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3D power spectrum sampling with ARES

by

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The ARES Code

ARES (Algorithm for REconstruction and Sampling) is a software designed to perform joint estimations of the dark matter density field together with the according power spectrum from observations like galaxy redshift surveys.

The efficiency of ARES permits us to reconstruct many thousands of full 3D density fields per day on a usual desktop PC, and therefore to sample the joint probability distribution $f(s,\{P(k)\}|d)$ of 3D density field and Power spectrum conditional on the observed data.

In this fashion we can take into account all observational effects like selection functions and mask, and propagate the correct observational errors to the infered quantities by Gibbs sampling.

This can be done using the following Markov Chain Monte Carlo scheme:

$$s^{i+1} \Longleftarrow f(s|\{P(k)\}^{i},d)$$

$$\{P(k)\}^{i+1} \Longleftarrow f(\{P(k)\}|s^{i+1},d) \ .$$

Here the power spectrum is drawn from an inverse Gamma distribution $f(P(k)|s,d) \sim \exp(-\sigma(k)/2\mathrm{P}(k))$, which is a highly non-Gaussian distribution. The 3D density maps are created by calculating the Wiener mean field map and adding the correct Wiener variance as demonstrated in figure 1. For a successful application to CMB see ref 2.

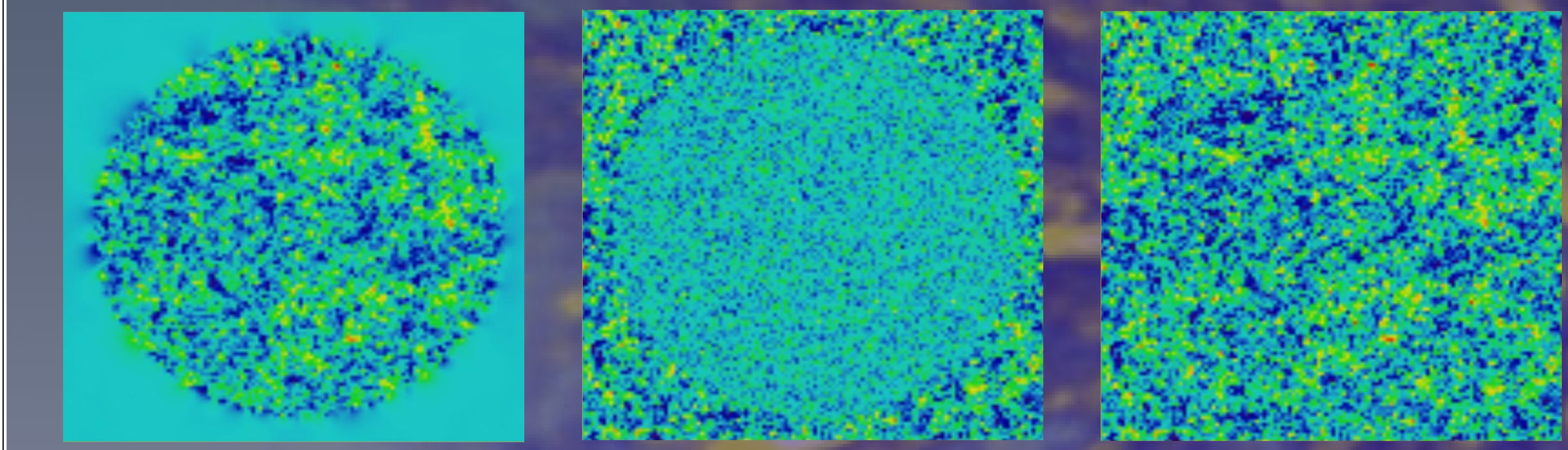


Fig1.: (from left to right) biased Wiener mean field map obtained from windowed data, Wiener Variance and correct augmentation in the windowed region and finally the total unbiased 3D density sample.

The Reconstructions

Here we present some recent results of joint dark matter density field and power spectrum estimation from a Galaxy Mock catalog. In figure 2 we show a slice through the mean density field obtained from 1400 samples. The reconstruction was done on a 128^3 grid, which implies inverting matrices of size ~2.1 10^6x 2.1 10^6 .

