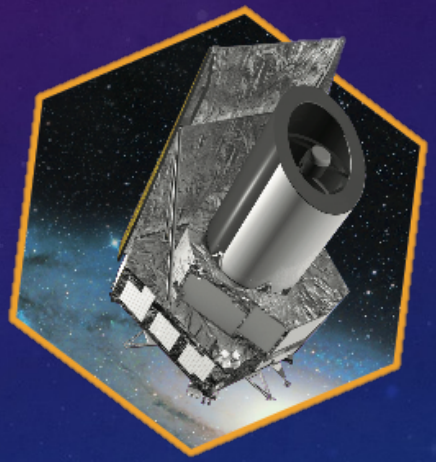
EUCLID: WEAK LENSING MASS MAPS



SANDRINE PIRES, CEA SACLAY

In behalf of the Euclid Consortium

SANDRINE.PIRES@CEA.FR

cea

france for euclid

Euclid consortium

OUTLINE

- Introduction
- Weak lensing data analysis
- Weak lensing mass maps systematics
- Ongoing projects

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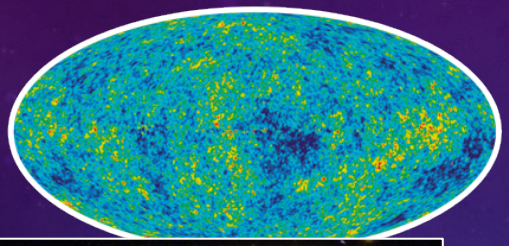
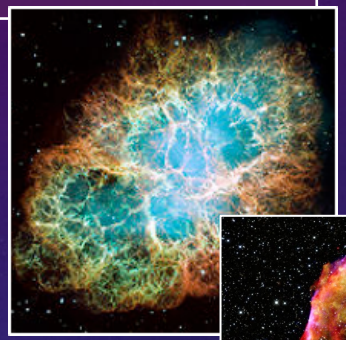
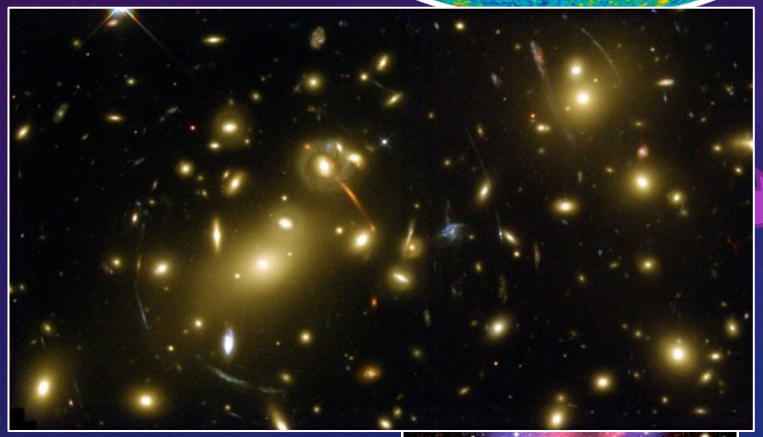
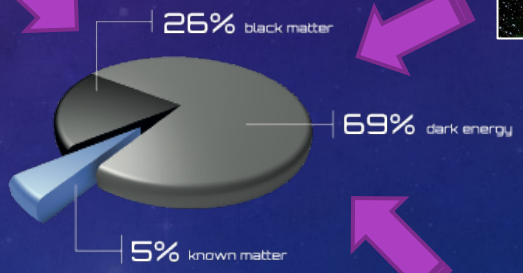
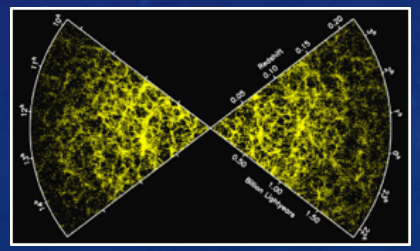
COSMOLOGY



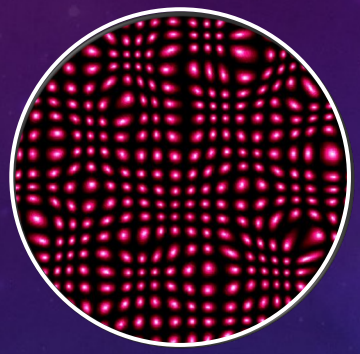




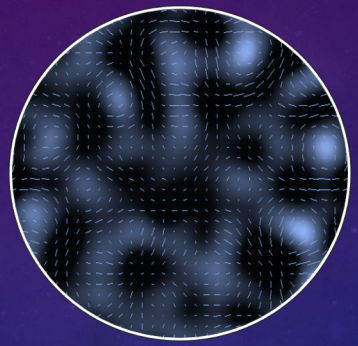




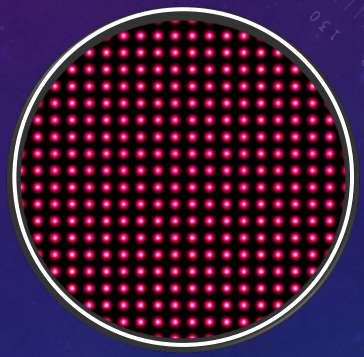
THE WEAK LENSING EFFECT



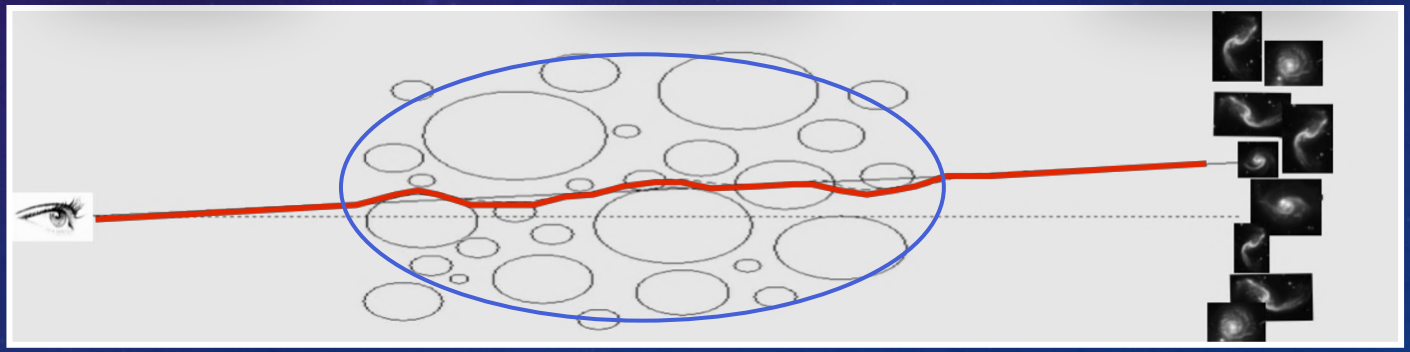
Observer



Gravitational lens

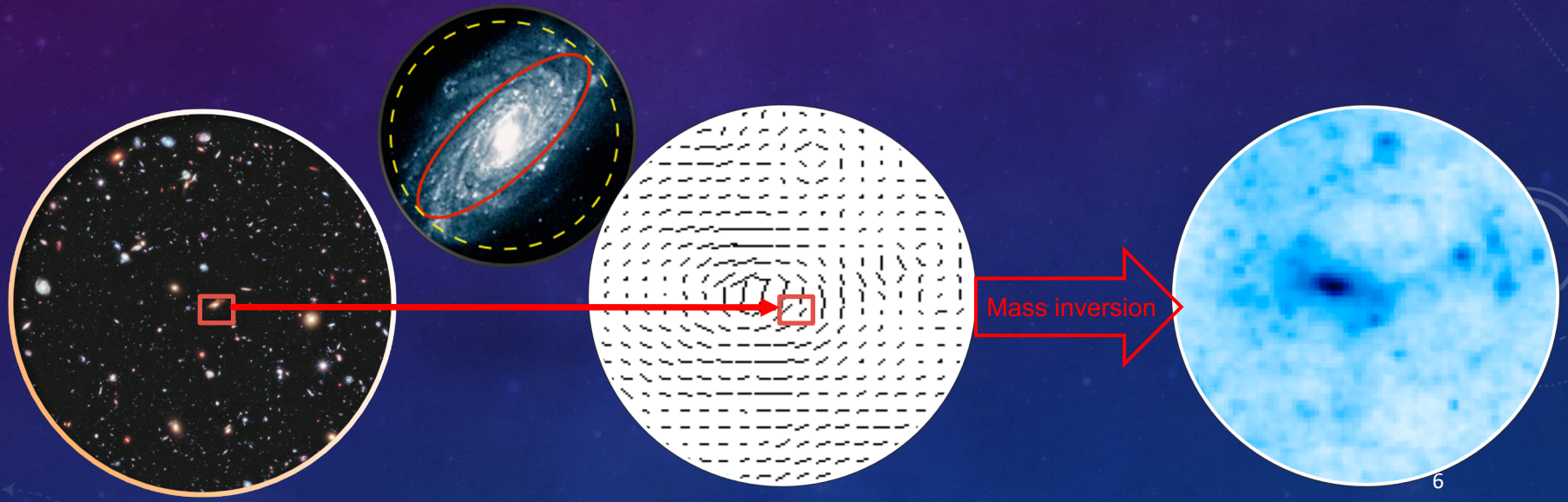


Background galaxies



FROM SHEAR TO CONVERGENCE MAPS

$$\begin{pmatrix}\epsilon_1\\ \epsilon_2\end{pmatrix} = \frac{1-\beta}{1+\beta}\begin{pmatrix}\cos 2\phi\\ \sin 2\phi\end{pmatrix}$$



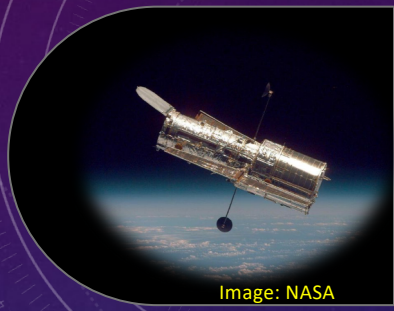
Observed region

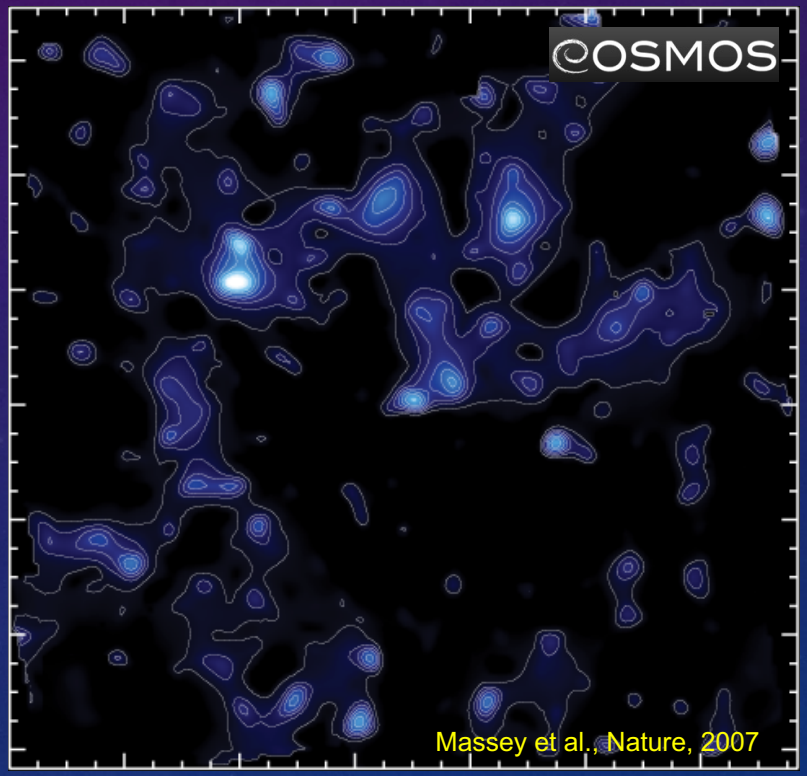
Image distortions called **shear**

$$\gamma_i = < \epsilon_i >$$

Projected dark matter distribution called **convergence**

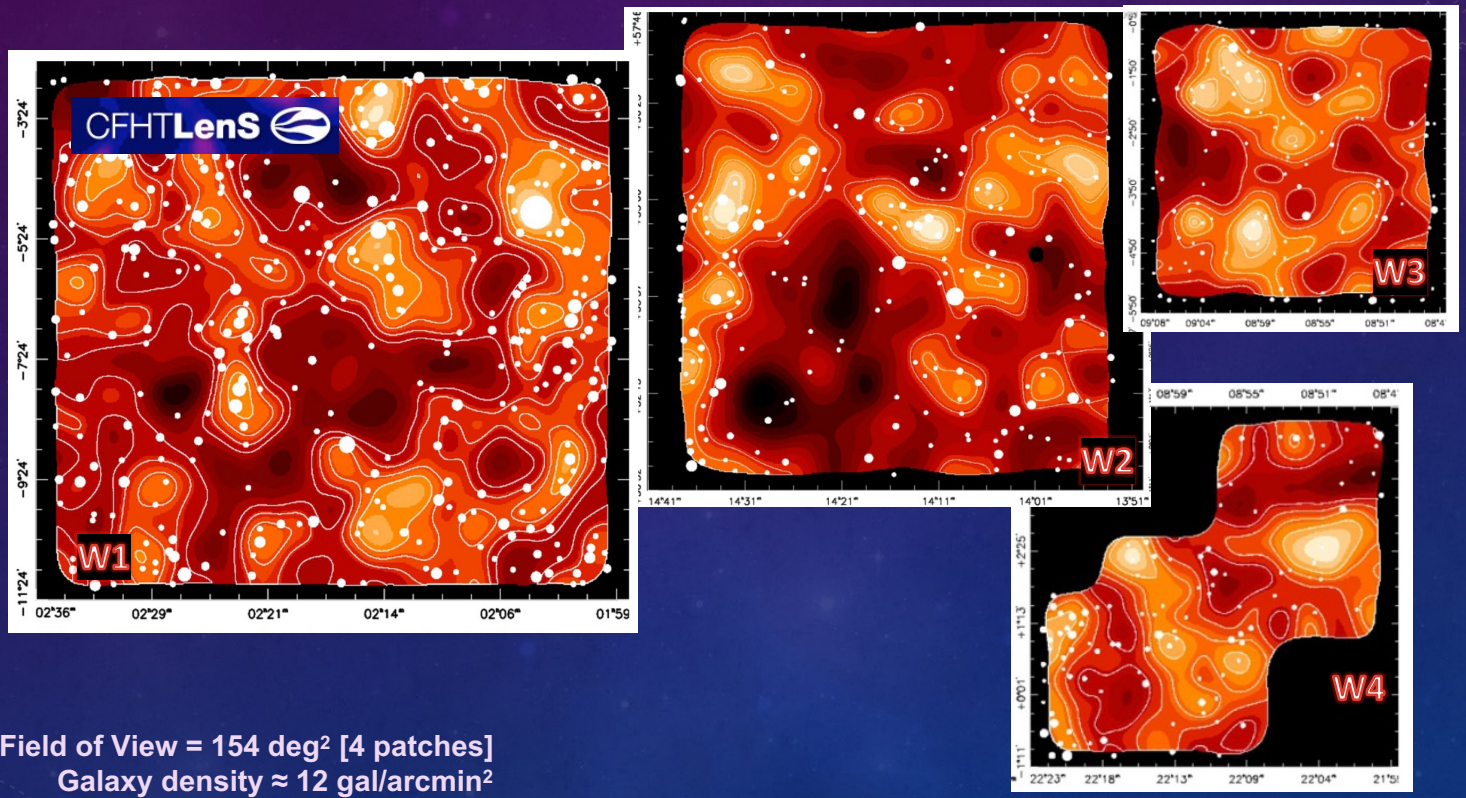
THE COSMOS SURVEY (HST)

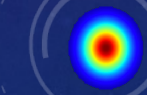




Field of View = 1.64 deg² [1 patch]
Galaxy density ≈ 67 gal/arcmin²
Telescope: Hubble Space Telescope

THE CFHTLENS SURVEY



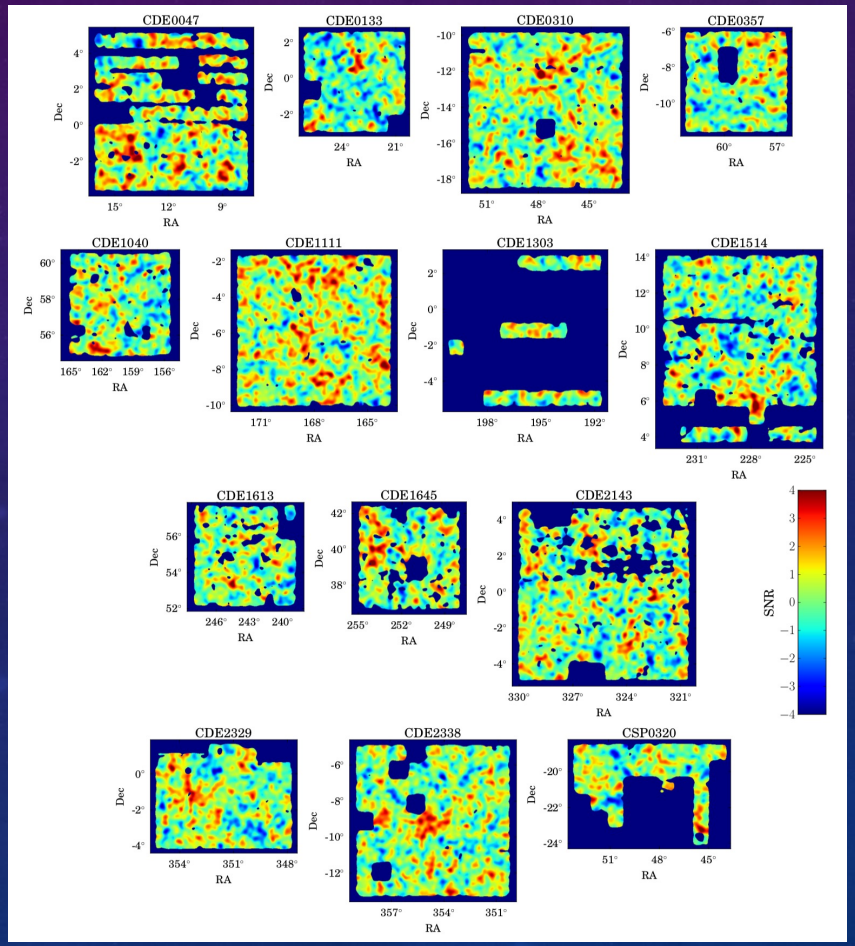


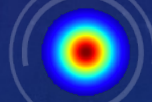
σ = 8.9 arcmin

Field of View = 154 deg² [4 patches]
Galaxy density ≈ 12 gal/arcmin²
Telscope : CFHT

