Weak Gravitational Lensing
Tables Rondes

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Weak-lensing tables rondes

Topic A: B-modes from varying z?

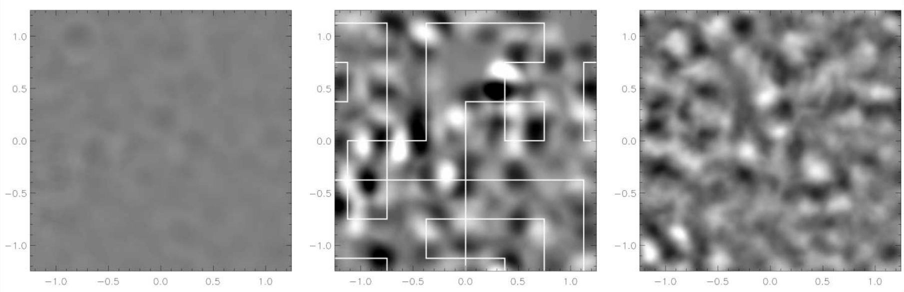
Topic B: Fisher matrix fit with `CosmoSIS`

Topic C: Peak counts and shear bias with `camelus`

Topic A: B-modes from varying z?

B-modes from varying z?

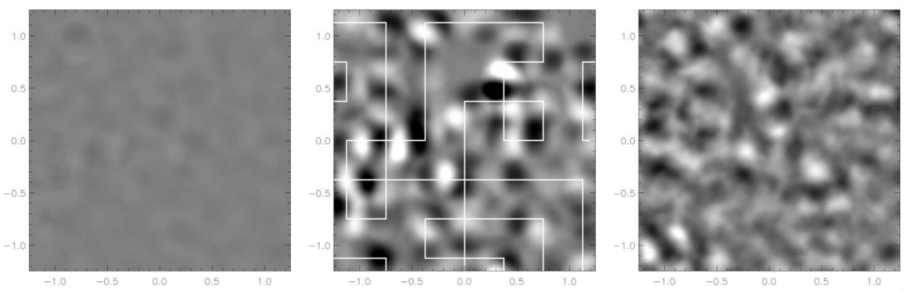
A claim was made in (Vale et al. 2004) that modulations in source redshift creates B-modes.



B-mode from aperture mass at 15 arcmin. *Left:* No modulation; *Middle:* 10% seeing modulations; *Right:* 10% depth modulation.

B-modes from varying z?

A claim was made in (Vale et al. 2004) that modulations in source redshift creates B-modes.



B-mode from aperture mass at 15 arcmin. *Left:* No modulation; *Middle:* 10% seeing modulations; *Right:* 10% depth modulation.

I believe that this claim is wrong.

Why do I have doubts about this claim?

Shear field at different depth still stays E-mode field.

Possible resons for the observed B-mode in (Vale et al. 2004):

- Artifact of the simulation. E.g. discontinuity in shear field.
- Artifact of measurement. E.g. problems with pixelisation, aperture-mass estimator.
- Increased noise.

Possible aspects of study

Even if it is true, this is worth studying in more detail:

- Euclid will face problem of varying depth due to different quality photo-z's from inhomogeneous ground-based data.
- Appearing B-mode means it is leaked from E-mode, so change in cosmological weak-lensing signal. Important to quantify potential systematic.
- There is also information in the B-mode, e.g. induced by intrinsic alignment, higher-order effects, which might be exploited. Important to quantify systematic B-mode.
- We can study ways to reduce this B-mode. Smooth data across varying z-regions? Use different aperture-mass estimator (integral over 2PCF, or other)?
- The authors did a purely numerical study. Worth to check analytically if possible.

A related analytical approach has been developed in (Guzik & Bernstein 2005).

