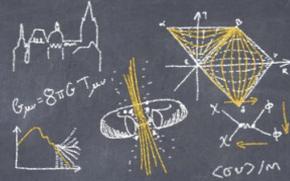


# The Lensing Imprint of Cosmic Voids on the Cosmic Microwave Background (CMB)



COSMO'19

RWTH Aachen University  
2-6 September, Germany



Institut de Física  
d'Altes Energies

**UMUT EMEK DEMIRBOZAN**

*02 September 2019*

Andras Kovacs, Pauline *Vielzeuf*, Pablo Fosalba and Ramon Miquel

Millennium Simulation, Springel et al. 2005

# CMB LENSING

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- 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.

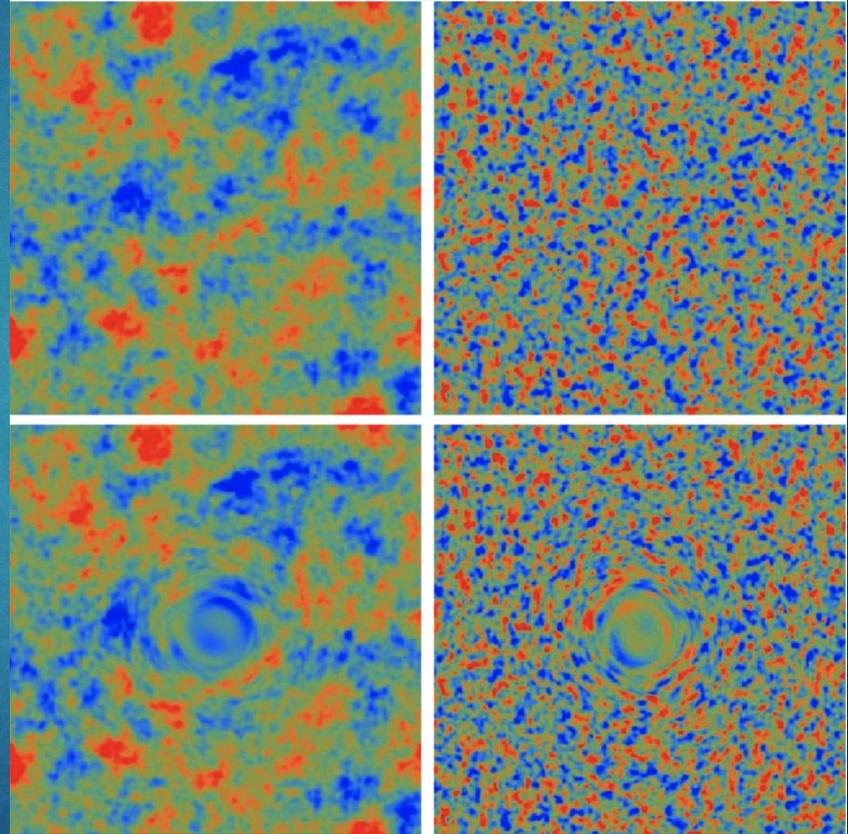
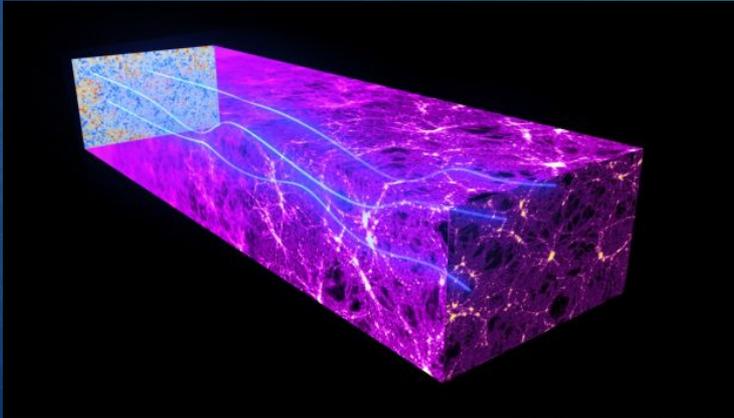


Image Credited to (Wayne Hu and Takemi Okamoto/University of Chicago)

# MOTIVATION

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- **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...

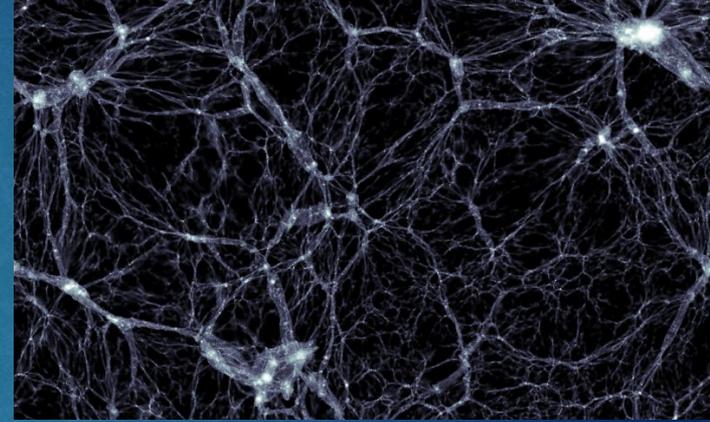


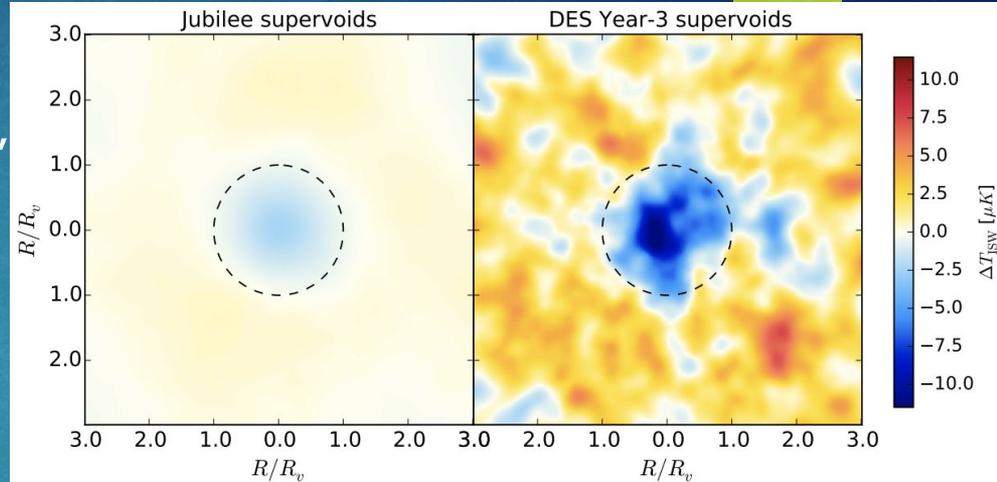
Image Credited to Illustris Simulation

# MOTIVATION

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- 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.



