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Cardiff University

Testing the Cosmological Principle with *Rubin LSST*

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UNIVERSITY OF OXFORD

To advertise the projects :

DESC Projects
#252 Testing the isotropy of the universe
#253 Testing the homogeneity of the cosmic matter field
#254 Testing tilted cosmology

Cosmology some time ago

Excerpt from *Conversation: Salam, Sciama, Witten and Budinich*

https://www.youtube.com/watch?v=AmUI2qf9uyo

Abdus Salam: *Don't you find Dennis, you and I are old people, that things have changed so much in our lifetime…*

Dennis Sciama: *The new deal in astrophysics really began in 1952… at the time it [became] clear that one could see objects in the radio that would be too far away to be visible optically so you could survey the Universe out to much greater distances.*

Cosmology some time ago

Excerpt from *Conversation: Salam, Sciama, Witten and Budinich*

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$$ds^2 = g_{\mu\nu} dx^\mu dx^\nu = -dt^2 + a^2(t)\, d\Sigma^2$$

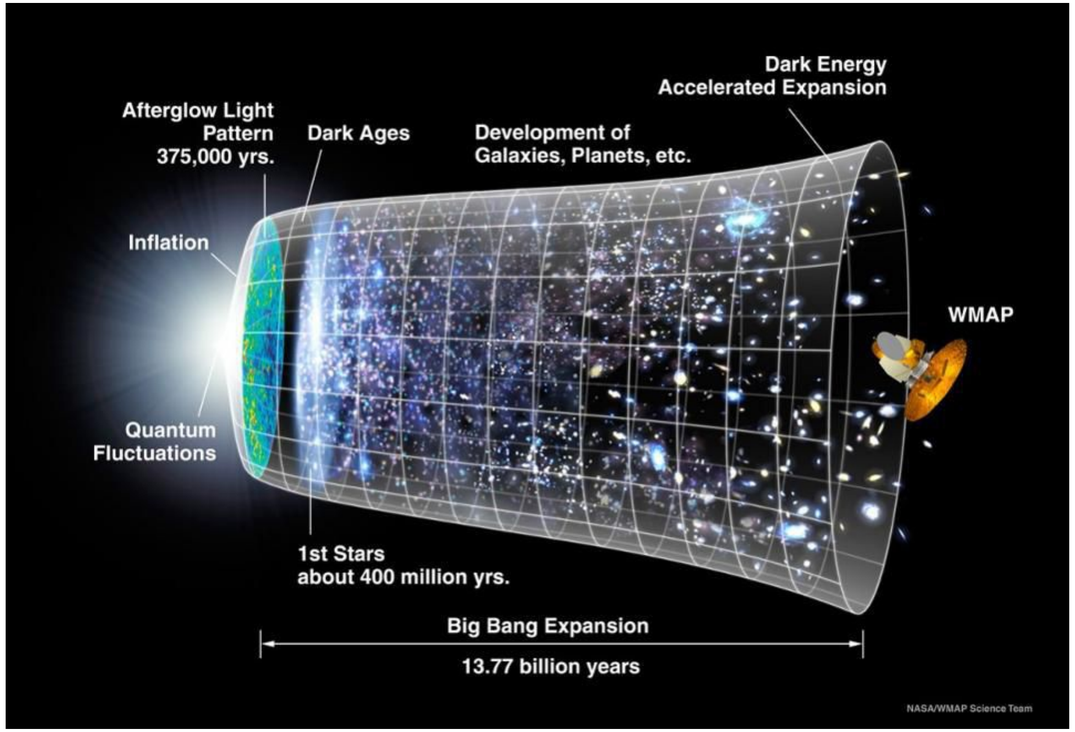
$g_{\mu\nu}$ is chosen to be spatially symmetric thereby fulfilling homogeneity and isotropy

$$R_{\mu\nu} + \frac{1}{2} R g_{\mu\nu} + \lambda g_{\mu\nu} = 8\pi G\, T_{\mu\nu}$$

$T_{\mu\nu}$ is an ideal fluid that in the homogeneous limit reduces to $diag(-\rho, p, p, p)$

Observations constrain the energy content in our universe using $1 = \Omega_\gamma + \Omega_m + \Omega_\Lambda + \Omega_k$, $\Omega_i = \rho_i / \rho_{cr}$.

Cosmology today



Obligatory cosmology slide

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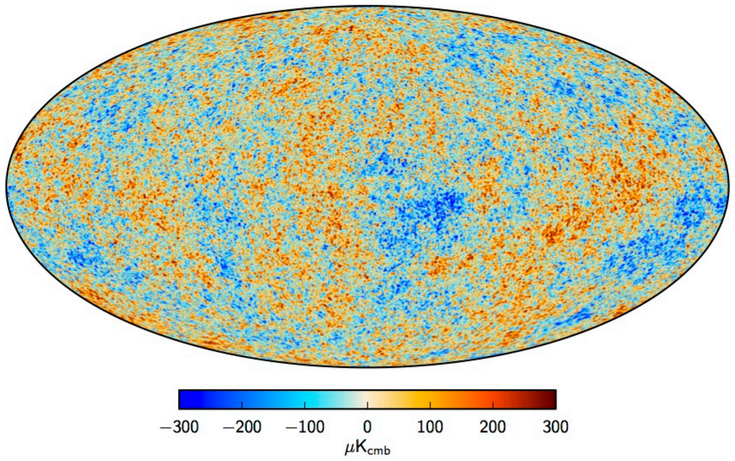
The Cosmological principle

Definitions from *Thoughts on the Cosmological Principle* - Schwarz [0905.0384]

