# Scale-dependent non-Gaussianities in WMAP: Surrogates analysed with Minkowski Functionals

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Cosmological Non-Gaussianity Workshop

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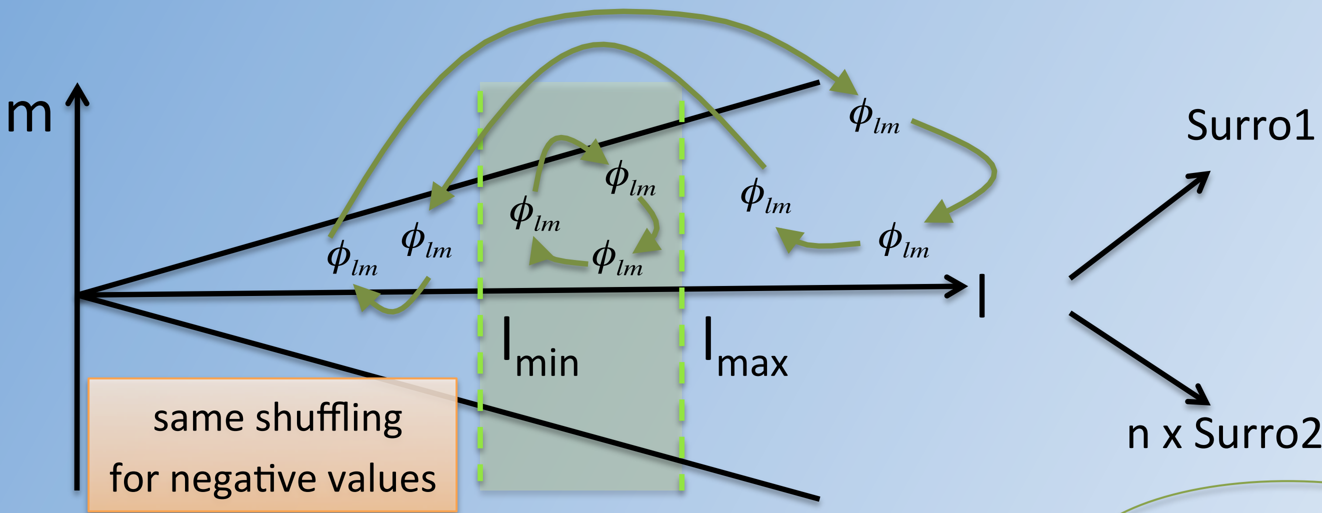
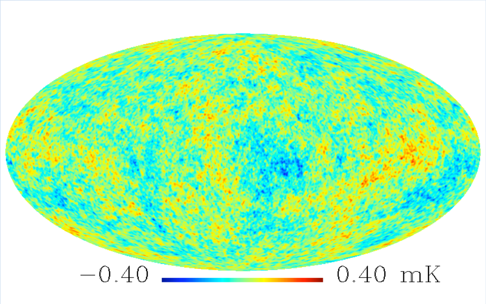
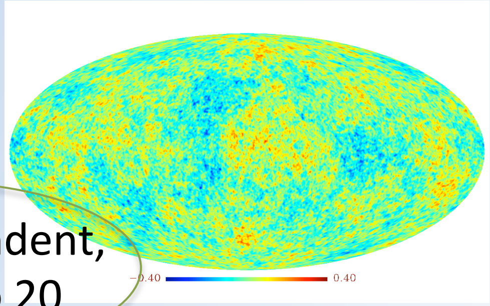
# Shuffling of CMB Fourier Phases $\phi_{lm} = \arctan\left(\frac{\mathrm{Im}(a_{lm})}{\mathrm{Re}(a_{lm})}\right)$

IDEA: If CMB gaussian → Fourier phases uncorrelated → all information in the power spectrum → phase shuffling should not change anything

