A maximum-probability method for weak lensing reconstruction with physical priors

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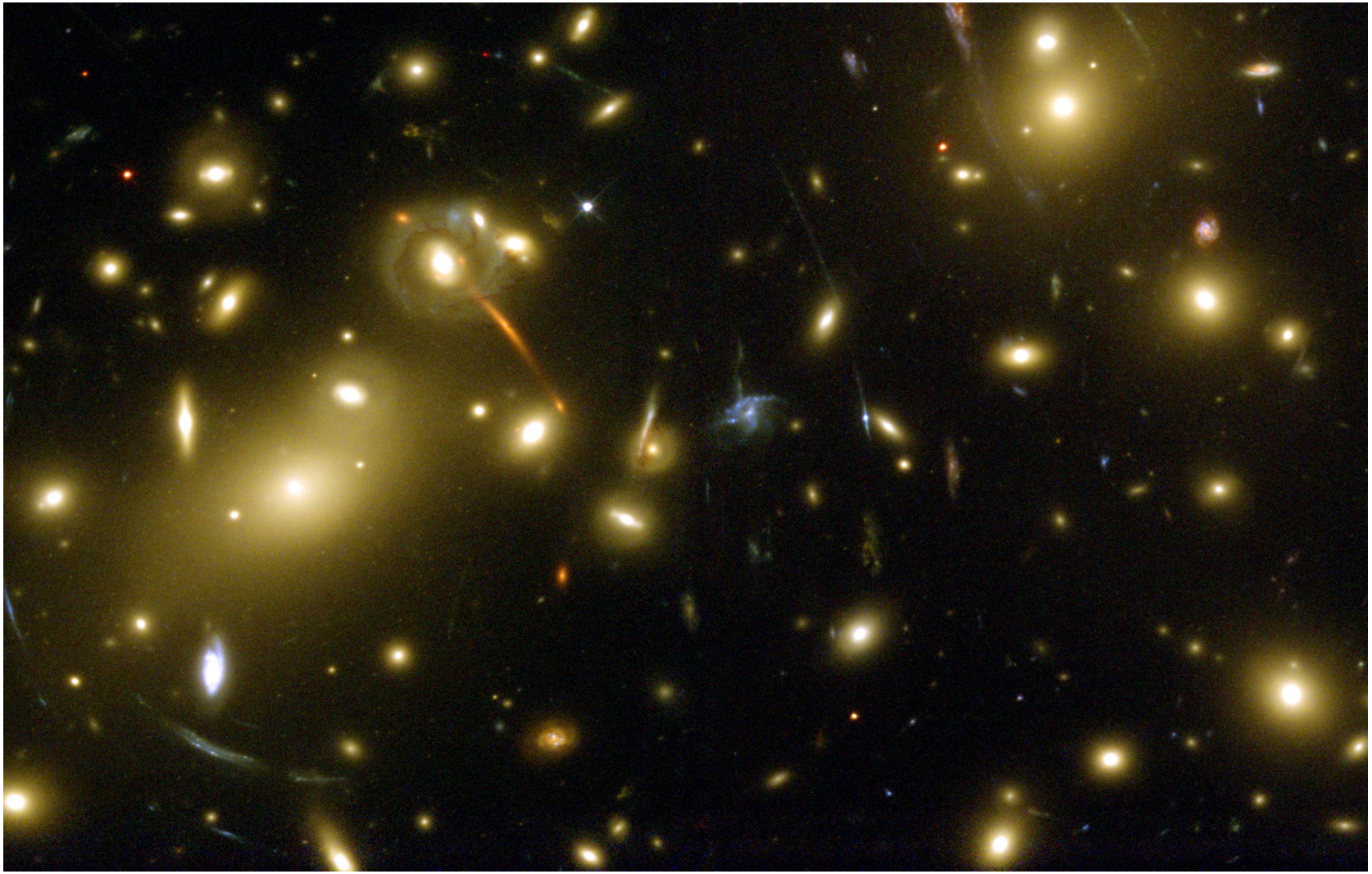
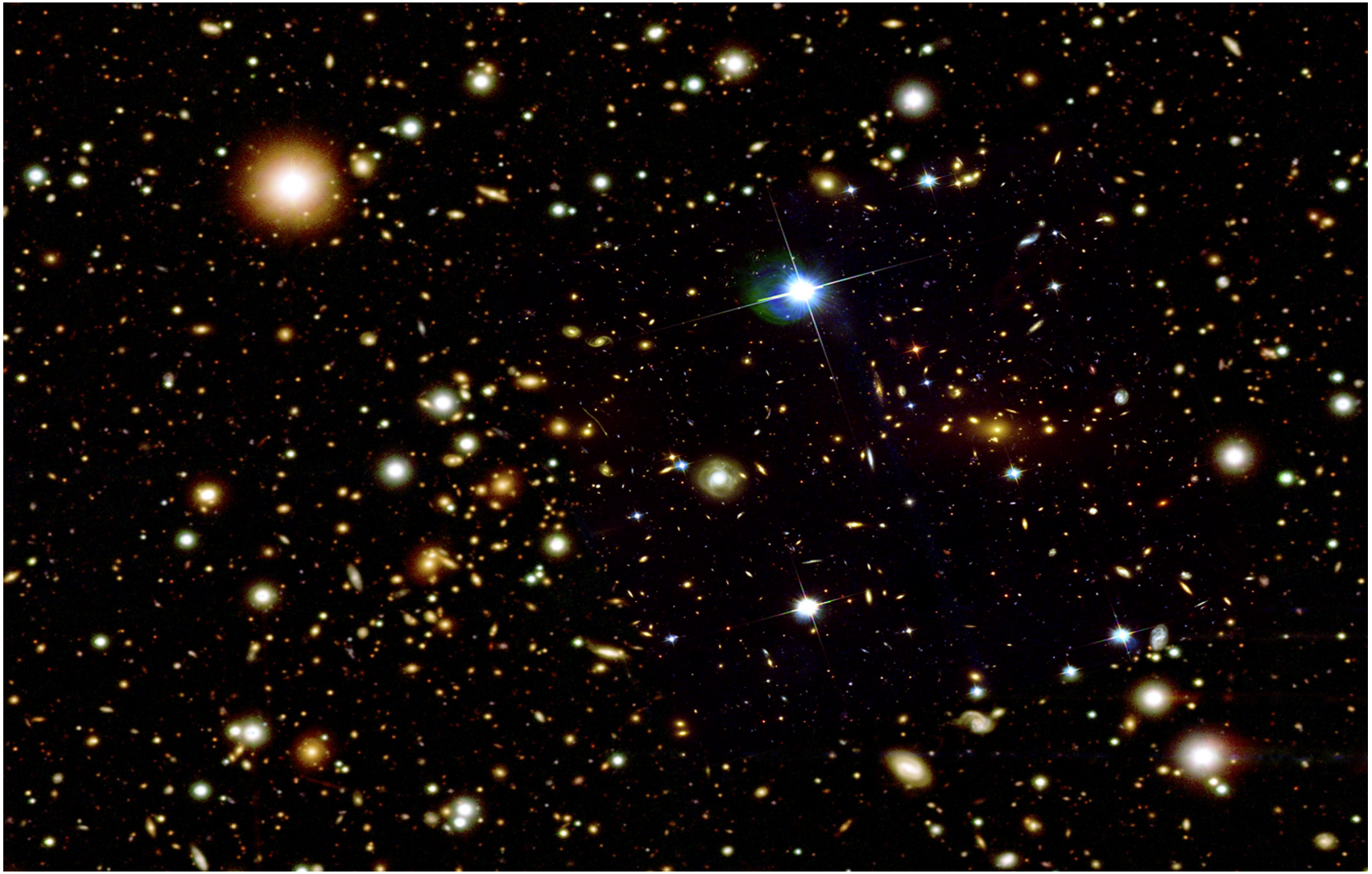
Outline

