The Lensing Imprint of Cosmic Voids on the Cosmic Microwave Background Radiation(CMB)

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IFAE
Institut de Física d'Altes Energies

UMUT EMEK DEMIRBOZAN

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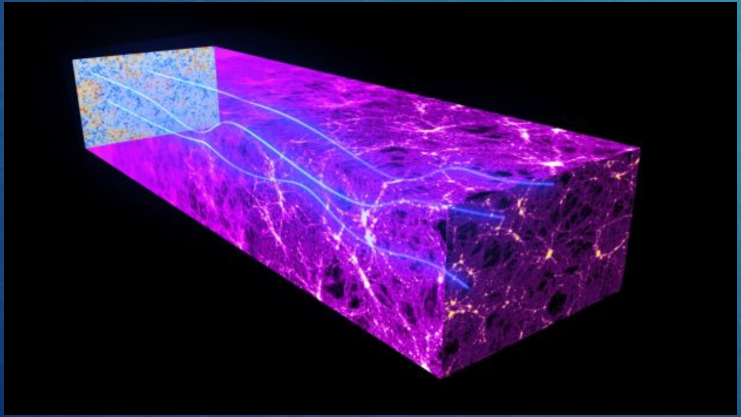
Millennium Simulation, Springel et al. 2005

CMB LENSING

- Photons are deflected due to underlying dark matter(weak lensing)
- Gravitational potential can be reconstructed from the lensed images and the **convergence(kappa)** is directly related to lensing potential.



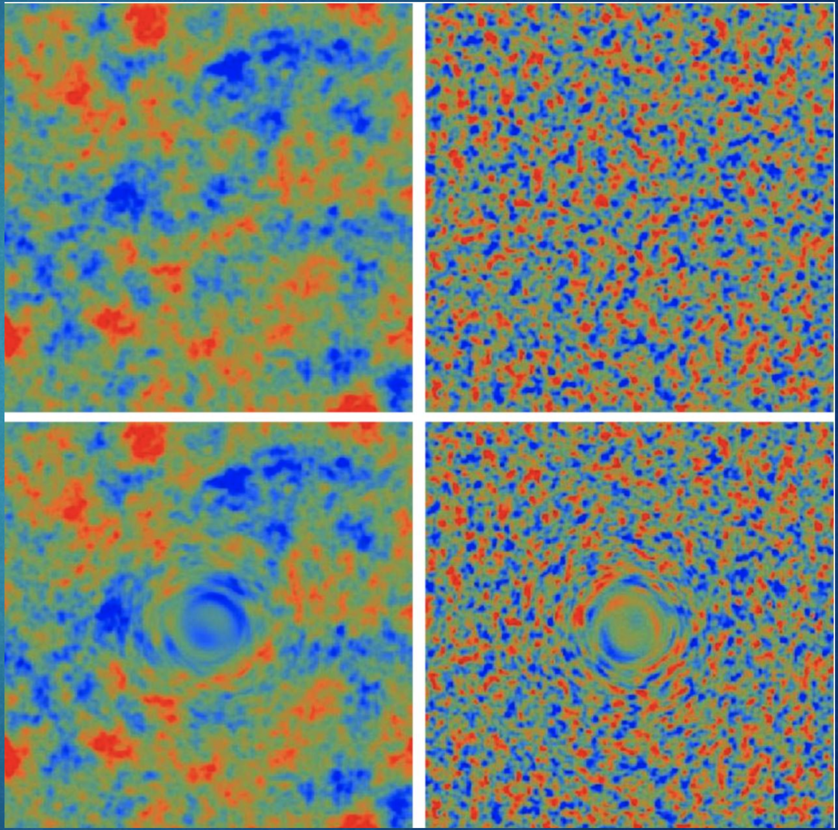


Image Credited to (Wayne Hu and Takemi Okamoto/University of Chicago)

MOTIVATION

- Clampitt et al.2016 shows that low density void environments can be very useful for testing gravity theories(i.e chameleon,Modified Gravity and F(R).
- Potential to differentiate between **GR** and **MG**
- Paillas et al 2018 studies how different types of void(i.e 2D,3D etc..) can be used to differentiate GR and nDGP models…
  - Kovacs et al 2019 reported an "***excess***" signal for Integrated Sachs Wolfe effect .The CMB lensing is sourced by the potential, while the ISW depends on its time derivative. These two are actually related, but different things.
- This excess has also been observed in the very same DES Y1 data set.
- We are testing the CMB lensing counterpart in the same very data set using DES Y1 voids.

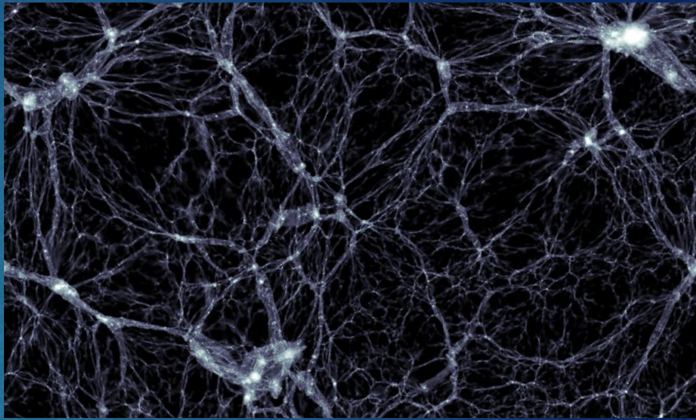
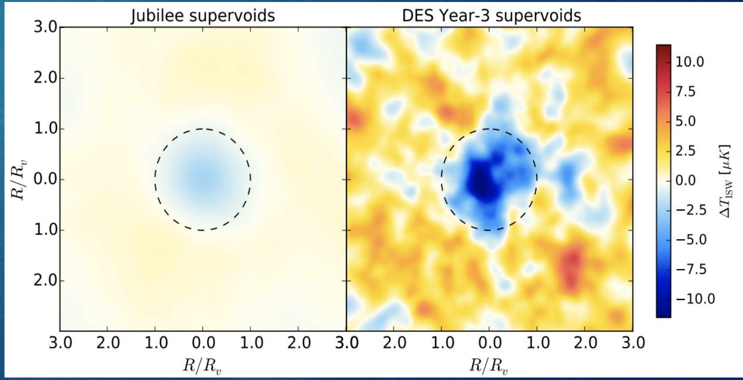


