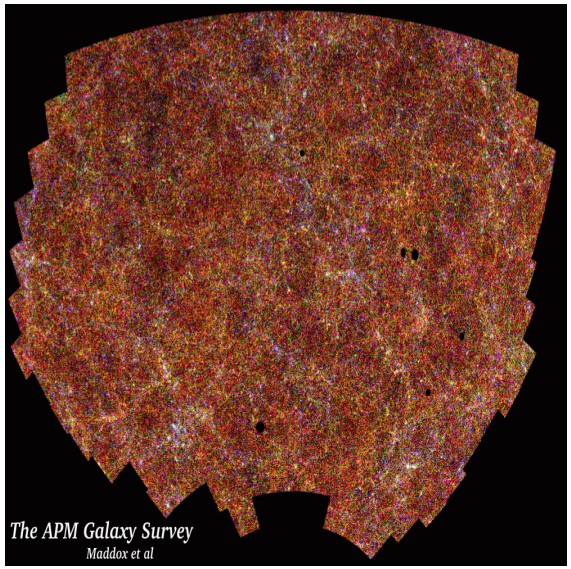
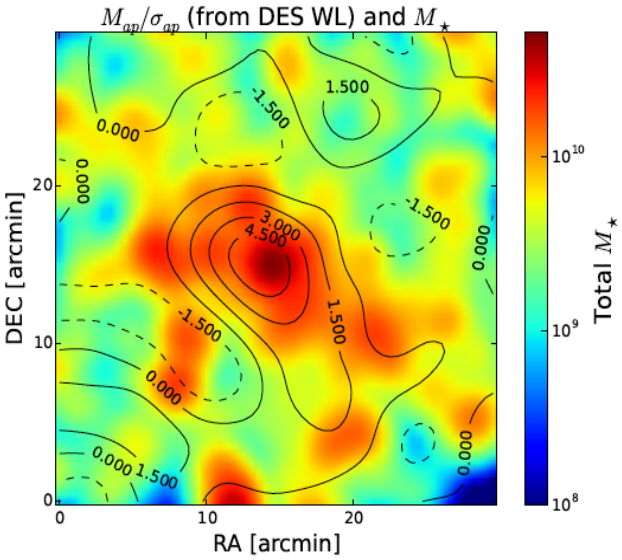
Maps of the Universe: Past, Present and Future





Ofer Lahav (UCL)

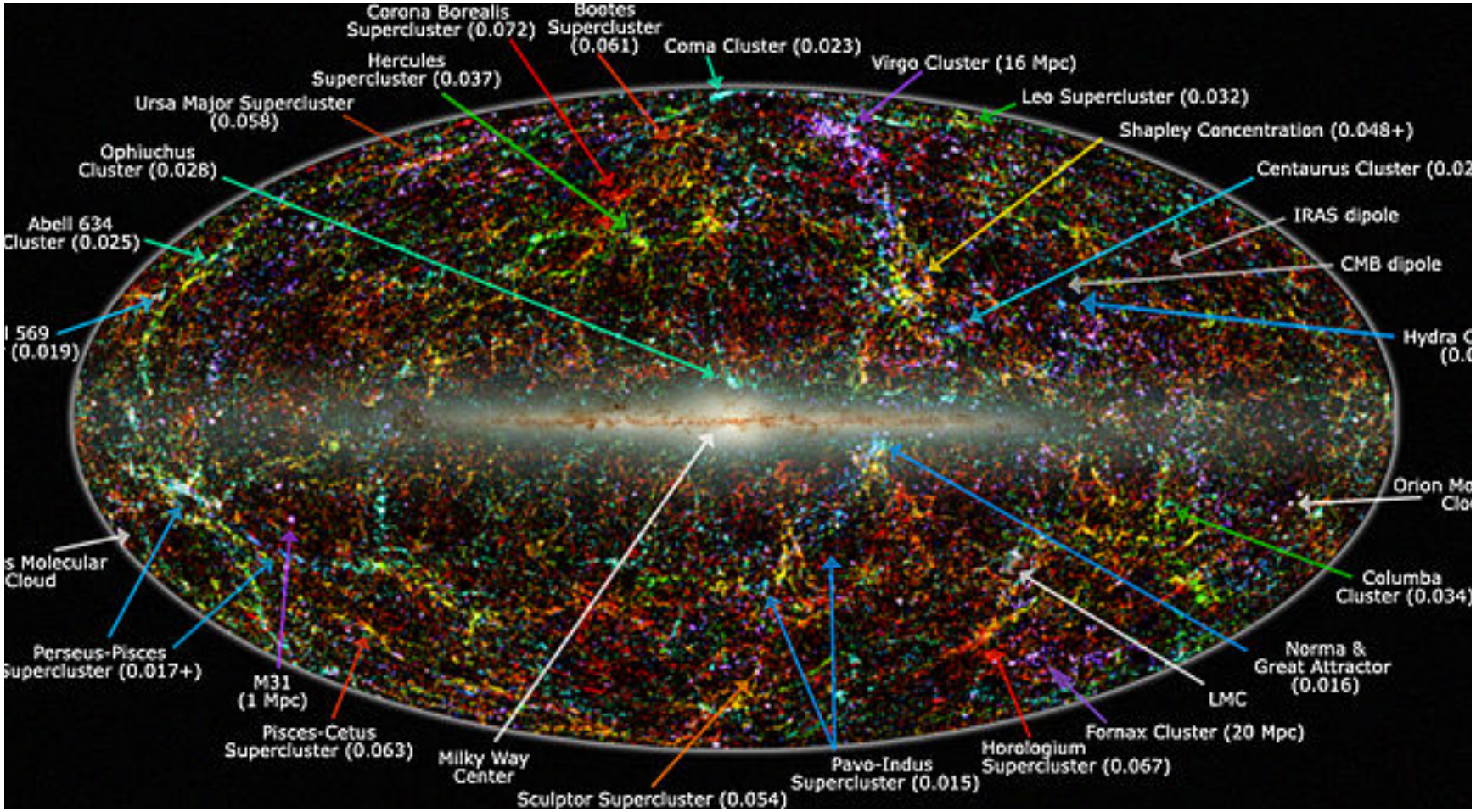
Outline

- What are maps good for?
- Visual impressions of the cosmic web vs. statistical measures
- Amplitudes vs. phases
- Discovering ‘America’:

  from the Great Attractor to the CMB Cold Spot
- Galaxy vs. mass maps (peculiar velocities, weak lensing of galaxies & the CMB)
- Non-Gaussianity, galaxy biasing
- What’s next?

