Recent Progress in Non-Canonical WL Statistics

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Longer-Term Task-1 WL

Develop non-canonical WL statistics that have the potential to improve dark energy constraints

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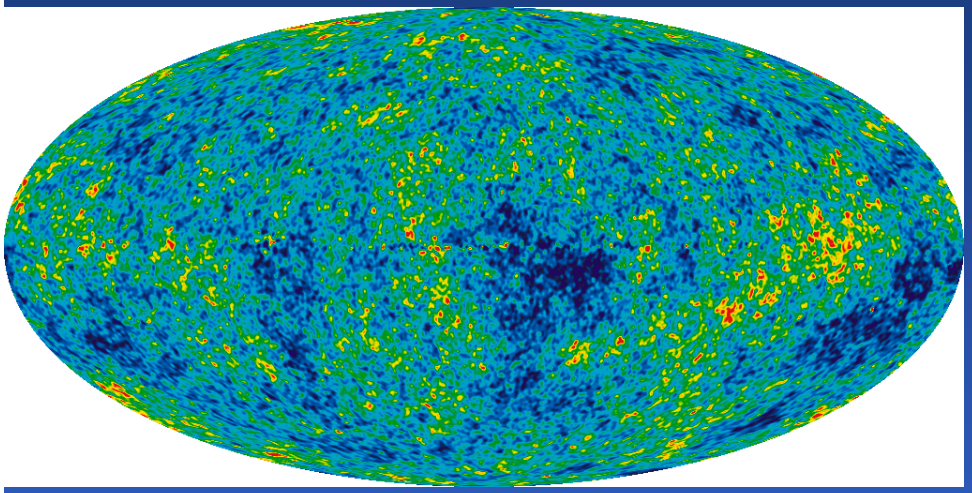
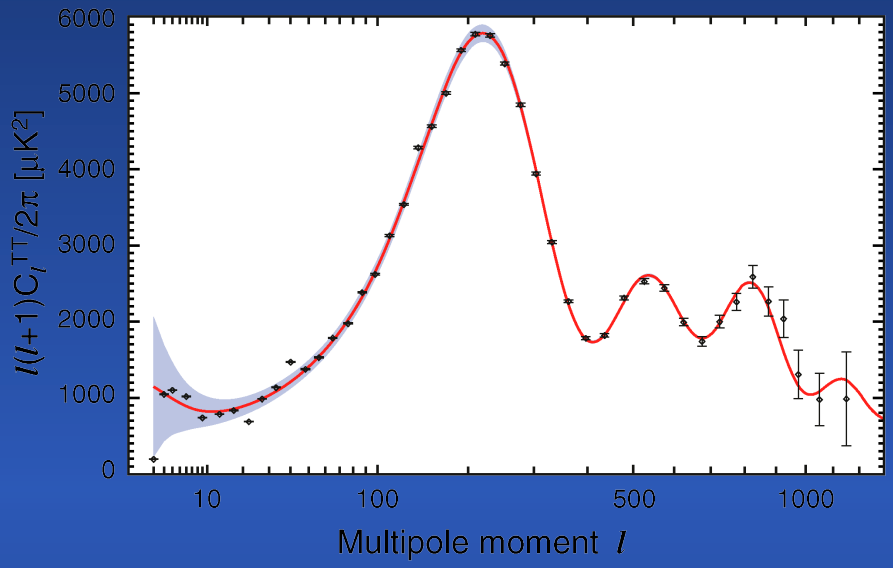
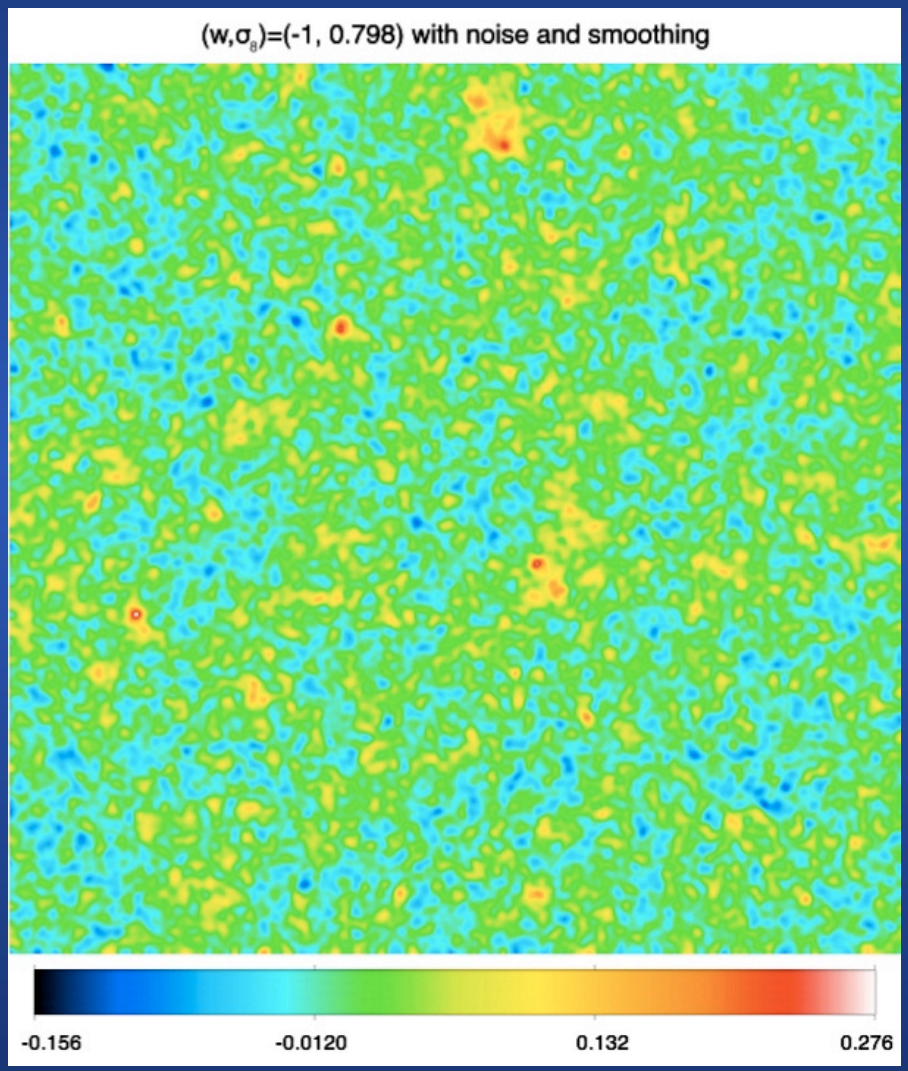
Power spectrum