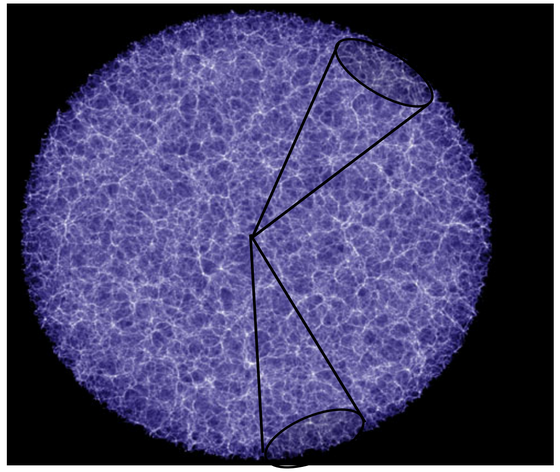


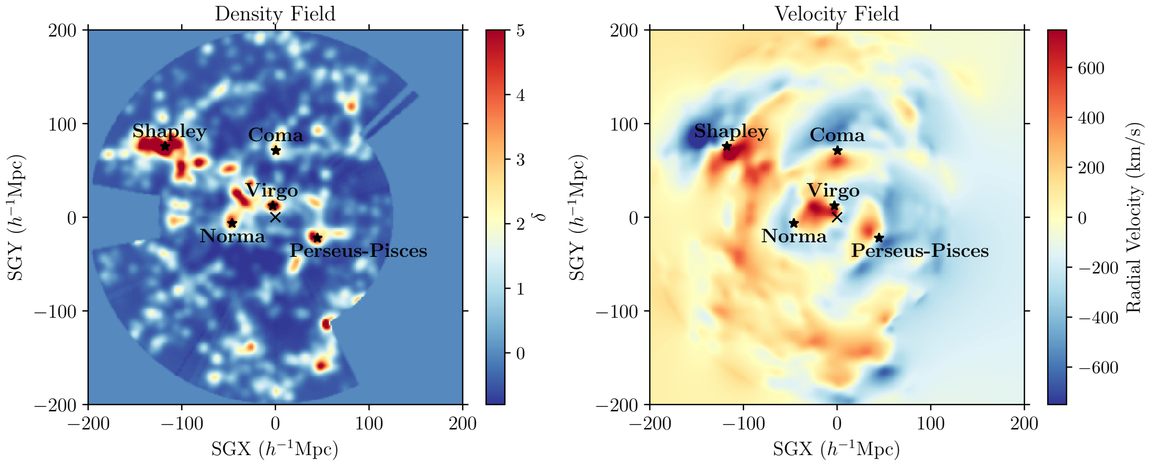
Fluctuations with $\ell > 1$:

Statistically isotropic and Gaussian to high degree

$\mathcal{O}(10^{-5})$ fluctuations, mostly primordial

"The distribution of light and matter in the Universe is statistically isotropic around any point, apart from anisotropies of local origin."





Boruah, Hudson, Lavaux [1912.09383]

Testing the Cosmological principle with *Rubin LSST*

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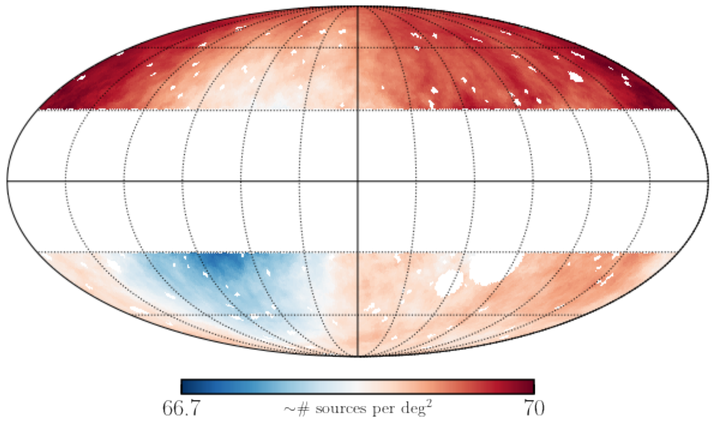
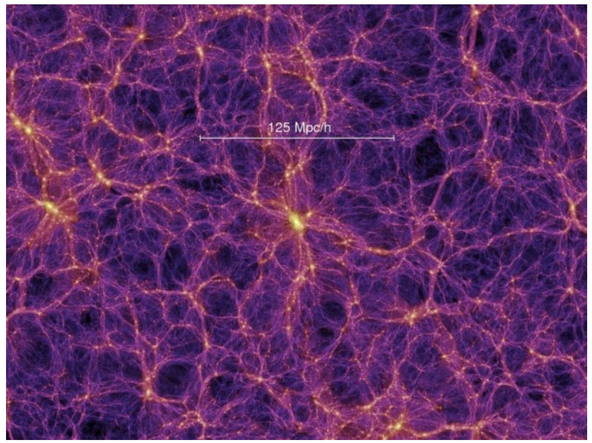
Isotropy



Homogeneity



Testing the isotropy of the Universe

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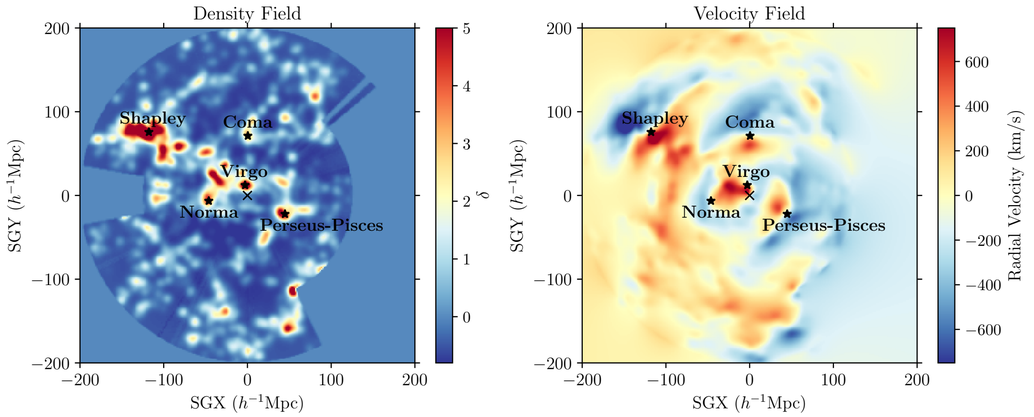