1. Motivation
2. Lensing theory and Kaiser-Squires reconstruction
3. Maximum-likelihood and maximum-probability
4. Our approach – physical priors
5. Application to simulated data
6. Current work
7. Summary

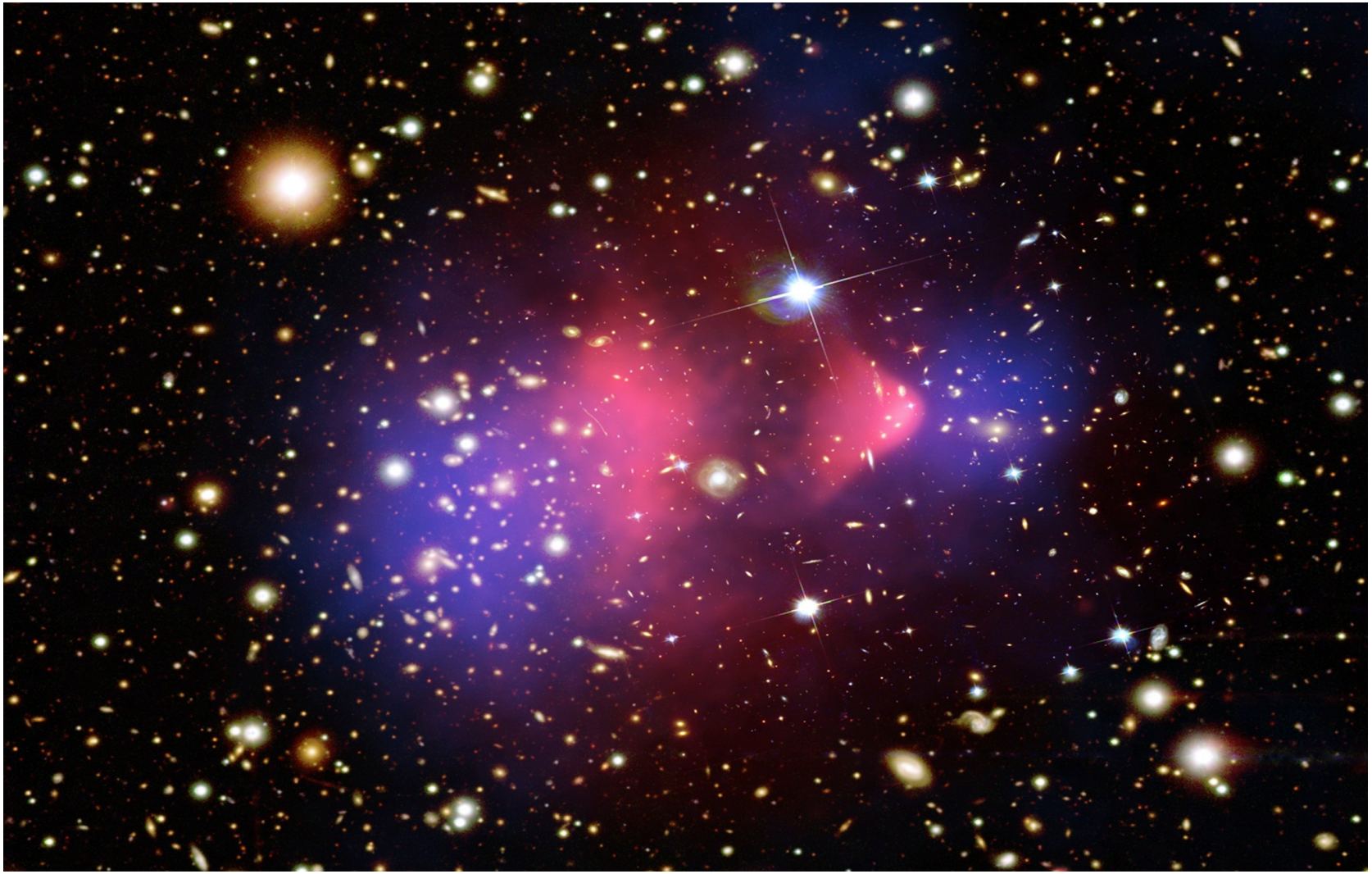
Motivation



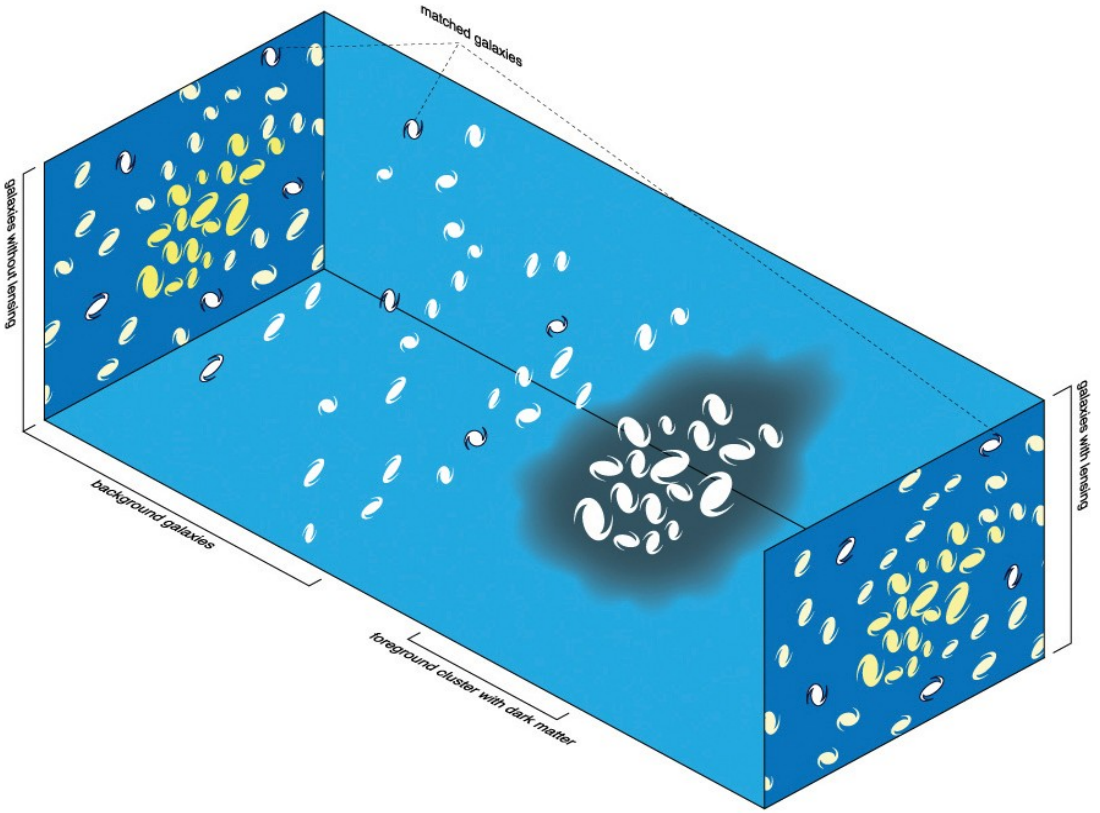
Motivation



Motivation



Lensing theory



Lensing is caused by the integrated gravitational potential along the line of sight – the ***lensing potential***:

$$\phi(r) \equiv \frac{2}{c^2} \int_0^r dr' \frac{r - r'}{r\, r'} \Phi(r')$$