Van Waerbeke et al., MNRAS, 2013

RED-SEQUENCE CLUSTER LENSING SURVEY



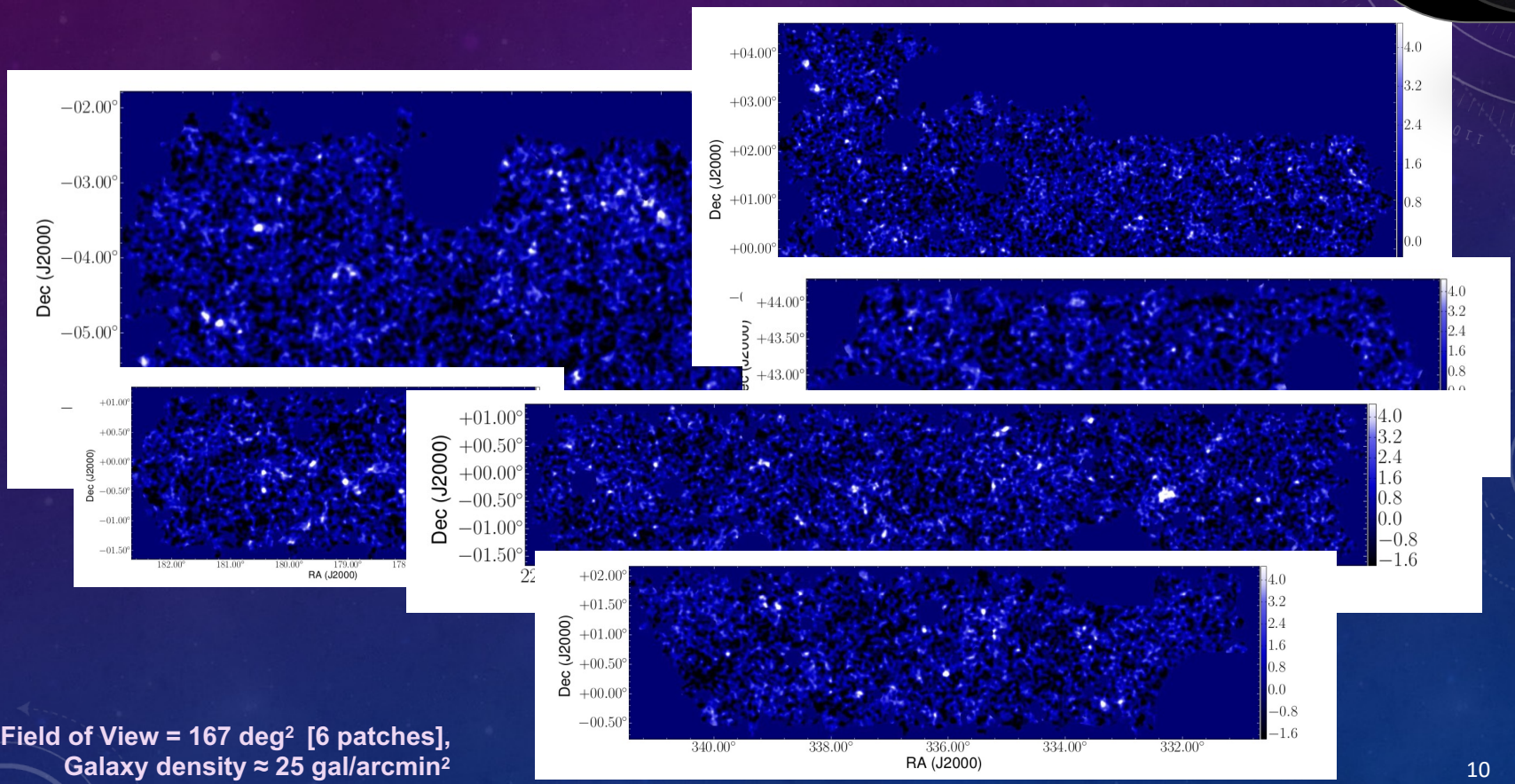


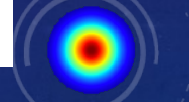
σ = 16 arcmin

Field of View = 785 deg², [14 patches]
Galaxy density ≈ 5 gal/arcmin²
Telescope: CFHT

H. Hildebrandt et al, MNRAS, 2016

THE HYPER SUPRIME-CAM SURVEY (HSC)



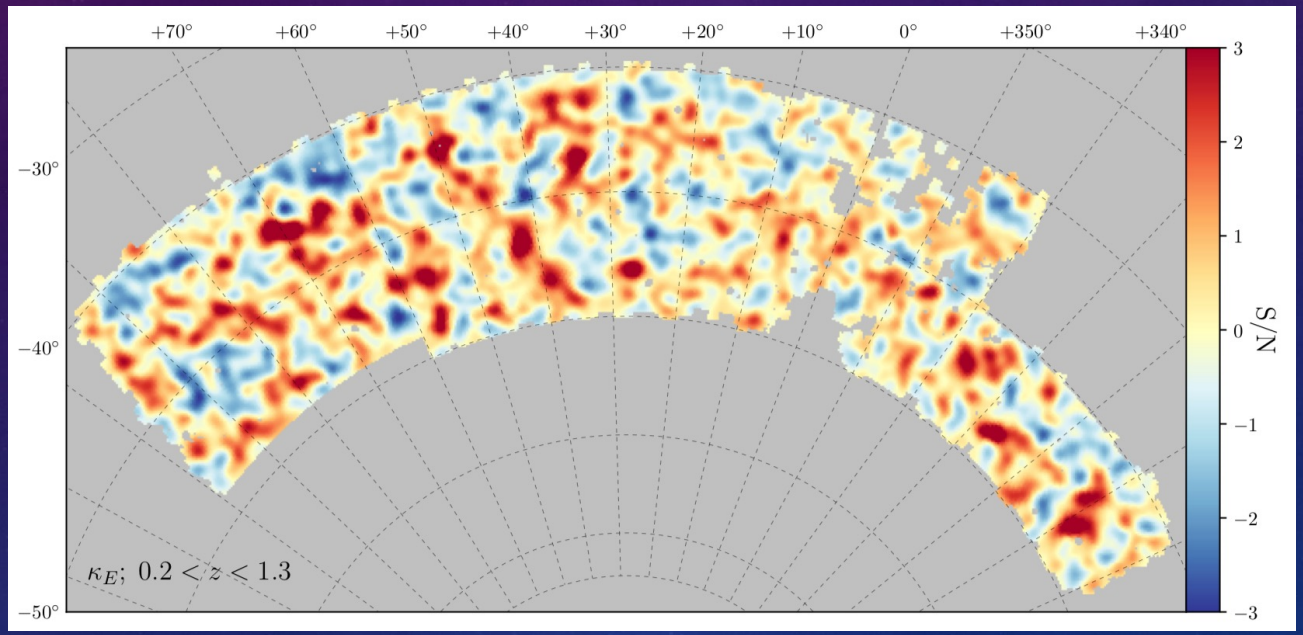


σ = 2 arcmin

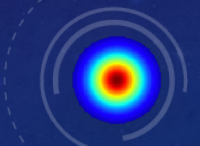
Field of View = 167 deg² [6 patches],
Galaxy density ≈ 25 gal/arcmin²
Telescope: Subaru

M.Oguri et al, PASJ, 2018

THE DARK ENERGY SURVEY (DES)



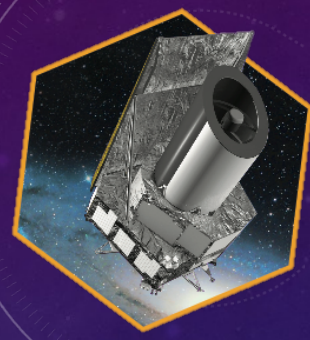
C.Chang et al, MNRAS, 2018

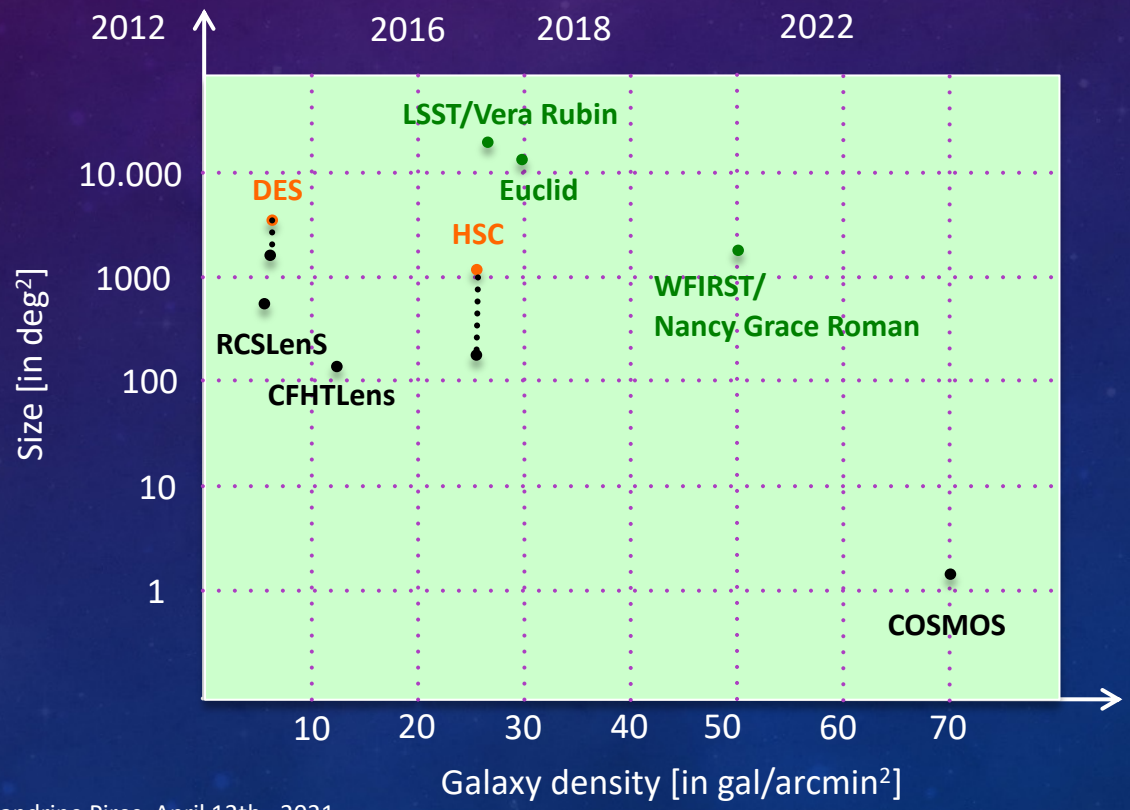


σ = 30 arcmin

Field of View = 1500 deg² [1 patch]
Galaxy density ≈ 5 gal/arcmin²
Telescope: Victor M. Blanco (Chile)

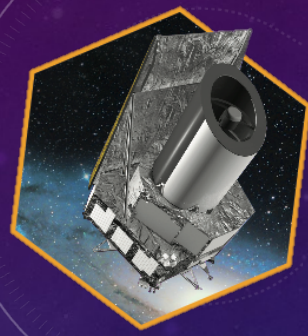
WEAK LENSING SURVEYS





Sandrine Pires, April 12th, 2021

THE EUCLID MISSION



Launch foreseen in 2023 from Kourou space base, by a Soyouz rocket

6-year mission around the Sun / Earth L2 Lagrange point,
A sky survey covering 15 000 deg²

- Telescope
  Primary mirror diameter 1,20 m
  Field of view : 0,5 deg2 (twice the apparent size of the full Moon)
  Silica carbide structure (for its ultra stability).
- Instruments
  VIS, the visible photometer
  NISP, the infra red spectro photometer
  [0,9 µm ; 2,0 µm].

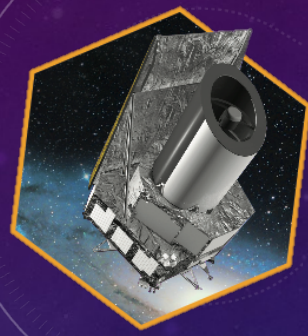
Euclid
is an ESA mission
European Space Agency

It is the second mission of the Cosmic Vision program

France has the scientific leadership of the experience.

Slide courtesy of Rodolphe Clédassou

THE EUCLID MISSION



Weak lensing

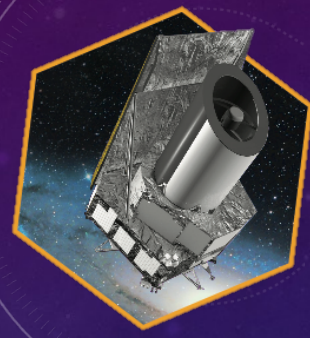
- **Visible: Galaxy shape measurements in R+I+Z<24.5 (AB,10σ), 40 resolved galaxies/amin^2, median resdshift of 0.9**
- **NIR photometry: Y,J,H<24 (AB, 5σ PS), photometric redshifts rms 003-0.05(1+z) with ground based complement**

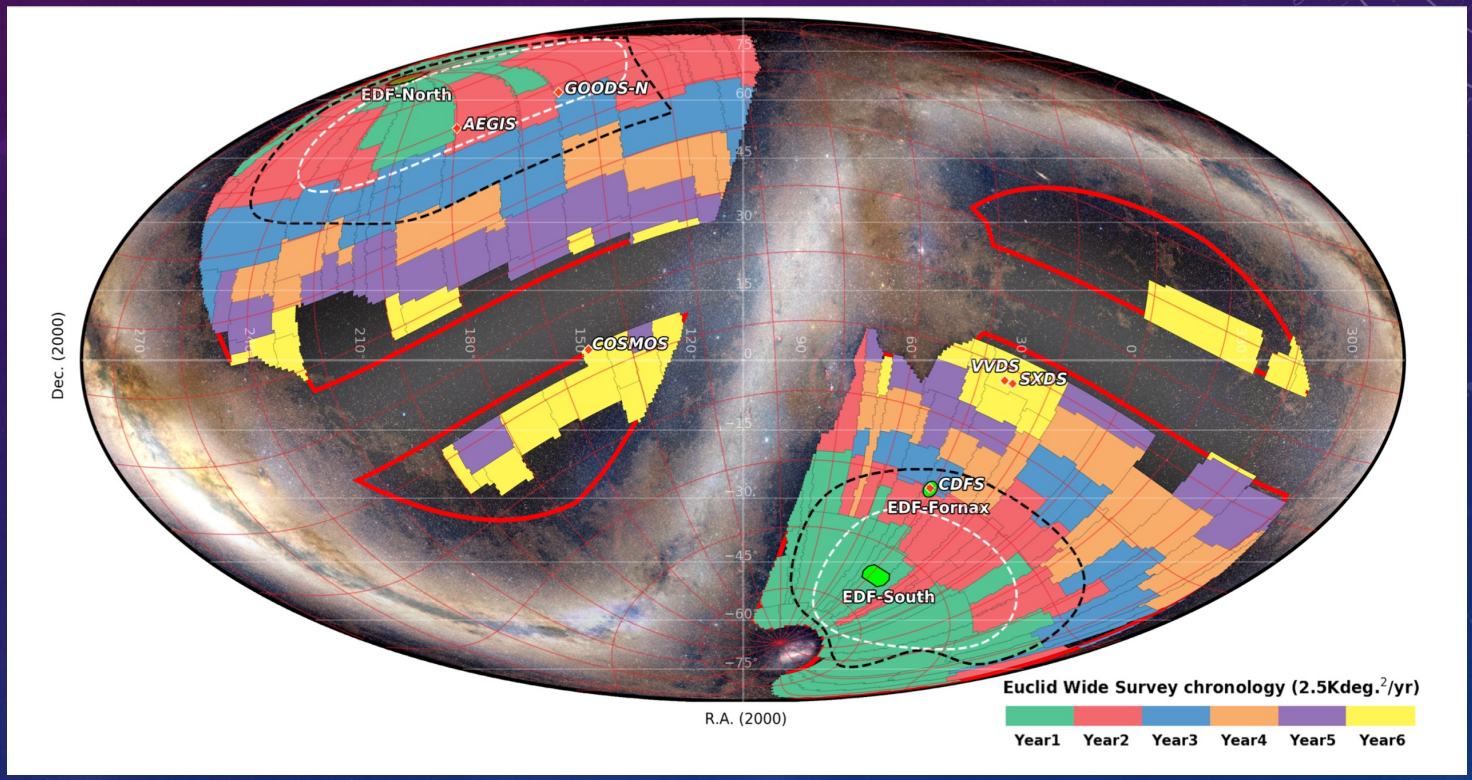
BAO

- **Spectroscopic redshifts for 33% of all galaxies with H(AB)<22 mag, σ_z<0.001**

Euclid Consortium
more than 2000 members in 280 institutes in 18 countries.