Add systematics field ε to shear field:

$$\boldsymbol{d}(\boldsymbol{\theta}) = (1 + \epsilon(\boldsymbol{\theta}))\, \boldsymbol{\gamma}(\boldsymbol{\theta})$$

If uncorrelated to shear, results in separated correlation function:

$$\begin{aligned} \xi^d(\theta) &\equiv \langle \boldsymbol{d}(\boldsymbol{\phi})\, \boldsymbol{d}(\boldsymbol{\phi} + \boldsymbol{\theta}) \rangle \\ &= (1 + \langle \epsilon(\boldsymbol{\phi})\, \epsilon(\boldsymbol{\phi} + \boldsymbol{\theta}) \rangle)\ \langle \boldsymbol{\gamma}(\boldsymbol{\phi})\, \boldsymbol{\gamma}(\boldsymbol{\phi} + \boldsymbol{\theta}) \rangle \\ &= (1 + \xi^\epsilon(\theta))\ \xi^\gamma(\theta). \end{aligned}$$

This can produce a residual B-mode power spectrum:

$$\Delta P^\epsilon_{E,B}(l) = \pi \int_0^\infty d\theta \theta \xi^\epsilon(\theta) \left[\xi^\gamma_+(\theta) J_0(l\theta) \pm \xi^\gamma_-(\theta) J_4(l\theta) \right]$$

GB05 consider as one of their cases a systematic signal constant in circular patches (e.g. calibration error dependent on pointing), and find B-modes. Is this the correct description of varying depth?

Tasks

A. Numerical study, redo (Vale et al. 2004) analysis.

1. Download (N-body +) ray-tracing/ray-shooting simulations. Need positions x, y, shear γ (and/or convergence κ) and redshift z.
2. Produce E-/B-mode estimates: Compute the 2PCF, e.g. with `athena`, and $\langle M_{\mathrm{ap},\times}^2 \rangle$ with `pallas.py`. Make sure there are no intrinsic significant B-modes.
3. Introduce redshift variations: Select galaxies at different z in patches. Redo step A.2, see whether B-modes are introduced.

B. Analytical study.

1. Use the (Guzik & Bernstein 2005) or a different approach to model redshift variations over a field.
2. Compute the expected B-mode signal to see whether or not it is zero.

C. Advanced studies.

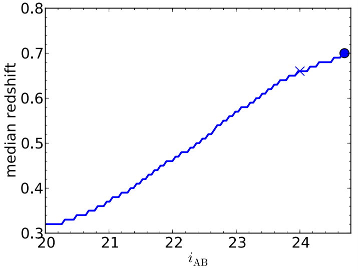
- Use realistic redshift variations on a large (Euclid-like?) field.
- Study other systematic effects, seeing variations, shear calibration, environment biases that correlated with density, ...

Simulations to download

- Log-normal simulations, B. Joachimi, 08/2013, 25 fields, one z-bin, with masks, used for code testing and validation in OU-LE3.
  `www.astro.uni-bonn.de/~reiko/le3sim/simpublic/euclid_le3_versim_v1.3.tar.gz`
- Log-normal simulations, B. Joachimi, 04/2016, 1 field, two z-bins, with masks, used for code testing and validation in OU-LE3.
  Get link from `http://www.cosmostat.org/ecole17`
- MICE v2.0 simulation, $5,000$ deg^2, some issues with the lensing signal, fixed?
  `https://cosmohub.pic.es/#/catalogs/1` (login required)
- Euclid Flagship v1.0 simulation, $5,000$ deg^2, much deeper, to lower halo mass, higher resolution than MICE.
  `https://cosmohub.pic.es/#/catalogs/53` (login required)

Simulating varying redshift

You can use the following relation between limiting magnitude and median redshift, for a realistic simulation of varying z given ground-based survey specifications on limiting magnitude.



From (Duncan et al. 2014).