# MICE SIMULATION and DES

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**MICE**

Marenostrum Institut  
de Ciències de l'Espai  
Simulations

- "The MICE grand challenge lightcone simulation - I. Dark matter clustering". Fosalba, P.; Crocce, M.; Gaztañaga, E.; Castander, F. J., MNRAS, 448, 2987 (2015)
- "The MICE Grand Challenge Lightcone Simulation II: Halo and Galaxy catalogues". Crocce, M.; Castander, F. J.; Gaztañaga, E.; Fosalba, P.; Carretero, J., MNRAS, 458, 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)



THE DARK ENERGY SURVEY

- Approximately **200 million** Galaxies
- 5000 square deg<sup>2</sup>
- Redshift up to  $z \sim 1.4$
- Created by Marenostrum Supercomputer in Barcelona
- It is a **photometric** survey with almost 5000deg<sup>2</sup> 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

# COSMIC VOIDS

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- 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**

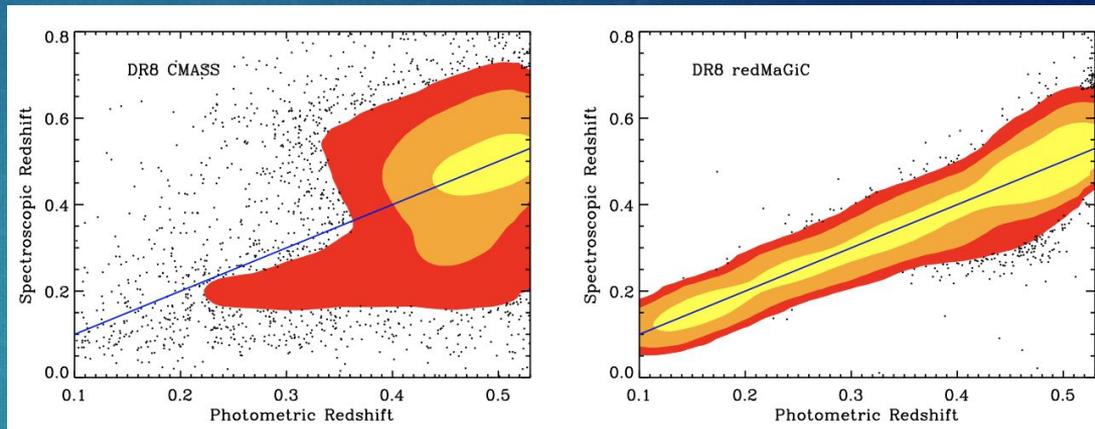


Image Credited to Rozo et al,2015

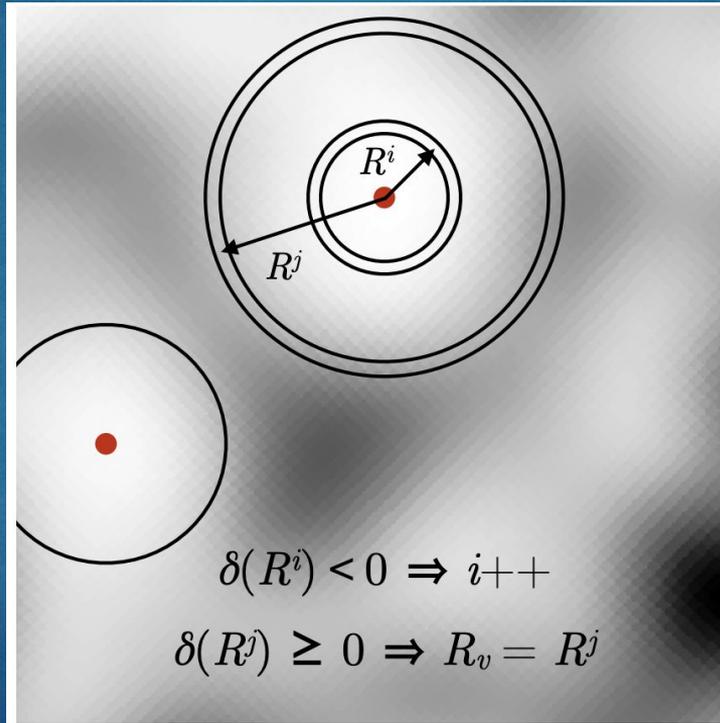
- Redshift range  $z \in [0.2, 0.8]$
- A comoving space density of  $10^{-3} (h^{-1} \text{Mpc})^{-3}$ ,
- Median photo-z bias ( $z_{\text{spec}} - z_{\text{photo}} = 0.005$ )
- Scatter ( $\sigma_z / (1 + z) = 0.017$ )
- 5 sigma outliers fraction is 1.4% of the galaxies
- Two sets of High Density(HD)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

