Orsay (and everywhere), 19 March 2020

CMBXC - meeting
Updates on Simulations

M. Calabrese (OAVdA) , C. Carbone (INAF - IASF-MI), G. Fabbian (UniSussex), M. Baldi (UniBO), S. Miati (UniMI), V. Picciano (UniPd), E. Carella (UniMI), and P. Vielzeuf (SISSA)

Euclid consortium

Starting point: Nbody numerical simulations

What do we have?

(Big) N-Body simulation for CMB-XC

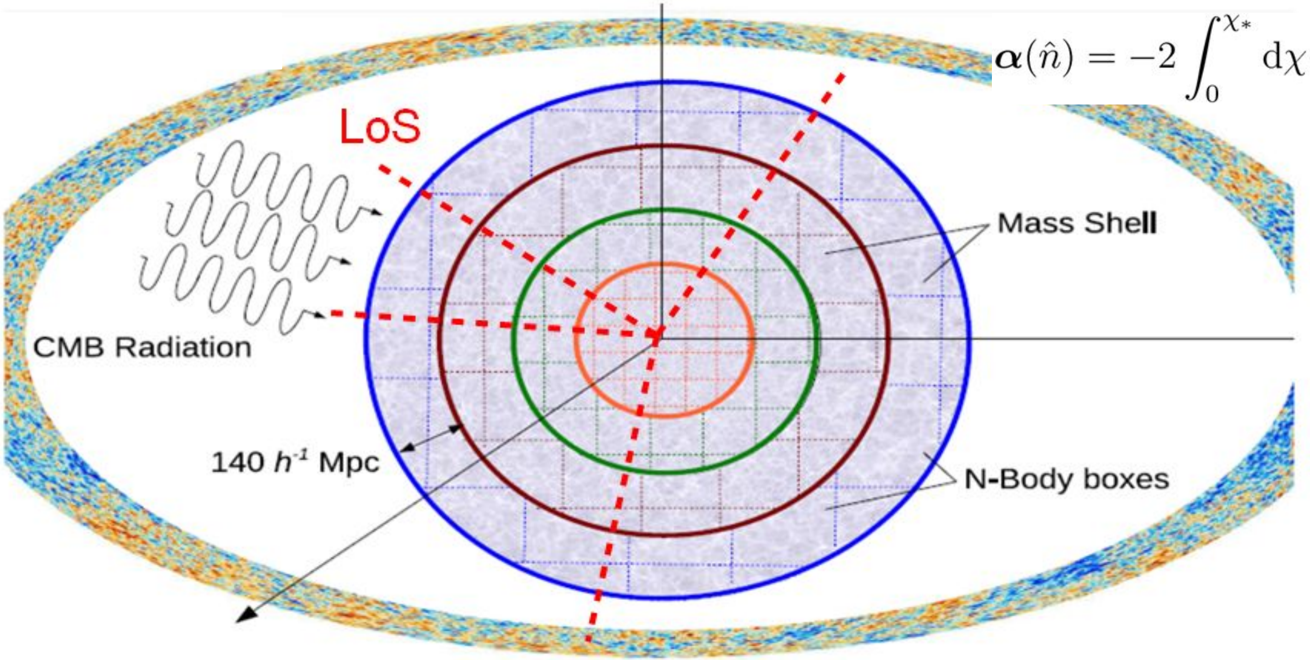
DUSTGRAIN (M. Baldi)

volume: (2 Gpc/h) and N : 2 x 2048 (CDM+v) particles
baseline Planck cosmology + f(R) gravity with massive neutrinos

DEMNUni (C. Carbone)

volume: (2 Gpc/h) and N : 2 x 2048 (CDM+v) particles
baseline Planck cosmology + neutrinos & DE

Light-cone production: map making



$$\boldsymbol{\alpha}(\hat{n}) = -2\int_0^{\chi_*} \mathrm{d}\chi \frac{\chi_* - \chi}{\chi_* \chi} \nabla_{\hat{n}} \Psi(\chi\hat{n}, \chi)$$

The **standard way to build lightcones** (up to high z) is to **pile up high-resolution boxes** within concentric cells to fill the lightcone up to the maximum desired source redshift. Mass and structures are then projected onto **2D HEALpix maps**.

DUSTGRAIN

Dark Universe Simulations to Test GRAvity In the presence of Neutrinos

[**M. Baldi**, C. Giocoli, C. Carbone, M. Calabrese, C. Arnold, P. Fosalba]

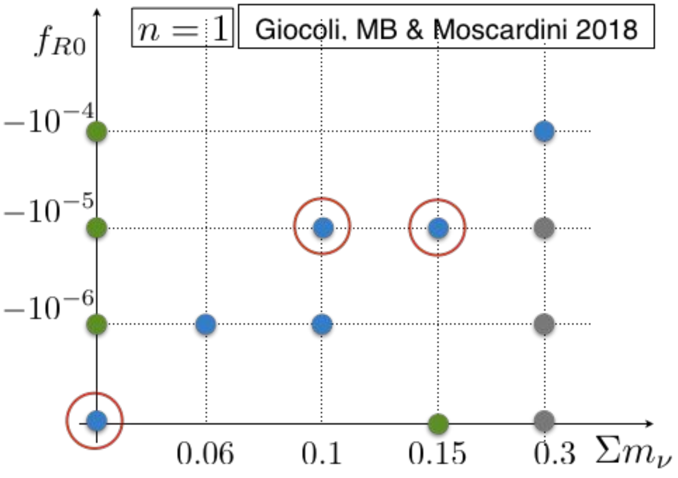
Combining **an f(R) gravity solver** (MG-GADGET, Puchwein, Baldi & Springel 2013) with the **particle-based implementation of massive neutrinos** (Viel, Haehnelt & Springel 2010)

PATHFINDER

21 models: *fR0* in [-10^{-6},-10^{-4}], m_ν in [0.06, 0.3] eV

Box = 750 Mpc/h
Np = (2x)768^3
Mp ~ 8x10^10

Planck 2015 cosmology (and small variations)



Datasets

- 34 **comoving snapshots**
- **WL light-cones** up to z=4,128/256 different realisations, 27 different source redshifts for lensing maps available, with an aperture of *5x5 deg*.
- **Halo** (FoF, b=0.16) and **SubHalo** (SubFind & Denhf) catalogs at 34 comoving snaps and in WL light-cones

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Euclid Applications

- **Howls (see splinter S08)**
- **MG emulator (Winther et al. 2019)**
- Data fully available to the collaboration (contact: M. Baldi)

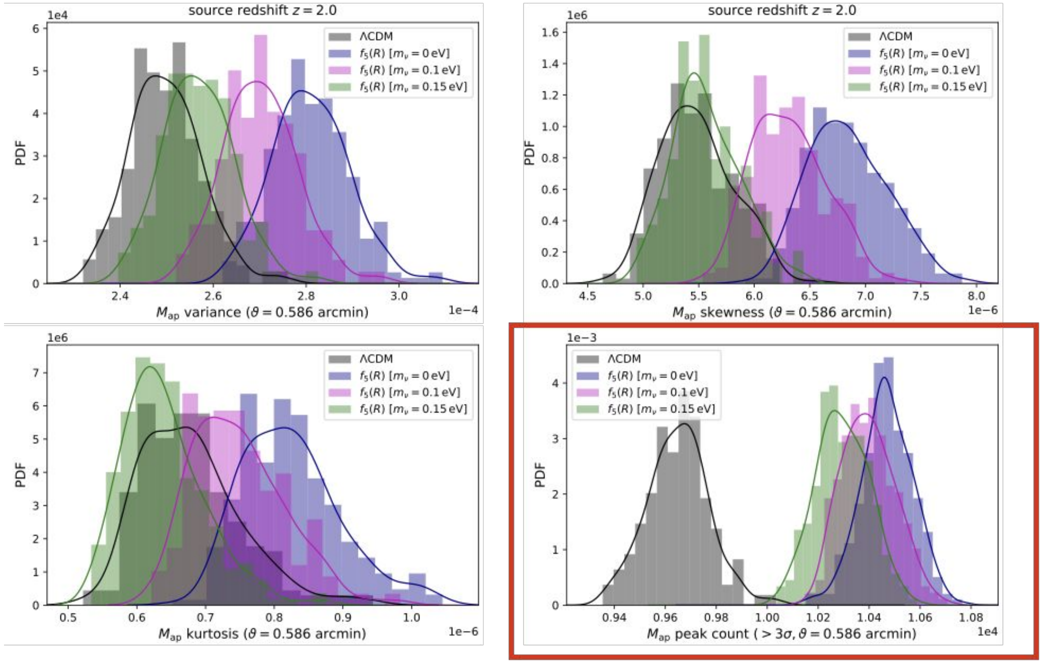
Model	Gravity	m_ν	Ω_m	σ_8	w
LCDM	GR	-	0.313448	0,842	-1
LCDM_Om_0.300912	GR	-	0.300912	0,842	-1
LCDM_Om_0.325988	GR	-	0.325988	0,842	-1
LCDM_s8_0.808240	GR	-	0.313448	0,808240	-1
LCDM_s8_0.875594	GR	-	0.313448	0,87559	-1
LCDM_w_-0.96	GR	-	0.313448	0,842	-0.96
LCDM_w_-1.04	GR	-	0.313448	0,842	-1.04
LCDM_Om_0.2	GR	-	0.2	0,842	-1
LCDM_Om_0.4	GR	-	0.4	0,842	-1
fR4	$f_{R0} = -1x10^{-4}$	-	0.313448	0,967	-1
fR5	$f_{R0} = -1x10^{-5}$	-	0.313448	0,903	-1
fR5_Om_0.2	$f_{R0} = -1x10^{-5}$	-	0.2	0,903	-1
fR5_Om_0.4	$f_{R0} = -1x10^{-5}$	-	0.4	0,903	-1
fR5x5	$f_{R0} = -5x10^{-5}$	-	0.313448	0,935	-1
fR6	$f_{R0} = -1x10^{-6}$	-	0.313448	0,861	-1
LCDM_0.15eV	GR	0.15 eV	0.313448	0,806	-1
fR4_0.3eV	$f_{R0} = -1x10^{-4}$	0.3 eV	0.313448	0,893	-1
fR5_0.15eV	$f_{R0} = -1x10^{-5}$	0.15 eV	0.313448	0,864	-1
fR5_0.1eV	$f_{R0} = -1x10^{-5}$	0.1 eV	0.313448	0,878	-1
fR6_0.1eV	$f_{R0} = -1x10^{-6}$	0.1 eV	0.313448	0,836	-1
fR6_0.06eV	$f_{R0} = -1x10^{-6}$	0.06 eV	0.313448	0,847	-1

DUSTGRAIN

Dark Universe Simulations to Test GRAvity In the presence of Neutrinos

[**M. Baldi**, C. Giocoli, C. Carbone, M. Calabrese, C. Arnold, P. Fosalba]

Peel et al. 2018



Modified Gravity and Massive neutrinos are **quite degenerate in standard low-order statistics** of the mass distribution

Higher order stats shown to break the degeneracy (Peel et al. 2019)

We want to check how CMB lensing, ISW, or CMB-x correlations with GC and WL perform in this situation

Useful testbed for other degenerate models

DUSTGRAIN

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FULL SCALE

3 models: LCDM, fR5-0.16eV, fR5-0.1eV

Box = 2 Gpc/h
Np = (2x)2048^3
Mp ~ 8x10^10

Same ICs as the DEMNUni-II sims by C. Carbone, Planck 2013 cosmology

Outputs: 63 full comoving snaps, 463 group catalogs, full-sky group lightcone and WL lightcone

15 M CPU hours through a PRACE allocation (P.I. M. Baldi)

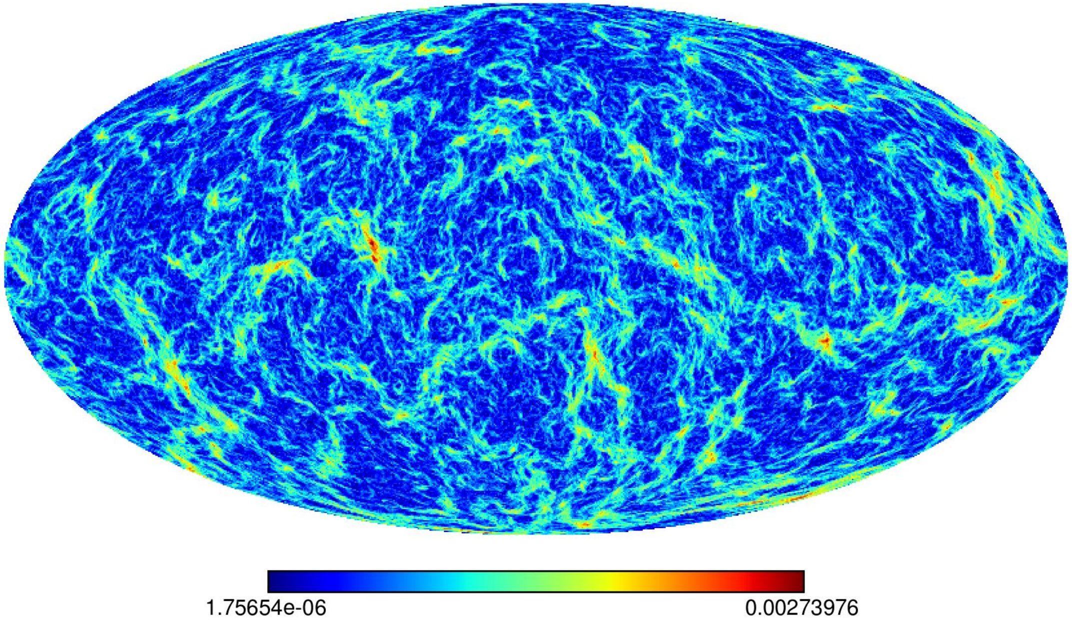
Total data size: ~185 TB

DUSTGRAIN

Dark Universe Simulations to Test GRAvity In the presence of Neutrinos

[**M. Baldi**, C. Giocoli, C. Carbone, M. Calabrese, C. Arnold, P. Fosalba]

Effective κCMB convergence for [fR5, DM+$m_\nu = 0.10$ eV], DM particles



Deflection angle maps integrated on all snapshots (z in [0,99]) by M. Calabrese

Comparing ΛCDM with fR5 with 0.16 eV neutrino mass and fR5 with 0.10 eV neutrino mass

Ongoing production of spherical overdensity and FoF halo catalogs in the same realisation → possibility of x-correlation in self consistent realisations

Dark Matter only particles (simulation fR5 with DM and nu, Mnu=0.10 eV)

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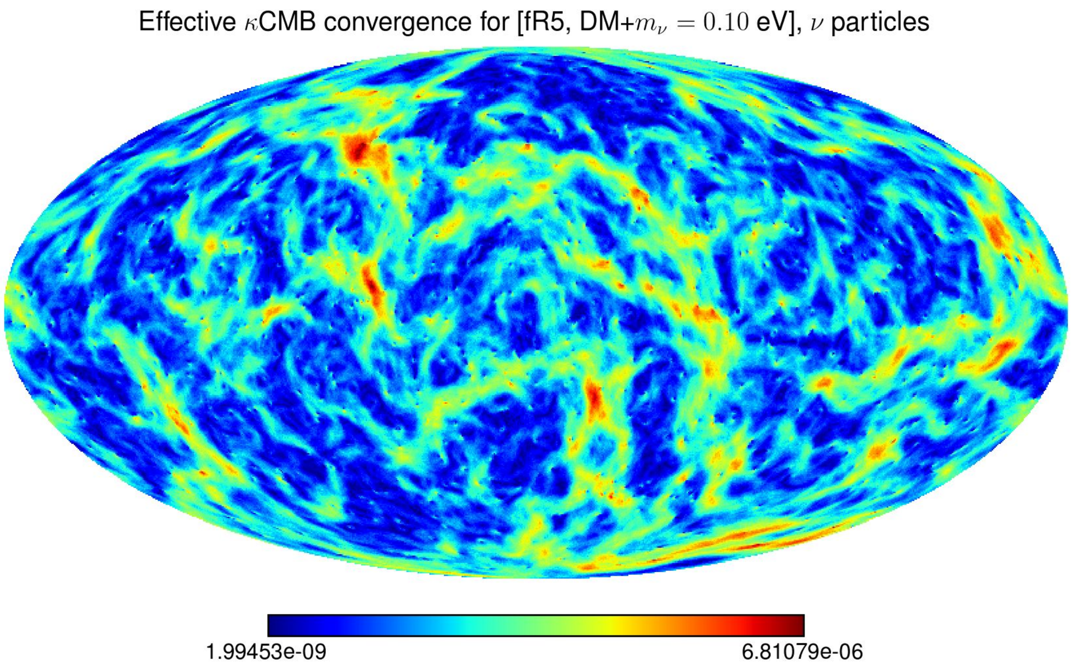

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Neutrino only particles (simulation fR5 with DM and nu, Mnu=0.10 eV)

DUSTGRAIN

Dark Universe Simulations to Test GRAvity In the presence of Neutrinos

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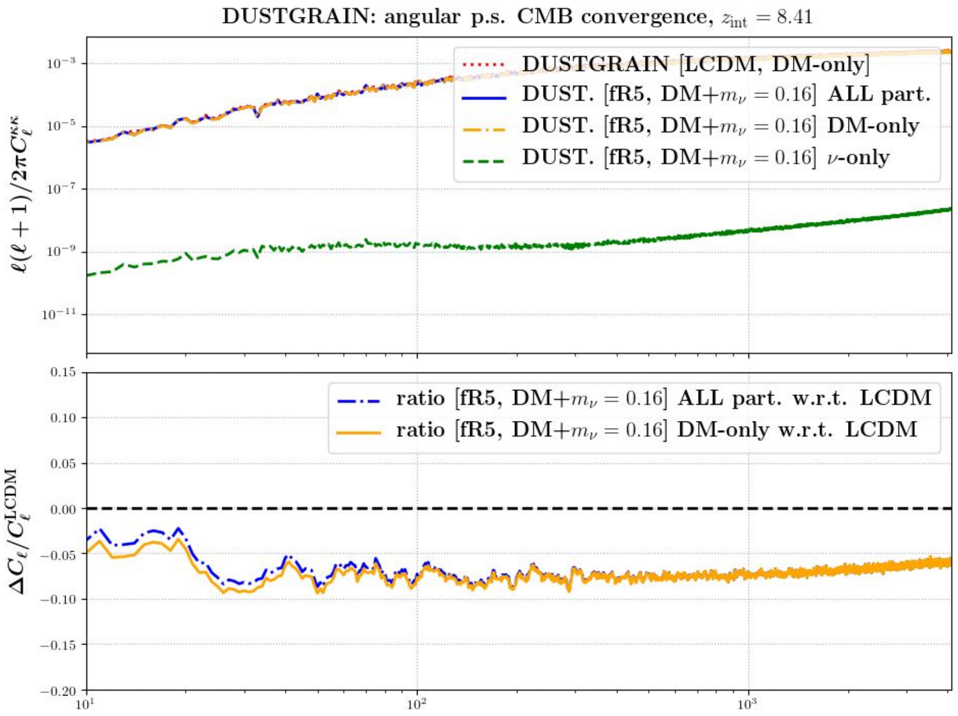

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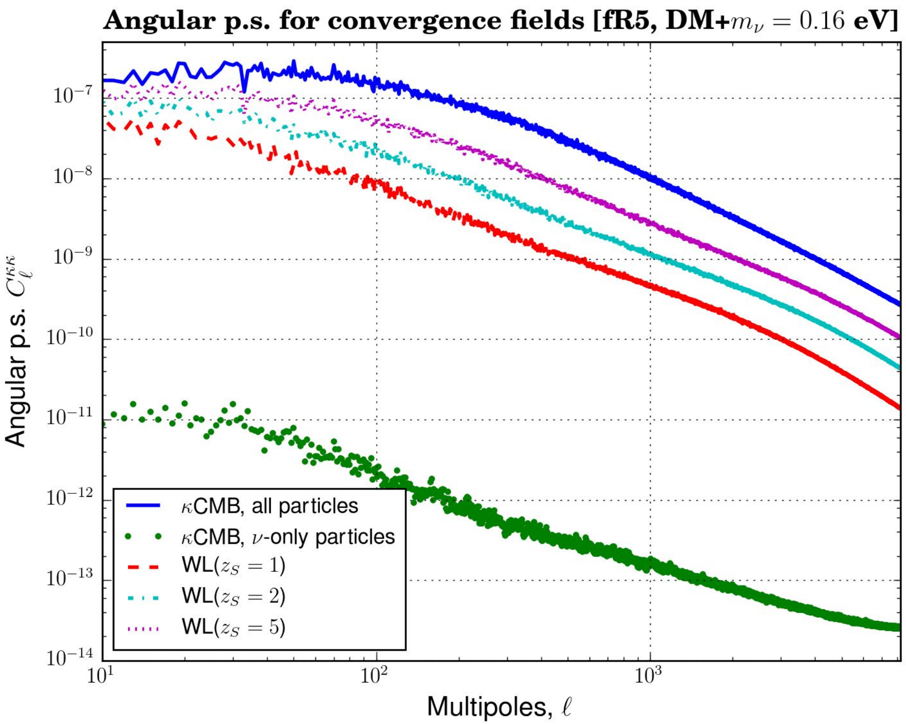
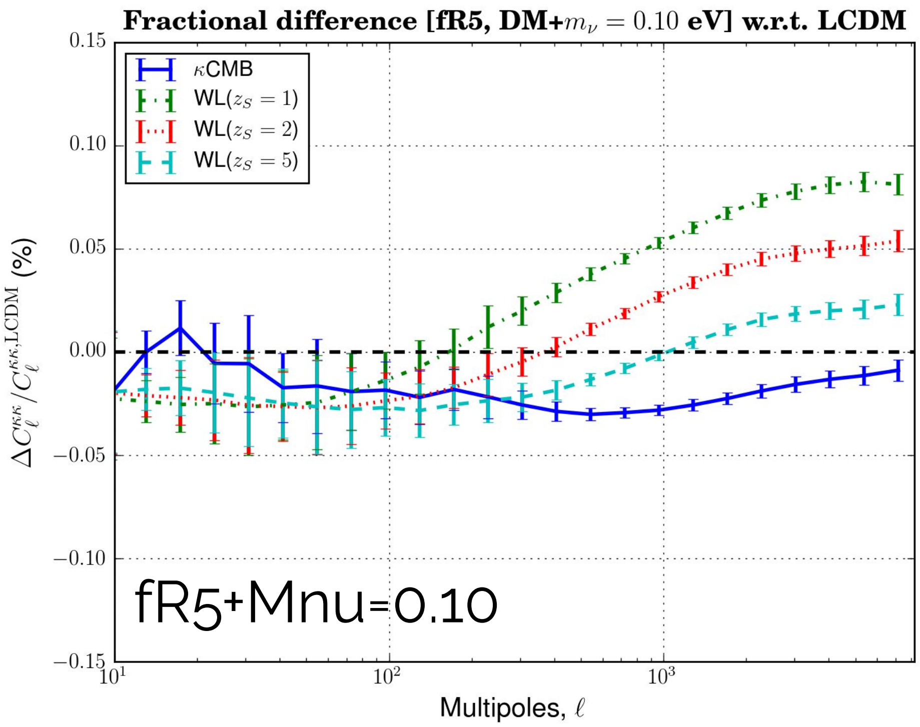
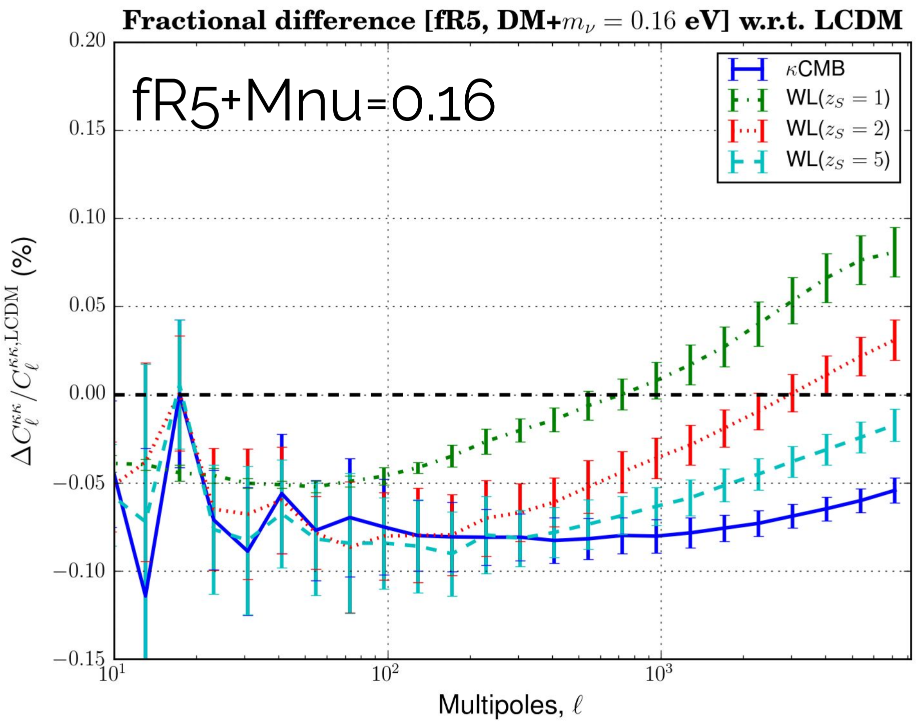


Angular power spectrum for several lensing observables: kCMB, Weak Lensing (WL) with sources at different redshift zs (zs=1, 2, 5, 8)

Signal comparison

fractional difference (wrt LCDM) in the auto-a.p.s.

