Probabilistic image reconstruction and power spectrum inference from radio interferometers

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References:

Sutton and Wandelt, astro-ph/0604331 (ApJS 2006)

Sutter, Wandelt, Malu, arXiv:1109.4640 (ApJ 2011)

Sutter et al., arXiv:1309.1469 (MNRAS 2014)

Collaborators:

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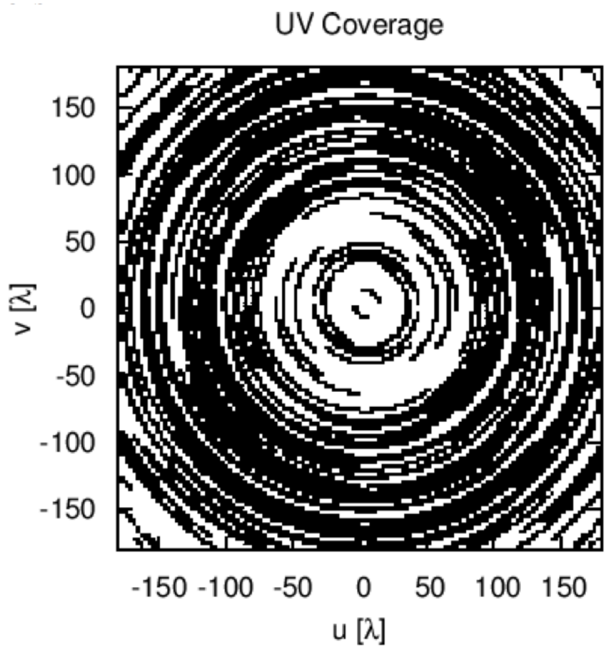
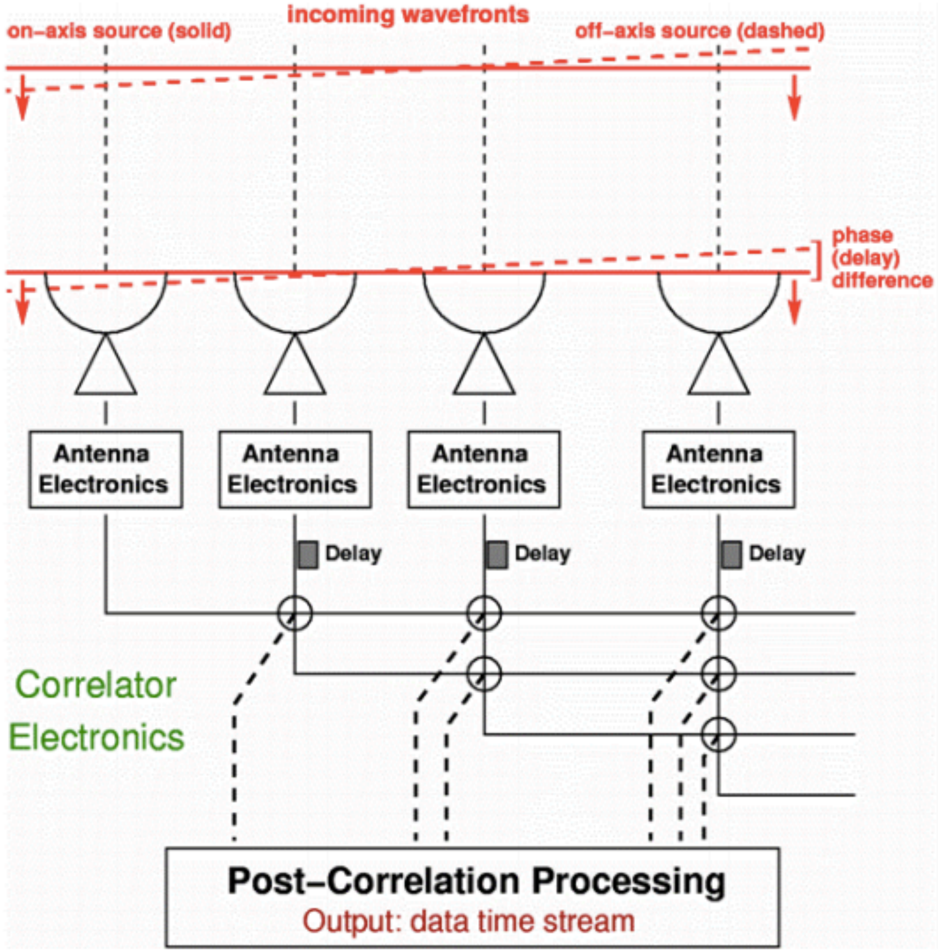
Jason McEwen, Peter Timbie,
Ted Bunn, Greg Tucker, Ata Karakci, Le Zhang

