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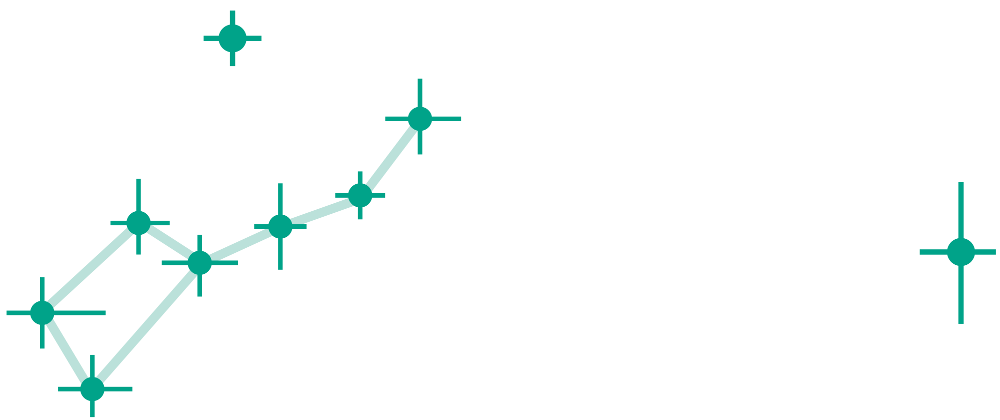
Bayesian Analysis of Weak Lensing on the Largest Scales

Alan Heavens

with Justin Alsing, Andrew Jaffe, Alina Kiessling, Ben Wandelt & Till Hoffmann



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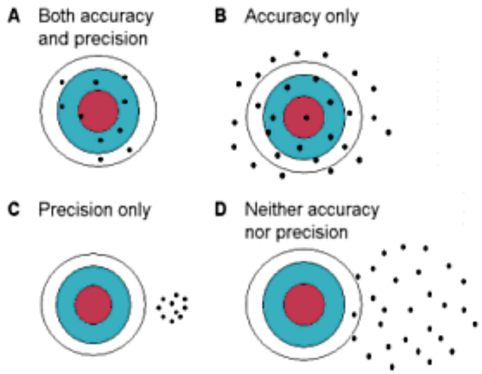
Gravity at the Largest Scales
IWH Heidelberg 26-28 Oct 2015

The opportunities and risks of surveys to test gravity

- Surveys such as Euclid and LSST will test the gravity law with exquisite *precision* (small error bars)
- Why should we be careful?
- *Inaccurate* results may be interpreted as new physics, when they should not be
- Incorrect analysis may lead to inaccuracies



B.Hargreaves

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The goal of scientific inference

- *Bayesian inference:* given some new data, the posterior probability (of model parameters) encompasses all we know
- P(Parameters | Data, Model, Prior Information)*
- Complicated function - not analytic
- Alternative: *sample* from the posterior (cf MCMC)
- *If we can do it,* there is no reason not to do it this way
- * Also P(Model | Data)

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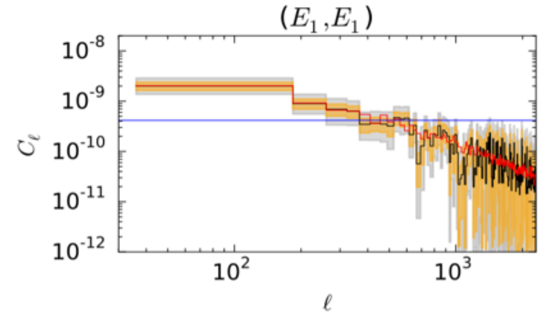
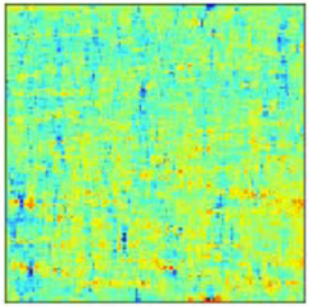
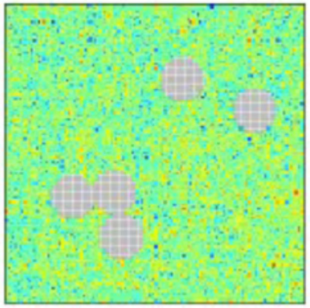
Bayesian Hierarchical Models



- Break the problem into steps:
- Parameters: Let C = (various) power spectra
- **s** = true shear map (many more parameters)
- Data: pixelised shear values **d** = **s** + **n** (noise)
- We typically want p(C|**d**)
- Conditional distributions, e.g. p(**s**|C), are often known