Lensing theory

The appearance of galaxies on the sky depends on the second derivatives of the lensing potential.

Convergence

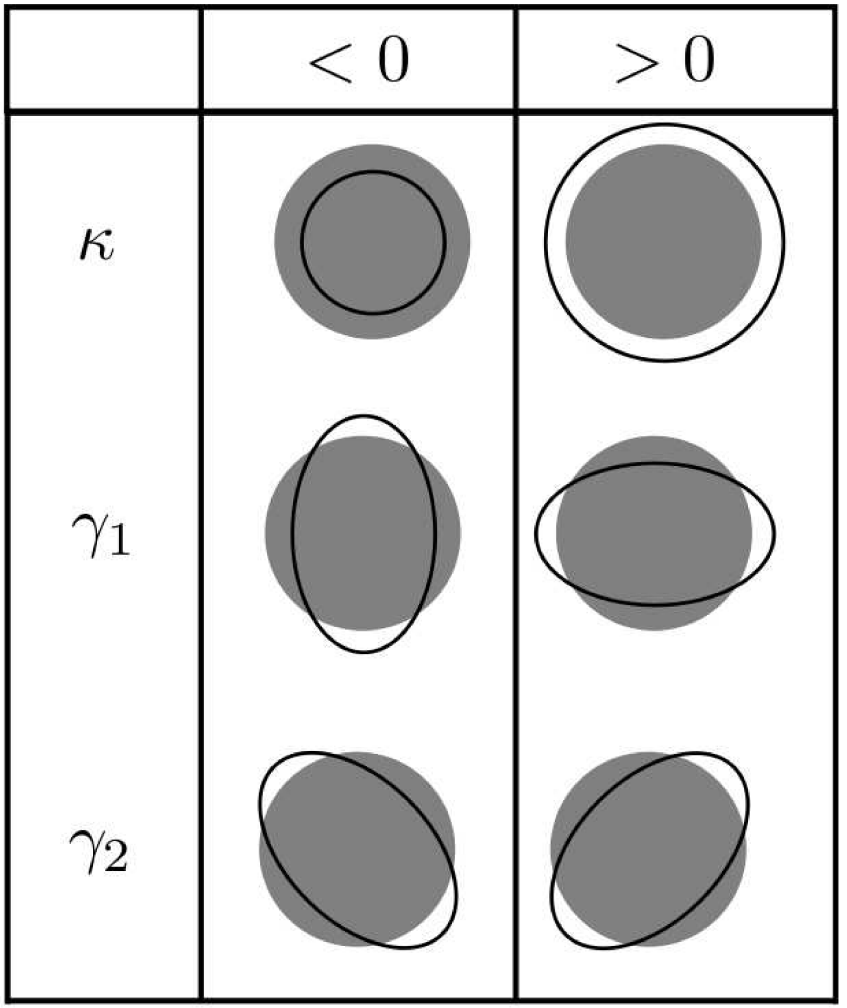
$$\kappa = \frac{1}{2}\left(\partial_1^2 + \partial_2^2\right)\phi$$

κ measures projected density.

Shears

$$\gamma_1 = \frac{1}{2}\left(\partial_1^2 - \partial_2^2\right)\phi$$

$$\gamma_2 = \partial_1 \partial_2 \phi$$



Kaiser-Squires reconstruction

κ as a linear combination of shears in Fourier space.