EUCLID REFERENCE SURVEY





σ ≤ 1 arcmin

Field of View ≈ 15000 deg^2,
Galaxy density ≈ 30 gal/arcmin^2

R. Scaramell et al., 2021 (submitted)

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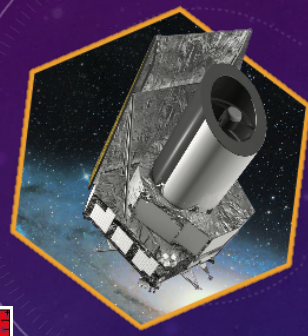
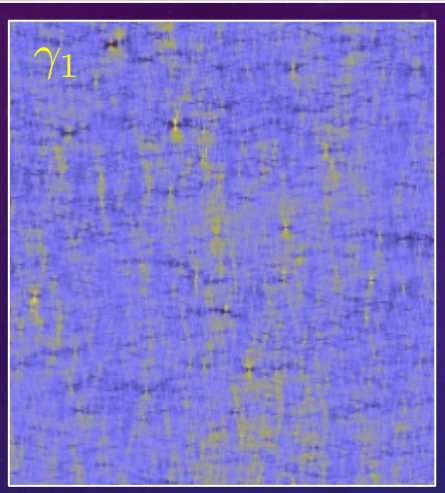
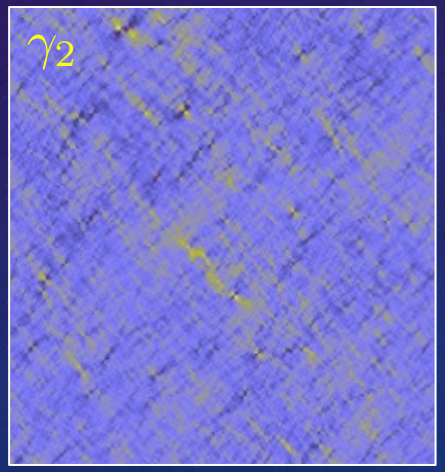
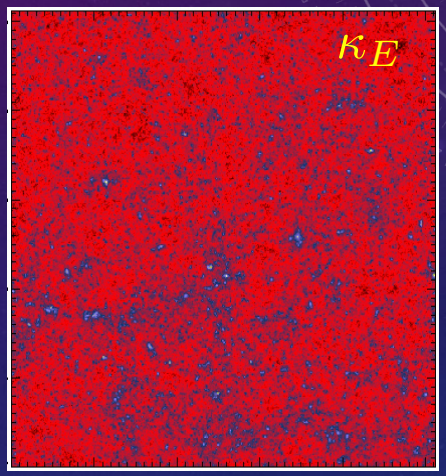
WEAK LENSING DATA ANALYSIS

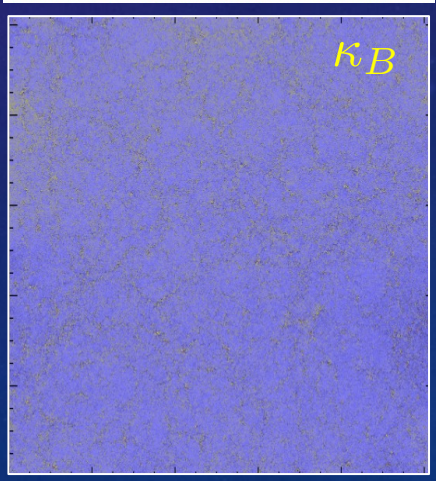






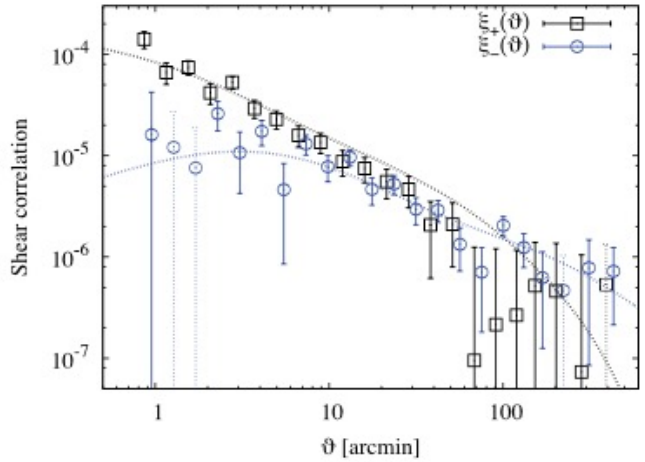
$\gamma = \gamma_1 + \mathrm{i}\gamma_2$



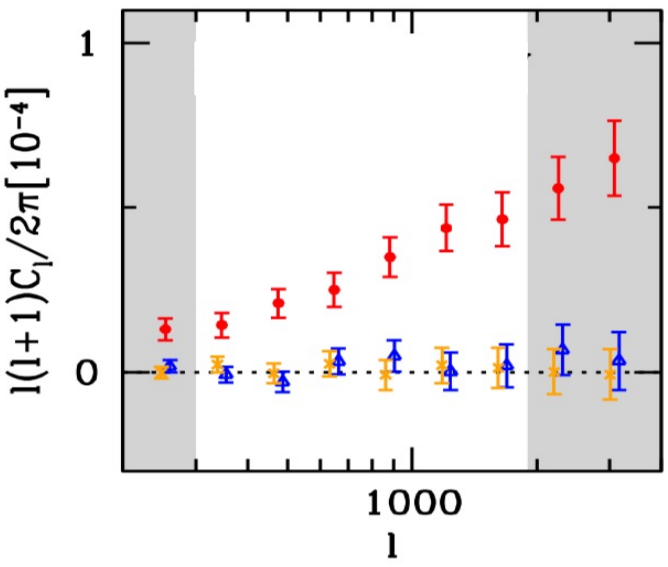


$\kappa = \kappa_E + \mathrm{i}\kappa_\mathrm{B}$

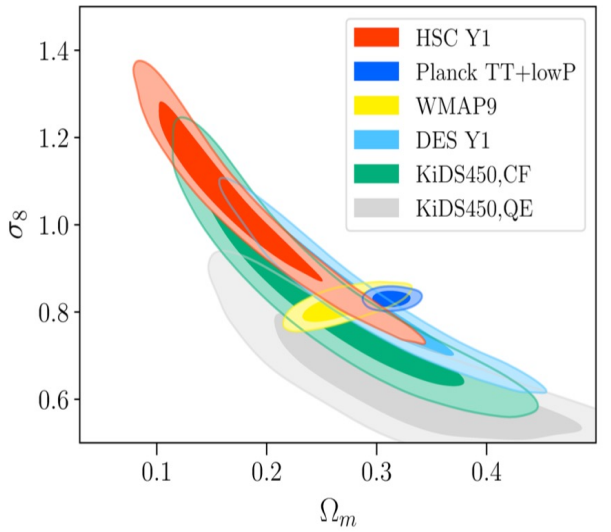
WEAK LENSING DATA ANALYSIS



Kilbinger et al., MNRAS, 2013 [CFHTLenS]

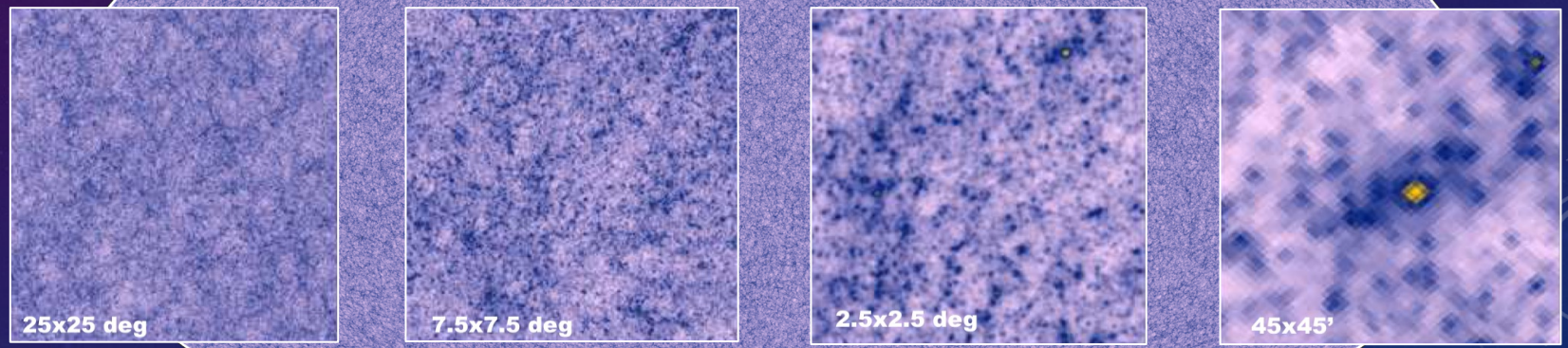


Hikage et al., PASJ, 2019 [HSC]



Hikage et al., PASJ, 2019 [HSC]

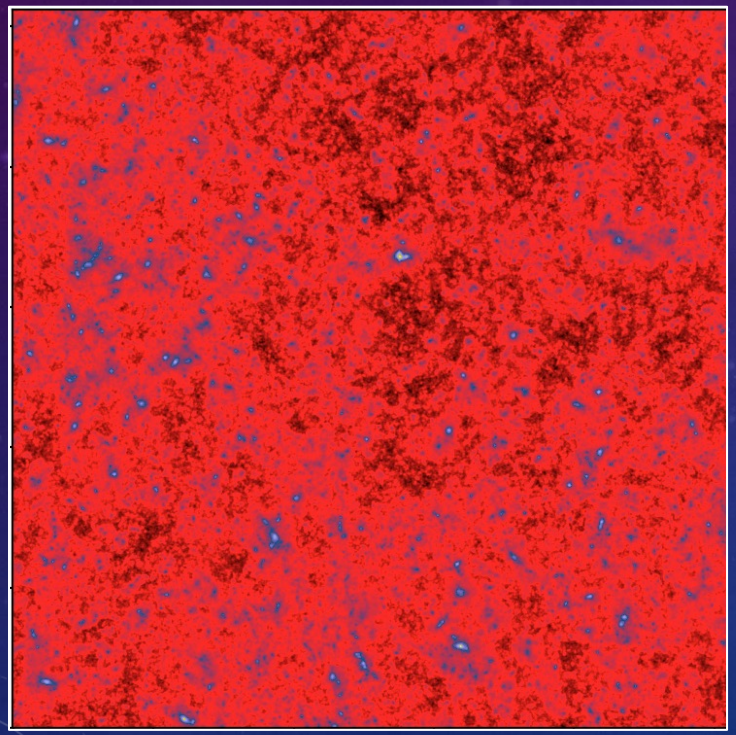
WEAK LENSING FIELD

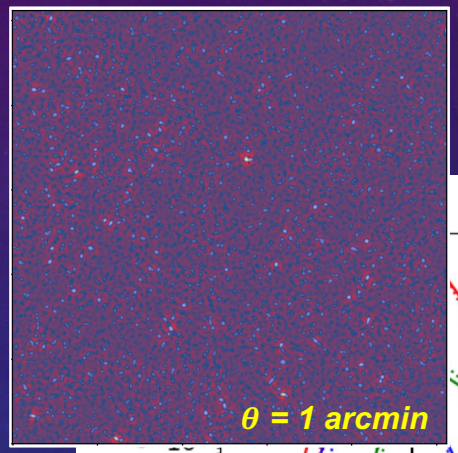


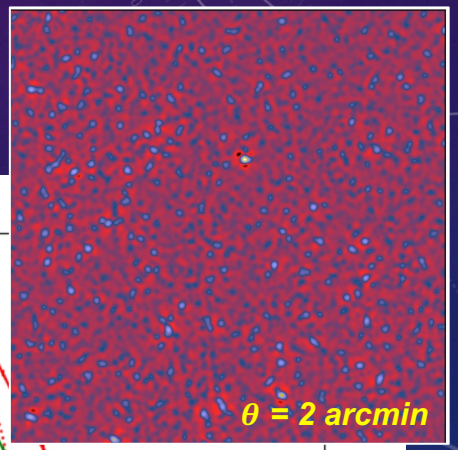
Teyssier, Pires et al, 2009

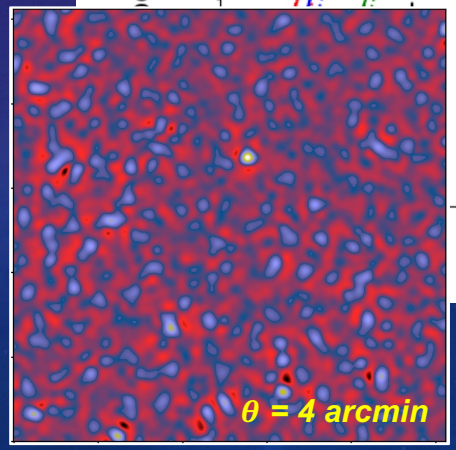
Full-sky convergence map derived from the Horizon simulation