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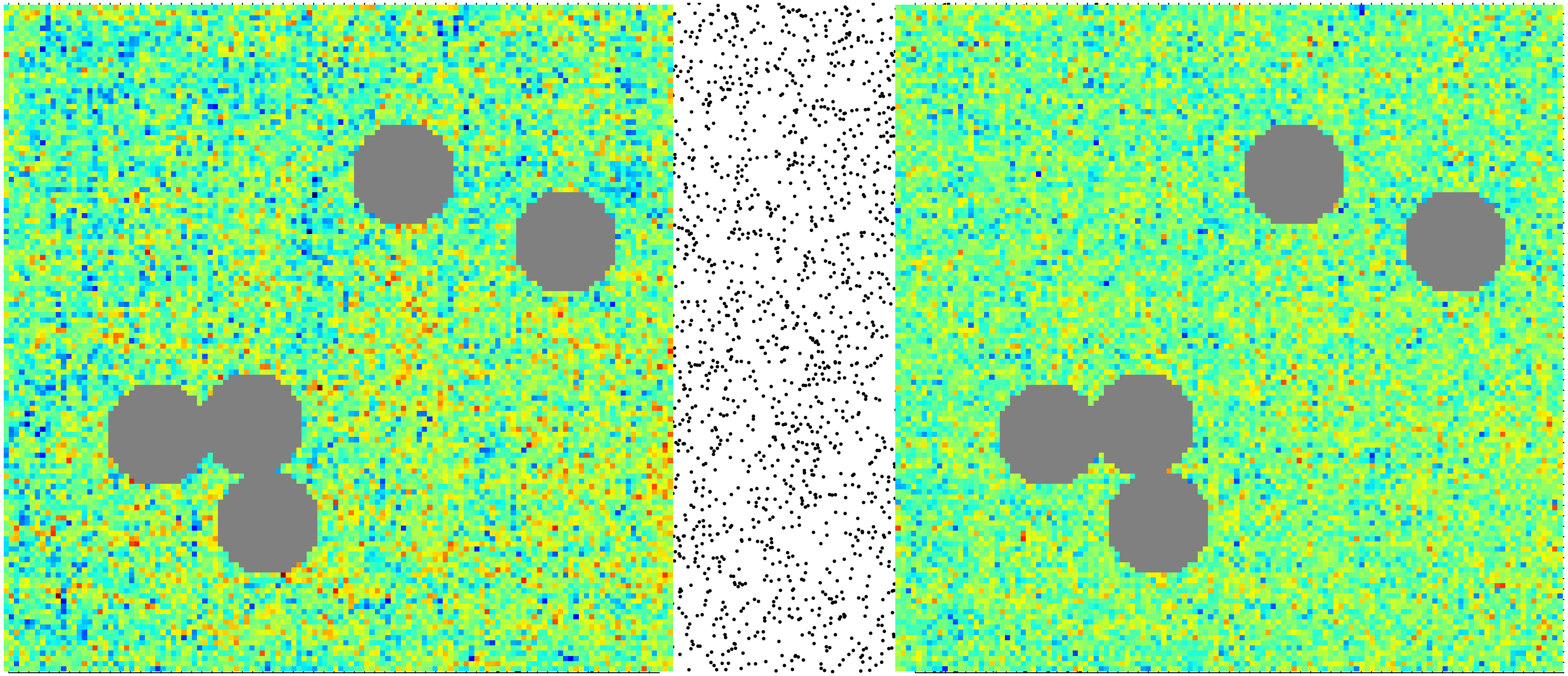

Credit: J. Alsing

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Joint map-power spectrum inference

- Link between **d** and C is the true map **s**
- Natural to sample from C and **s** jointly, conditioned on the data **d**: p(C, **s** | **d**)
- Marginalise over the map(s) **s** to get p(C | **d**)
- Assume gaussian fields for large scales

- How to do this inverse problem?
- Consider the forward model:

