computationally expensive.
- When generating simulations, we need to **optimize their accuracy vs computing resources** (charged node hours + storage) as a function of
  - volume.
  - mass resolution (mass/particle).
  - number of redshift snapshots.

Goal: optimize the generation of upcoming **lensing and clustering** simulations needed for the **analysis of LSST Y1 data with HOS**.

DESC project: [282] Simulations for Higher-Order-Statistics
https://portal.lsstdesc.org/DESCPub/app/PB/show_project?pid=282

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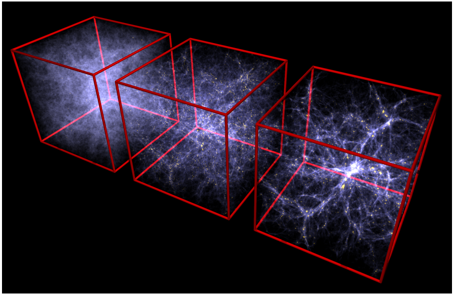
HACC simulations

We construct our lightcones from ***N*-body dark matter (DM) box simulations** produced with the Hybrid Accelerated Cosmology Code (HACC).

- Boxes are evolved from redshift 200 to 0.
- A total of **101 snapshots are stored**, from redshift 4 to 0 (linear spacing in a).

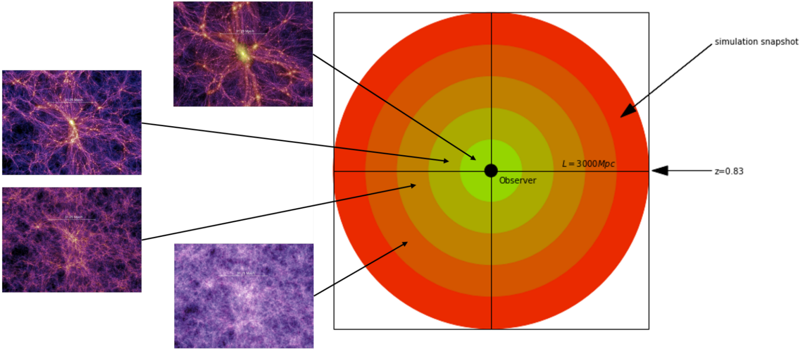
By default:

- Number of DM particles: $N_p = 2048^3$.
- Length of the box: $L = 600$ Mpc$/h$.



Credits: V. Springel - MPA-Garching Data Visualization

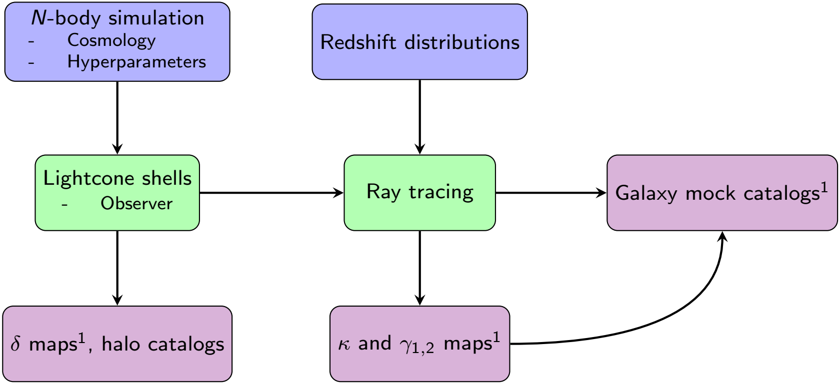
From HACC to lightcones



Credits: R. Booth (2024)

