The accuracy of WL simulations

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arXiv:1910.10625

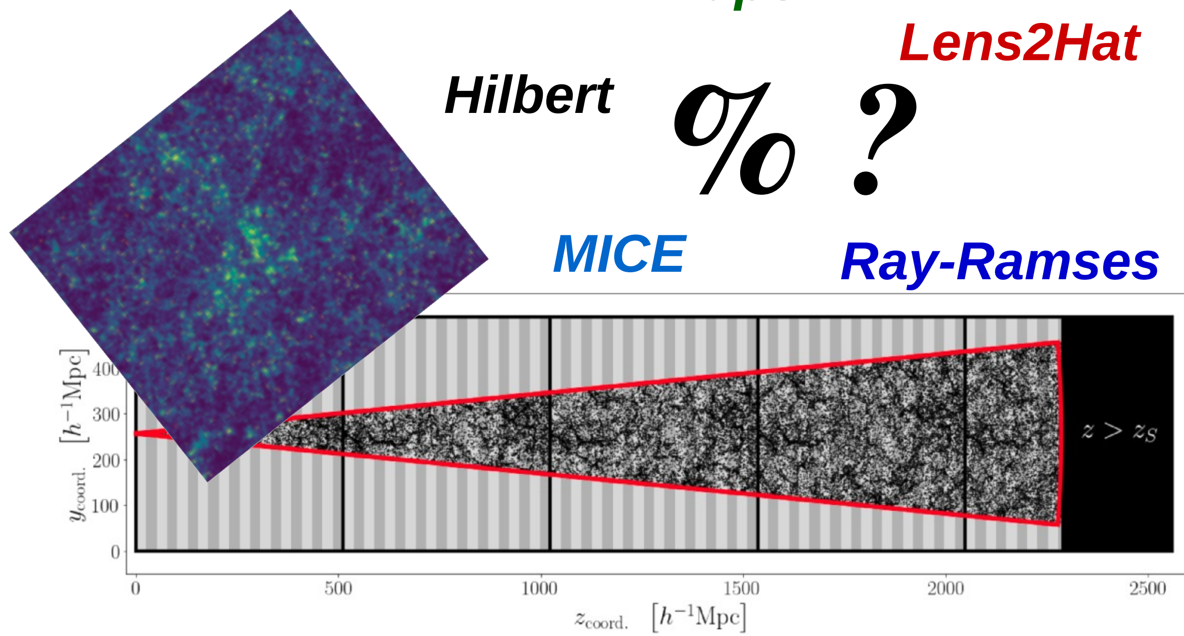
MapSim

Lens2Hat

Hilbert % ?

MICE

Ray-Ramses



GCCL seminar – January 2020

Motivation

Result confirmation and reproducibility are key to the scientific method!

Main objective

Investigate the current level of **accuracy of weak lensing simulations** by comparing the results of different lensing simulation codes ran on the same output of a N-body simulation of cosmic structure formation.

This adds to a large number of existing code comparison projects in the literature:

→ N-body simulations (Schneider+ 2016 (GR), Winther+2015 (MG))
→ Galaxy formation (Scannapieco+ 2012)
→ Structure identification (Knebe+2011, Onions+2012,Knebe+2013, Colberg+2008, Elahi+2013)
→ Halo merger trees/mock catalogues (Srisawat+2013, Chuang+2015)
→ ...

Comparison projects are crucial to identify and mitigate systematics in the theoretical predictions!

Main features of the codes

Name	HILBERT	LENS^{2}HAT	MAPSIM	MICE	RAY-RAMSES
Code paper	Hilbert et al. (2009)	Fabbian et al. (2018)	Giocoli et al. (2015)	Fosalba et al. (2008)	Barreira et al. (2016)
Code type	Post-process (multiple plane)	Post-process (multiple sphere)	Post-process (multiple plane)	Post-process (multiple sphere)	On the fly
LOS projection	‖ to central LOS	Radial	Radial	Radial	Radial
LOS resolution	Particle outputs	Particle outputs	Particle outputs	Particle outputs	RAMSES time steps
Ray grid scheme	Regular grid	HEALPIX[6]	Regular grid	HEALPIX	Regular grid
Full-sky maps	w/ development	✓	w/ development	✓	w/ development
Beyond-Born	✓	✓	w/ development	w/ development	w/ development

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Beyond-Born	✓	✓	w/ development	w/ development	w/ development

Main features of the codes

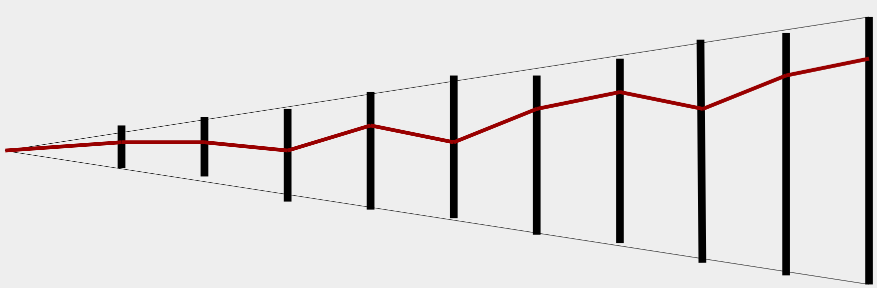
Post-process

- N-body snapshots are tiled up along the LOS and discrete density lens planes constructed.
- Backward ray-trace: the total lensing signal is the contribution from each lens plane.

Pros: Flexible to changes in lightcone specs. (source redshift, observer orientation, etc.)

Cons: Resolution along LOS set by number of particle snapshots.

Hilbert, LenS2Hat, MapSim, MICE



On the fly

- Lensing signal is accumulated at every time step of the N-body simulation by integrating the appropriate 2nd derivatives of the lensing potential.

Pros: Uses all of the time-resolution available in the simulation.

Cons: unflexible to certain changes in lightcone specs (a new simulation might be needed).

Ray-Ramses

$$\kappa_{\rm ts} = \frac{1}{c^2}\sum_{\rm cells}\int_{\chi_{\rm d}^{\rm cell,end}}^{\chi_{\rm d}^{\rm cell,start}} {\rm d}\chi_{\rm d}\,\frac{f_{\rm d} f_{\rm ds}}{f_{\rm s}}\nabla^2_{\rm 2D}\Phi$$

E.g. lensing convergence due to a ray crossing an AMR cells in Ray-Ramses

Main features of the codes

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Planes vs. Spheres

MICE and LenS2HAT construct by default full-sky maps by projecting matter onto concentric spheres around the observer.