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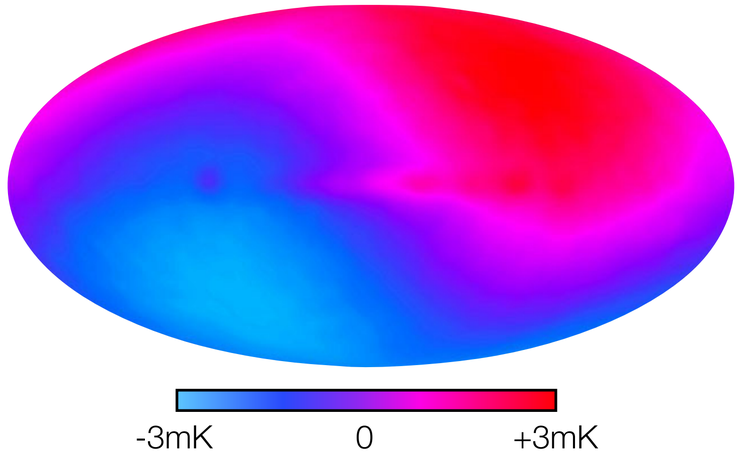
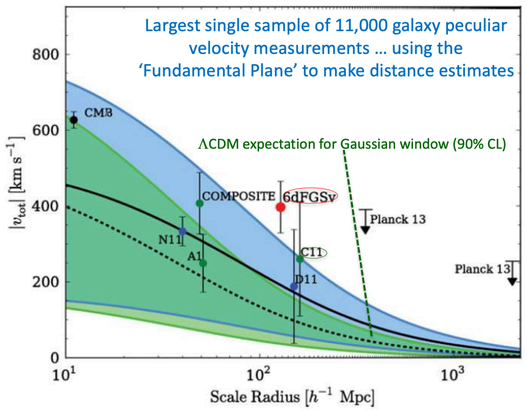


Bulk flows should die off with increasing volumes, but do they?



Magoulas et al. (2014) Proc.IAU 11 S308

Table 3. Relative velocities involving the CMB frame, the Galactic centre, and the Local Group.

Relative velocity	Speed [km s^{-1}]	l [deg]	b [deg]
Sun–CMB [a]	369.82 ± 0.11	264.021 ± 0.011	48.253 ± 0.005
Sun–LSR [b]	17.9 ± 2.0	48 ± 7	23 ± 4
LSR–GC [c]	239 ± 5	90	0
GC–CMB [d]	565 ± 5	265.76 ± 0.20	28.38 ± 0.28
Sun–LG [e]	299 ± 15	98.4 ± 3.6	−5.9 ± 3.0
LG–CMB [d]	620 ± 15	271.9 ± 2.0	29.6 ± 1.4

Planck Collab. 2018, I [1807.06205]

Testing the isotropy of the Universe

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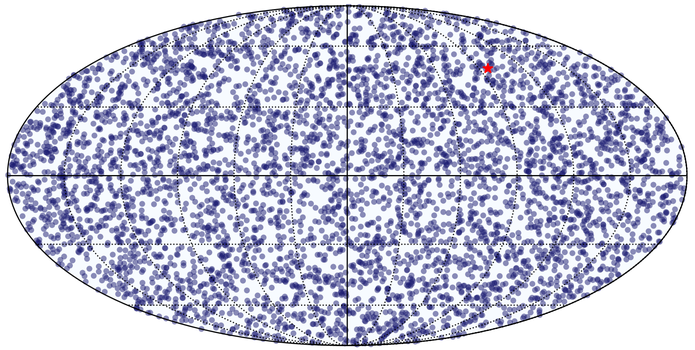


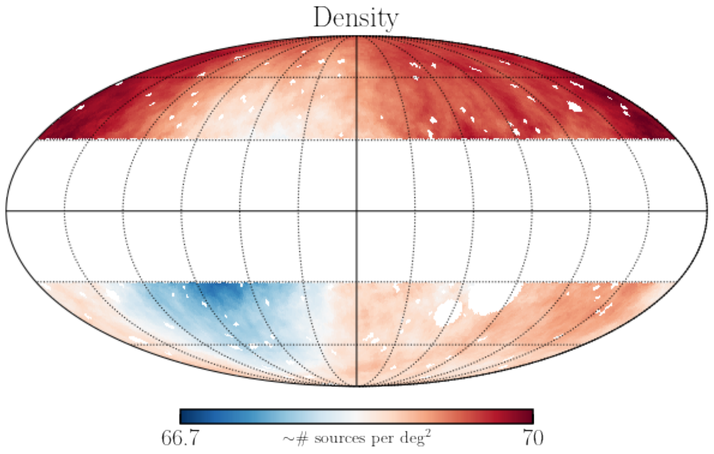
Ellis, Baldwin (1984)