↑ # snapshots ↔ ↑ info about z evolution ✓ ↔ ↑ expensive and ↑ storage ⚠

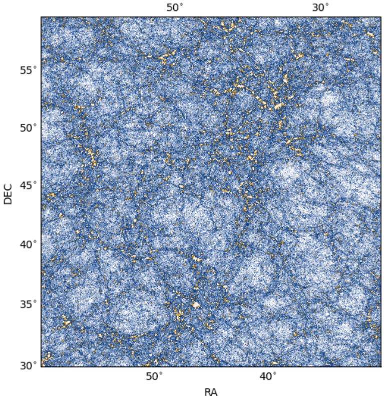
Pipeline flowchart



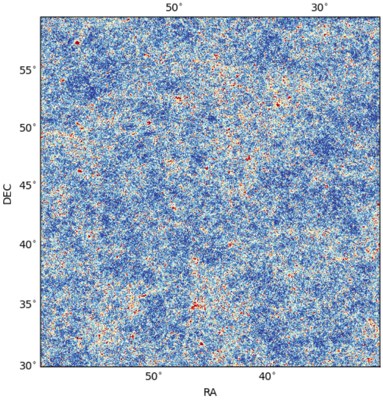
Code: `pollux` (https://github.com/LSSTDESC/pollux.git)

[1]We can measure HOS from these

Example: δ and κ maps



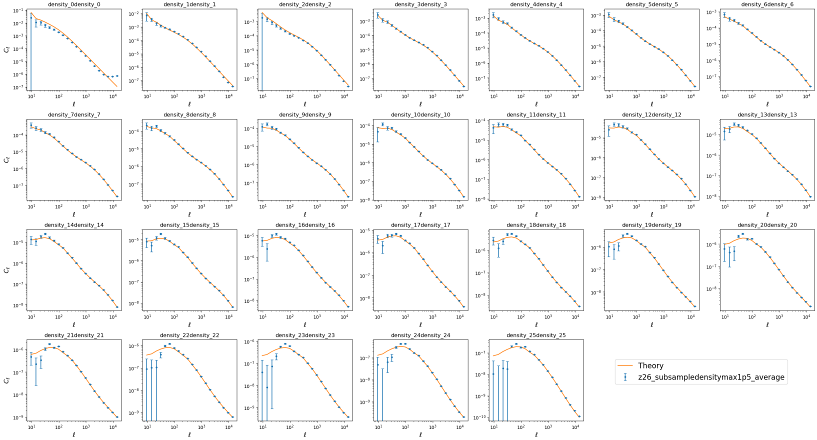
Example: δ map.



Example: κ map.

Example: C_ℓ of the δ maps

- `nshells` $= 26$.



Outline

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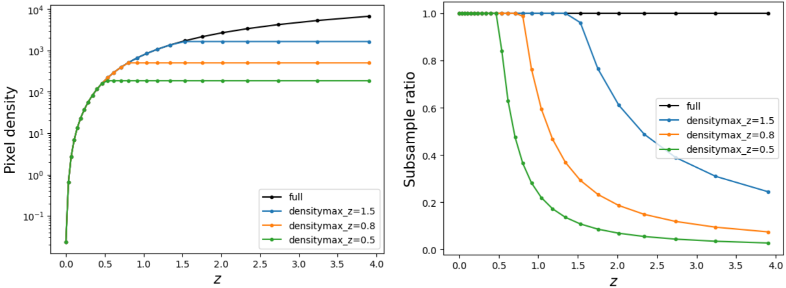
Test 1: downsampling at high z

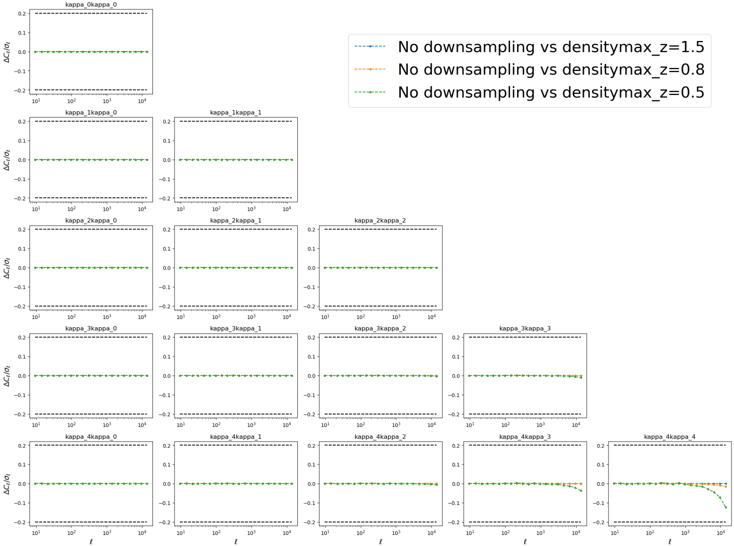
- Using all DM particles is computationally expensive, especially at high z.
- We downsample fixing the projected number density from z = densitymax_z.
- Three cases tested: densitymax_z = $\{1.5, 0.8, 0.5\}$.