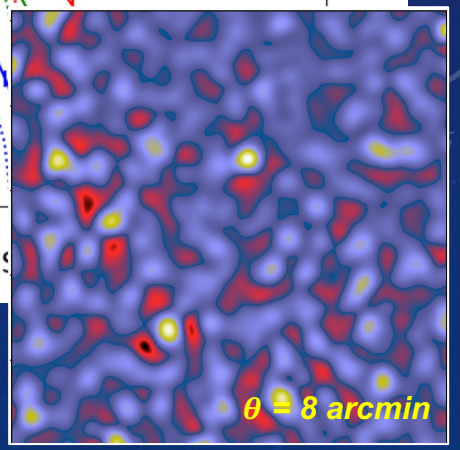
HIGHER-ORDER STATISTICS



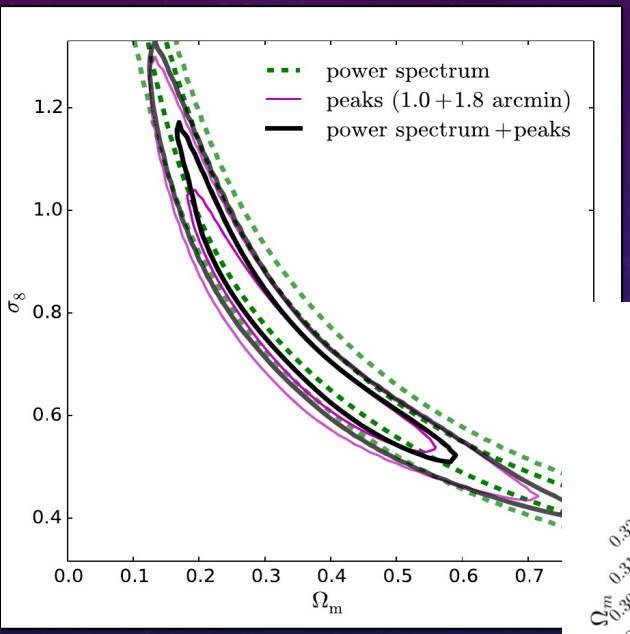




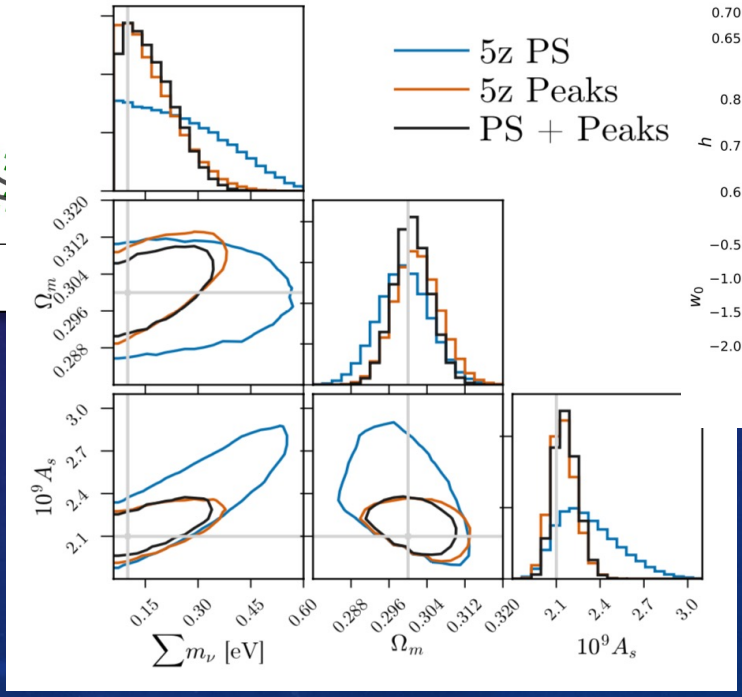




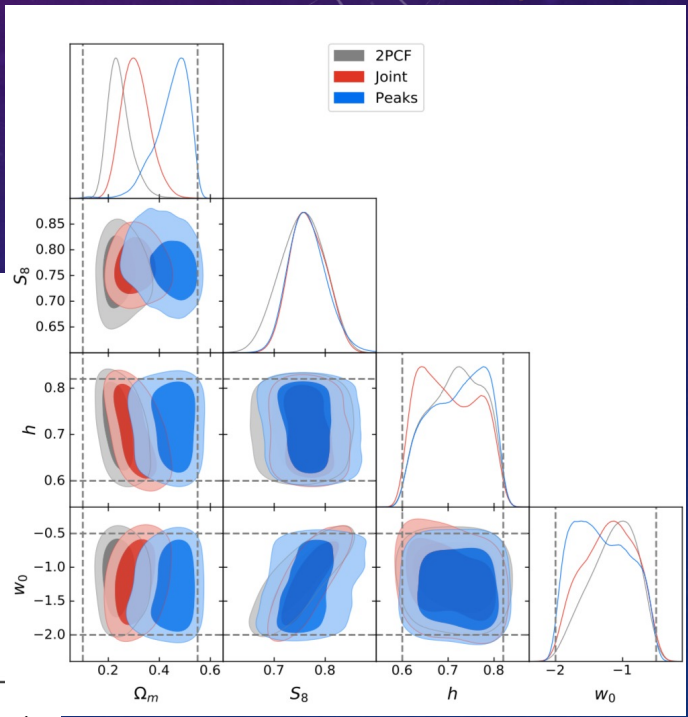
PEAK COUNT STATISTIC



CFHTLens results: J. Liu et al., PhRvD, 2015

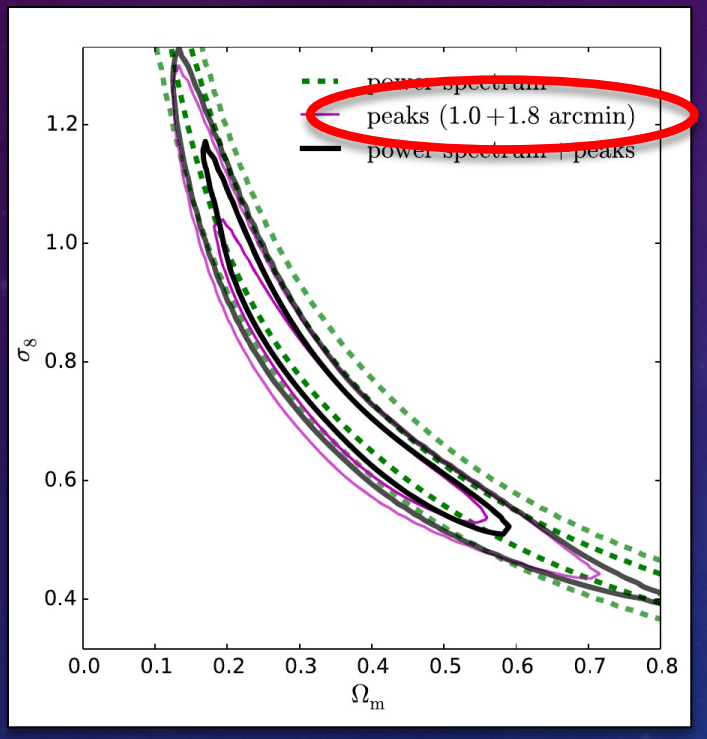


Vea Rubin forecast : Z. Li et al., PhRvD,

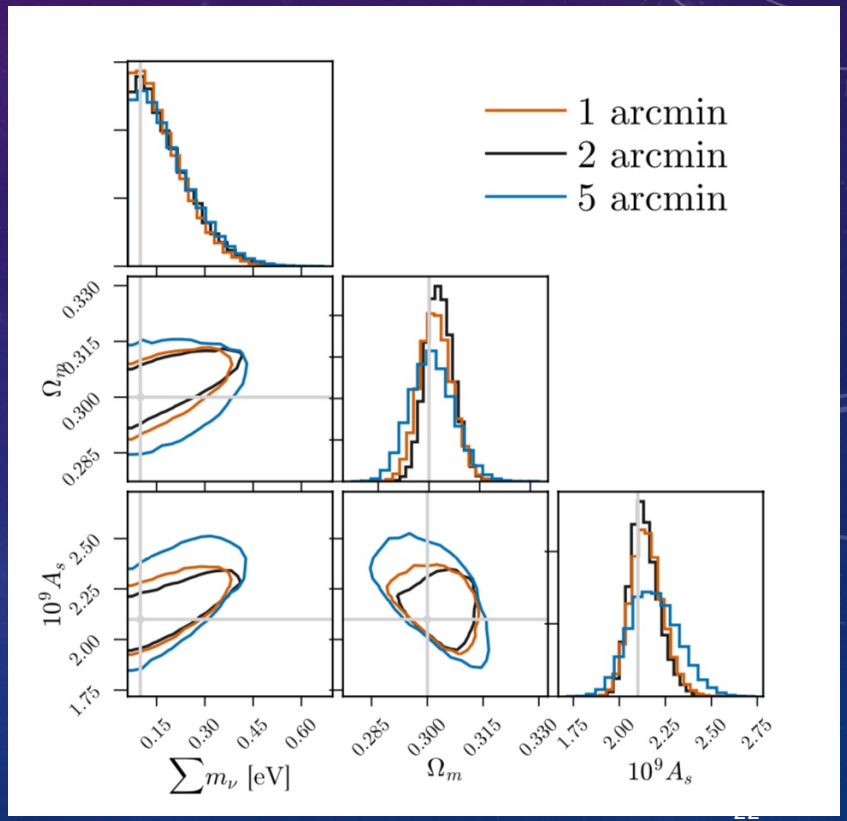


DES Y1 results: J. Harnois-DerapsZ. Li et al., PhRvD, 2020

PEAK COUNT STATISTICS

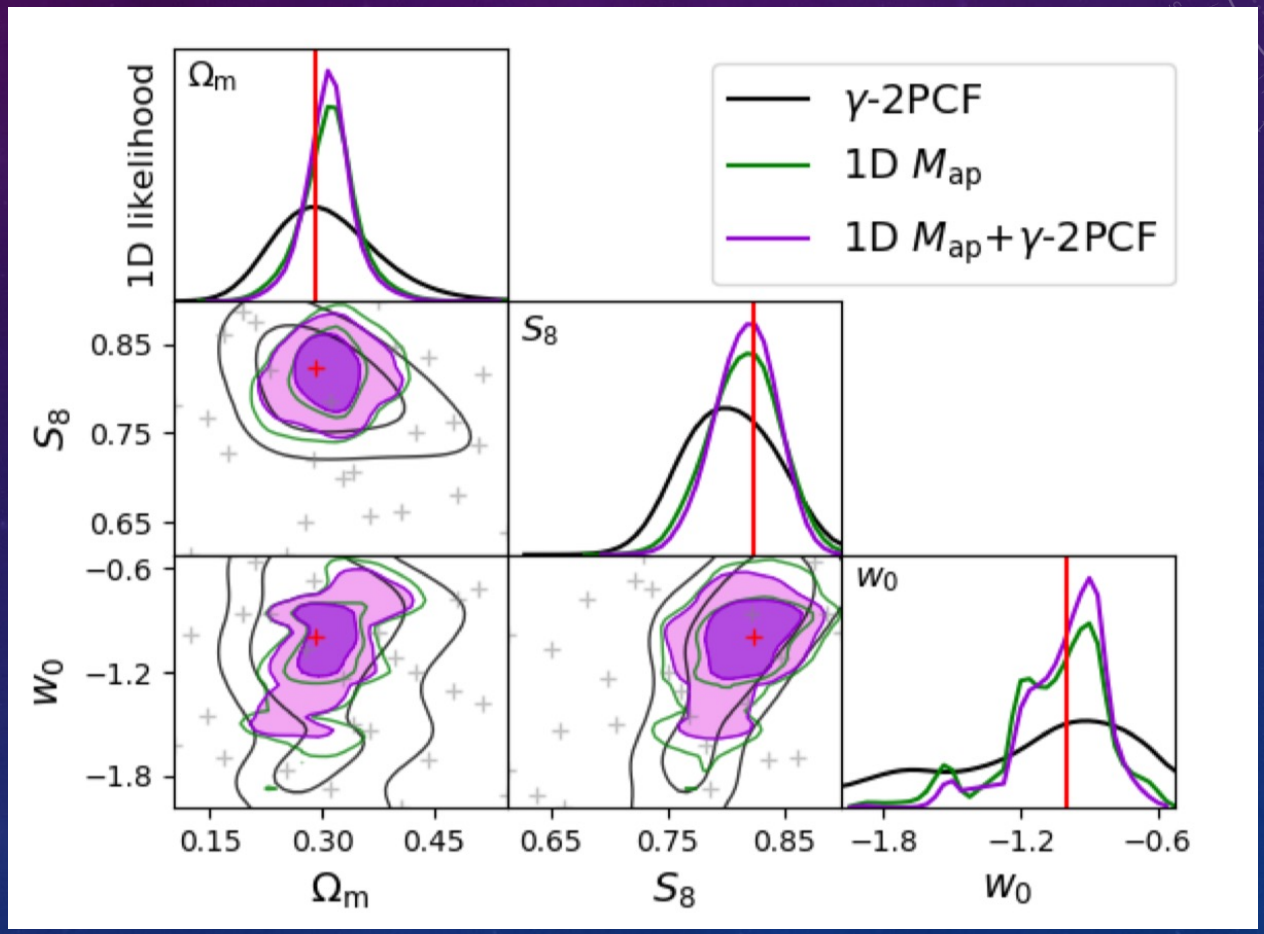


CFHTLens, J. Liu et al., PhRvD, 2015



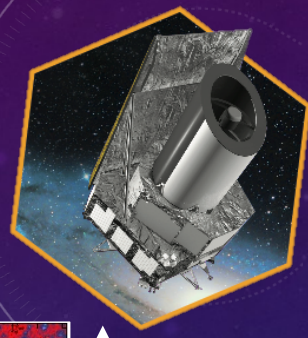
Vera Rubin forecast : Z. Li et al., PhRvD, 2019

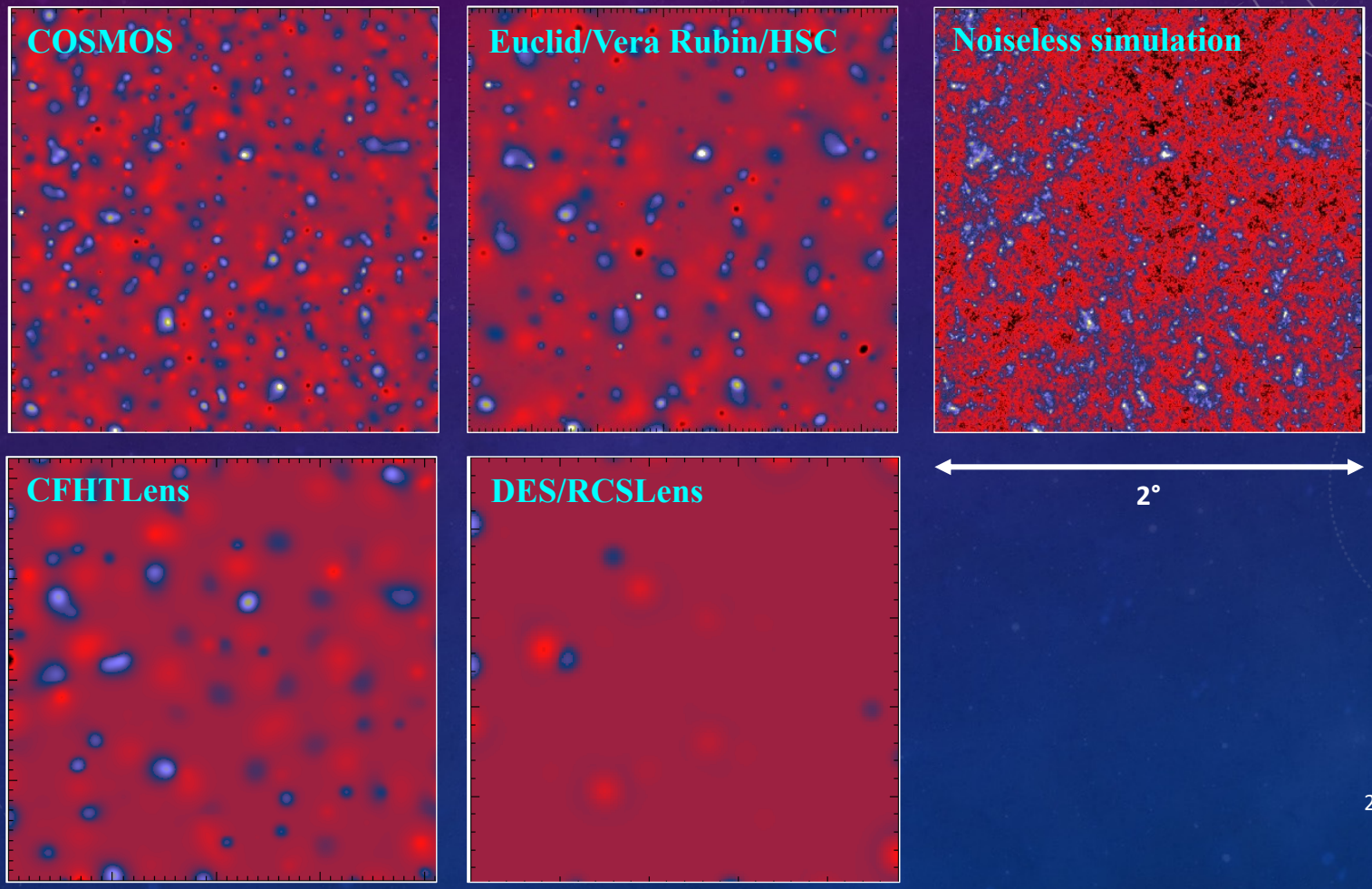
PROBABILITY DISTRIBUTION STATISTIC



Euclid forecast for θ=1.5 *arcmin*: Martinet et al., 2021

WEAK LENSING MASS MAP RESOLUTION





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WEAK LENSING MASS MAPS SYSTEMATICS

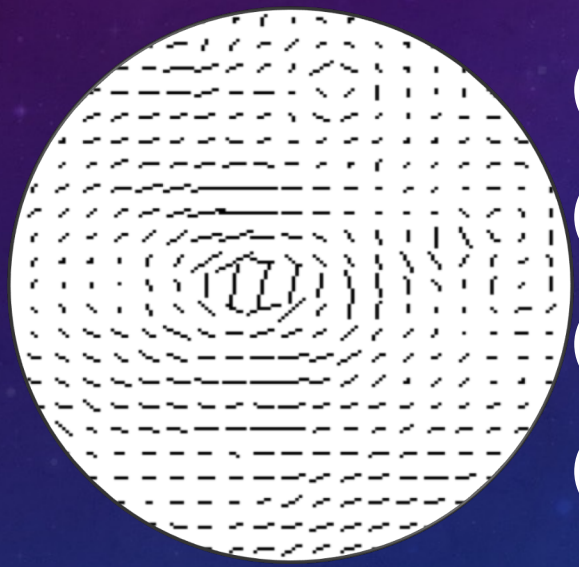
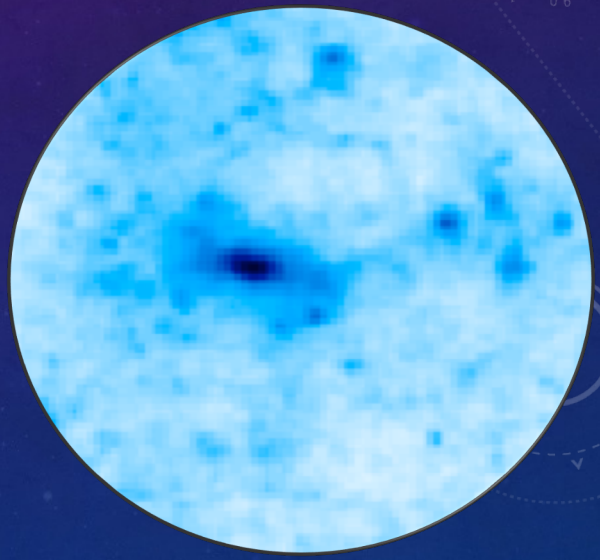


Image distortions called **shear**

- Missing data
- Border effects
- Noise effect
- Reduced shear observable



Projected dark matter distribution called **convergence**

EUCLID MASS MAPPING PIPELINE

- Standard kaiser and squires [Kaiser and squires 1993, KS]

$$\hat{\kappa} = \hat{P}^* \hat{\gamma} \qquad \hat{P}_1(\boldsymbol{\ell}) = \frac{\ell_1^2 - \ell_2^2}{\ell^2}, \qquad \hat{P}_2(\boldsymbol{\ell}) = \frac{2\ell_1\ell_2}{\ell^2},$$

- Improved Kaiser and squires [Pires et al., 2020, KS+]

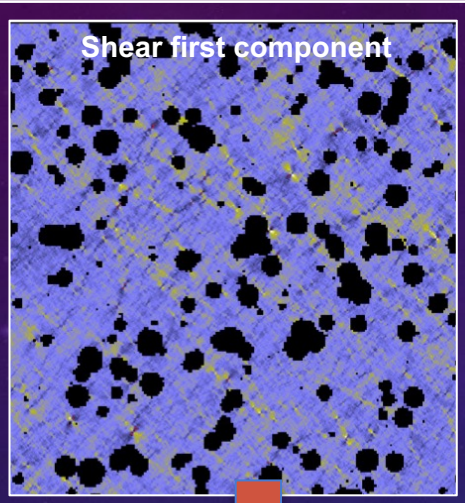
$$\min_{\boldsymbol{\kappa}^{\mathbf{n}}} \|\boldsymbol{\Phi}^{\mathrm{T}}\boldsymbol{\kappa}^{\mathbf{n}}\|_0 \text{ s.t. } \| \tilde{\boldsymbol{\gamma}} - \mathbf{MPW}^{\mathrm{T}}\mathbf{QW}\boldsymbol{\kappa}^{\mathbf{n}} \|^2 \leq \sigma^2$$

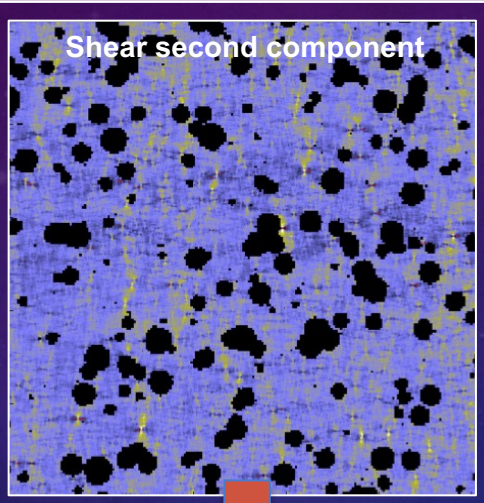
Astronomy & Astrophysics manuscript no. MassMapping_Euclid_AA_v7
May 7, 2020

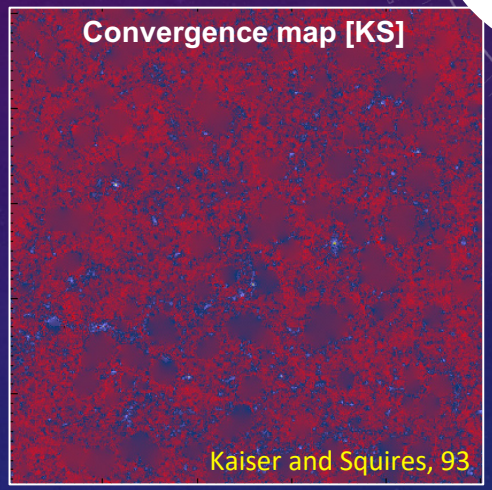
Euclid*: Reconstruction of Weak Lensing mass maps for non-Gaussianity studies