Ricci map 1602 map of the world

2MASS map

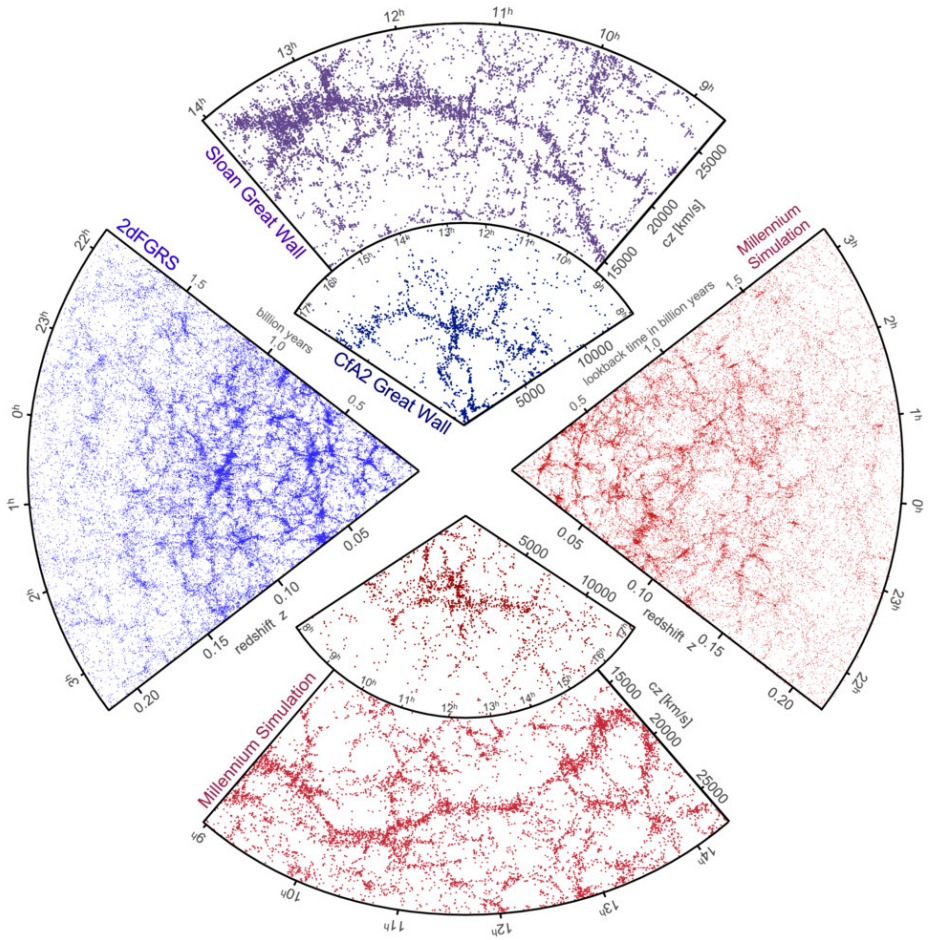

Corona Borealis Supercluster (0.072)
Bootes Supercluster (0.061)
Coma Cluster (0.023)
Virgo Cluster (16 Mpc)
Hercules Supercluster (0.037)
Leo Supercluster (0.032)
Ursa Major Supercluster (0.058)
Shapley Concentration (0.048+)
Ophiuchus Cluster (0.028)
Centaurus Cluster (0.02
Abell 634 Cluster (0.025)
IRAS dipole
CMB dipole
Hydra C
(0.
l 569
(0.019)
Orion Mo
Clo
s Molecular
Cloud
Columba Cluster (0.034)
Perseus-Pisces Supercluster (0.017+)
Norma & Great Attractor (0.016)
M31 (1 Mpc)
LMC
Pisces-Cetus Supercluster (0.063)
Fornax Cluster (20 Mpc)
Milky Way Center
Horologium Supercluster (0.067)
Pavo-Indus Supercluster (0.015)
Sculptor Supercluster (0.054)

Statistical measures of cosmic fields

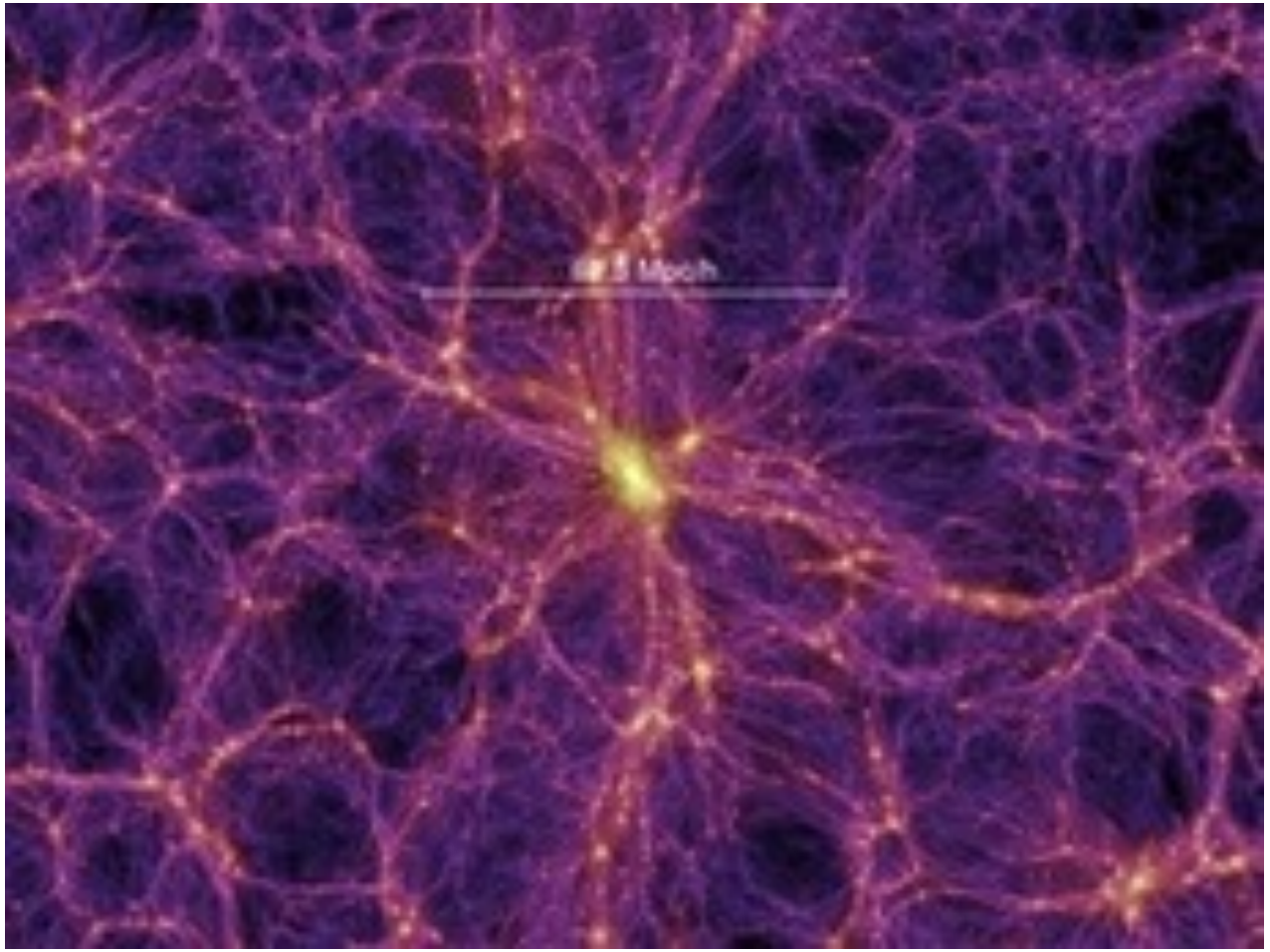
- 2pt correlation function (or its Fourier transform power spectrum)
- 3pt and higher moments
- Full PDF (1pt, 2pt)
- Peaks (e.g. clusters), voids, filaments, …
- Minkowski functions (N+1 for N dimensions)
- Cross correlations of fields (e.g. galaxies and CMB)