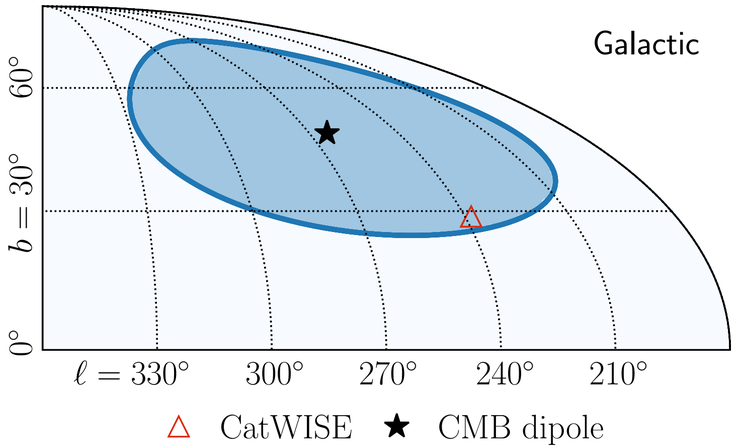
Isotropic sample of objects on the sky

Spectra are power laws in flux density $f_\nu \propto \nu^{-\alpha}$

Differential number counts of flux-limited catalog follows $dN/d\Omega\ (f_\nu > f_\nu^{\min}) \propto (f_\nu^{\min})^{-x}$

Dipole in the number density with amplitude $[2 + x(1 + \alpha)] \cdot \beta$





Secrest, von Hausegger, Rameez, Mohayaee, Sarkar, Colin [2009.14826]

Secrest, von Hausegger, Rameez, Mohayaee, Sarkar [2206.05624]

Testing the isotropy of the Universe

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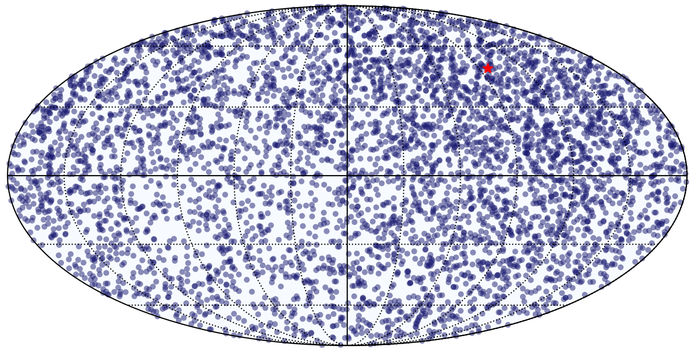

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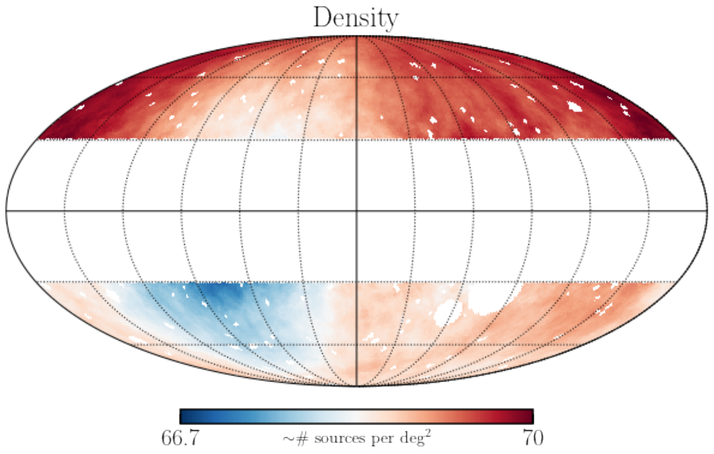

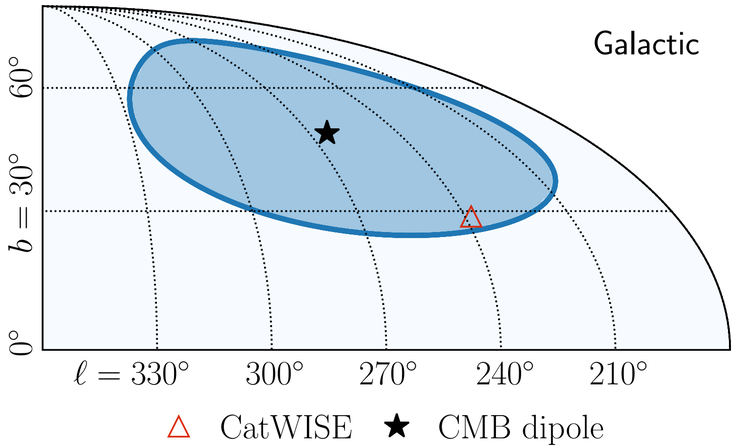

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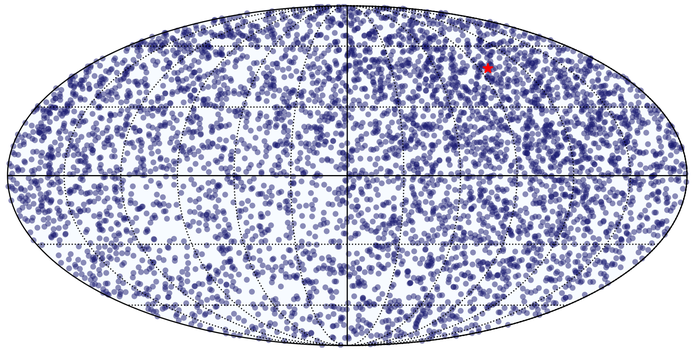