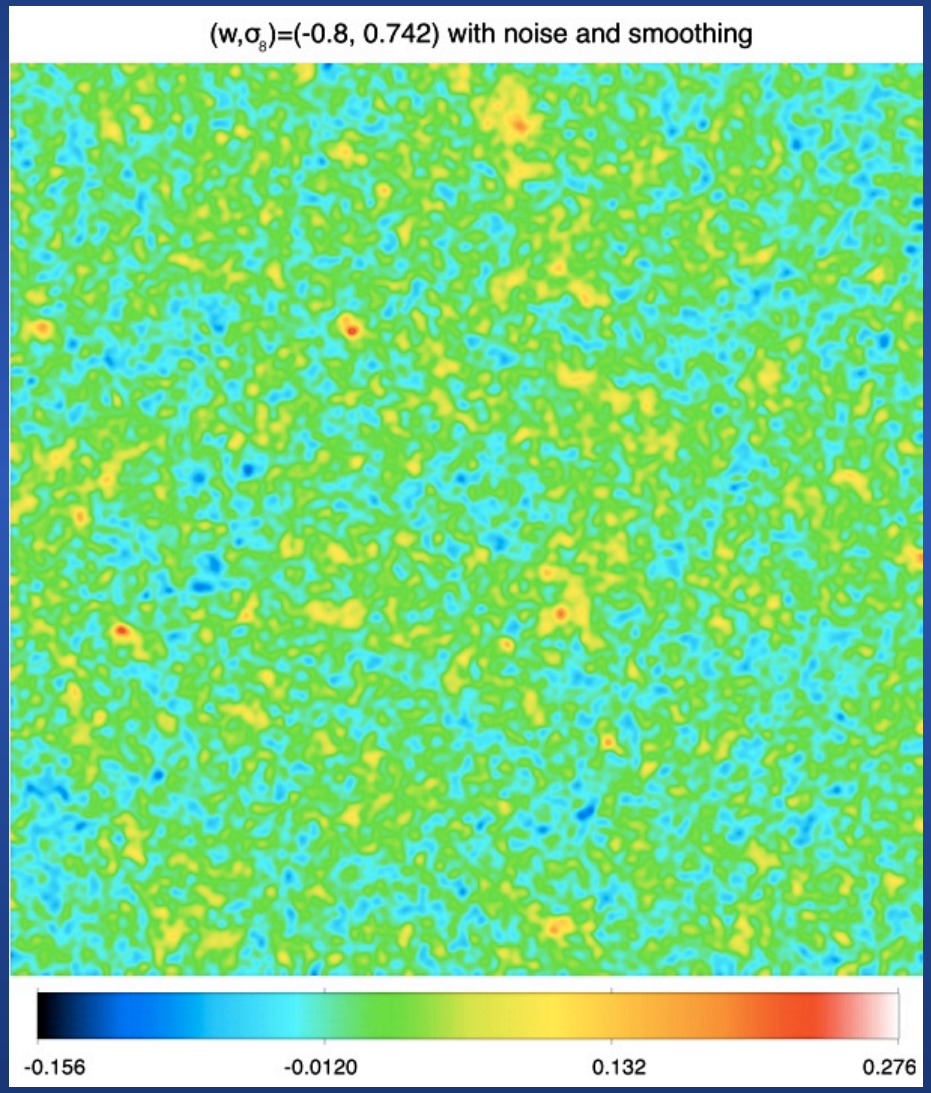




For the CMB, the power spectrum contains most of the information. Unlike the CMB, lensing maps are highly non-Gaussian, so the power spectrum misses a significant amount of information. Statistics which capture this non-Gaussian information can tighten constraints on dark energy parameters. These include lensing peaks, moments of the convergence distribution, and Minkowski functionals.