Swapping amplitudes and phases

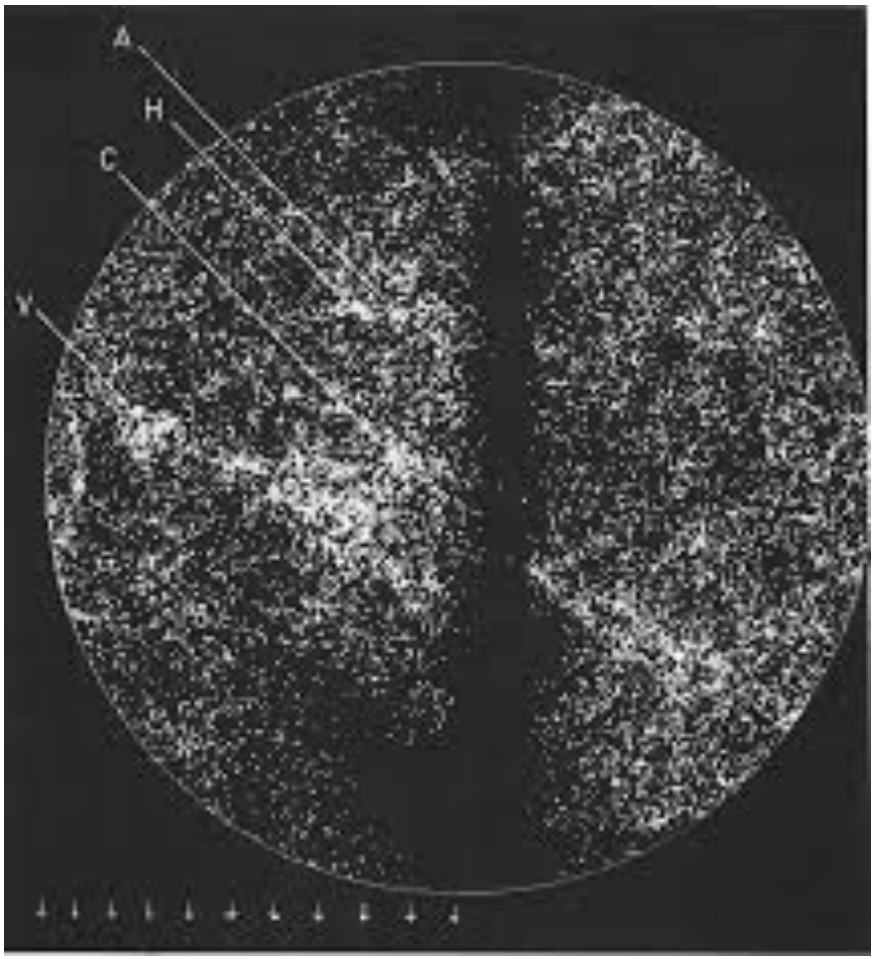
Galaxy surveys vs simulatios



Millennium simulation Cosmic WEb

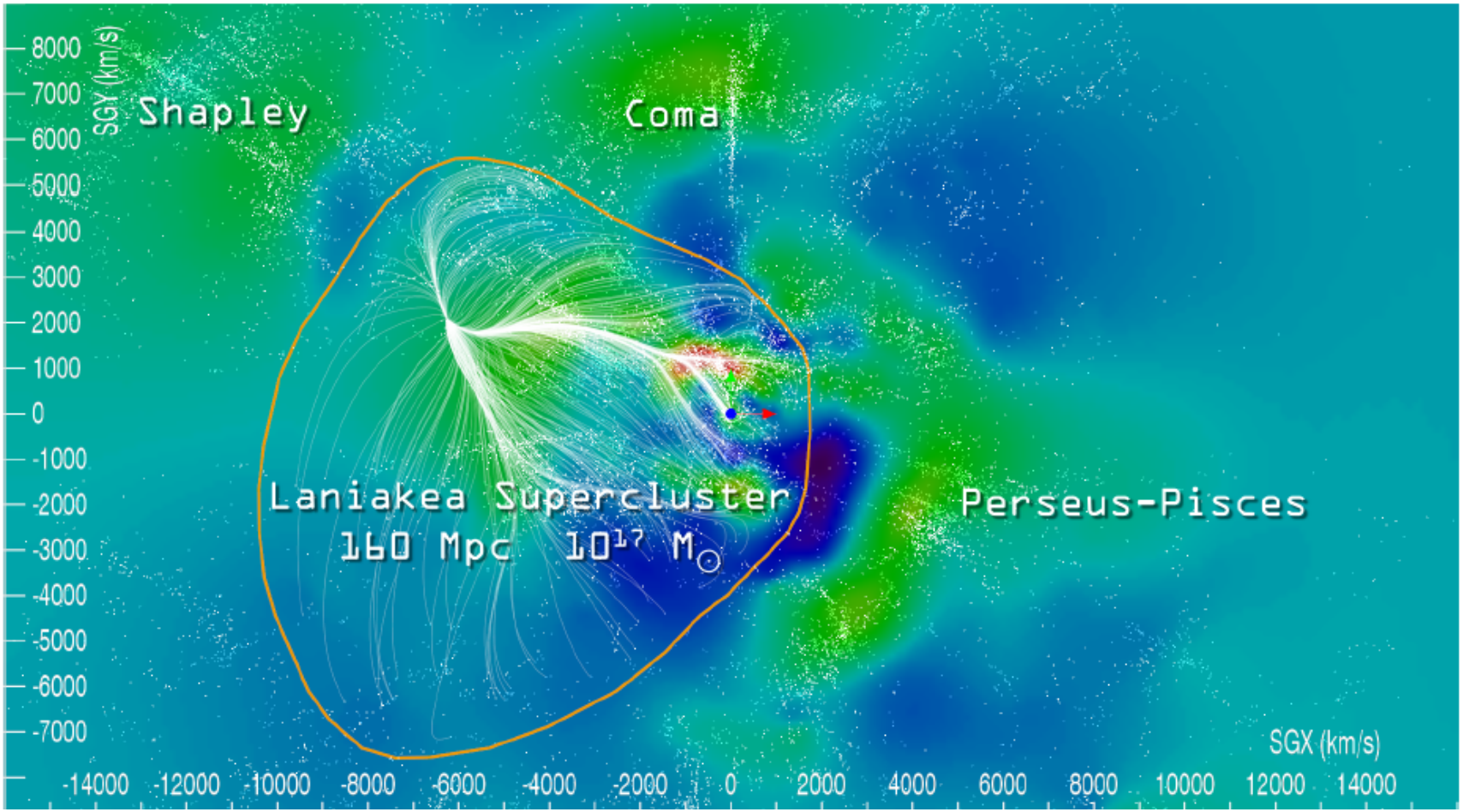


The Great Attractor



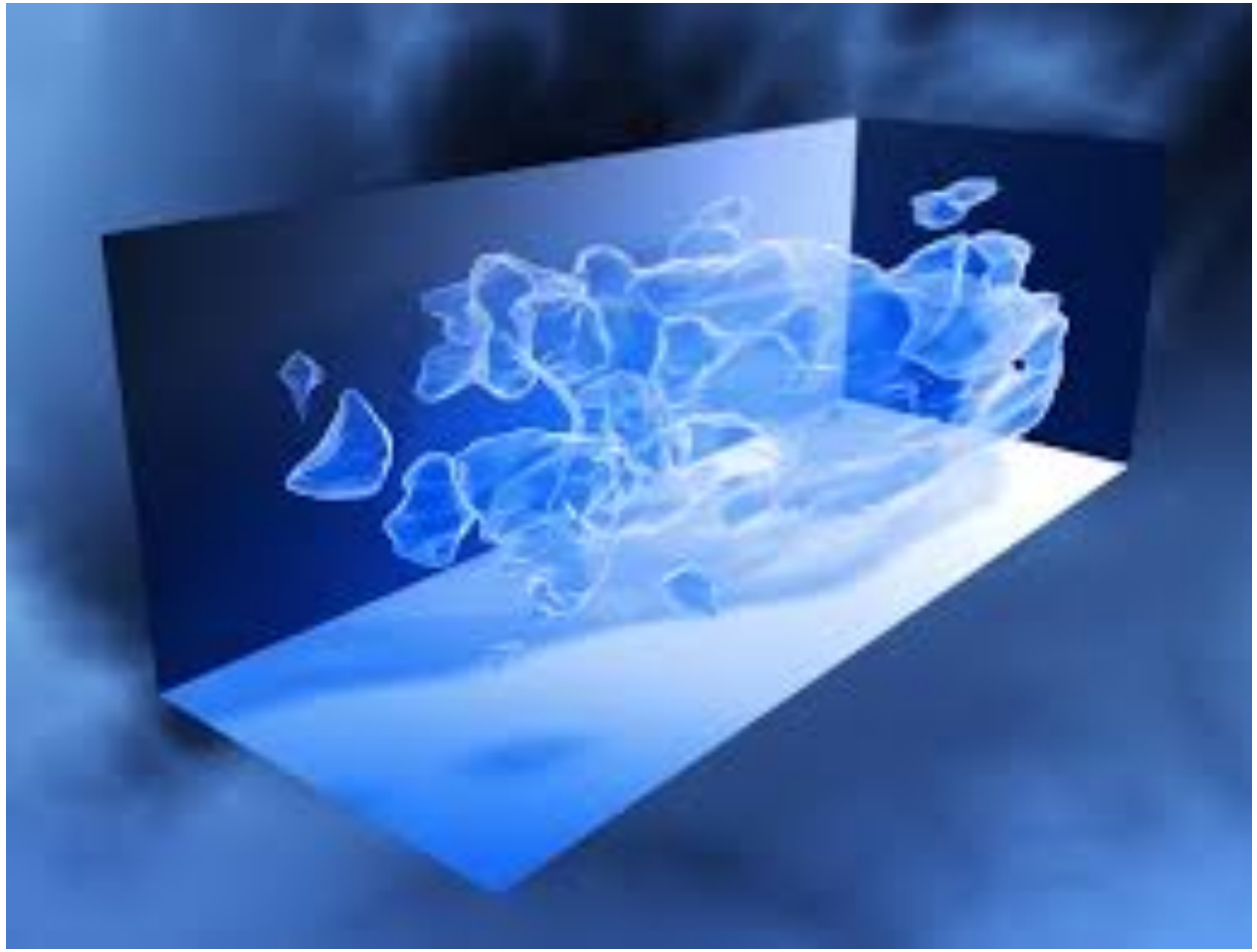
Plot by OL in Lynden-Bell et al. (7S,1988)