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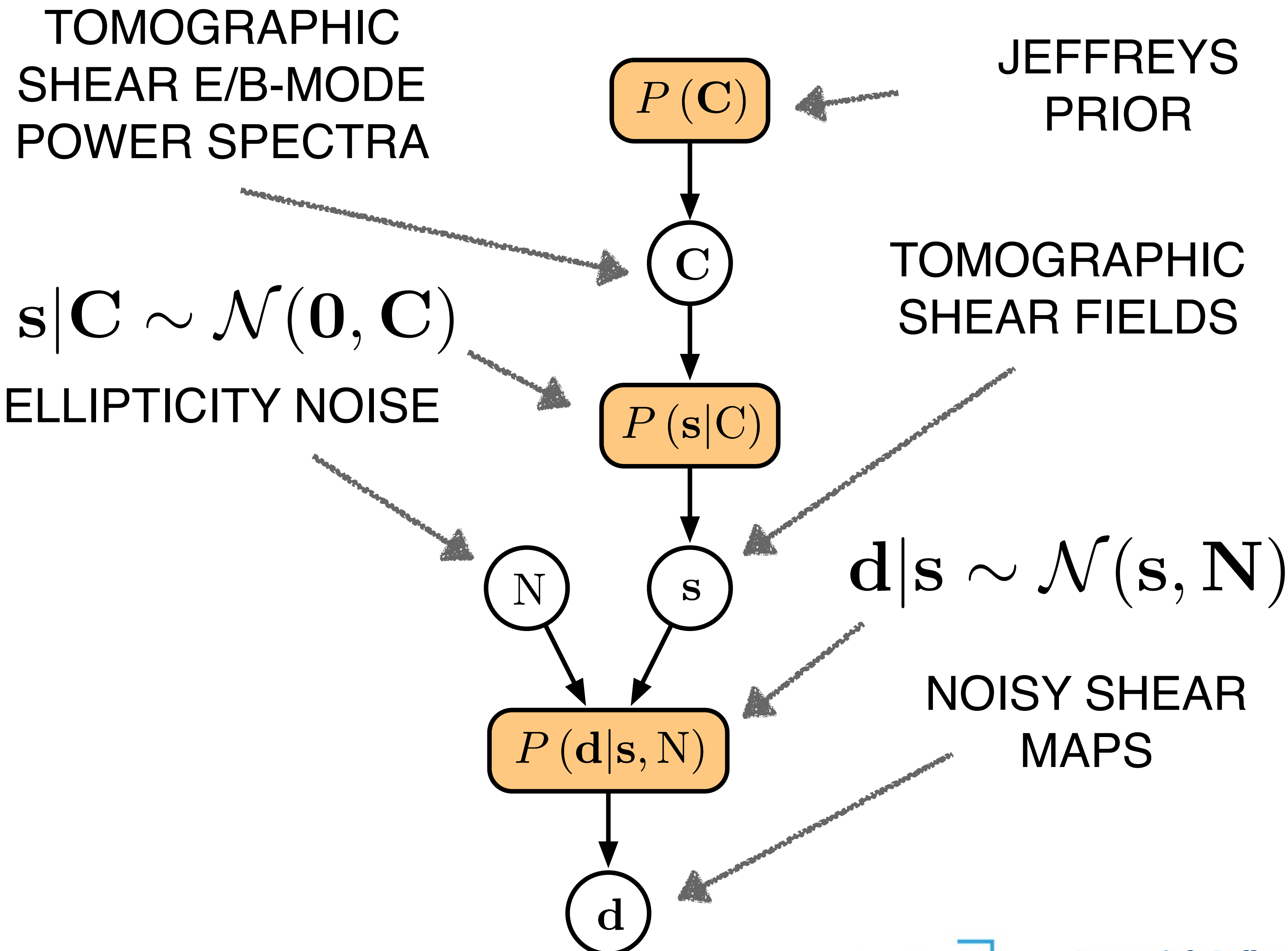

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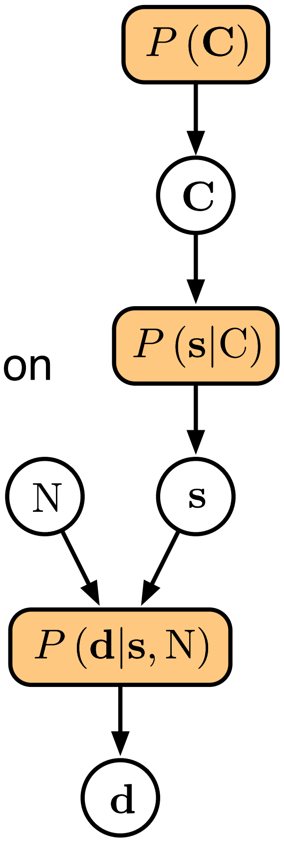
Gibbs Sampling

$$\mathbf{C}^{i+1} \leftarrow P(\mathbf{C}|\mathbf{s}^{i})$$

W^{-1} = Inverse Wishart distribution

$$\mathbf{s}^{i+1} \leftarrow P(\mathbf{s}|\mathbf{C}^{i+1}, \mathbf{N}, \mathbf{d})$$



WF = Wiener Filter:

$$\mathbf{d}_{\mathrm{WF}} = (\mathbf{C}^{-1} + \mathbf{N}^{-1})^{-1}\mathbf{N}^{-1}\mathbf{d}$$

$$\mathbf{C}_{\mathrm{WF}} = (\mathbf{C}^{-1} + \mathbf{N}^{-1})^{-1}$$

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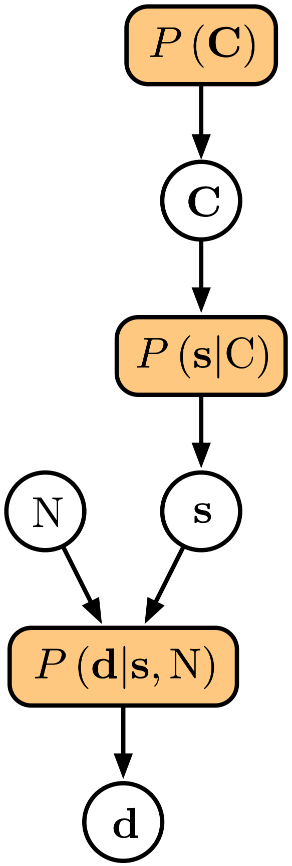
Messenger fields