# 2D CIRCULAR VOIDS

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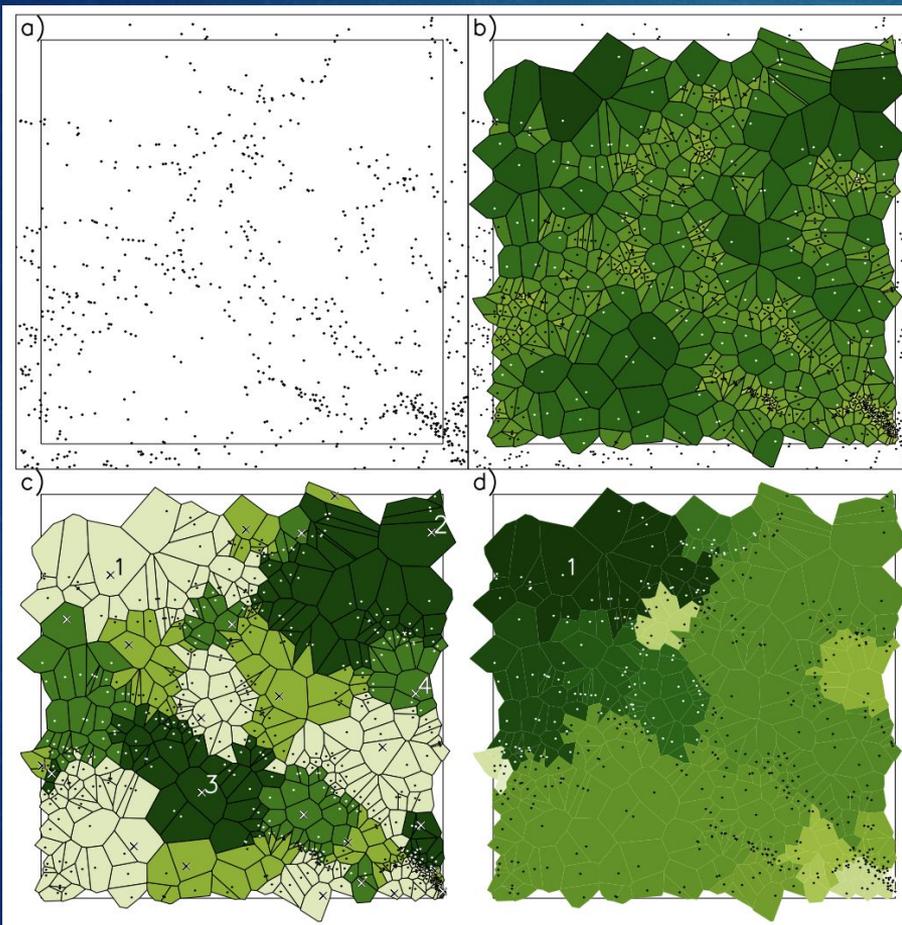
- Dark Energy Survey Y1 Data
  - **RedMAGic** Galaxy Sample run on both **DES** and **MICE**



Images Credited to Sanchez et al,2016

# 3D VIDE VOIDS

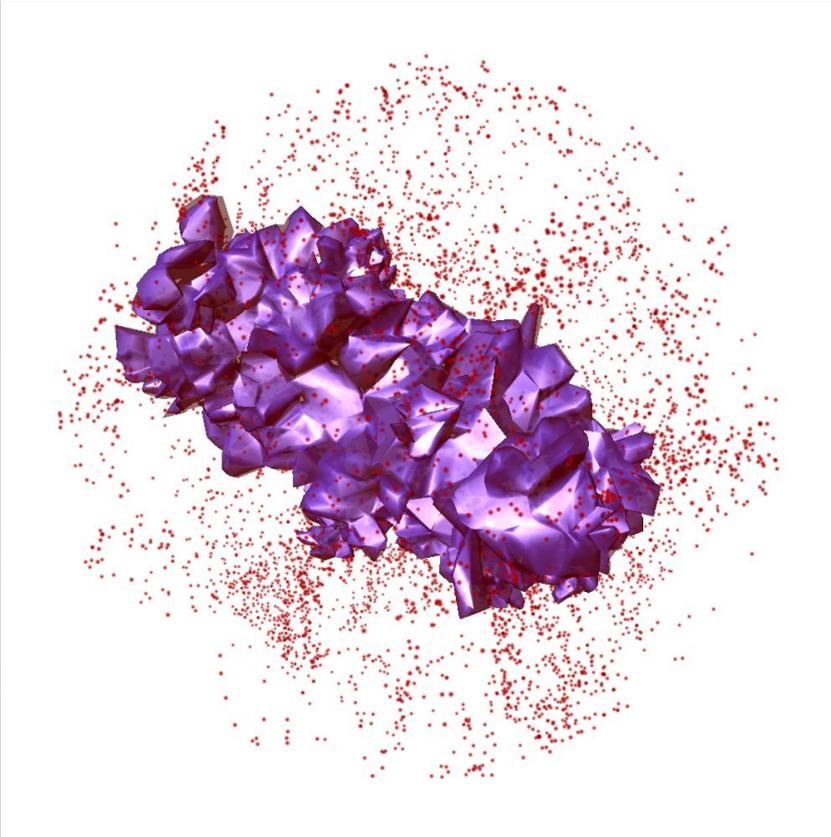
8



- Void Identification and Examination(VIDE) uses **Voronoi Tessellation** for identifying voids in **3D map** of galaxies.
- A modified version of parameter-free **ZOBOV** algorithm (Neyrinck 2008 and Lavaux & Wandelt 2011)
- Total volume is split into **"zones"**, with respecto a local minimum of the density field.
- Assembles these **"zones"** into voids by successively joining pairs of zones

# 3D VIDE VOIDS

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- We have collaborated with **Nico Hamaus** nad **Giorgia Pollina** from Munich who are also in DES