Hilbert and MapSim project density field onto planes perpendicular to the central LOS.

Main features of the codes

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Beyond-Born	✓	✓	w/ development	w/ development	w/ development

LOS projection

Hilbert first projects the matter onto lens planes in a manner parallel to the central LOS of the FOV; then rays are traced in radial directions.

Main features of the codes

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Ray grid scheme

LenS2Hat and **MICE**'s construction of full-sky maps makes HEALPix grids more appropriate.

Main features of the codes

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Full-sk					t
Beyon					

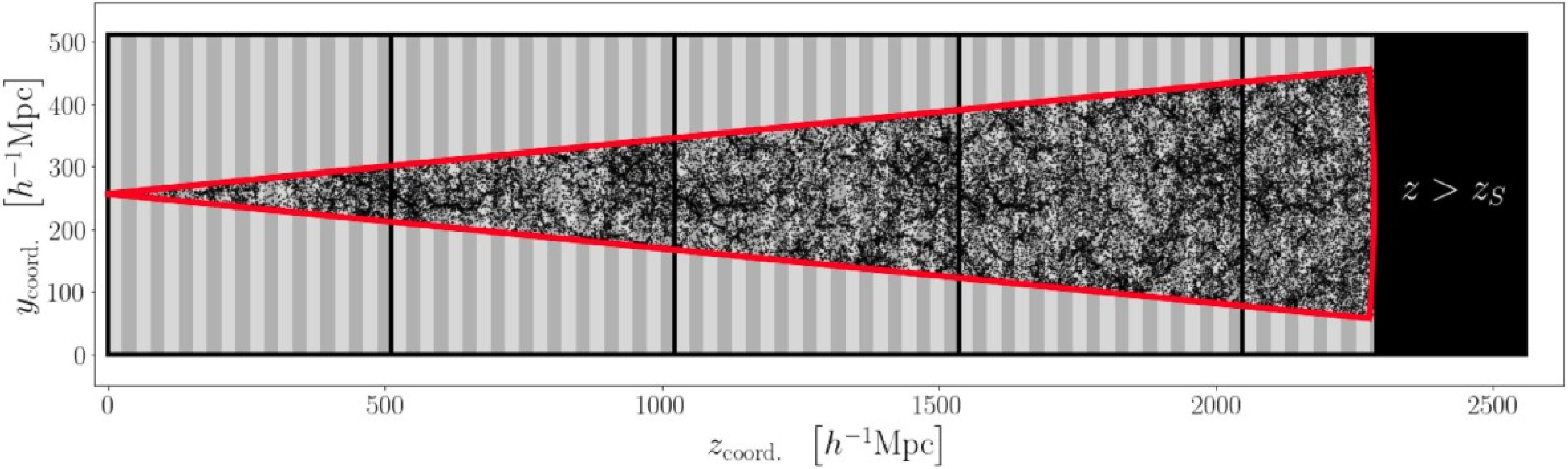
<u>To keep in mind</u>

The exact envisioned application determines which code is better suited.

<u>Key to us here:</u> current codes differ in the implementation of a number of potentially important sources of systematics.

What is the importance of these differences?

N-body simulation and lightcone setup



- Planck-like LCDM cosmology;
- Np = 512^3, Lbox = 512Mpc/h;
- Ray-Ramses produced the snapshots given to other codes;
- Single source redshift z = 1;
- Field of view 10x10 deg^2 ;
- 90 particle snapshots (every 25.6 Mpc/h);