Image Credited to Illustris Simulation



MICE vs DES

- "The MICE grand challenge lightcone simulation - I. Dark matter clustering". Fosalba, P.; Crocce, M.; Gaztañaga, E.; Castander, F. J., MNRAS, 448, 298
- "The MICE Grand Challenge Lightcone Simulation II: Halo and Galaxy catalogues". Crocce, M.; Castander, F. J.; Gaztanaga, E.; Fosalba, P.; Carretero, J., MNRAS, 453, 1513 (2015)
- "The MICE Grand Challenge light-cone simulation - III. Galaxy lensing mocks from all-sky lensing maps". Fosalba, P.; Gaztañaga, E.; Castander, F. J.; Crocce, M., MNRAS, 447, 1319 (2015)

MICE

MICE Marenostrum Institut de Ciències de l'Espai Simulations

- ➢ Approximately 200 million Galaxies
- ➢ 5000 square deg^2
- ➢ Redshift up to z~1.4
- ➢ Created by Marenostrum Supercomputer in Barcelona

DES

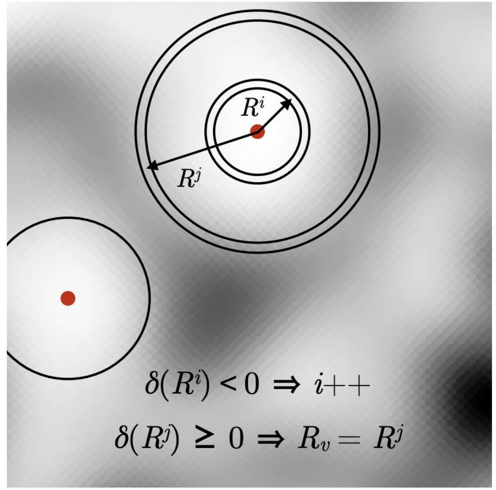
THE DARK ENERGY SURVEY

- ➢ It is a photometric survey with almost 5000deg^2 survey area.
- ➢ It is a U.S based collaboration which uses Decam mounted on CTIO in Chilean Andes.
- ➢ A total of 300 million galaxies are observed.
- ➢ It focuses on different area then the BOSS survey

VOID IDENTIFICATION and SELECTION

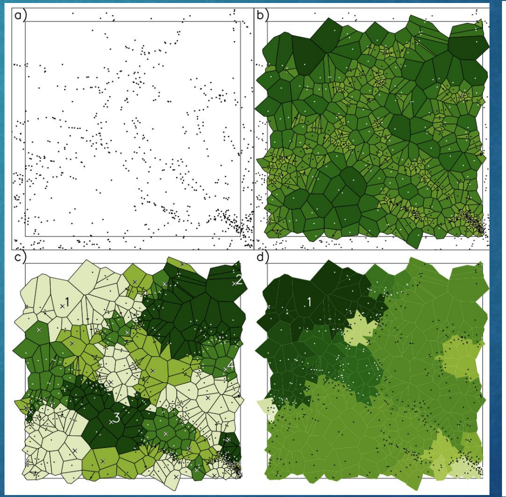
- Dark Energy Survey Y1 Data
  - **RedMAGic** (LRGs) Galaxy Sample run on both DES and MICE

2D CIRCULAR VOIDS



Images Credited to Sanchez et al,2016

3D VIDE VOIDS



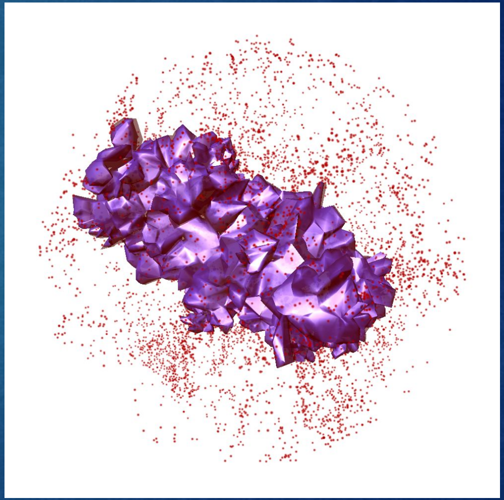
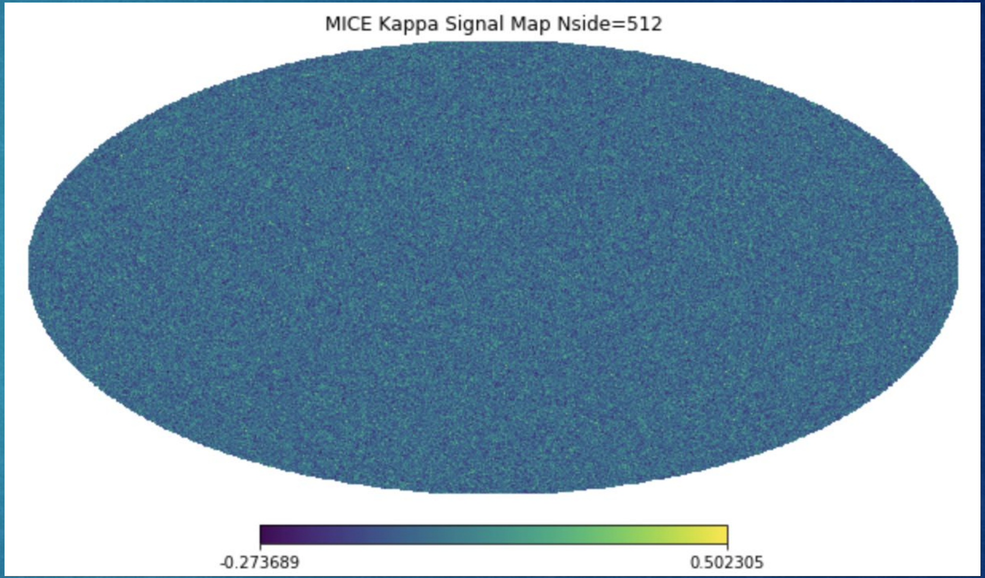