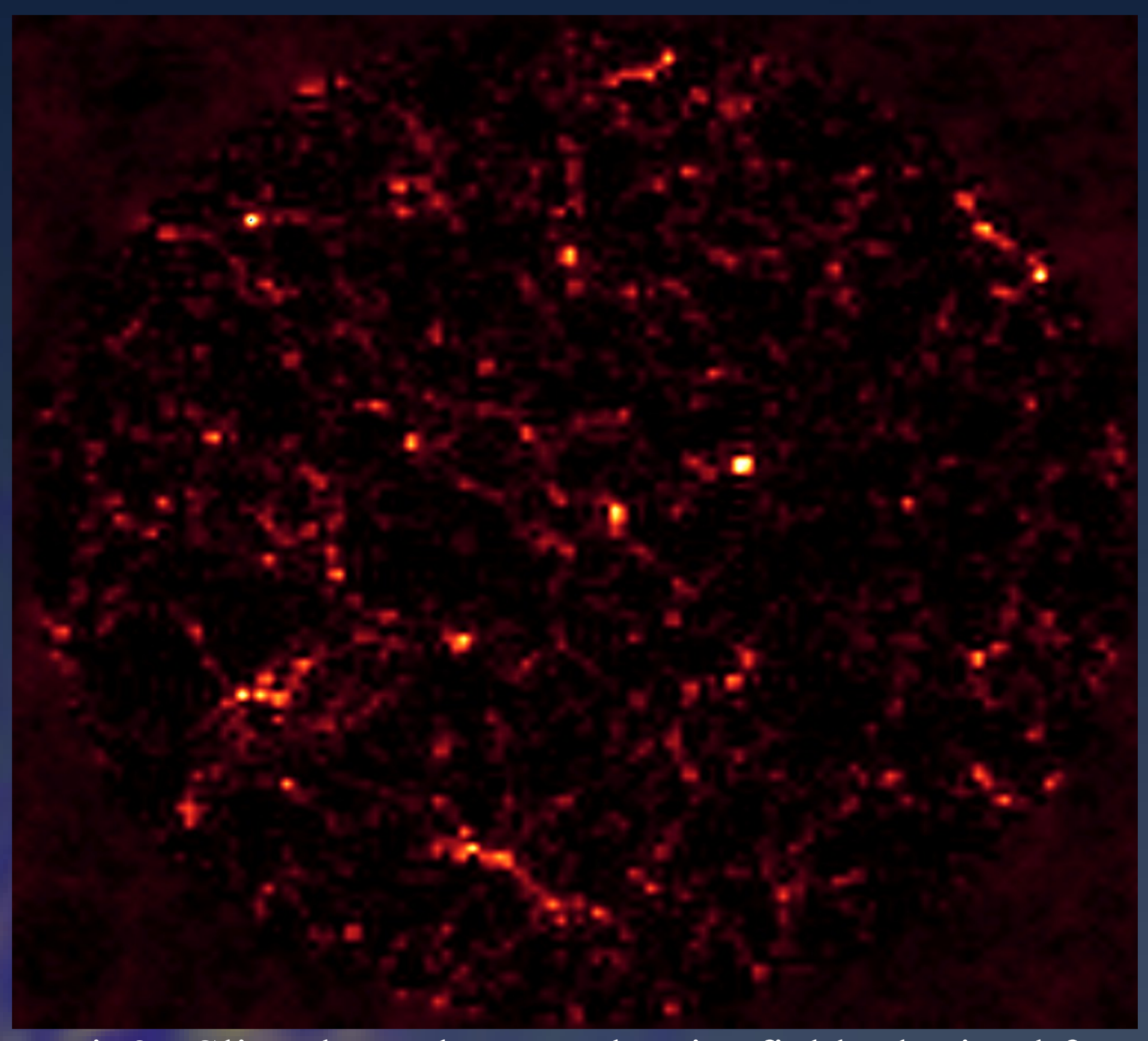


Fig2.: Slice through mean density field, obtained from 1400 Gibbs samples

This translates to a resolution of 3.9 Mpc pixel length. In figure 2 it can be observed that the reconstructed density field does not necessarily vanish in the windowed region. This fact is due to the correct correlation function which allows to carefully extrapolate the correct information into the unobserved regions. In figure 3 we demonstrate the mean power spectrum obtained from the 1400 samples together with the one sigma and two sigma confidence regions. The comparison with the underlying theoretical linear power spectrum shows, that the baryonic features are clearly detected.

ARES can be considered as an artificial intelligence learning machine. It iteratively learns the correct power spectrum from the observed data, and therefore improves in each sampling step the 3D density field and the power spectrum estimation. This ability is demonstrated in figure 4, where we initially started with a power spectrum with amplitude 5 orders of magnitude lower than that of the true underlying power spectrum. ARES successfully recovered the underlying structures after 80 iterations.