Elsner & Wandelt 2012, 2013
Jasche & Lavaux 2015



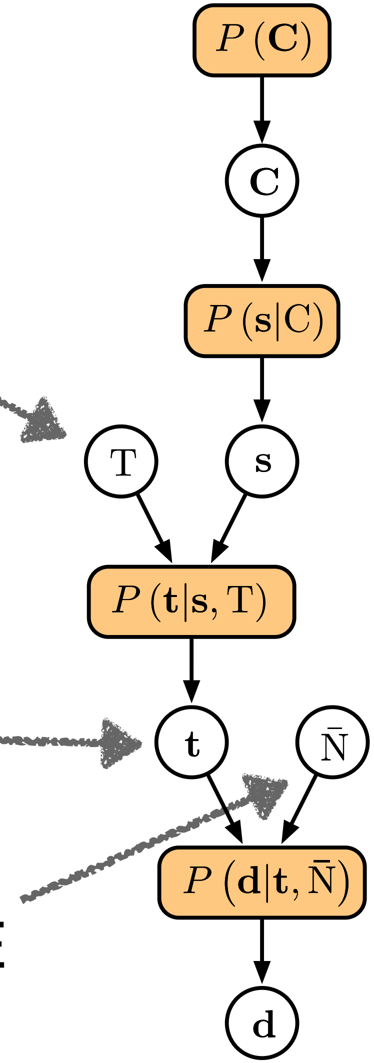
ISOTROPIC NOISE

$$\mathbf{T} = \tau \mathbf{I}$$

MESSENGER FIELD

ANISOTROPIC NOISE

$$\bar{\mathbf{N}} = \mathbf{N} - \mathbf{T}$$



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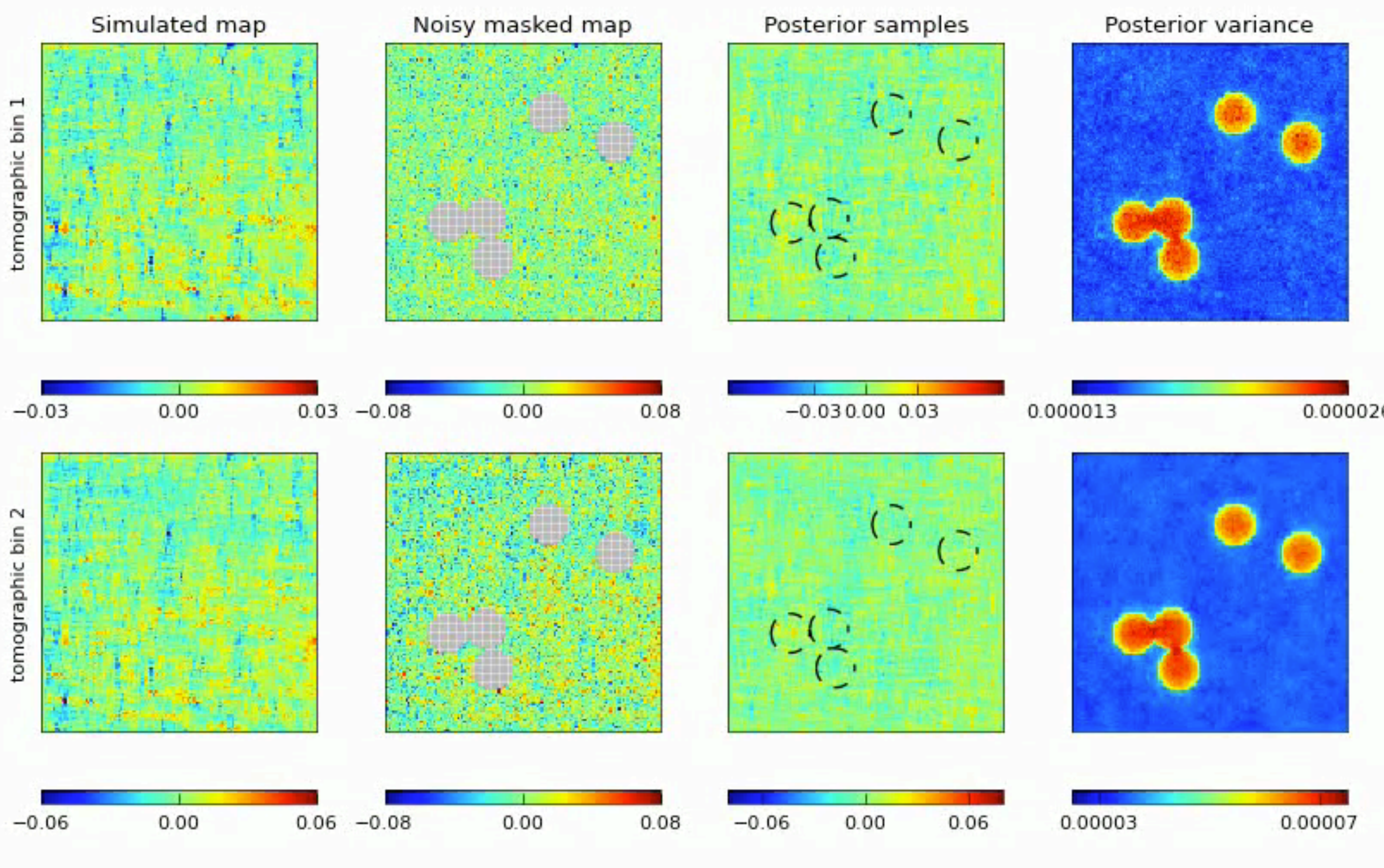