Lensing Simulations LSST field of view, 7 cosmologies, Vary σ_8, w, Ω_m 1000 realizations each, ray-trace at z=1, 1.5, 2

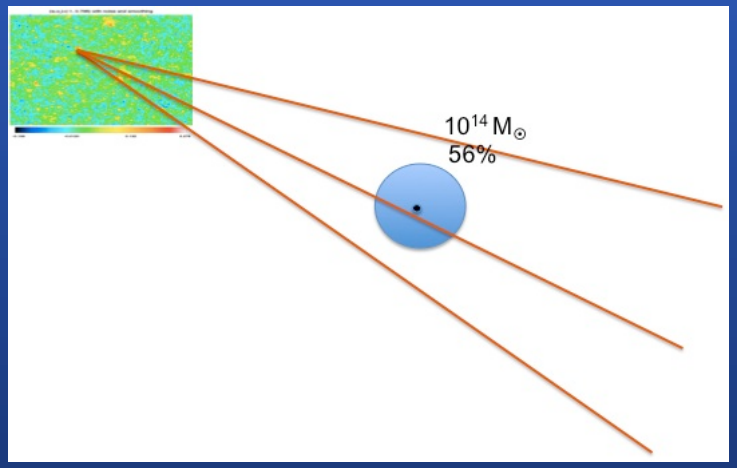


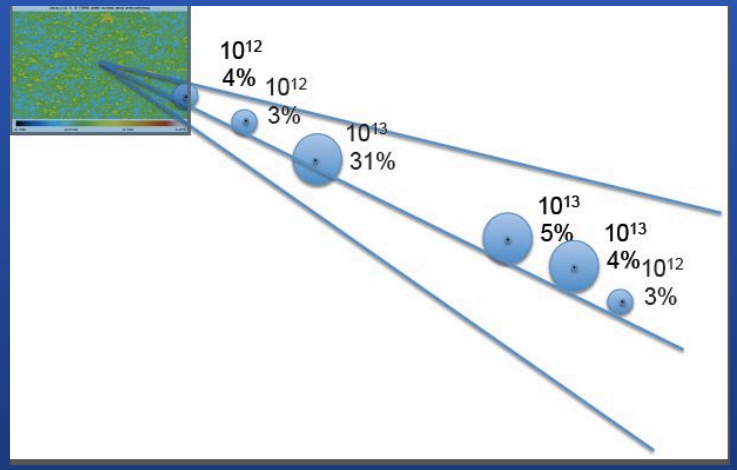


Lensing Peaks

Local maxima in the shear field in lensing maps due to single or multiple galaxy clusters along the line of sight