Results

1) Lensing convergence maps

2) PDFs

3) Power Spectrum

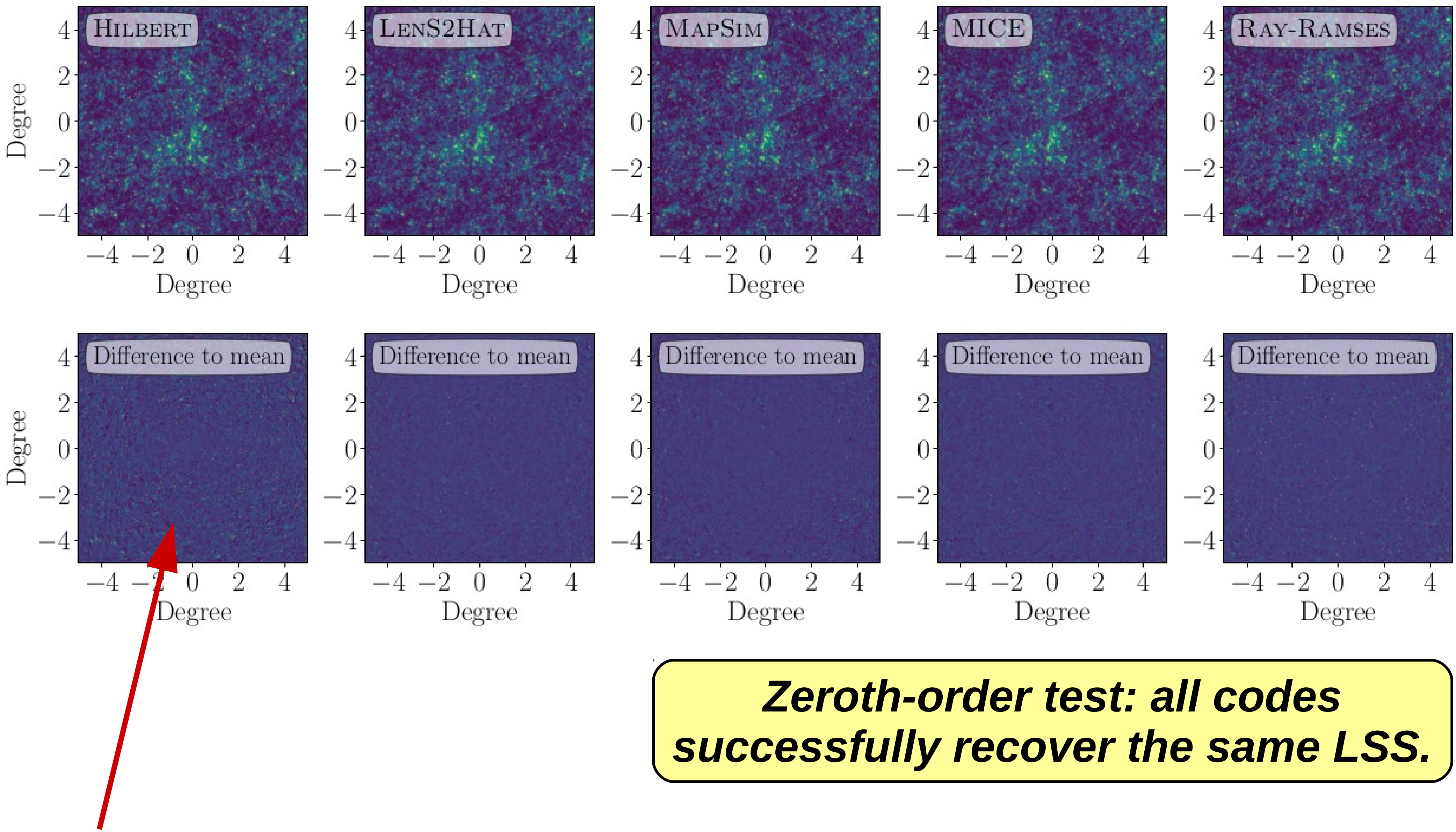
4) Peak counts

5) Shear vs. Convergence

6) LOS resolution

7) Born approximation

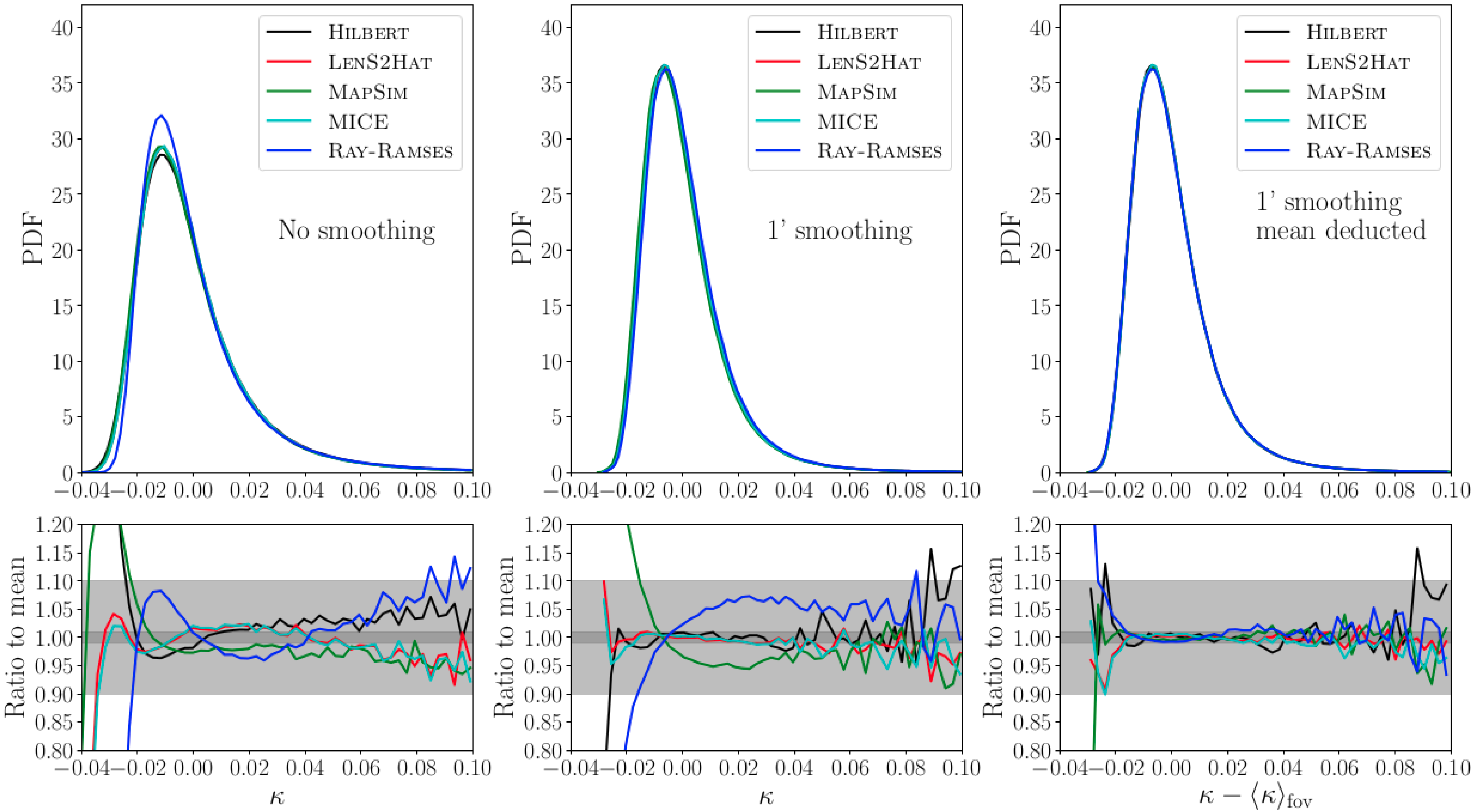
Lensing convergence maps



Zeroth-order test: all codes successfully recover the same LSS.

Small, yet noticeable circular patterns in the **Hilbert** difference due to parallel projection of the density field in this code.