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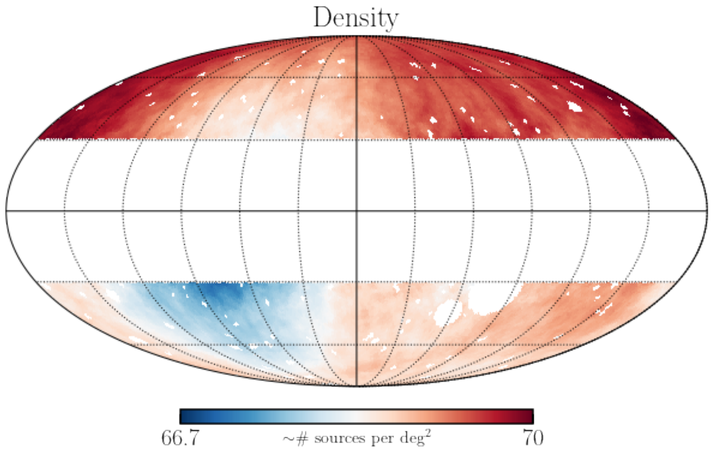
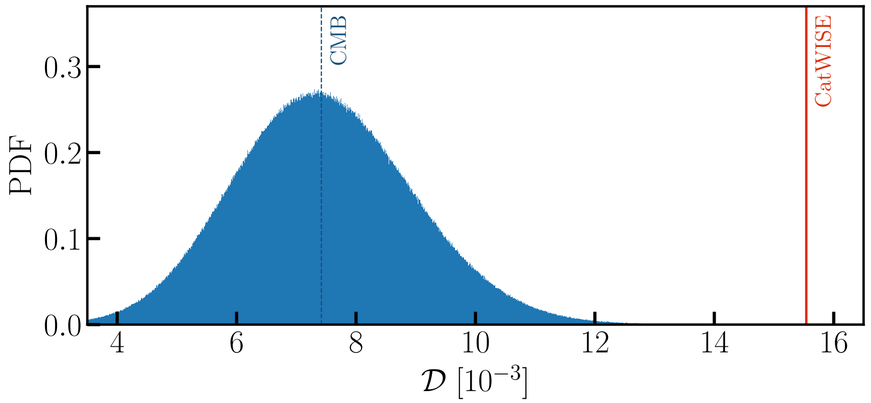




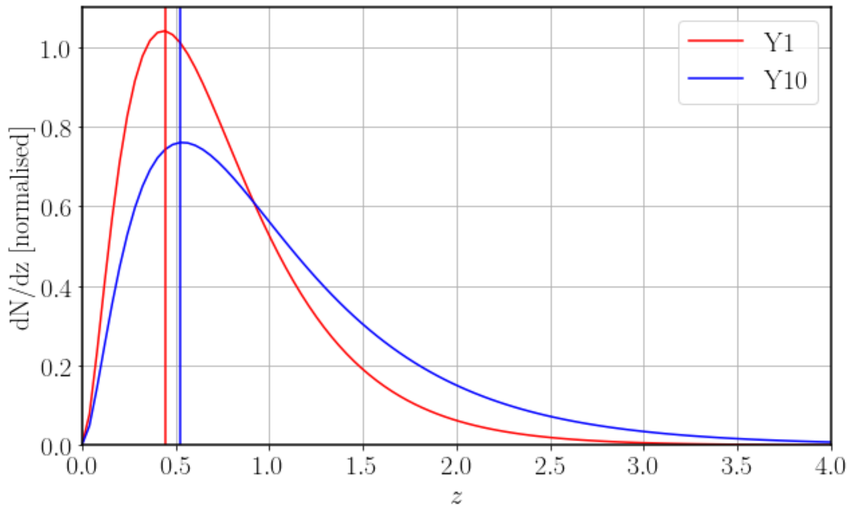
Secrest, von Hausegger, Rameez, Mohayaee, Sarkar, Colin [2009.14826]

Secrest, von Hausegger, Rameez, Mohayaee, Sarkar [2206.05624]

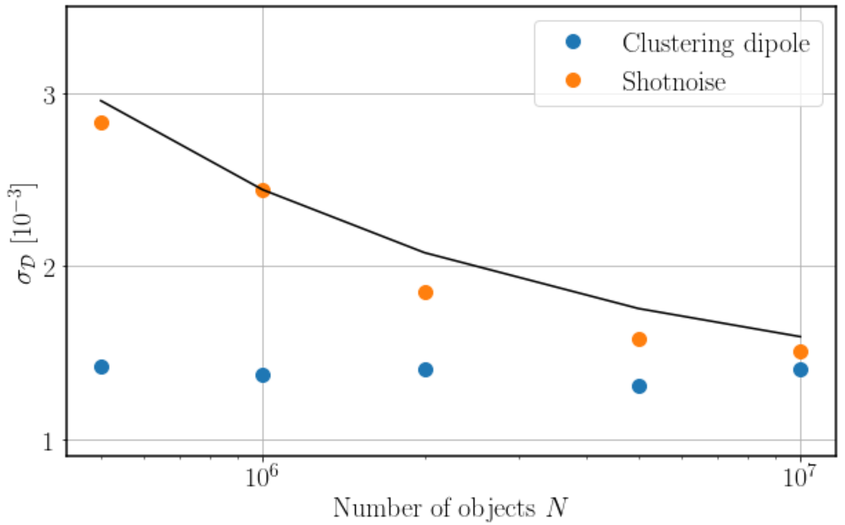
Inconsistent with CMB dipole expectation at ~5σ !