SUNGLASS simulations (Kiessling et al 2011)

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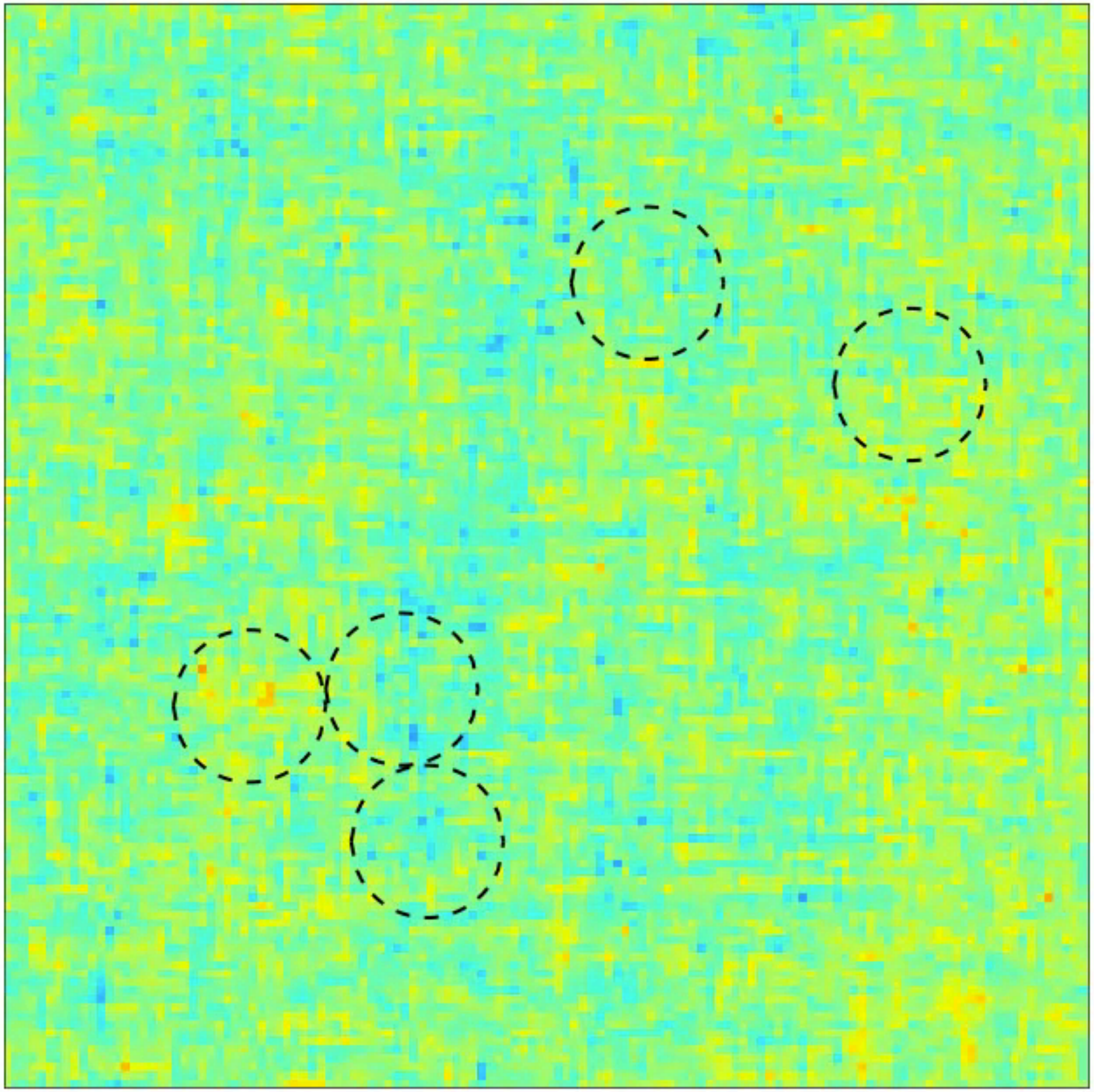