Image Credited to Neyrink et al,2008

Image Credited to Sutter P.M et al IAU Symp.308 (2014)

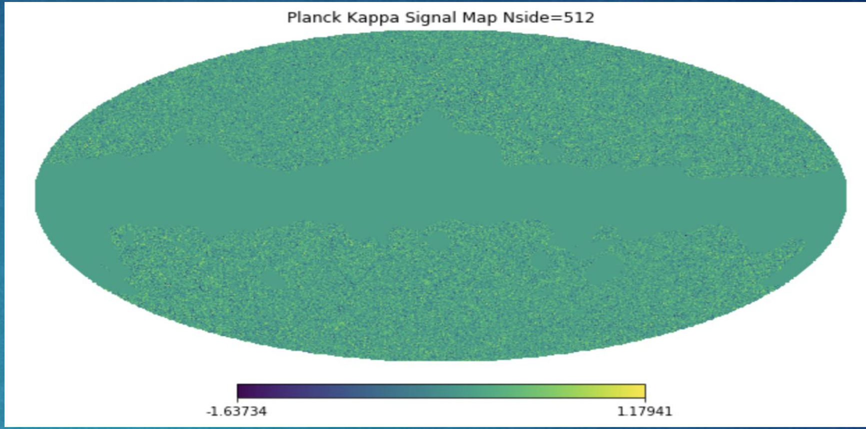
CMB LENSING MAPS
MICE KAPPA MAP

- Full sky Convergence map created by Fosalba et al 2013 using "*onion universe*" method.
- Represents Lambda-CDM Universe Convergence Map