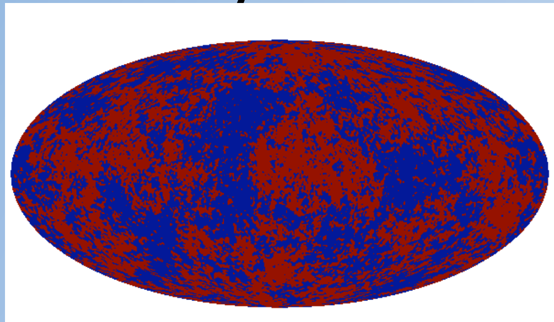



Scale-dependent,
l-range: 0 to 20

## Analysis with Minkowski Functionals, sensitive to HOCs



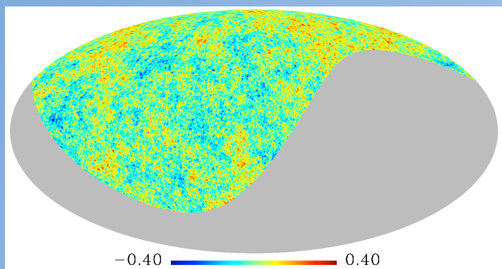
Excursion Set $R(\nu)$

$$M_0(\nu) = \int_{R(\nu)} dS$$
Surface Area

$$M_1(\nu) = \int_{\partial R(\nu)} dl$$
Integral mean curvature

$$M_2(\nu) = \int_{\partial R(\nu)} \frac{dl}{r} dl$$
Euler Characteristic

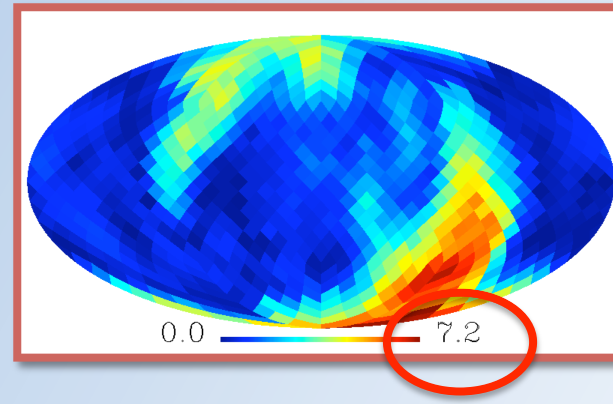
# Hemispherical Analysis of Topological Properties with diagonal $\chi^2$ - Statistics

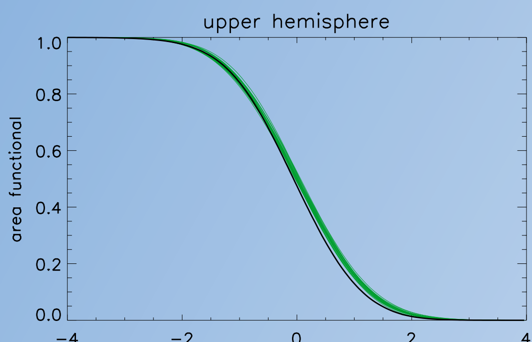


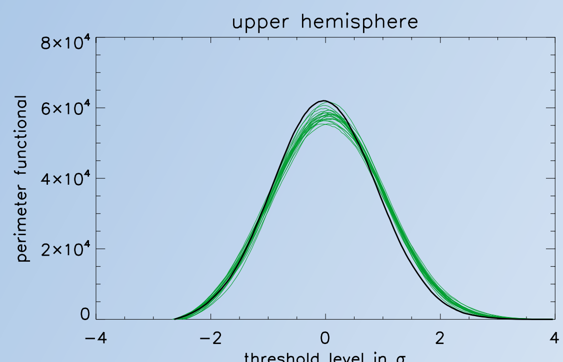

$$\chi^2_{surro1} = \sum_{\upsilon} \frac{M_{surro1} - \langle M_{surro2} \rangle}{\sigma_{M_{Surro2}}}$$

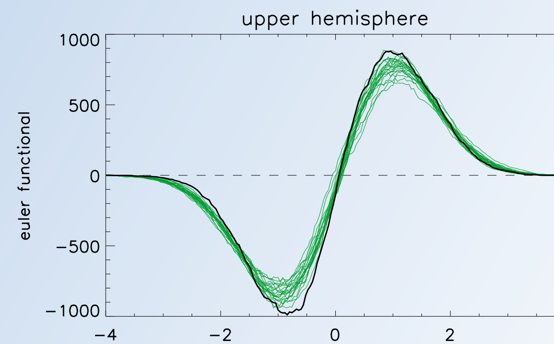
$$S(\chi^2) = \frac{\chi^2_{surro1} - \langle \chi^2_{surro2} \rangle}{\sigma_{\chi^2_{surro2}}}$$