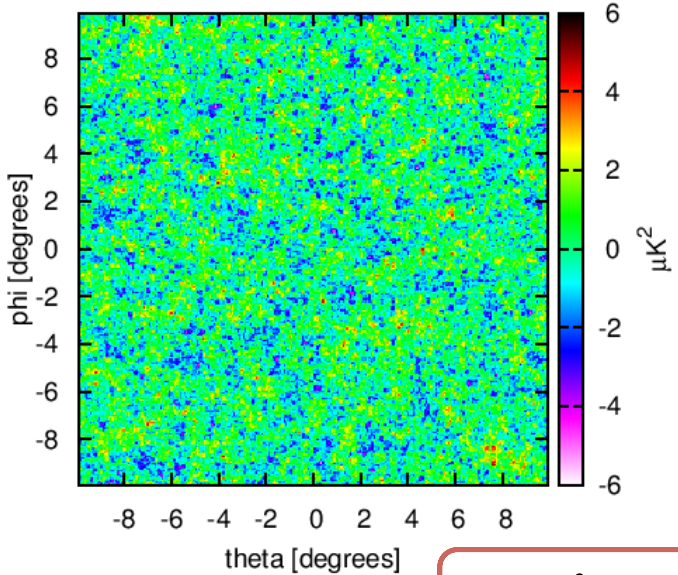
Interferometers



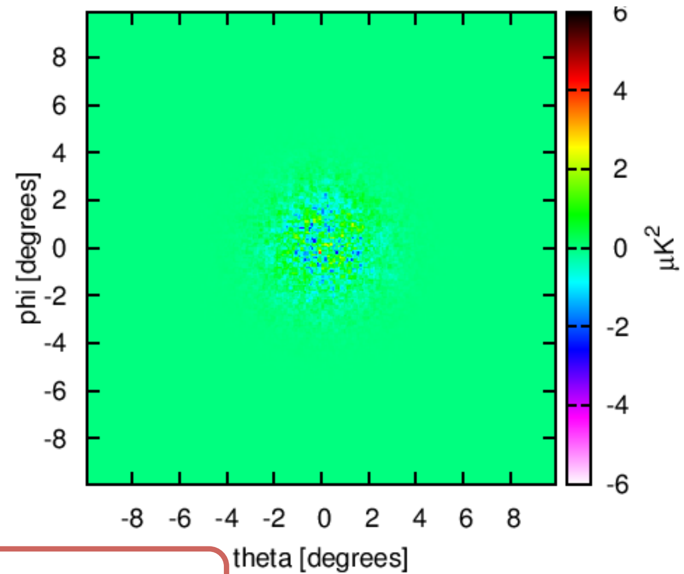


Data model

signal

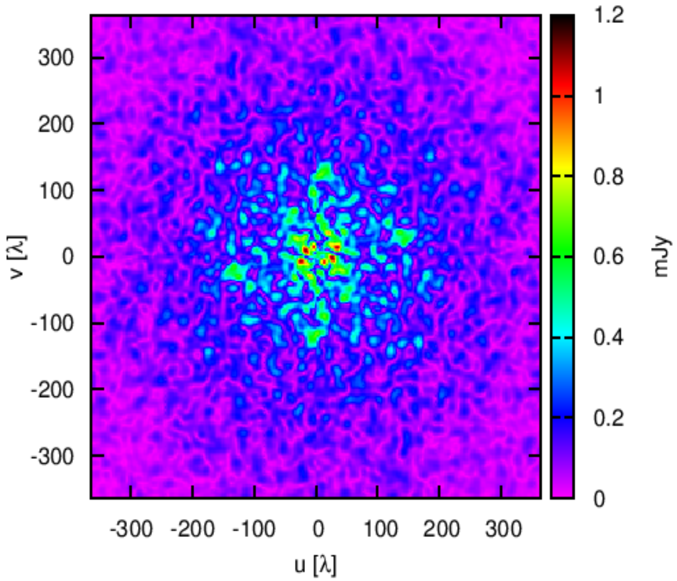


primary beam

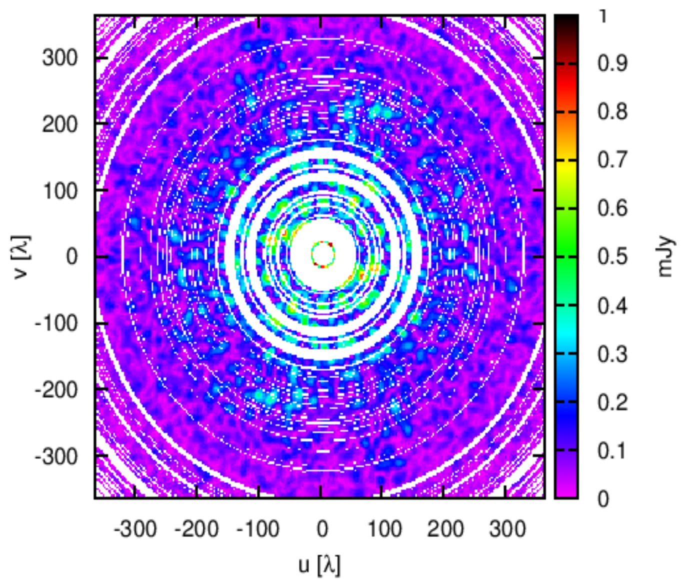


d = IFAs + n

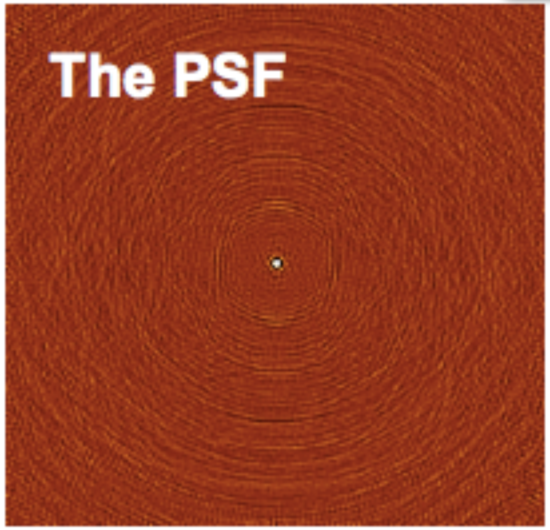
uv-plane

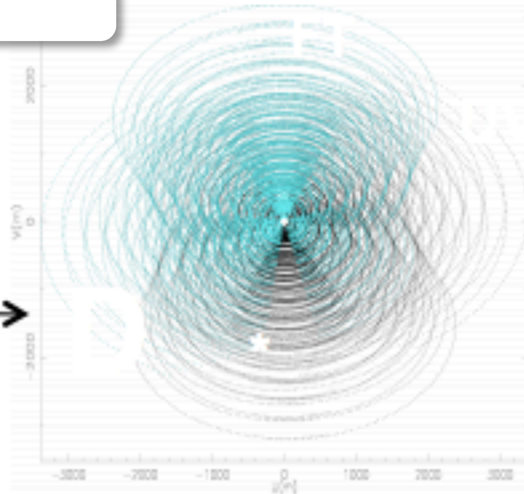


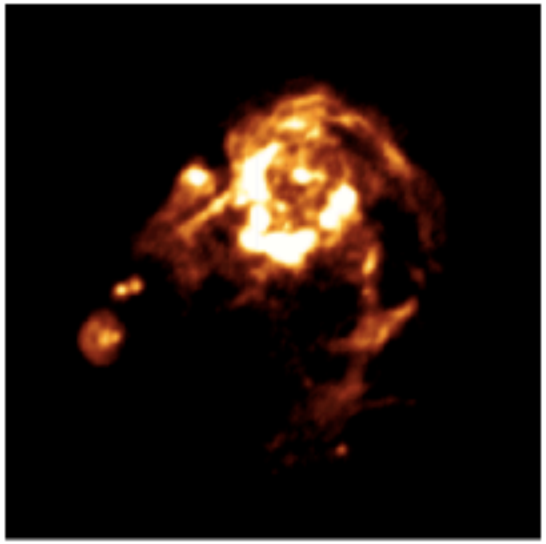
data



$d = IFAs + n$

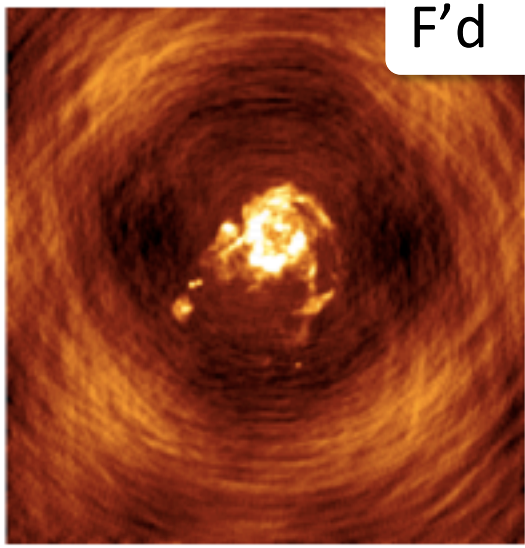






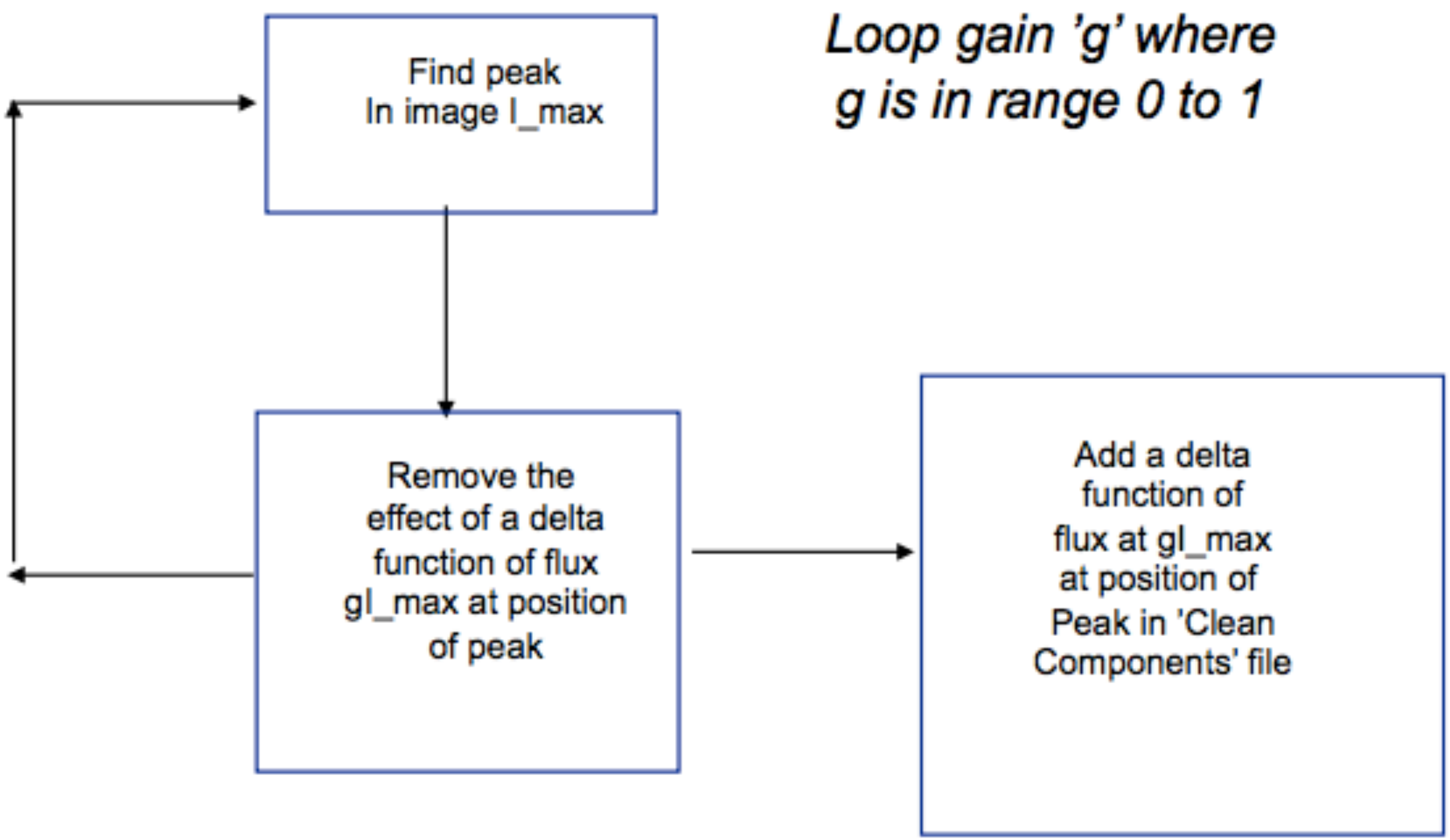
True image

$F'd$



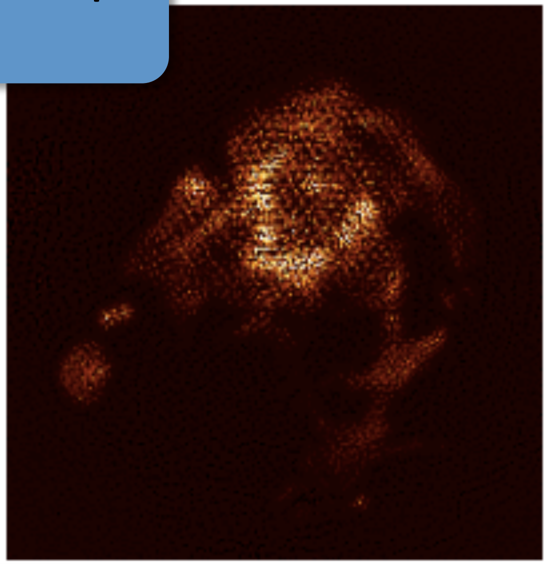
Dirty Image

traditional deconvolution: CLEAN

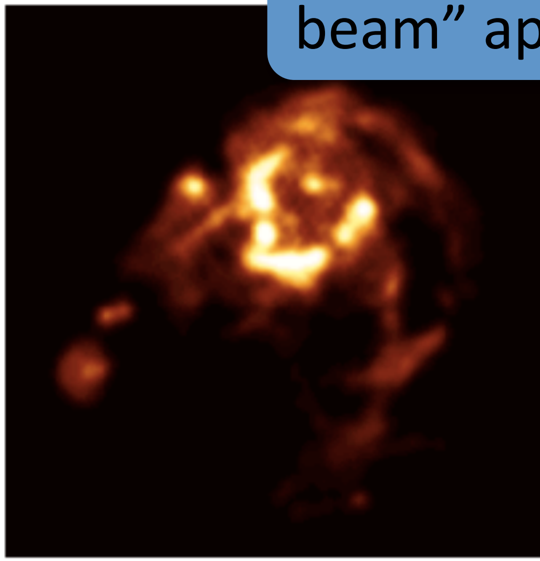


traditional deconvolution: CLEAN

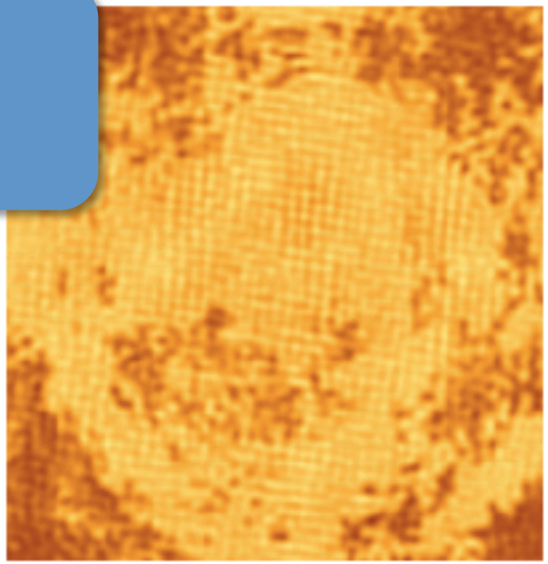
CLEAN Map



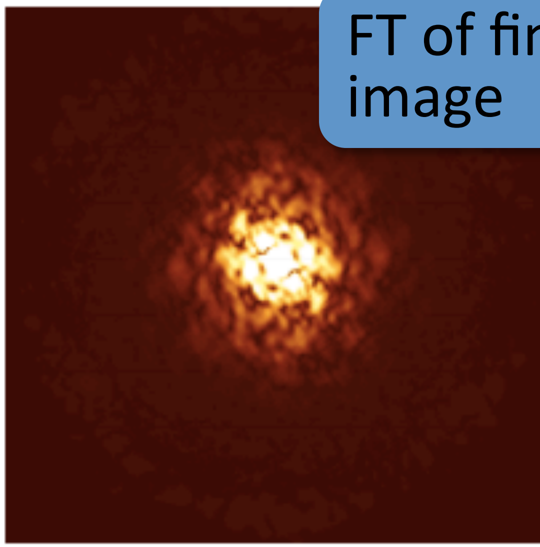
“restoring beam” applied



FT of CLEAN Map



FT of final image



CLEAN is...

~~robust~~

~~minimally parametric~~

data-driven?