The local peculiar velocity field



Tully et al. 2014

3D Mass map Weak lensing tomography

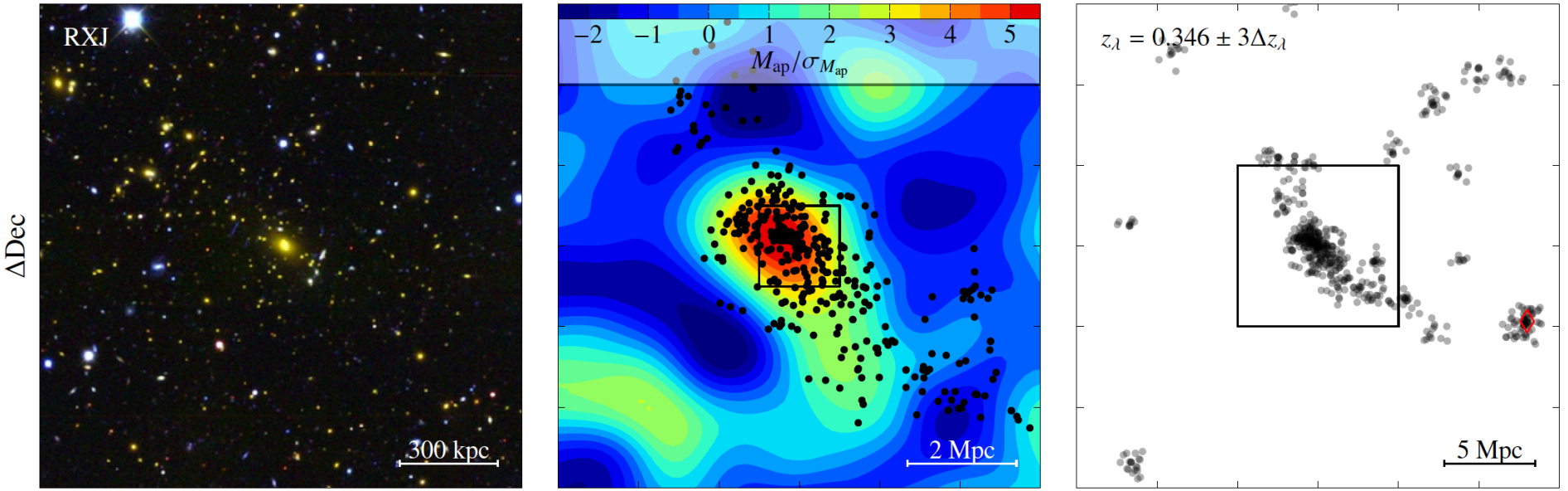


Massey et al .

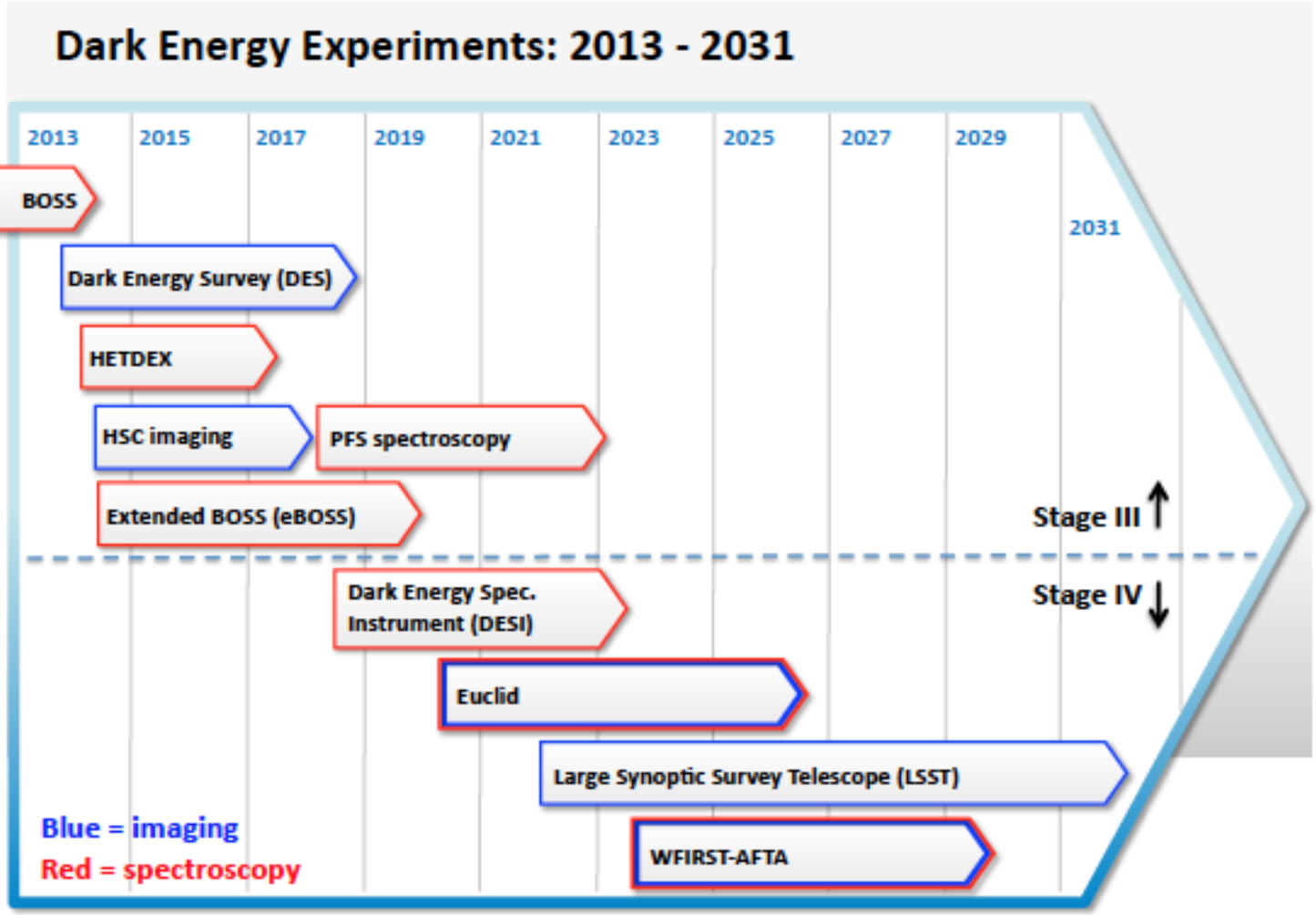
Cluster mass reconstruction from Weak Lensing