Provide information similar to that provided by galaxy clusters





Work on lensing peaks

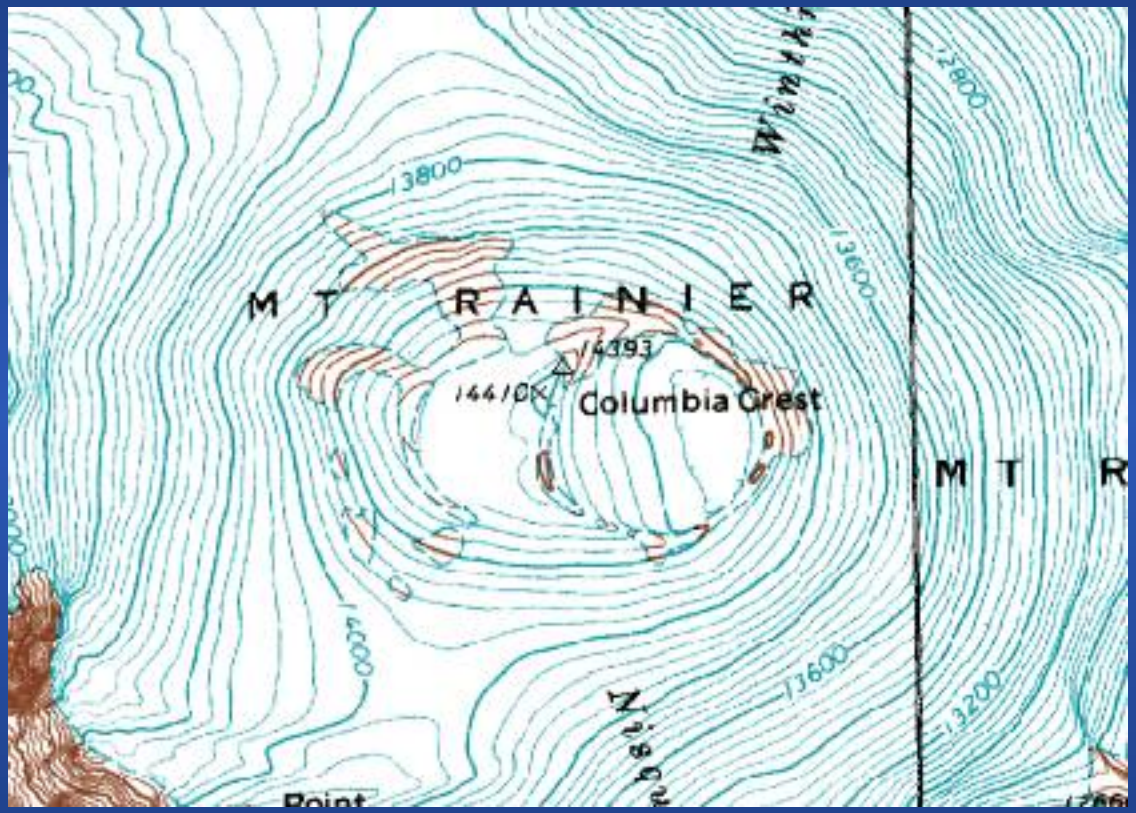
Lensing peaks capture substantial information beyond the power spectrum. Kratochvil et al. PRD 81, 043519 (2010)

Low peaks contain much of the information. Origin of low peaks. Yang et al, PRD 84, 043529 (2011)

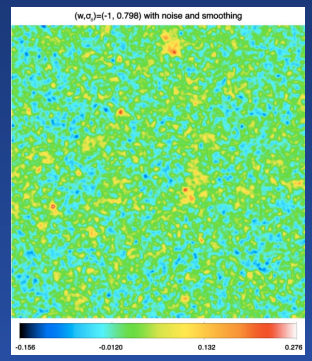
Comparable bias from simple baryon rearrangement model to lensing power spectrum. In a simple model, baryon cooling has very little effect on cosmological constraints from low peaks. X. Yang et al., Phys. Rev. D 87 023511(2013).

Constraining power retained in presence of realistic galaxy shape errors. D. Bard et al., Astrophysical Journal ApJ, 774, 49 (2013).