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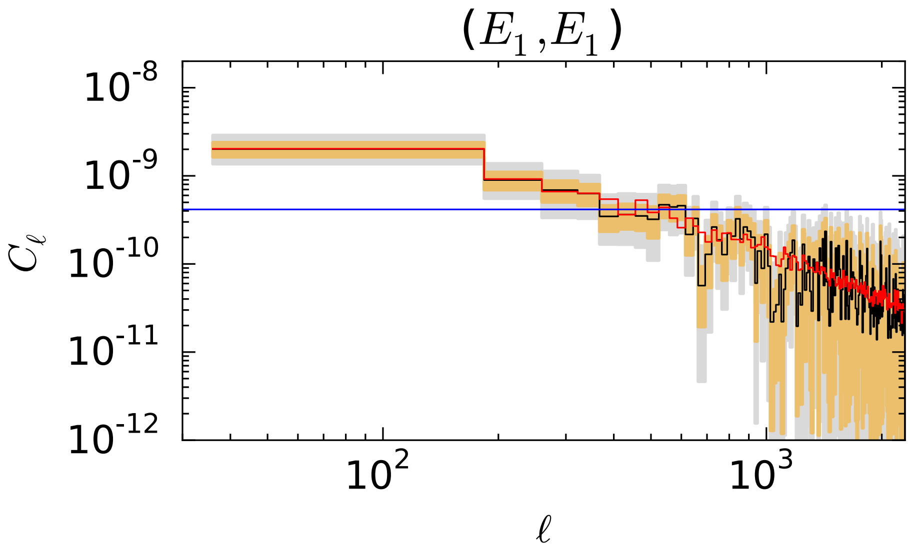