$$\kappa^p = \int \delta^m(z) w(z) dz$$

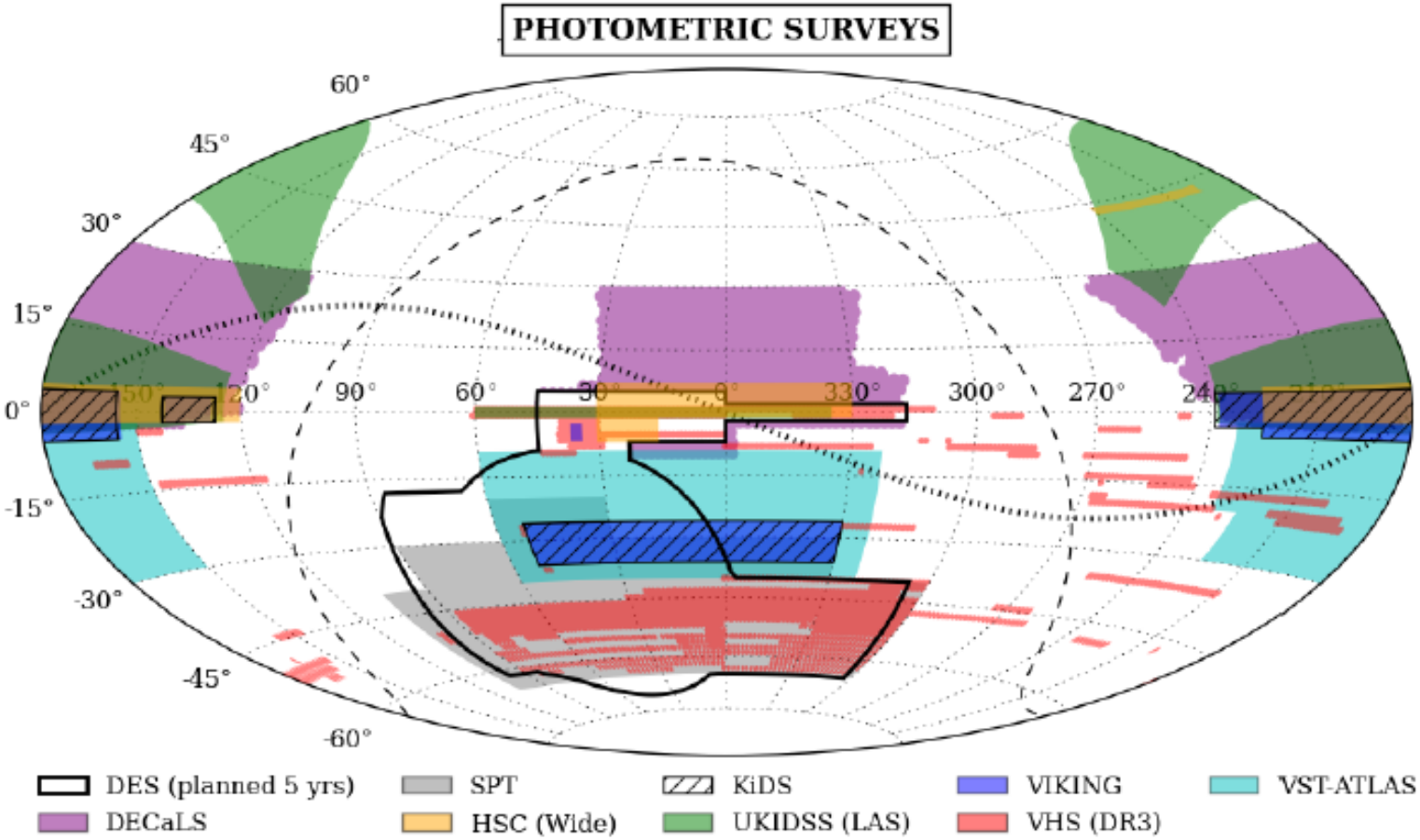
Melchior et al.



The DE Landscape and “the DES window”



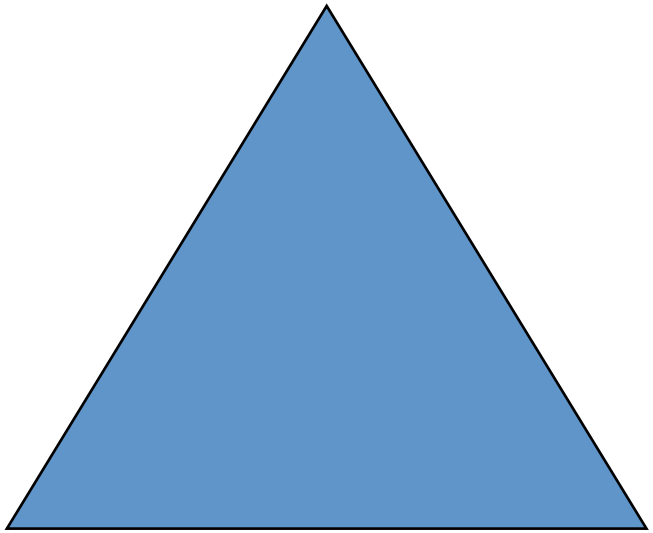
Covering the sky



Credit: Alex Merson et al.

Mass-Light Correlations

galaxies (per type)