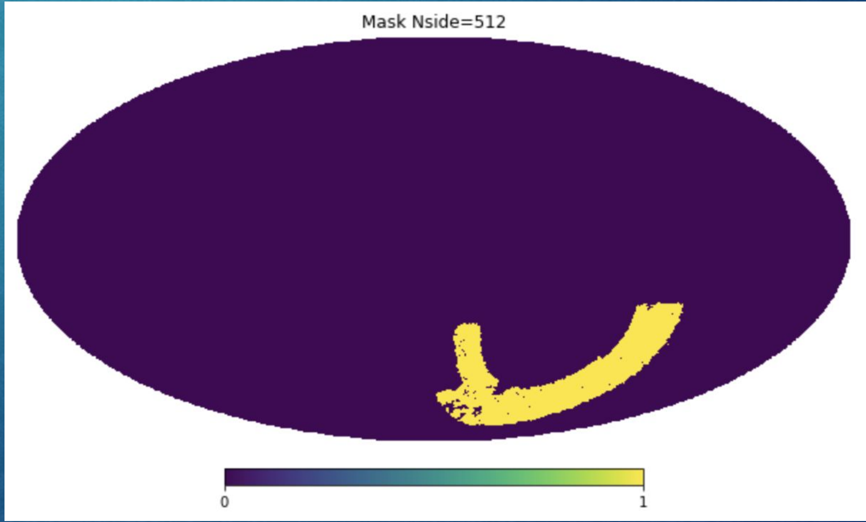


CMB LENSING MAPS

- ➢ PLANCK Lensing(Kappa) Map

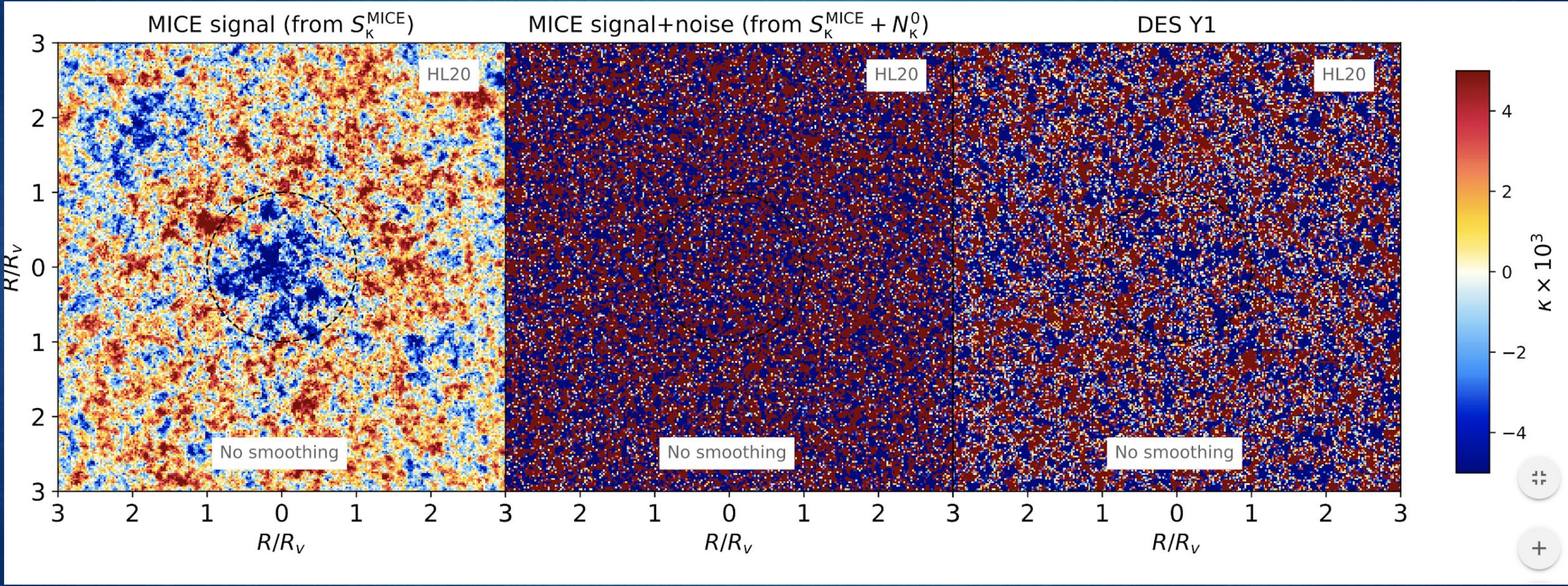


- ➢ **DES Y1 Mask** on the Map



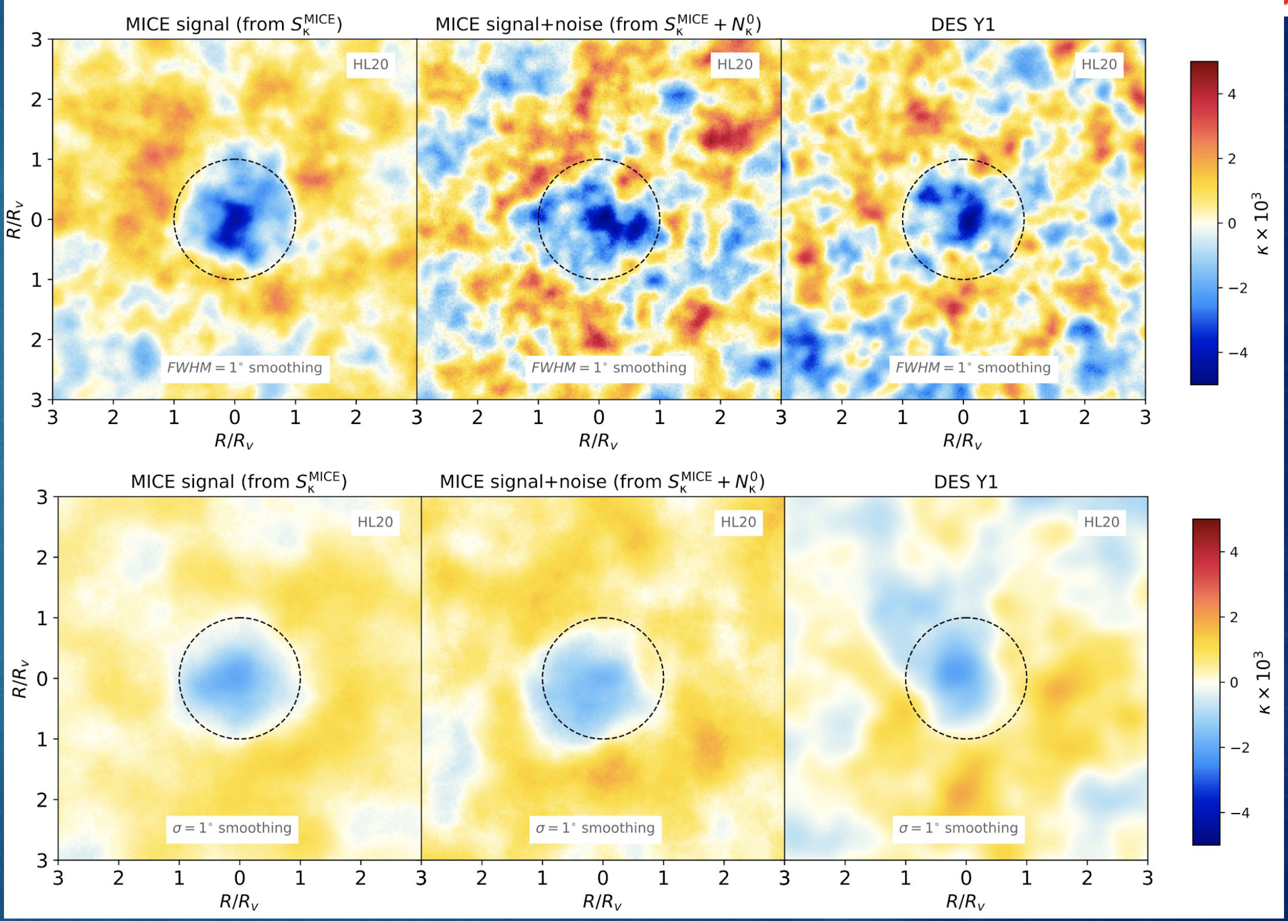
STACKING METHOD and NOISE

➢ Adding a **simulated Planck like noise** to the MICE CMB Kappa map before smoothing.