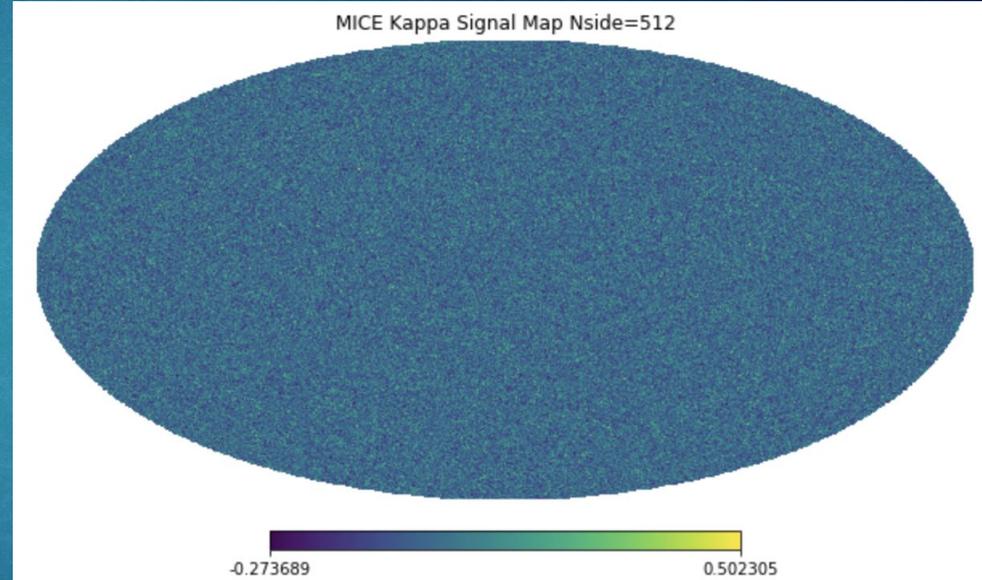
# CMB LENSING MAPS

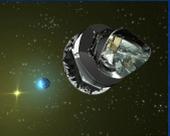
## MICE KAPPA MAP

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



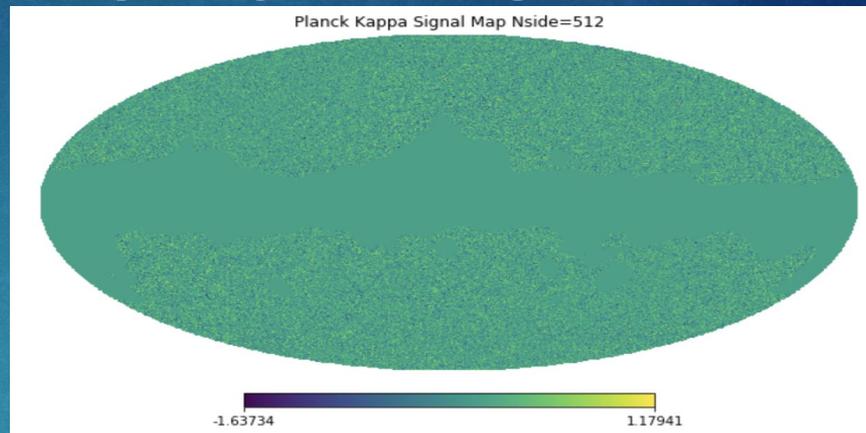


# CMB LENSING MAPS

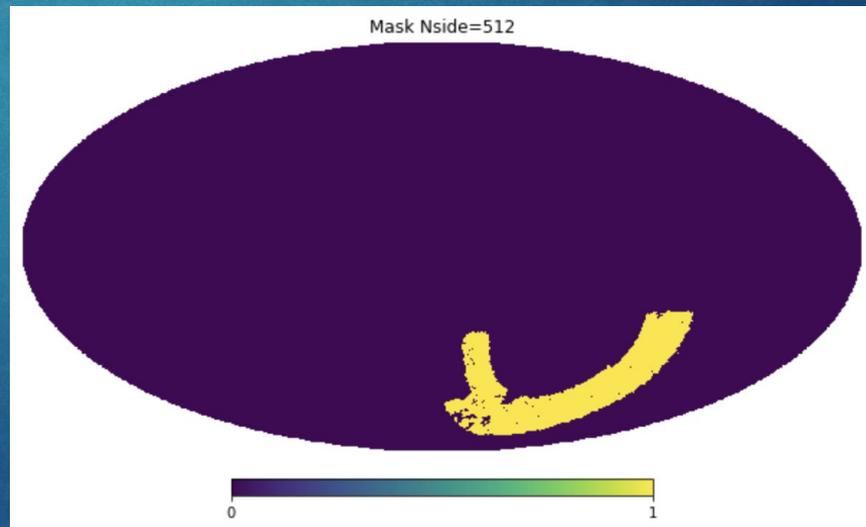
11



- PLANCK  
Lensing(Kappa)  
Map

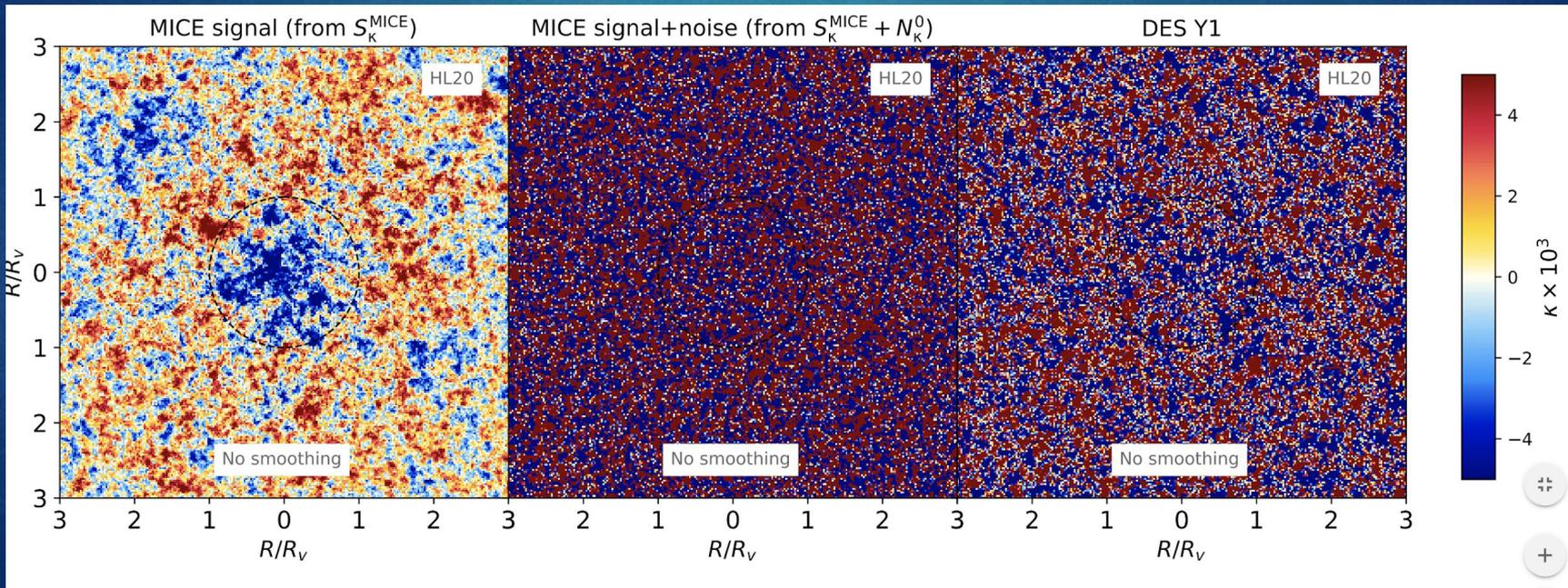


- **DES Y1 Mask** on the  
Map



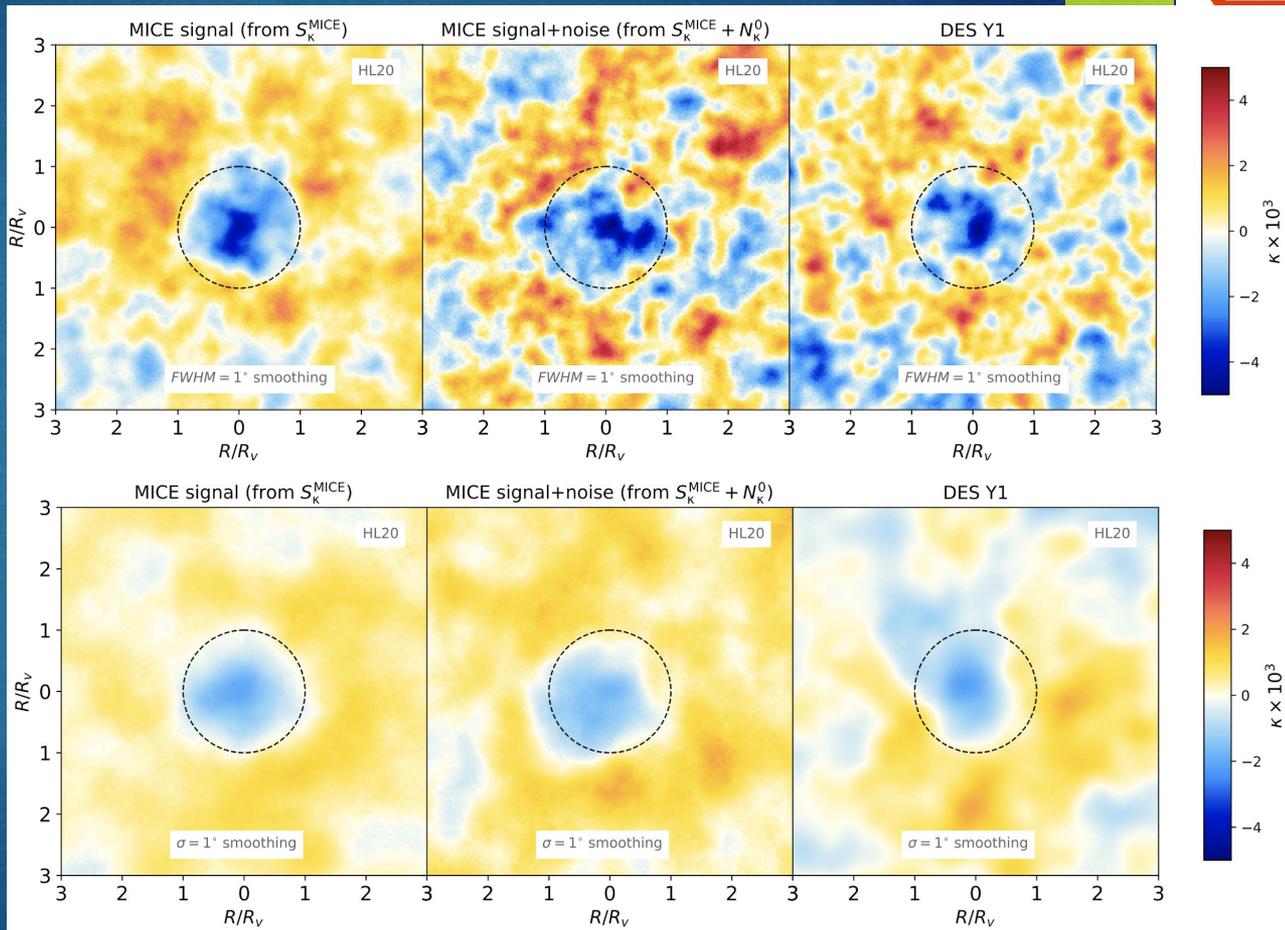


- Adding a **simulated Planck like noise** to the MICE CMB Kappa map before smoothing.