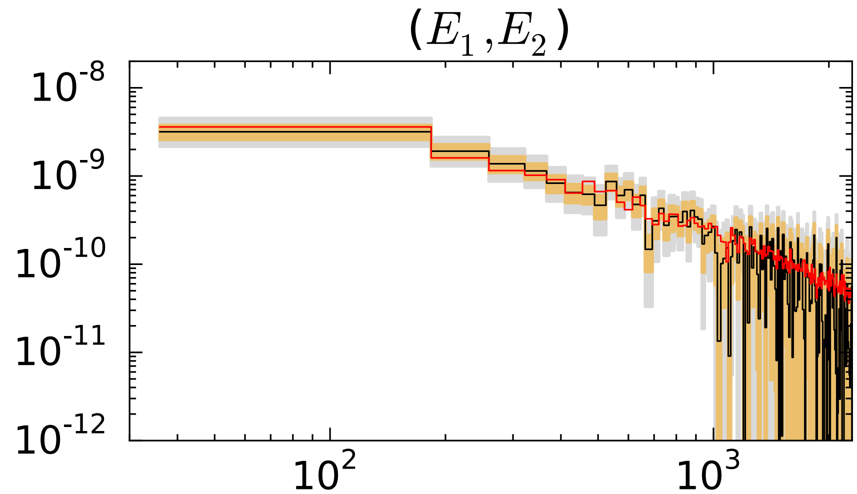

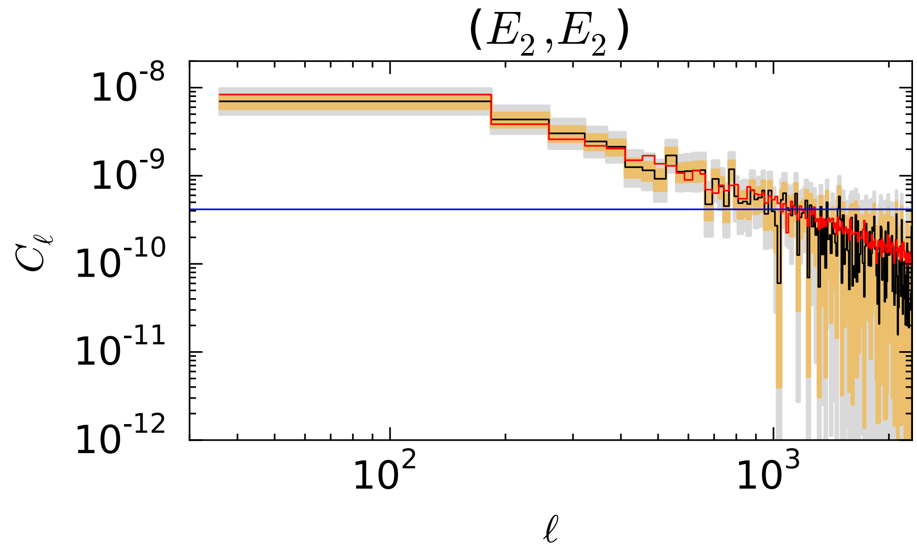

E-modes are recovered, well below the shot noise at high-*l*

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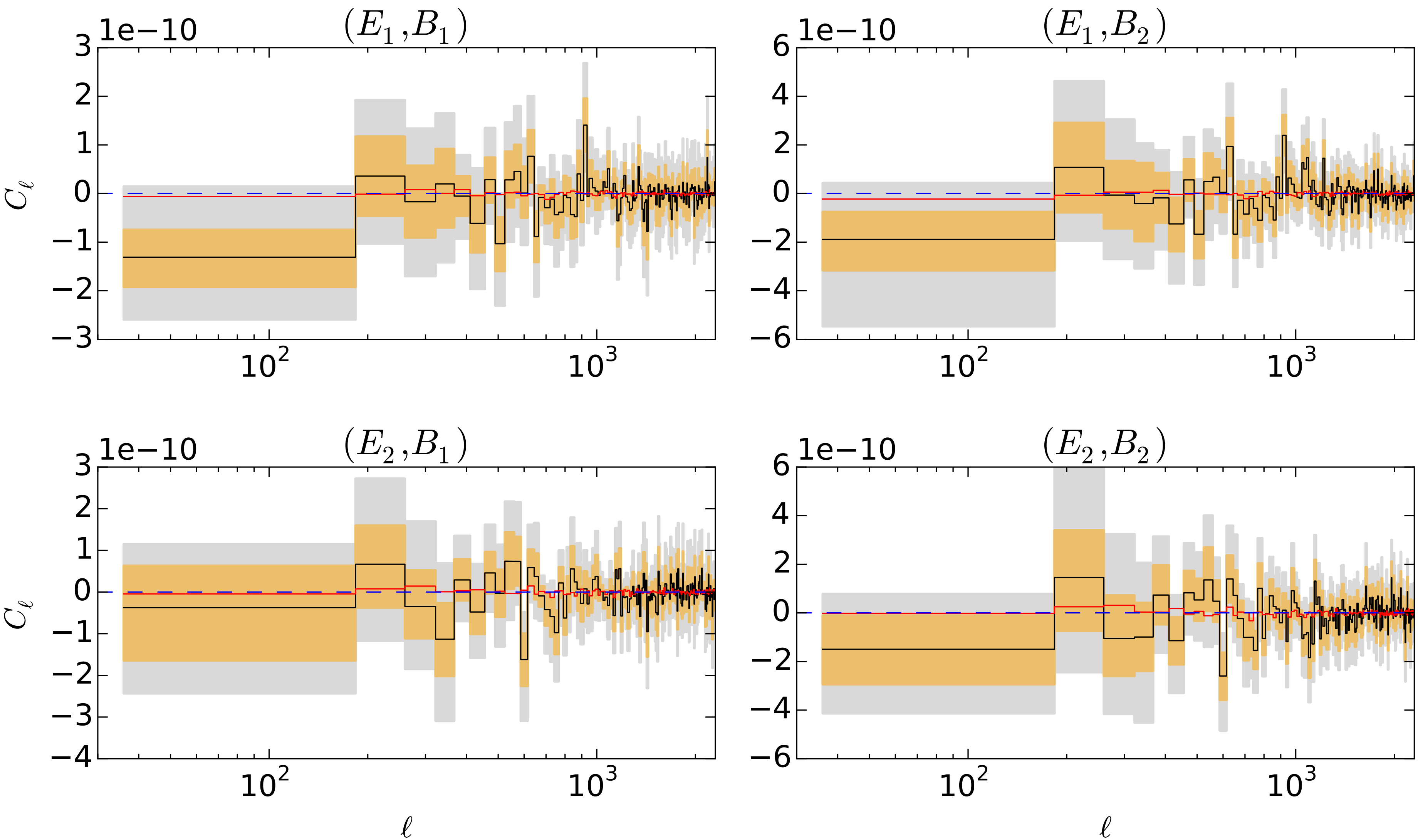

EB cross-power consistent with zero (as expected from parity)

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Cosmology

- Sampling the power spectrum first has advantages:
- Gibbs sampling is efficient (gaussian fields)
- Further cosmological parameter inference is straightforward:

$$\boldsymbol{\theta} \sim P(\boldsymbol{\theta}|\mathbf{d}) = P\left(\mathbf{C}(\boldsymbol{\theta})|\mathbf{d}\right) \frac{P(\boldsymbol{\theta})}{P\left(\mathbf{C}(\boldsymbol{\theta})\right)}$$

- Different theoretical models can be investigated (notably intrinsic alignment contribution)