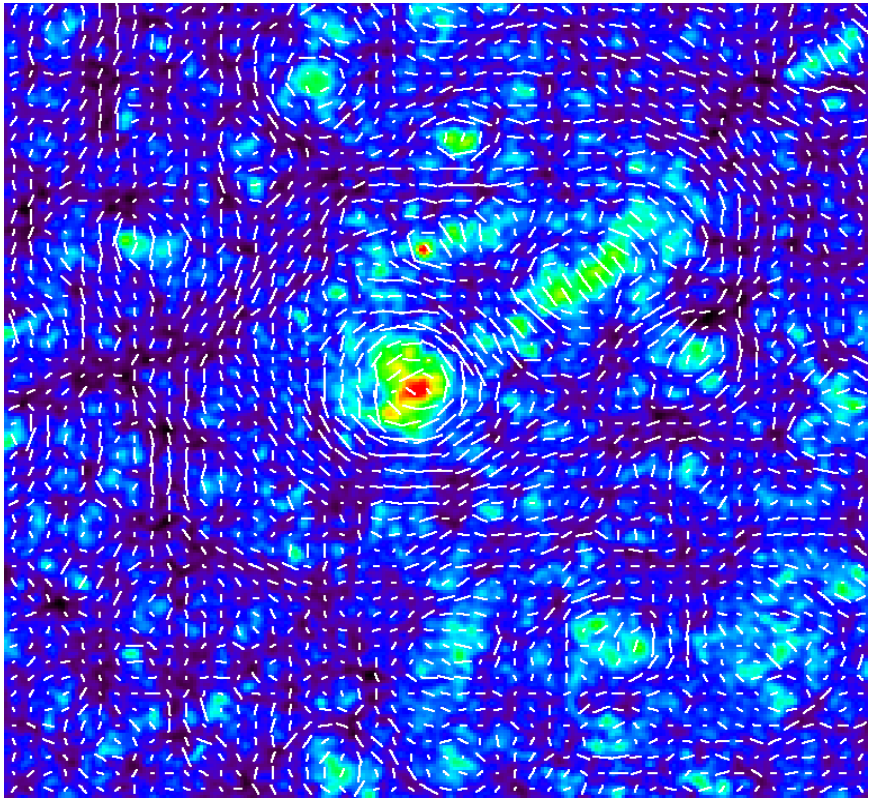
(Kaiser & Squires 1993; Kaiser, Squires & Broadhurst 1995)

$$\tilde{\gamma}_1 = -\frac{1}{2}(k_1^2 - k_2^2)\tilde{\phi}$$

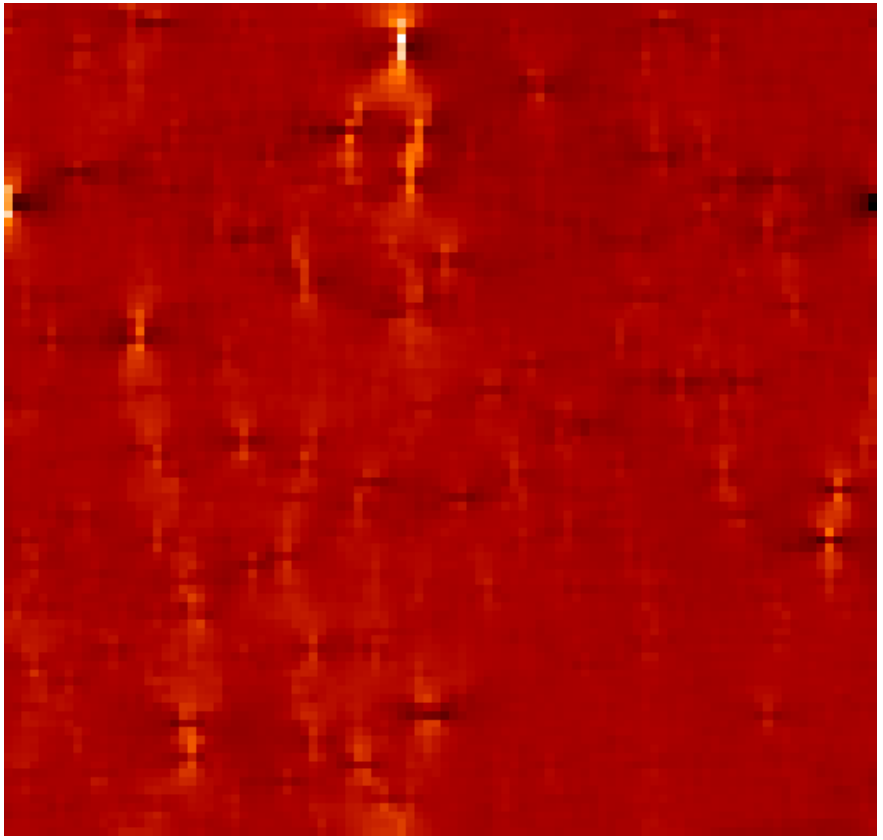
$$\tilde{\gamma}_2 = -k_1 k_2 \tilde{\phi}$$