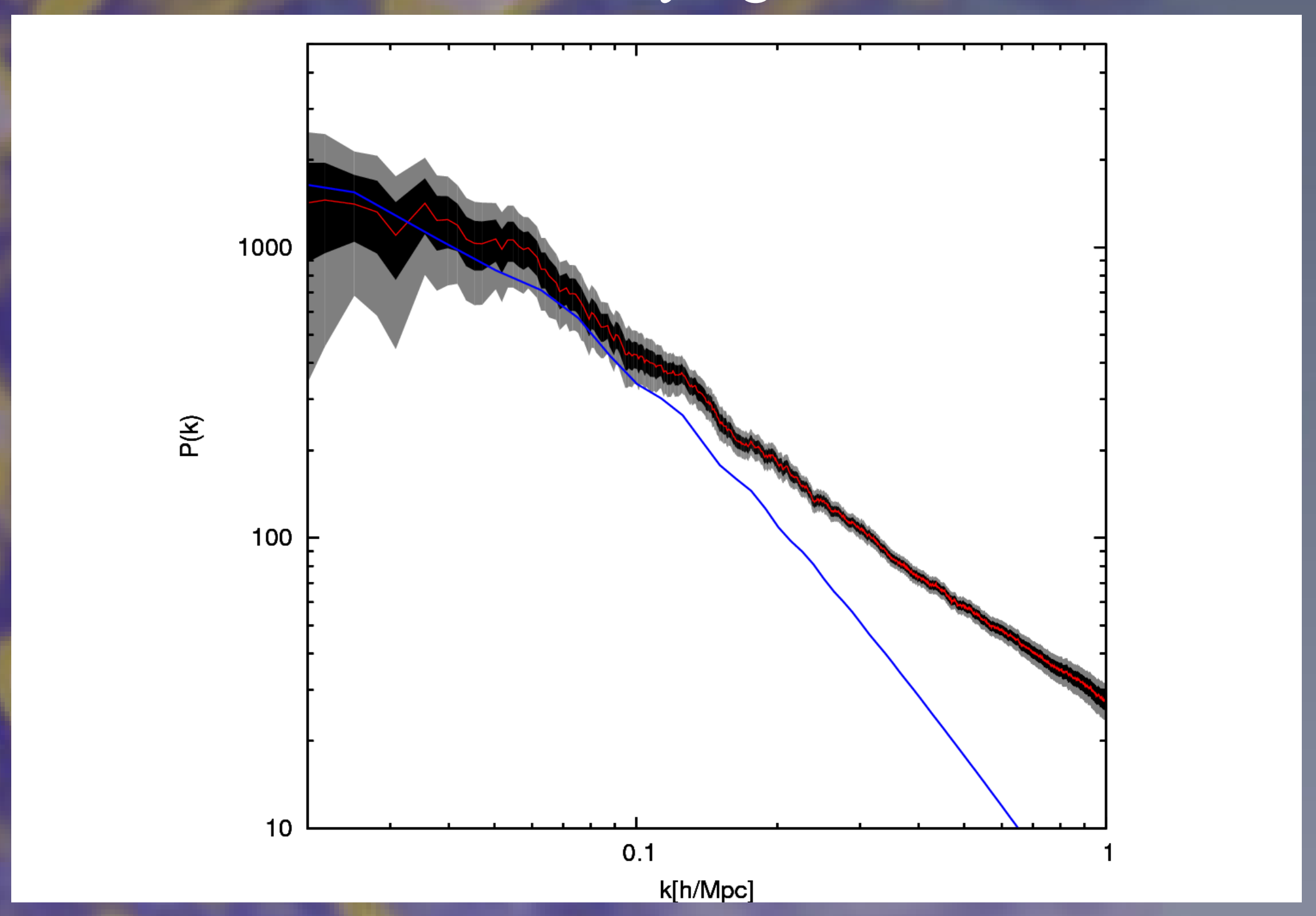
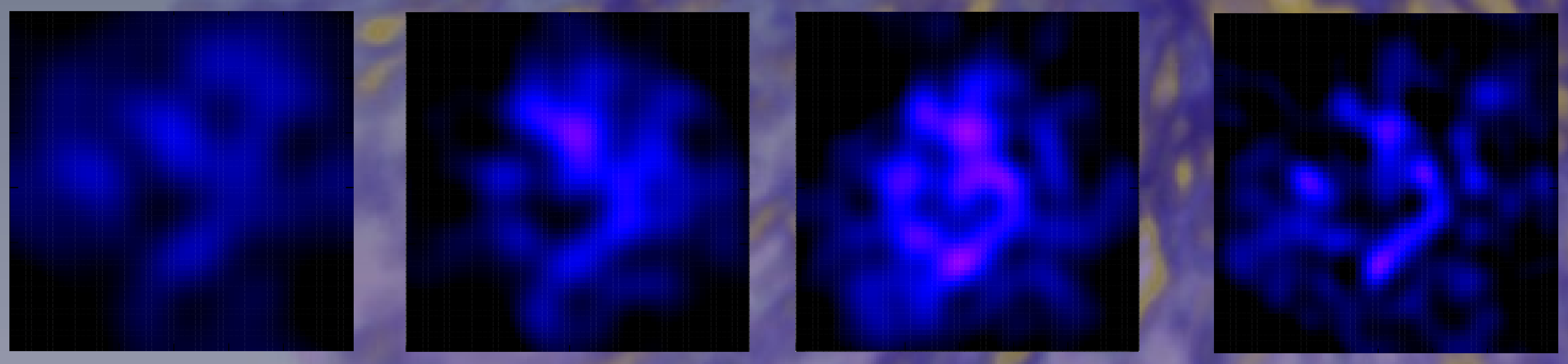