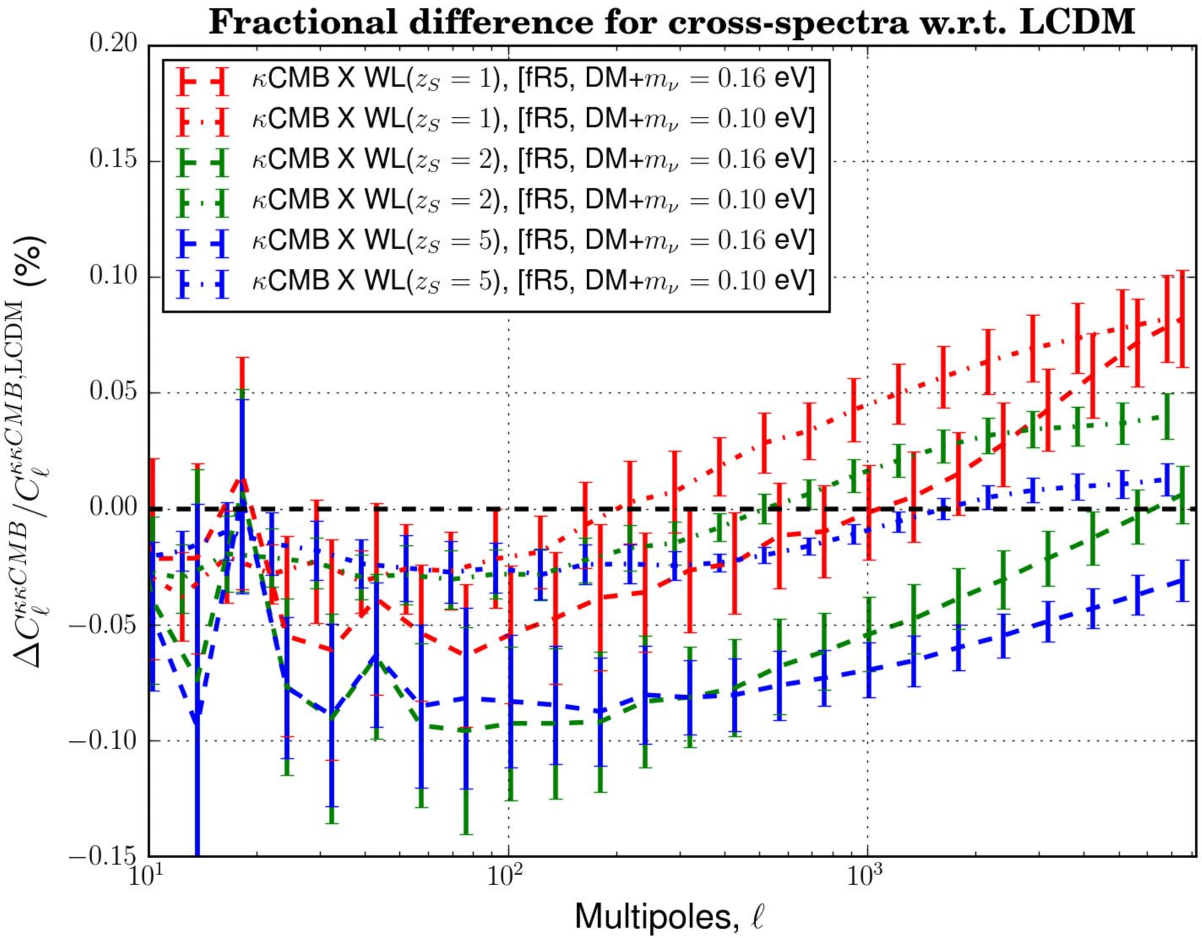




kCMB x WL

fR5+Mnu=0.10

fR5+Mnu=0.16



"Dark Energy and Massive Neutrino Universe"

(Carmelita Carbone & collaborators)

https://www.researchgate.net/project/DEMN-Universe-DEMNUni

DEMNUni simulations (Gadget-3)

14 cosmological simulations with volume: $(2\ \mathrm{Gpc/h})^3$, N_{part}: 2×2048^3 (CDM+ν)
baseline Planck-13 cosmology
+
M_ν=0, 0.17, 0.3, 0.53 eV (DEMNUni-I)
&
(M_ν, w_0, w_a)=(0÷0.16,-0.9,±0.3),(0÷0.16,-1.1,±0.3) + M_ν=0.32 (DEMNUni-II)

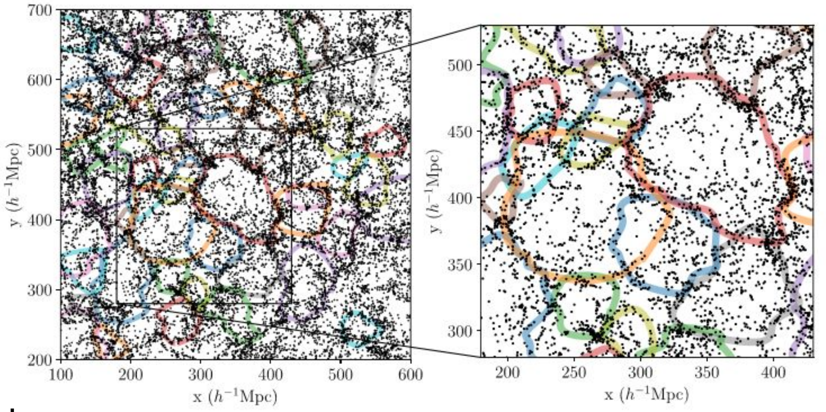
200 TB of stored data

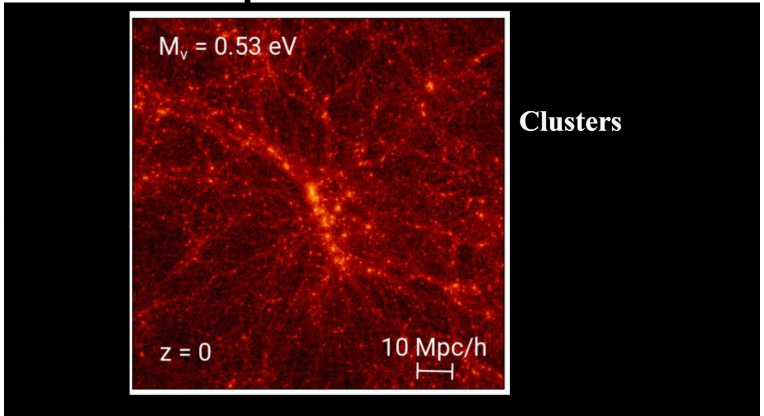
DEMNUni-Covariances

300 cosmological simulations with $V=1\ (\mathrm{Gpc/h})^3$ and $N_{part}=2 \times 1024^3$ (CDM+ν):
140 TB of stored data at project completion, stored at CINECA/CNAF/IA2-TS

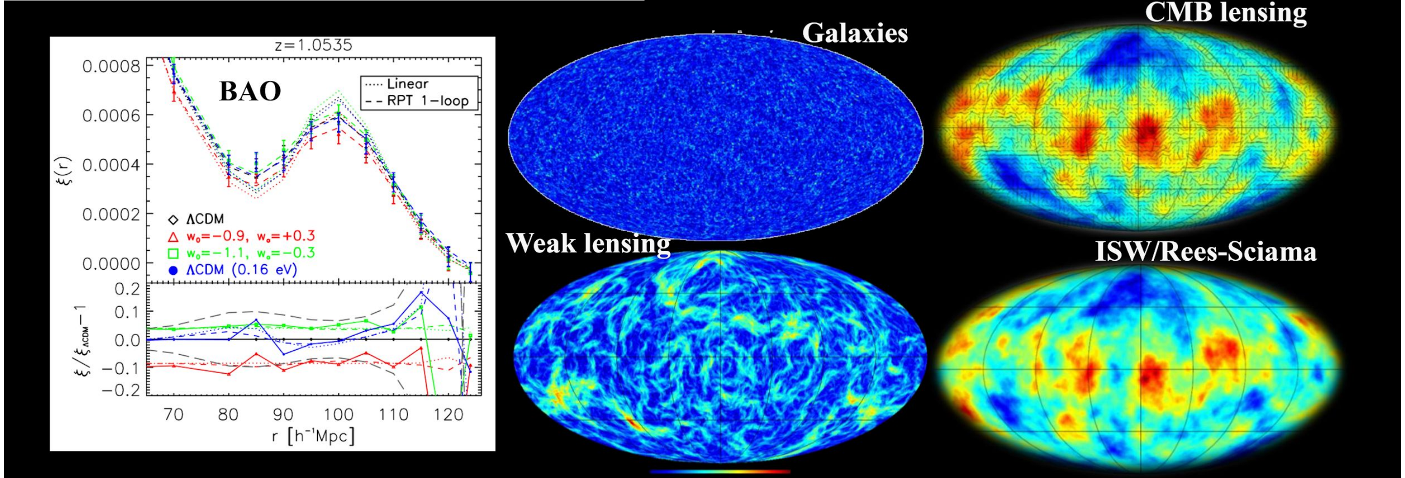
5 snaps per sim stored between z=0-2, all the halo/subhalo catalogs stored from z<2

DEMNUni outputs

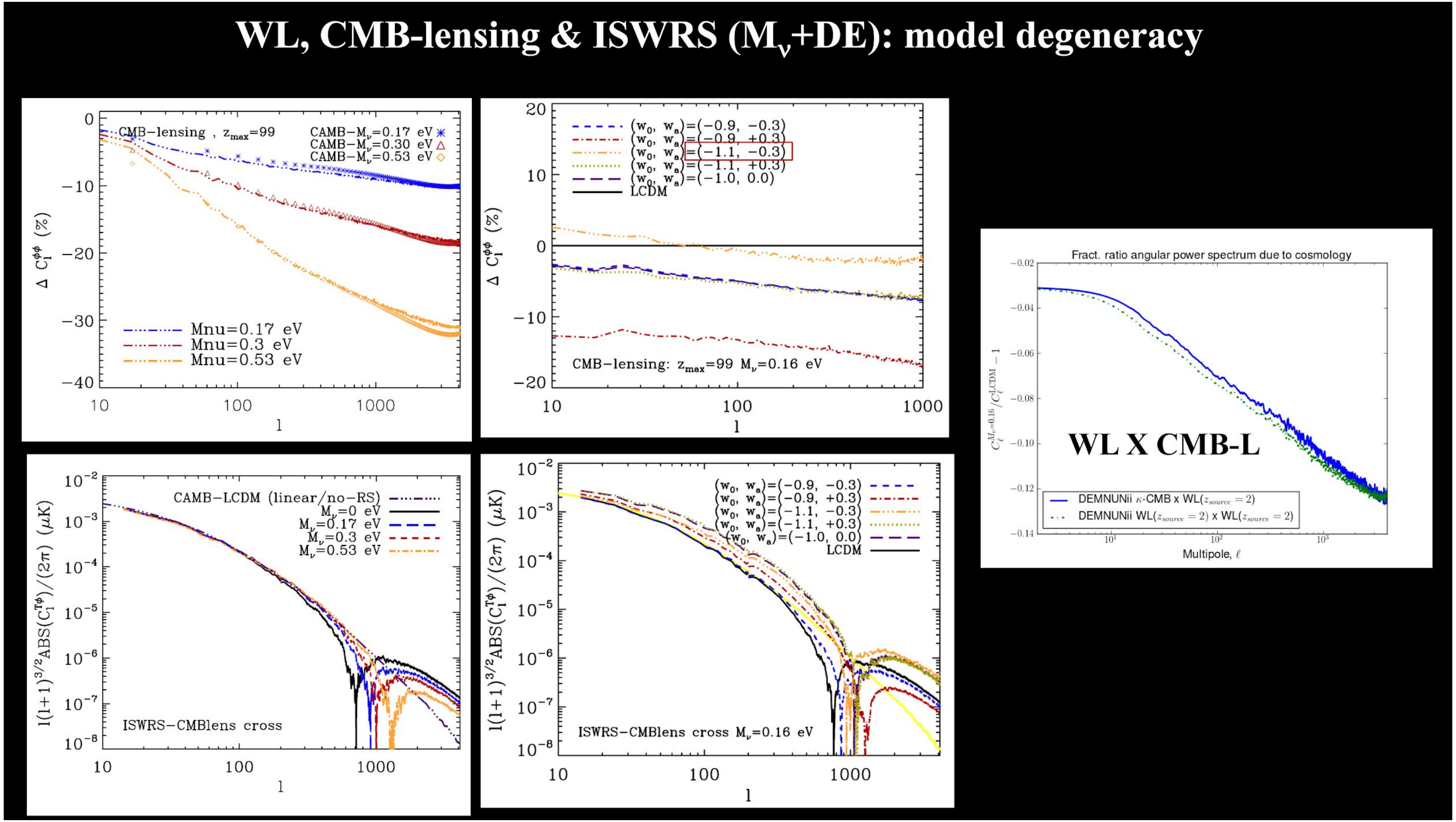




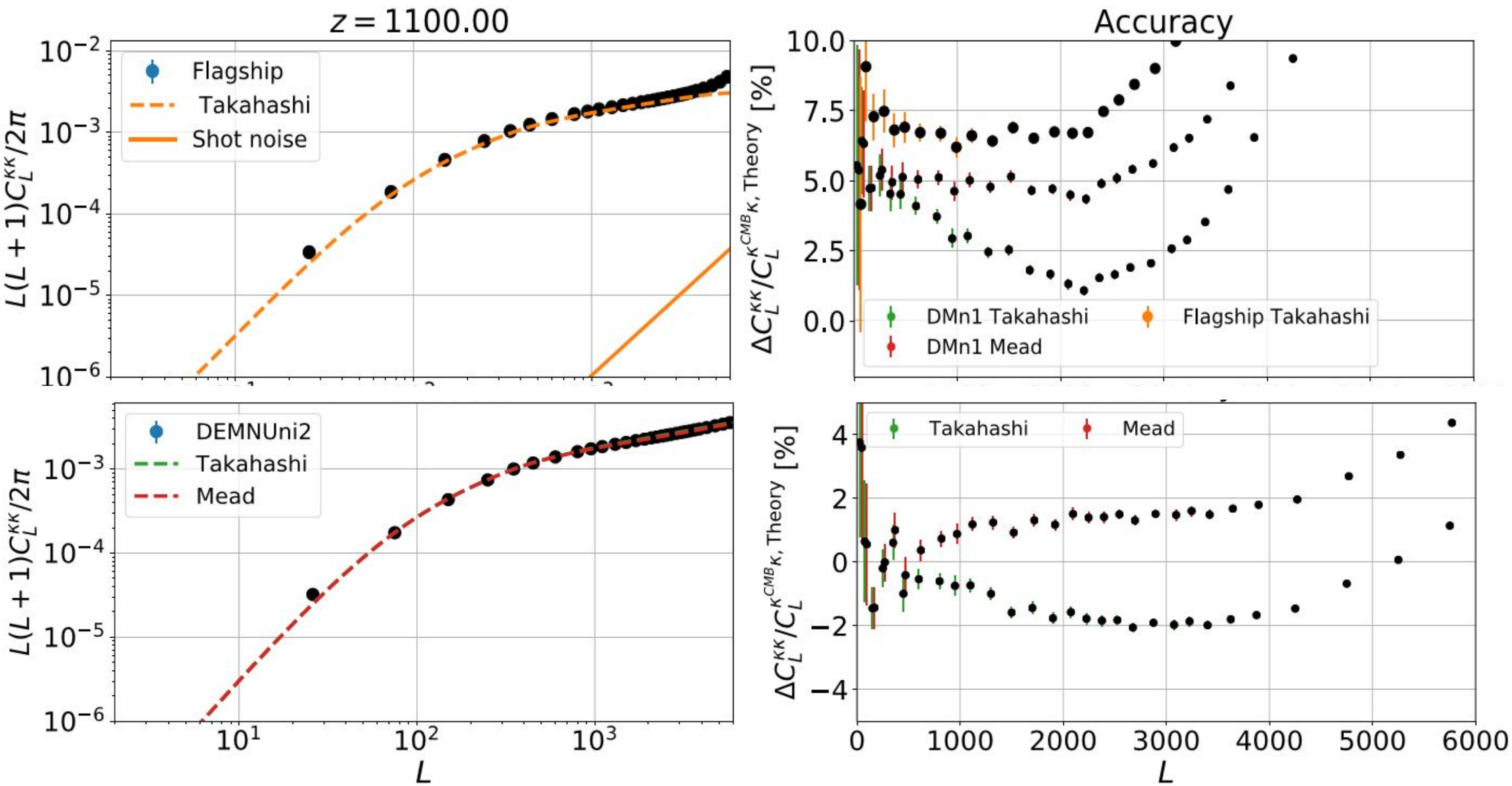
Voids
(Verza+2019)



DEMNUni WL & ISW/RS



kCMB a.p.s. comparison with Flagship, DEMNUNii



G. Fabbian,
C. Carbone

Covariances from particle maps

Towards tomography.

Goals: Cross-Covariances of different Euclid probes (from N-body simulations):

1. Weak lensing: fixed source planes, photo-z distribution n(z) (→ CoS-SWG WP6: WL sims.)

2. CMB lensing (→ SWG CMBXC)

3. Cross correlation of lensing observables with galaxies (SHAM, HOD in the next future), voids (see Pauline's talk) and clusters (in the next future)

(Small) N-Body sim for CMB-XC: **DEMNUni-Cov**

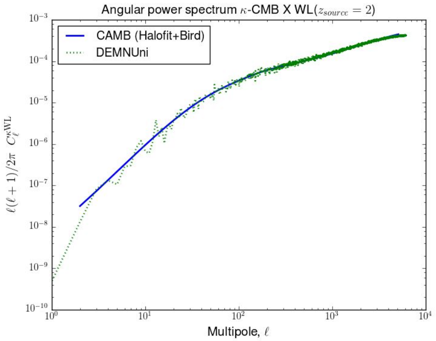
	Number of sims	Cosmology (background)	BoxSize / NumPart	Number of snapshot (+FoF, SubGroups, M200, ...)
LCDM (Euclid cosmology)	**50 sims (done) + 50 sims (in prod.)**	OmeBr = 0.05 OmNeu = 0.0 OmCDM = 0.27 OmLam = 0.6800	Box Size = 1 Gpc/h Num Part = 1024^3	63 z in [0,99]
LCDM + Mnu= 0.16 eV	**50 sims (done) + 50 sims (in prod.)**	OmeBr = 0.05 OmNeu = 0.0 OmCDM = 0.27 OmLam = 0.6800	Box Size = 1 Gpc/h Num Part = 1024^3	63 z in [0,99]

Covariances project: M. Calabrese, C. Carbone, G. Fabbian, ...

Available healpix maps

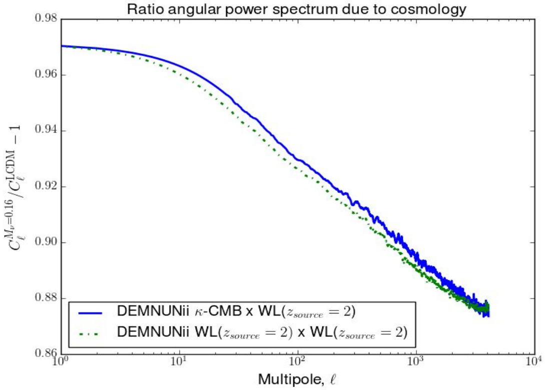
Particle Maps	● 50 x 63 Surface Mass Density Maps (for each snapshot/redshift, for each nbody simulation) ● 50 x 63 CMB-Convergence Maps (for each snapshot/redshift, for each nbody simulation) → 50 CMB-Convergence Integrated Map (in Born approx. for each nbody simulation) 50 CMB-Lensed maps (via LensPix) ● CMB lensing from DEMNUni 1 & 2 including post-Born corrections ● WL maps from DEMNUni 1 & 2 including post-Born corrections with sources placed at z=0.2, 0.35,0.6,1,2 ● Density maps from DEMNUni 1 including lensing corrections in 5 bins with median redshift z=0.2, 0.35,0.6,1,2
Grid maps	● 50 CMB-lensing potential & ISW/RS (in LCDM) ● 50 CMB-lensing potential & ISW/RS (in Mass(nu)=0.16 eV) ● 50 CMB-Lensed maps (via LensPix) (in LCDM) ● 50 CMB-Lensed maps (via LensPix) (in Mass(nu)=0.16 eV) ● 50 WL maps with sources placed at z=8,5,2,1 (in LCDM) ● 50 WL maps with sources placed at z=8,5,2,1 (in Mass(nu)=0.16 eV)

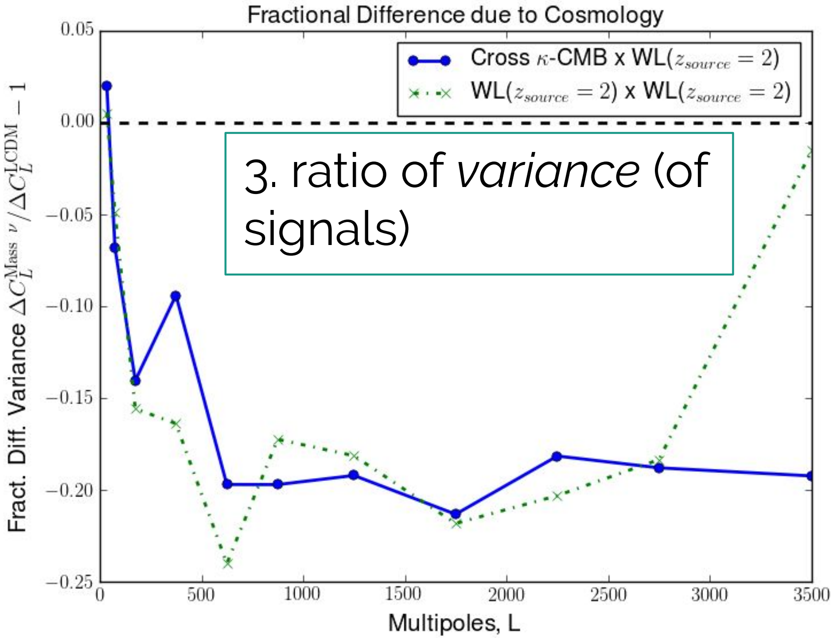
Cosmology dependence of signals and errors



1. Signals from 2d maps (angular power spectrum)

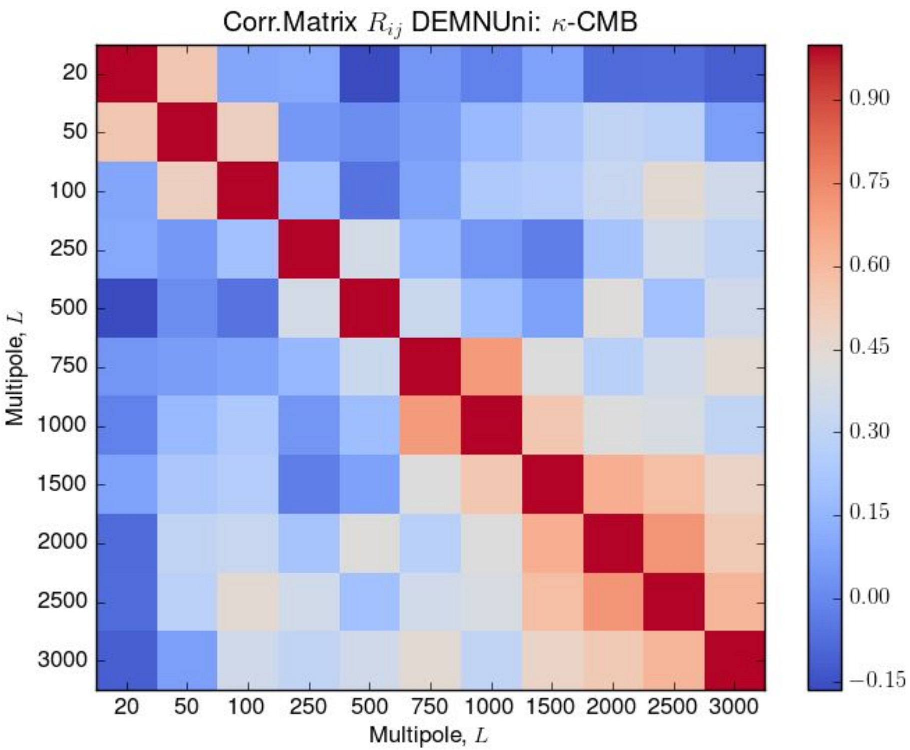
2. ratio of signals





3. ratio of *variance* (of signals)

Corr. Matrix: k-CMB auto-spectrum [LCDM]



C_L CMB-Convergence DEMNUni → Covariance Matrix

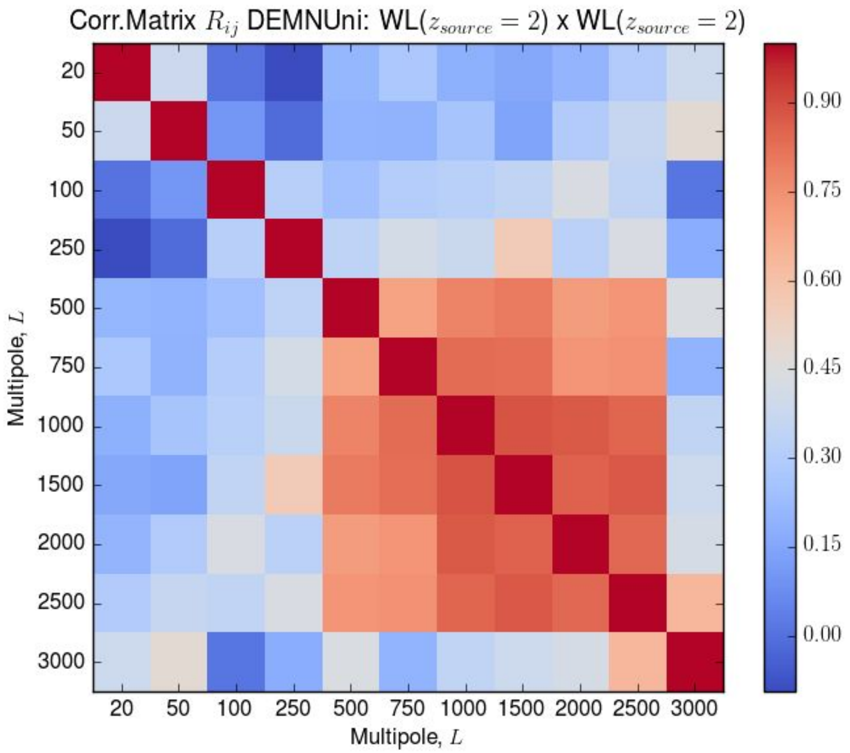
11 Bins in multipole, L = {20,50,100,250,500,750,1000,1500,2000, 2500,3000}