STACKING

- We aim at a **blind analysis** by trying to **optimize** the signal with different smoothings.
- No smoothing !
- Gaussian smoothing of **Fwhm(2.38sigma)=1 degree**
- Gaussian smoothing of **Sigma=1 degree**
- **Extracting a profile by slowly increasing the radii of annuli**



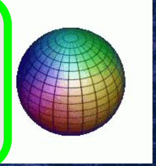
METHOD

Take the MICE CMB Kappa Map

Add a random Planck-like noise to the map

Smooth the map with a specific scale(FWHM,SIGMA)

Randomly rotate the map along horizontal and azimuthal axes



Stack the **DES Y1** voids on this final **MICE** map

Measure the signal from the final stacked image

Repeat this process 500 times

Calculate the covariance from these 500 profiles

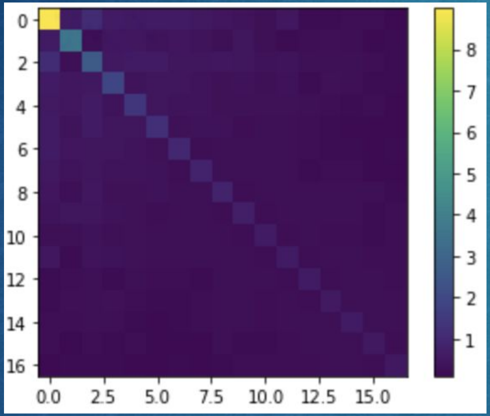
Estimate the A values from chi2 method and find out S/N ratio of the signal

ERROR ESTIMATION and S/N

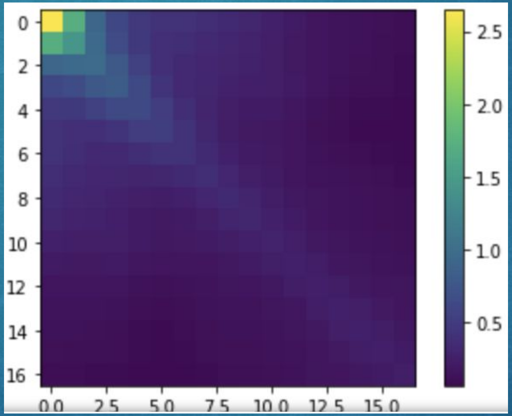
We compute 500 random runs to obtain the covariance matrices. By realizing 500 random runs with 17 bins to measure the signal throughout the void radius, we keep the **Anderson-Hartlap Factor** minumum.This affect our results about 3.7%

$$\hat{C}^{-1} = \frac{n-p-2}{n-1}\,\hat{C}_*^{-1} \text{ for } p < n-2\,.$$

No Smooth(VIDE)



FWHM=1 deg Smooth(VIDE)



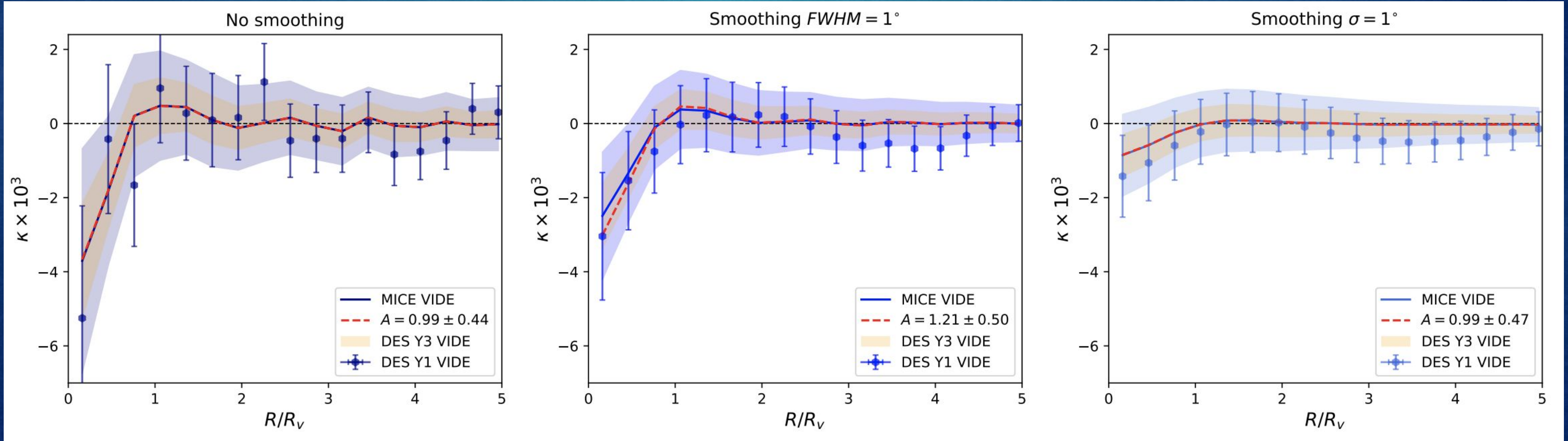
$$\chi^2 = \sum_{ij} (\kappa_i^{\rm DES} - A\kappa_i^{\rm MICE}) C_{ij}^{-1} (\kappa_j^{\rm DES} - A\kappa_j^{\rm MICE})$$