Euler Significance Map

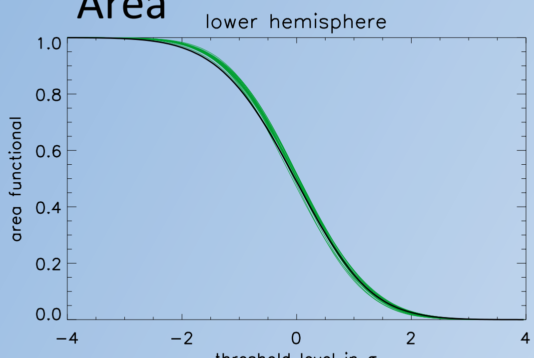


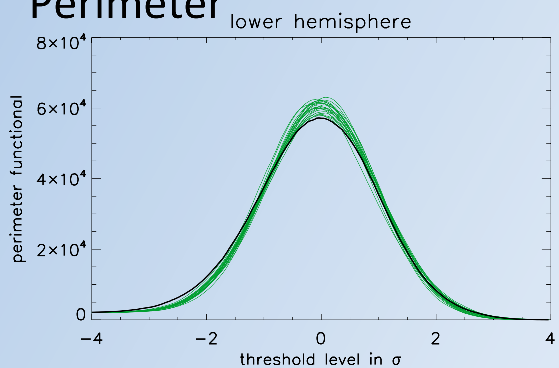



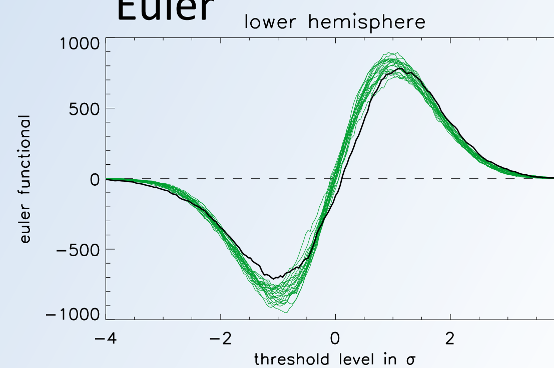

Area




Perimeter

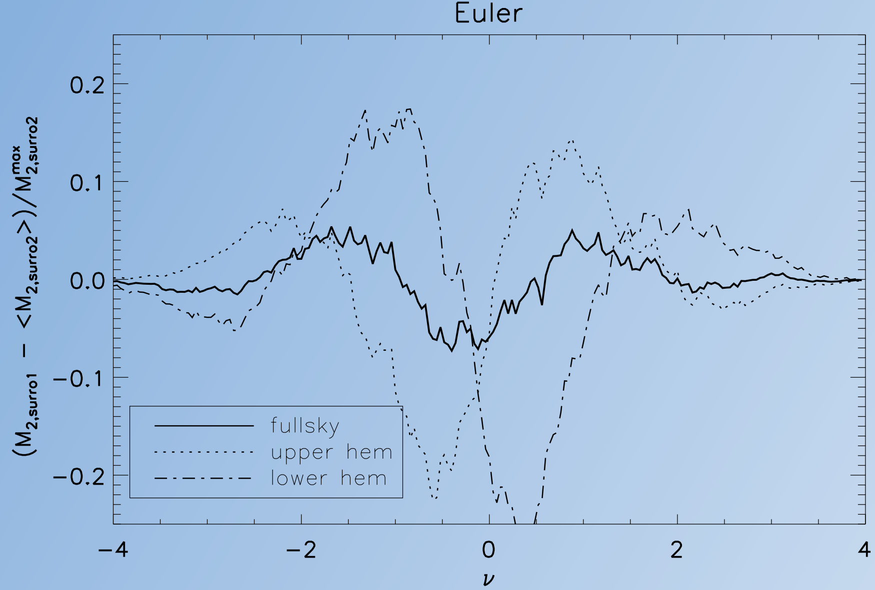


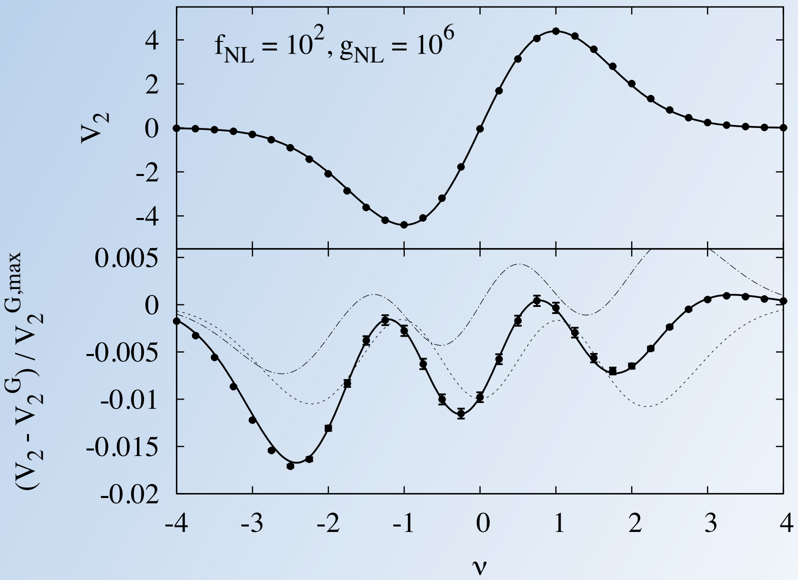

Euler



# Surrogate Method versus $f_{NL}, g_{NL}$ Models

$MF_{surro1} - MF_{surro2}$ ←→ $MF_{fNL,gNL}$ - $MF_{gaussian}$




Analytic Minkowski Functionals, and from Simulations, Matsubara et al 2010