Cosmology with the Shear-Peak Statistics

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with friendly support from
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Evolution of cluster mass function is cosmological probe.

A number of papers (e.g., Takada & Bridle 2007) showed that cluster cosmology and cosmic shear are complementary probes for dark energy.
Weak Lensing Searches

- Weak lensing searches will always be incomplete, except at the highest masses (Hamana et al. 2004).
- Weak lensing searches will always have false positives from projections of LSS. These projections occur with all significances.

Dietrich et al. (2007)
The Peak Statistics

- At low SNR false positives are mainly caused by shape noise; at high SNR peaks are due to projections of large-scale structure.
- The weak lensing peaks caused by LSS are false positives only if one searches for galaxy clusters.
- LSS peaks caused by real mass along the line of sight.
- LSS peaks caused by real structure, part of the power spectrum.
- LSS peaks contain cosmological information.

Problem: Filaments and sheets are not collapsed structures. How do we predict the number of peaks as a function of cosmology?
M–N-body simulations

Make many N-body simulations for various cosmological parameters and raytrace through them.

- 200 N-body simulations in the $\Omega_m - \sigma_8$ plane.
- 166 different cosmologies ($\Omega = 1$).
- 35 simulations at the fiducial cosmology (0.27, 0.78).
- Each simulation: $256^3$ particles, 200 Mpc box (like GIF).
- Big enough to give $10^{15} \, M_\odot$ halos.

From each simulation: five $6 \times 6 \, \text{deg}^2$ fields. CFHTLS like survey.
Why $\Omega_m$, $\sigma_8$ and not Dark Energy?

Hetterscheidt et al. 2007

Hetterscheidt et al. 2007
Peak Finder

How we find peaks:

- Aperture mass, $M_{\text{ap}}$, with various SNR cuts. Filter follows NFW profile tuned to $6 \times 10^{14} \, M_\odot$ cluster at $z = 0.3$.

Constraints from $M_{ap}$ Peaks

- Popular attempt to get only galaxy clusters: $\sigma(M_{ap}) > 6$.
- Use $\sigma$ as mass proxy.
- $N(\sigma)$ starting from $\sigma = 6.0$, steps of $0.5\sigma$.
- How much information is in the lower SNR peaks?
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Constraints from Tomographic Peaks

- $N(z)$ with 10 bins from $z = 0.1 \ldots 1.0$. All peaks above detection threshold counted.
- $N(\sigma)$ also works.
- Ideally, we would use $N(z, \sigma)$, but not enough simulations at fiducial cosmology.
- Maybe some linear combination of $N(z)$ and $N(\sigma)$? Work in progress (PCA).
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Peak Statistics and Cosmic Shear

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- $\xi_{+/-}$ with 10 bins each.
- The “bananas” are slightly inclined.

![Graph showing constraints on $\sigma_8$ vs. $\Omega_m$]
Peak Statistics and Cosmic Shear

- Does the peak statistics probe something other than cosmic shear?
- $\xi_{+/-}$ with 10 bins each.
- The “bananas” are slightly inclined.
- The combination of cosmic shear and peak statistics gives stronger constraints.

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$\sigma_8$ vs $\Omega_m$

$\sigma_8 = 0.81^{+0.17}_{-0.15}$

$\Omega_m = 0.28^{+0.10}_{-0.07}$
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Shear tomography with 2 redshift bins ($z < 0.6$ and $z > 0.6$).

The cosmic shear banana tilts into the peak banana.
How about the combination of peak tomography and shear tomography?

Shear tomography with 2 redshift bins ($z < 0.6$ and $z > 0.6$).

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The combination of both statistics gives only marginally improved constraints.

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30,000 element Markov chain needs 2,500,000 CPUh. Normal programs: 1,000,000 CPUh. Large programs: >2,000,000 CPUh. Pressure factor on HPC \(\sim\) 1. Ideal for grid computing.
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- Use pure PM code instead of TreePm
- Raytracing is I/O limited. Could be done in memory (if you have 32 GB).

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Conclusions

- Peak statistics can constrain $\Omega_m$, $\sigma_8$ with projected peaks containing cosmological information.
- Peak tomography does much better than $M_{\text{ap}}$.
- Peak tomography can partially break the $\Omega_m$, $\sigma_8$ degeneracy of cosmic shear but adds little additional information to shear tomography.
- Modeling current surveys with N-body simulations is challenging but not entirely unrealistic.

Open issues

- Influence of the redshift distribution. The one used here is a bit weird, few projections.
- Maybe a combination of $N(z)$ and $N(\sigma)$ works better?
- How does the peak statistics perform for dark energy?