- 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**



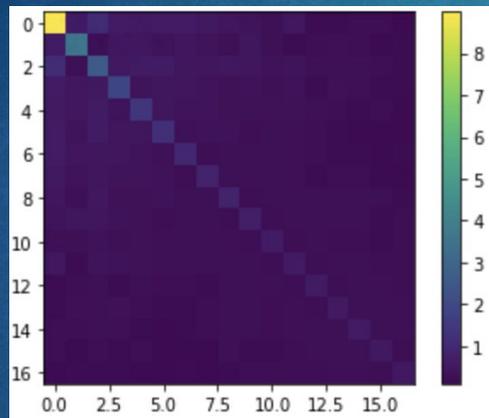
# ERROR ESTIMATION and S/N

14

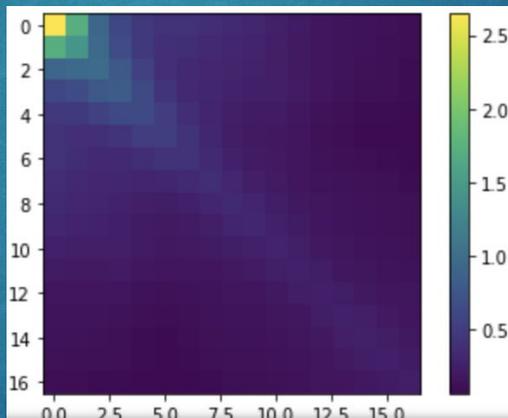


We compute 500 random runs to obtain the covariance matrices. By realizing 500 random runs with 17 bins to measure the signal throughout the void radius, we keep the **Anderson-Hartlap Factor** minimum. This affects our results about **3.7%**

No Smooth(VIDE)



FWHM=1 deg Smooth(VIDE)