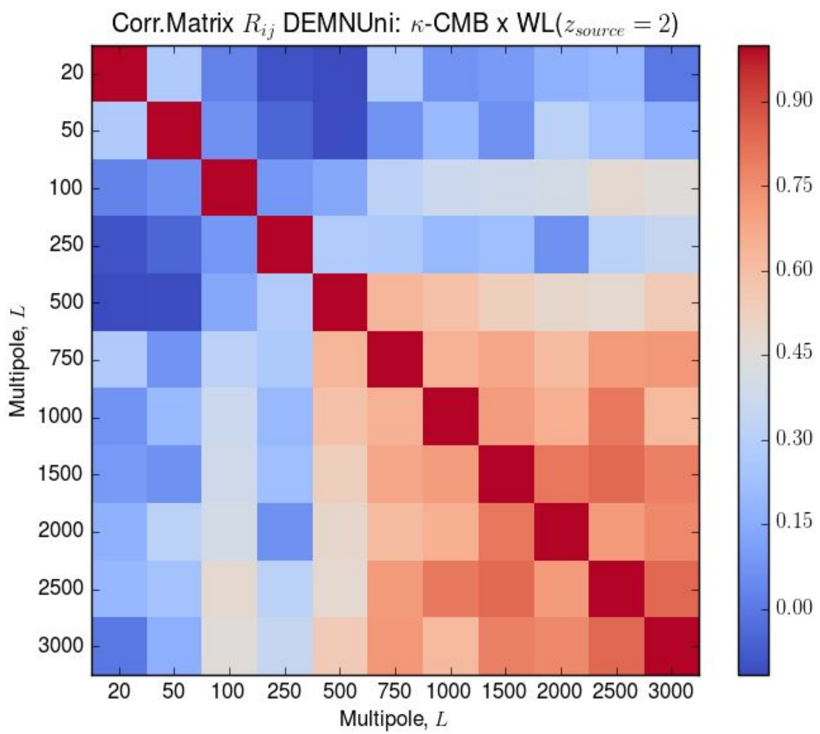
Nside Convergence maps = 2048
Number of Simulations = 50

LCDM and Mnu=0.16

Figures are Correlation Matrix *(Covariances normalized to diagonal variances)*

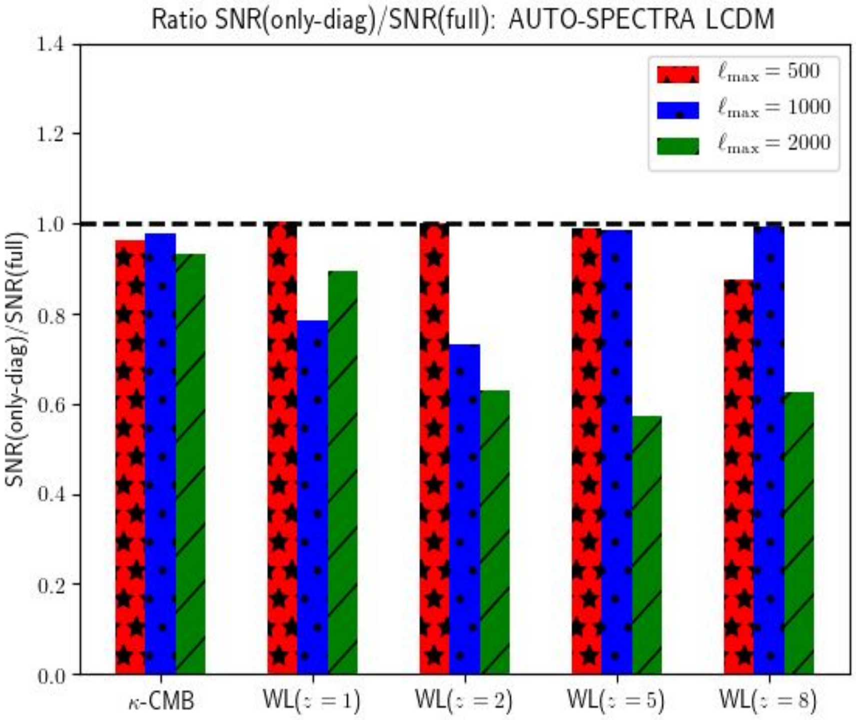
Corr. Matrix: k-CMB, WL (both auto- and cross-a.p.s)

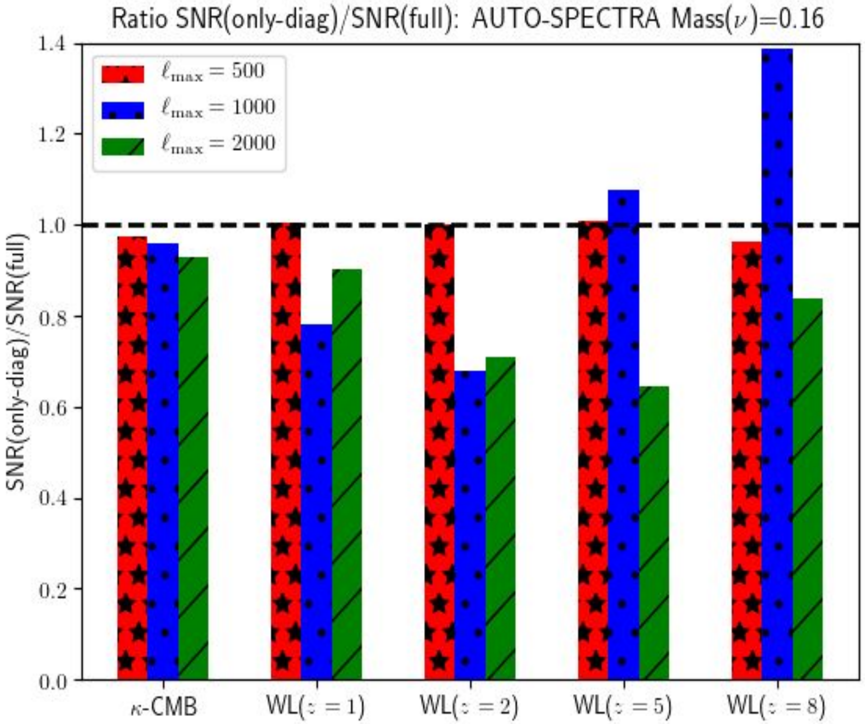


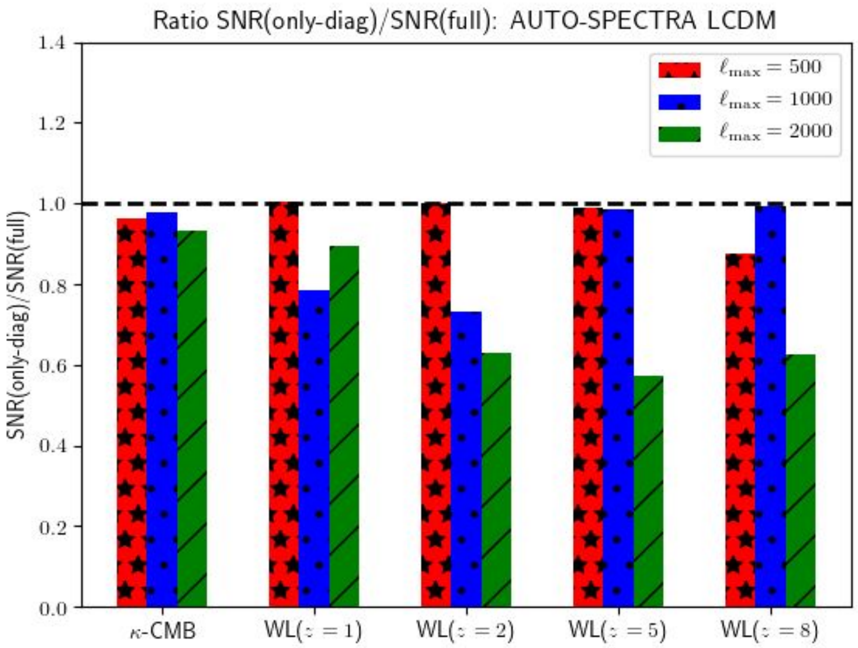


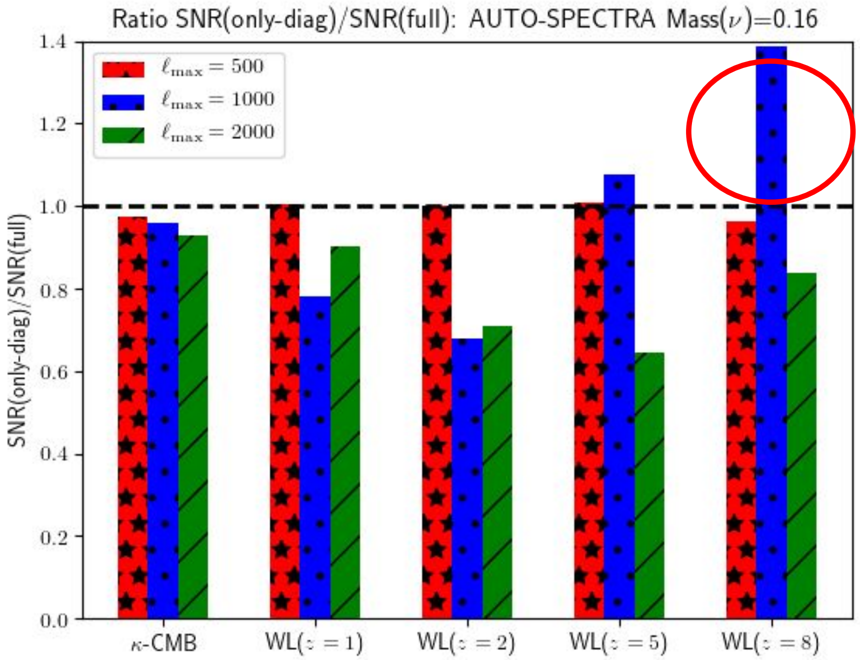
Signal-to-noise ratio
(only diag. vs full)

$$(S/N)^2 = \sum_{\ell,\ell'}^{\ell_{\max}} C_\ell^{\rm XY} {\rm Cov}^{-1}_{\ell\ell'} C_{\ell'}^{\rm XY}$$









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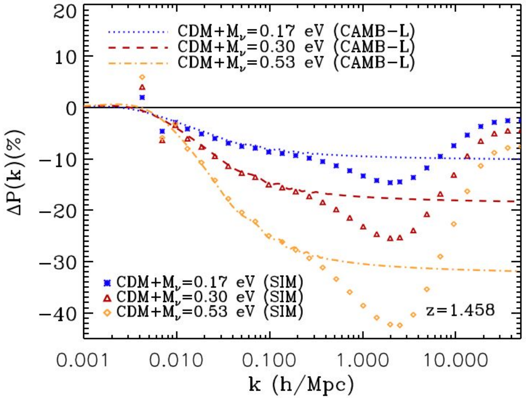
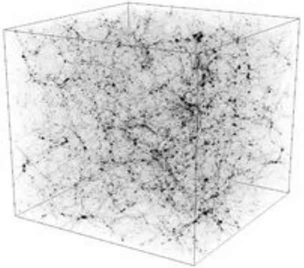


Mock catalogues

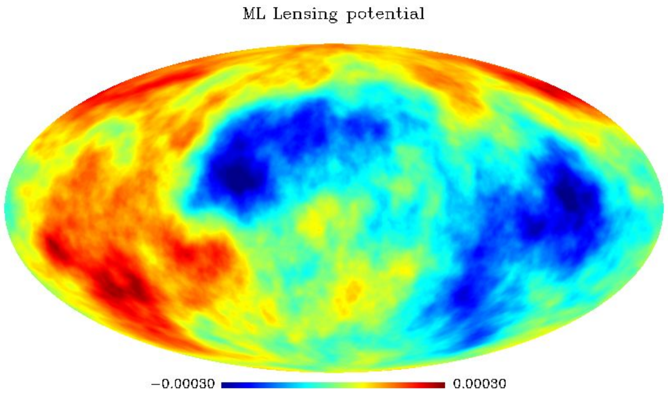
Same realization, different tracers.

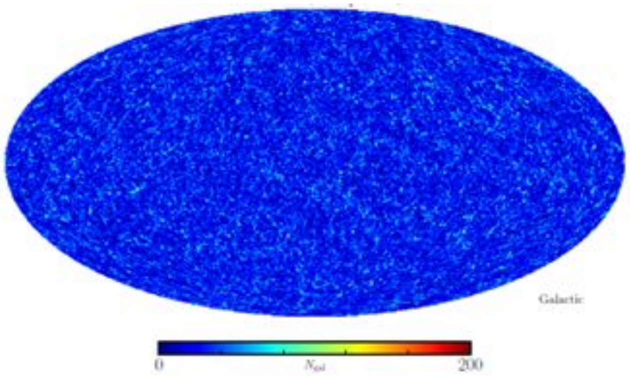
Building an end-to-end pipeline



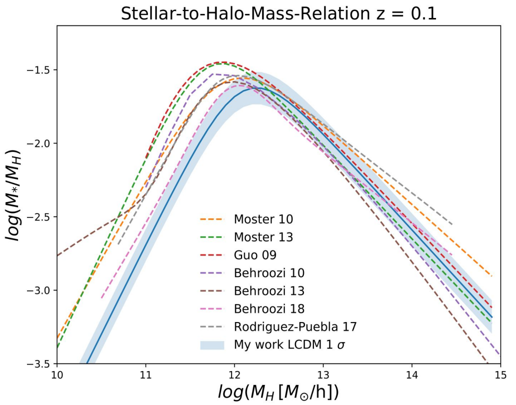
- Identify same matter distribution
- *Weak Lensing maps*

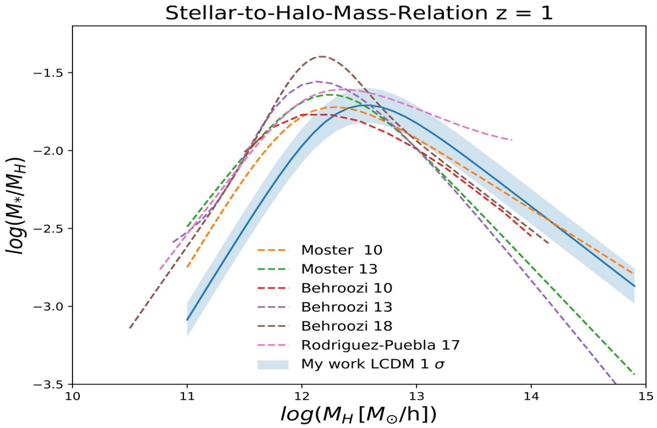
- Identify Halos and SubHalos
→ Proxy for Potential wells
- *Galaxies map (SHAM)*





Adding galaxies with **SHAM** (E. Carella @UniMi)



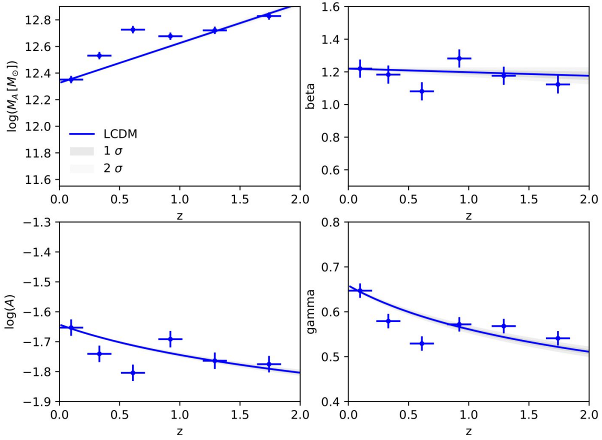


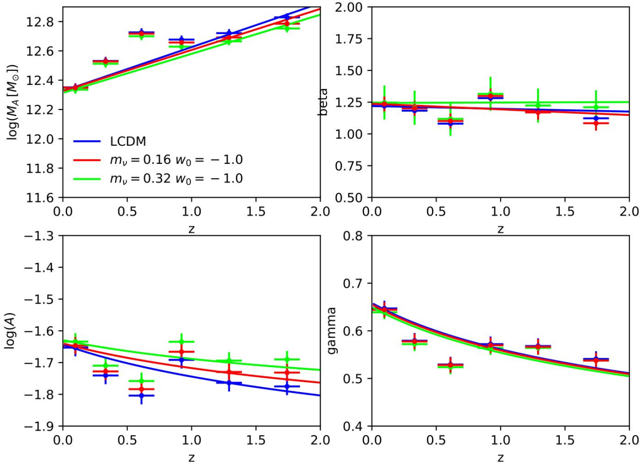
Different SMF models from different datasets and HMF prescriptions

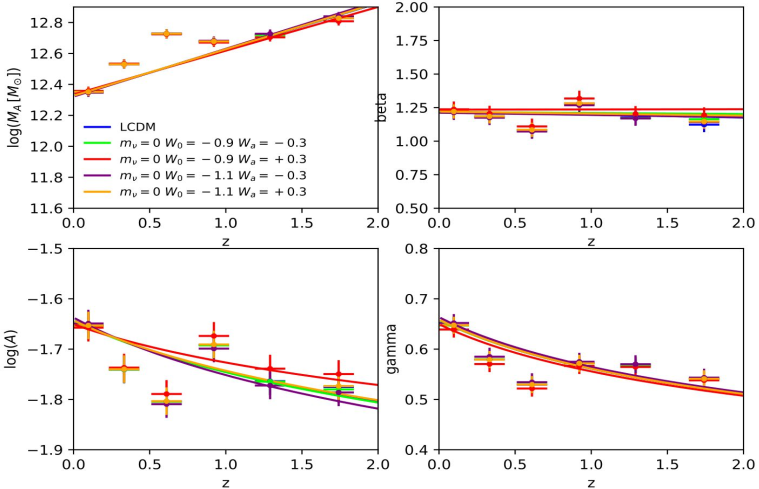
- MCMC fit of the SHMR (Moster et al. 2010)

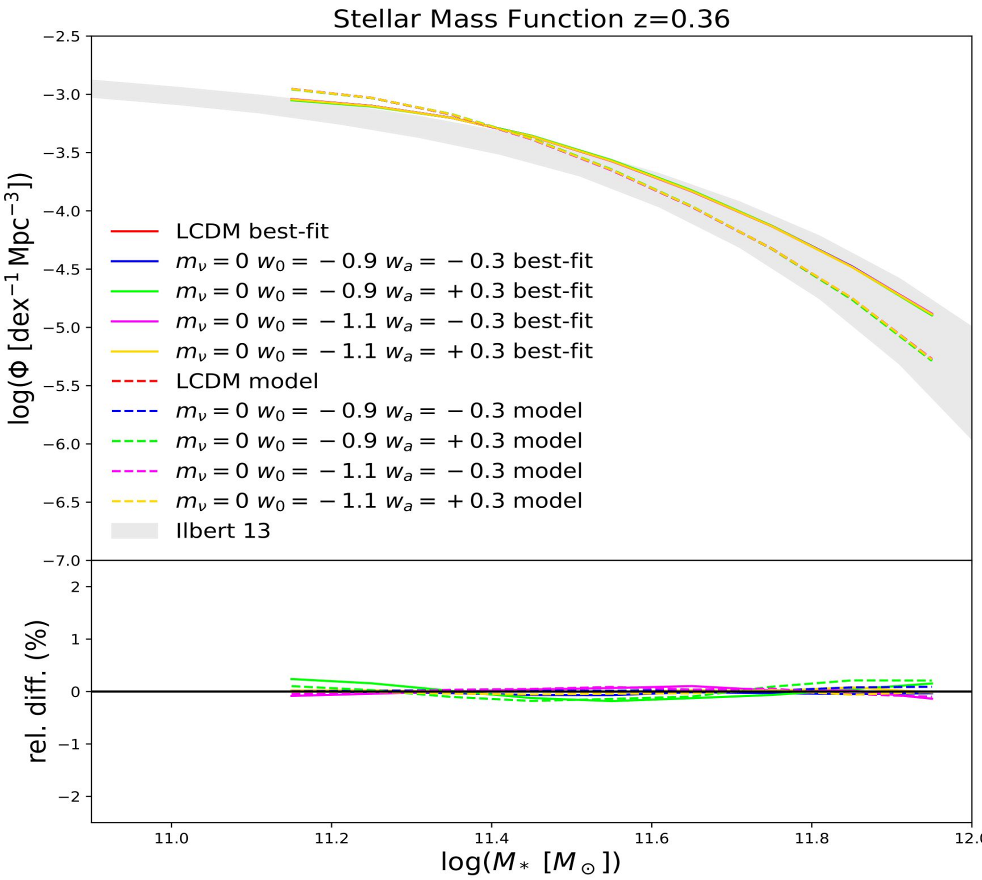
$$\frac{M_*}{M_H} = 2A\left[\left(\frac{M_H}{M_A}\right)^{-\beta} + \left(\frac{M_H}{M_A}\right)^{\gamma}\right]^{-1}$$

- z - parametrisation of SHMR (Girelli et al. 2020) in different cosmology
- <u>Fit parameters against observations</u>



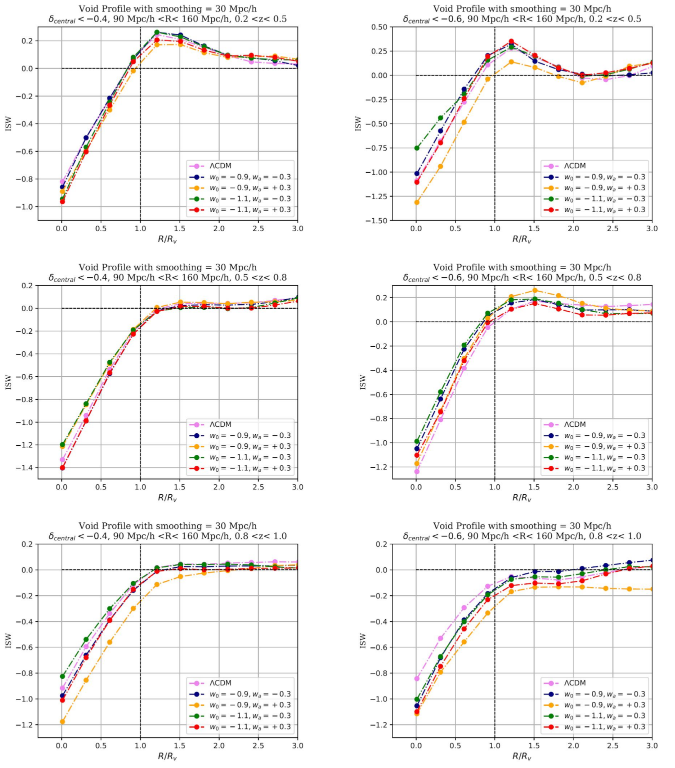






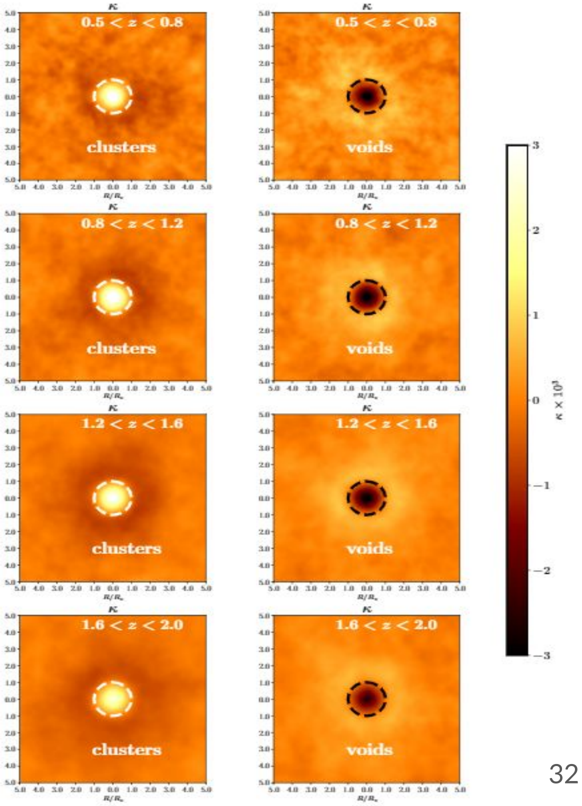
[different DE / neutrino masses]

Cross-correlation with Voids



S. Miati (@ UniMi)
Void profiles from cross-correlation with ISW (DEMNUNii)

P. Vielzeuf (@ SISSA)
Void finder and XC with CMB



Ongoing activities

Covariances. Again.