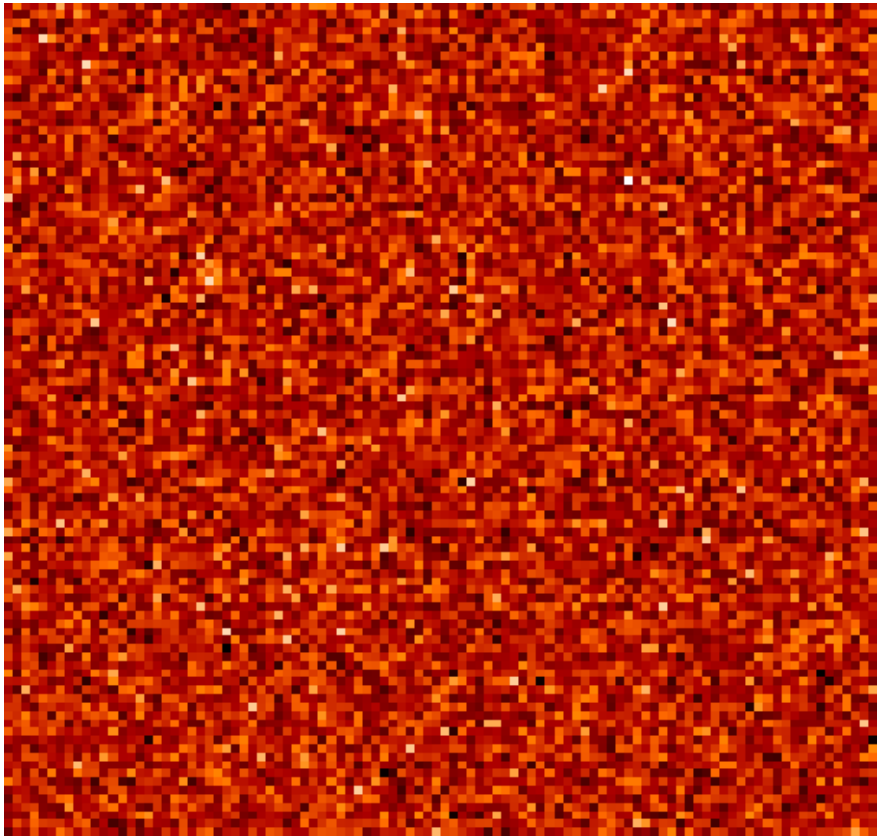
$$\tilde{\kappa} = -\frac{1}{2}(k_1^2 + k_1^2)\tilde{\phi}$$

$$\tilde{\kappa} = -\frac{k_1^2 - k_2^2}{k^2}\tilde{\gamma}_1 - \frac{2k_1^2 k_2^2}{k^2}\tilde{\gamma}_2$$



Shear maps





Maximum-likelihood & maximum-probability

From Bayes theorem:

$$P(\phi|\underline{\gamma}) \propto L(\underline{\gamma}|\phi) P(\phi)$$

Maximise the likelihood to find the best model:

$$L(\underline{\gamma}|\phi) = L(\underline{\gamma}|\underline{\gamma}_\phi) \propto \prod_i \exp -\frac{(\gamma_i - \gamma_i^\phi)^2}{2\sigma_i^2}$$

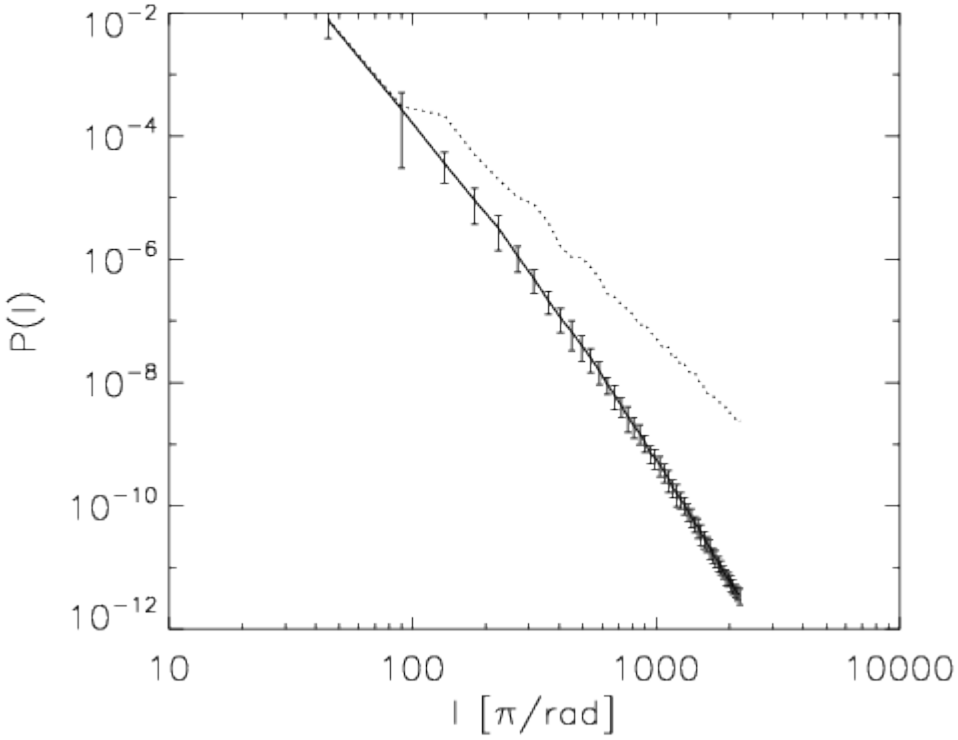
Maximum-likelihood will overfit the data by fitting noise.
Regularisation is required – maximum-probability.