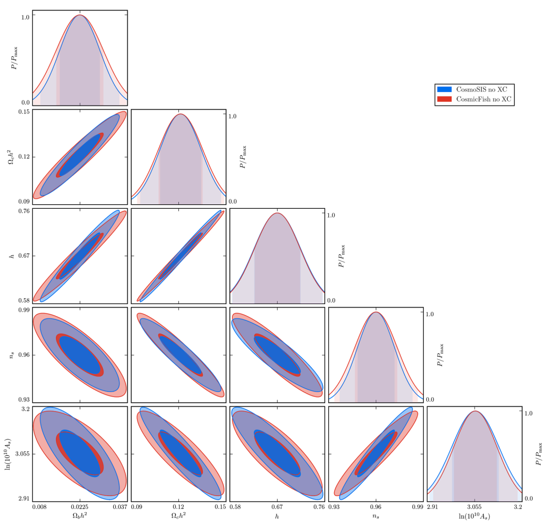
Topic B: Fisher matrix fit with CosmoSIS

The Fisher matrix: use

The Fisher matrix is an extremely useful tool in cosmology, see Elena Sellentin's lectures.

It allows very fast estimation of (cosmological) parameter errors for given observables and their errors (covariance), even in high dimensions.

This is routinely used to forecast the performance of planned surveys.



The Fisher matrix: definition

The Fisher matrix is an approximation of the likelihood function that circumvents the need of Monte-Carlo sampling.

Instead of tens of thousands of evaluation of the likelihood, only a few 10 or so evaluations of the likelihood or related functions are required.

It is defined as the matrix of second derivatives of the log-likelihood,

$$F_{\alpha\beta} = \left\langle \frac{\partial^2[-\ln L]}{\partial\theta_\alpha \partial\theta_\beta} \right\rangle .$$

The Cramér-Rao bound indicates then the lower bound on the variance σ_α^2 of parameter p_α, with

$$\sigma_\alpha = \sqrt{(F^{-1})_{\alpha\alpha}}.$$

The Fisher matrix: in practice I

Weak lensing

For example, the Fisher matrix for the weak-lensing power spectrum can be written as

$$F_{\alpha\beta} = \sum_{\ell} \sum_{pq} \frac{\partial P_p(\ell)}{\partial \theta_\alpha} (\mathbf{C}^{-1})_{pq}(\ell) \frac{\partial P_q(\ell)}{\partial \theta_\beta},$$

where the indices p, q denote redshift bin combinations, $p, q = 1 \ldots n_z(n_z + 1)/2$, and P_p is the tomographic weak-lensing power spectrum.

Practical difficulties with the Fisher matrix

Computing numerical derivations can be problematic, since often a very high precision is required. Which is the case for the Fisher matrix, where small errors in the derivatives propagate in a non-linear way to the parameter constraints due to the non-linear process of matrix inversion.

Such errors can be introduced by interpolation of cosmological quantities for speed-up, insufficient accuracy of numerical integration, too large discretisation steps etc.

The Fisher matrix: in practice II

Codes that compute theoretical models for Monte-Carlo sampling do not need to be as accurate as Fisher-matrix codes (Wolz et al. 2012).

Often the Fisher matrix changes substantially with small algorithmic changes, for example

- step size h of the numerical derivatives
- number of points n that are used (n-point stencil).

In addition the Fisher matrix is often ill conditioned in the presence of parameter degeneracies, or badly constrained parameters. Inversion is then tricky; often a prior is added to "regularize" the Fisher matrix.

An alternative method to compute the Fisher matrix?

Instead of relying on derivatives, how about the following idea:

Around the maximum-likelihood (or posterior) point in parameter space $\boldsymbol{p}_0$, the likelihood for n points are computed, and a quadratic function is fitted to those points.

This quadratic form is then an estimate of the Fisher matrix.

This circumvents the necessity for numerical derivatives.
Questions:

- How many points are required? Does this number scale linearly with the dimension?
- How do we choose the step size? Adaptive if possible.
- Should the steps only vary one direction at a time, or be a combination of parameters?
- How does the precision of this approach compare to the traditional Fisher matrix?