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

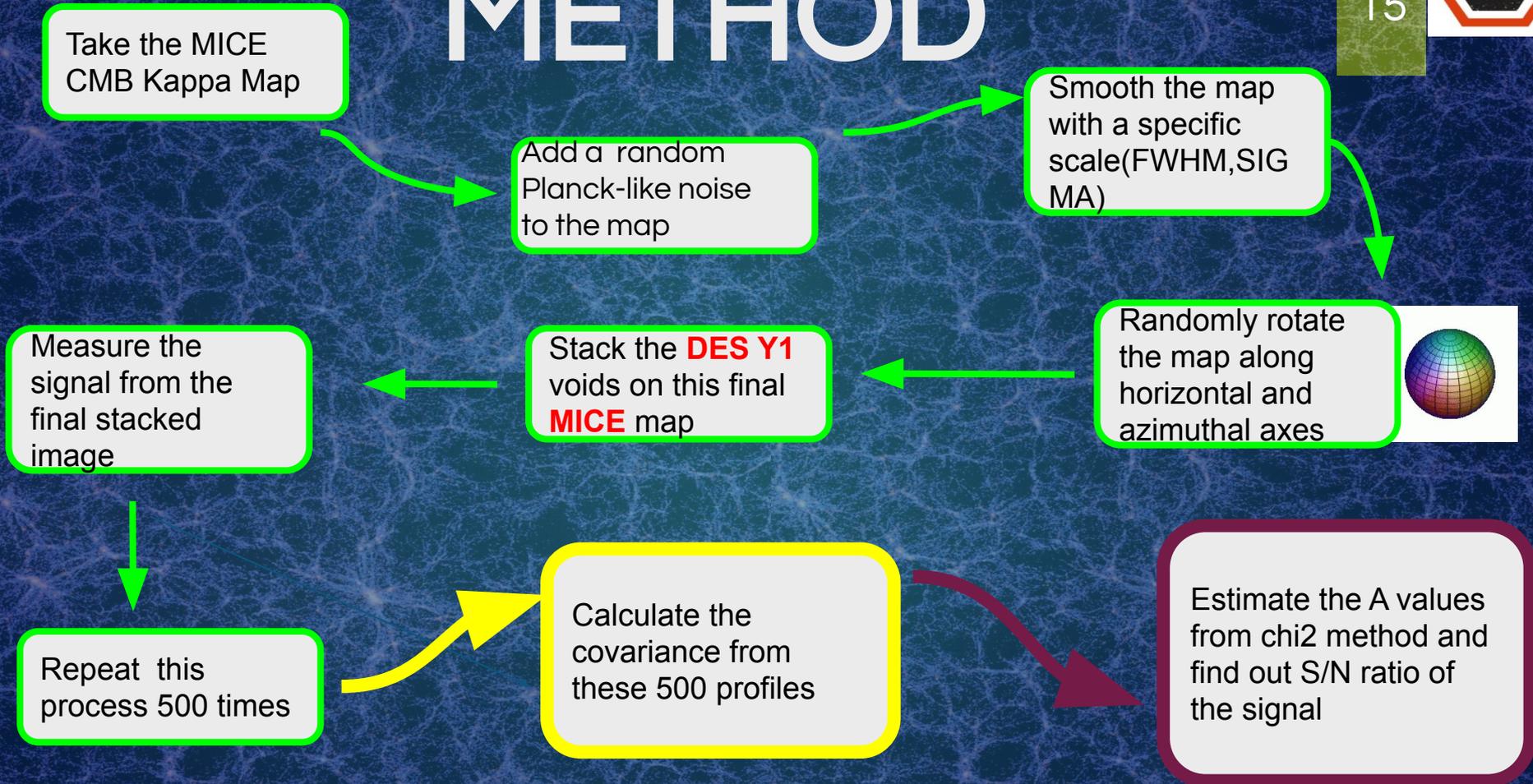
$$\chi^2 = \sum_{ij} (\kappa_i^{\text{DES}} - A\kappa_i^{\text{MICE}}) C_{ij}^{-1} (\kappa_j^{\text{DES}} - A\kappa_j^{\text{MICE}})$$

## MINIMIZING CHI SQUARED AND OBTAINING A VALUE

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

# METHOD

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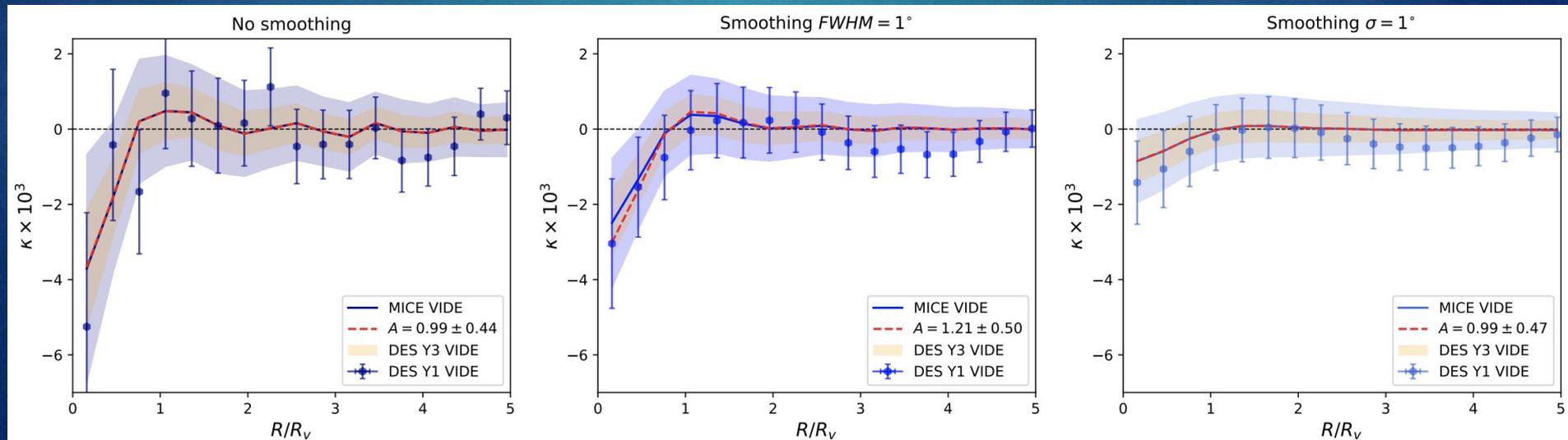