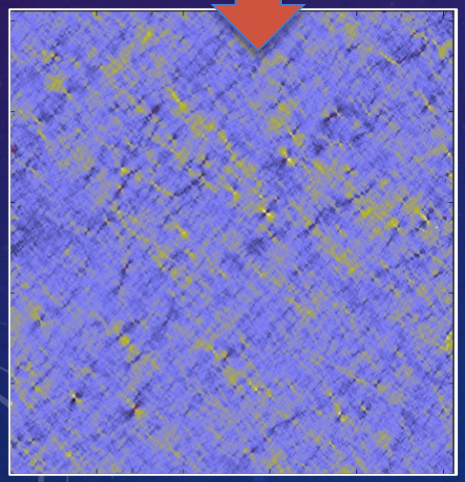
S. Pires[1**], V. Vandenbussche[1], V. Kansal[1], R. Bender[2,3], L. Blot[4], D. Bonino[5], A. Boucaud[6], J. Brinchmann[7], V. Capobianco[5], J. Carretero[8], M. Castellano[9], S. Cavuoti[10,11,12], R. Clédassou[13], G. Congedo[14], L. Conversi[15], L. Corcione[5], F. Dubath[16], P. Fosalba[17,18], M. Frailis[19], E. Franceschi[20], M. Fumana[21], F. Grupp[3], F. Hormuth[22], S. Kermiche[23], M. Knabenhans[24], R. Kohley[15], B. Kubik[25], M. Kunz[26], S. Ligori[5], P.B. Lilje[27], I. Lloro[17,18], E. Maiorano[20], O. Marggraf[28], R. Massey[29], G. Meylan[30], C. Padilla[8], S. Paltani[16], F. Pasian[19], M. Poncet[13], D. Potter[24], F. Raison[3], J. Rhodes[31], M. Roncarelli[20,32], R. Saglia[2,3], P. Schneider[28], A. Secroun[23], S. Serrano[17,33], J. Stadel[24], P. Tallada Crespí[34], I. Tereno[35,36], R. Toledo-Moreo[37], Y. Wang[38]