Prob. Distribution Functions

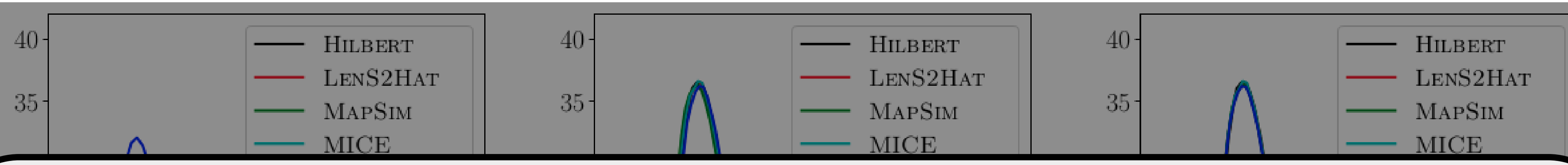


10-20% differences without smoothing

Smoothing improves agreement

Subtracting the mean gives 1% agreement

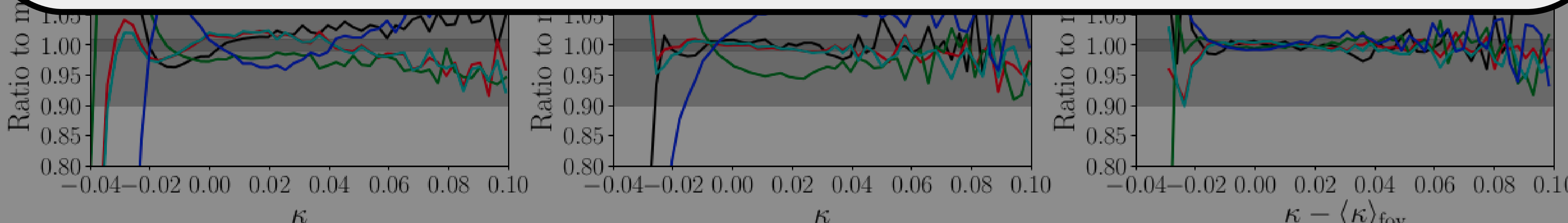
Prob. Distribution Functions



Take away on PDFs

1) Differences on PDFs reflect varying levels of effective smoothing by the codes (ray griding, interpolations, etc.) – difference