Lensing pot. reconstruction

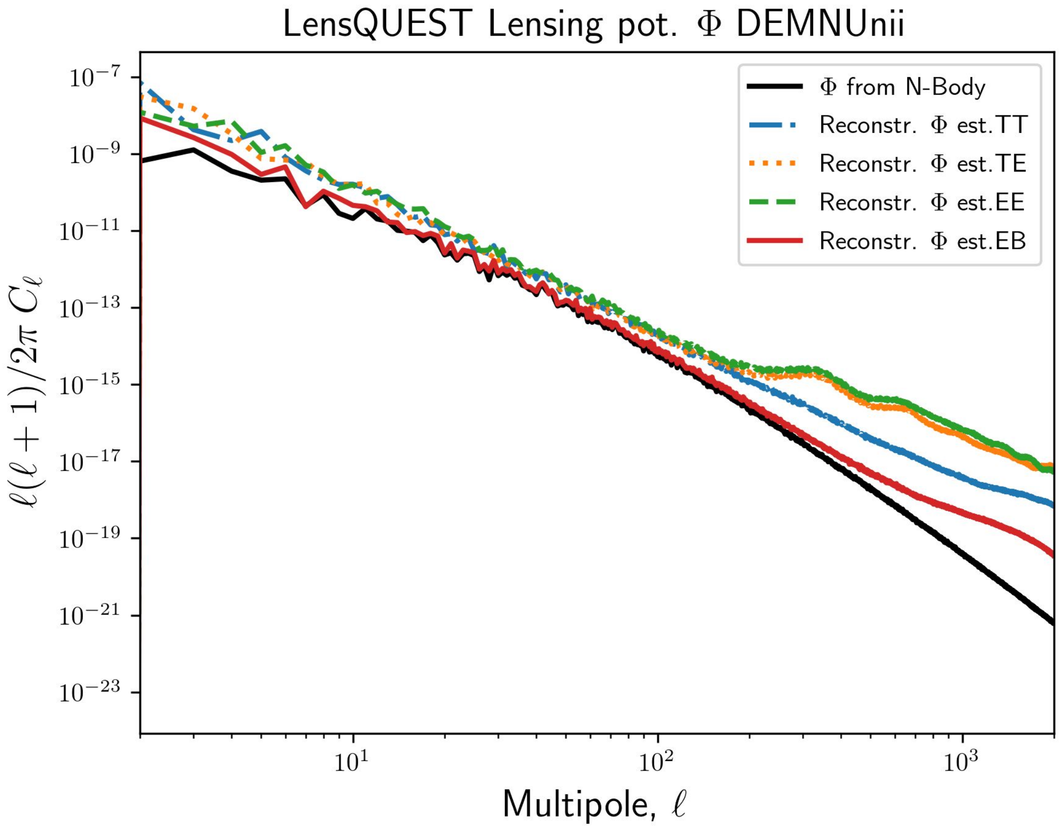
from Nbody Simulations → Light-cone and 2D maps of matter

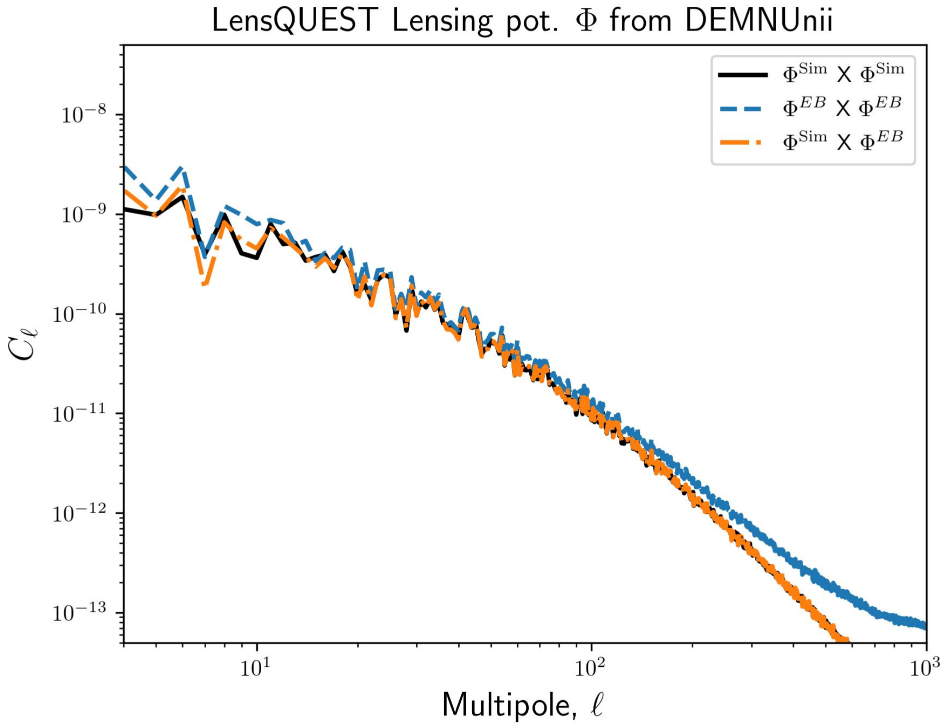
↓

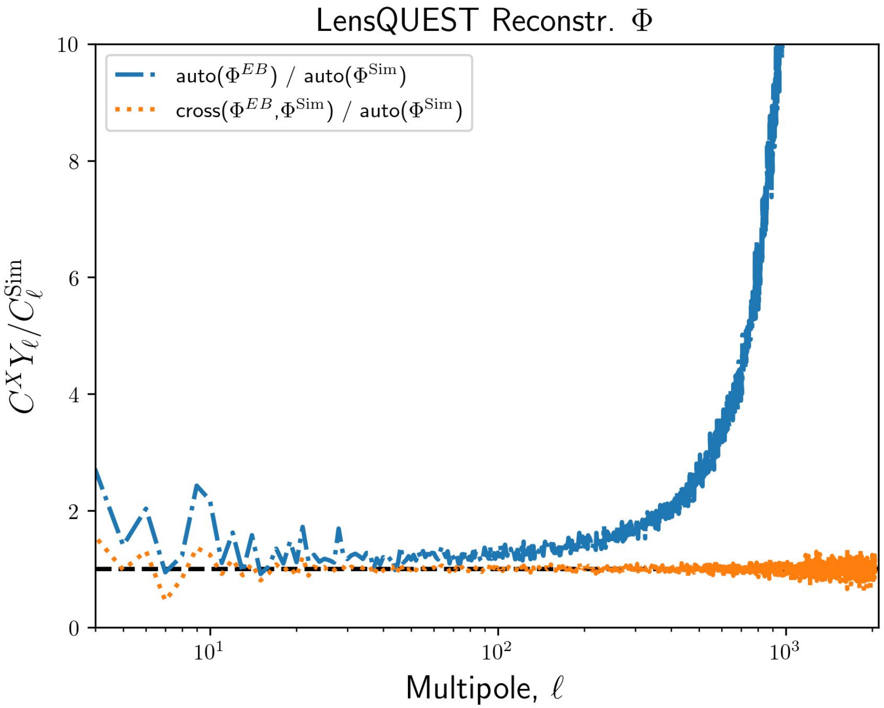
from CMB unlensed power spectrum → Lensed CMB field using LensPix and lensing potential maps from sims.

↓

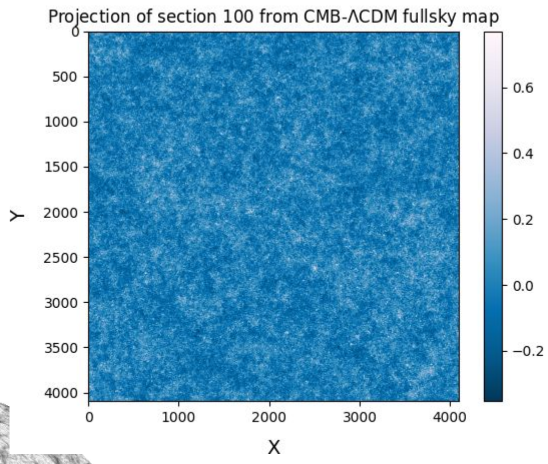
from lensed CMB field → lensing potential reconstruction via Hu&Okamoto (lensQUEST by D. Beck)

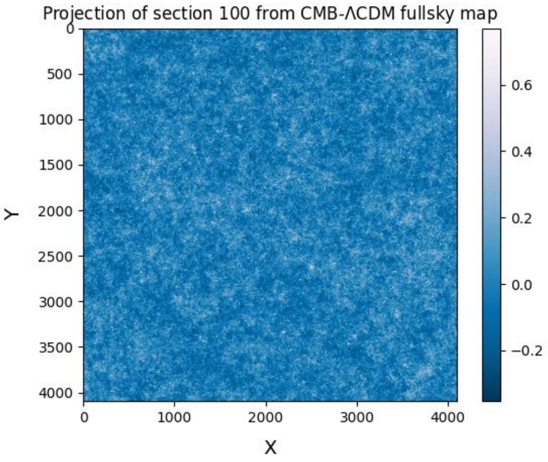



LensQUEST Lensing pot. Φ from DEMNUnii
$\Phi^{\rm Sim}$ X $\Phi^{\rm Sim}$
Φ^{EB} X Φ^{EB}
$\Phi^{\rm Sim}$ X Φ^{EB}
C_ℓ
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^1
10^2
10^3
Multipole, ℓ

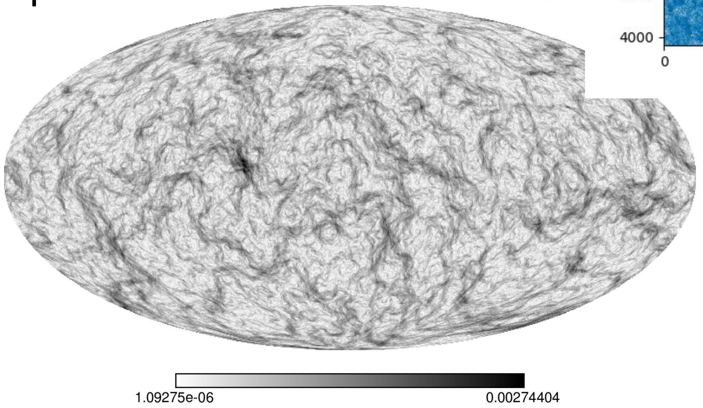

LensQUEST Reconstr. Φ
auto(Φ^{EB}) / auto($\Phi^{\rm Sim}$)
cross(Φ^{EB},$\Phi^{\rm Sim}$) / auto($\Phi^{\rm Sim}$)
$C^{XY}_\ell / C^{\rm Sim}_\ell$
10
8
6
4
2
0
10^1
10^2
10^3
Multipole, ℓ

Voids in flat-patches and XC (V. Picciano @UniPd, INAF-Mi)



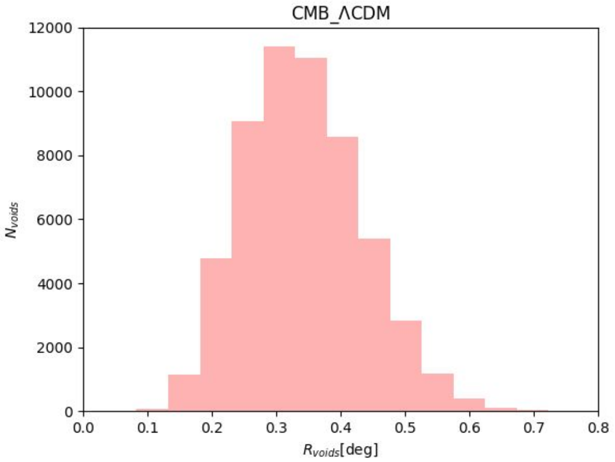


from 1 full-sky map to several flat-sky patches

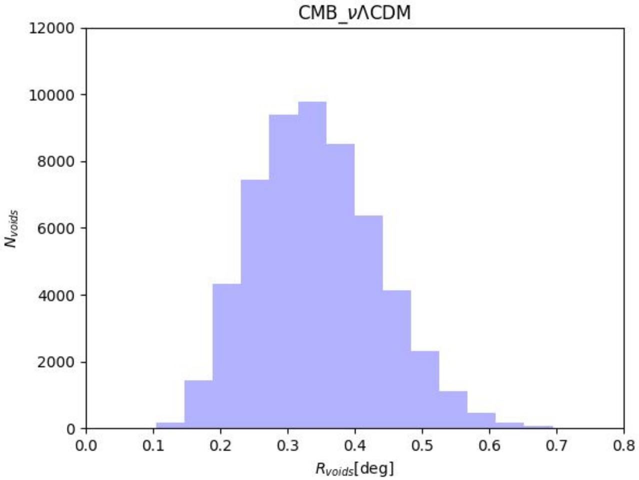


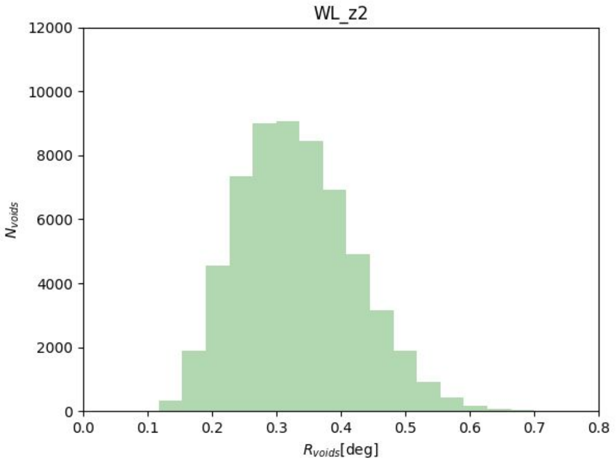
Voids detection in WL maps using algorithm by Davis, Cautun, Li 2018

Voids in flat-patches and XC (V. Picciano @UniPd, INAF-Mi)



LCDM + Mnu 0.16
(DEMNUNii)
kCMB lensing maps

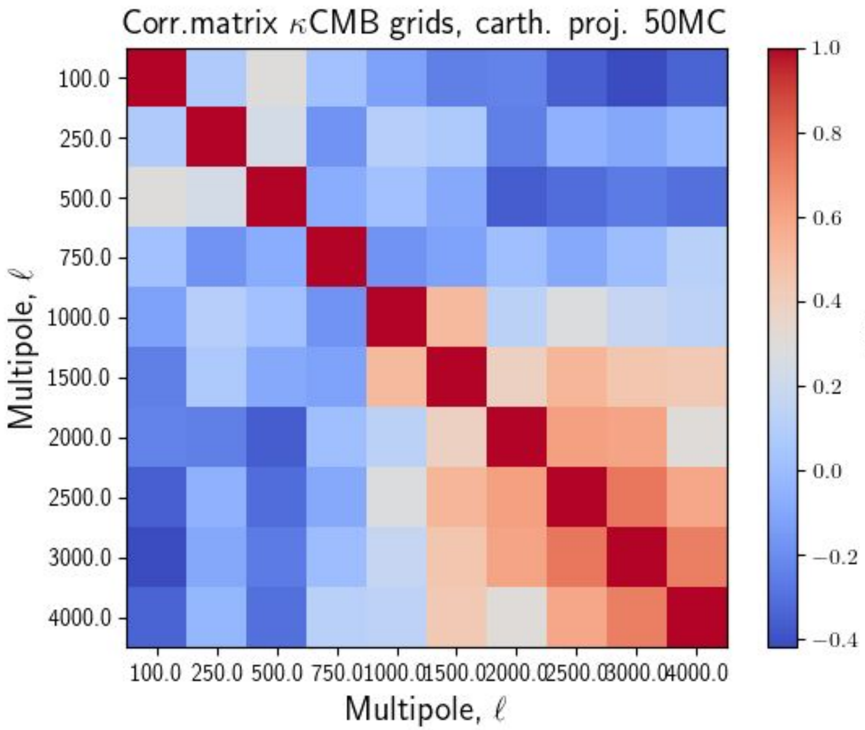


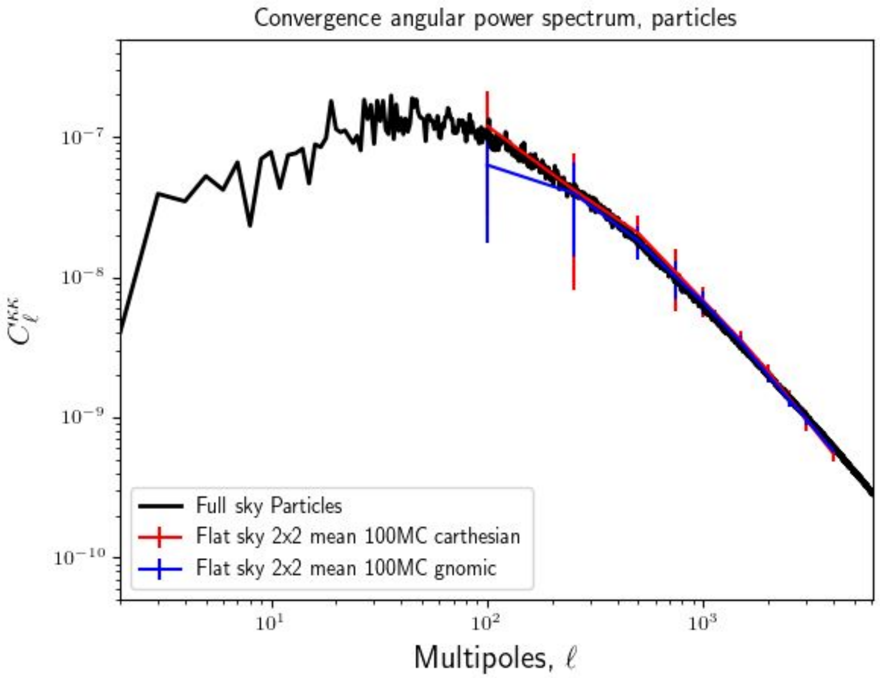


Voids radii distribution
LCDM (DEMNUNii)
kCMB lensing maps

LCDM + Mnu 0.16
(DEMNUNii)
WL (zs=2) lensing

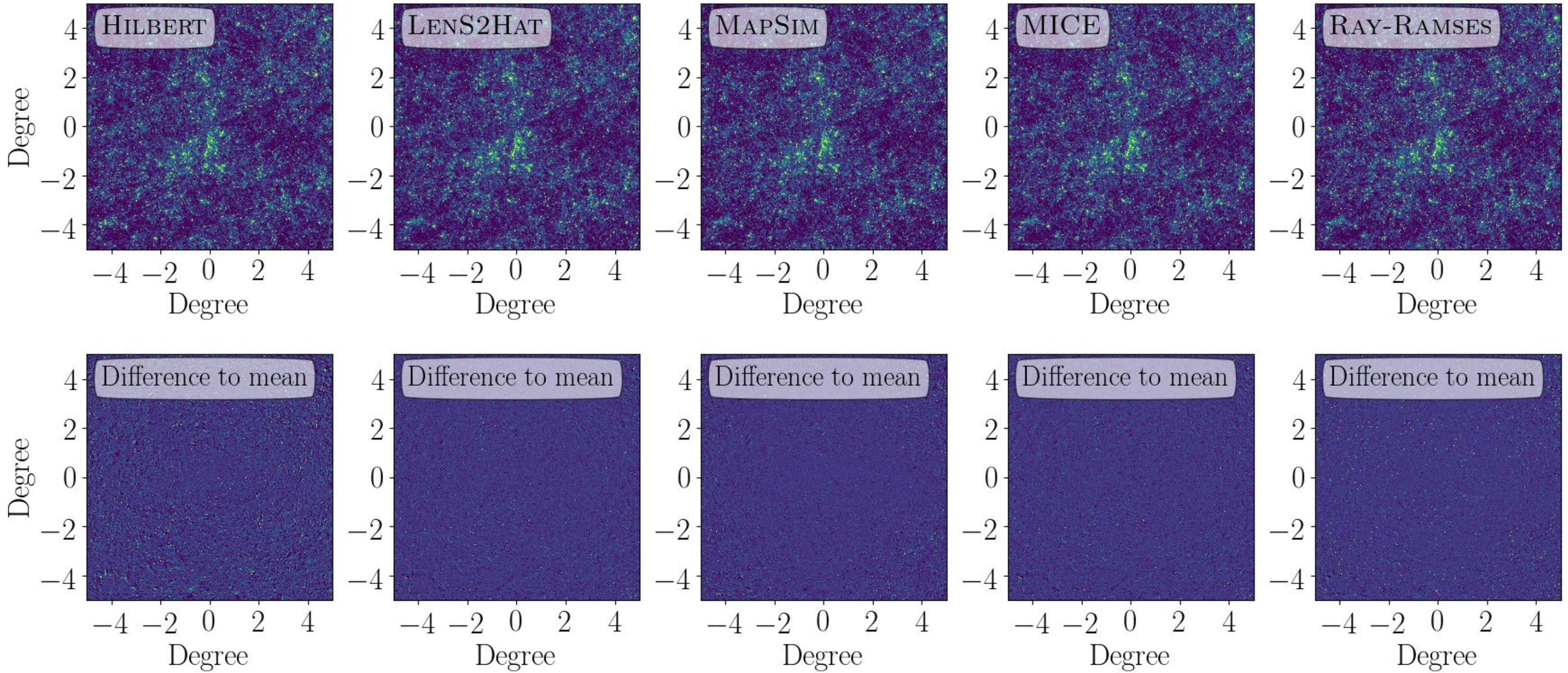
Covariances for flat-patches





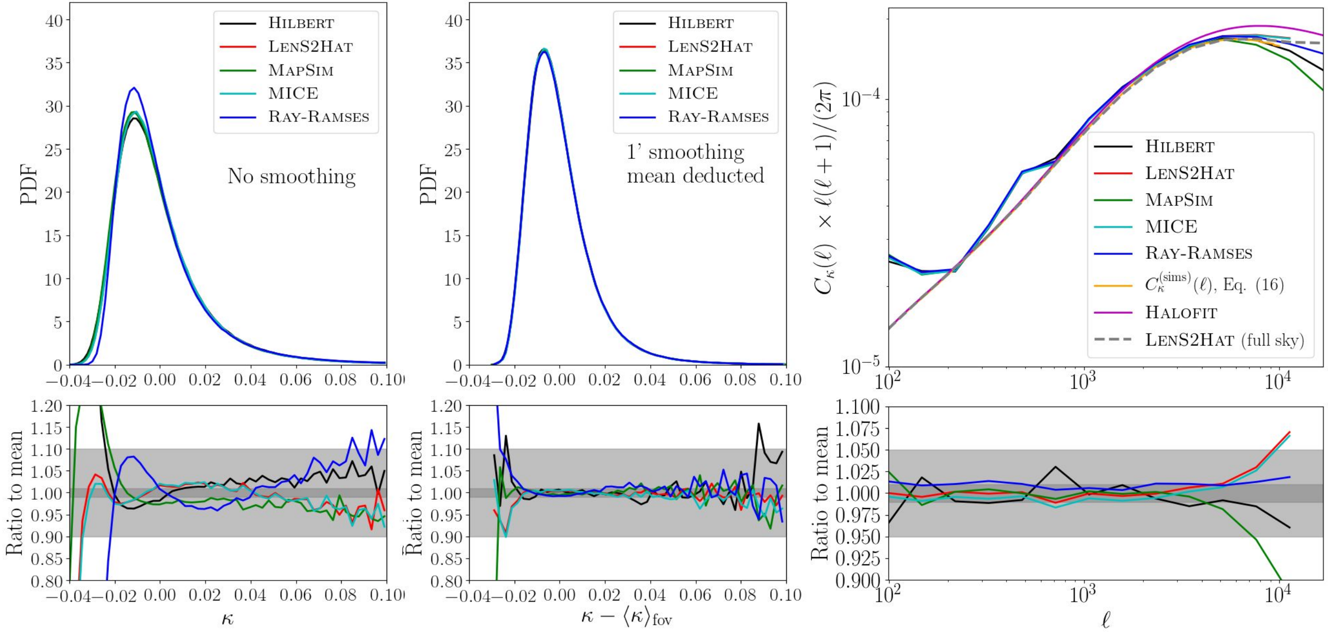
Lightcone comparison project (lens. convergence z<1)

- Finalized and paper submitted to arXiv and MNRAS (ECB approved).
- Flagship (MICE) code included in the comparison -> provide validation of CMBX sims (LenS2HAT).



Lightcone comparison project concluded

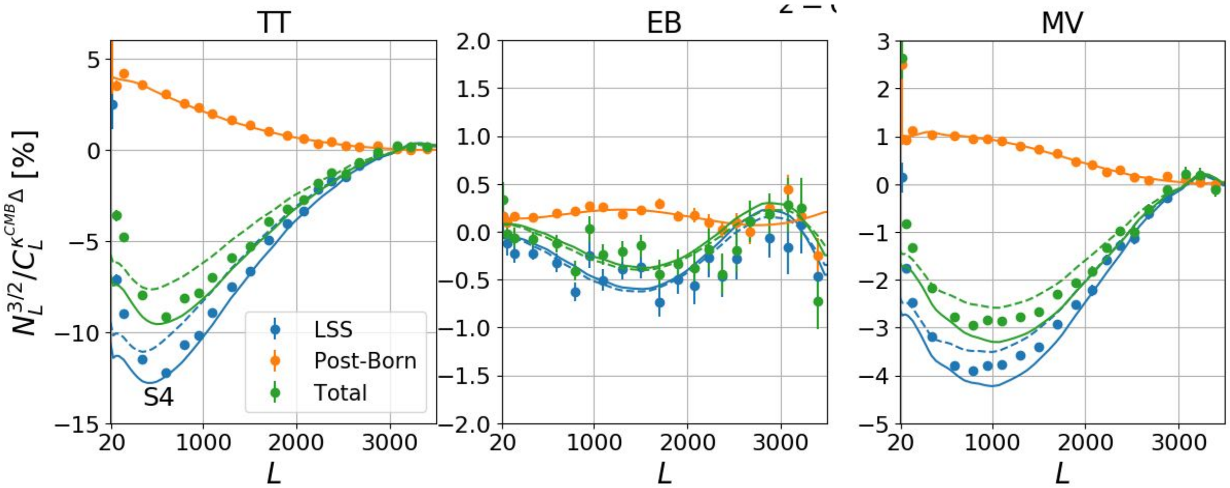
- Excellent agreement between codes (e.g. MICE) on power spectrum, non-Gaussian stats (e.g. PDF)/
- All numerical effects understood and accounted (smoothing, interpolation, post-Born only matters for PDF.

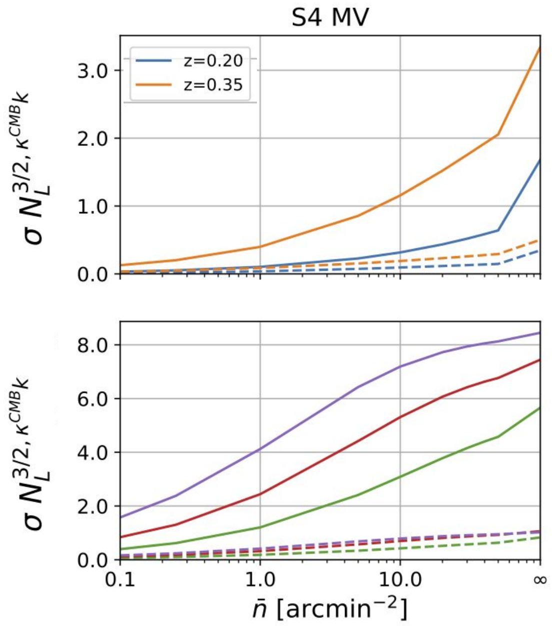


Hilbert, Barreira, Fabbian, et al. (2020), mnras, 493, 305

N3/2 bias for cross-correlation

- N3/2 bias due to non-linear+post-Born CMB lensing corrections will affect Euclid cross correlation with LSS tracer (e.g. shear auto-calibration with SO/S4). It can be mistaken for fake intrinsic alignment
- Detection significance for galaxy cross-correlation potentially enhanced by non-linear halo bias and cosmic variance cancellation in cosmological constraints.
- Ongoing study with non-quadratic max. likelihood reconstruction





Recap and conclusions

Finally!

What we have so far...