Testing the isotropy of the Universe with *Rubin LSST*

DESC Project #252



From Fig. F2 from LSST SRD [1809.01669]



		LSST	Euclid
Obs. parameters	$N_{\rm tot}$	10^9	10^9
	$\sigma_z/(1+z)$ and σ_ϕ	5%	5%
	$z_{\rm min}$ and $\phi_{\rm min}$	0.2	0.2
	$f_{\rm sky}$	40%	38%
Forecast	$\sigma(\beta)/\beta$	1.4%	1.3%
	$\langle\theta_\beta\rangle$	1.2°	0.9°
	$\sigma(d_{\rm int})/d^{\rm t}_{\rm int}$	4.6%	4%
	$\langle\theta_{\rm int}\rangle$	3.1°	2.7°

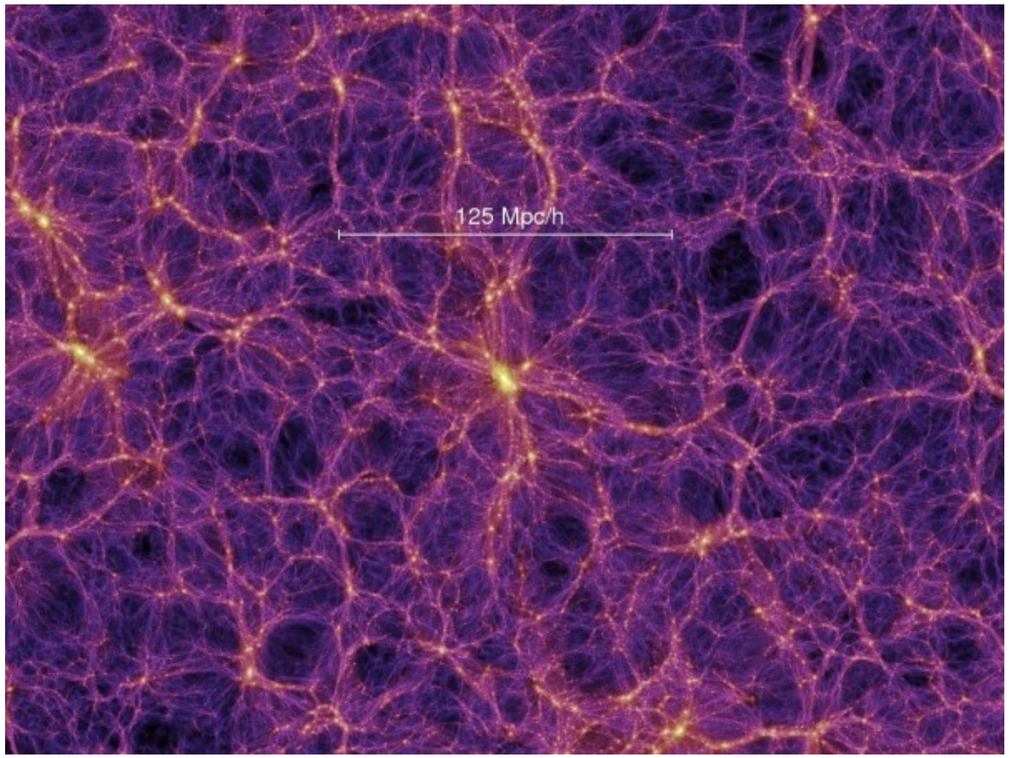
Table 1 from Nadolny et al. [2106.05284]; see also Dalang et al. [2209.12812]

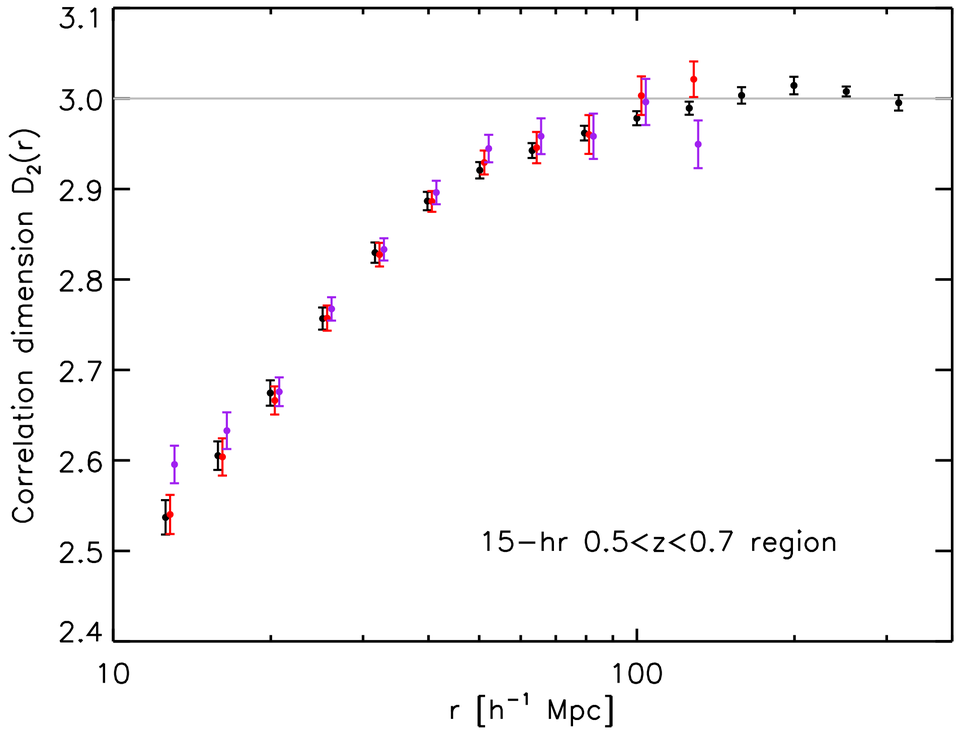
Testing the homogeneity of the cosmic matter field

DESC Project #253

Estimator of homogeneity: Fractal dimension

$$D_2(r) = \frac{\mathrm{d}\ln N(<r)}{\mathrm{d}\ln r} \qquad N(<r) \propto r^d$$