goes away with a more aggressive smoothing.

2) Different mean convergence is a systematic that carries little consequence to observable quantities (mass sheet degeneracy, shear probes convergence differences.)



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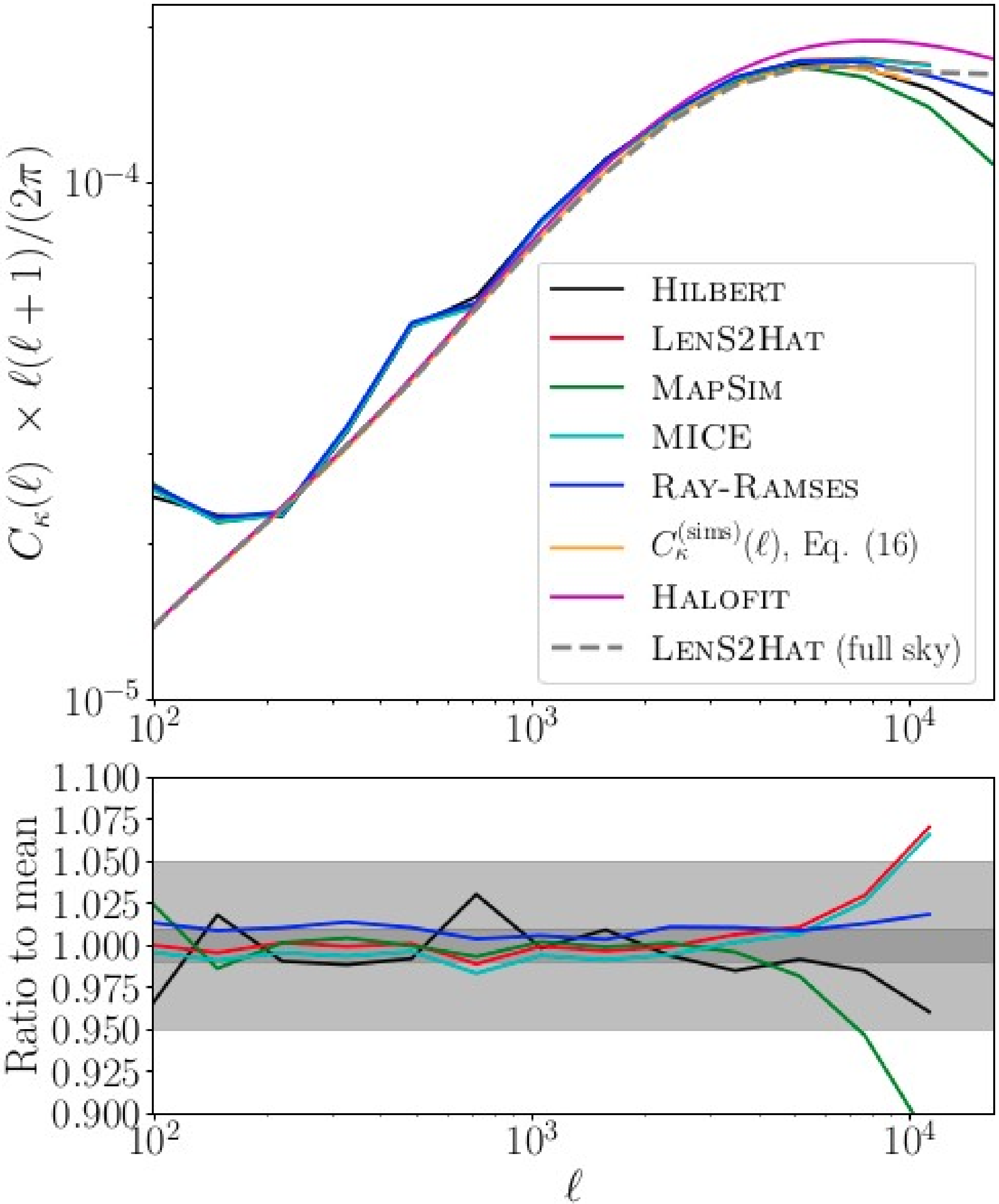
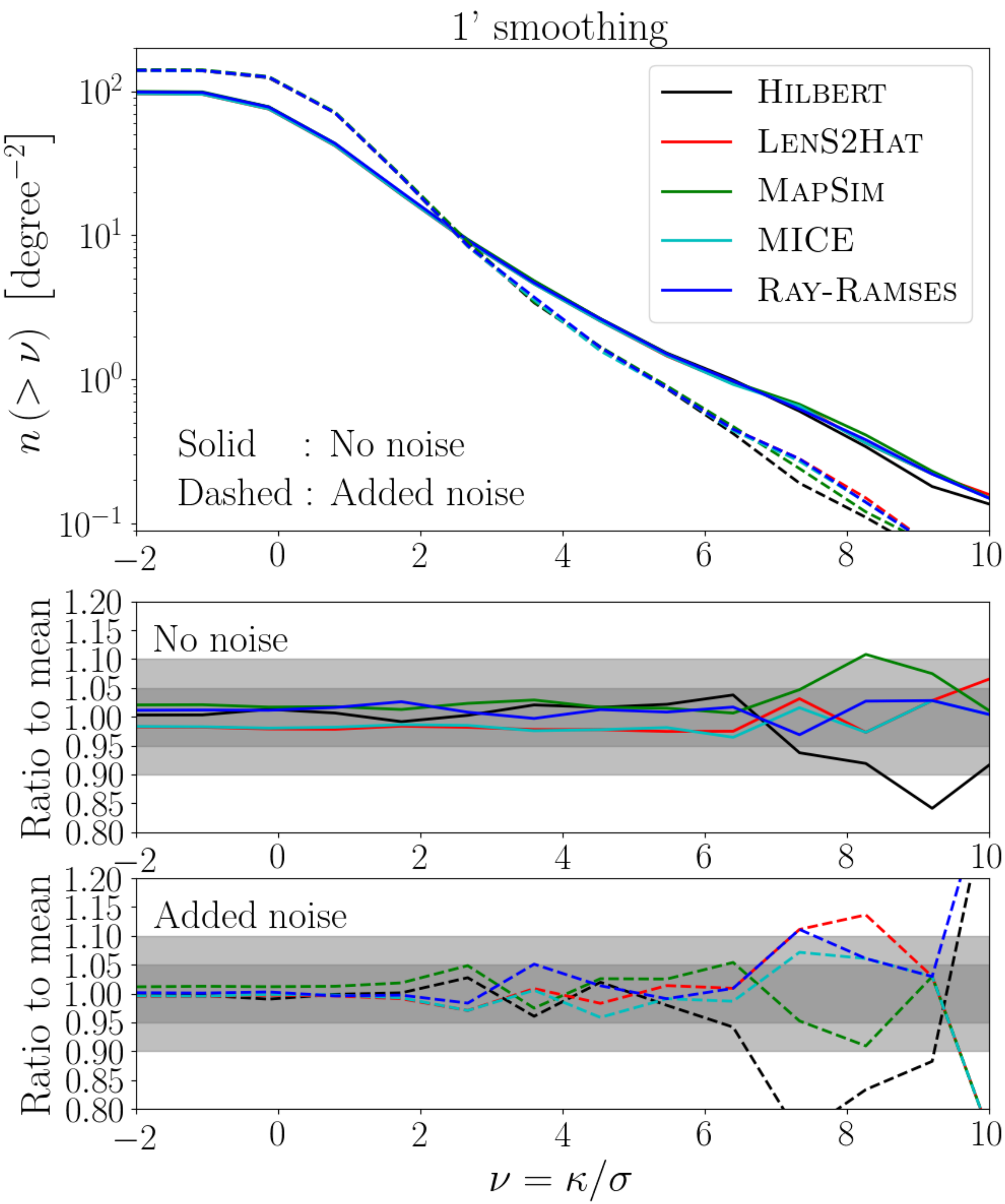
Power spectrum