(Bartelmann 1996, Squires & Kaiser 1996)

Power spectrum prior

Regularise the reconstruction by including a model power spectrum of the field as a prior.

$$P_{prior}(\phi) \propto \prod_l \exp - \frac{\left(P_l^{\phi} - P_l^{fid}\right)^2}{2\sigma_l^2}$$



Model power spectrum obtained from the Horizon simulation.
(Teyssier et al. 2009)

Baryon prior

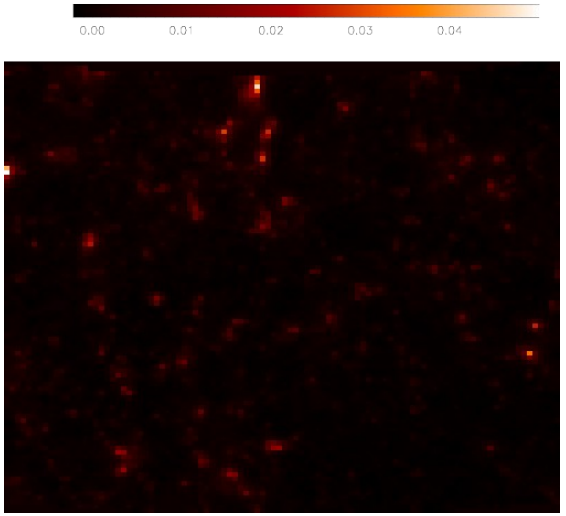
The power spectrum prior constrains only the statistics of the field.

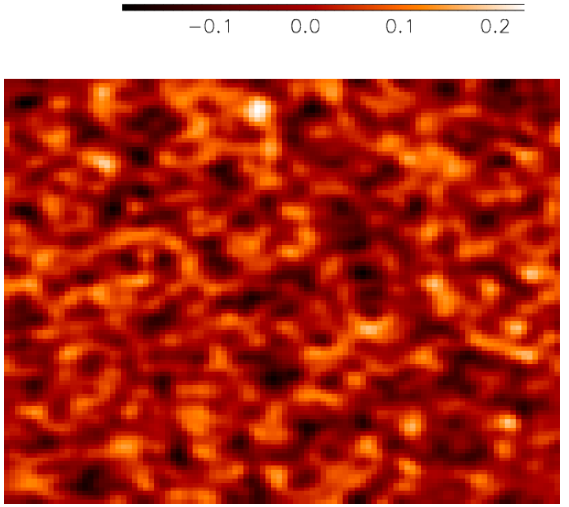
To improve the precision in the spatial distribution of the convergence field we assume that matter very approximately follows light.

$$P_{prior}(\phi) \propto \prod_i \exp -\frac{\left(\kappa_i^{\phi} - \kappa_i^{b}\right)^2}{2\sigma_g^2}$$