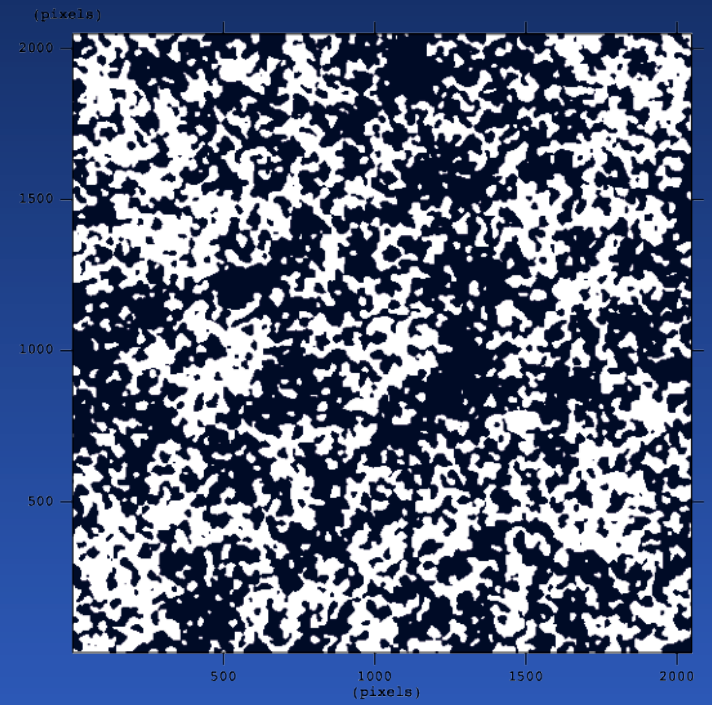
Other ways to characterize a 2D map



Map above a threshold

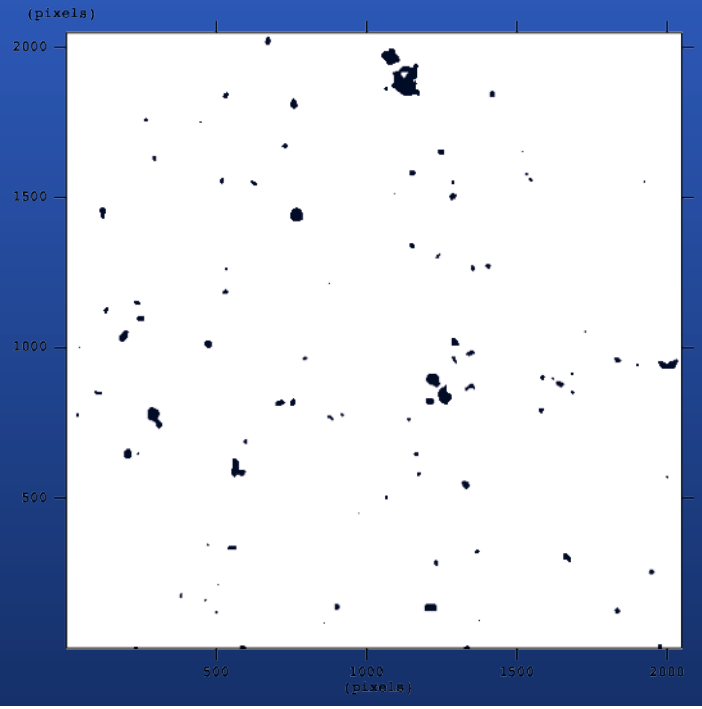


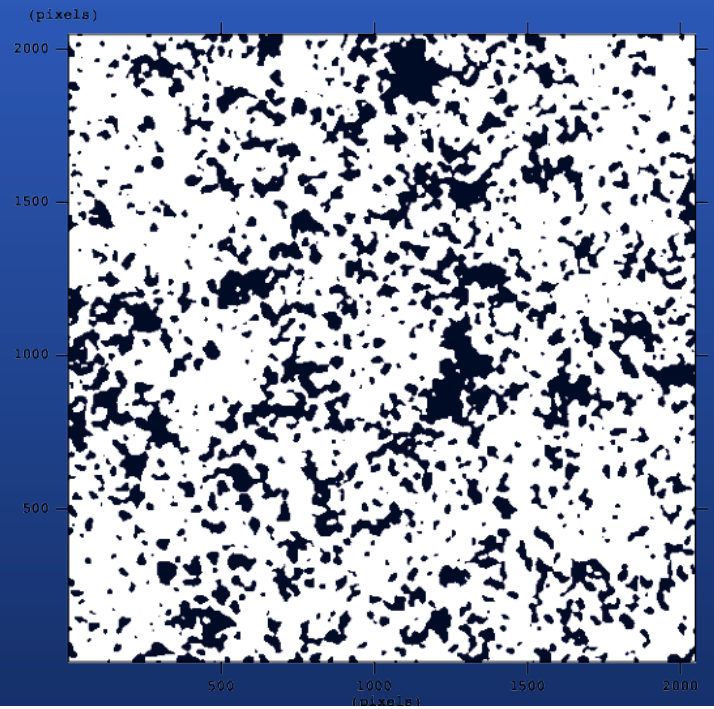
$\nu = 0$



$\nu = 0.025$

$\nu = 0.1$





Area, boundary length, genus

- V0: Area above threshold
- V1: Boundary length
- V2: Topology: genus=number of disconnected regions minus number of holes in them →peak counts for high threshold
- Minkowski functionals invariant under coordinate transformation, additive