Scrimgeour et al. (2012) [1205.6812]

Testing the homogeneity of the cosmic matter field

DESC Project #253

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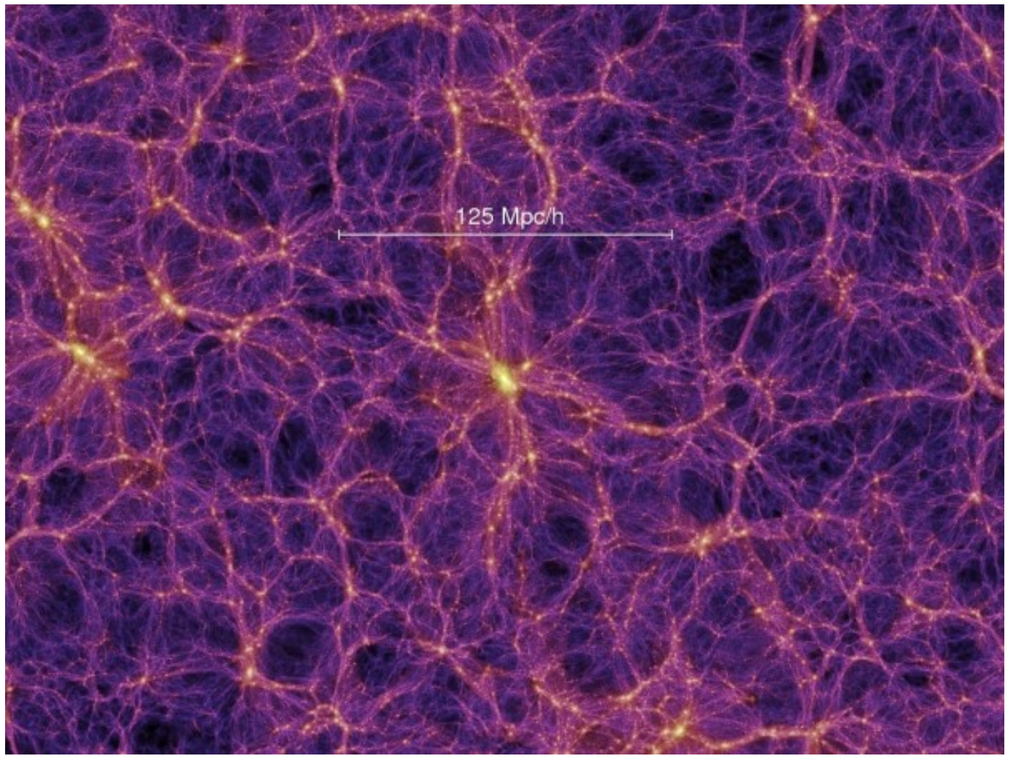
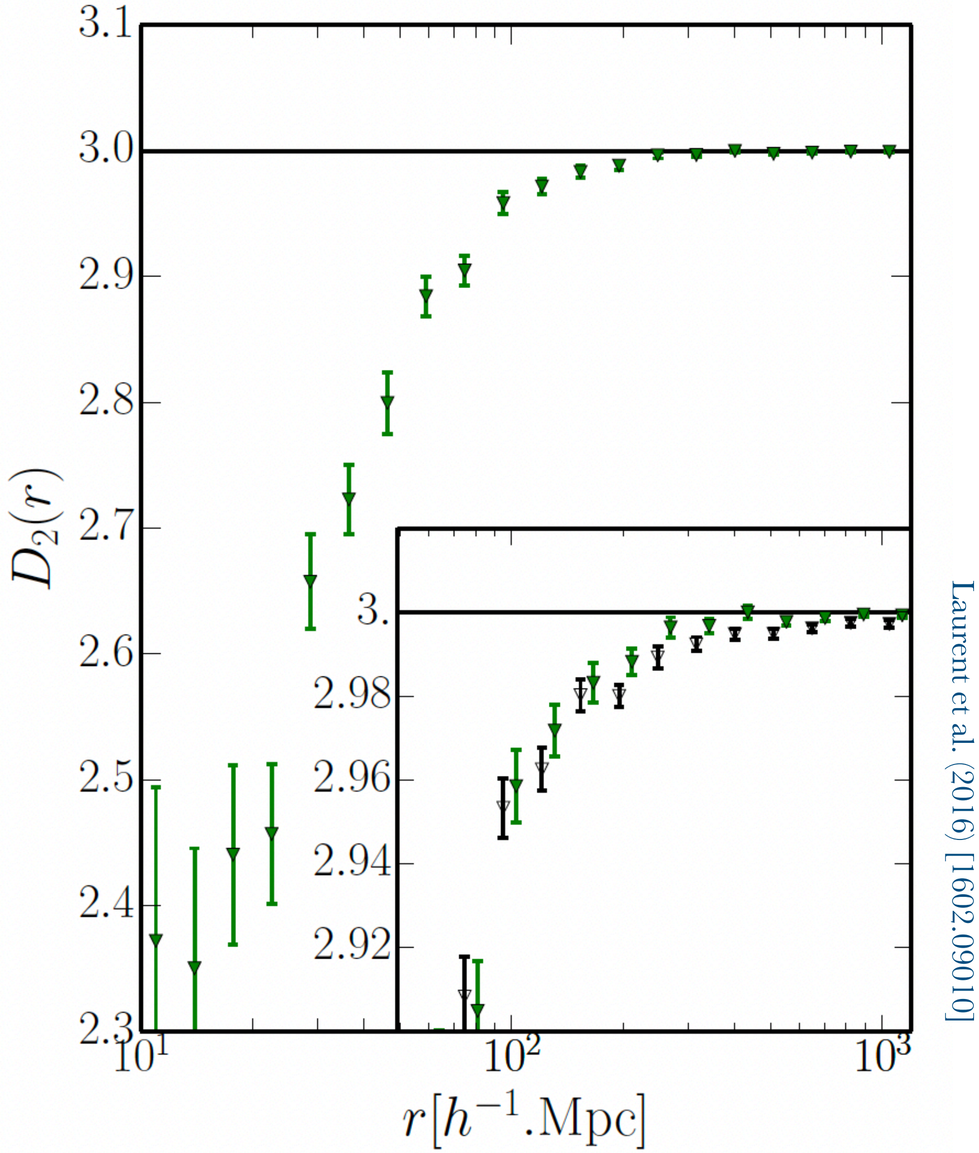