Application to simulated data with DES noise

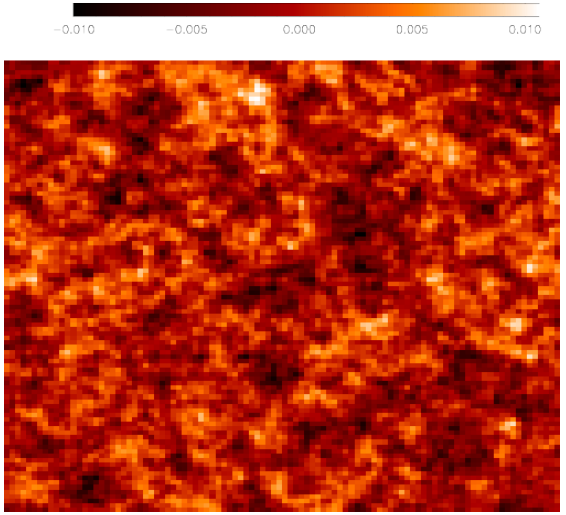
Simulation

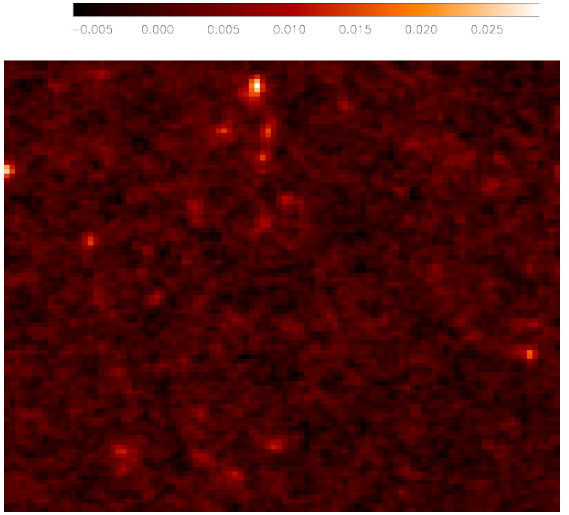




Smoothed Kaiser--Squires

Power spectrum prior only



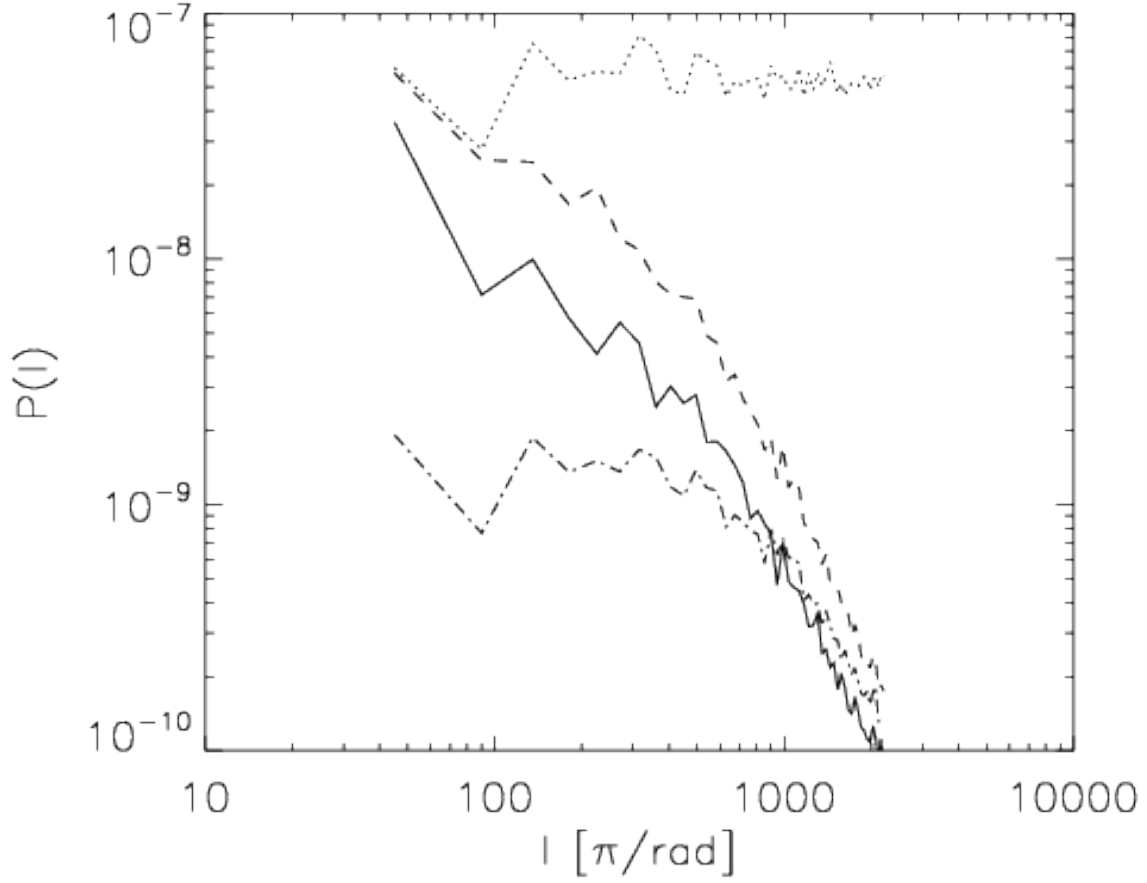


Both priors

Performance of the method

Including the baryon prior greatly improves the reconstruction quality on big and medium scales.

$$P_{err}(l) = \langle |\tilde{\kappa}_l^{\phi} - \tilde{\kappa}_l^{true}|^2 \rangle_l$$



Current work

- Understanding the noise properties of the reconstruction.
- Improving the galaxy distribution prior.
(Kitaura & Enßlin 2009)
- Understanding the information content of κ maps.
(Seo et al. 2011)
- Applying the method to the Dark Energy Survey DC6 mock catalogue.

Summary

- Mass mapping allows to study not only the statistics of the matter density field but also its spatial distribution.
- Due to high noise in weak lensing observations additional constrains are required to make maps of the density field.
- Using physically motivated priors seems promising but requires a good understanding of the information included in the reconstruction.