- N-body numerical simulations in different cosmologies (DEMNUni & DUSTGRAIN):
  → Objective 1: **cosmology-dependent signal** from Numerical simulations
- 2D healpix maps for different lensing observables
  → Objective 2: Covariances from different observables (k-CMB, WL, ISW, lensed-CMB,...)
  → Objective 3: Impact of non-linearities and off-diagonal terms on covariances matrix
- Numerical simulation to forecast model accuracy and estimations:
  → Objective 4: **Signal-to-noise** ratio measurement and its impact
- Lightcone and map-making
  → Objective 5: Potential grids vs particle grids (and in the future vs Dynamic Zoom projected maps)
  → Weak Lensing Convergence maps → **tomographic covariances with Euclid-n(z) sources**
- Cross correlation between different lensing observables
  → Objective 6: **Cross correlation** CMB-Temperature (lensed) X WeakLensing
  → **tomographic covariances of Tk cross-correlation with Euclid-n(z) sources**

… what we plan to do

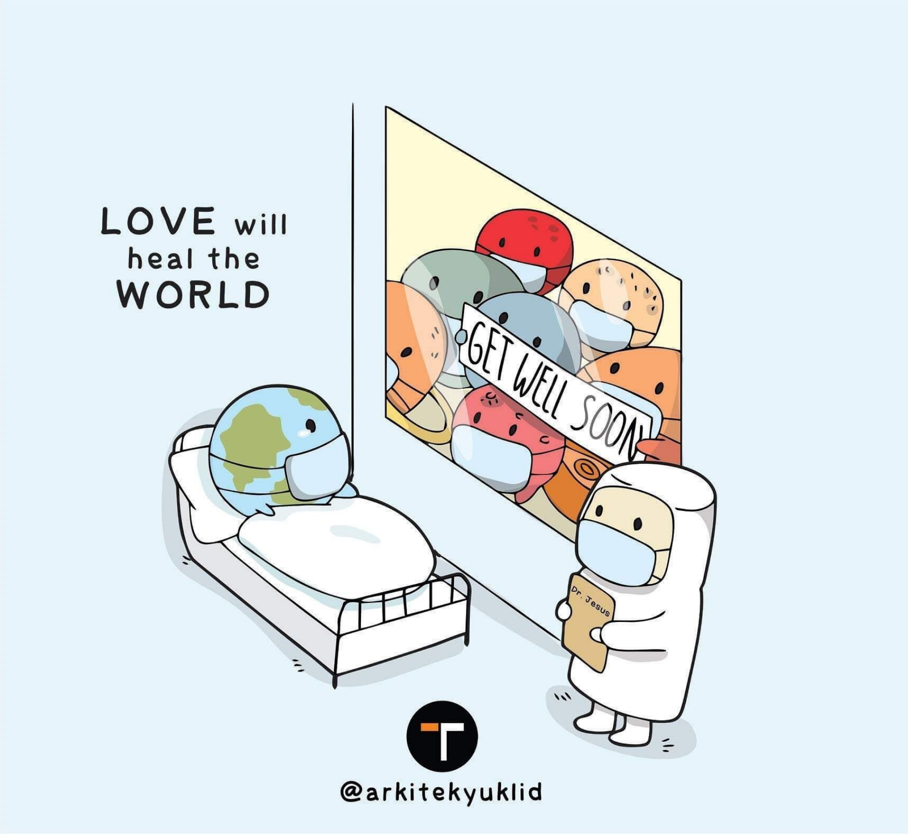
- Galaxy maps from simulations (in different cosmologies)
  → SHAM methods → **Cross (CMB-Convergence / WL-Convergence) X (Galaxies)** (In prep)
  → HOD methods → **Cross (CMB-Convergence / WL-Convergence) X (Cluster / SZ)**
- New covariances from different observables: ISW and Lensing potential reconstruction from Hu&Okamoto
- Mock catalogues and cross-correlation with **voids** (see Pauline's talk)
- Dynamic Zoom simulations for CMB-x, exploiting the new DZS method implemented in Gadget3
- Cross correlation (T-ISW) X (CMB-Convergence / Lensed CMB)

WIP

- Comparison Born approximation vs Multiple Lens CMB-lensing and WL covariances
- New observables extracted from simulations, e.g. SZ

Planned/next

Thanks.


LOVE will
heal the
WORLD
GET WELL SOON
Dr. Jesus
@arkitekyuklid

Dynamic Zoom Simulations

Euclid simulations lightcones (see e.g. Flagship) are **limited to low redshifts (z<2)** as they are aimed to focus on galaxy clustering and WL in the z-range of Euclid.

However, **CMB-X requires a continuous lightcone up to the CMB last scattering** surface (z~1100)

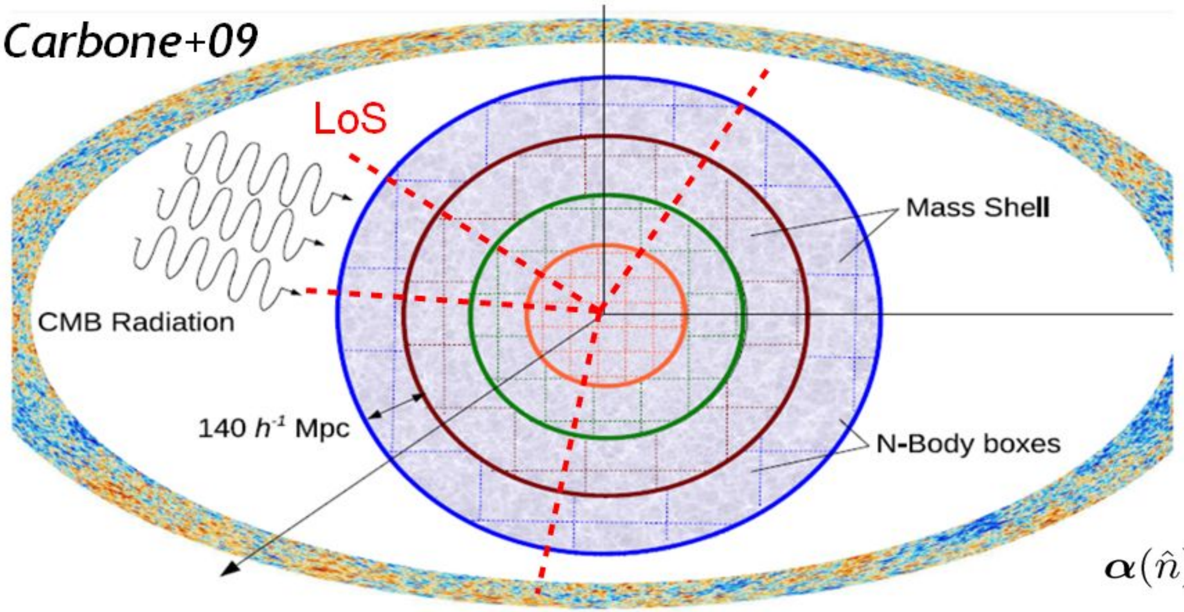
Covering such volume with enough particles to resolve individual galaxies in the Euclid observable range would **result in a humongous dynamic range** (i.e. an unbearable computational cost)

This is due to a simple fact:

- The **VOLUME** of the simulation is dictated by the comoving volume at the **maximum redshift** to be probed
- The **PARTICLE NUMBER** is dictated by the **minimum galaxy mass** (luminosity) that has to be resolved at z=0

Dynamic Zoom Simulations

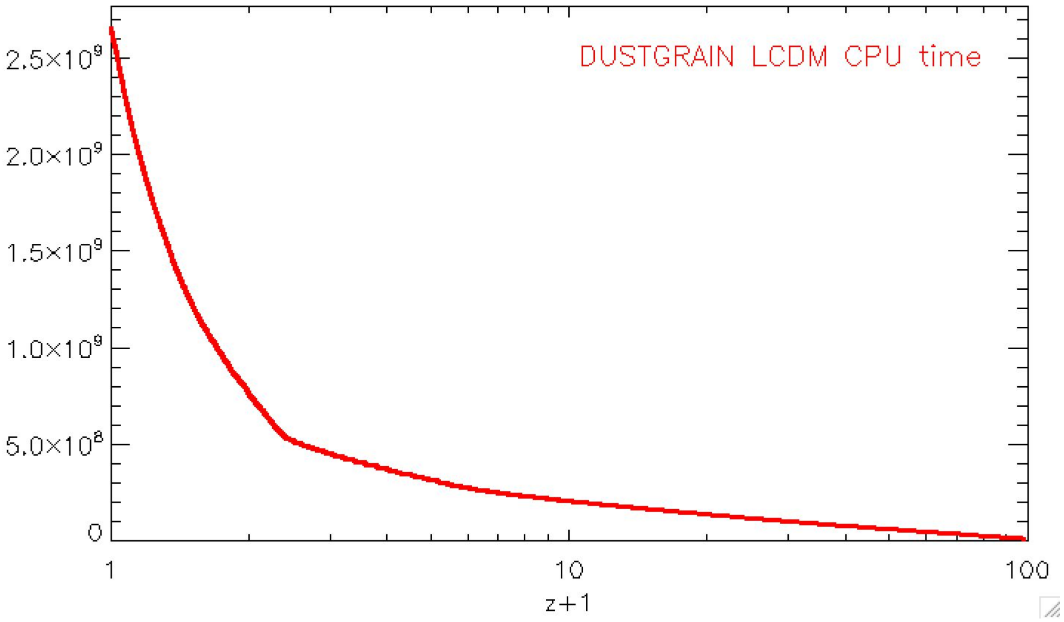
Therefore, the **standard way to build lightcones** (up to high z) is to **pile smaller high-resolution boxes** within concentric cells (with randomisation, i.e. rotations and flips) to fill the lightcone up to the maximum desired source redshift



$$\boldsymbol{\alpha}(\hat{n}) = -2\int_0^{\chi_*} \mathrm{d}\chi \frac{\chi_* - \chi}{\chi_* \chi} \nabla_{\hat{n}} \Psi(\chi\hat{n}, \chi)$$

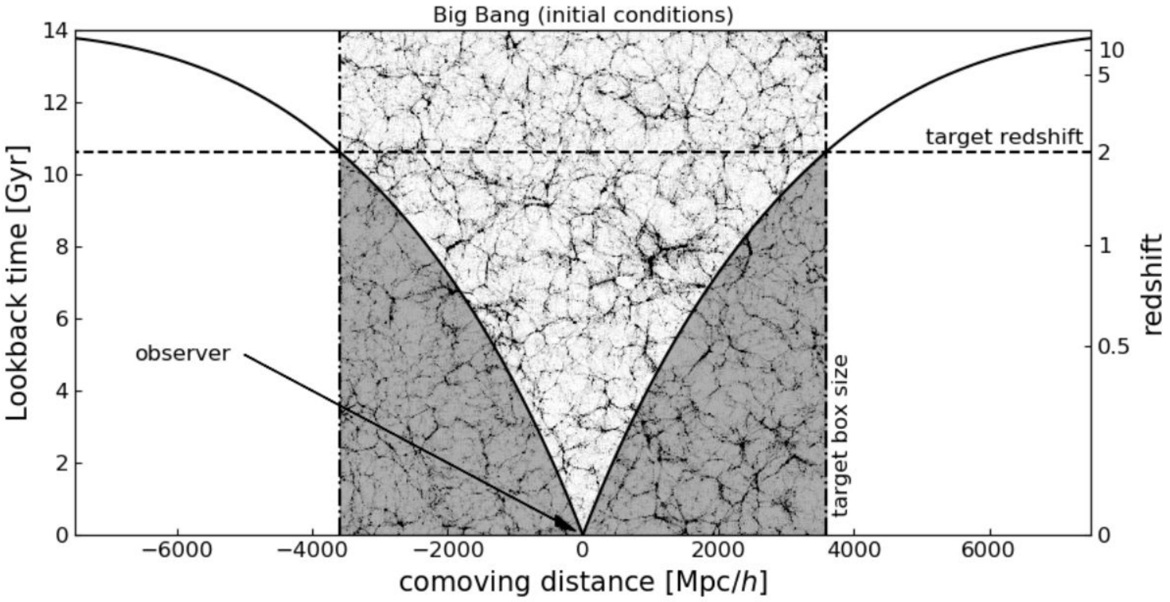
Dynamic Zoom Simulations

The **major fraction of the CPU cost is spent to evolve the system at low redshifts**



Dynamic Zoom Simulations

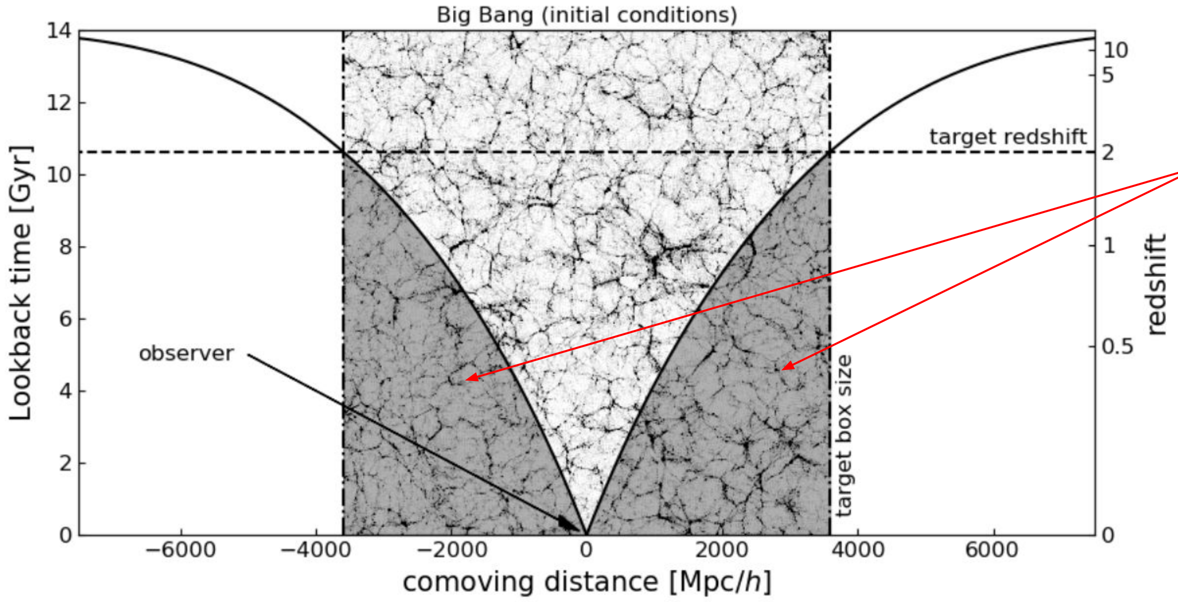
The **major fraction of the CPU cost is spent to evolve the system at low redshifts**
However, at low redshifts **MOST OF THE SIMULATED VOLUME IS NOT OBSERVABLE as it lies outside the past lightcone**



Plot from
Garaldi, Nori & Baldi in prep.

Dynamic Zoom Simulations

The **major fraction of the CPU cost is spent to evolve the system at low redshifts**
However, at low redshifts **MOST OF THE SIMULATED VOLUME IS NOT OBSERVABLE as it lies outside the past lightcone**

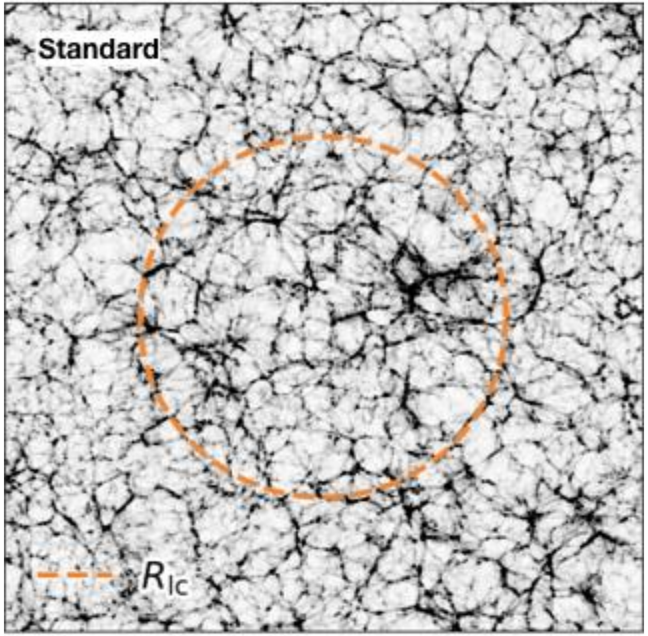


Most of the CPU cost is actually wasted to simulate regions of the universe that are then discarded when building the lightcone
This was already noticed by Llinares 2017

Plot from
Garaldi, Nori & Baldi in prep.

Dynamic Zoom Simulations

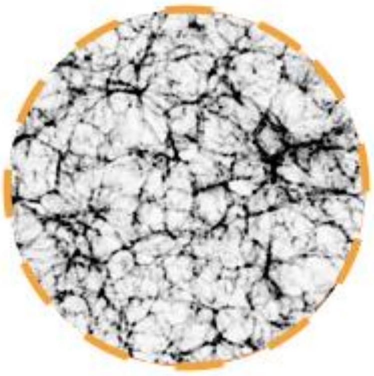
A possible way to alleviate the problem was proposed in 2017 by Llinares with the **“Shrinking Domain Approach”**



Dynamic Zoom Simulations

A possible way to alleviate the problem was proposed in 2017 by Llinares with the **“Shrinking Domain Approach”: just delete ALL particles that at a given timestep lie out of the lightcone**

Shrinking Domain (Llinares 2017)



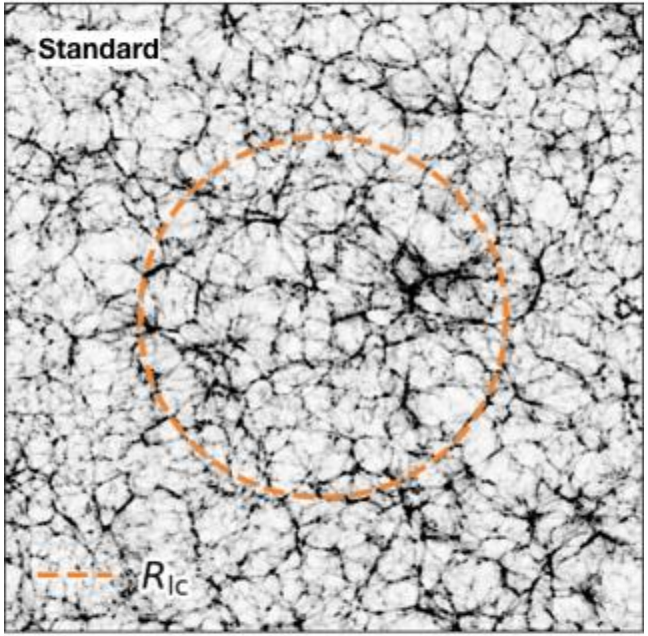
This allows to avoid spending time in evolving regions of the universe that would be anyway unobservable.

<u>However</u>:

- Problems at the boundary
- No longer periodic boundary conditions
- Need to modify the gravitational solver to “correct” for the absence of outward gravitational forces
- Affects the evolution within the lightcone

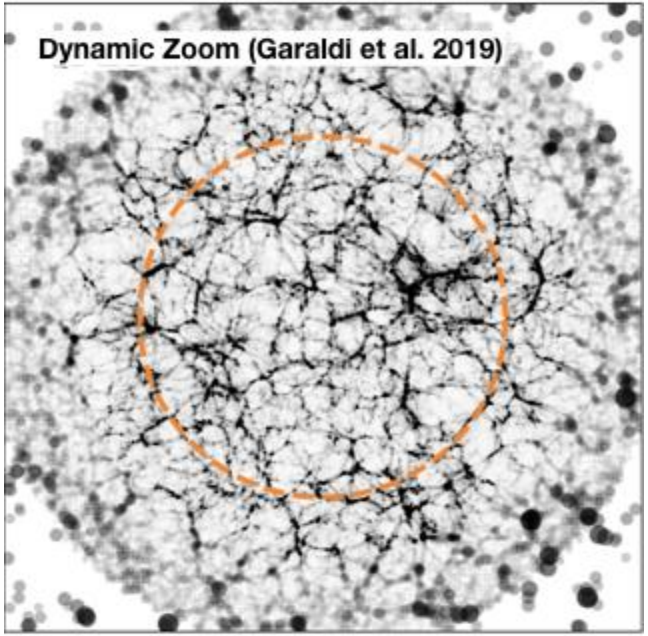
Dynamic Zoom Simulations

We are presently developing (Garaldi, Nori & Baldi in prep., likely to be submitted in a few weeks) a new method implemented in Gadget3 that **b**.



Dynamic Zoom Simulations

We are presently developing (Garaldi, Nori & Baldi in prep., likely to be submitted in a few weeks) a new method implemented in Gadget3 that **automatically de-refines simulation resolution in regions outside the past lightcone**.

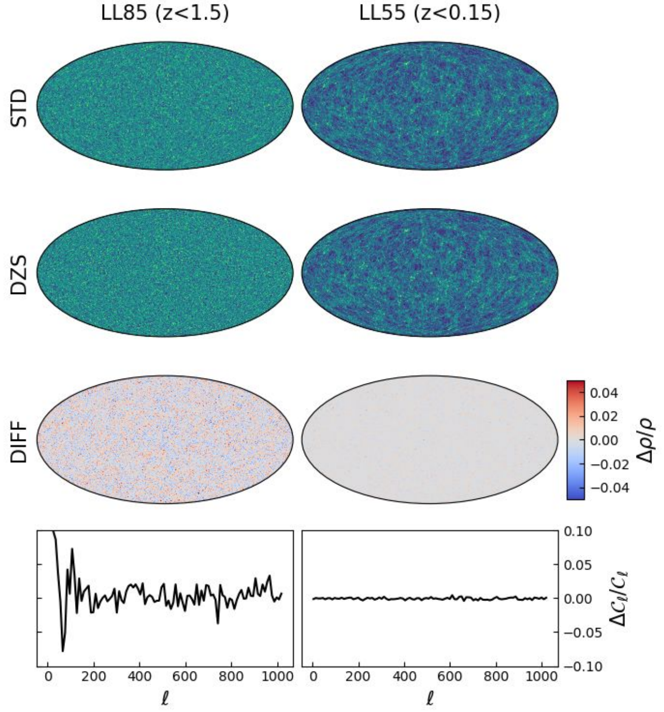


This is **based on the concept of Zoom-in simulations** normally employed to simulate individual objects at high resolution still maintaining the large-scale tidal field:

- Particles are **not deleted, but de-refined** outside the lightcone
- No sharp boundary
- Periodic boundary conditions preserved
- No need to correct for unrealistic large-scale forces
- **No need to modify the gravity solver**

Dynamic Zoom Simulations

Preliminary tests seem to confirm that **the method does not introduce spurious features**...



Relative deviation in integrated mass per pixel (HealPix with Nside=256) always below a few percent.

<10% particles with $|\Delta\Phi/\Phi|>0.01$ and <1% particles with $|\Delta\Phi/\Phi|>0.1$

Relative deviation in the angular power spectrum of the integrated full-sky maps generally below 5%

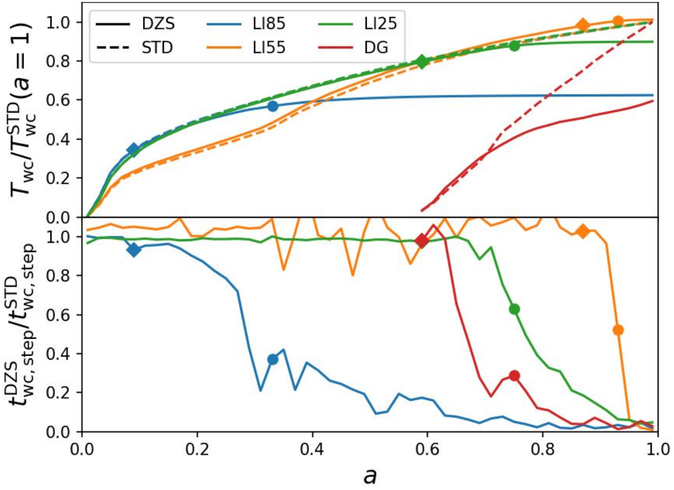
All these tests are based on "one-shot" runs of the DZS module, NO FINE TUNING of the numerical parameters (de-refinement buffer, opening angle, etc.) yet performed

Garaldi, Nori & Baldi in prep.

Dynamic Zoom Simulations

Preliminary tests seem to confirm that **the method does not introduce spurious features…**
And that **computational cost is highly suppressed (the more so the larger is the simulation box)**

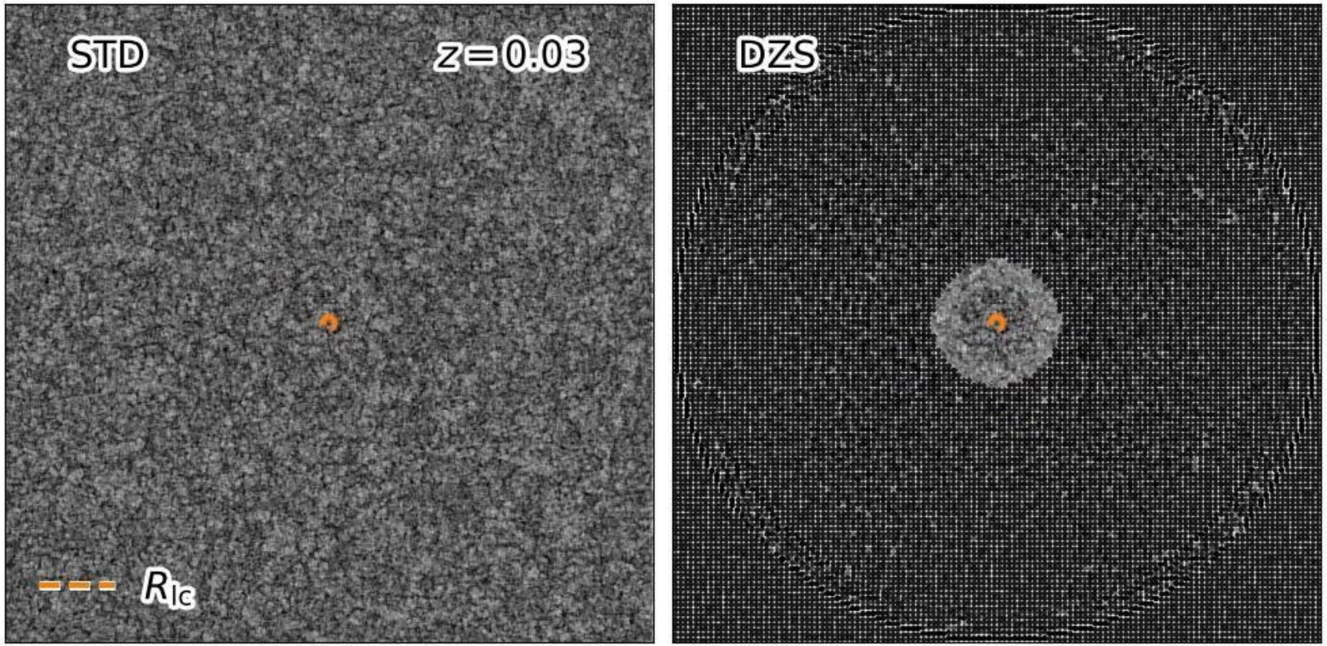
Name	L_{box} (h^{-1} Mpc)	N_p
LI55	512	512^3
LI25	2048	512^3
LI85	8192	512^3
LI81	8192	1024^3
DUSTGRAIN	2000	2048^3



- **Reduction of cumulative CPU time for our tests can reach 50% for sufficiently large boxes** (for small boxes DZS basically never kicks in)
- This gain will increase with simulation resolution, as **the wall-clock time per timestep decreases by up to 95% when using DZS**
- **Even this estimate is still conservative**, as it assumes a static allocation of resources while the reduction of particle number **will allow a dynamic reduction of the required CPUs**

Garaldi, Nori & Baldi in prep.