~~informative~~

~~scalable~~

fast

the community responds…

Maximum Entropy

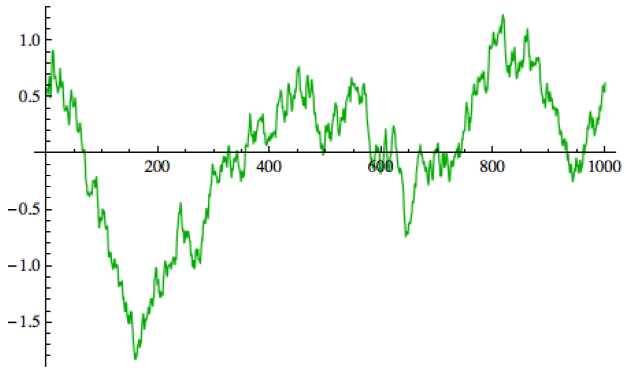
Multi-scale Multi-frequency

Compressed Sensing

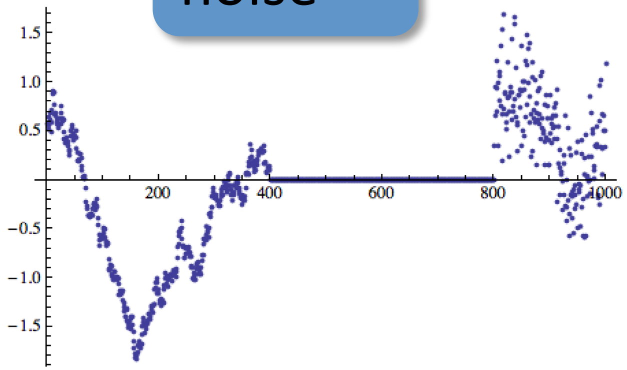
…

The Wiener filter

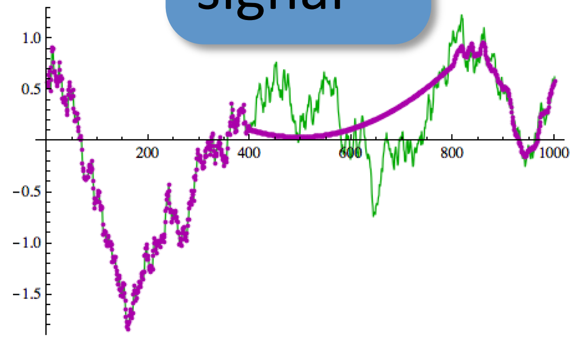
signal



signal + noise



Wiener filtered signal

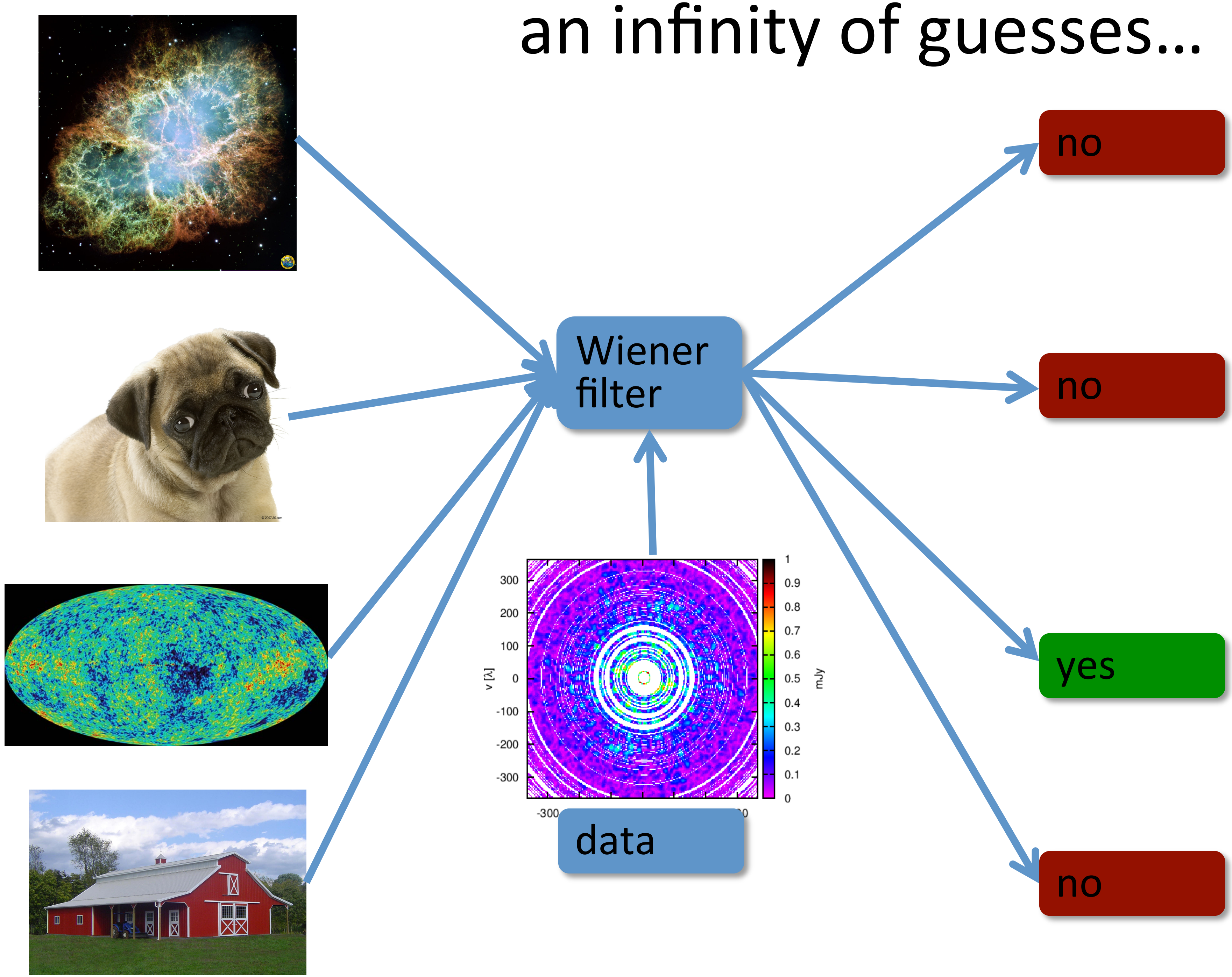


$$WF = \frac{IFA^{*}\ S}{IFA^{2}\ S + N}$$

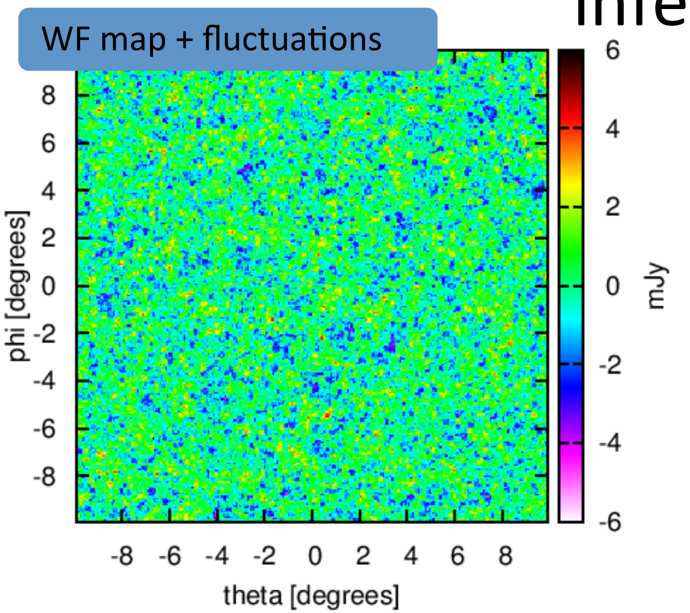
need to know signal covariance

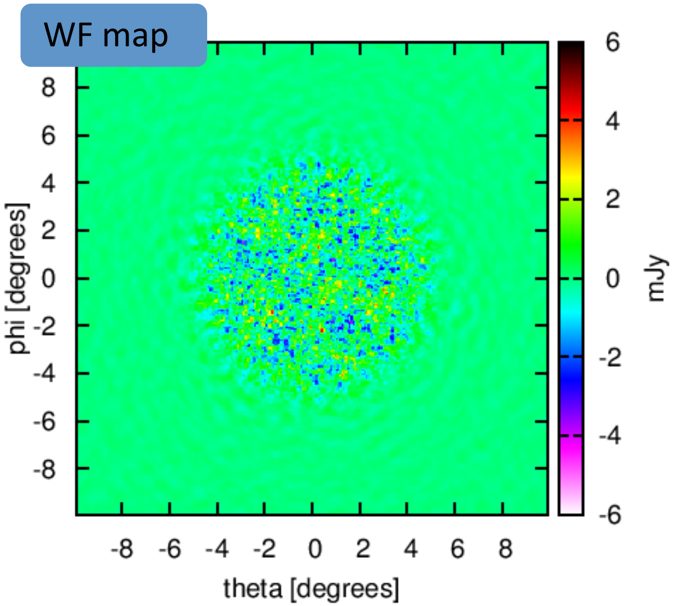
need to know noise covariance

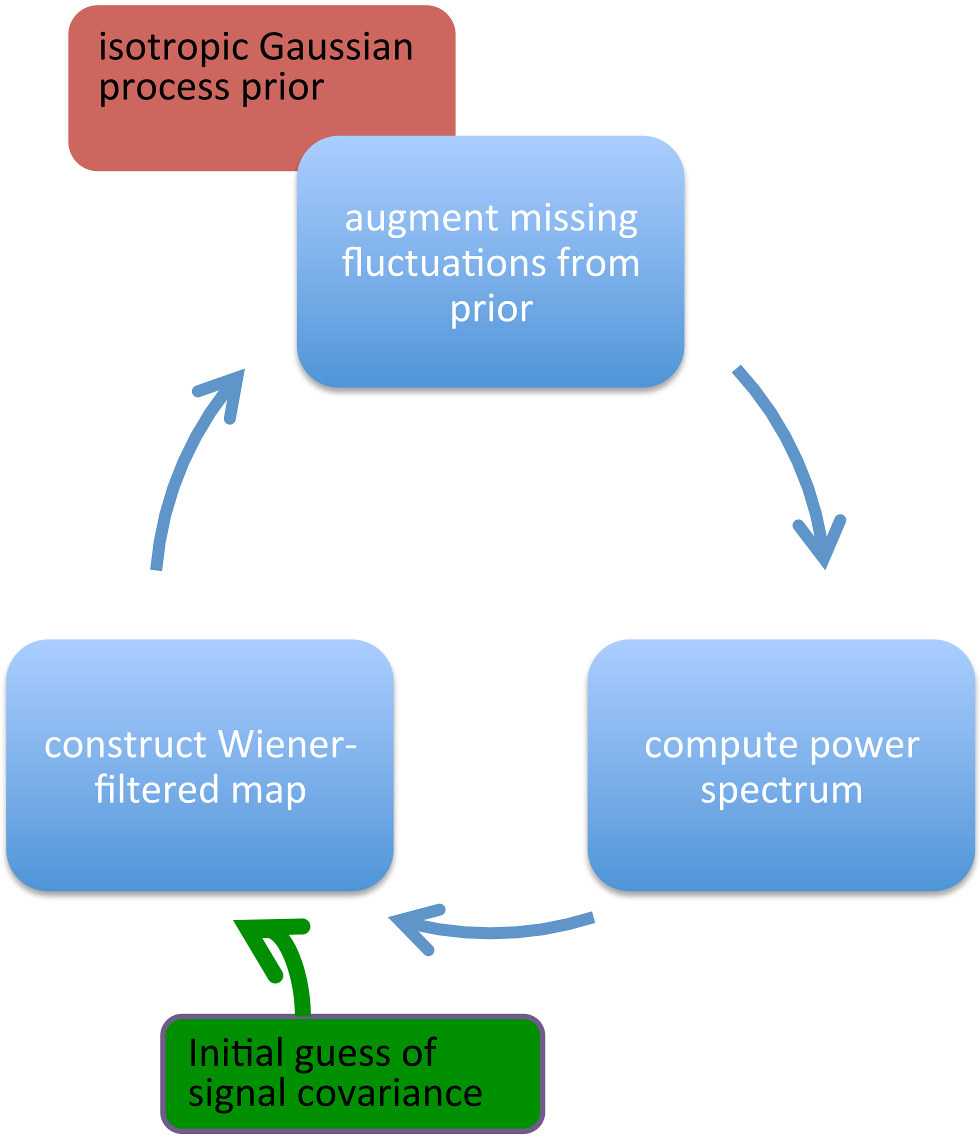
an infinity of guesses…



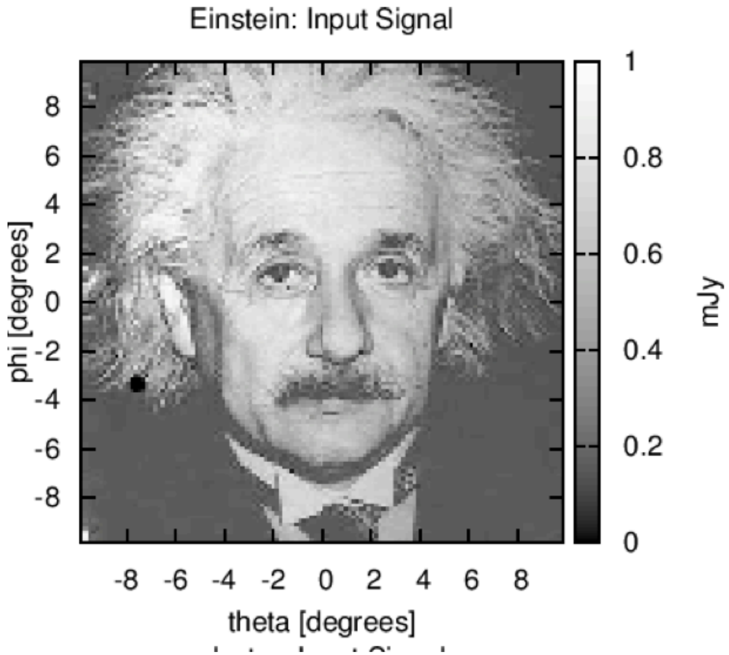
Gibbs sampling is a both power spectrum inference and non-linear Wiener filter