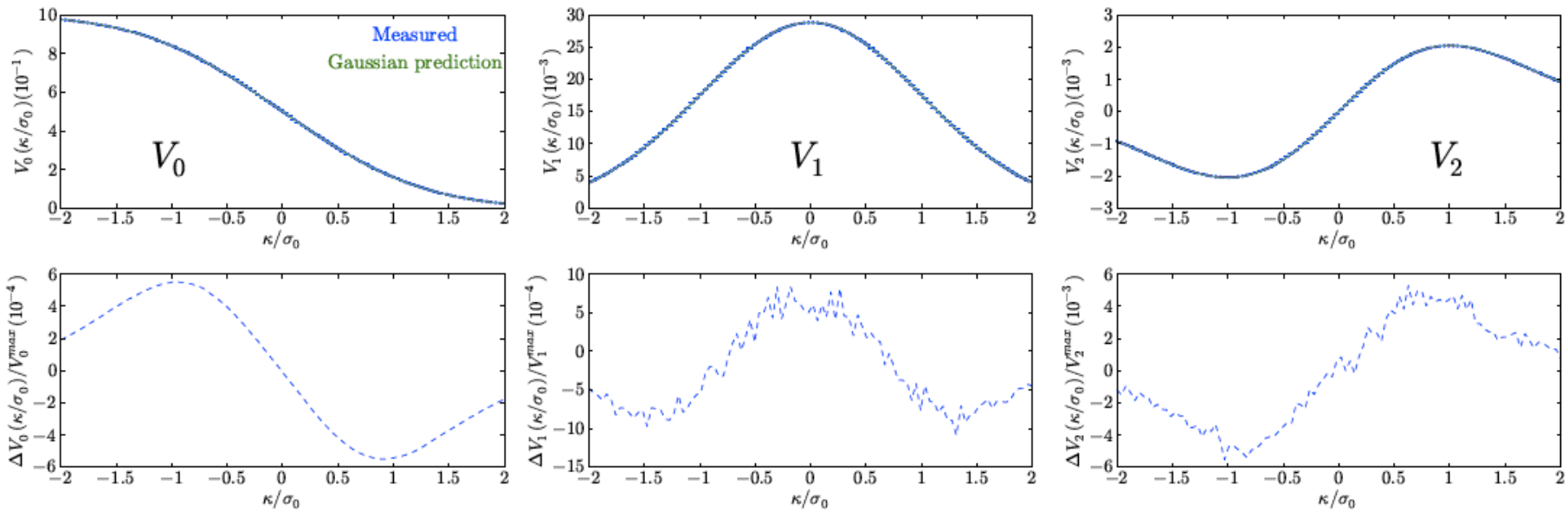
Minkowski functionals, moments

Probing cosmology with weak lensing Minkowski functionals, Kratochvil et al., Phys. Rev. D 85, 103513 (2012).

Cosmology with Minkowski functionals and moments of the weak lensing convergence field, Andrea Petri et al. http://arxiv.org/abs/1309.4460, accepted for publication in Phys. Rev. D.

- Moments are another way to characterize the map
- Minkowski functionals can be expressed as a series expansion in powers of the variance σ_0 with moments and moments of derivatives as coefficients. Useful for CMB. Are moments and MFs equivalent for lensing maps?

$$O(\sigma_0) \rightarrow \langle \kappa^3 \rangle, \langle \kappa^2 \nabla^2 \kappa \rangle, \ldots$$
$$O(\sigma_0^2) \rightarrow \langle \kappa^4 \rangle_c, \langle \kappa^2 |\nabla \kappa|^2 \rangle_c, \ldots$$



Comparison between the Minkowski functionals measured numerically on simulated Gaussian maps, and the analytical predictions

Cosmological constraints

Observable mean and covariance from simulations
1000 realizations of fiducial cosmology

$$\langle O_i \rangle = \frac{1}{R} \sum_{r=1}^{R} O_i^r$$

$$C_{ij} = \frac{1}{R-1} \sum_{r=1}^{R} (O_i^r - \langle O_i \rangle)(O_j^r - \langle O_j \rangle)$$

Derivatives from simulations in alternate cosmologies; linear dependence assumed

$$O_i(p) = \langle O_i(p^0) \rangle + X_{i\alpha} \delta p_\alpha$$

$$X_{i\alpha} = \partial \langle O_i \rangle / \partial p_\alpha$$

Cosmological Constraints

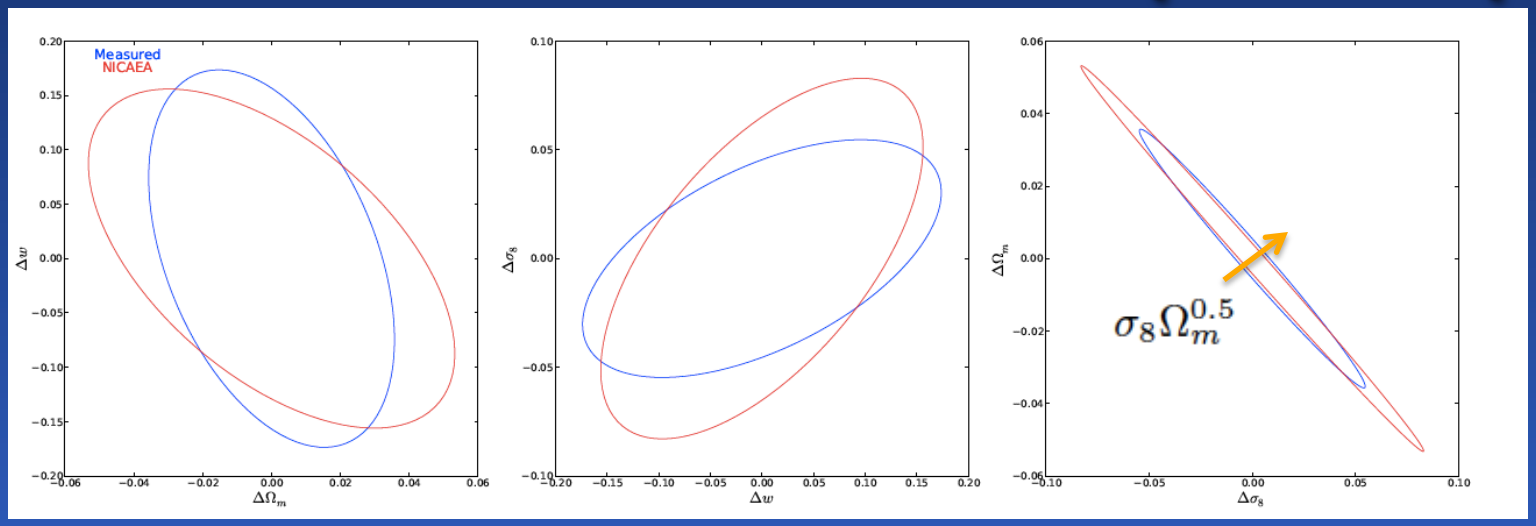
χ^2 minimization to determine implied cosmological parameters and parameter covariance