Laurent et al. (2016) [1602.09010]

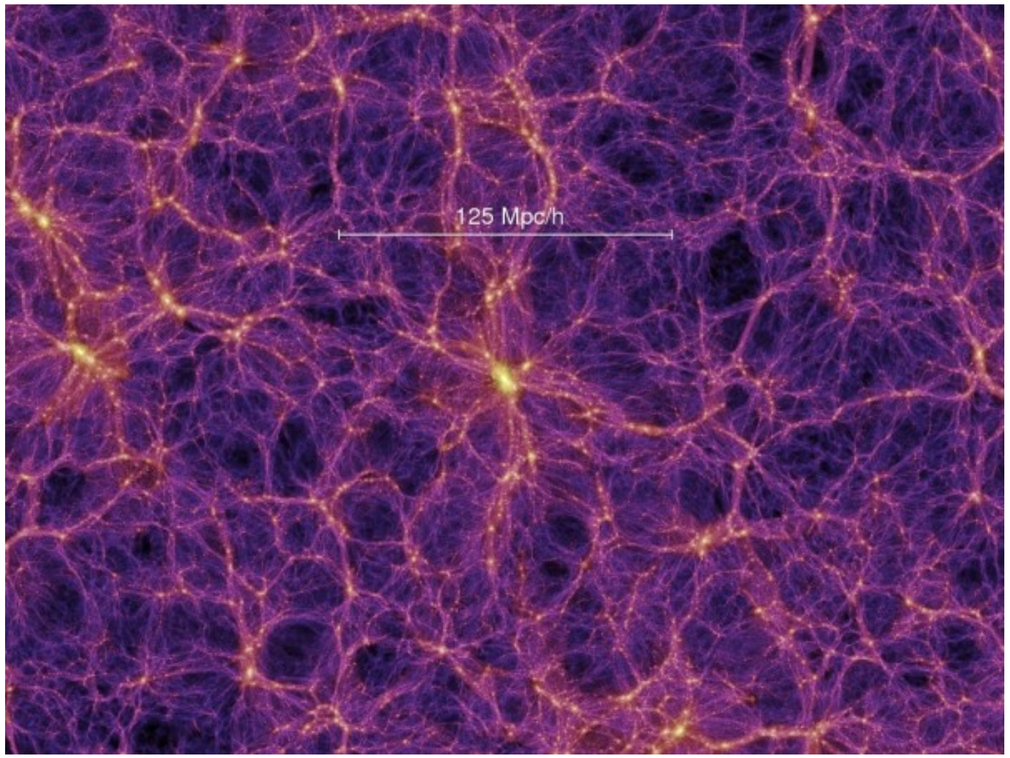
Testing the homogeneity of the cosmic matter field

DESC Project #253

Estimator of homogeneity: Fractal dimension for projected fields

$$H_2(\theta) = \frac{\mathrm{d}\ln N(<\theta)}{\mathrm{d}\ln V(\theta)}$$

Alonso et al. (2014) [1312.0861] + Alonso et al. (2015) [1412.5151]



Collapsing radial dimension:
photo-z + no model-dependency for distances

Incompleteness, selection function, and Gal. contamination must still be addressed

When have we reached the scale of homogeneity? — Mocks…

Testing tilted cosmology (in just one slide)

DESC Project #254

Is our universe better described by theoretical models that inherently contain anisotropies?

Ellis et al. (1985) Phys.Rep. 124, 5&6, pp.315-417

If so:

Estimators of homogeneity affected? *e.g.*, Heinesen [2006.15022]

Do local bulk flows affect measurements of cosmological quantities? *e.g.*, Filippou&Tsagas [2003.01186]

Global bulk flows present? *e.g.*, Domenech et al. [2207.01569]. *See also Gunn (1988), and Turner (1991)*

Different topology behind anisotropies?

e.g., Constantin et al. [2212.03234], Awwad&Prokopec [2211.16893]; *also* Ellis et al. (1985) Phys.Rep. 124

Addressing these questions might require a more general approach to analysing data, *e.g.*, peculiar velocities etc.

Testing the Cosmological principle with *Rubin LSST*

High-redshift galaxy catalogs from *Rubin LSST* will measure statistical isotropy and homogeneity

— Ellis&Baldwin ``84 and related tests at high significance even separately in redshift slices
— Measure projected fractal dimension
— Space for many synergies with other surveys!
— Mostly same data products and requirements as other LSS analyses

Lower redshift measurements, such as SNIa catalogs allow for testing specific “beyond LCDM” models dubbed “tilted cosmologies”

Join our DESC projects!

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Current members: David Alonso, Farrukh Azfar, Biprateep Dey, Eric Gawiser, Mustapha Ishak, Jon Loveday, Erick Pasten, Mohamed Rameez, Animesh Sah, Subir Sarkar, Ian Shipsey, Jeff Tseng, Tony Tyson, Sebastian von Hausegger