# RESULTS

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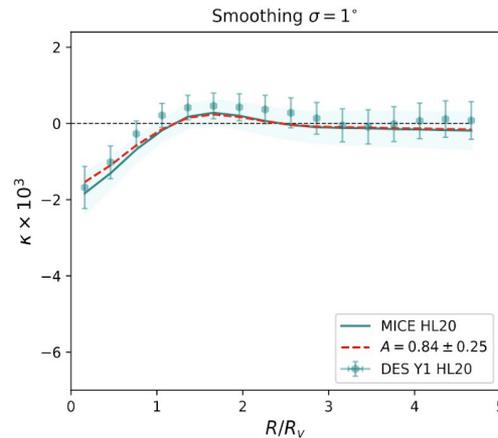
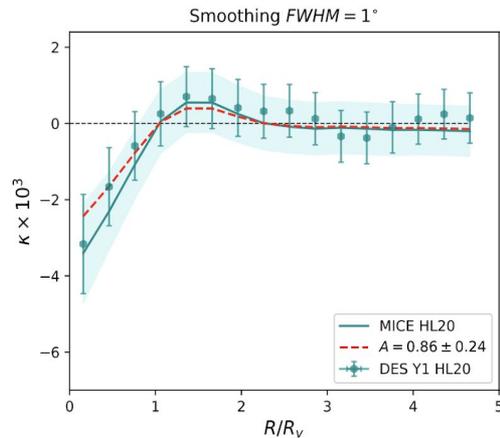
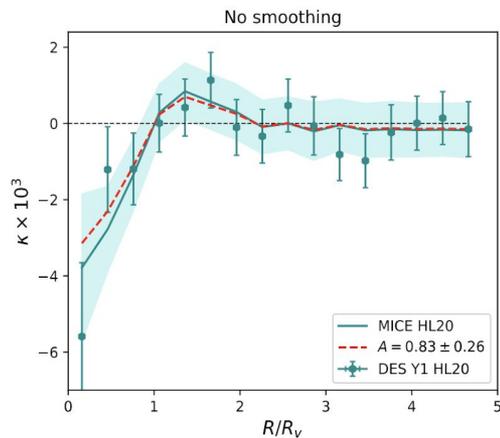
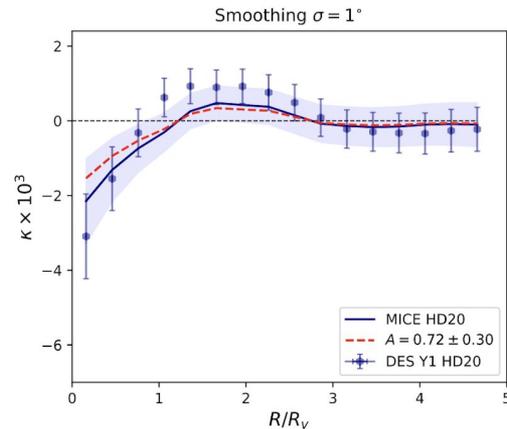
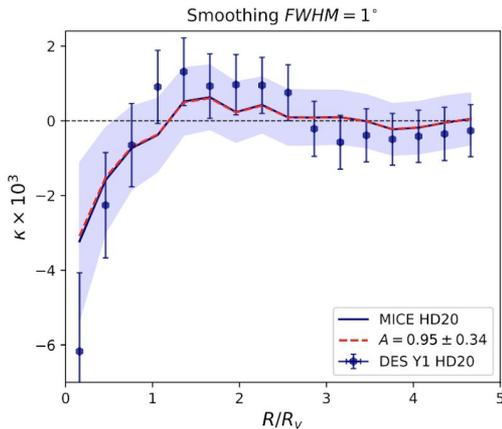
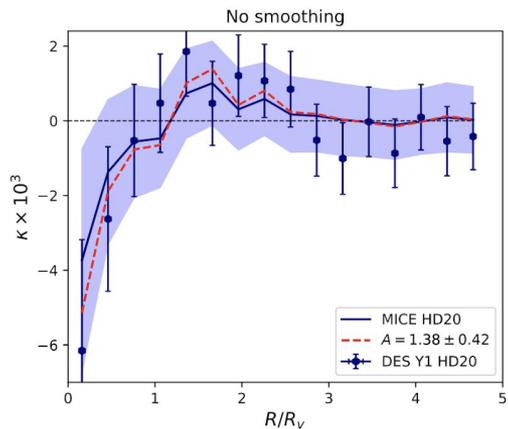


- **CMB lensing( $\kappa$ )** signal profiles by **VIDE** voids as a function of **void radius**
- Gaussian smoothing of  **$Fwhm(2.38\sigma)=1$  degree** and  **$\Sigma=1$  degree**
- Using a larger smoothing scale both reduces the noise and the signal as we try to optimize our signal measurement. 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



# RESULTS

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## 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

## $FWHM = 1^\circ$ 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

## $\sigma = 1^\circ$ smoothing

Catalog	VIDE	HD10	HD20	HL10	HL20
MICE	2.13	3.70	3.33	<b>4.55</b>	3.85
DES Y1	2.11	2.89	2.40	<b>4.91</b>	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.