$$\chi_r^2(p) = [O_i^r - O_i(p)]C_{ij}^{-1}(p^0)[O_j^r - O_j(p)]$$

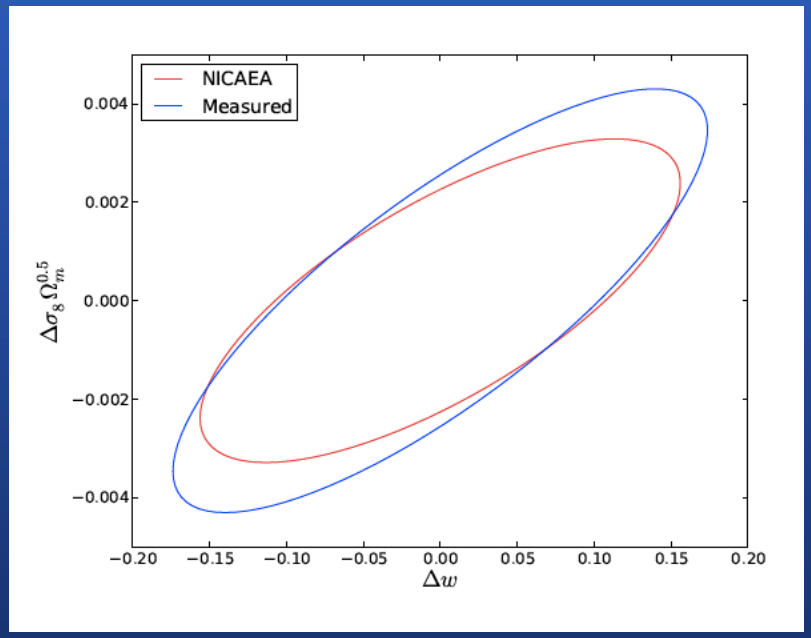
From map set A

From map set B

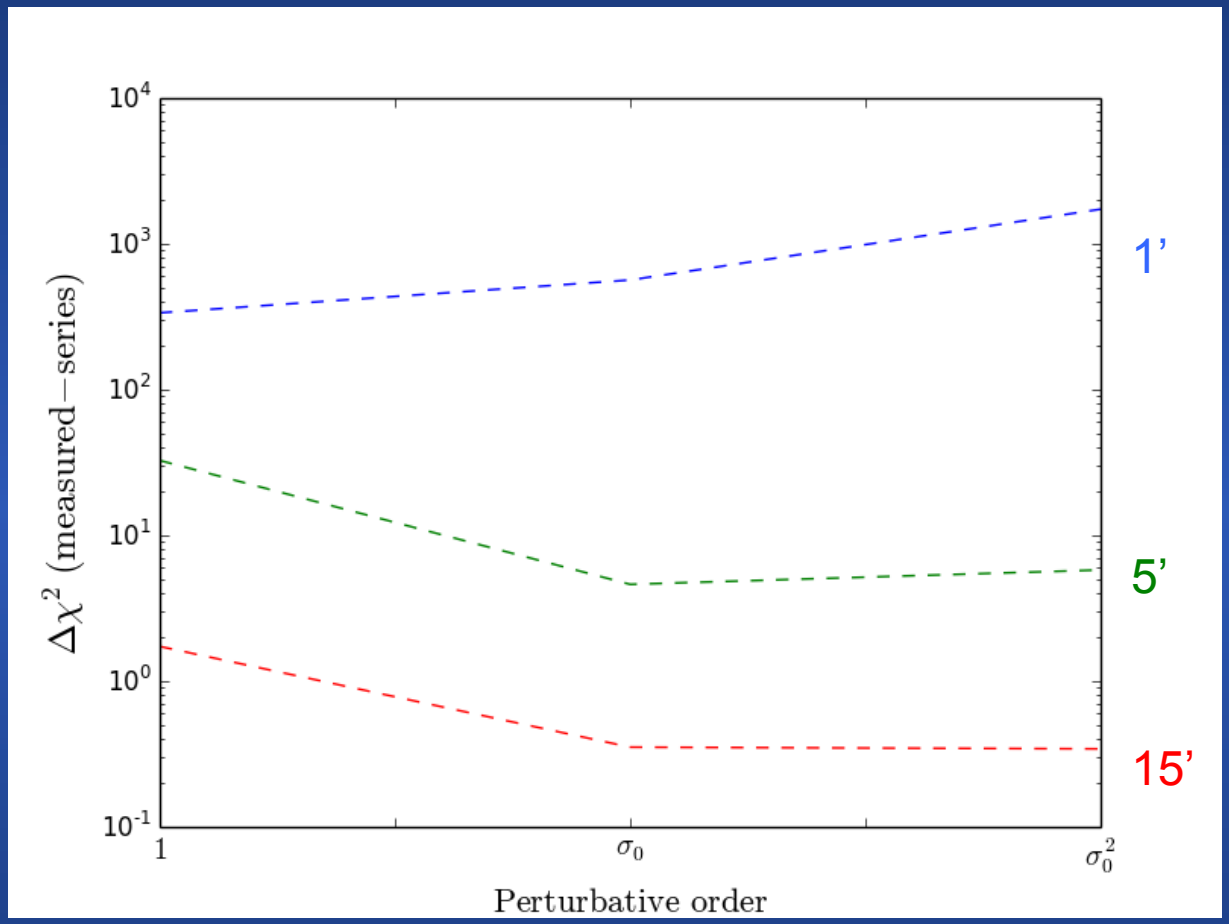
Can check constraints for power spectrum