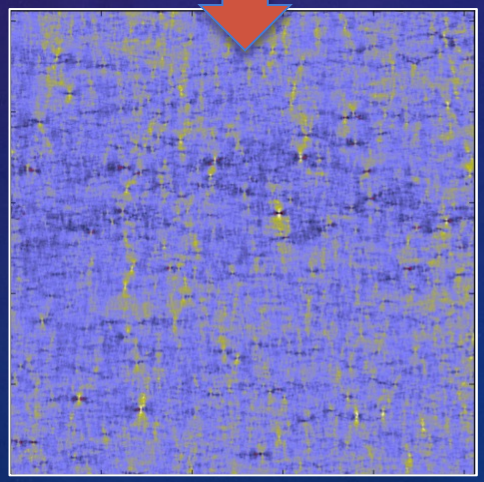
DEALING WITH MISSING DATA

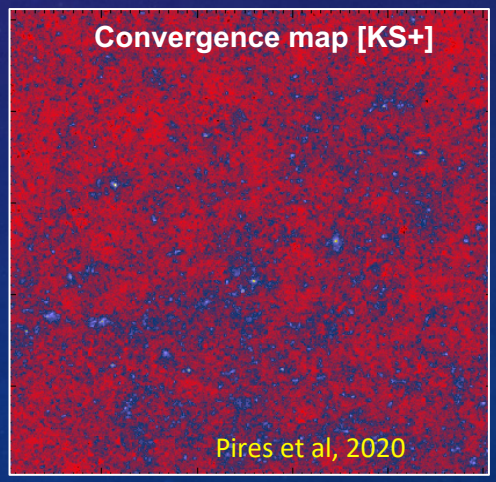






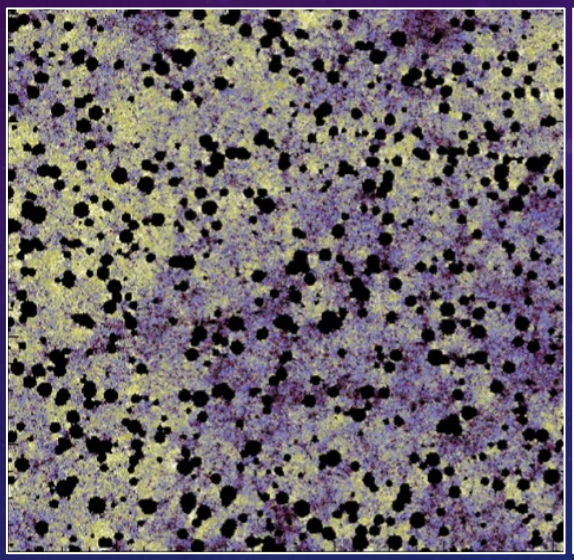




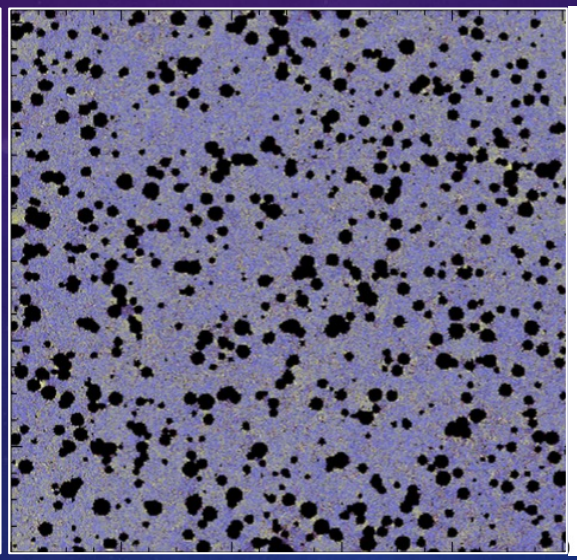


DEALING WITH MISSING DATA

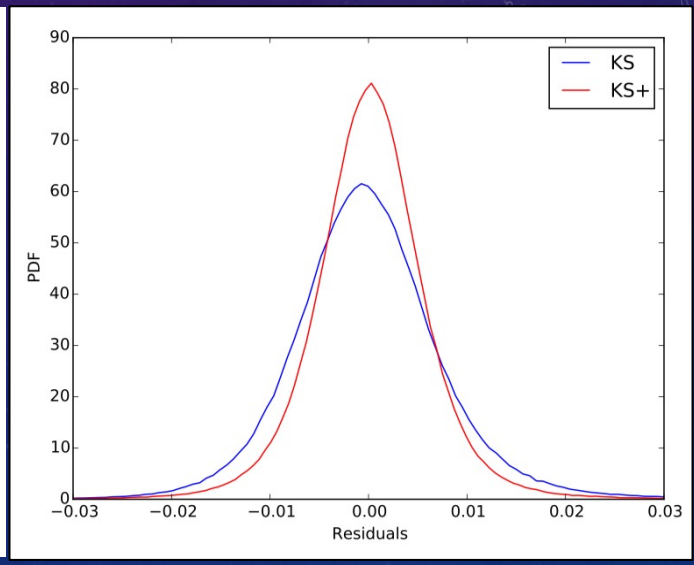
FIRST-ORDER STATISTICS



KS residual errors



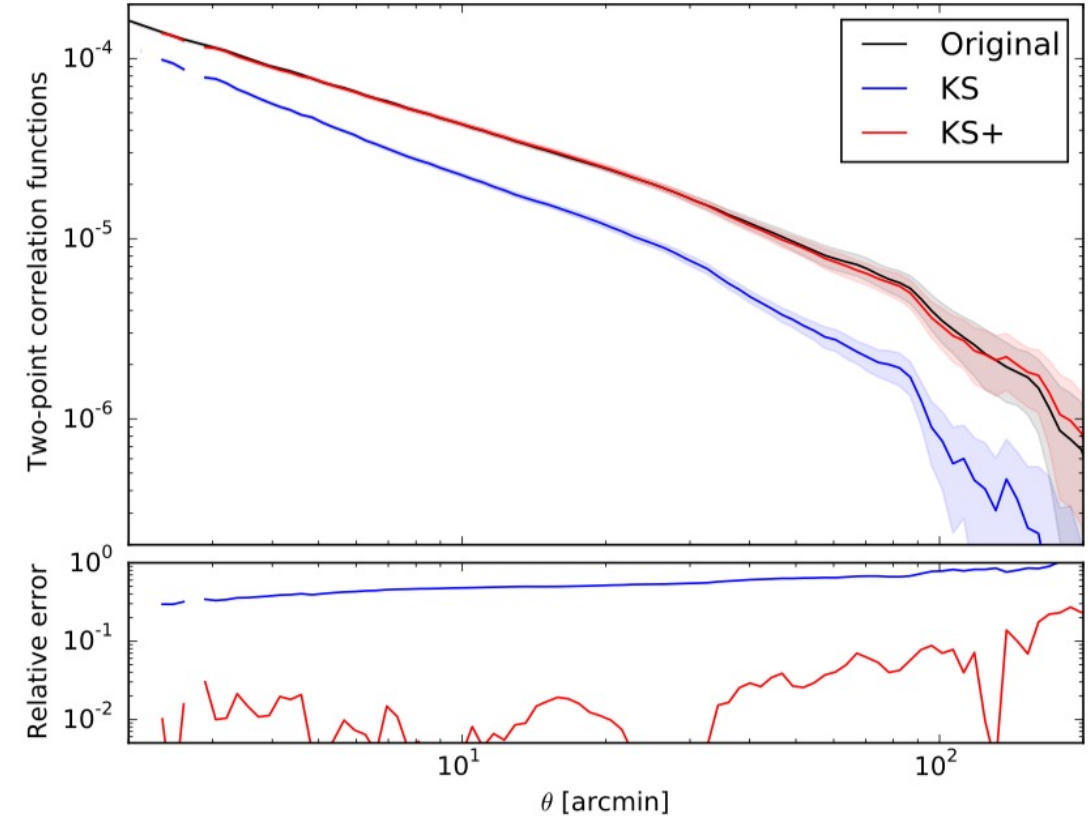
KS+ residual errors



PDF of residual errors

DEALING WITH MISSING DATA

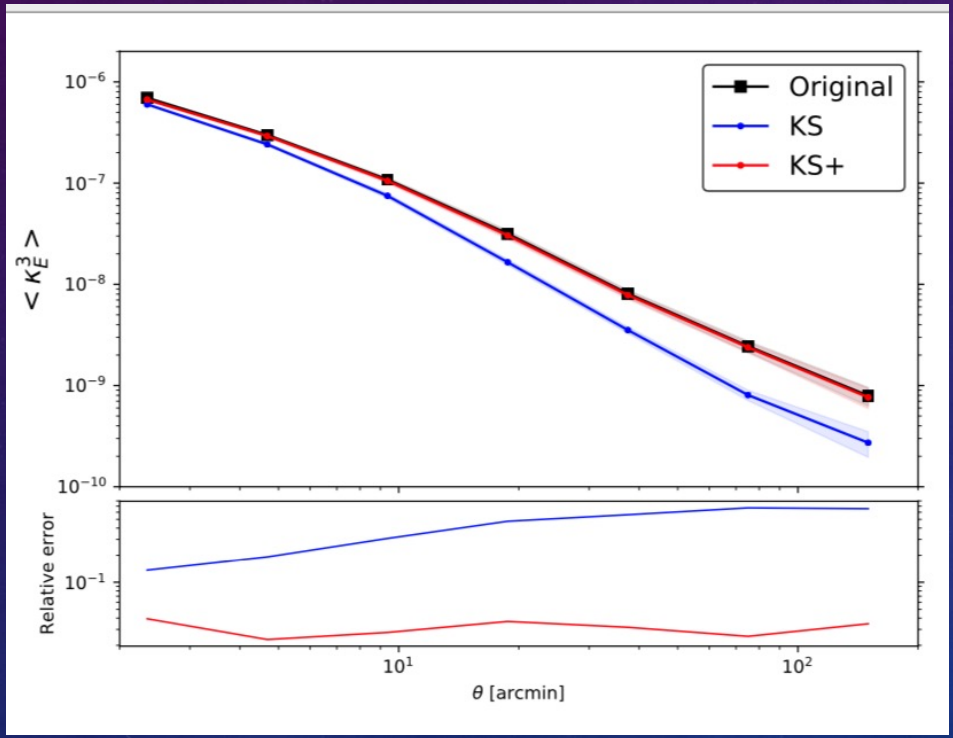
SECOND-ORDER STATISTICS

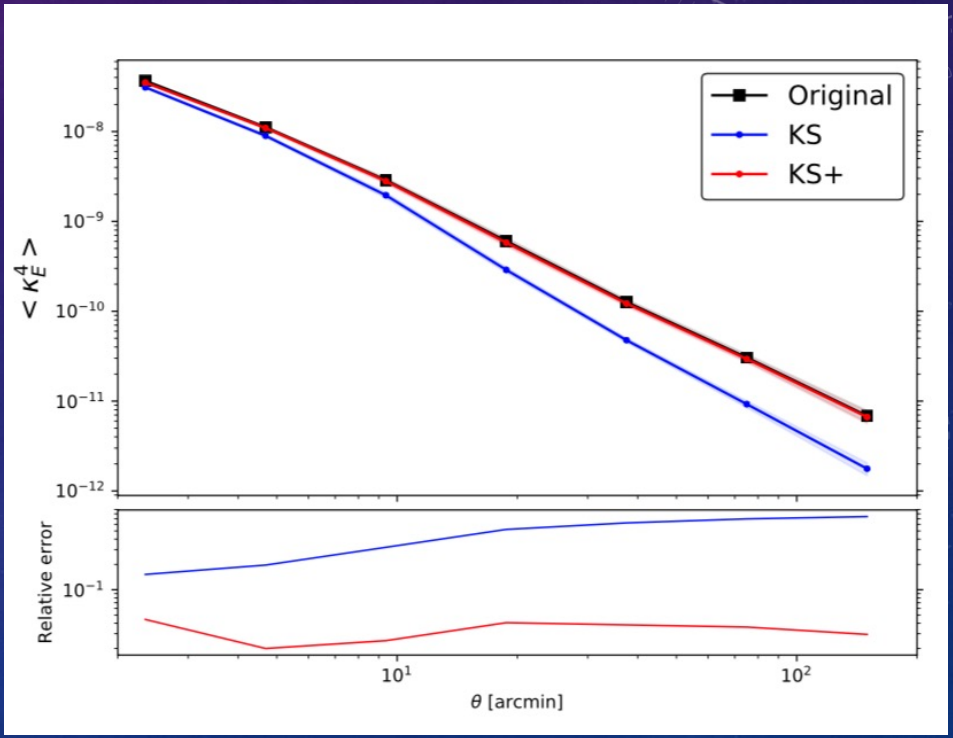


Shaded area represent the standard error on the mean estimated from 1000° sq

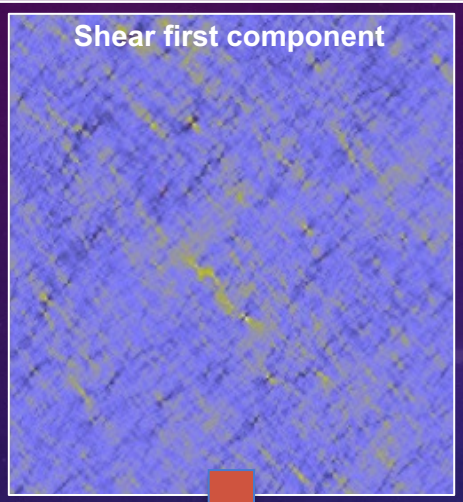
DEALING WITH MISSING DATA

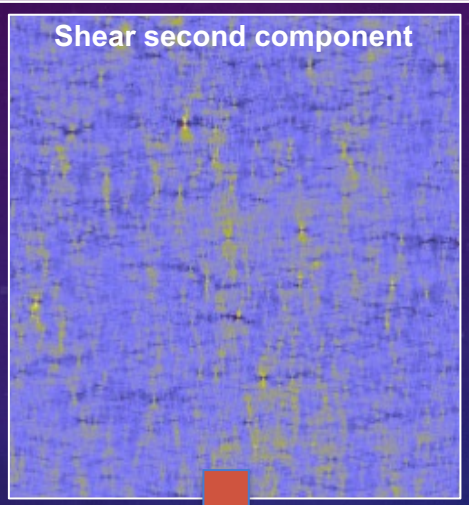
THIRD- AND FOURTH-ORDER MOMENTS

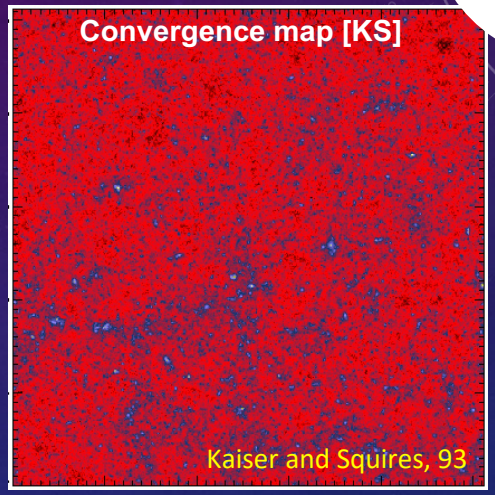


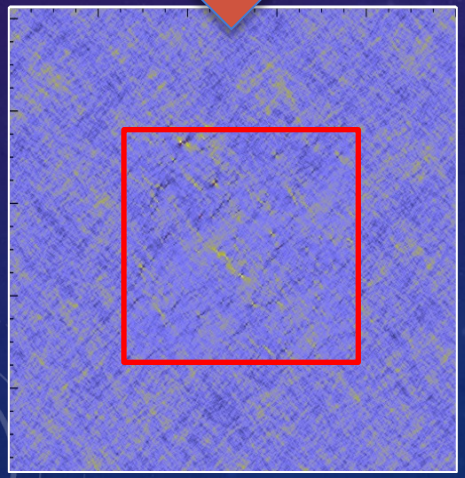


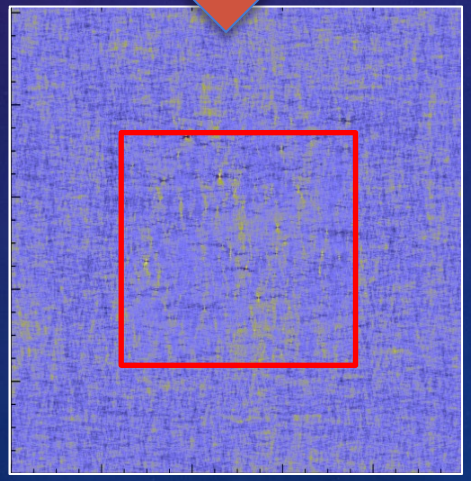
DEALING WITH BOUNDARY EFFECT DATA

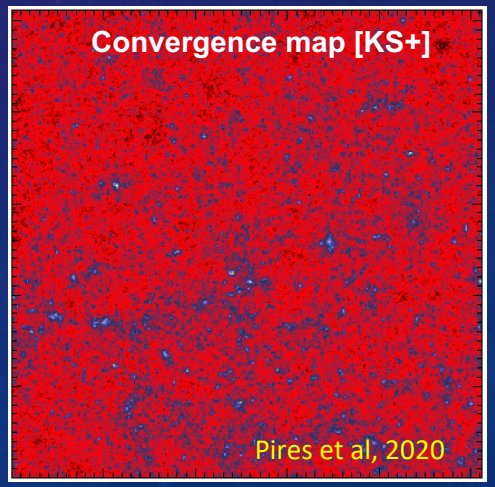






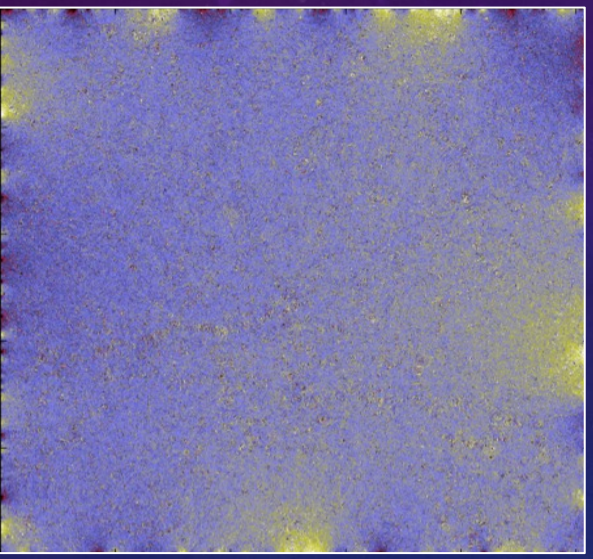




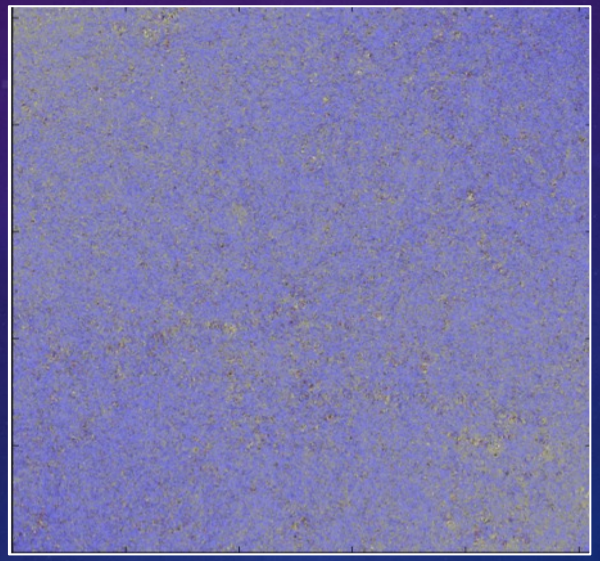


DEALING WITH BOUNDARY EFFECT

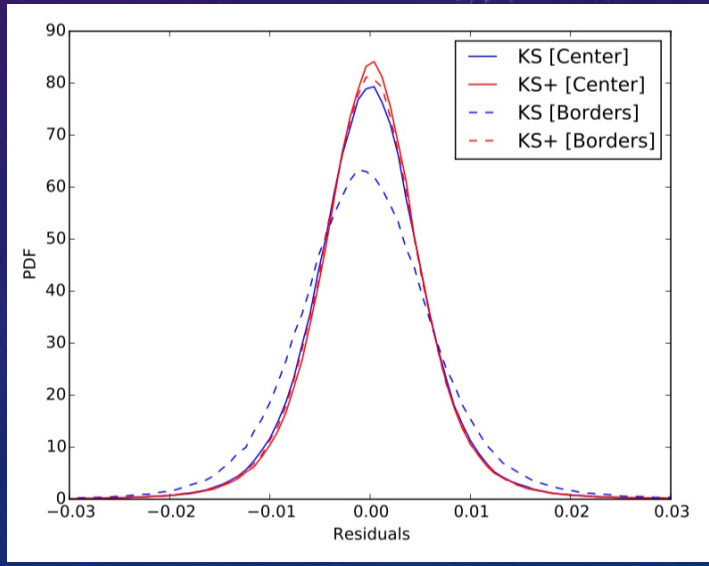
FIRST-ORDER STATISTICS



KS residual errors

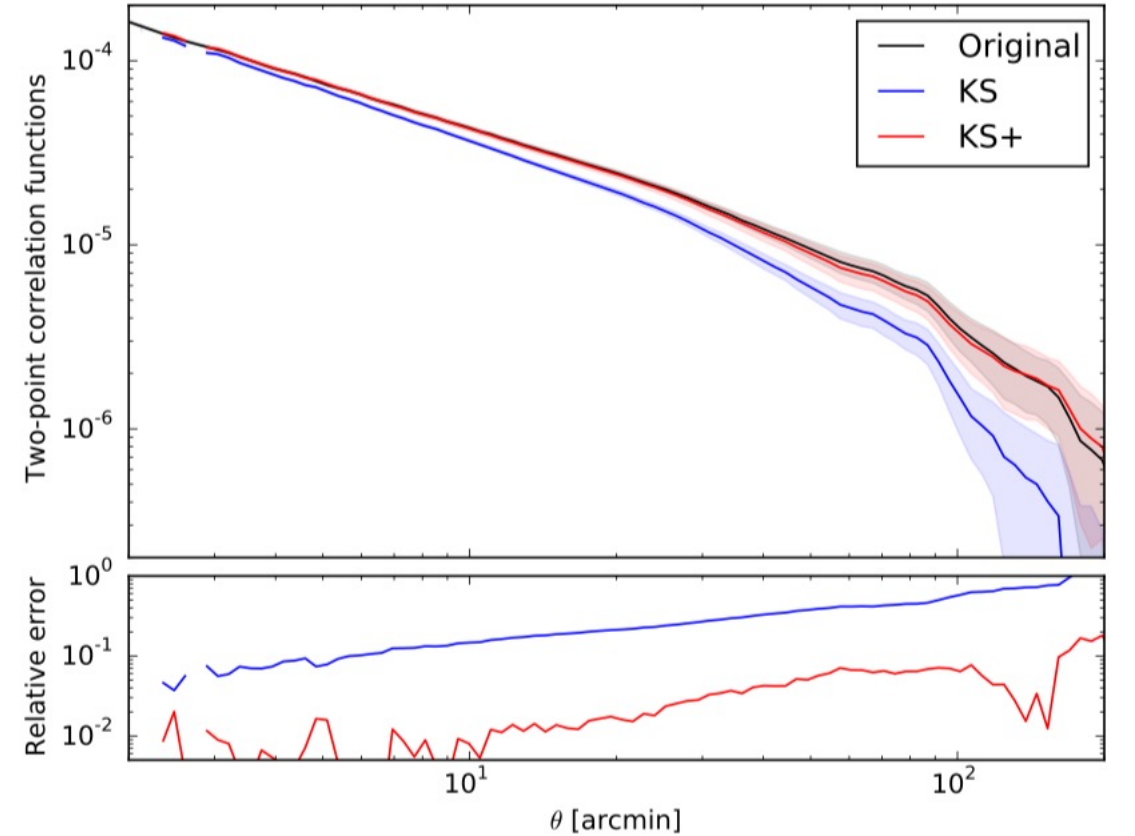


KS+ residual errors



DEALING WITH BOUNDARY EFFECT

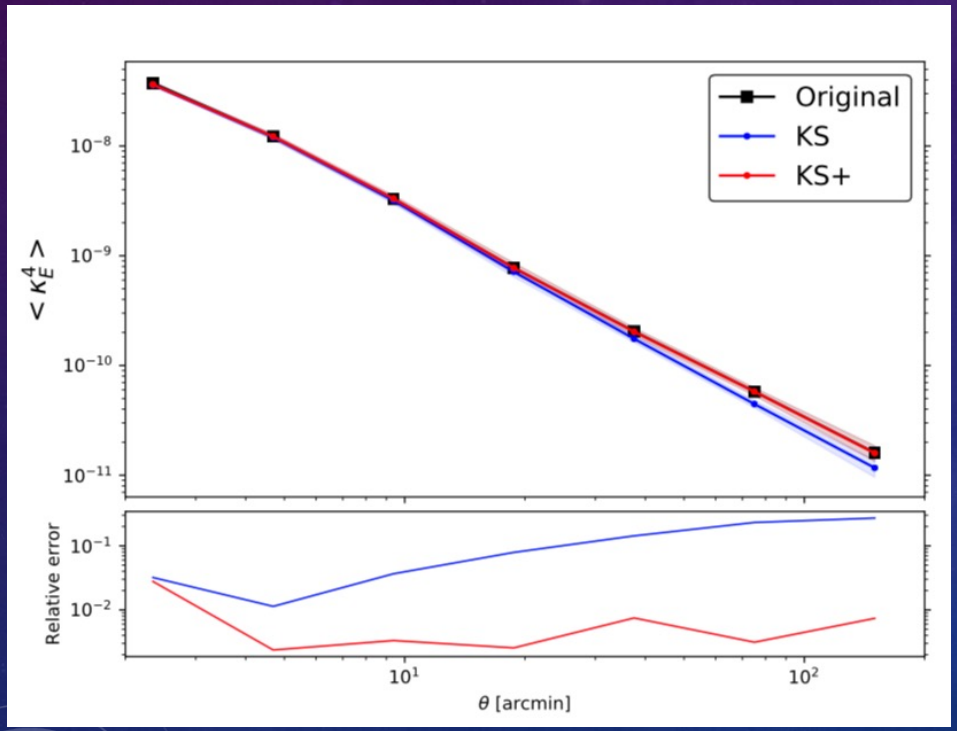
SECOND-ORDER STATISTICS

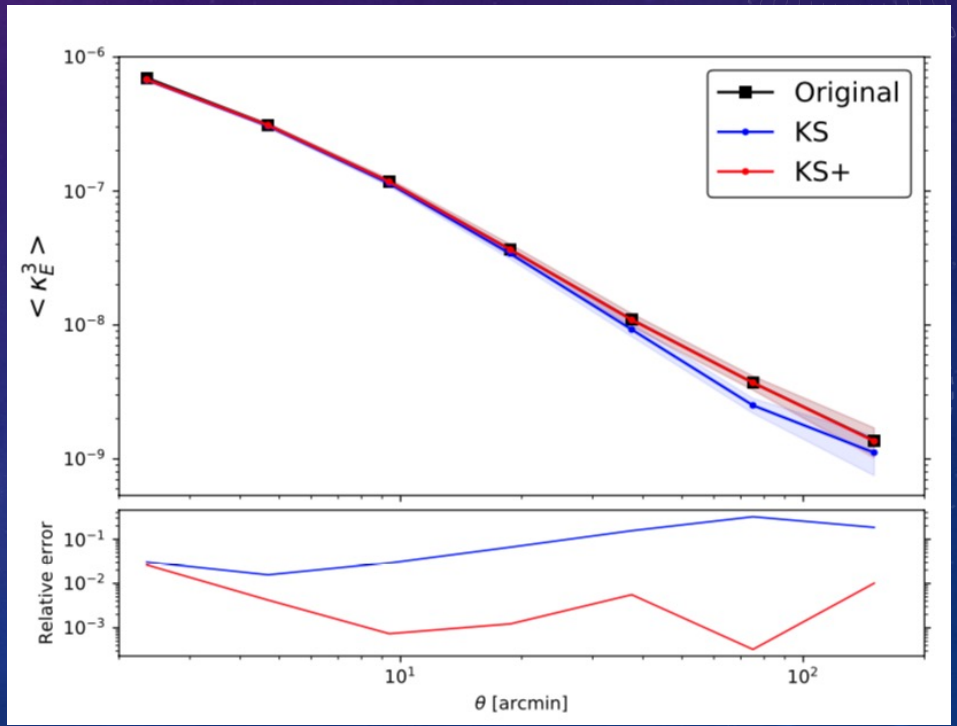


Shaded area represent the standard error on the mean estimated from 1000° sq

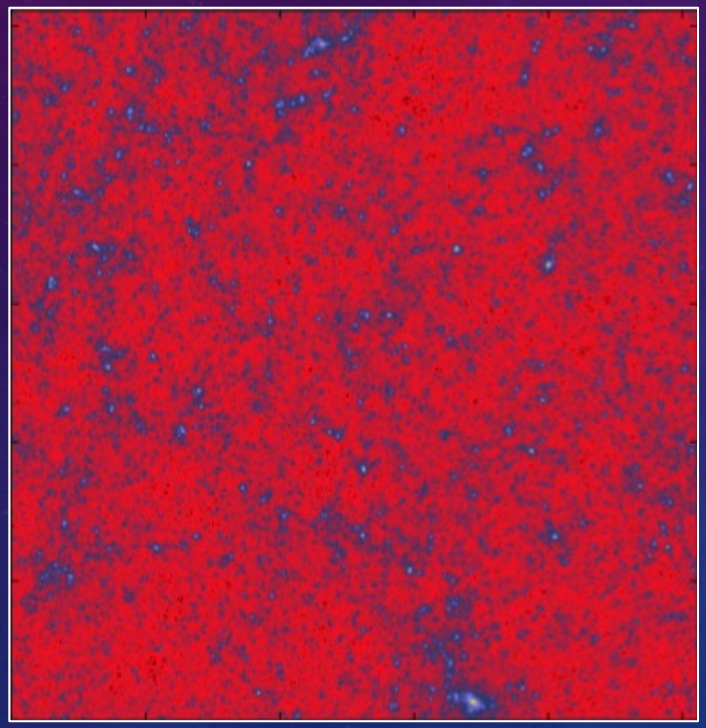
DEALING WITH BOUNDARY EFFECTS

THIRD- AND FOURTH-ORDER MOMENTS

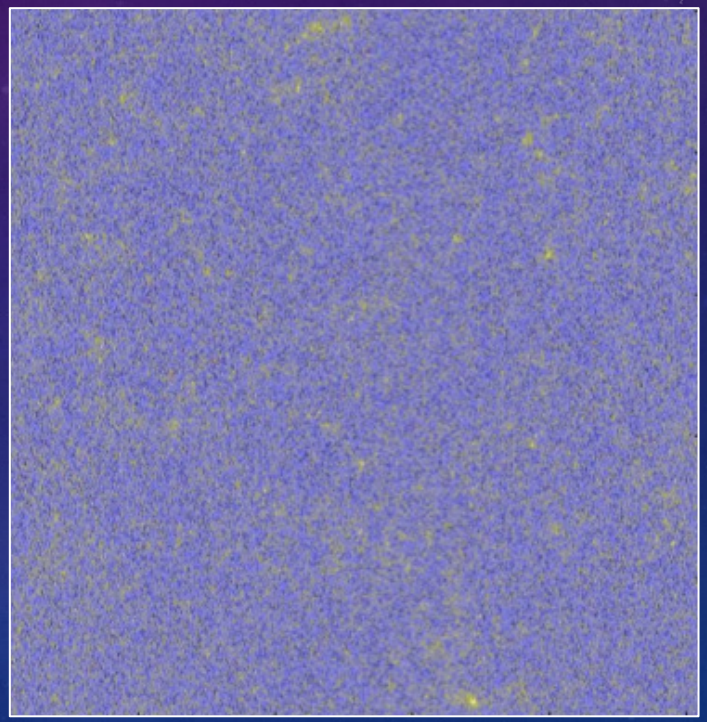




DEALING WITH NOISE



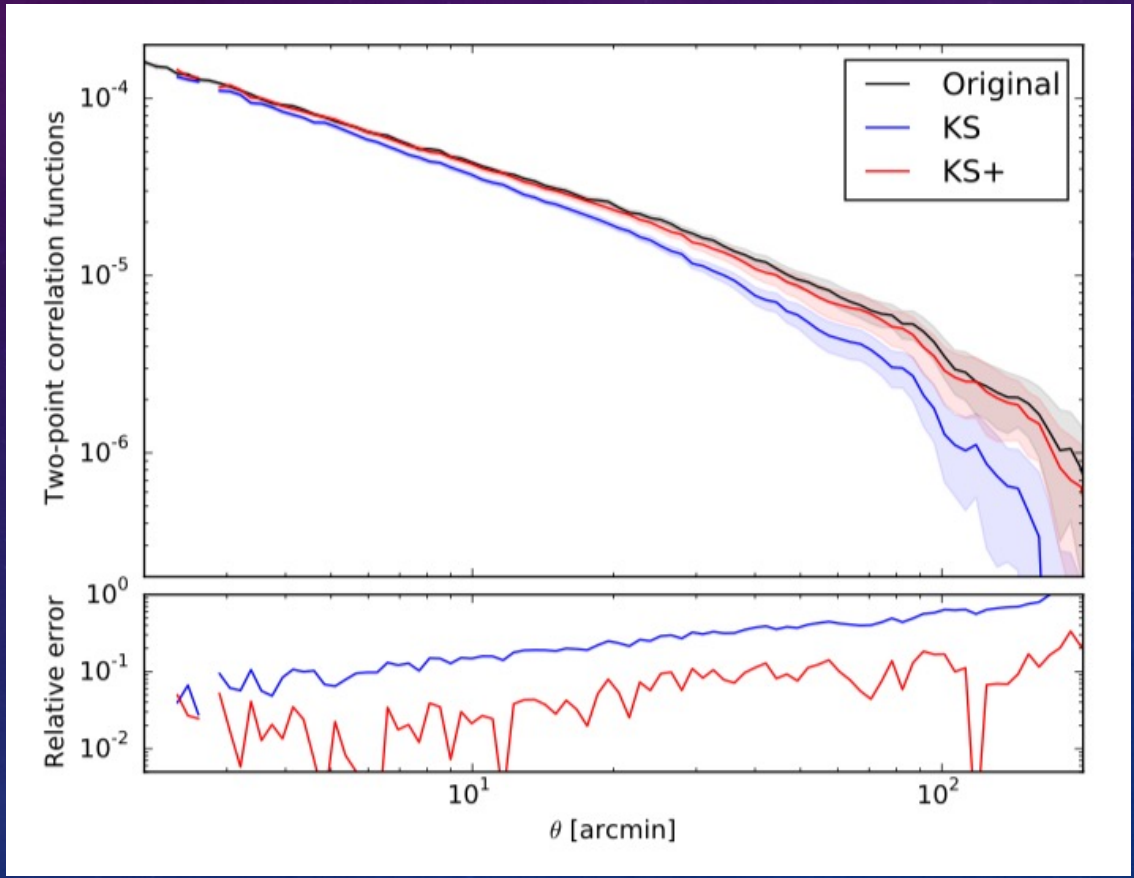
Without noise



With noise

DEALING WITH NOISE

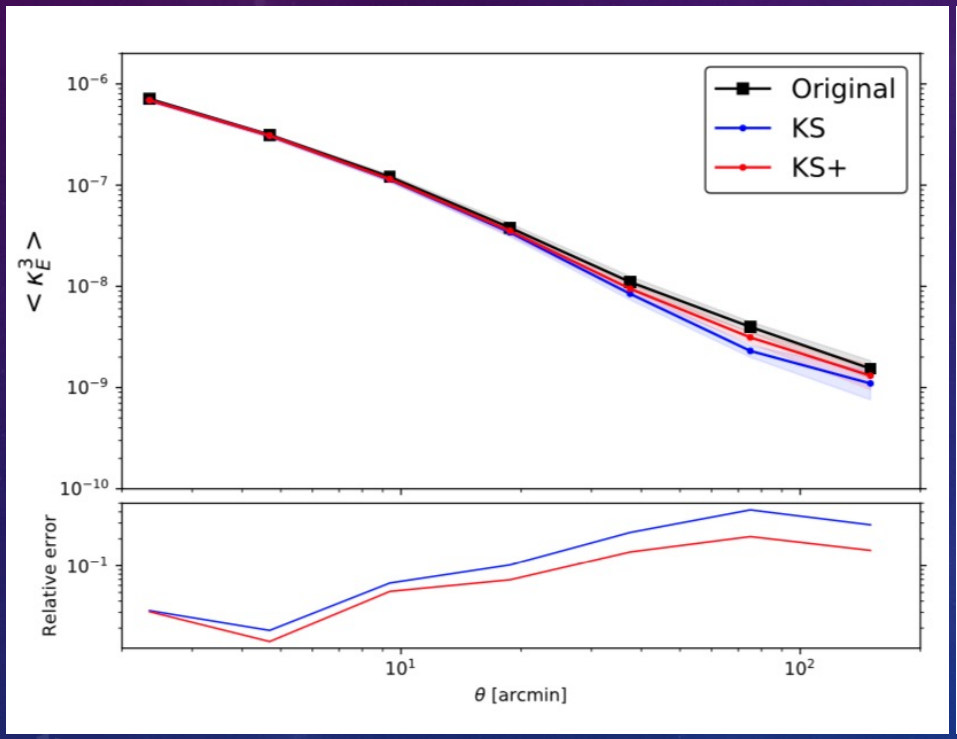
SECOND-ORDER STATISTICS

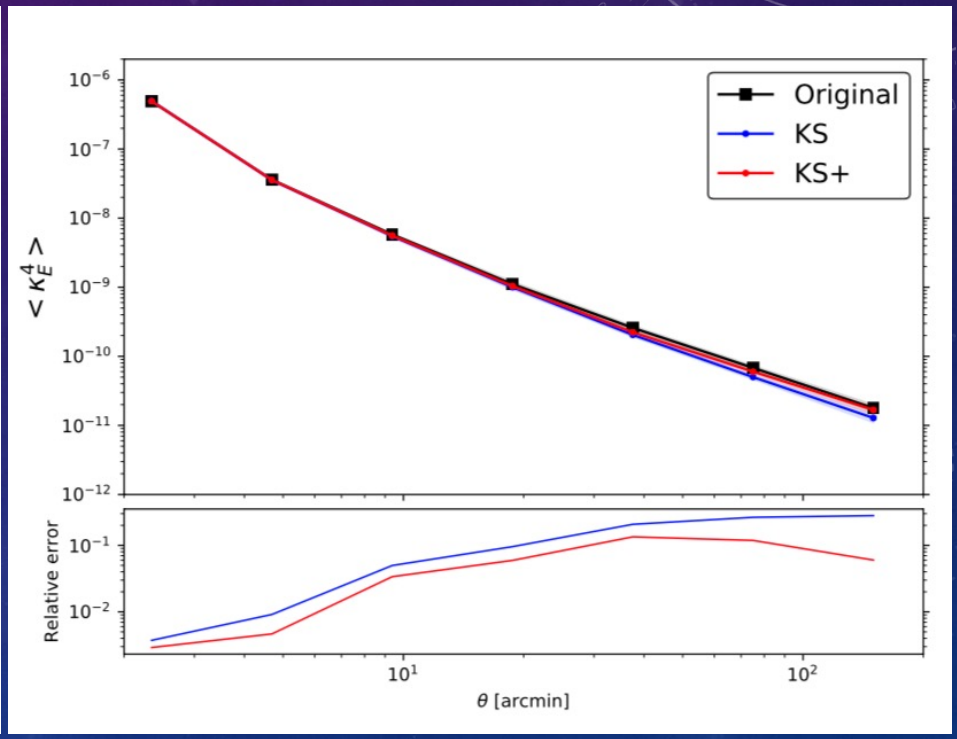


Shaded area represent the standard error on the mean estimated from 1000° sq

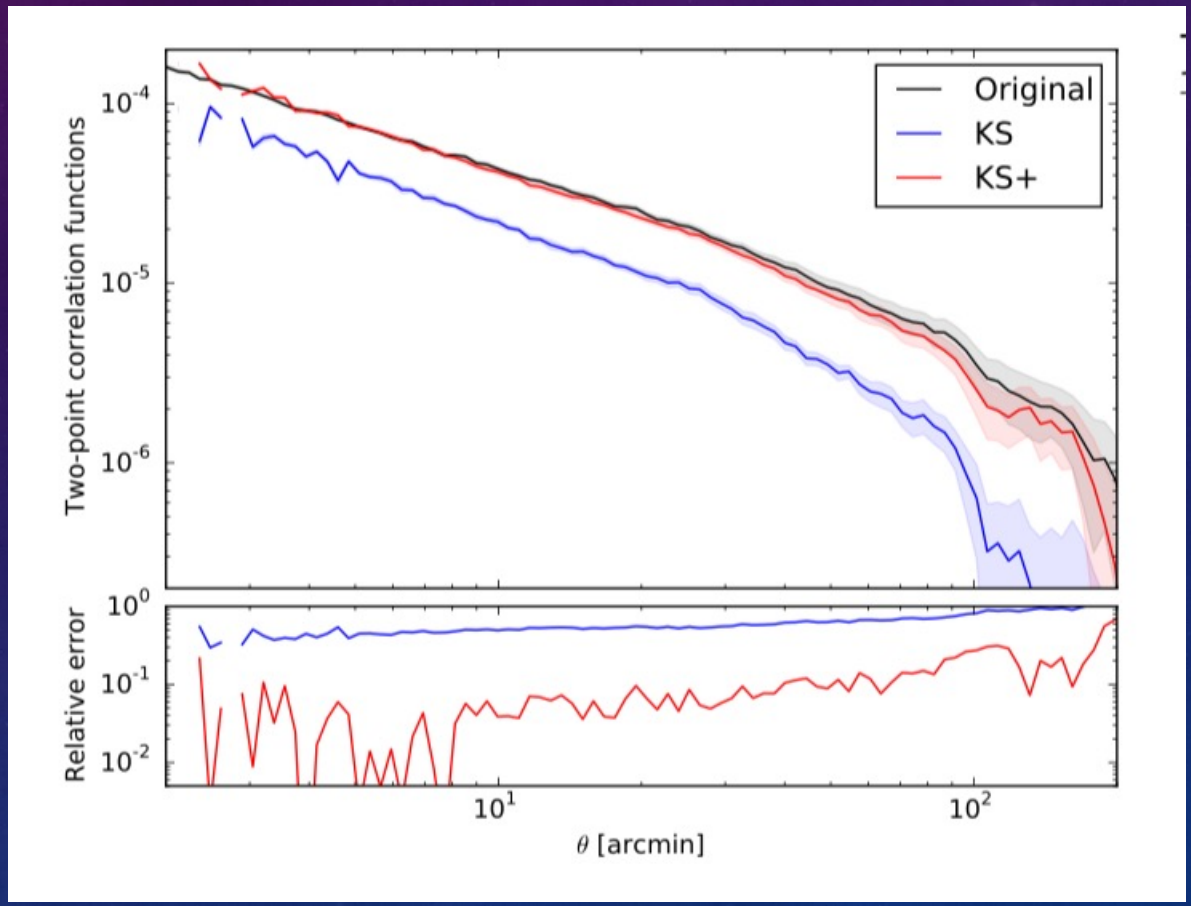
DEALING WITH NOISE

THIRD- AND FOURTH-ORDER MOMENTS



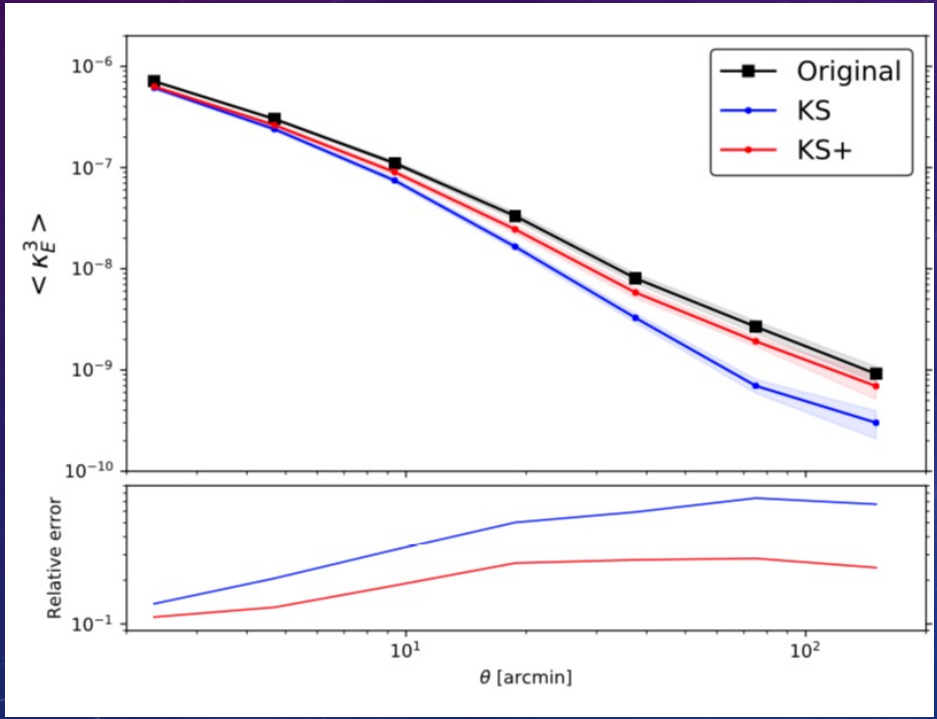


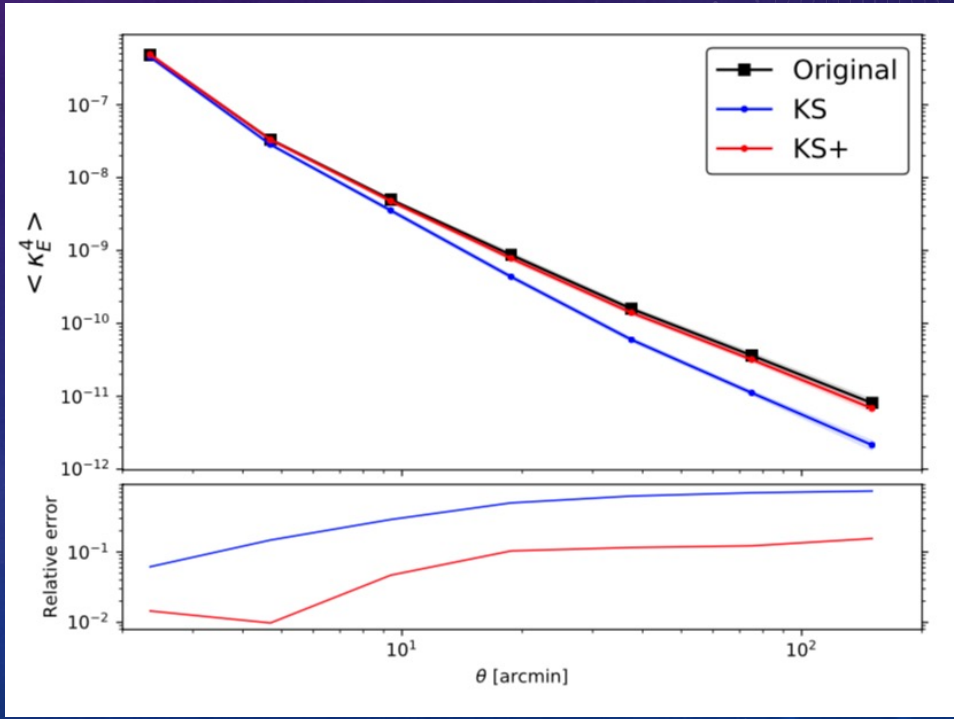
DEALING WITH ALL SYSTEMATIC EFFECTS