2% agreement for ell < 4000

- The "spikes" discernable in the **Hilbert** difference (ell = 150, 700) are due to the parallel projection in this code.
- Different scale-dependence on large scales compared to Halofit due to small field of view. **(not critical in a comparison project)**
- Lower power on smaller scales compared to Halofit due to limited resolution. **(not critical in a comparison project)**

Peak Counts



Peak value from each code (counted on mean-subtracted maps)

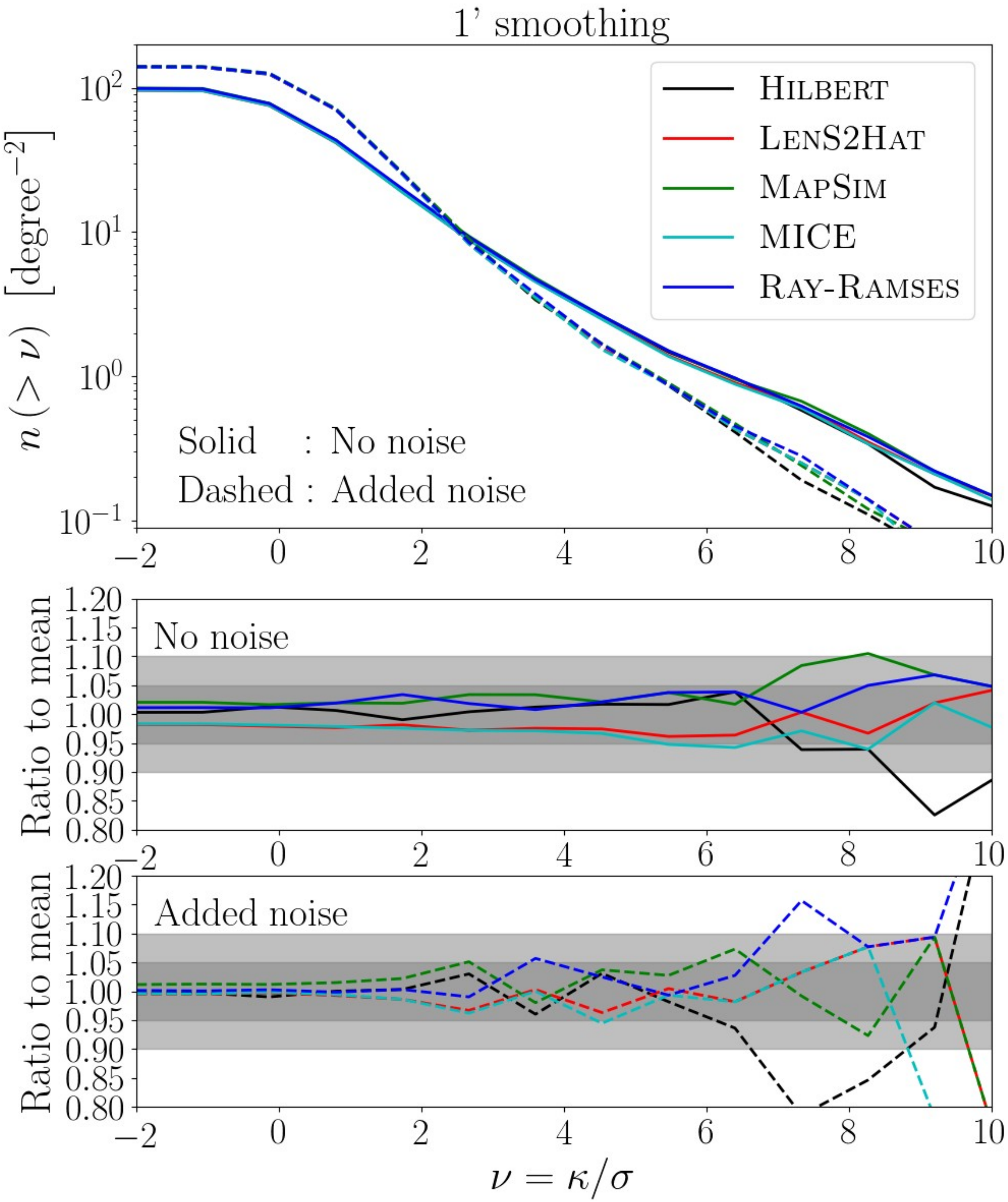
$$\nu = \frac{\kappa}{\sigma}$$

Signal-to-noise

Standard Deviation from each code

5% agreement for S/N < 6

Peak Counts



Peak value from each code (counted on mean-subtracted maps)

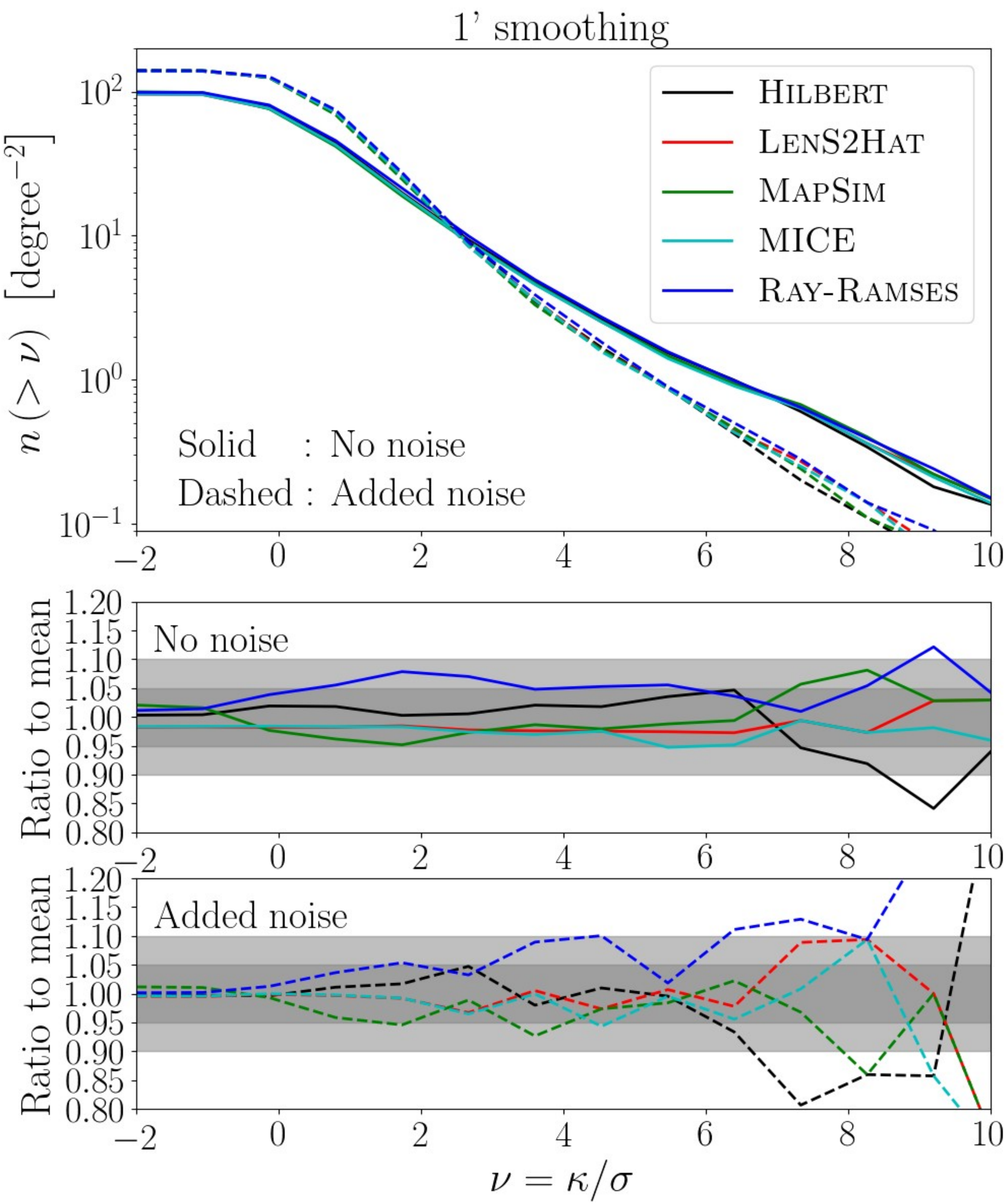
$$\nu = \frac{\kappa}{\sigma}$$

Signal-to-noise

Standard Deviation of one of the codes

5% agreement for S/N < 6

Peak Counts



Peak value from each code
(counted without subtracting the mean)