MINIMIZING CHI SQUARED AND OBTAINING A VALUE

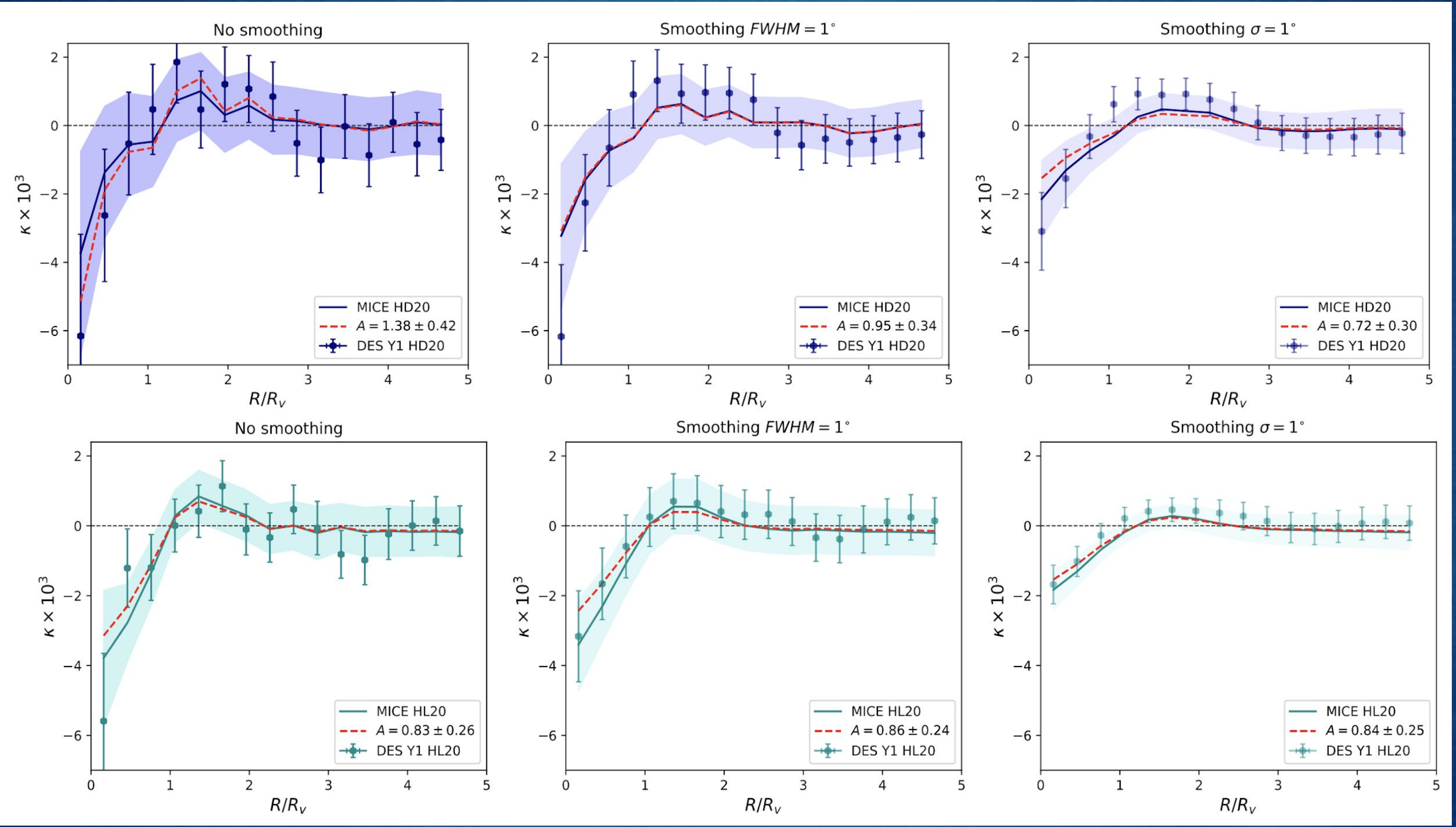
We calculate the A value by minimizing Chi squares in order to obtain S/N ratio

RESULTS

- **CMB lensing(kappa)** signal profiles by **VIDE** voids as a function of **void radius**
- Gaussian smoothing of **Fwhm(2.38sigma)=1 degree and Sigma=1 degree**
- Using a larger smoothing scale both reduces the noise and the signal as we try to optimize our signal measurement. **FWHM=1 degree** seems to be a good choice.
- We **roughly estimate** how the error bars would be seen in **DES Y3** data



RESULTS


No smoothing
Smoothing $FWHM = 1^\circ$
Smoothing $\sigma = 1^\circ$
$\kappa \times 10^3$
R/R_v
MICE HD20
$A = 1.38 \pm 0.42$
DES Y1 HD20
MICE HD20
$A = 0.95 \pm 0.34$
DES Y1 HD20
MICE HD20
$A = 0.72 \pm 0.30$
DES Y1 HD20
No smoothing
Smoothing $FWHM = 1^\circ$
Smoothing $\sigma = 1^\circ$
MICE HL20
$A = 0.83 \pm 0.26$
DES Y1 HL20
MICE HL20
$A = 0.86 \pm 0.24$
DES Y1 HL20
MICE HL20
$A = 0.84 \pm 0.25$
DES Y1 HL20

RESULTS

No smoothing

Catalog	VIDE	HD10	HD20	HL10	HL20
MICE	2.27	3.13	2.38	4.00	3.36
DES Y1	2.25	2.47	3.29	3.04	4.00

$FWHM = 1°$ smoothing

Catalog	VIDE	HD10	HD20	HL10	HL20
MICE	2.00	3.70	2.94	4.76	4.17
DES Y1	2.42	3.30	2.79	3.78	3.58