Shaded area represent the standard error on the mean estimated from 1000° sq

DEALING WITH ALL SYSTEMATIC EFFECTS





OUTLINE

- Introduction
- Weak lensing data analysis
- Weak lensing mass maps systematics
- Ongoing projects

HOWL'S PROJECT

HIGHER-ORDER WEAK LENSING STATISTICS

Euclid Collaborative project to compare different higher-order estimators based on the same set of reconstructed convergence maps.

Coordinators: N. Martinet, S. Pires, V. Cardone,. Tereno, Carlo Giocoli, M. Baldi

Going higher than 2nd order to break parameters degeneracies

- *Check for correlations among probes and with 2nd order statistic*
- *Compare different mass inversion methods to find the best strategy*
- *Quantify the impact of systematics in self consistent way*
- *Compare different HOS to find the best strategy*

HOWL'S PROJECT

STEP 3 [ANALYSIS IN PROGRESS]

LCDM cosmologies with 4% and 16% variations of the parameters Ω_M, σ_8, and w_0

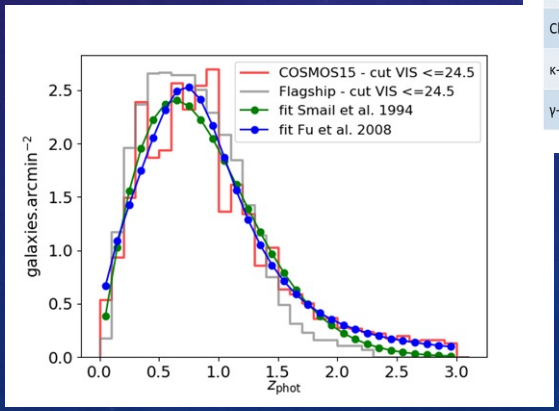
Model	Gravity	m_ν	Ω_m	σ_8	w
LCDM	GR	-	0.313448	0,842	-1
LCDM_Om_0.2	GR	-	0.2	0,842	-1
LCDM_Om_0.4	GR	-	0.4	0,842	-1
LCDM_Om_0.300912	GR	-	0.300912	0,842	-1
LCDM_Om_0.325988	GR	-	0.325988	0,842	-1
LCDM_s8_0.707210	GR	-	0.313448	0,707	-1
LCDM_s8_0.808240	GR	-	0.313448	0,808	-1
LCDM_s8_0.875594	GR	-	0.313448	0,876	-1
LCDM_s8_0.976624	GR	-	0.313448	0,977	-1
LCDM_w_-0.84	GR	-	0.313448	0,842	-0.84
LCDM_w_-0.96	GR	-	0.313448	0,842	-0.96
LCDM_w_-1.04	GR	-	0.313448	0,842	-1.04
LCDM_w_-1.16	GR	-	0.313448	0,842	-1.16

14 different data vectors
9 different statistics

	Carolina Parroni	Martina Vicinanza	Cora Uhlemann	Sihao Cheng	Sandrine Pires	Virginia Ajani & Francois Lanusse	Nicolas Martinet
Moments	√	√	√				
Peaks					√	√ x 2	
Lensing PDF			√				
Minkowski functionals	√	√					
Betti numbers	√						
Scattering Transform				√			
Cluster counts					√		
κ-2PCF	√						
γ-2PCF							√

Euclid-like systematics:

- Mask
- Redshift distribution
- Noise
- Mass mapping pipeline KS and KS+



FISHER ANALYSIS

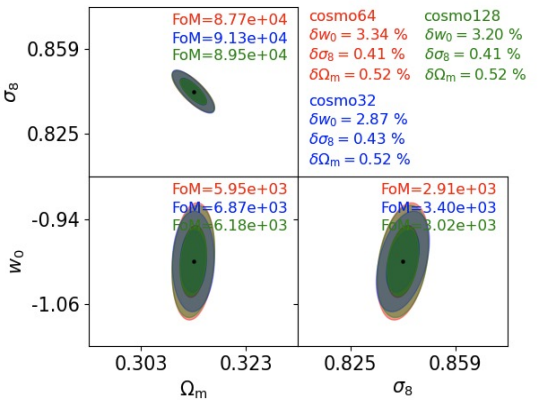
On behalf of the Howl's project members

HOWL'S PROJECT

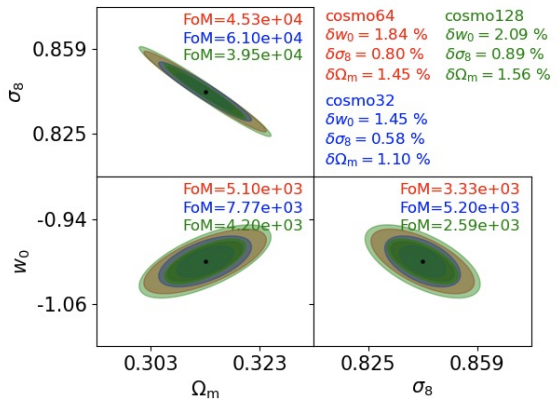
STEP 3 [ANALYSIS IN PROGRESS]