But... how does this impact our measurements?

Test 1: downsampling at high z

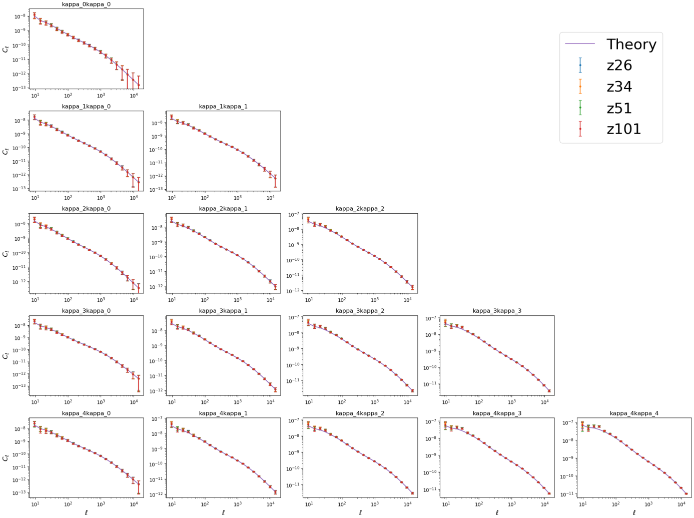
- Three cases tested: densitymax_z $= \{1.5, 0.8, 0.5\}$.



Outline

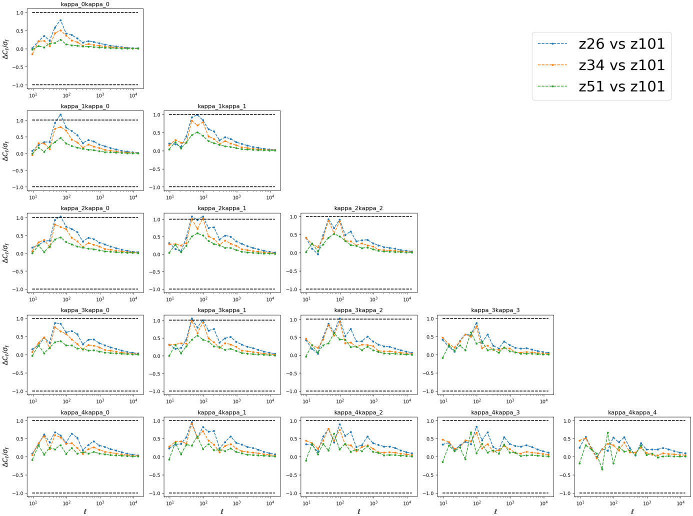
Test 2: number of snapshots

- We construct the lightcones using 101 (all), 51, 34 and 26 snapshots.



Test 2: number of snapshots

- We construct the lightcones using 101 (all), 51, 34 and 26 snapshots.



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Conclusions

Goal: optimize the generation of upcoming **lensing and clustering** simulations needed for the **analysis of LSST Y1 data with HOS**.

- Tests
  - downsampling at high z: we set `densitymax_z` $= 1.5$ as our default.
  - number of shells.
- Related ongoing and upcoming projects:
  - development of `pollux` (C. Doux).
  - halo-occupation distribution (HOD) models (A. Halder).
  - baryonification of the dark matter shells (A. Vera).
  - systematic effects (A. Nicola).
- Next steps:
  - validate the mock catalogs (J. Harnois-Deraps).
  - measure different HOS (J. Armijo).
  - vary the volume and mass resolution (K. Heitmann).
- Example notebook to load the data:

https://github.com/LSSTDESC/pollux/blob/main/pollux_io_tutorial.ipynb

Thank You!