Dynamic Zoom Simulations



Garaldi, Nori & Baldi in prep.
Movie by E. Garaldi

Dynamic Zoom Simulations

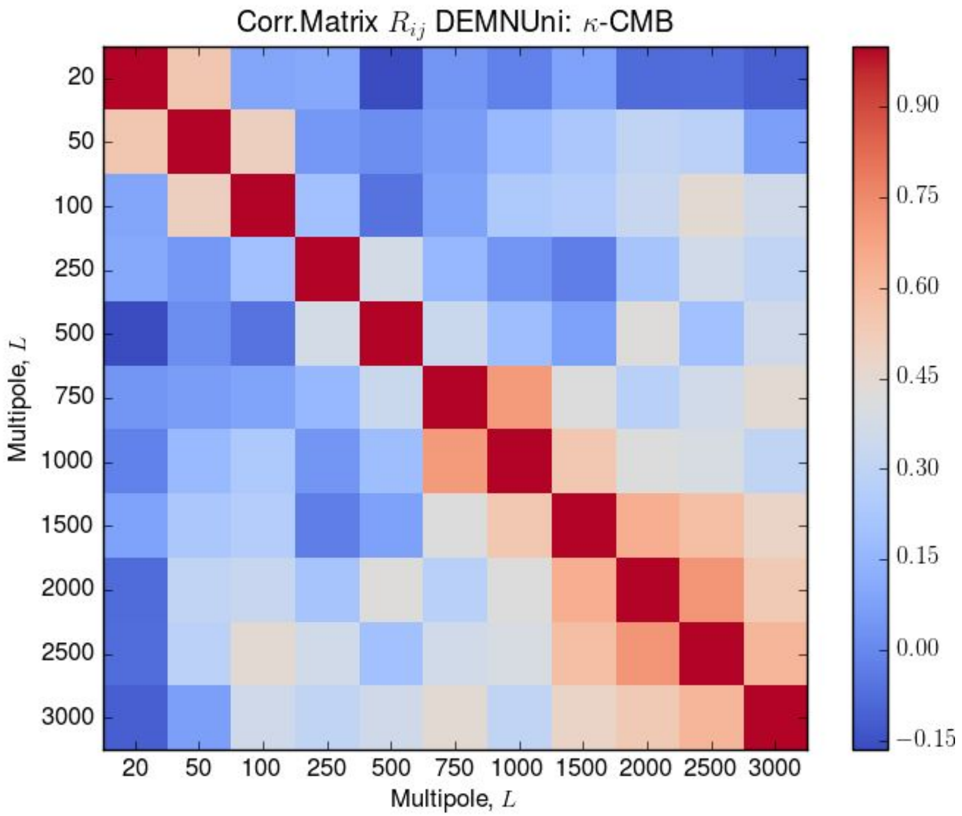
Next steps:

- Implementation of dynamic allocation of computational resources ⏳
- Extension to Dark Energy and Modified Gravity versions of Gadget ❌
- Implementation of on-the-fly lightcone generation and projected HealPix Maps ✓
- Implementation of on-the-fly projected HealPix maps of Φ and $d\Phi/dt$ ❌
- Application to Full-Universe lightcone simulations ❌

Covariances from Grid potential maps

First steps.

Cov. Matrix: k-CMB auto-spectrum [LCDM]



C_L CMB-Convergence DEMNUni → Covariance Matrix

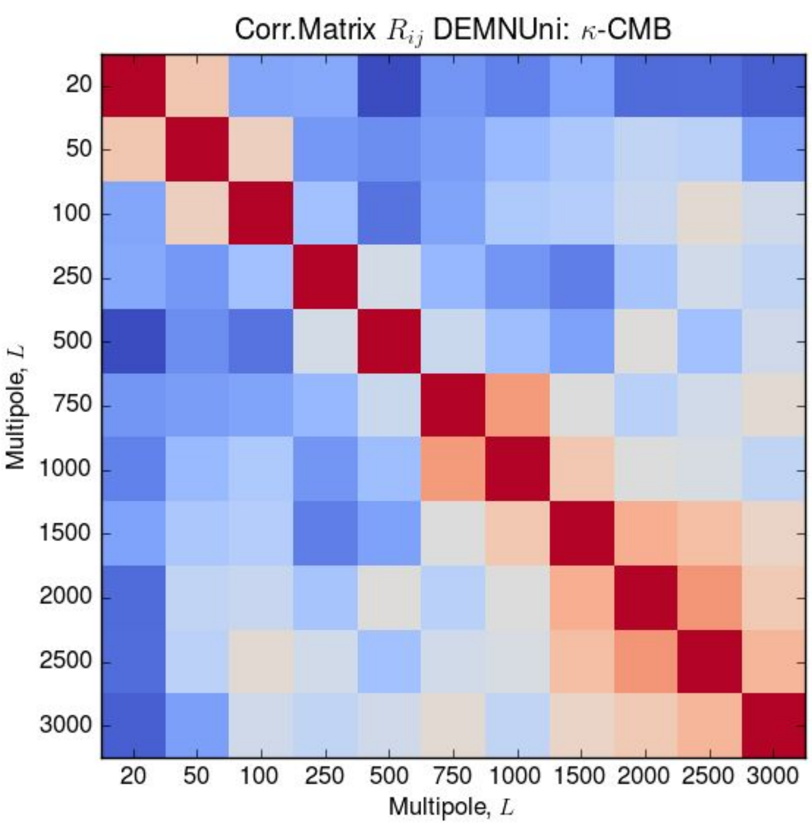
11 Bins in multipole, L = {20,50,100,250,500,750,1000,1500,2000, 2500,3000}

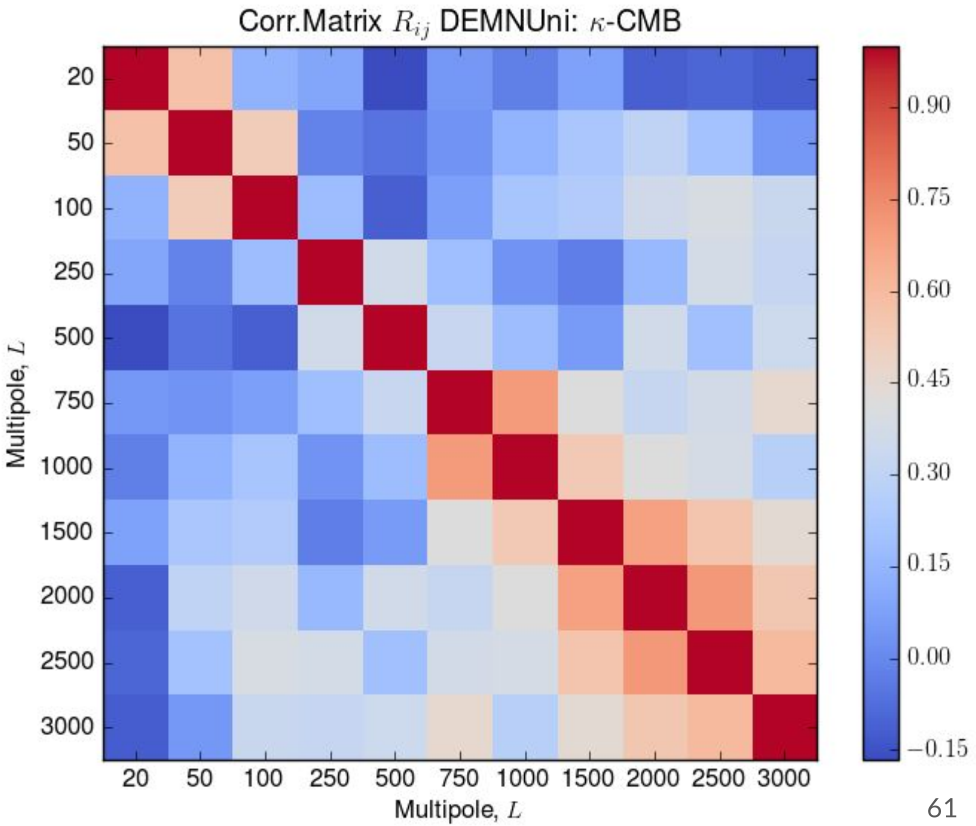
Nside Convergence maps = 2048
Number of Simulations = 50

LCDM and Mnu=0.16

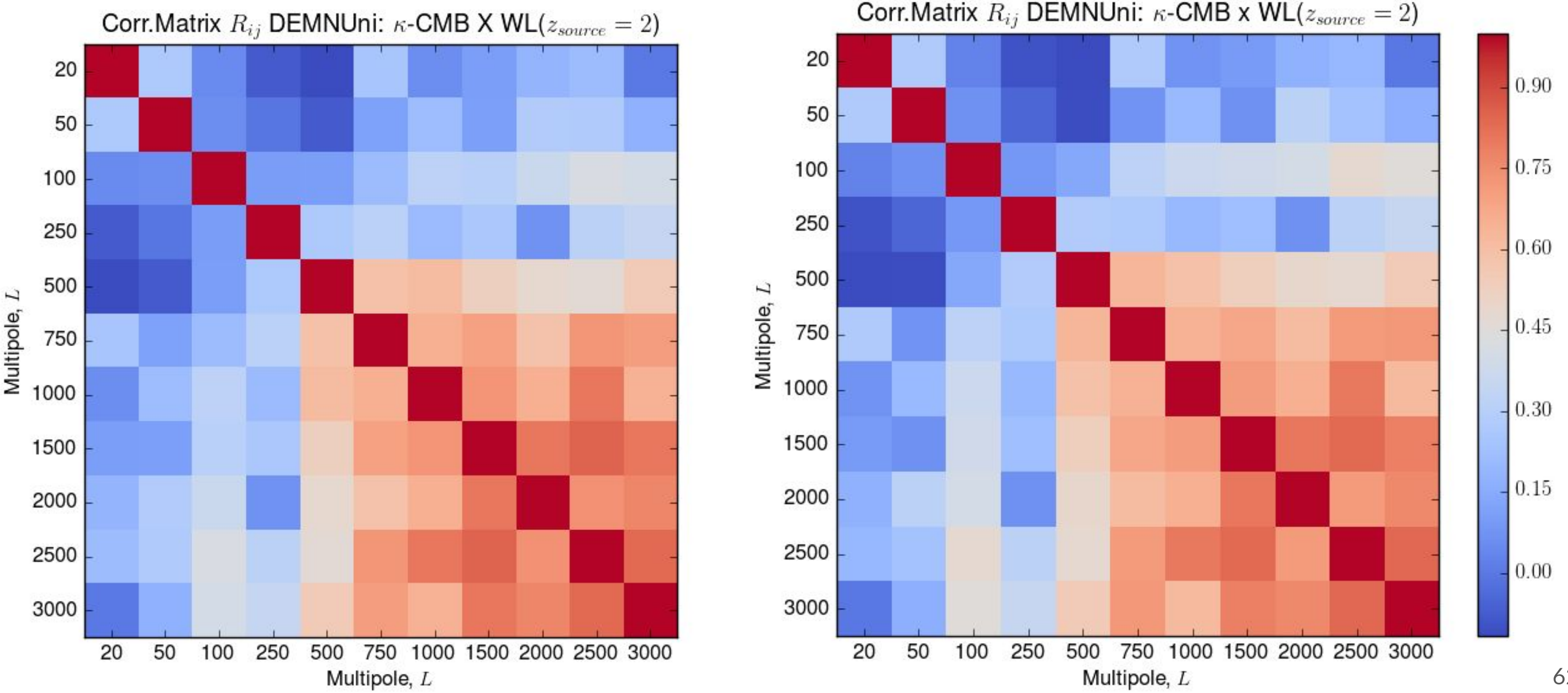
Figures are Correlation Matrix
(Covariances normalized to diagonal variances)

k-CMB auto-spectrum [LCDM vs M(nu)=0.16 eV]

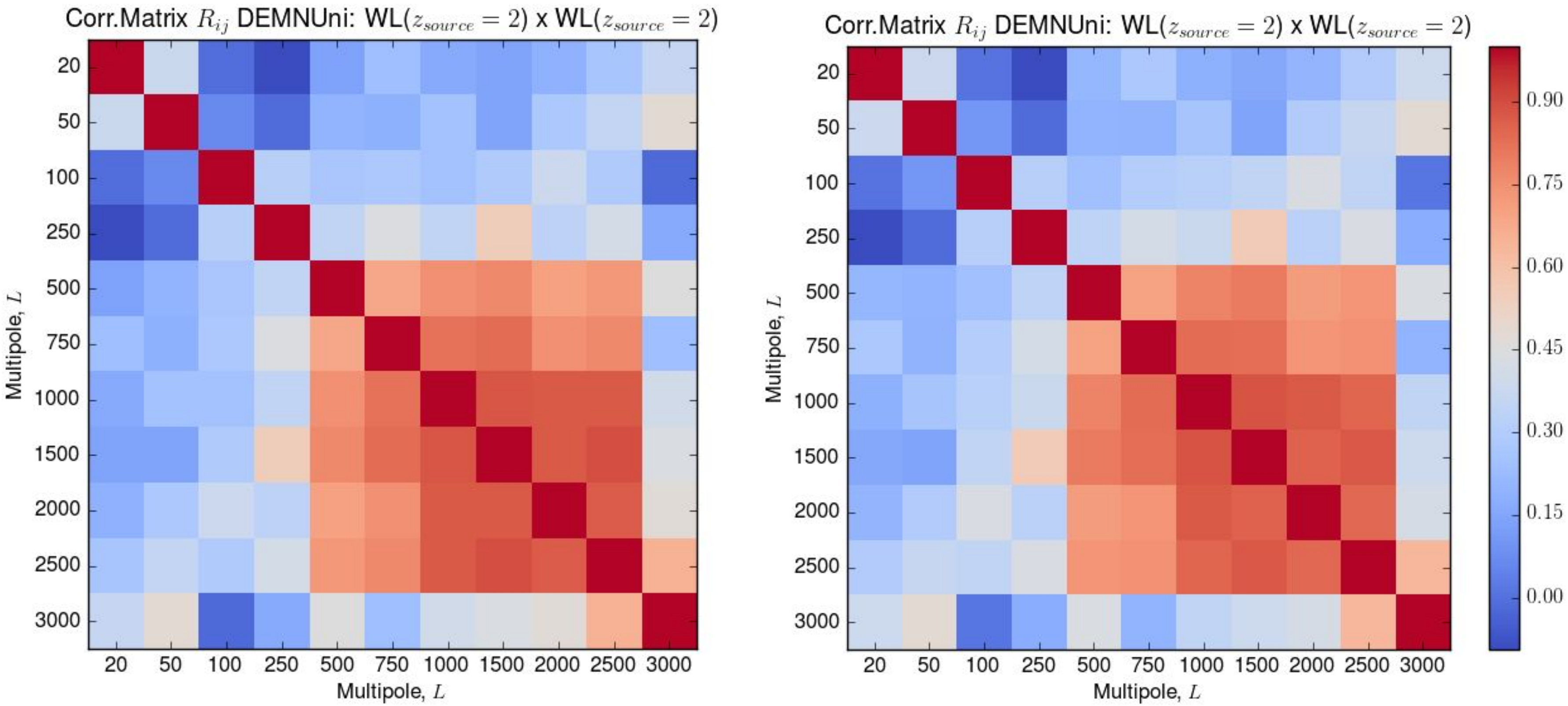


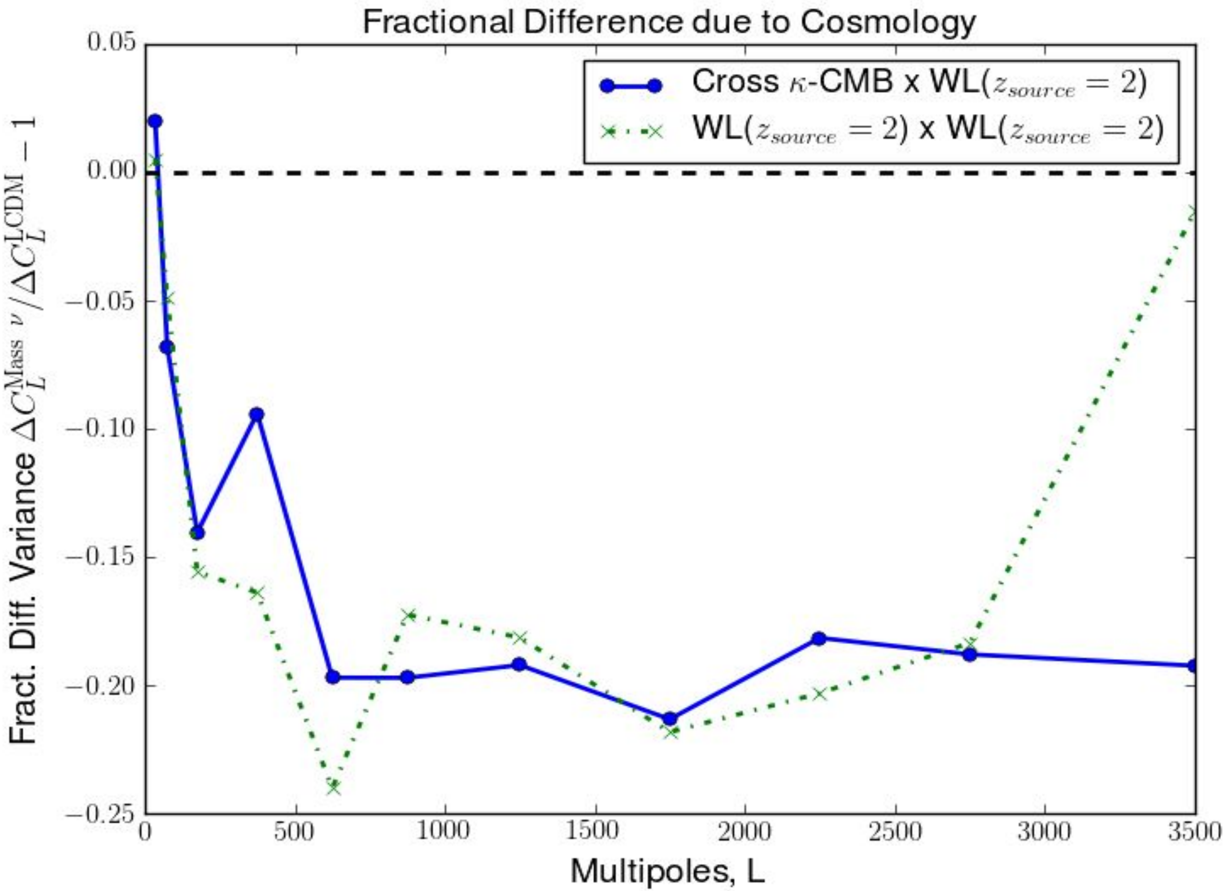


cross k-CMB X WL(z=2) [LCDM vs M(nu)=0.16 eV]



WL(z=2) auto-spectrum [LCDM vs M(nu)=0.16]




Fractional Difference due to Cosmology
Cross κ-CMB x WL($z_{source} = 2$)
WL($z_{source} = 2$) x WL($z_{source} = 2$)
Fract. Diff. Variance $\Delta C_L^{\mathrm{Mass}\ \nu} / \Delta C_L^{\mathrm{LCDM}} - 1$
Multipoles, L
0.05
0.00
−0.05
−0.10
−0.15
−0.20
−0.25
0
500
1000
1500
2000
2500
3000
3500

Signal-to-noise from covariances

Measuring significance.

From Covariances to Signal-to-Noise Ratio (SNR)

from Nbody Simulations → Light-cone and 2D maps of matter

↓

from maps → angular power spectrum and covariances

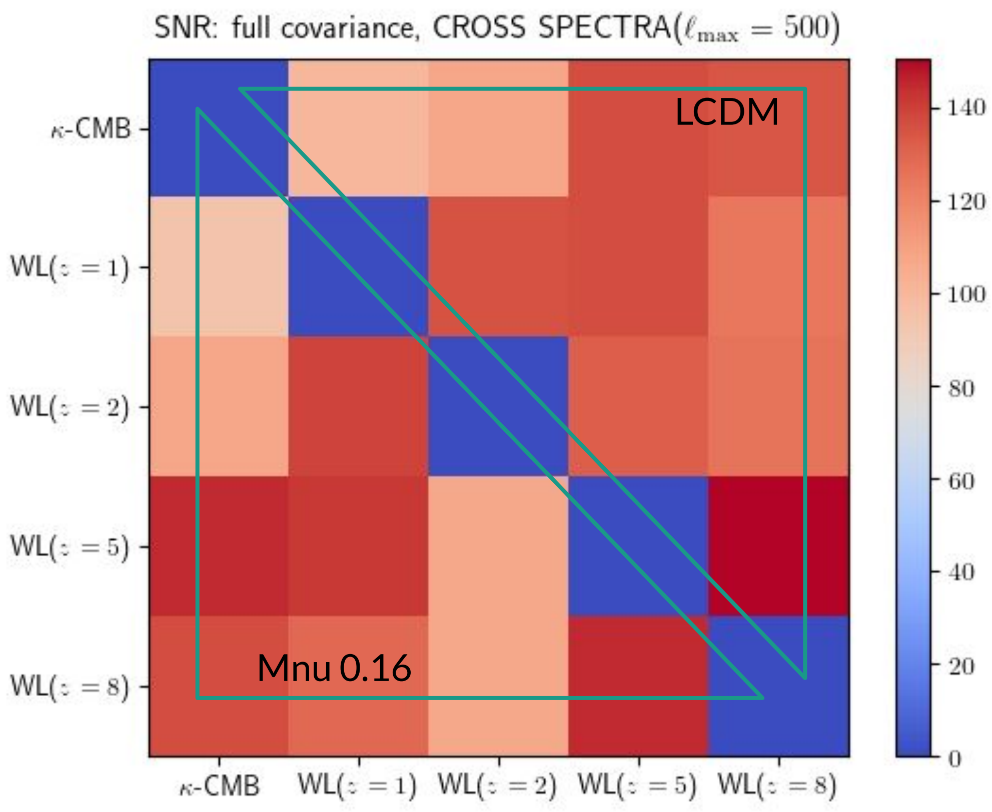
↓

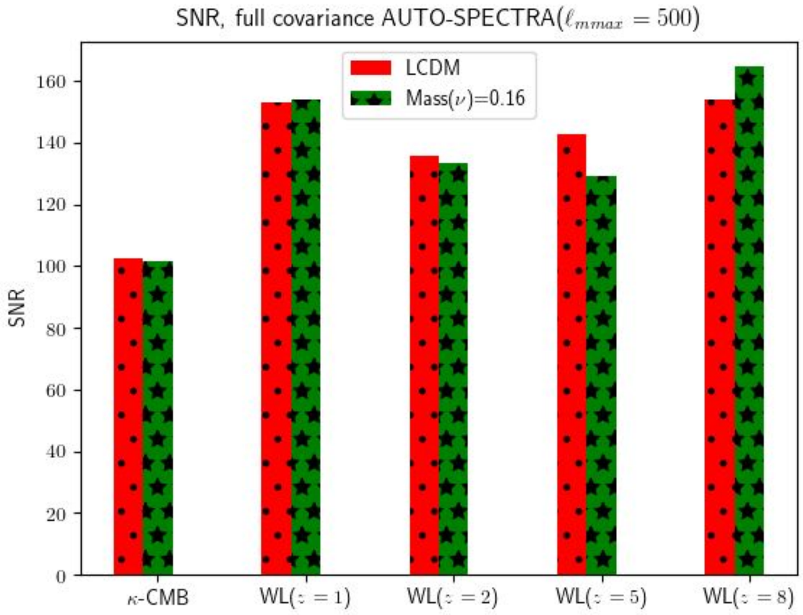
from covariances → signal-to-noise ratio

Observable	k-CMB	WL(z=1)	WL(z=2)	WL(z=5)	WL(z=8)
k-CMB					
WL(z=1)					
WL(z=2)					
WL(z=5)					
WL(z=8)					