Compare lensing power spectrum
Constraints from simulations computed with the public code NICAEA

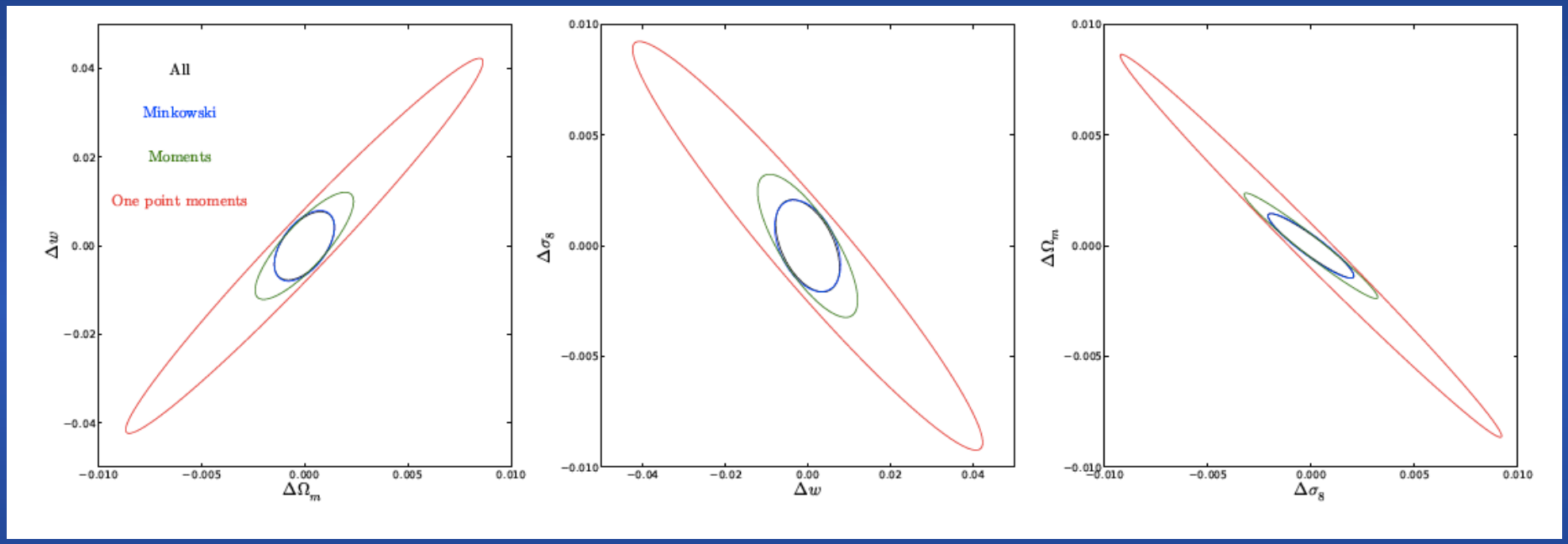


MFs equivalent to moments?



$$\Delta\chi^2(\theta_G = 1') \approx 6000$$
$$\Delta\chi^2(\theta_G = 15') \approx 0.01$$

MFs, moments: Constraints



15 galaxies/sq arcmin z=2

Conclusions on moments

- 1. Expansion of Minkowski functionals in terms of moments and moments of derivatives which converges for the CMB temperature field, doesn't converge for the lensing map.
- 2. Moments of the convergence field and its derivatives contain cosmological information beyond the power spectrum resulting in >50% tighter limits on w.
- 3. Adding variance of the gradient to variance, skewness, kurtosis of kappa gives most of the constraining power.
- 4. Though this is a subset of the information, it is contained in only 4 parameters.

Plan

- Run simulations with better sampling of parameter space, more realizations to improve accuracy and checks.
- Work with realistic galaxy distribution rather than few z planes. Better mimic data analysis of surveys and consider sensitivity to systematic errors, and to baryon effects.
- Which statistics will tighten constraints without introducing bias?