Fig3.: Estimated mean power spectrum (red line) calculated from 1400 samples. The black and gray shaded regions are the one sigma and two sigma confidence regions respectively. The blue line is the theoretical underlying linear matter power spectrum.



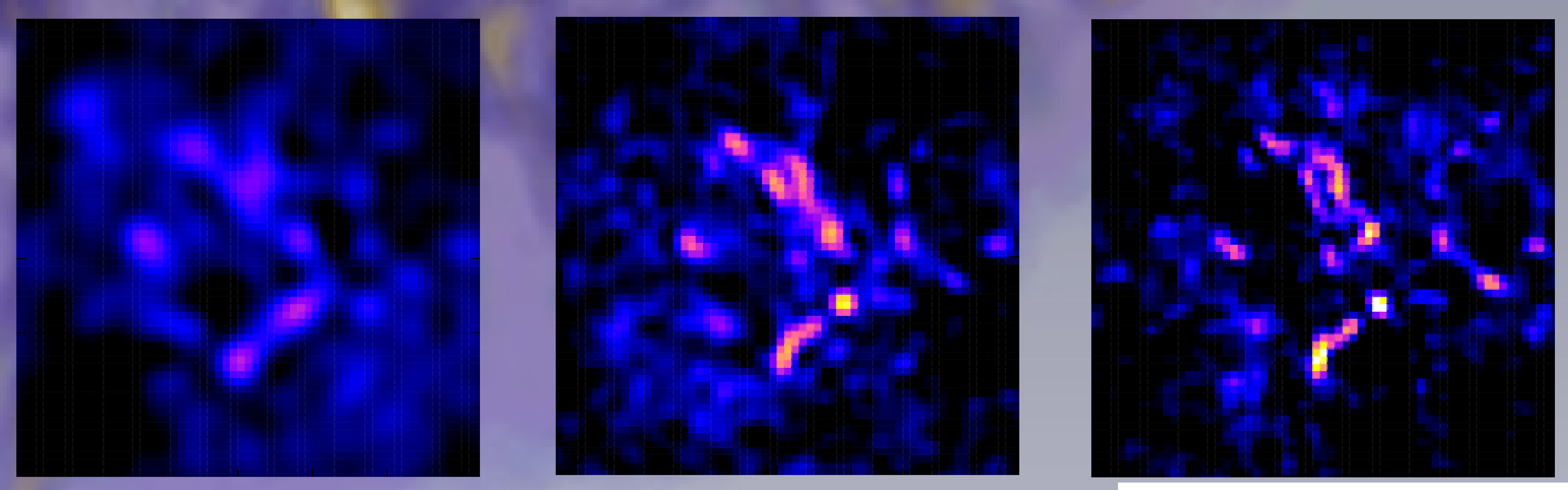


Fig4.: Slices through successive density field reconstructions, of a sampling run where we started with an initial guess for the Power spectrum 5 orders of magnitude too low in amplitude. The reconstructions are improved in each Gibbs sampling step and converge after 80 iterations.

References
1) Kitaura, Ensslin, 2007, arXiv:0705.0429v2
2) Wandelt et al, 2004, PhysRev, 70h3511W

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