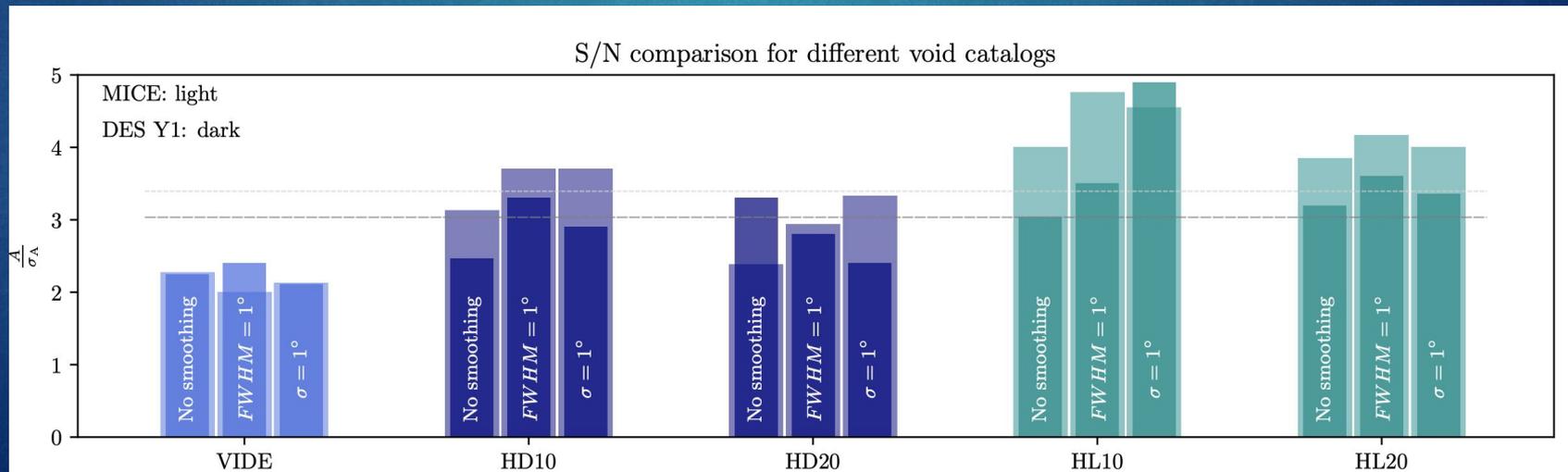
➤ We also use a **very conservative** cut to select **VIDE** voids, but in the future more diverse samples should be tried.

# CONCLUSION

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- We detect **4.9 Sigma void x CMB lensing** by **DES Y1 voids highest** to date in the literature
- There is **no indication** of an **EXCESS** CMB lensing signal in **DES Y1 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

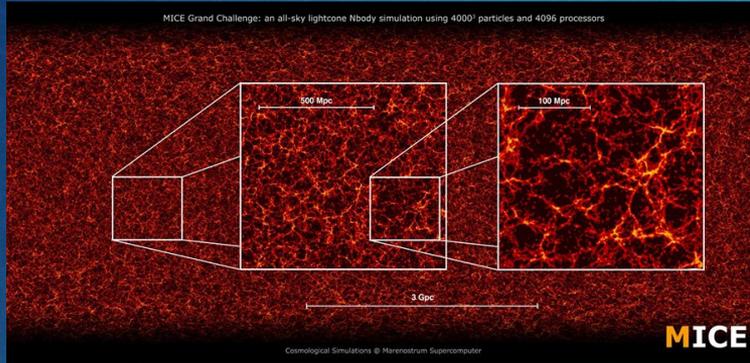




# APPENDIX

# MICE SIMULATION PARAMETERS

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- Baryon density,  $\Omega_b = 0.044$
- Matter density,  $\Omega_m = 0.25$
- Dark-energy density,  $\Omega_\Lambda = 0.75$
- Scalar spectral index,  $n_s = 0.95$
- Rms matter fluctuation amplitude,  $\sigma_8 = 0.8$
- Hubble parameter (in units of 100 km/sec/Mpc),  $h = 0.7$

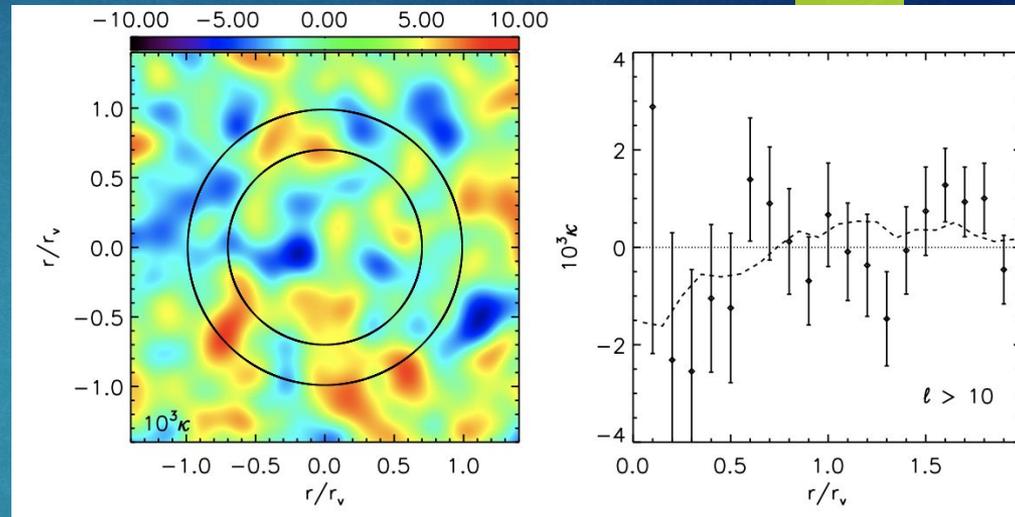
# MOTIVATION

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➤ 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

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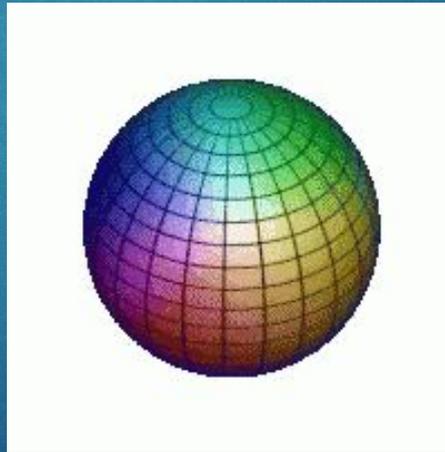


- PLANCK-LIKE NOISE ADDED to the MICE CMB CONVERGENCE MAP
  - **A simulated noise** produced by the parameters from the **Planck Collaboration** used to simulate the noise in the map, we used different seed to generate different noises.
- MAPS ARE GAUSSIAN SMOOTHED WITH DIFFERENT SCALES
  - We aim at 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)=1 deg** 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.



- 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.





## 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.
- We also use a **very conservative** cut to select **VIDE** voids, but in the future more diverse samples should be tried.