$$\nu = \frac{\kappa}{\sigma}$$

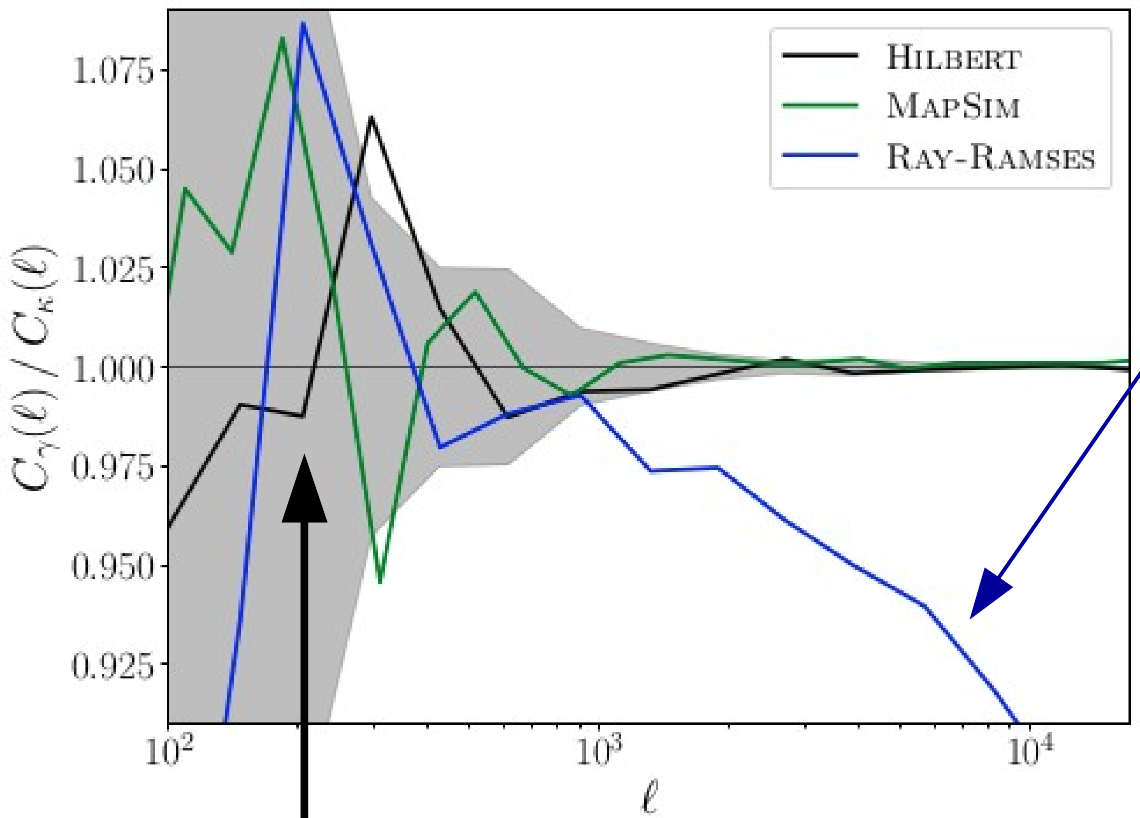
Signal-to-noise

Standard Deviation
of one of the codes

10% agreement for S/N < 6

Shear vs. Convergence

Ratio of shear to convergence power spectrum
(should be unity to leading order)



Shear in Ray-Ramses has less power than the convergence.

$$\kappa \sim \nabla^2_{2D}\Phi$$

$$\gamma_1 \sim \nabla_1\nabla^1\Phi - \nabla_2\nabla^2\Phi$$

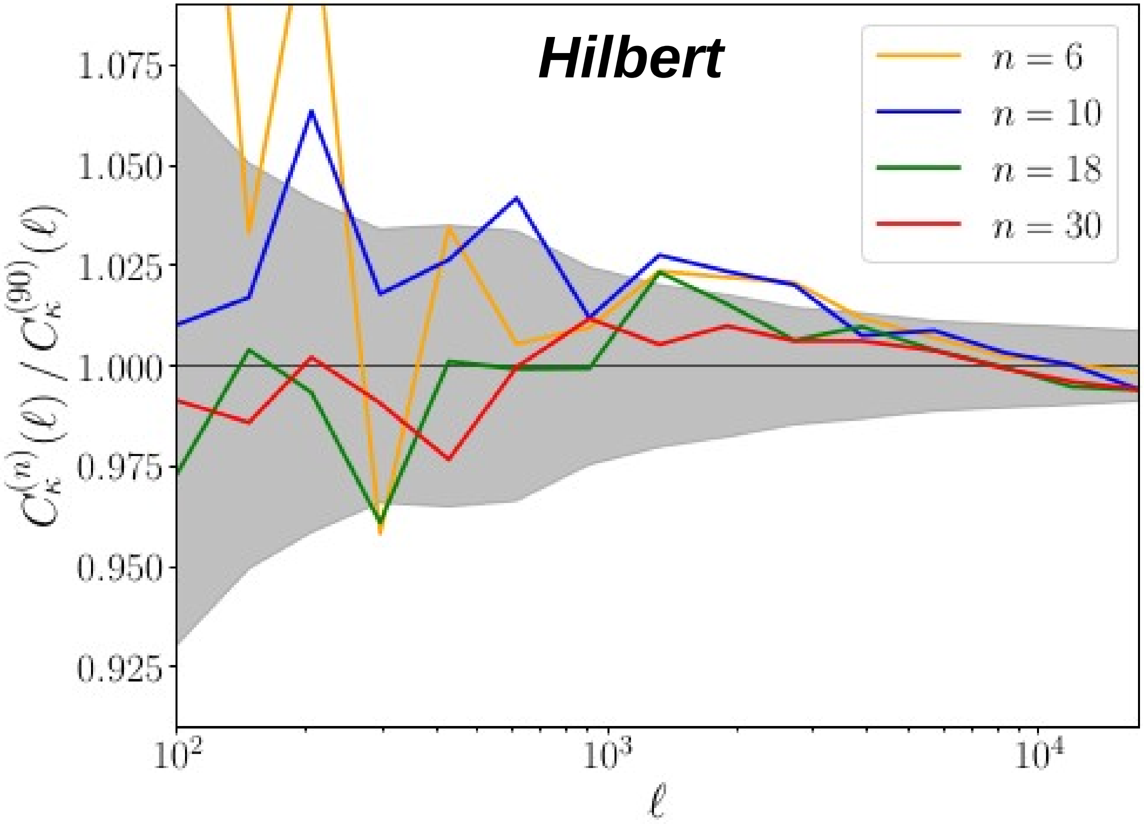
$$\gamma_2 \sim \nabla_1\nabla^2\Phi$$

Finite-differencing to calculate these derivatives in Ray-Ramses involves more AMR cells.
(effective more smoothing)

Sample variance noise
Grey band is the variance over 16 observer orientations

LOS resolution

Impact of number of planes used
Grey band is the variance over 16 observer orientations



Errors within sample variance even if only 10 planes are used
(lens thickness ~ 230 Mpc/h)