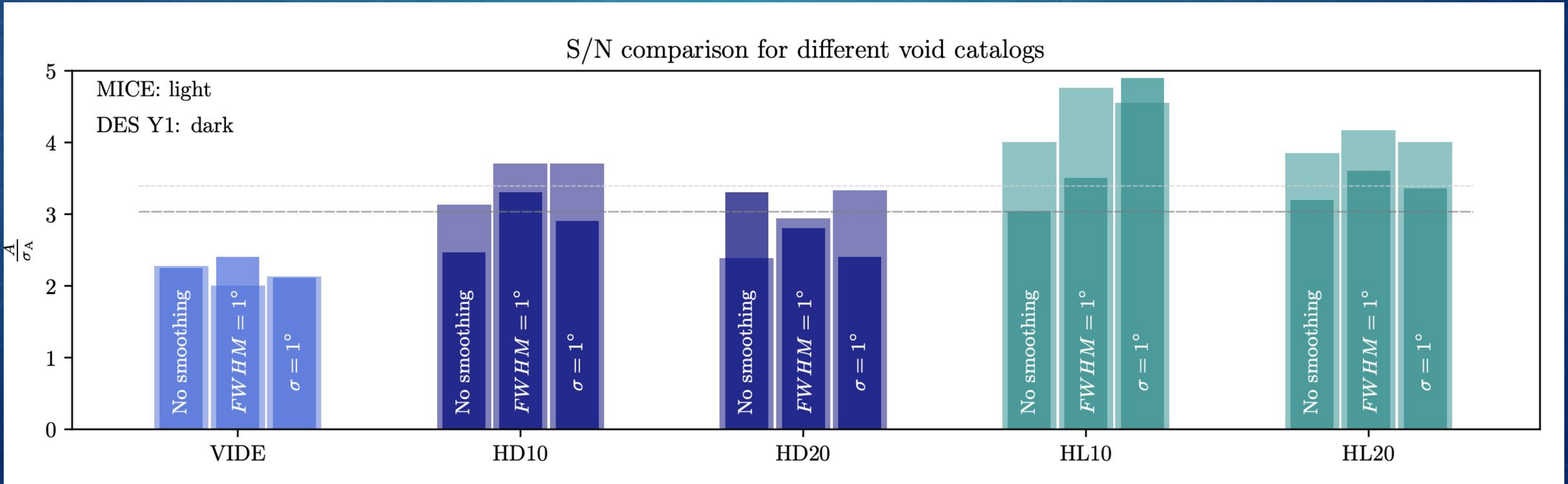
$\sigma = 1°$ smoothing

Catalog	VIDE	HD10	HD20	HL10	HL20
MICE	2.13	3.70	3.33	**4.55**	3.85
DES Y1	2.11	2.89	2.40	**4.91**	3.19

- The number of **DES Y1 2D Circular** voids with different tracer density and luminosities roughly **agree** with each MICE Y1-like single patches.
- As for **VIDE** voids, MICE has significantly more voids, this is because MICE octant covers **much bigger area** with respect to DES Y1.
- We also use a **very conservative** cut to select **VIDE** voids, but in the future more diverse samples should be tried.

CONCLUSION

- We detect **4.9 Sigma void x CMB lensing** by **DESY1 voids highest** to date in the literature
- There is no indication of an **EXCESS** CMB lensing signal in **DESY1 VOIDS** with respect to a **LCDM** simulation(MICE). This means the excess signal of ISW by voids has no counterpart in the CMB lensing by voids.
- The **highest S/N** comes from 2D Circular voids defined on High Luminosity(HL)10 sample with a sigma=1 degree Gaussian smoothed CMB map.
- Future studies(DES Y3) can investigate to improve the optimization by VIDE voids for a **better S/N**



QUESTIONS ?


COSMOLOGY MARCHES ON
where did it all come from?
where did it all come from?
s. harris

APPENDIX

COSMIC VOIDS

- Dark Energy Survey Y1 Data
  - **RedMAGic** Galaxy Sample run on both DES and MICE(Rozo et al, 2015)
- **RedMAGic** algorithm uses luminous red galaxies(**LRGs**)
- These galaxies have been shown to have better ***photometric redshifts***

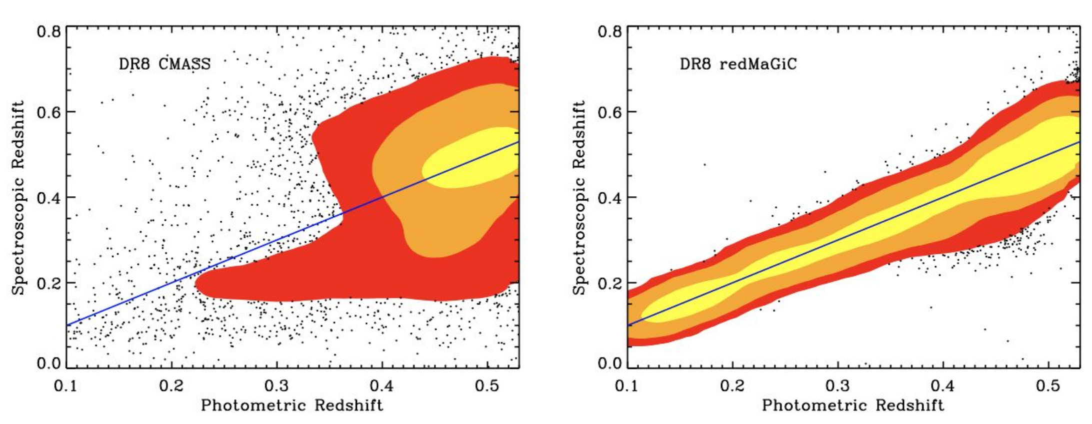
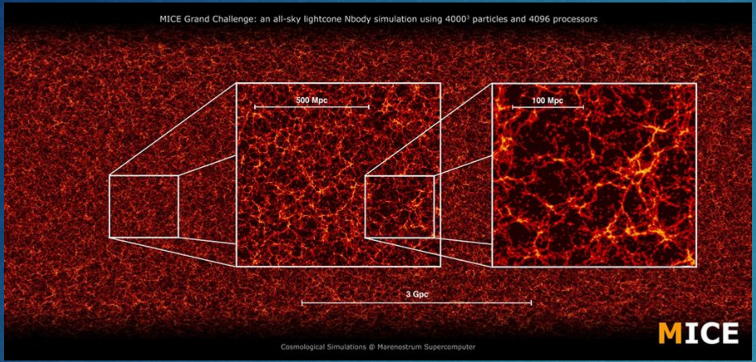