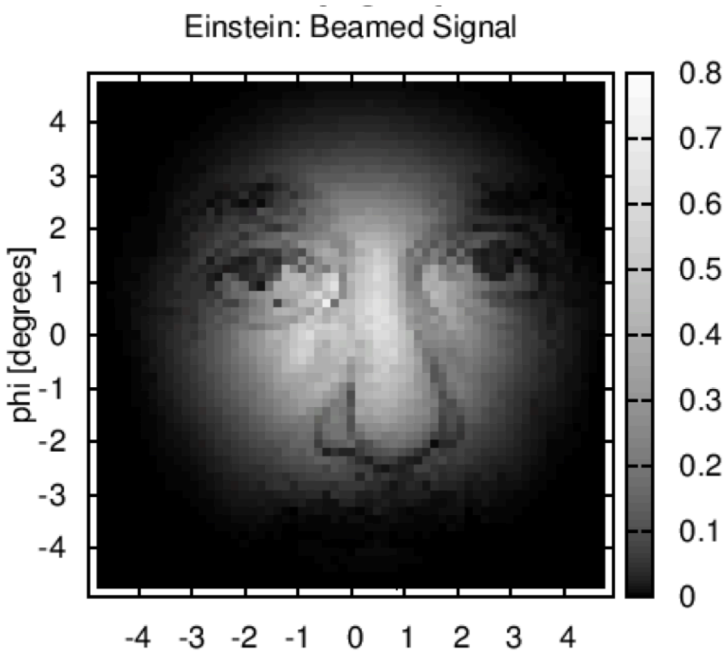


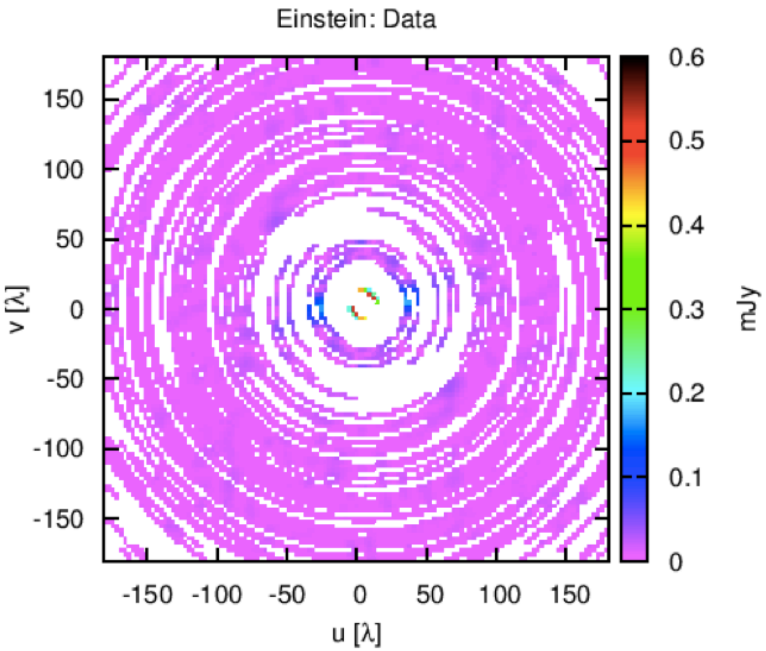




(Sutter, Wandelt, Malu. 2011; Karakci et al. 2013)

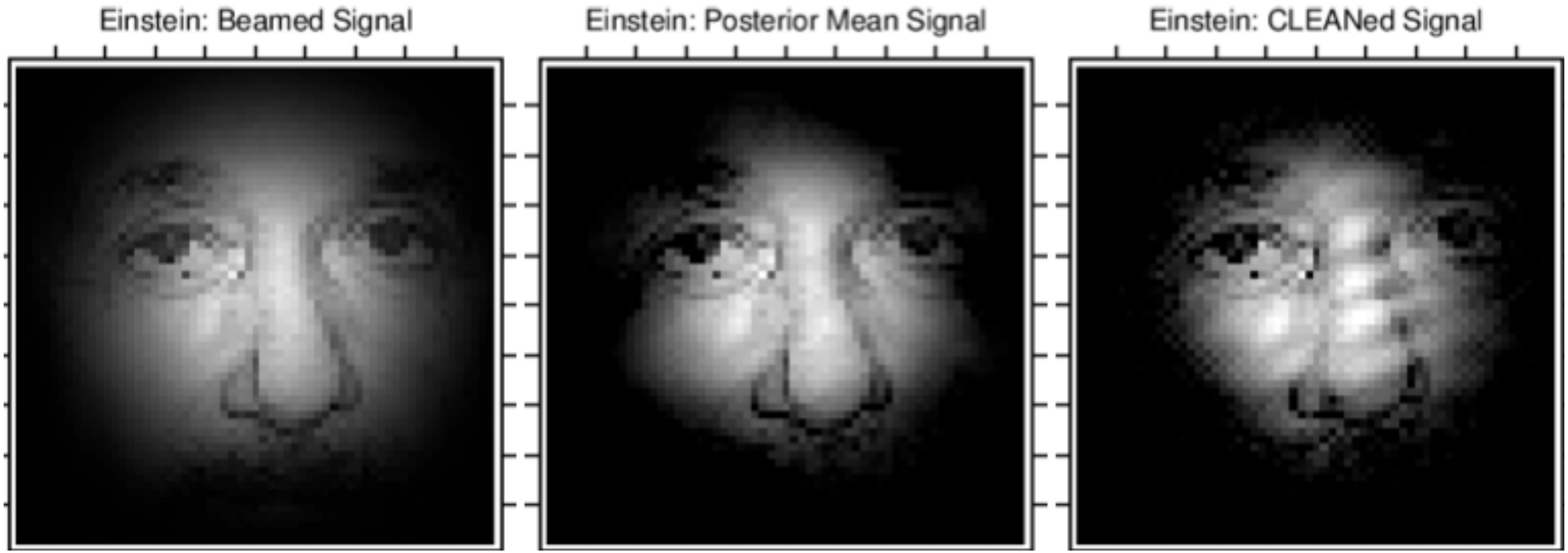






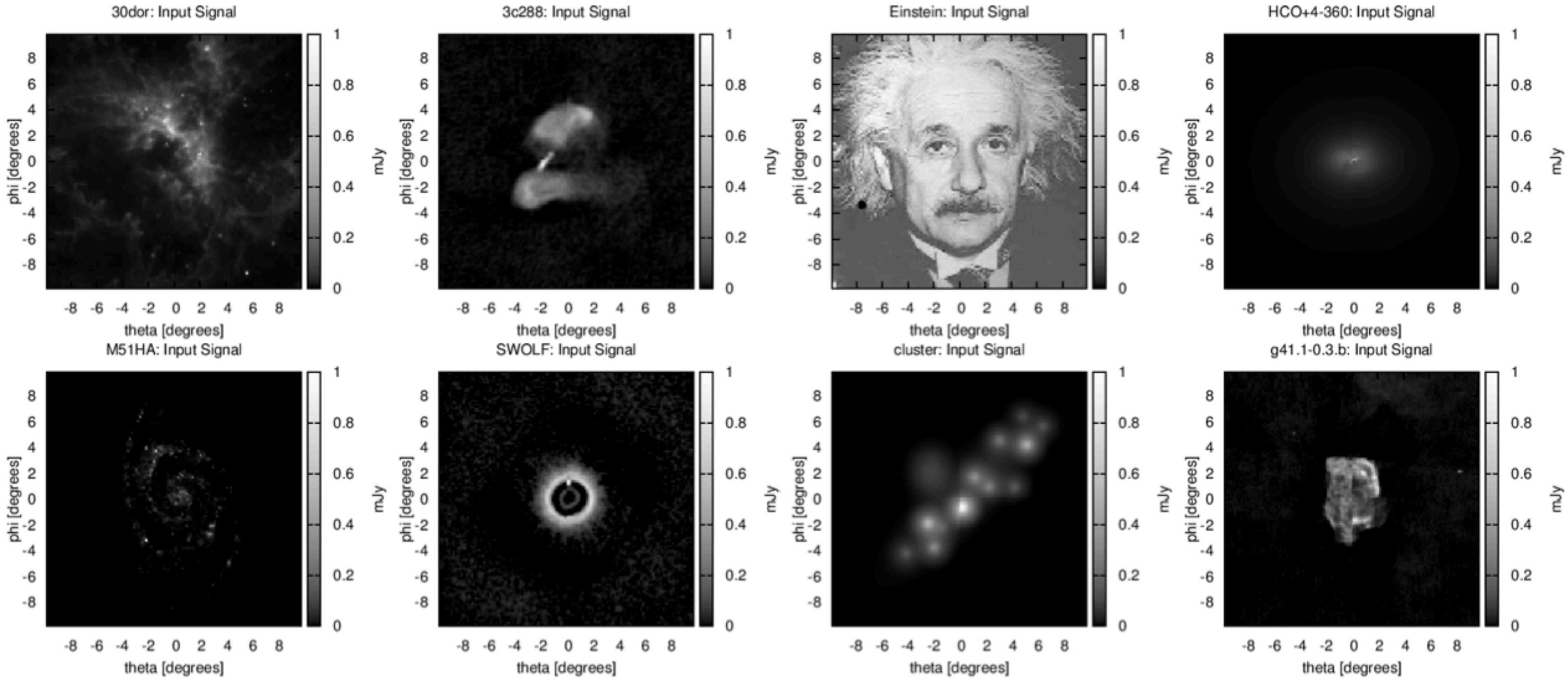
(Sutter et al. 2013)

example: Einstein



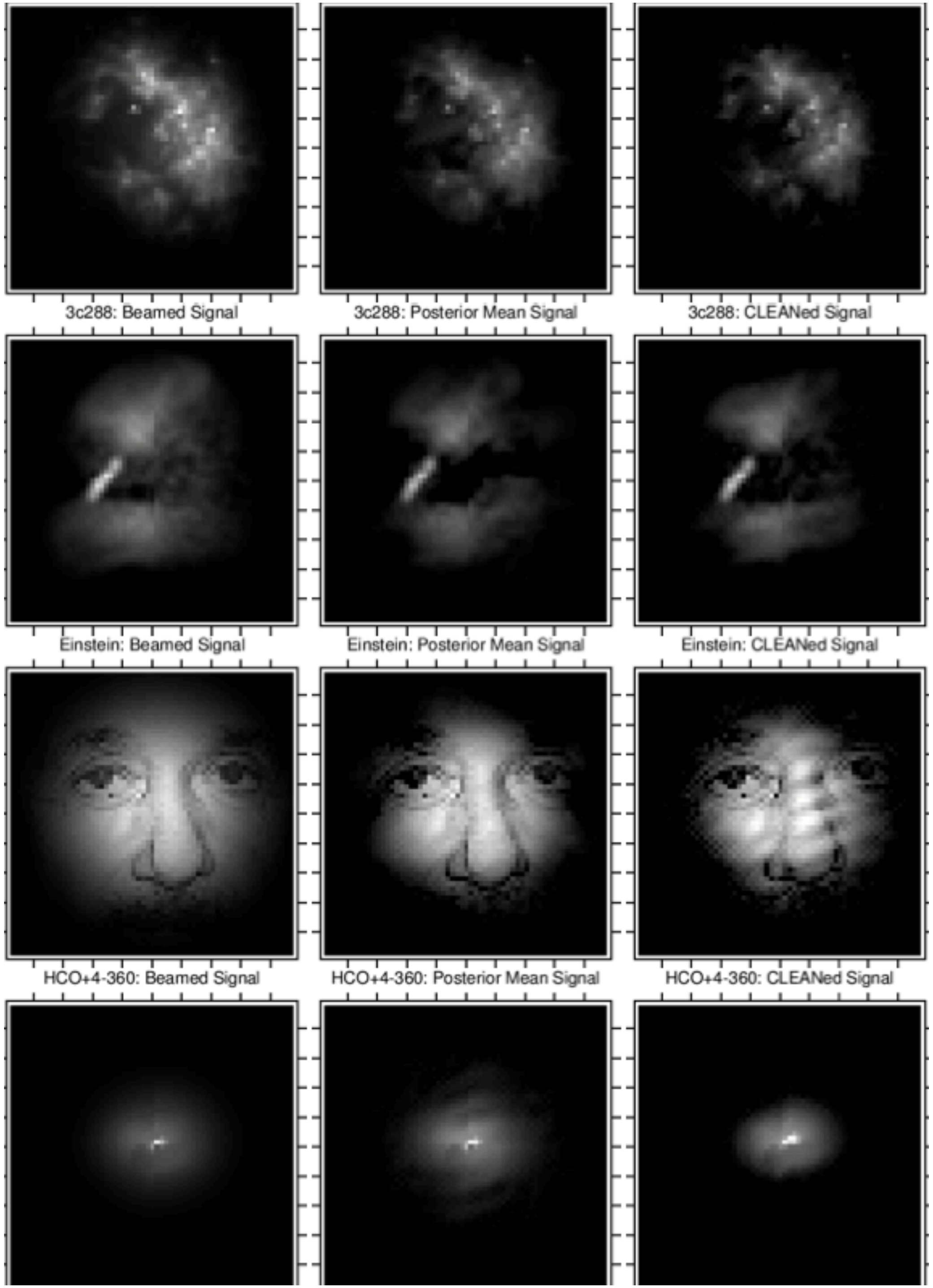
(Sutter et al. 2013)