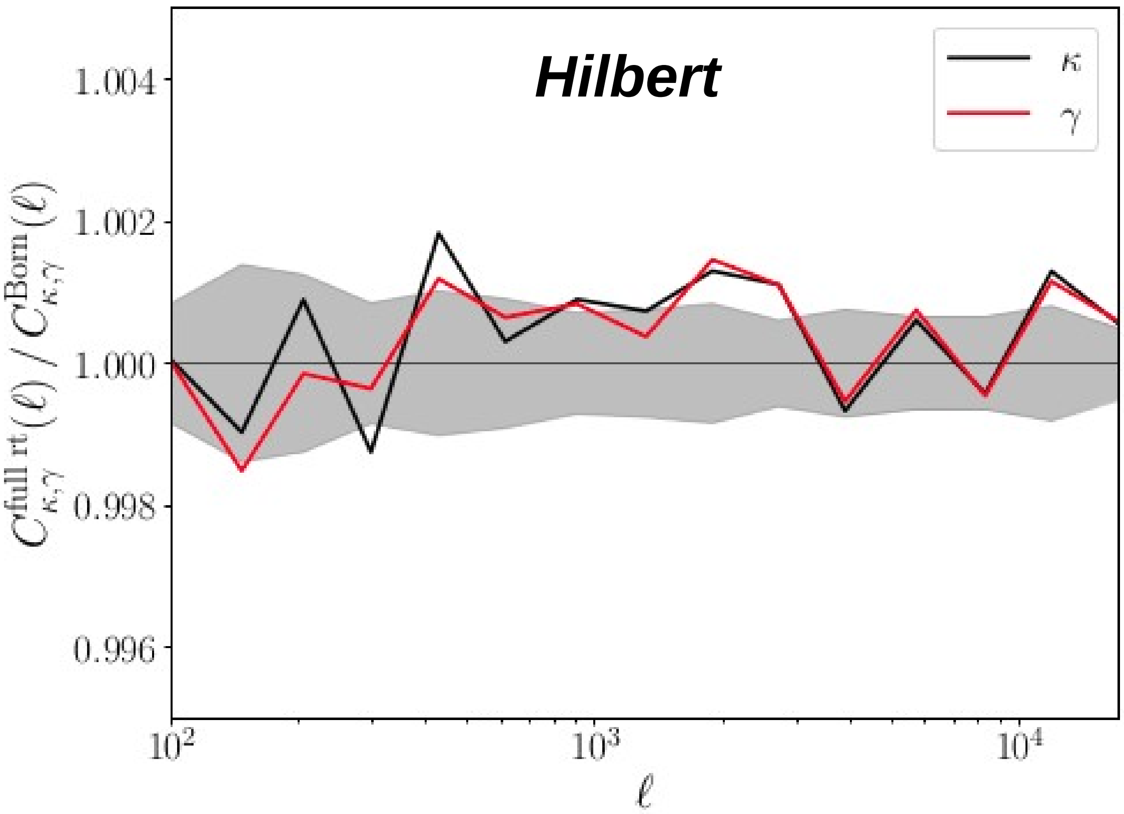
With Hilbert, <u>these are worse case scenario values</u> because of the parallel projection this code adopts.

<u>Resolution along the LOS is not a critical source of error.</u>
at least for lenses with width < 25 Mpc/h (90 planes)

Born approximation *(tested again)*

Deflected rays vs. undeflected rays

Grey band is the variance over 16 observer orientations



Born approximation has at most 0.1% impact for ell<10^4

<u>**In line with many other Born approximation tests in the literature!**</u>

Future improvements

1) Expand comparison to full-sky codes

Test other aspects of code development, more focused on large-scales.

2) Extend the comparison to codes that generate fast (approximate) realizations of the deflector mass.

E.g.
→ **Ice-Cola (Izard+ 2018)**
→ **Pinocchio (Monaco+ 2012, Munari+ 2017)**
→ **PeakPatch (Stein+2019)**
→ **Giocoli+ 2017**

Summary & Conclusions

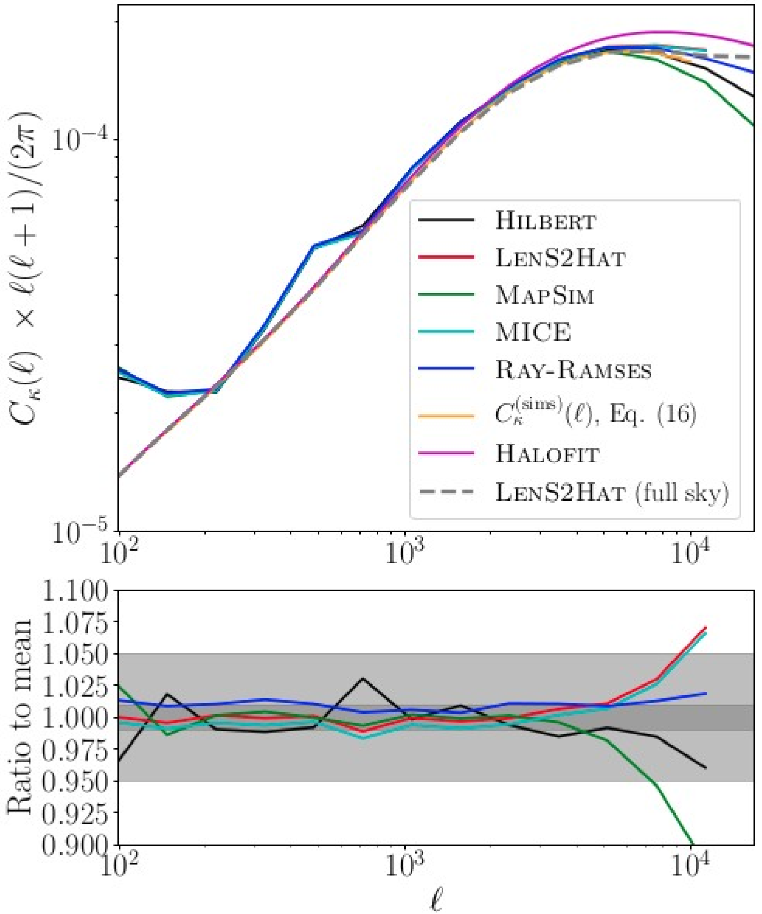
WL code comparison project

- Assessment of the level of agreement of WL simulation codes using a common realization of cosmic structure.

MapSim

Hilbert *Lens2Hat*

MICE *Ray-Ramses*



Satisfactory level of agreement !

- 2% agreement on the power spectrum for ell < 4000.
- 5-10% agreement on peak counts for S/N < 6.