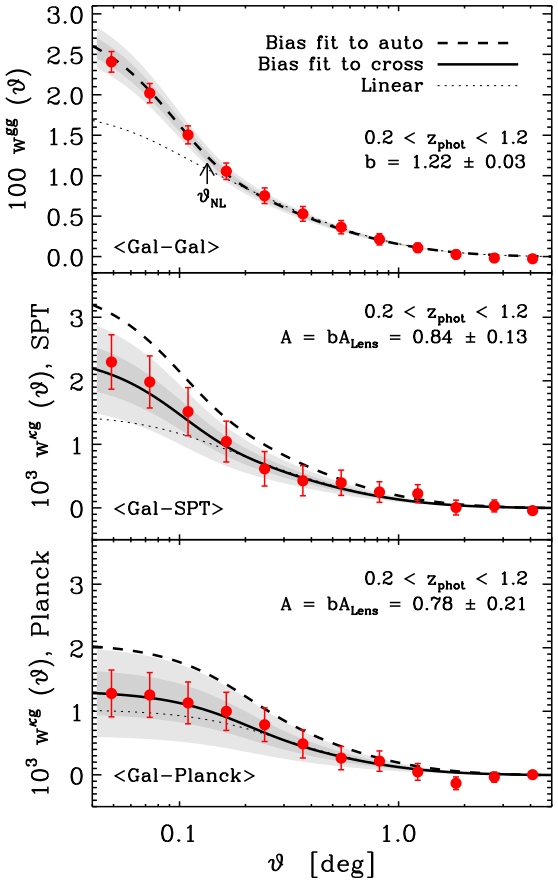


Mass galaxy WL

Mass CMB WL

Useful for: testing systematics, galaxy biasing, testing models

Cross correlation of DES galaxies and mass fluctuations derived from the CMB



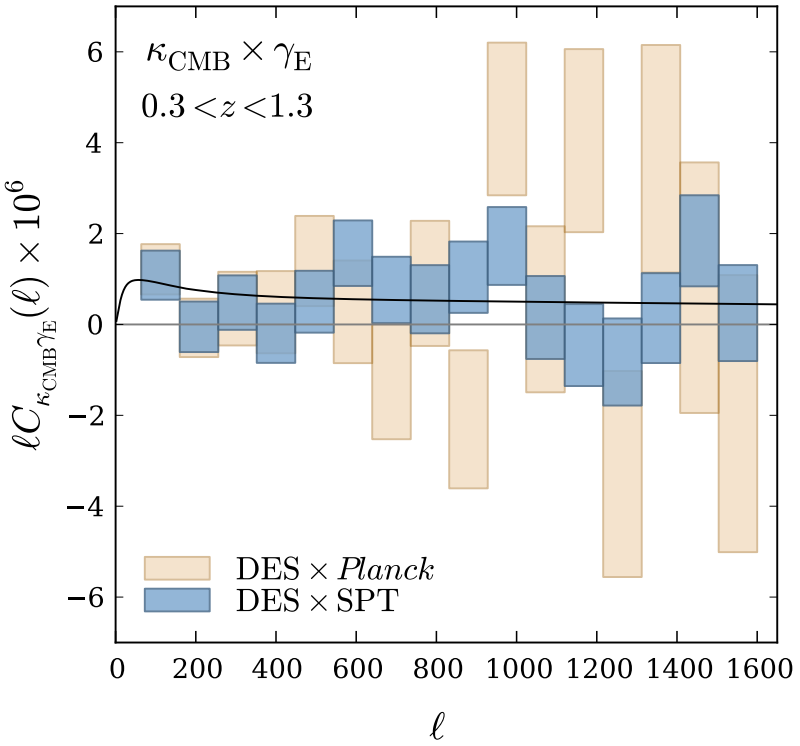
DES Gal-Gal
(0.2<z<1.2)
(cf. Crocce et al)

DES Gal – SPT mass
(6-sigma)

DES Gal – Planck mass
(4-sigma)

Giannantonio et al

Cross correlation of mass: DES-WL x CMB-WL

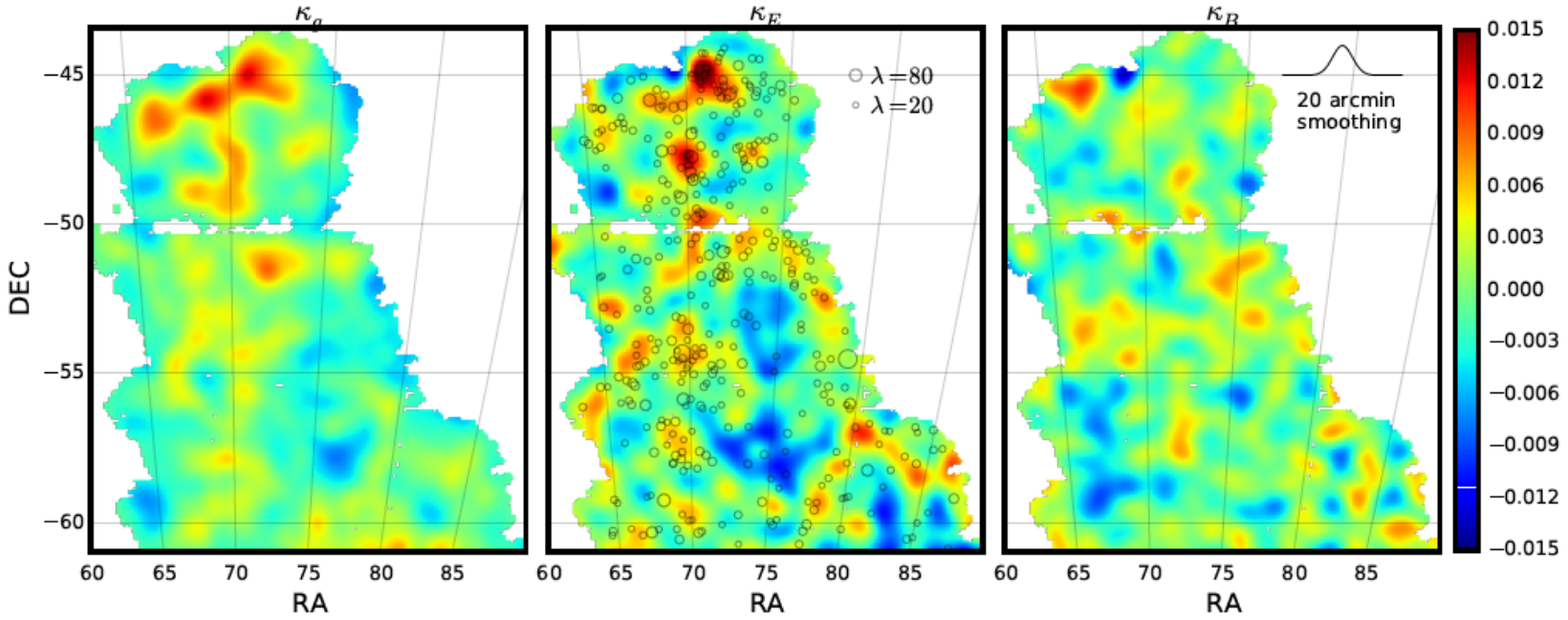


Redshift Range	$0.3 < z < 1.3$	
$\kappa_{\rm CMB}\gamma_{\rm E}$	A	χ^2/dof
ngmix × SPT	0.88 ± 0.30	0.93
ngmix × *Planck*	0.86 ± 0.39	1.52

Kirk & DES collaboration, arXiv:1512.04535

Dark Matter map from Weak Lensing

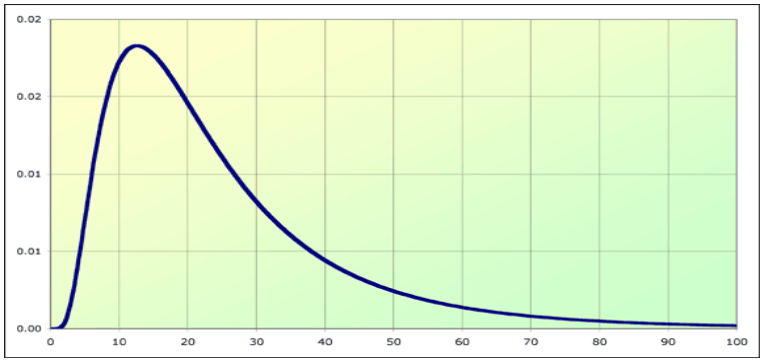
SV area 139 sq deg (only 3% of final DES)
Cross correlation signal: 5-7 sigma

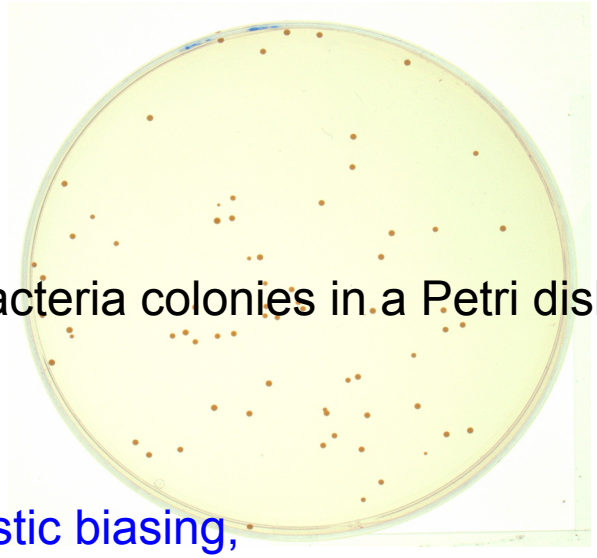


Chang, Vikram, Jain et al. (PRL) 1M Background sources @ z ~0.8
Vikram, Chang, Jain et al. (PRD) 1M Foreground lenses @ z ~ 0.3