test images



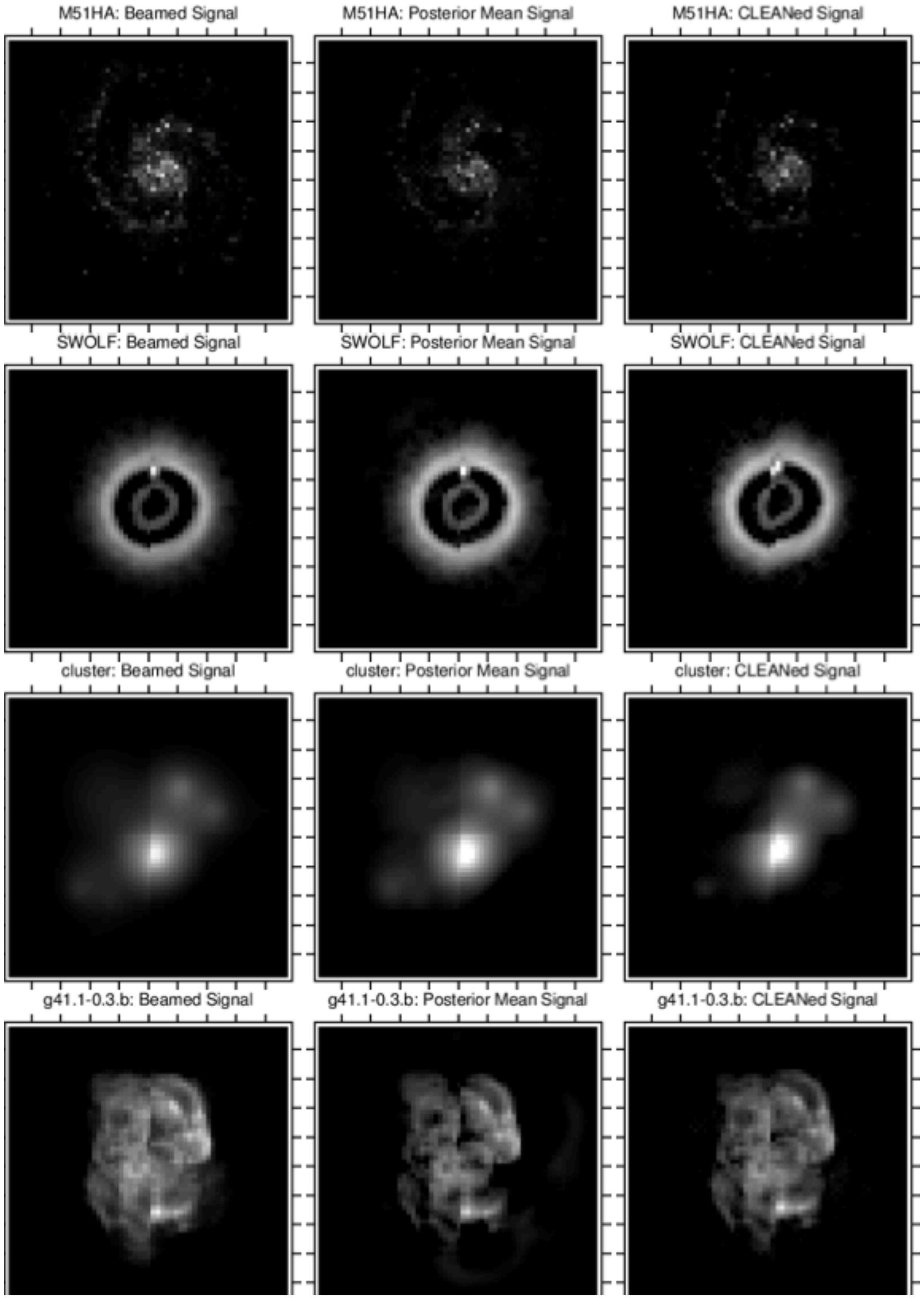
(Sutter et al. 2013)

image results



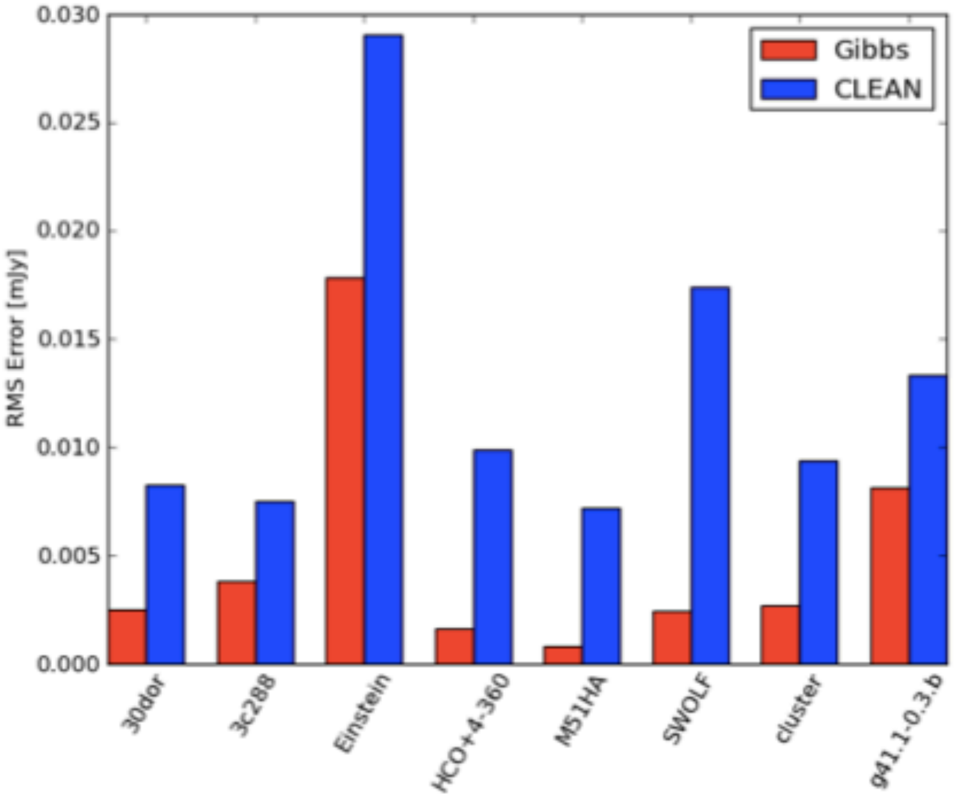
(Sutter et al. 2013)

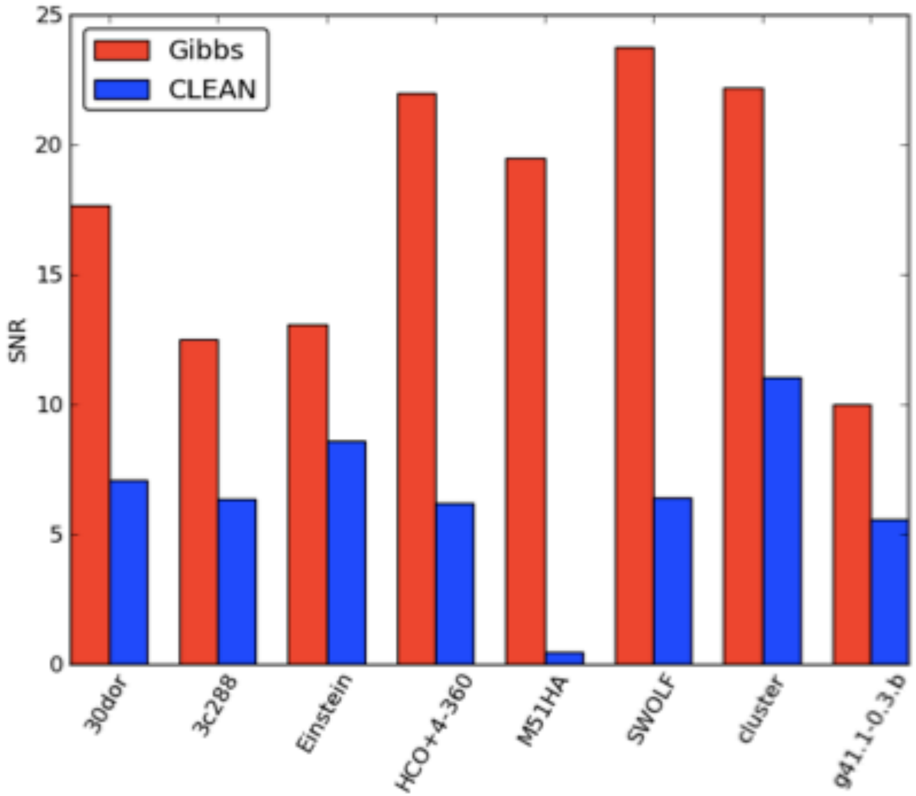
image results



(Sutter et al. 2013)