Feasibility

- 2 bin (128^2 pixels) tomography runs on quad-core desktop, generating ~4 million samples in a few days

$$\text{FFT, SPH} \sim n_{\rm pix}\log(n_{\rm pix}),\quad n_{\rm pix}^{3/2}$$

- 10-bin tomography (Euclid-like survey) is probably feasible now with supercomputers

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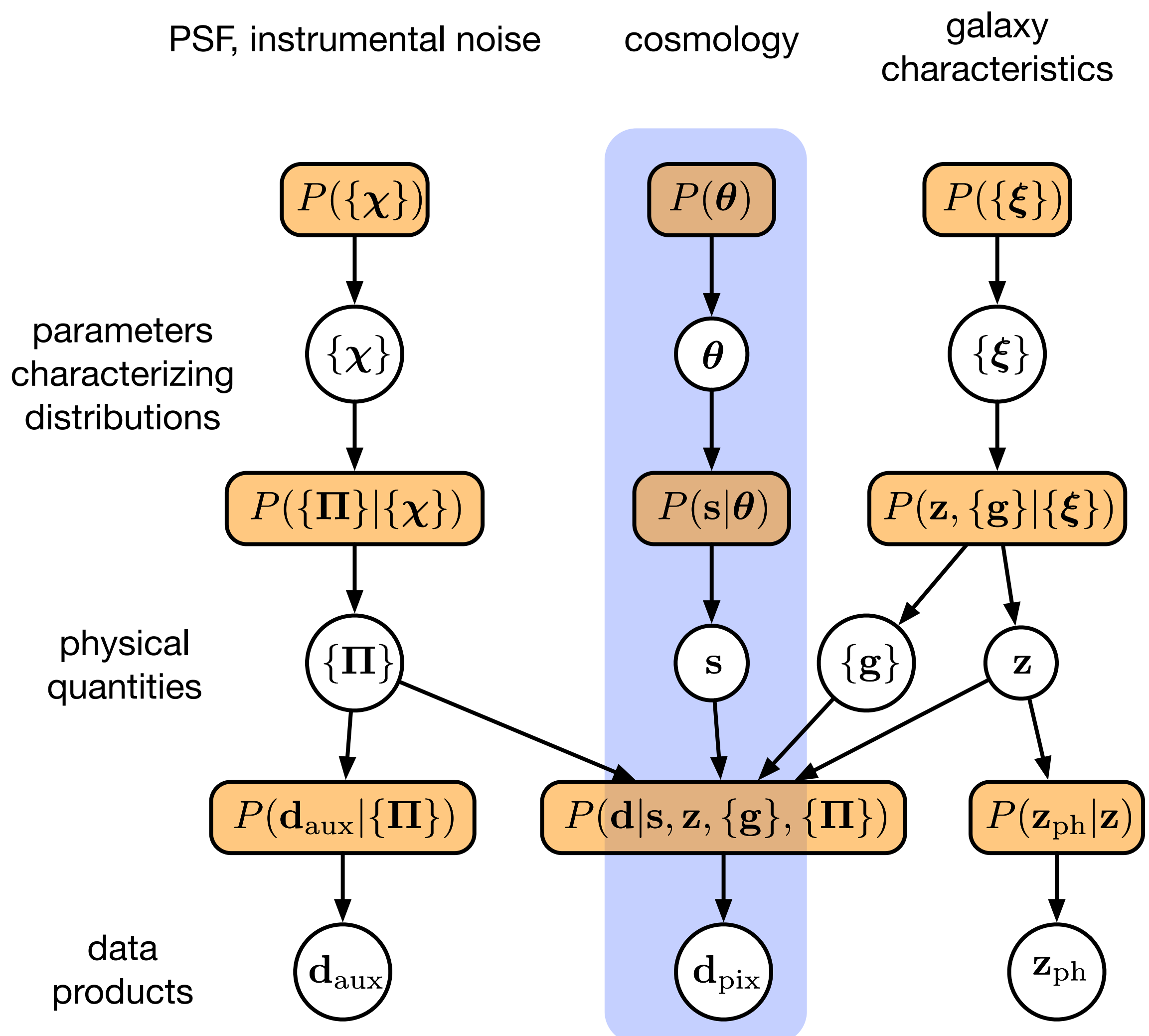
Global BHM:



Alsing, J., AFH, et al., 2015
Schneider M., et al., 2014

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Conclusions

- Bayesian hierarchical models are the natural way to do principled Bayesian statistical inference from weak lensing
- Messenger fields now make it possible
- Joint map and power spectrum inference with $\sim 10^5$ parameters (or more) is feasible
- Masks and intrinsic alignments are easily included
- In progress: CFHTLenS analysis; non-gaussian likelihoods; possible Euclid pipeline
- Alsing et al. arXiv:1505.07840

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