Image Credited to Rozo et al,2015

- Redshift range $z \in [0.2,0.8]$
- A comoving space density of 10−3 (h −1Mpc)−3 ,
- Median photo-z bias (zspec – zphoto) =0.005
- Scatter (σz/(1 + z)) =0.017
- 5 sigma outliers fraction is 1.4% of the galaxies
- Two sets of High Density(HD) and High Luminosity(HL) sample of galaxies

MICE SIMULATION PARAMETERS

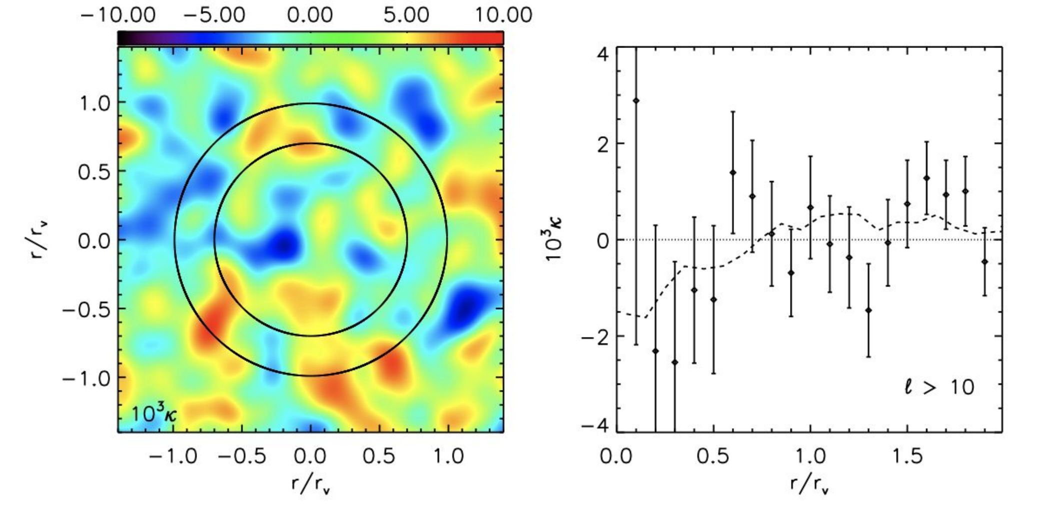


- Baryon density, Ω_b = 0.044
- Matter density, Ω_m = 0.25
- Dark-energy density, Ω_Λ = 0.75
- Scalar spectral index, n_s = 0.95
- Rms matter fluctuation amplitude, σ_8 = 0.8
- Hubble paramter (in units of 100 km/sec/Mpc), h = 0.7

MOTIVATION

- **Cai et al 2016** reported an **3.2 sigma(highest to date)** detection of CMB lensing. (by cosmic voids using SDSS CMASS DR12 ZOBOV voids and Planck lensing map.)

- **Baxter et al, 2017** found **8.1 sigma** CMB lensing signal by *DES Y1 clusters.* (using South Pole Telescope(SPT) lensing maps)



Credited to Cai et al.2016

METHODS

- PLANCK-LIKE NOISE ADDED to the MICE CMB CONVERGENCE MAP
  - **A simulated noise** produced by the parameters from the **Planck Collaboration** used to simulate the noise in the map, we used different seed to generate different noises.

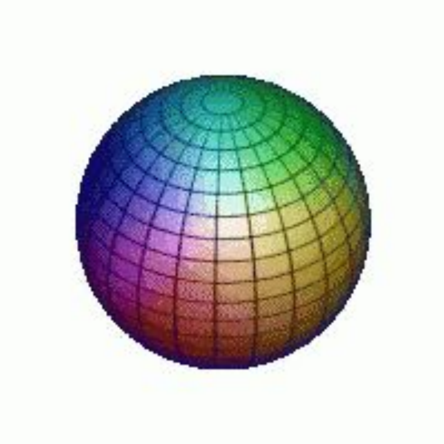
- MAPS ARE GAUSSIAN SMOOTHED WITH DIFFERENT SCALES
  - We aim at a **blind analysis** of real data by calibrating and checking the best configuration using the MICE simulation. **Different Gaussian smoothing** is part of this optimization. That is why different scales of Gaussian smoothing(**no smoothing**, **Fwhm**(2.35sigma)=1deg and **Sigma**=1 deg applied to the CMB kappa maps and then voids stacked.

- VOID POSITIONS ARE STACKED

  A patch image is taken around each void up to **5 void radius** for every void in the sample and then stacked into one final image.

ERROR ESTIMATION and S/N

- 500 RANDOM ROTATIONS OF SMOOTHED -NOISE ADDED(FOR MICE) KAPPA MAPS
  - By using Healpix, we randomly rotate the CMB convergence maps add a random Planck-like noise and stack our selected void sample again. We repeat the process 500 times and we obtain 500 measurements of stacked void profiles.



RESULTS

High luminosity			
Smoothing	DES Y1	MICE 1	MICE 2
10 Mpc/h	1218	1158	1219
20 Mpc/h	411	364	400
High density			
Smoothing	DES Y1	MICE 1	MICE 2
10 Mpc/h	518	521	495
20 Mpc/h	122	85	106
VIDE	DES Y1	MICE	
All	7383	36115	
Pruned	239	1687	

- The number of **DES Y1 2D Circular** voids with different tracer density and luminosities roughly **agree** with each MICE Y1-like single patches.
- As for **VIDE** voids, MICE has significantly more voids, this is because MICE octant covers **much bigger area** with respect to DES Y1.
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