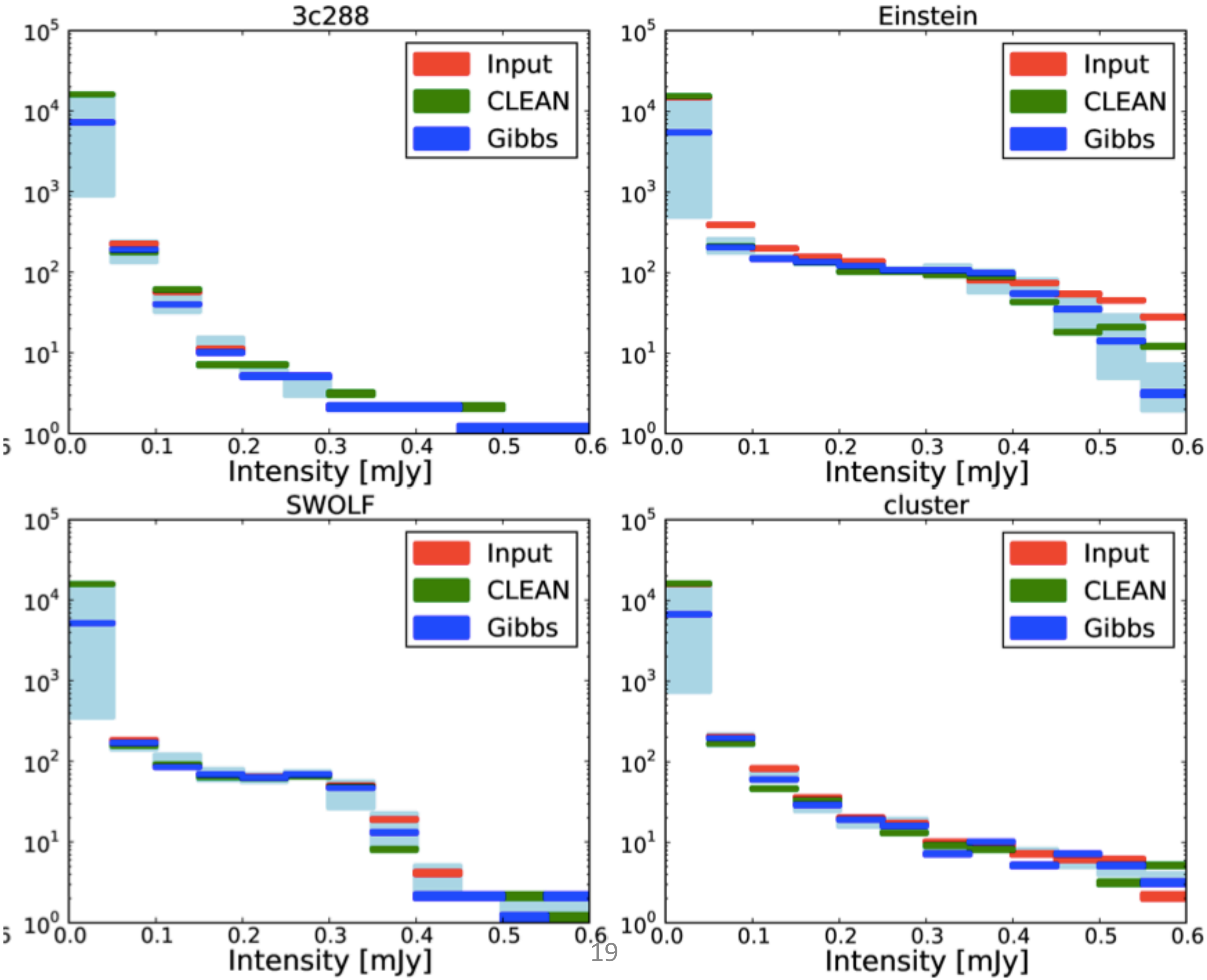
Gibbs performs better than CLEAN



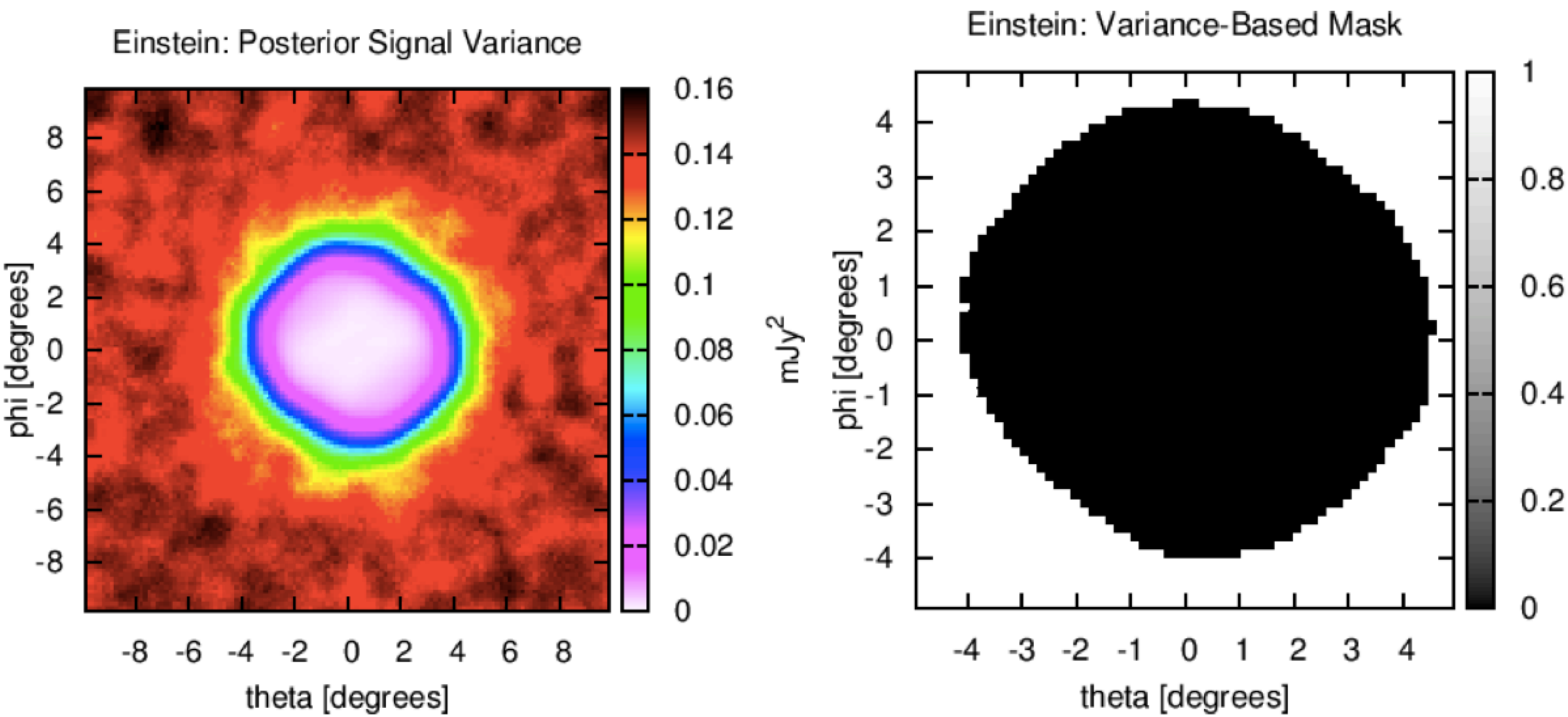


(Sutter et al. 2013)