Testing Log-normality of DES Kappa & Galaxy fluctuations

Lucinda Clerkin, Donnacha Kirk, Marc Manera, OL + others in DES
(in preparation)



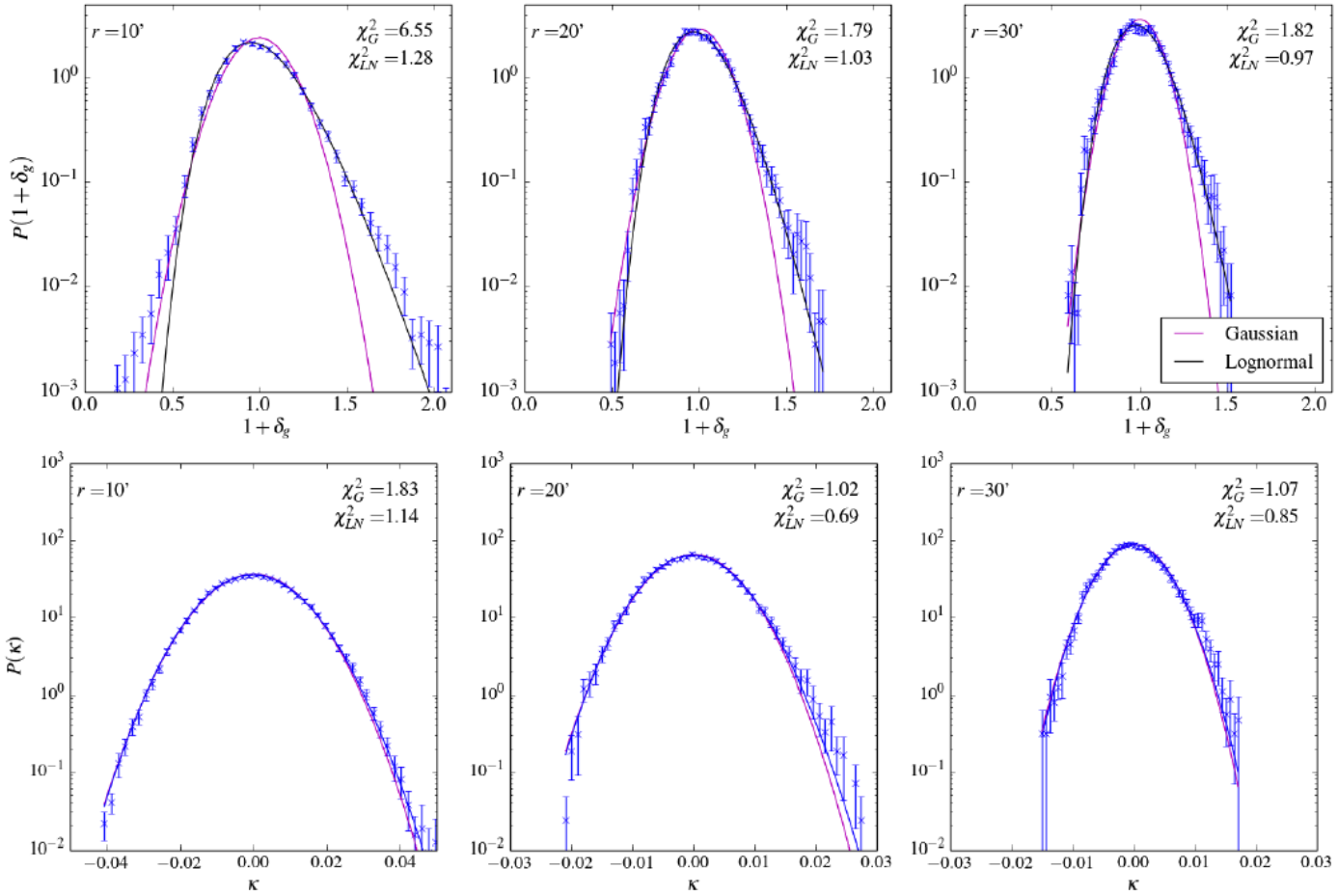


Cf. Bacteria colonies in a Petri dish

Useful for testing gravity, inferring non-linear and stochastic biasing, consistency checks with moments and for testing systematics
(Cf. Wild et al 2005 for 2dF red and blue galaxies)

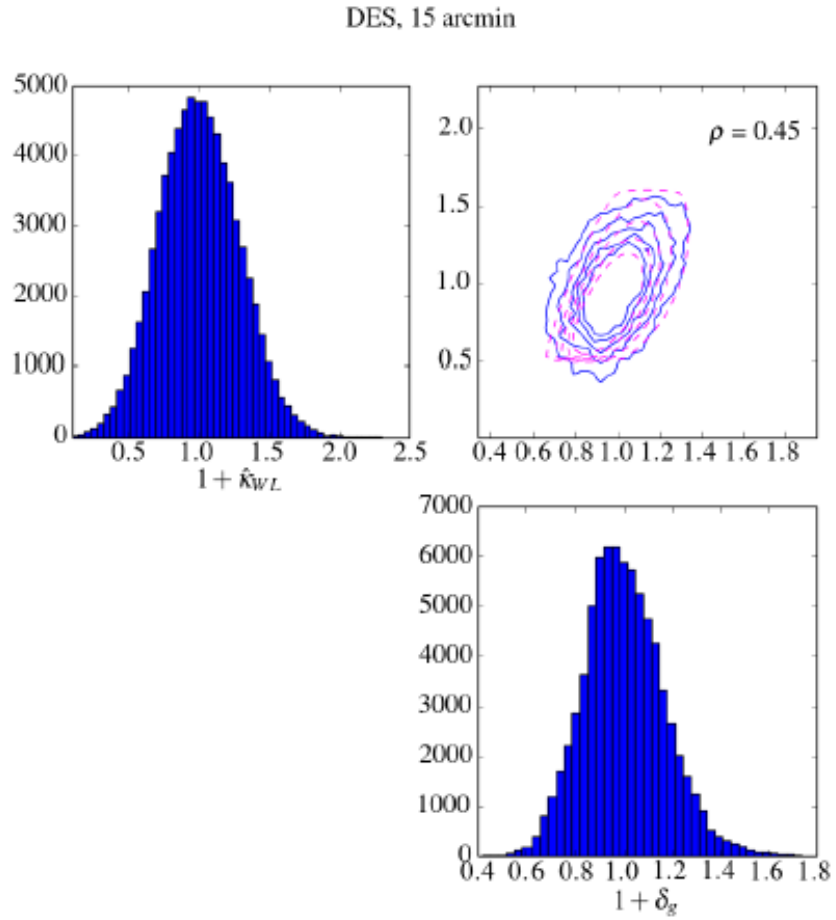
DES galaxy and kappa pdf: Are they log-Normal?

10’ => 5 Mpc/h @ z=0.8

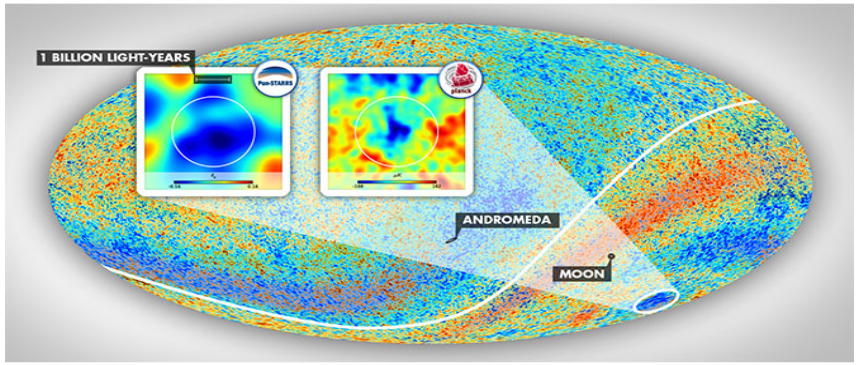


Clerkin et al. (in preparation)

Join (galaxies, kappa) pdf



Could a void explain the CMB Cold Spot?