Tasks

A. Implementation

Implement this alternative Fisher matrix estimator in `CosmoSIS`.

Implementation of likelihood evaluation around fiducial point, fitting, convergence testing.

B. Comparison

Compare with the traditional Fisher matrix, that is already part of `CosmoSIS`. Play around with parameters, number of points, different probes, cosmological parameter, ...

C. Further studies

This could also be implemented in `nicaea`, or `MontePython`, which computes directly the derivative of the likelihood for the Fisher matrix.

(From my obscure notes from recent IST Euclid meeting in Heidelberg): Eric Linder mentioned minuit minimizer and quadratic interpolation, see `https://pypwa.jlab.org/mntutorial.pdf`.

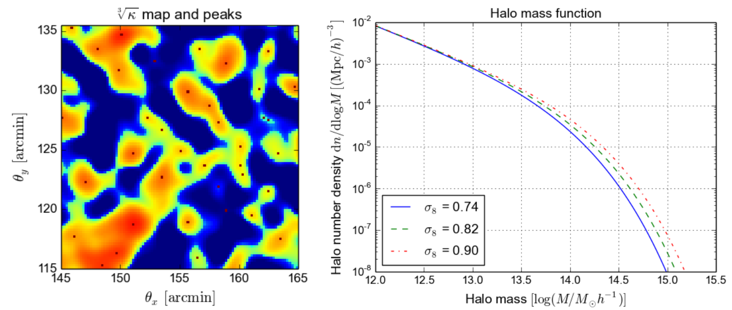
Topic C: Peak counts and shear bias with `camelus`

Peak counts and shear calibration

In the lecture we will discuss the multiplicative shear bias m,

$$\langle \varepsilon_i^{\rm obs} \rangle = \gamma_i^{\rm obs} = (1 + m_i)\gamma_i^{\rm true} + c_i; \quad i = 1, 2.$$

This bias can depend on the environment of galaxies.
In particular, it depends on the local density of galaxies. Galaxies trace dark matter, which produces the weak-lensing signal. Thus, a density-dependent bias will be correlated with the lensing signal.
This might be particularly important for weak-lensing peaks, which trace regions of very high density.



The problem

This cannot easily be simulated and then calibrated, for example with simple galaxy image simulations.

The correlation with the local desity means that the cosmological signal needs to be simulated as well.

This typically is an N-body simulation.

However, at least for a simple WL peak model (see lecture Part I day 3 [3/6]), this step can be replace by simple, fast simulations, implented in `camelus` (Lin & Kilbinger 2015).

Tasks I

A. Run the C-code `camelus`

Download from `https://github.com/Linc-tw/camelus`.

Perform a few test runs and familiarize with the produced output.

B. Model and test density-dependent m

1. Simple model
   For the galaxies simulated by `camelus`, estimate local density δ (e.g. count in cells), and apply $m(\delta)$ with some fonctional dependence. See for example (Hoekstra et al. 2016).
2. More realistic model
   The galaxies should follow (trace) the halo distribution, this is not yet implemented in `camelus`.

   Relatively easy: Produce WL map with random galaxies from first run of `camelus`, re-distribute galaxies according to 2D density, re-run camelus using this new distribution, and some model $m(\delta)$.

   Even better, the galaxies should follow the halo distribution in 3D. This can be implemented by modifying the code, but might be quite involved.

Tasks II

C. Quantify influence of m

In all of the above cases: Produce WL peak histograms with and without density-dependent m, compare using Euclid-like survey setting (area, depth, etc.).
Compare these changes to the sensitivity of peak histograms from dark-energy.
From this, actual requirements on $m(\delta)$ for WL peak counts could be derived.

D. Advanced studies

Parametrize $m(\delta)$, add as sampling parameters to `camelus`.
Perform joined analysis of cosmology and $m(\delta)$.
Detailed analysis of influence of m on cosmological parameters, including correlations and degeneracies.

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