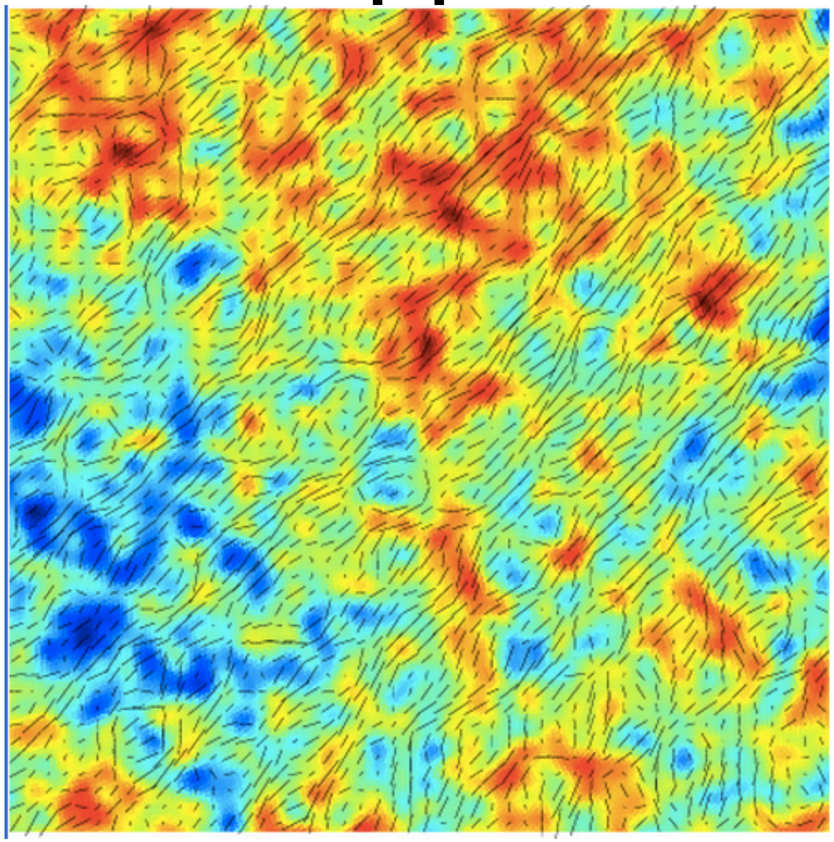
Gibbs gives uncertainty information

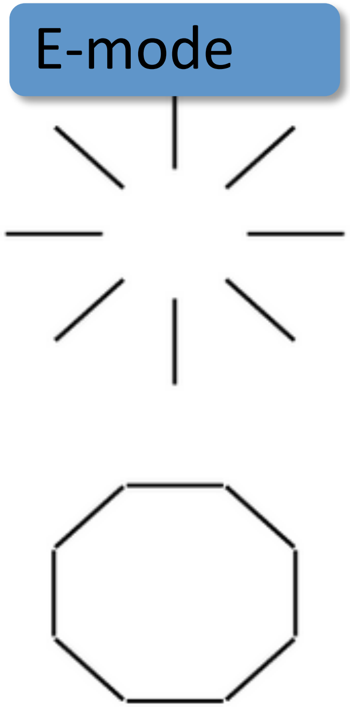


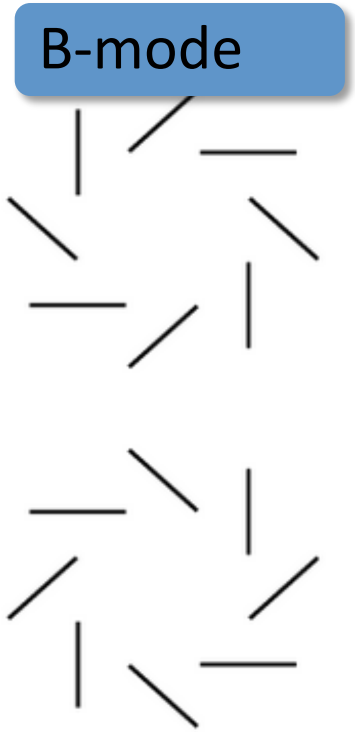
Uncertainty information

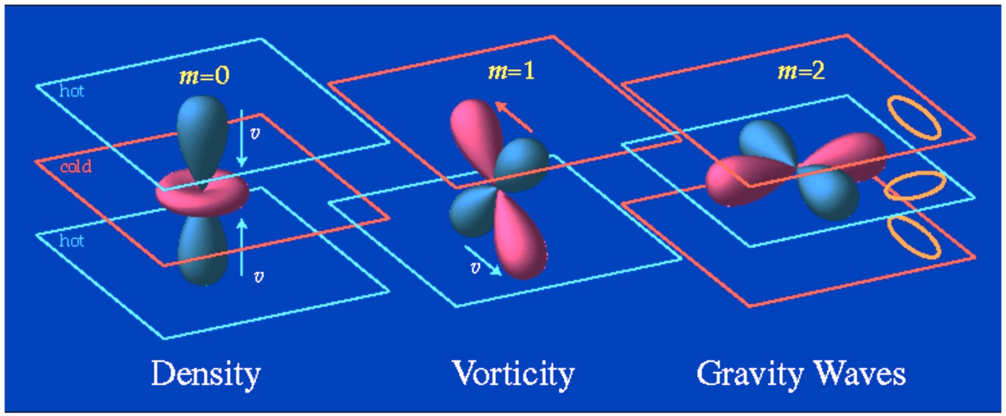


application: CMB B-modes

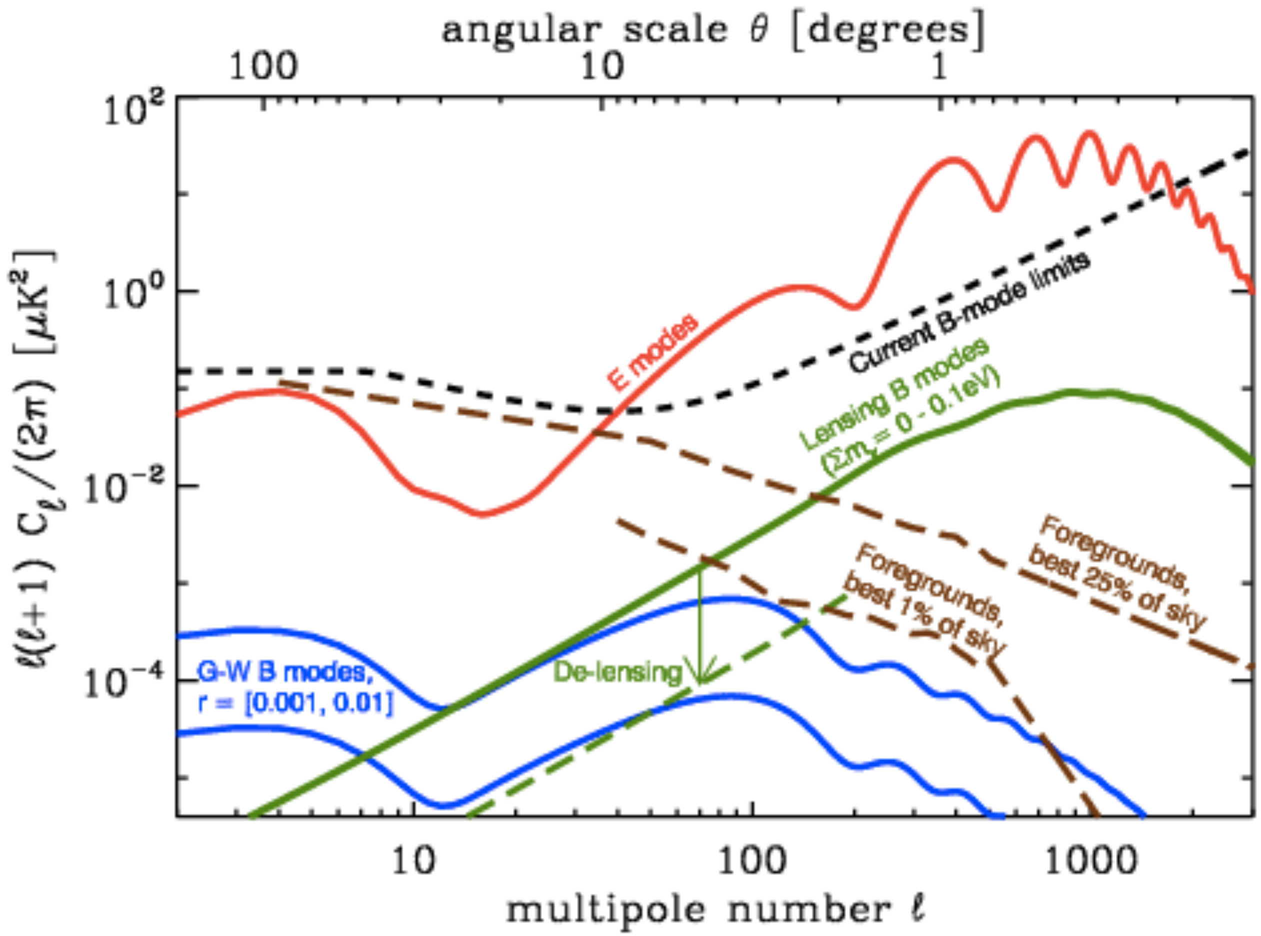




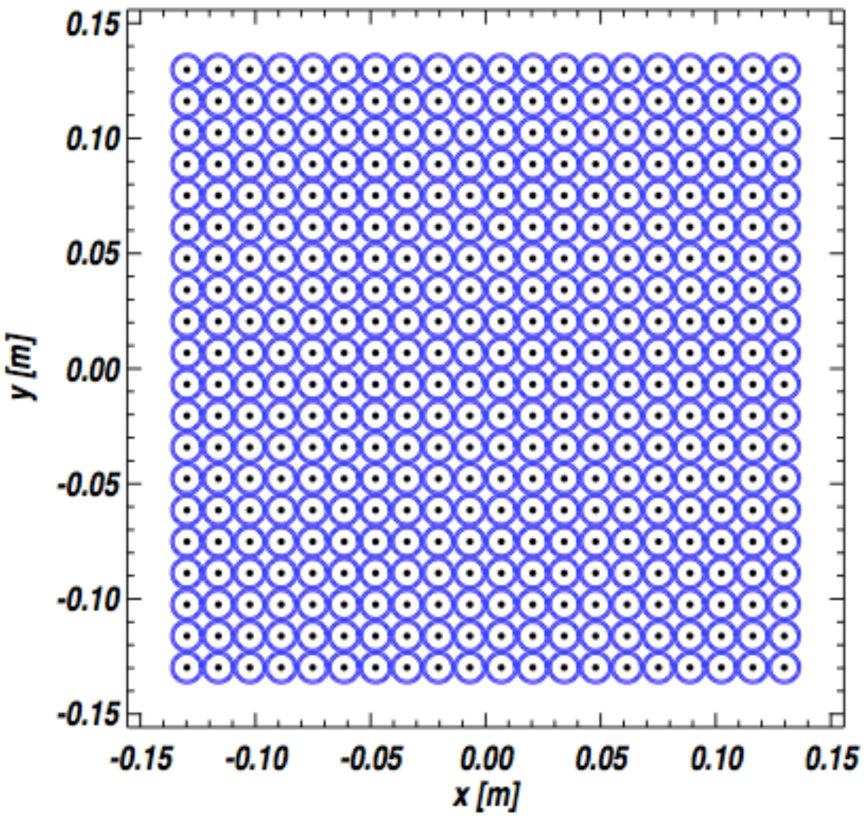


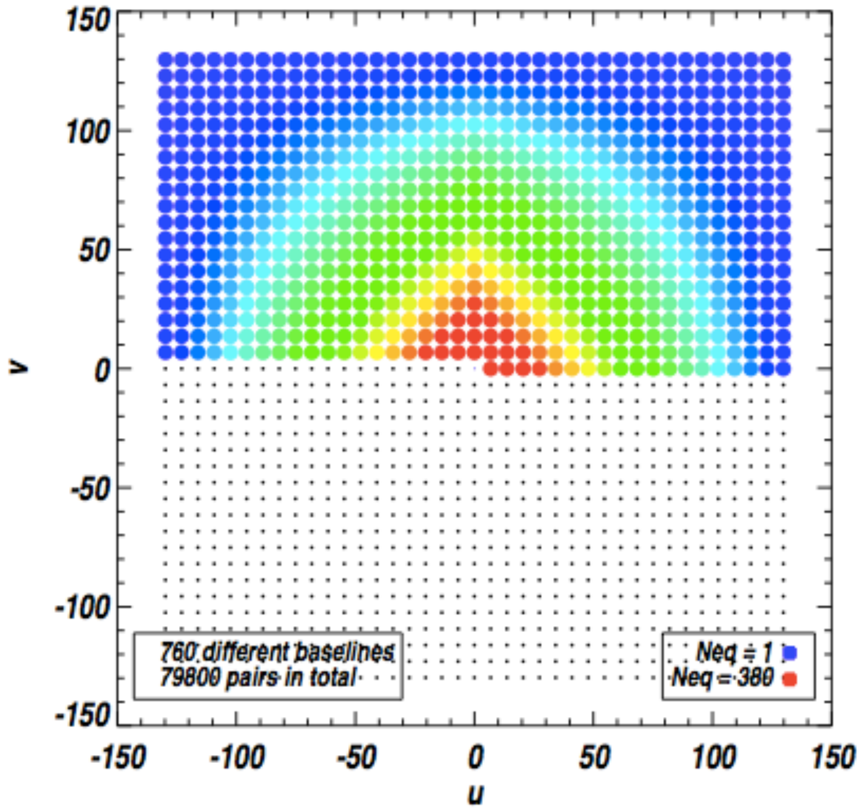


application: CMB B-modes

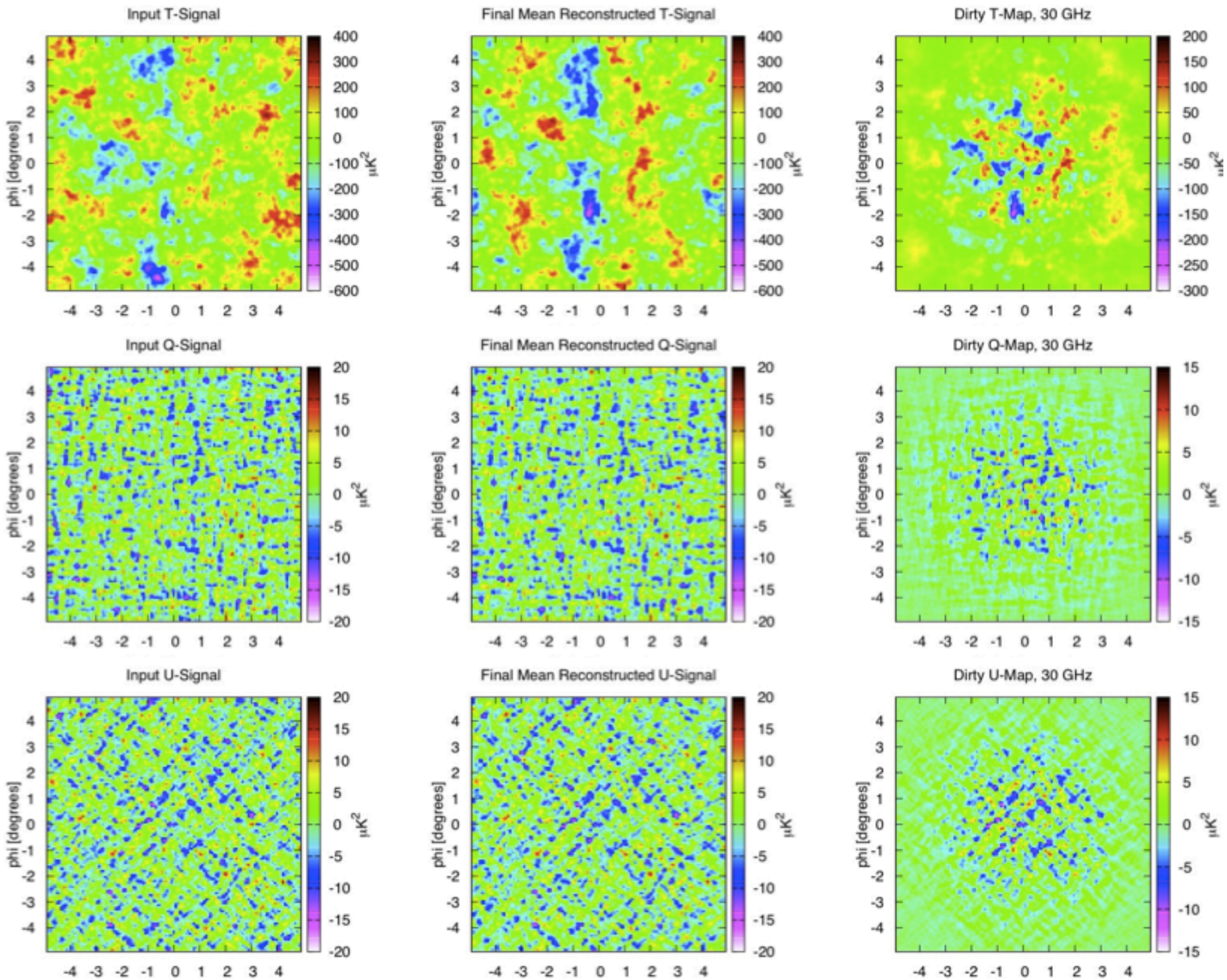


Antenna placement for a fiducial experiment





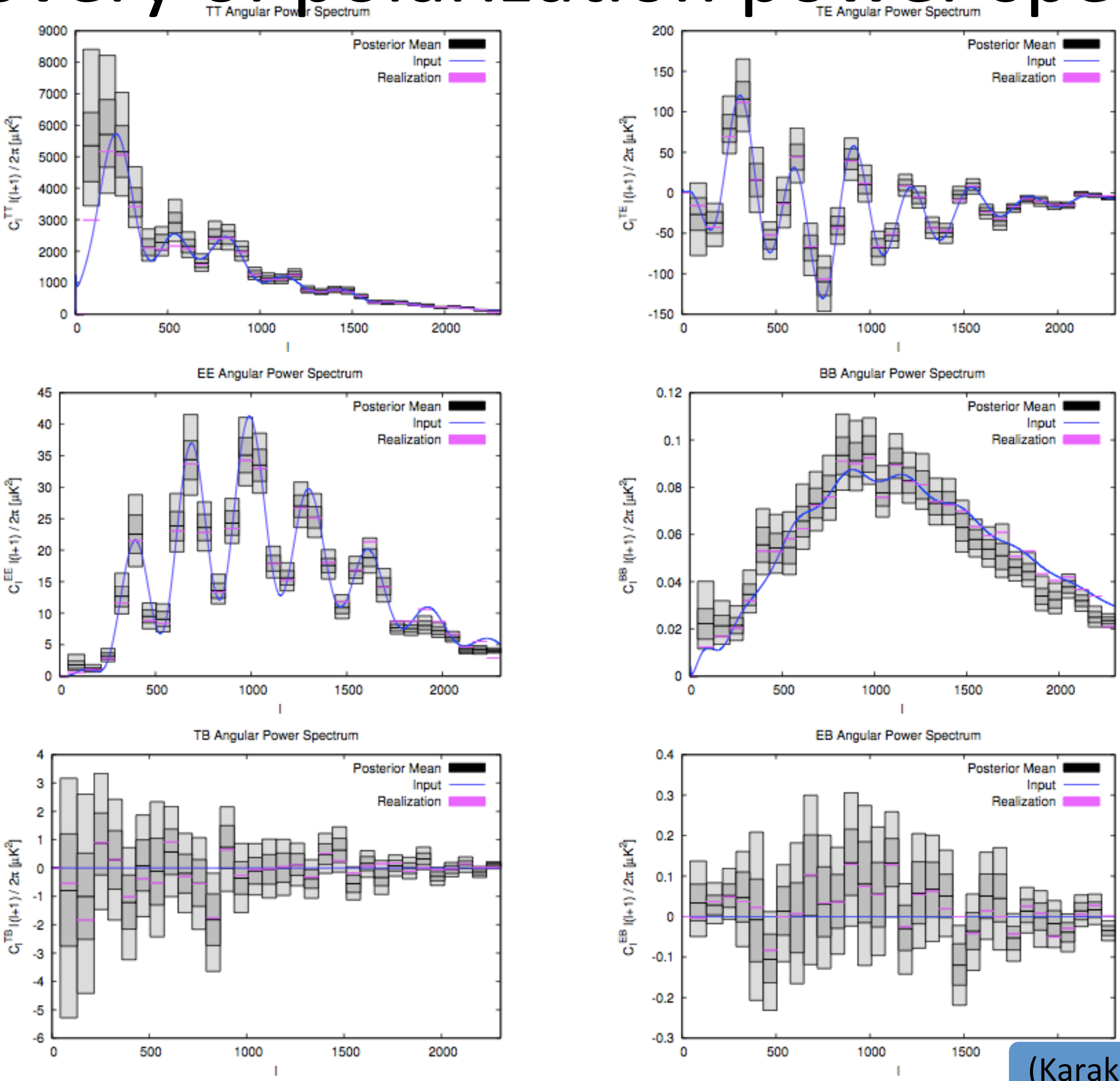
recovery of polarization maps



(a) Signal Realization (c) Final Mean Posterior Map (c) Dirty Map

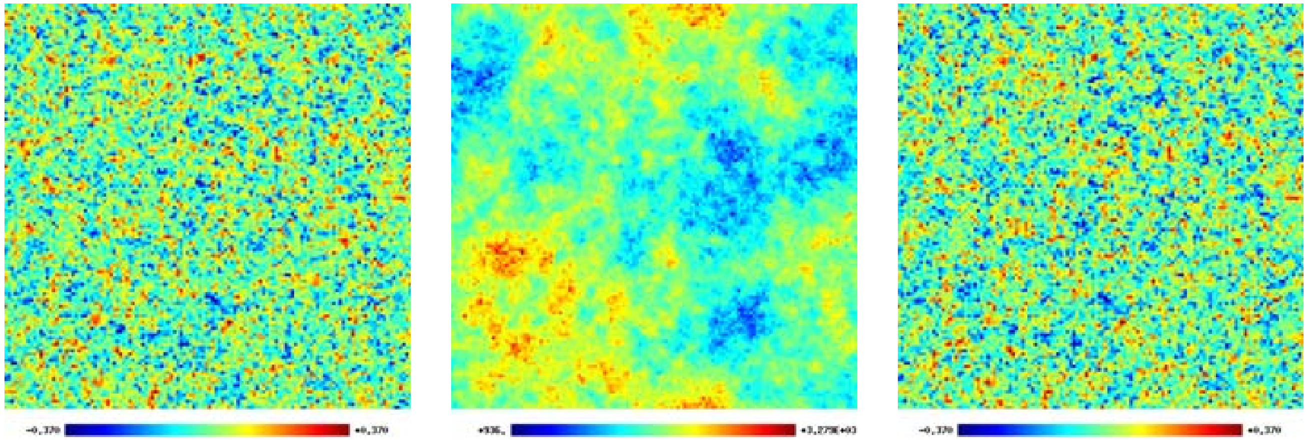
(Karakci et al 2012)

recovery of polarization power spectra



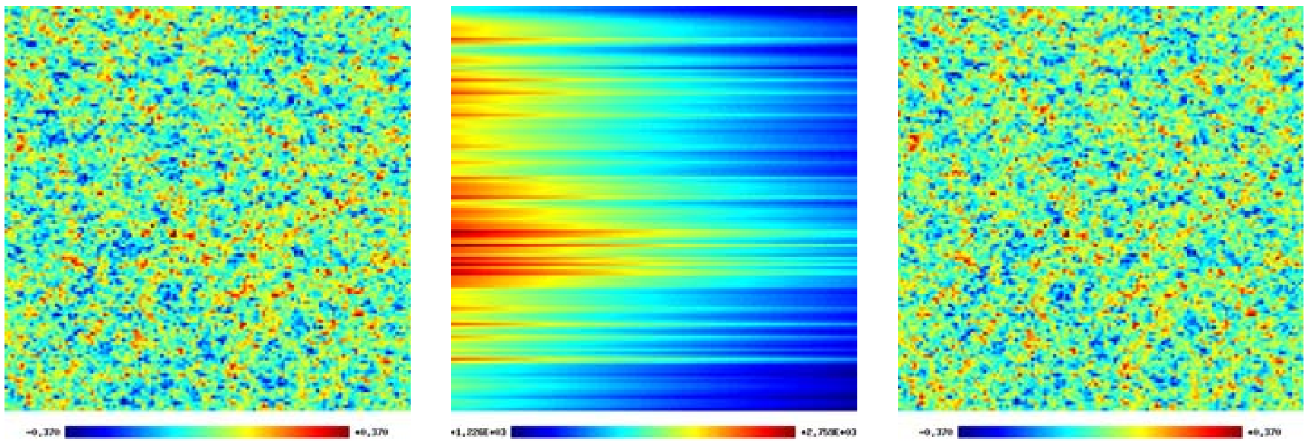
(Karakci et al 2012)

Bayesian methods for 21cm cosmology: extension to 3-D



(a) Input $T_{21\mathrm{cm}}(\theta_x, \theta_y)$ (b) $T_{\mathrm{sky}}(\theta_x, \theta_y)$ (c) Recovered $T_{21\mathrm{cm}}$