SLICS – 928 realisations

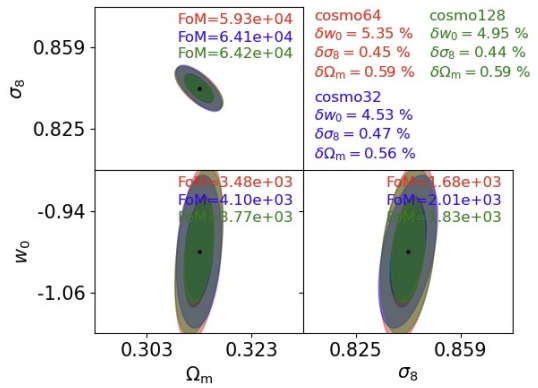
DustGrain-256 realisations

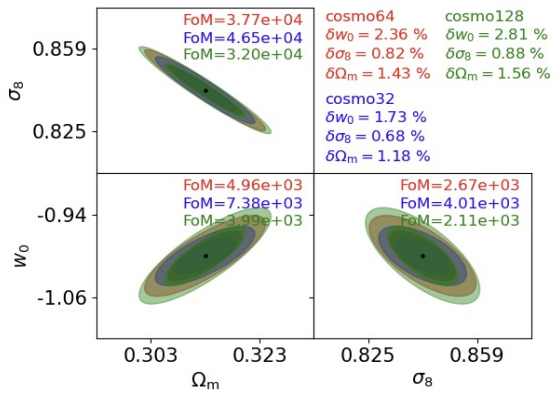


2PCF



Peaks





Euclid Key Project

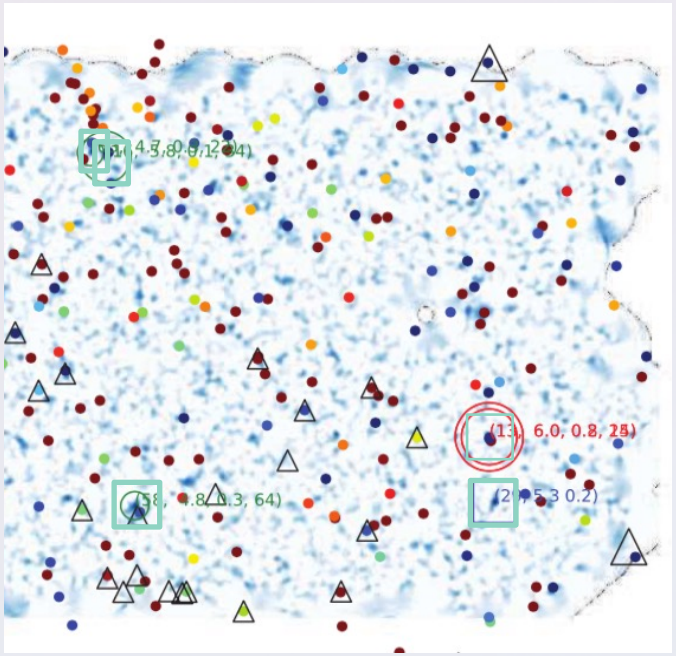
On behalf of the Howl's project members

WEAK LENSING CLUSTER DETECTION

Contributors: G. Leroy, S. Pires, G. Pratt, M. Arnaud

Application on the HSC data - XMM patch of 20° squared degree

Miyazaki et al, 2018



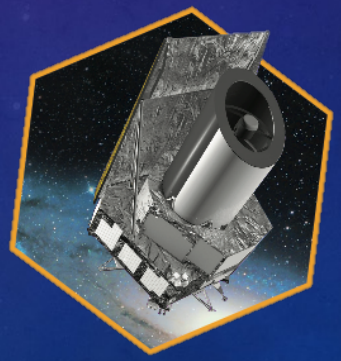
Standard approach

Leroy et al

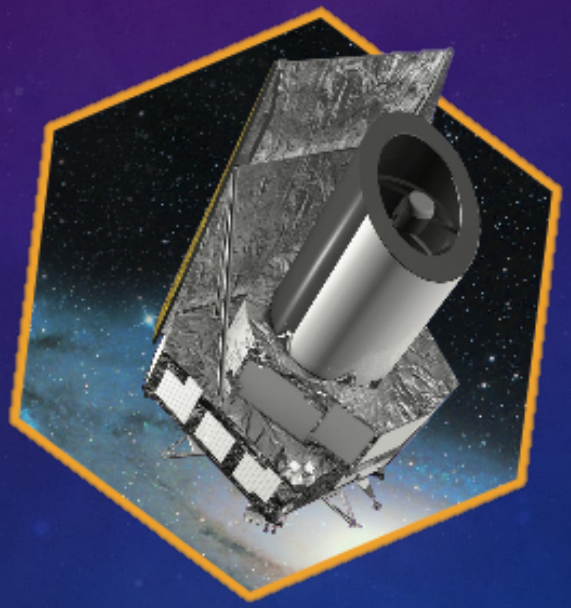
Multiscale approach

CONCLUSION

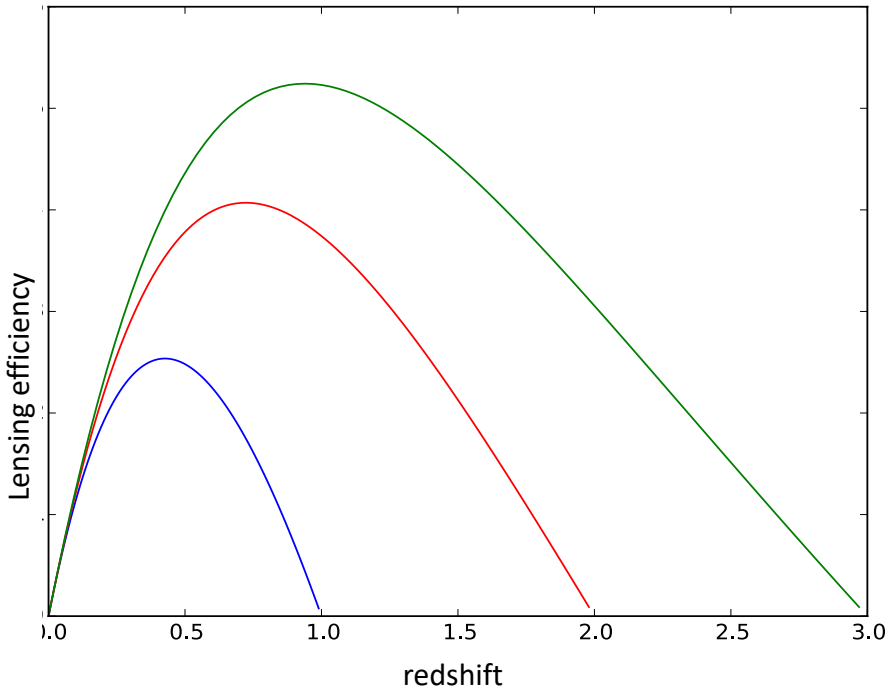
- Second-order statistics are not sufficient to constrain the weak lensing field
- The non-Gaussian information is easier to extract from the convergence maps
- The convergence maps contain the same infomation than the shear maps
- Mass Mapping Systematic effects can be controlled during the mass inversion
- The convergence maps are a very promising tool



THANK YOU FOR YOUR ATTENTION



WL CLUSTER MASS ESTIMATION

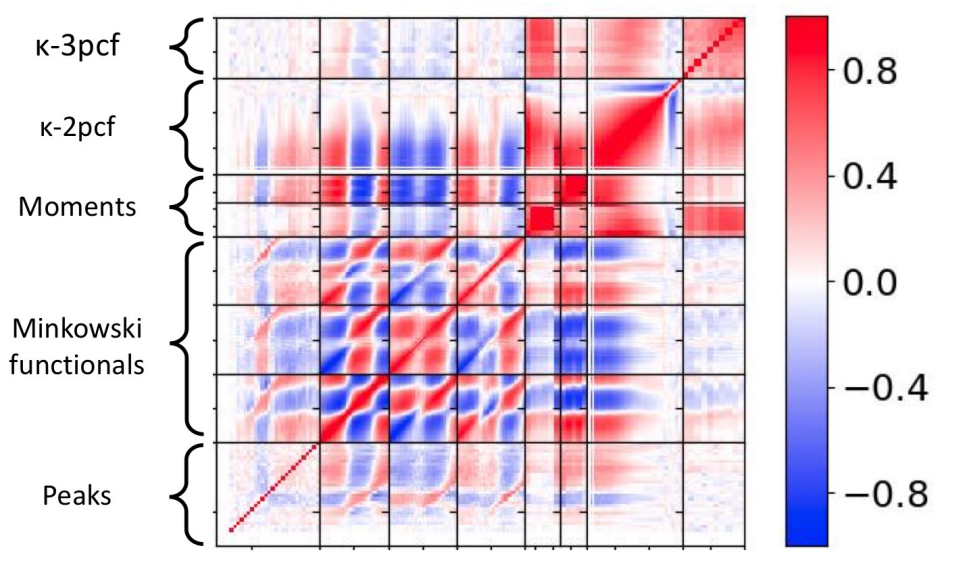


$$\kappa(\theta) = \frac{\Sigma(\theta)}{\Sigma^{\infty}_{\rm crit}}$$

$$\Sigma^{\infty}_{\rm crit} = \frac{c^2}{4\pi G}\frac{D_S}{D_L D_{LS}}$$

HOWL'S PROJECT

STEP 1 [NOVEMBER 2018] / STEP 2 [JUNE 2019]



Conclusions STEP1:

- High correlation between statistics
- Importance of the filtering (Gaussian vs wavelet/Mass Aperture)

Statistics	$\delta\Omega_m$ for $\Delta\Omega_m = 0.2$	$\delta\Omega_m$ (%) for $\Delta\Omega_m = 0.2$
peaks	4.12×10^{-4}	0.13
MFs	7.33×10^{-4}	0.23
Betti	-	-
moments	4.51×10^{-4}	0.14
κ2pcf	6.45×10^{-4}	0.21
peaks+MFs+moments	6.02×10^{-4}	0.19
peaks+MFs+moments+κ2pcf	4.34×10^{-4}	0.14

Conclusions STEP2:

- Importance of the redshift distribution
- Importance of the choice of the points in parameter space

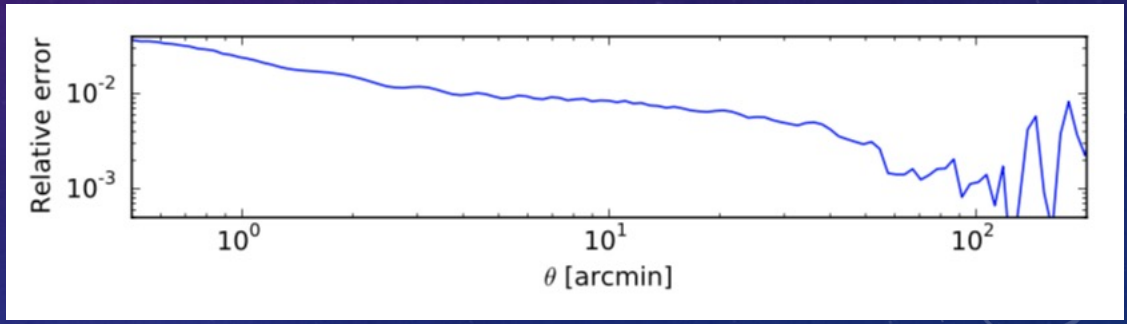
On behalf of the Howl's project members

DEALING WITH REDUCED SHEAR

Reduced shear: $$g \equiv \frac{\gamma}{1-\kappa}.$$

- **KS mass inversion:**

$$\hat{\kappa} = \hat{P}^* \hat{\gamma}$$



- **KS+ mass inversion (iterative scheme):**

$$\hat{\kappa}_{\mathrm{i}} = \hat{P}^* \hat{\gamma}_{\mathrm{i}} \quad \text{using} \quad \gamma_{\mathrm{i}+1} = \gamma_{\mathrm{i}} * (1 - \kappa_{\mathrm{i}})$$

PRE-LAUNCH KPS RELATED TO HOWLS

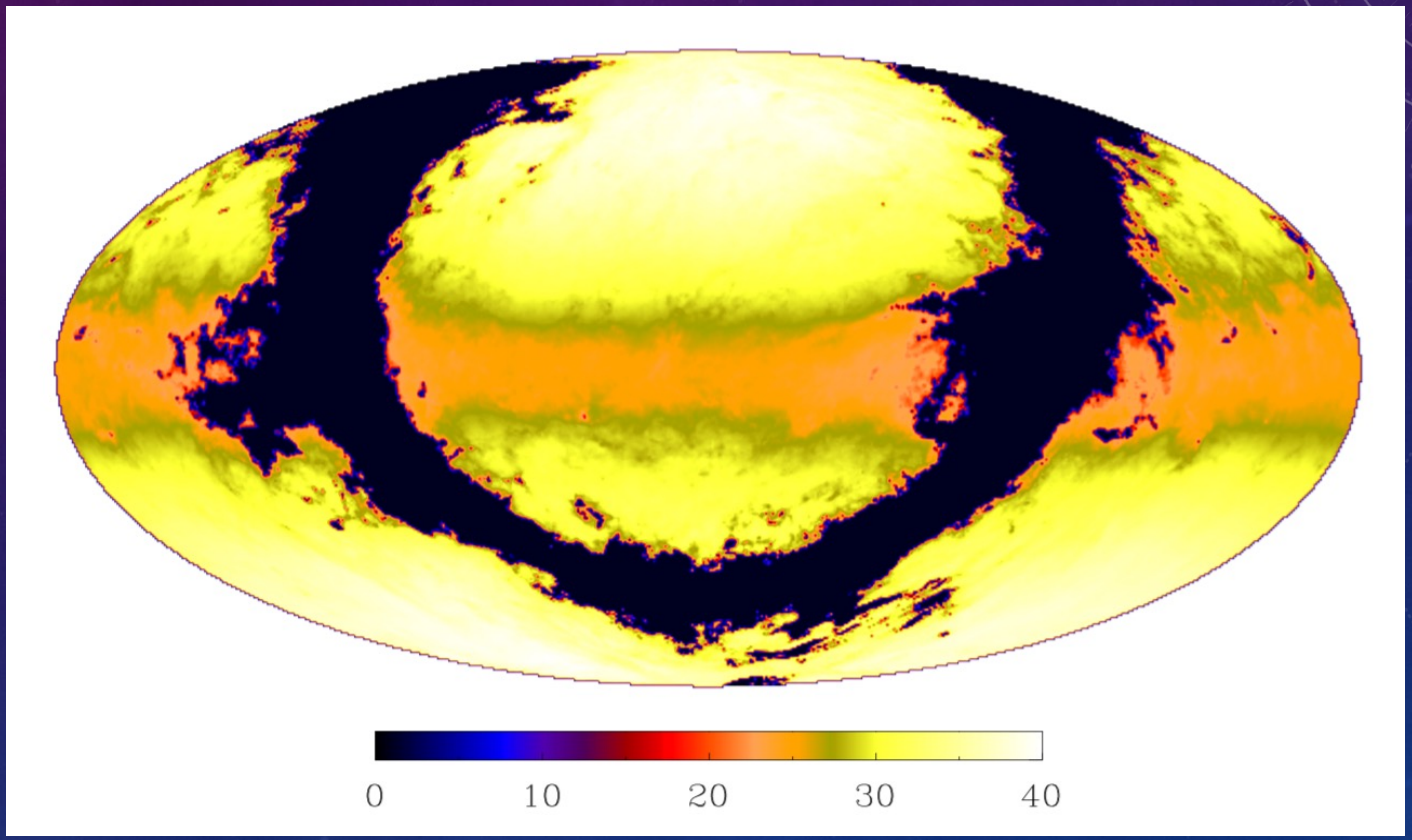
- **KP-WL-3: Higher-order statistics preparation** (coordinators: Ismael, Vincenzo)
  This KP is related to the work carried out inside the WL-SWG **through the Howl's project** (Higher-Order Weak Lensing Statistics), based on both theoretical investigations and simulated data. The aim of the project is to describe the preparatory work on using WL Higher Order Statistics (HOS) as a way to improve the FoM from weak lensing data. It involves the implementation and testing of different estimators, which are applied to the same set of reconstructed mass maps, as to identify the best strategy for constraining cosmological parameters.

  Paper 1: Comparison of the different HOS (Fisher forecasts from step 3)
  Paper 2: Cosmological constraints from HOS (Emulator)

- **KP-WL-4: Mass-mapping preparation** (coordinators: Sandrine, Nicolas)
  The aim of this project is to describe the preparatory work ongoing in the Mass Mapping WP to use mass maps for cosmological studies. These analyses will rely on simulated data.

  Paper 1: Optimize the mass mapping methods for HOS studies (KS vs. KS+, masks; **also base on HOWLS**)

EUCLID REFERENCE SURVEY



σ ≤ 1 arcmin

Field of View ≈ 15000 deg^2,
Galaxy density ≈ 30 gal/arcmin^2

R. Scaramell et al., 2021 (submitted)

SURVEYS	In ~6 years	
	Area (deg2)	Description
Wide Survey	**15,000 deg²**	Step and stare with 4 dither pointings per step.
Deep Survey	**40 deg²**	In at least 2 patches of > 10 deg² 2 magnitudes deeper than wide survey

PAYLOAD					
Telescope	1.2 m Korsch, 3 mirror anastigmat, f=24.5 m				
Instrument	VIS	NISP			
Field-of-View	0.787×0.709 deg²	0.763×0.722 deg²			
Capability	Visual Imaging	NIR Imaging Photometry		NIR Spectroscopy	
Wavelength range	550– 900 nm	Y (920-1146nm),	J (1146-1372 nm)	H (1372-2000nm)	1100-2000 nm
Sensitivity	24.5 mag 10σ extended source	24 mag 5σ point source	24 mag 5σ point source	24 mag 5σ point source	$3\ 10^{-16}$ erg cm-2 s-1 3.5σ unresolved line flux
	Shapes + Photo-z of n = 1.5 x10⁹ galaxies			**z of n=5x10⁷ galaxies**	
Detector Technology	36 arrays 4k×4k CCD	2k×2k NIR sensitive HgCdTe detectors		16 arrays	
Pixel Size Spectral resolution	0.1 arcsec	0.3 arcsec		0.3 arcsec R=250	

Ref: Euclid RB Laureijs et al arXiv: 1110.3193

Weak Lensing

Galaxy Clustering