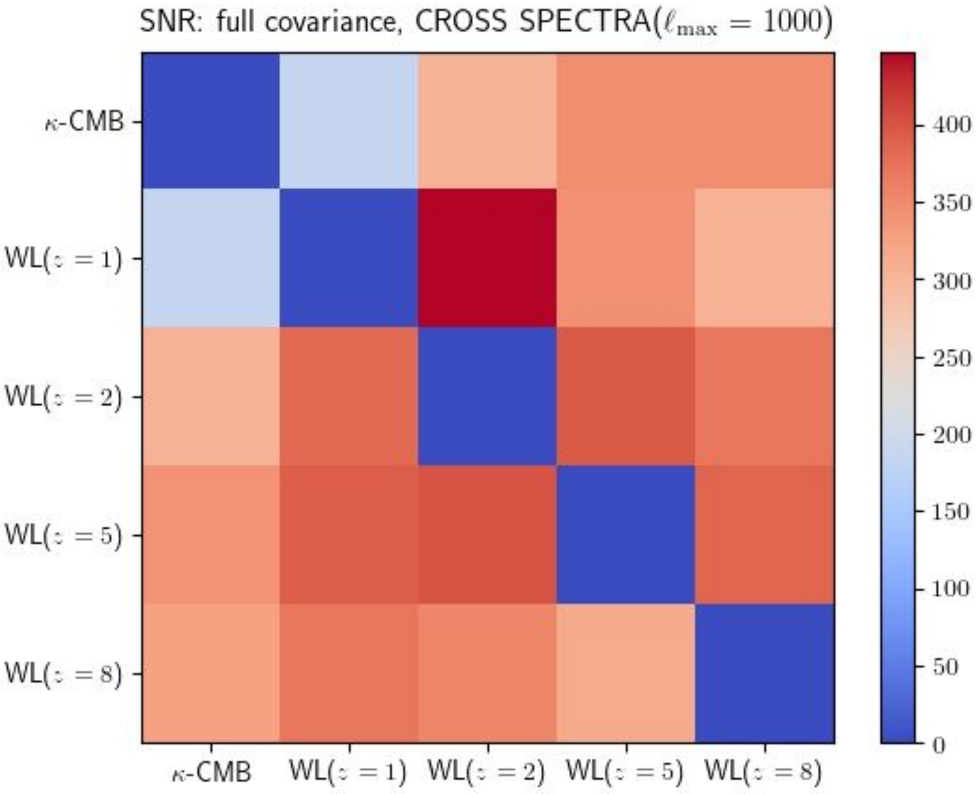
$$(S/N)^2 = \sum_{\ell,\ell'}^{\ell_{\max}} C_\ell^{\mathrm{XY}} \mathrm{Cov}_{\ell\ell'}^{-1} C_{\ell'}^{\mathrm{XY}}$$

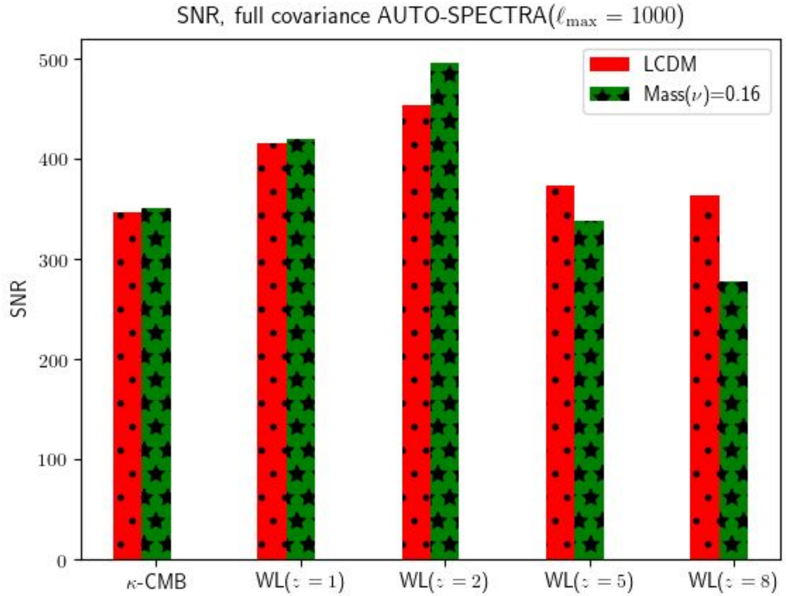
SNR for different observ. lmax = 500



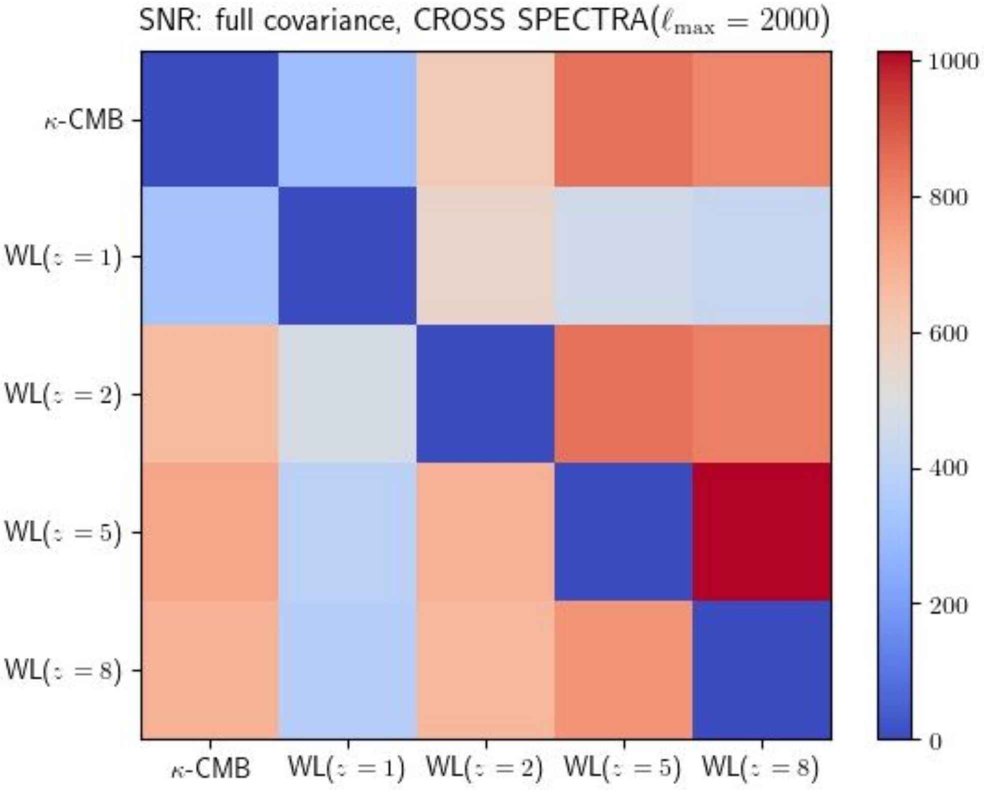


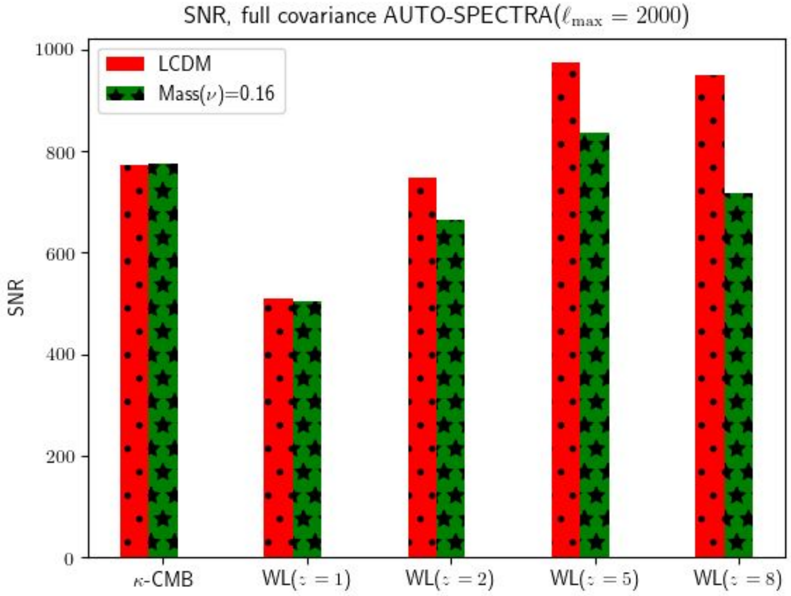
SNR for different observ. lmax = 1000



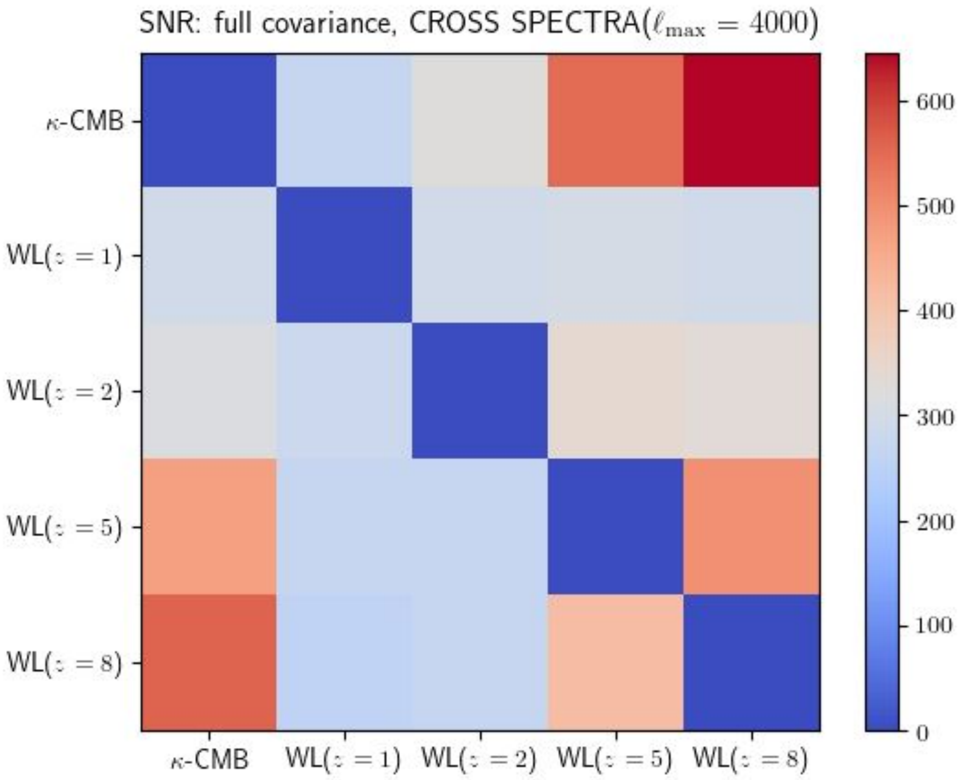


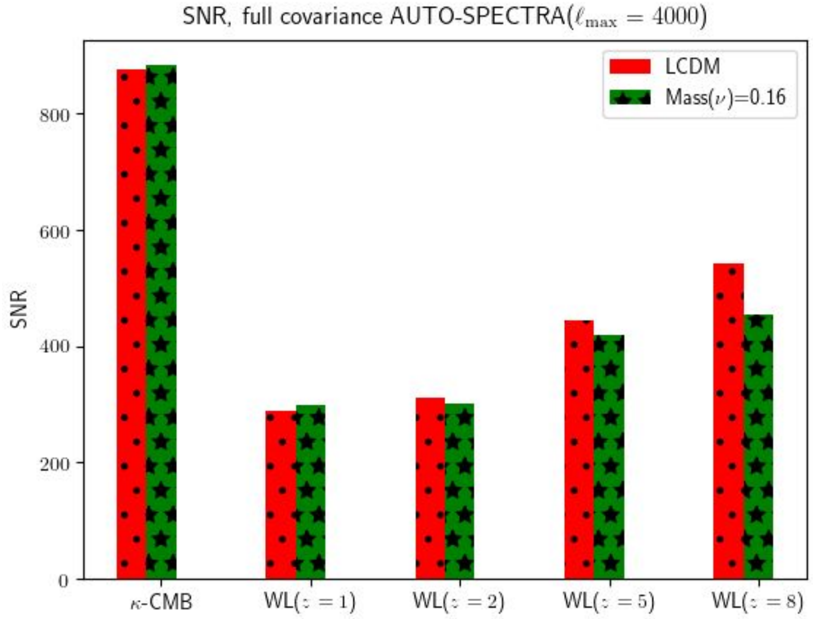
SNR for different observ. lmax = 2000

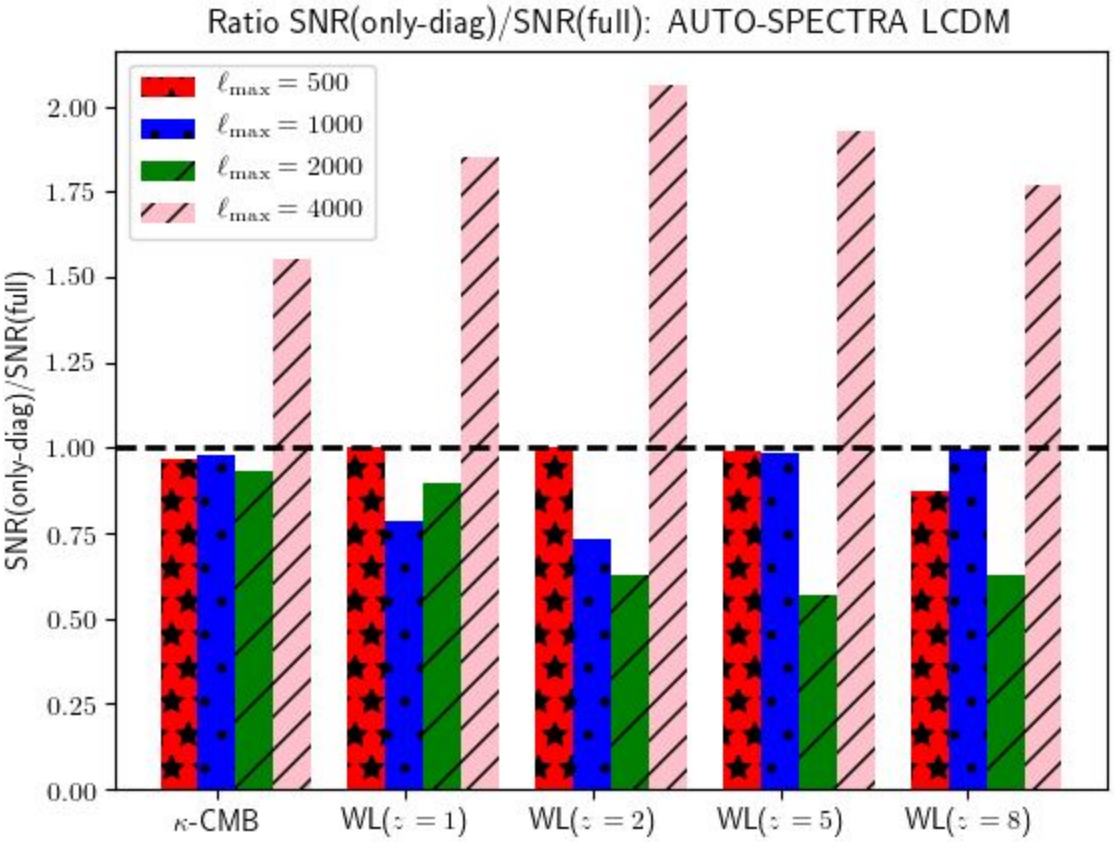




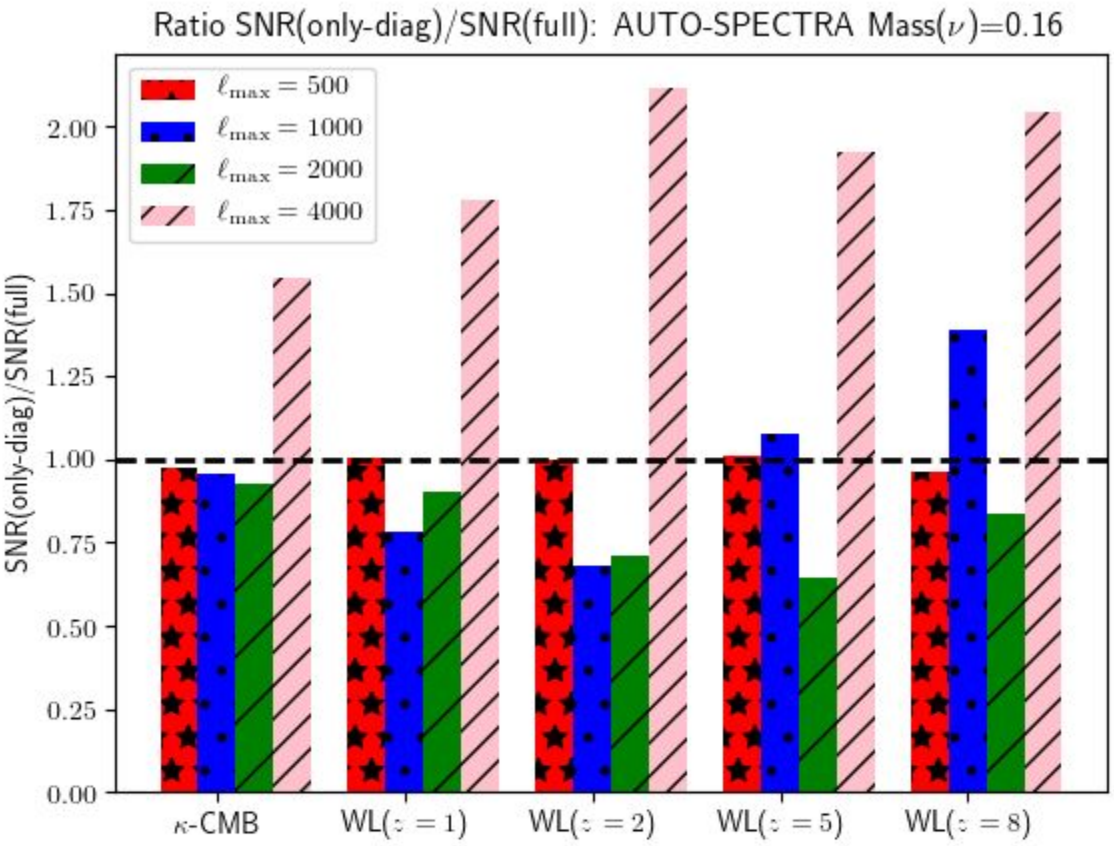
SNR for different observ. lmax = 4000







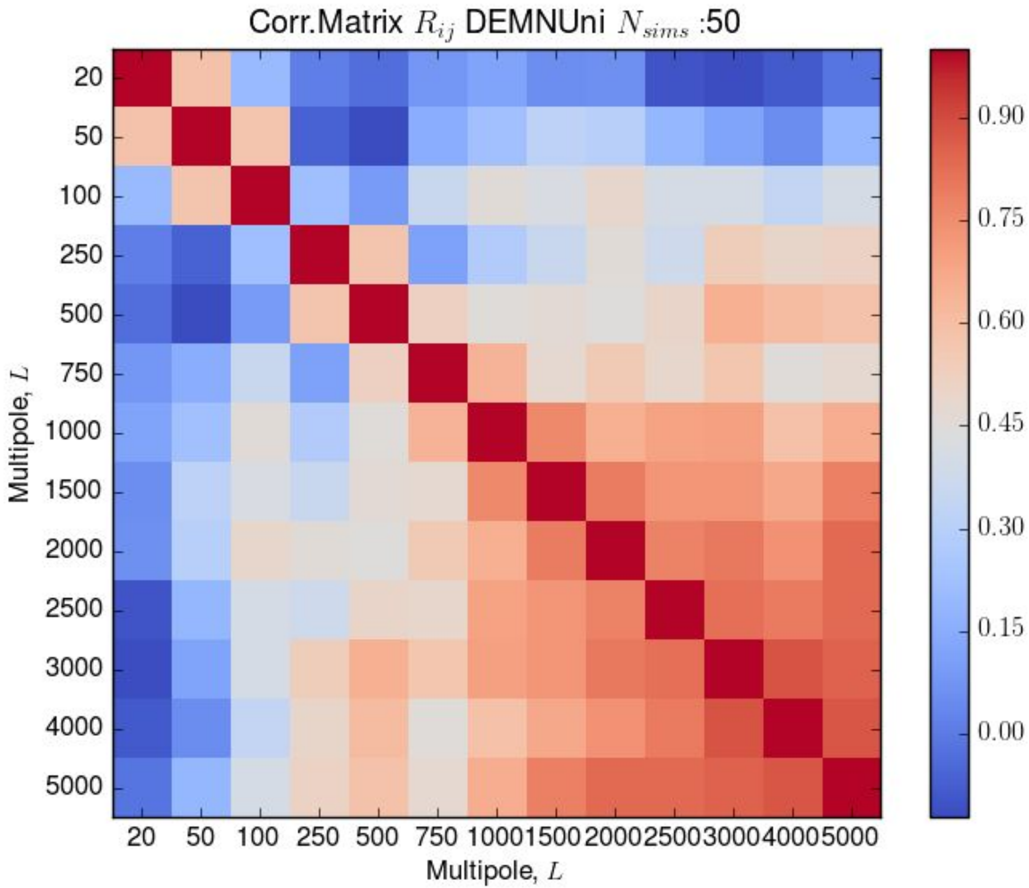
Ratio SNR(only-diag)/SNR(full): AUTO-SPECTRA LCDM
$\ell_{\max} = 500$
$\ell_{\max} = 1000$
$\ell_{\max} = 2000$
$\ell_{\max} = 4000$
SNR(only-diag)/SNR(full)
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
κ-CMB
WL(z = 1)
WL(z = 2)
WL(z = 5)
WL(z = 8)



Ratio SNR(only-diag)/SNR(full): AUTO-SPECTRA Mass(ν)=0.16
$\ell_{\rm max} = 500$
$\ell_{\rm max} = 1000$
$\ell_{\rm max} = 2000$
$\ell_{\rm max} = 4000$
SNR(only-diag)/SNR(full)
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
κ-CMB
WL($z = 1$)
WL($z = 2$)
WL($z = 5$)
WL($z = 8$)

Covariances from particle maps

Towards tomography.



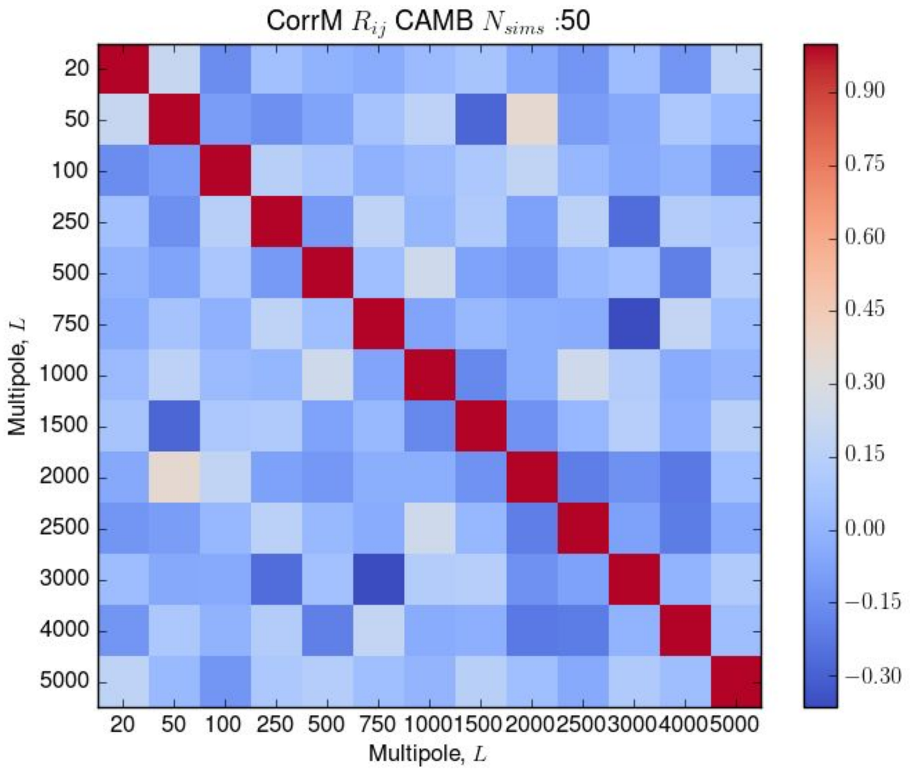
C_L CMB-Convergence DEMNUni → Covariance Matrix

13 Bins in multipole, L = {20,50,100,250,500,750,1000,1500,2000, 2500,3000,4000,5000}

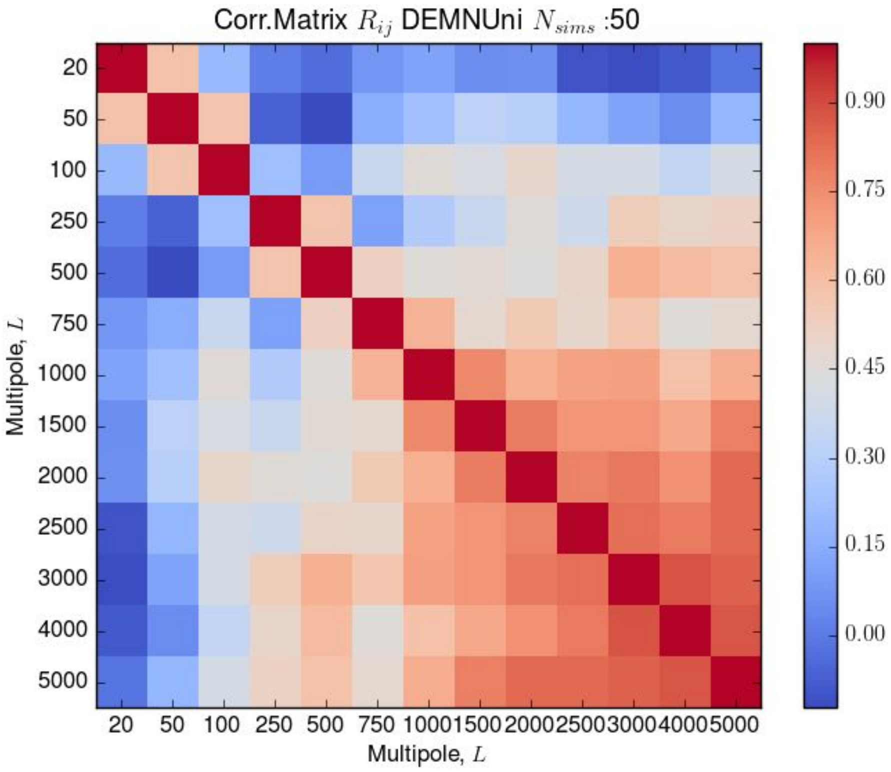
Nside Convergence maps = 4096
Number of Simulations = 50

LCDM and Mnu=0.16

<u>Figures are Correlation Matrix</u>
(Covariances normalized to diagonal variances)