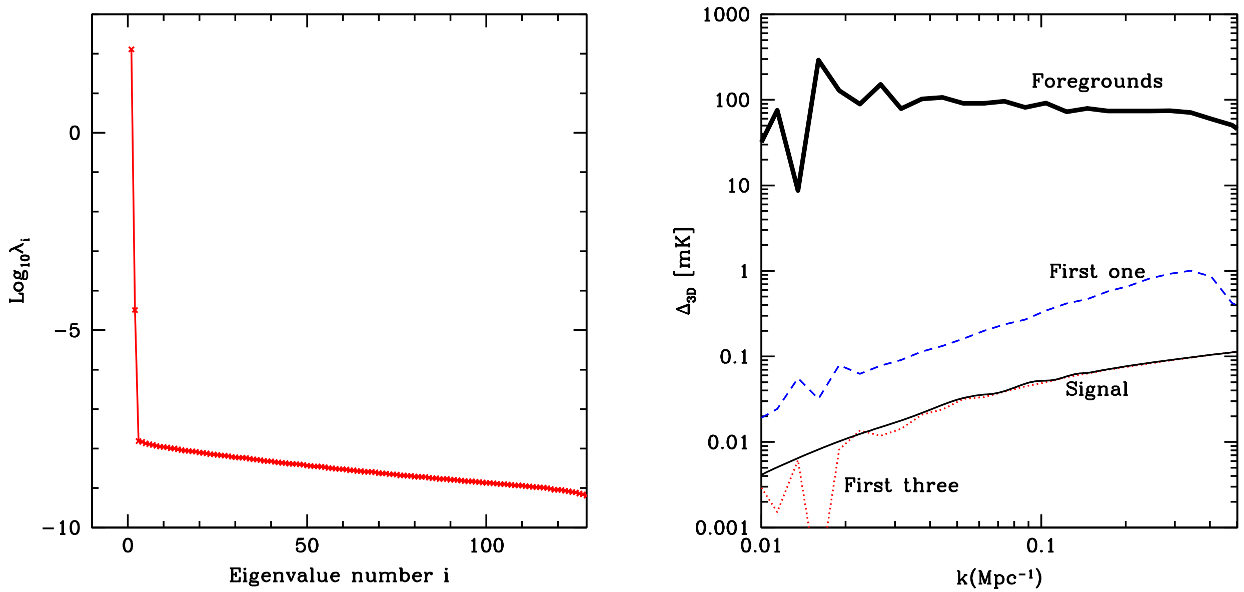
Slice perpendicular to the plane of the sky



(d) Input $T_{21\mathrm{cm}}(\nu, \theta_y)$ (e) $T_{\mathrm{sky}}(\nu, \theta_y)$ (f) Recovered $T_{21\mathrm{cm}}$

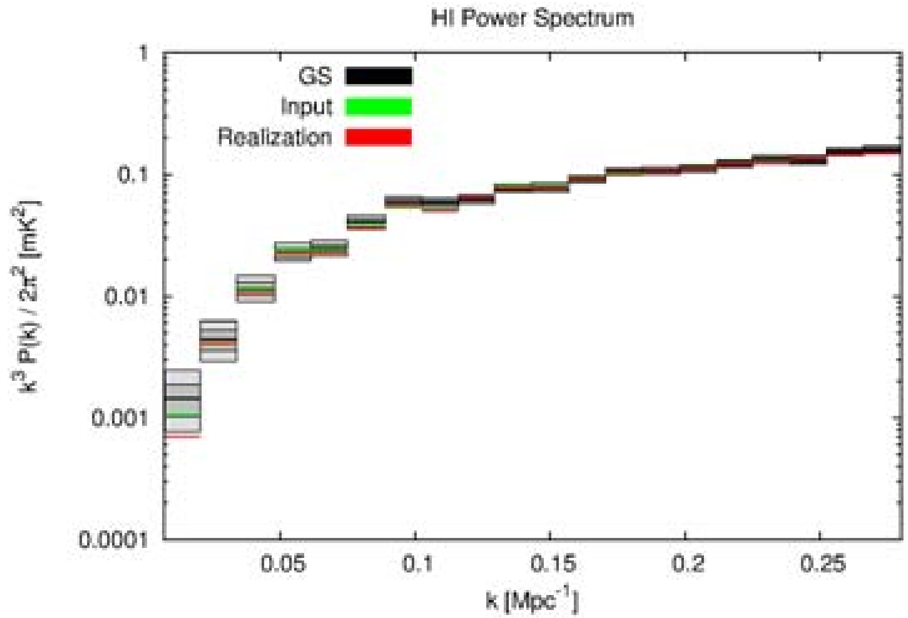
Frequency $\longrightarrow$

Foreground projection cleans the power spectrum



(a) Eigenvalues of $\mathbf{R}$ (b) Dimensionless power spectra

Bayesian power spectrum recovery from multi-frequency (3D) interferometric observations



Conclusions/future work

- Probabilistic imaging is a powerful, broadly applicable, parameter-free technique
- Power spectrum inference is a free bonus
- Now have a 3D implementation for radio data cubes
- The formalism allows inclusion of any foreground prior based on Gaussian random fields (e.g. KL approach)
- Next steps: application of (semi-) blind approaches to CMB analysis in 21cm context?