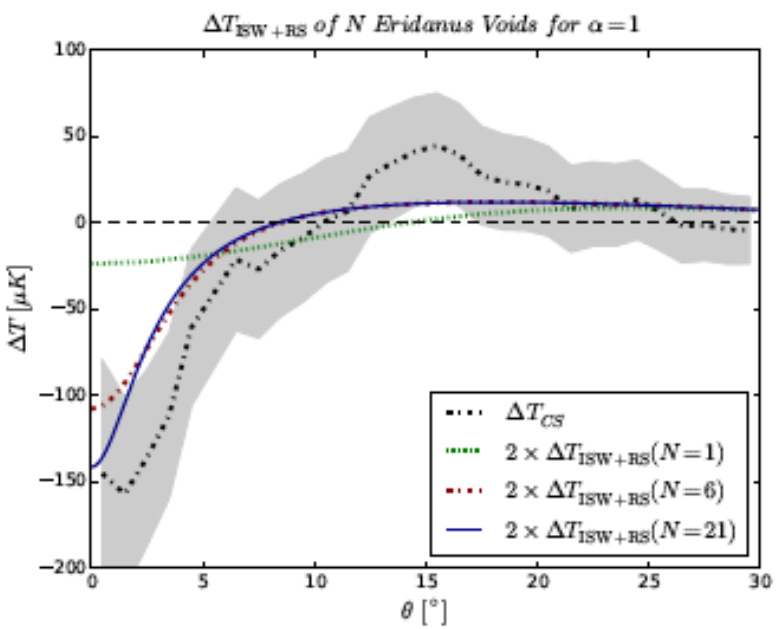


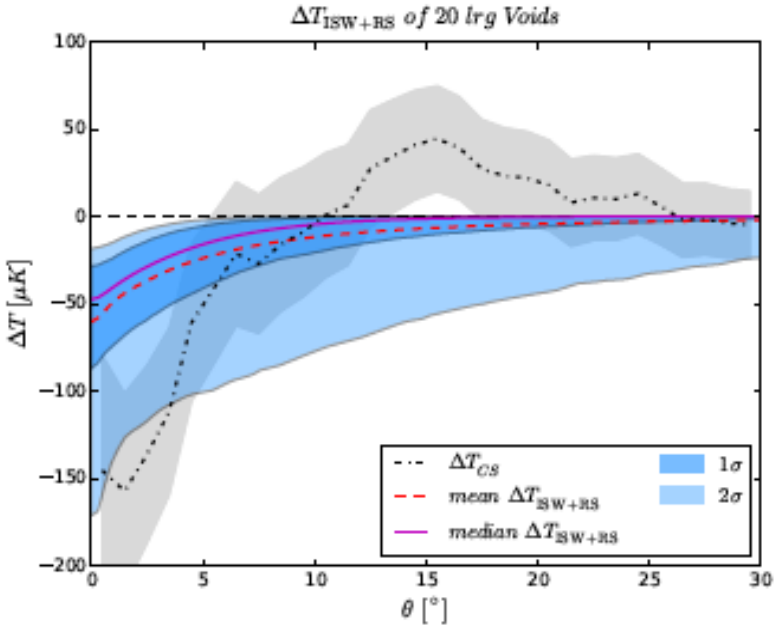
δT = -150 μK,
detected by WMAP & Planck
3 sigma if a Gaussian fluctuation

- A super-void with δ_m= -0.4, R = 220 Mpc/h, z = 0.2 found in the direction of the Cold Spot. (Szapudi et al, Nadathur et al)

- But ISW & Rees-Sciama can only account for a fraction of it.

Cold Spot Temperature profiles assuming a multi-void array along the LOS

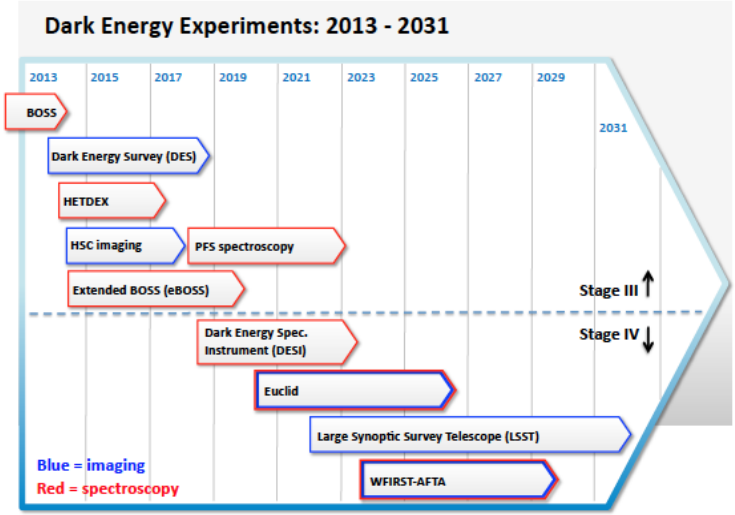


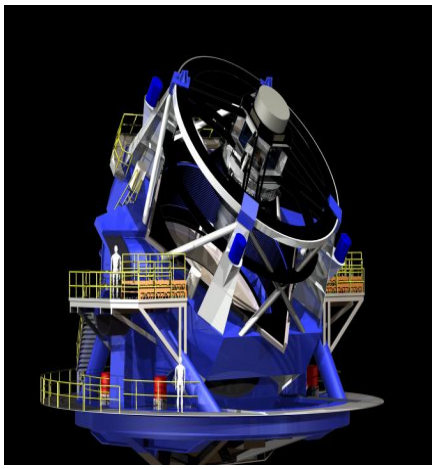


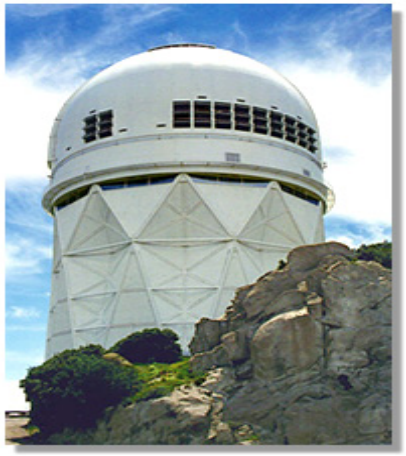
The tension between the CMB CS and LCDM can be reduced if a multi-void array in the cosmic web is taken into account, but big voids would also be in tension with LCDM

Naidoo, Benoit-Levy, OL (arXiv 1512.02694)

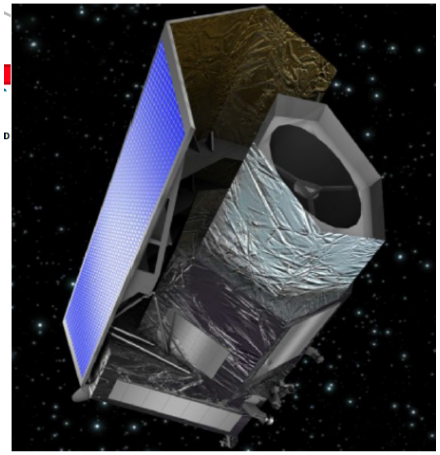
The era of DESI, Euclid, LSST,…







Mayall 4-Meter Telescope



Summary

- Wealth on information in maps of light and mass
- Main motivation: find interesting structures, learn about biasing, non-Gaussianity, testing new models
- Need to use the right statistical tool for the relevant question (note the “look elsewhere effect”)
- Great prospects for new maps coming years