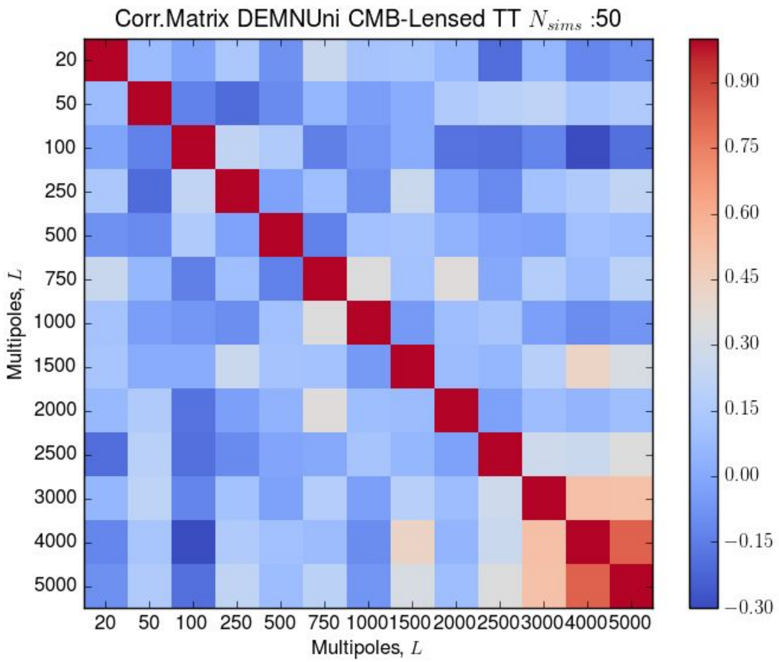


C_LCAMB → Covariance Matrix

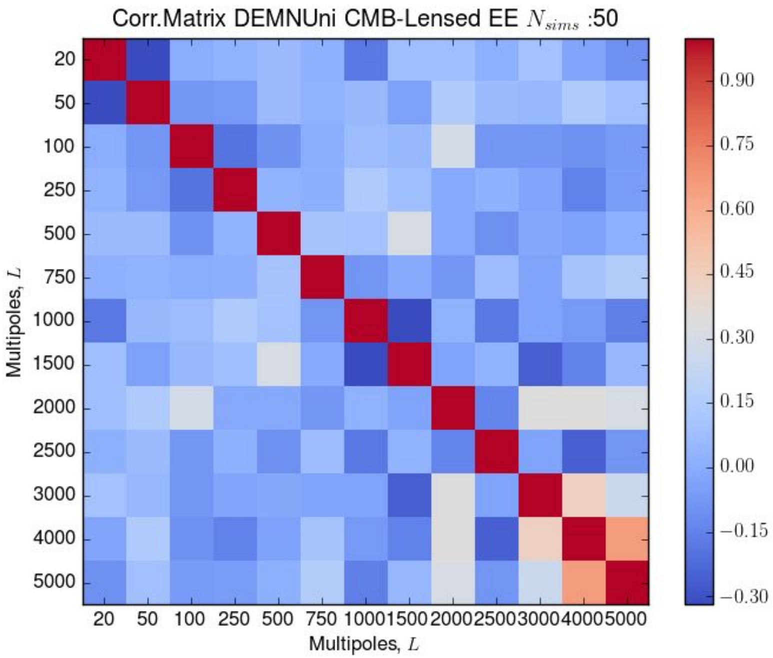


C_LDEMNUni → Covariance Matrix

Lensed CMB Covariances: TT and EE

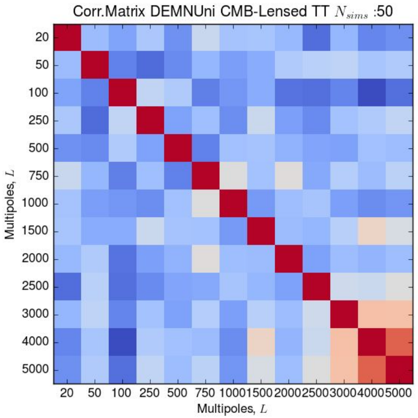


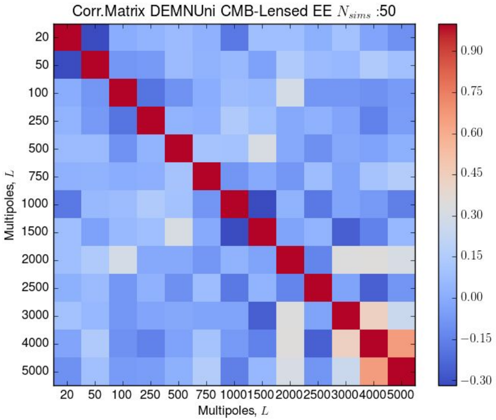
TT: CMB + Lensed(DEMNUni) →
Covariance Matrix on TT spectrum



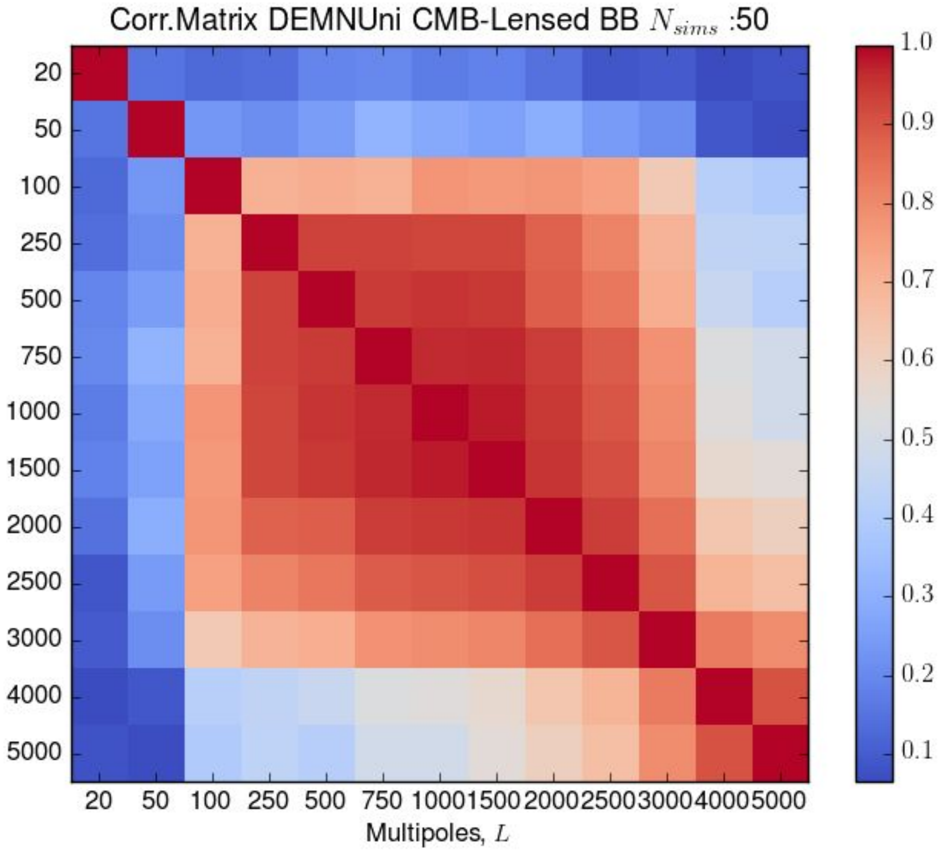
EE: CMB + Lensed(DEMNUni) →
Covariance Matrix on EE spectrum

Cov. on lensed BB



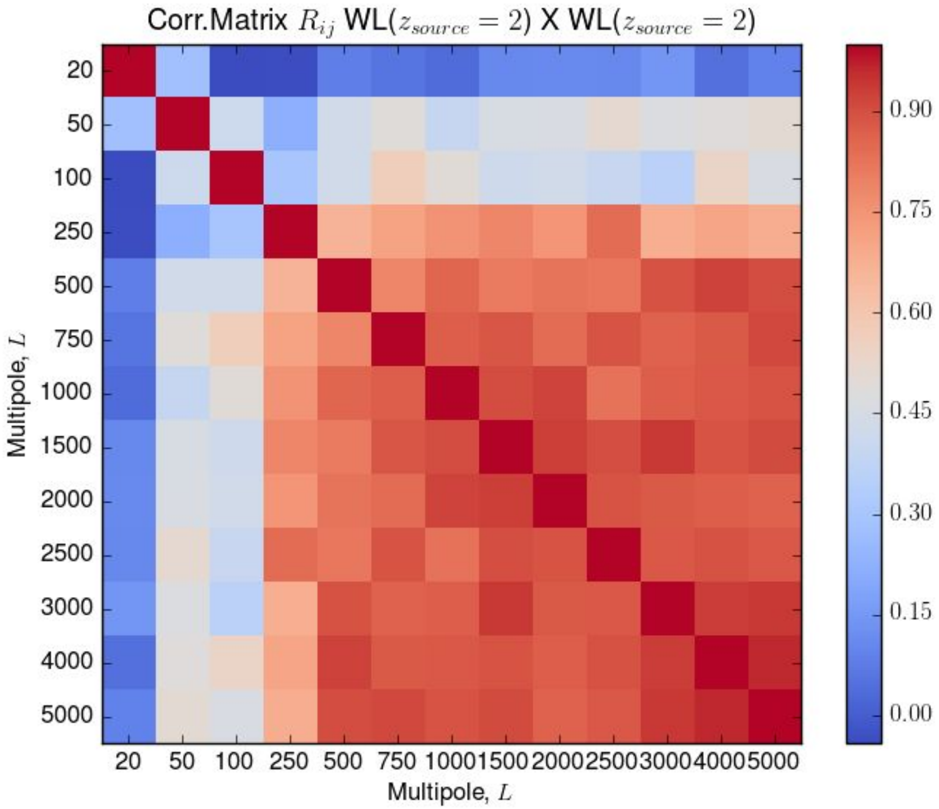


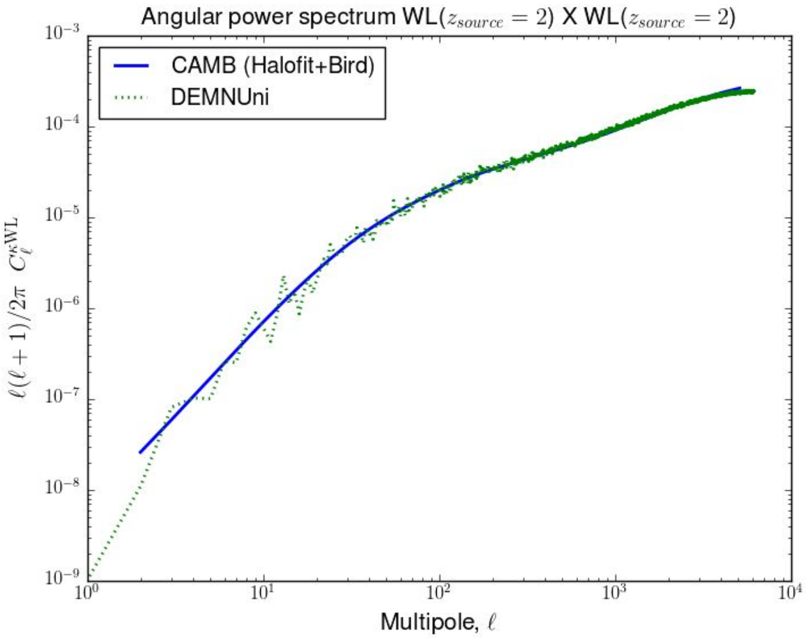
primordial-CMB + DEMNUni-Convergence using LensPix → Covariance Matrix on TT, EE and BB spectrum



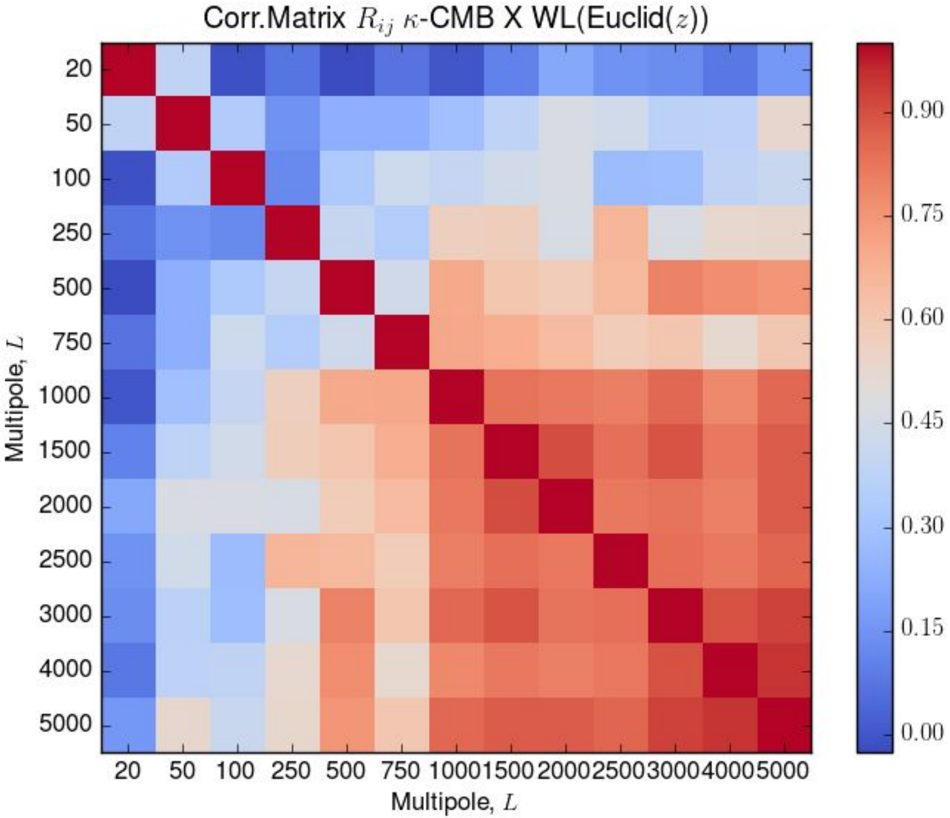
BB: CMB + Lensed(DEMNUni) → Covariance Matrix on BB spectrum

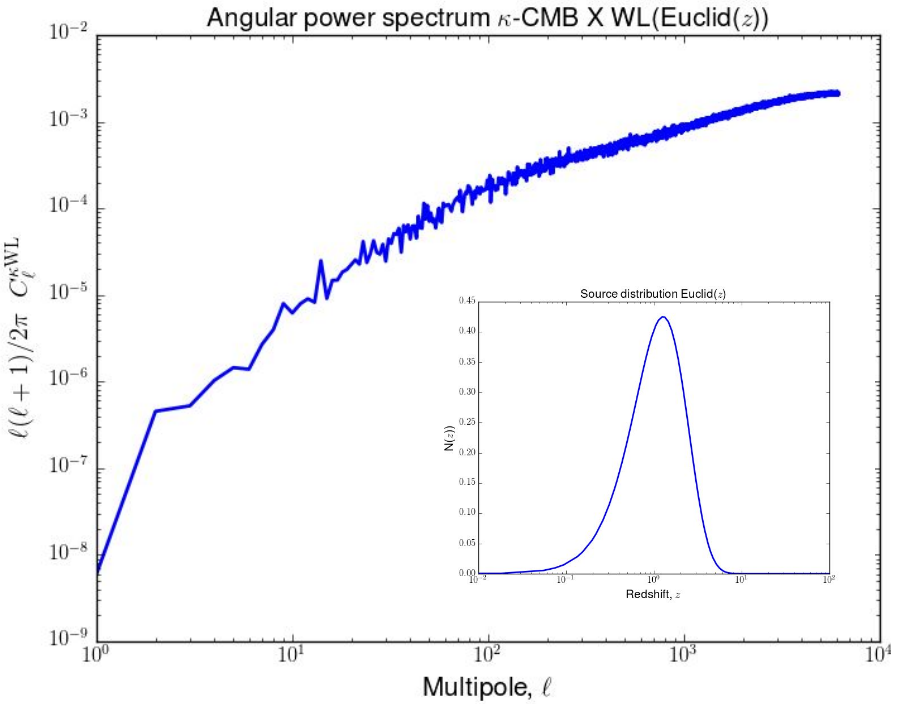
Covariances from Particle grids: WL(z=2) auto-spec.



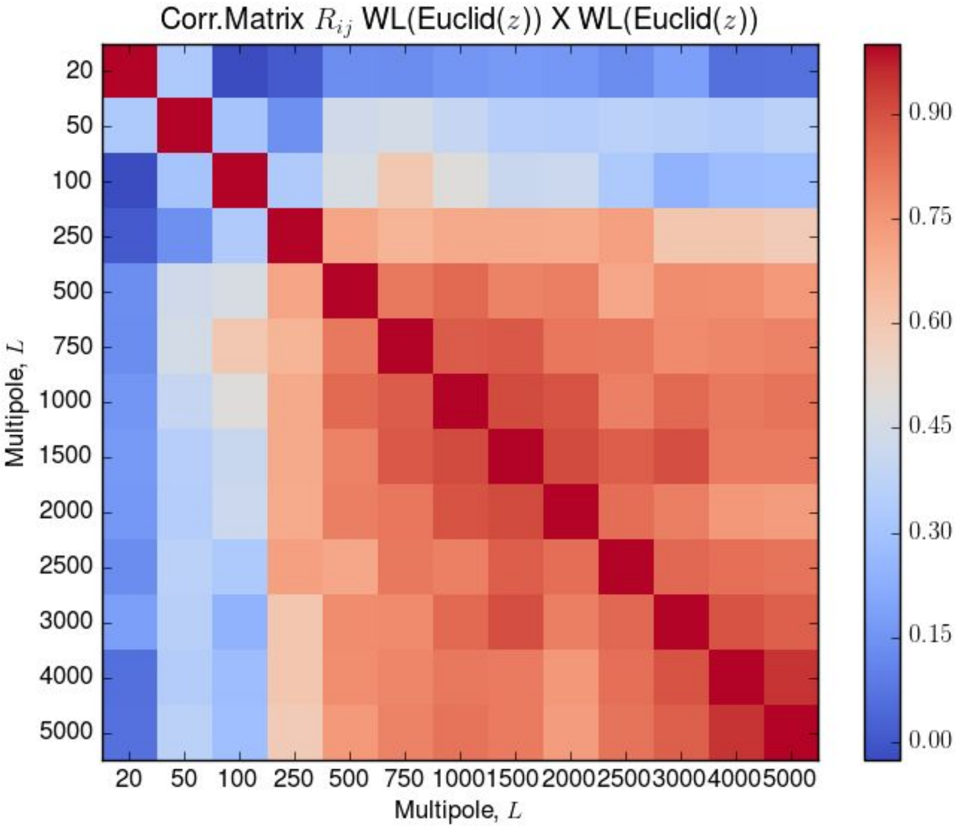


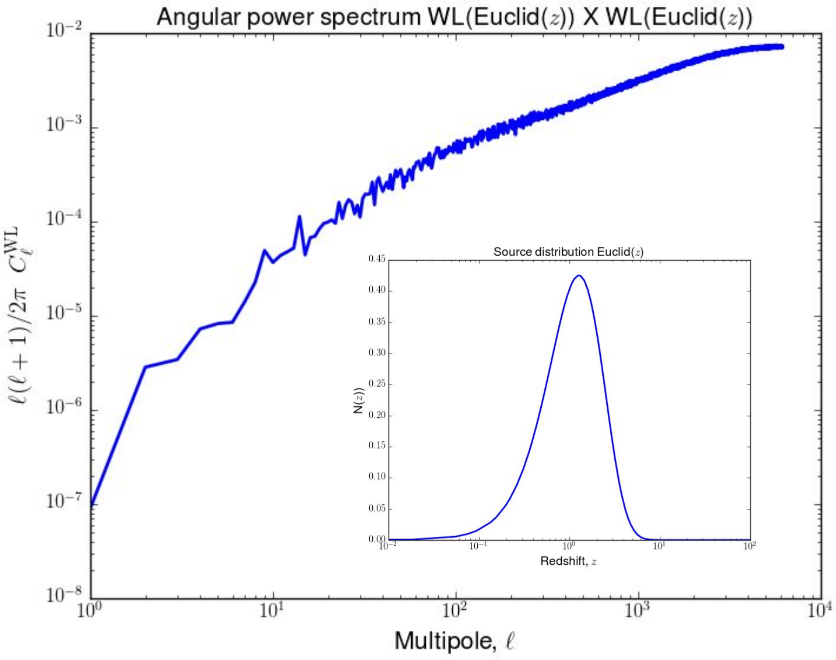
Cov. from Particle grids: WL(euclid) x kCMB



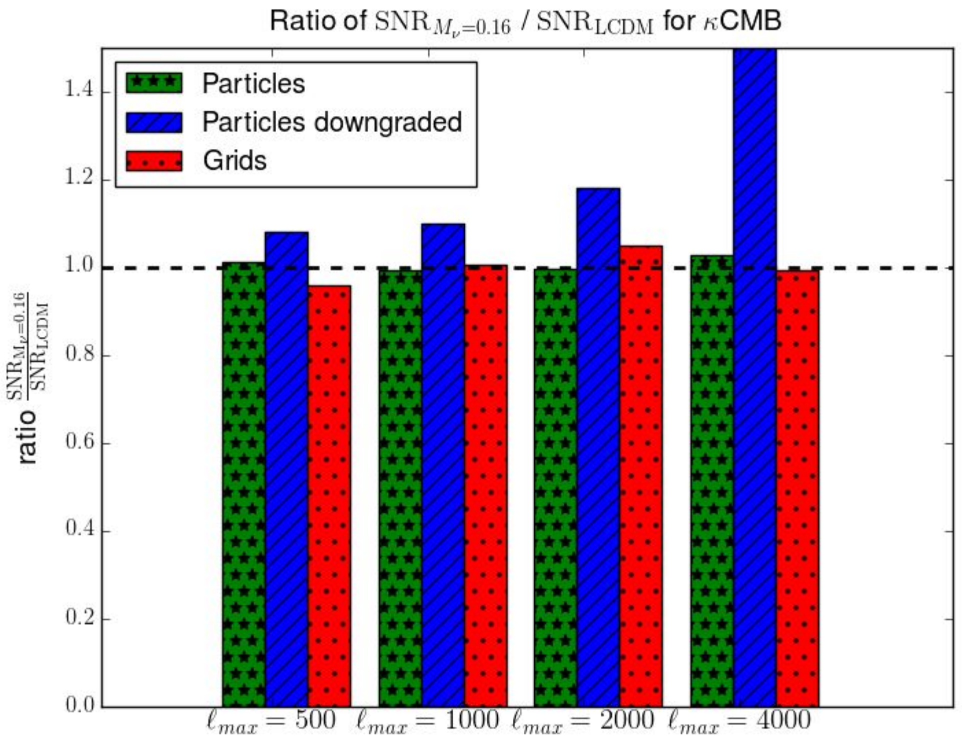


Cov. from Particle grids: WL(euclid) x WL(euclid)

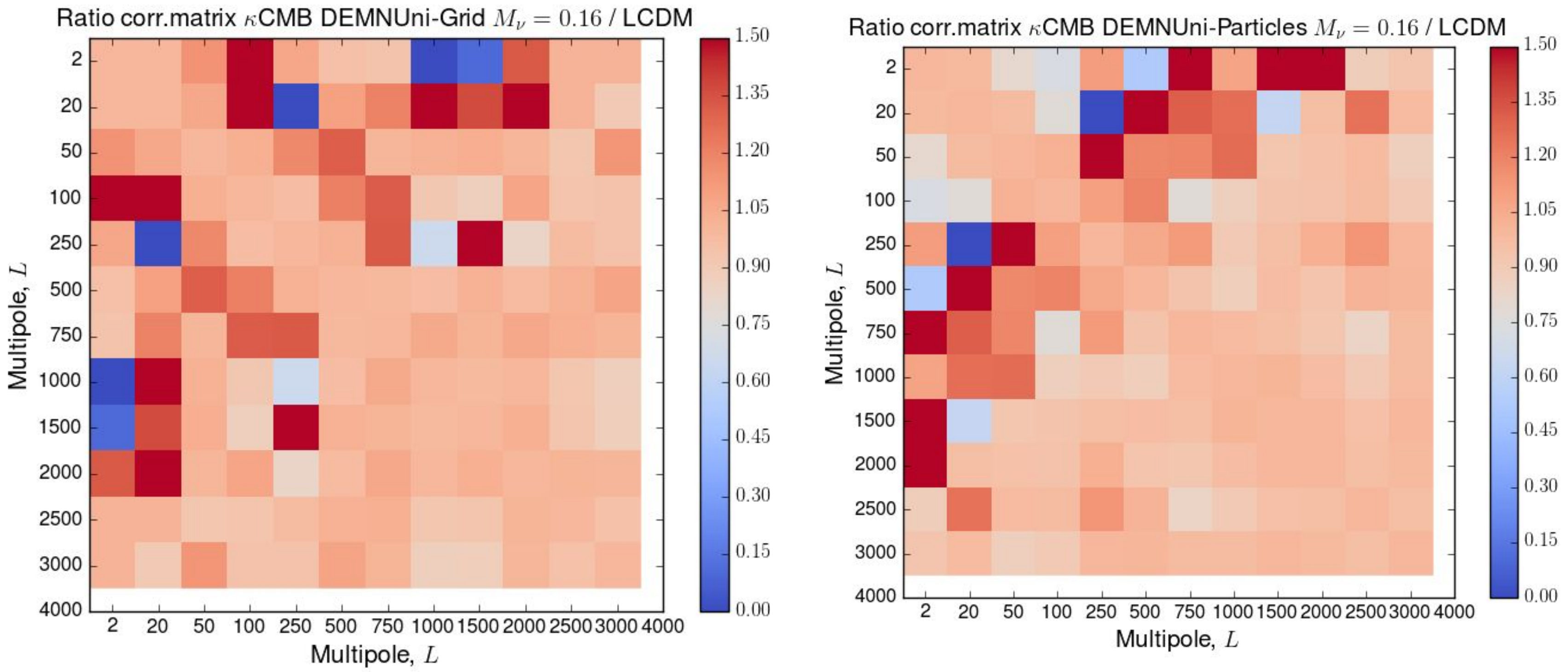




Particles vs Grids: cosmology ratios (SNRs)



Particles vs Grids: cosmology ratios (matrix)



Ongoing activities

Covariances. Again.