Parallel CLEAN: beyond the frequency domain

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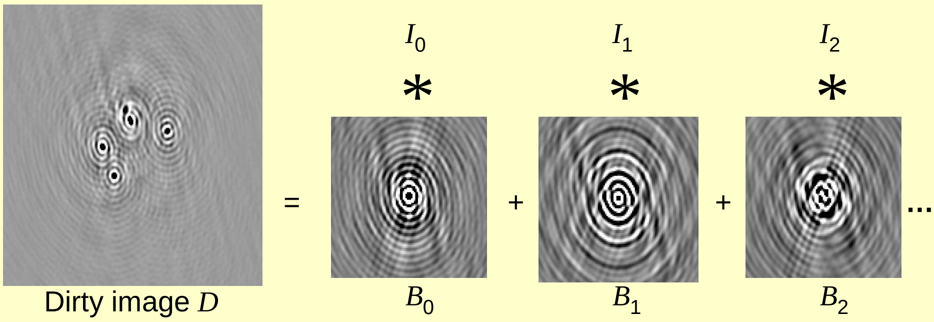
The CLEAN algorithm[1,2], despite its problematic convergence properties and its need for heuristic intervention and tuning, is the most commonly used means of attenuating sampling artifacts in images made through radio interferometry. Subsequent modifications by Conway[3] and Sault and Wieringa[4] adapted CLEAN to observations made using a wide fractional bandwidth, which are not well handled by the original algorithm. Here a generalized version of the Sault-Wieringa algorithm is applied to other cases where standard CLEAN also fails, including time-variable[5] and off-pixel-centre sources[6]. A 1-dimensional version of the latter technique can also be applied to extract non-integer frequency values from periodograms.

Generalized parallel CLEAN: dirty image as a sum of convolutions.



The parallel CLEAN algorithm[4]:

$R_i = D * B_i$ (* here represents correlation)
$A_{ij} = B_i * B_j$
Construct $\mathbf{M}$ such that $m_{ij} = A_{ij}(0,0)$
for k=1, N_{iter}:
- $R = \Sigma R_i$
- Find $\mathbf{r}_{max}$, the location of max(R)
- $c'_i = \lambda R_i(\mathbf{r}_{max})$
- $R_i = R_i - \Sigma_j c'_j A_{ij}(\mathbf{r}-\mathbf{r}_{max})$ (λ usually <<1)
- $\mathbf{c} = \mathbf{M}^{-1}\mathbf{c'}$
- Save the vector clean component $\mathbf{c}$

Time-varying sources: the wide-band case

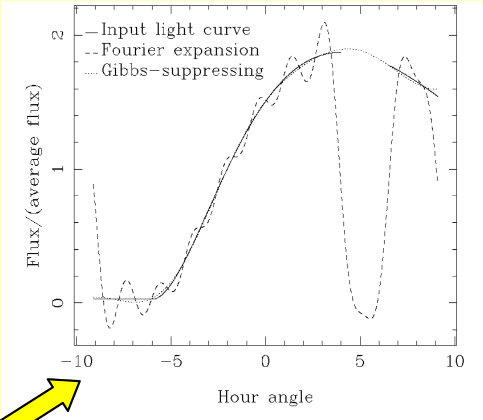
Expand the sky brightness map $I(\mathbf{r},\nu,t)$ in basis functions:

$$I(\mathbf{r},\nu,t)=\sum_{p=0}^{N_f-1}\sum_{q=0}^{N_t-1} A_{p,q}(\mathbf{r})F_p(\nu)T_q(t)$$

Each F_pT_q generates a 'dirty beam', giving $N = N_f \times N_t$ beams in total.

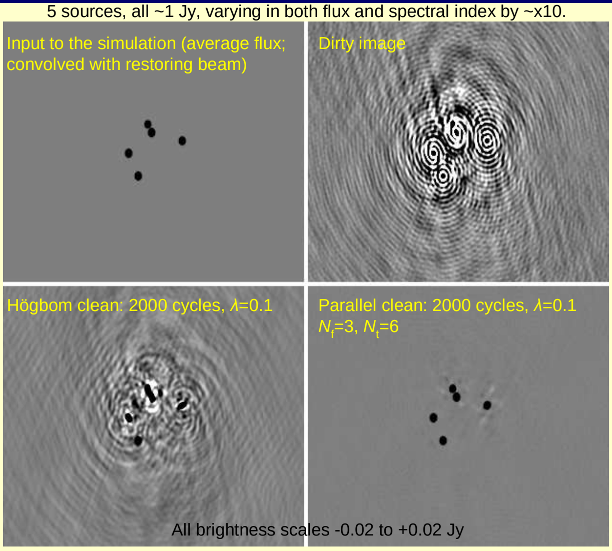
Just as Högbom CLEAN models $I(\mathbf{r})$ as sum of scalar clean components, so Sault-Wieringa CLEAN models $A_{p,q}(\mathbf{r})$ as a sum of vector clean components $c_{p,q}$.

With a proper choice of time basis function, this expansion in the image plane allows one to avoid Gibbs ringing either at the boundaries or at gaps in the time sequence of the data.



Since light curves are expected to be more rapidly varying than spectra, N_t and therefore the total number of beams N may need to be large to obtain good modelling of the sources. But the algorithm (see top right) requires O(N^2) images to be stored. This can be reduced to O(N) if the beams are orthogonalized (eg via Gram-Schmidt) before commencing cleaning. Clean components can be recovered afterwards via a matrix inversion.

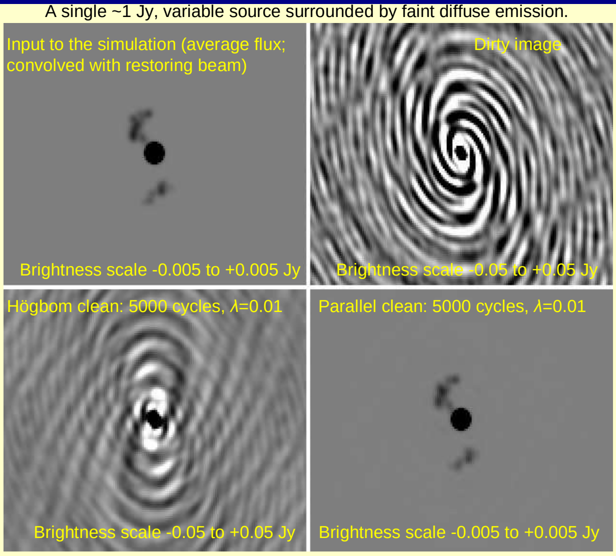
5 sources, all ~1 Jy, varying in both flux and spectral index by ~x10.



Time-varying sources: narrow-band observation, unresolved source

If time-variation is restricted to a single point source in a narrow-band observation, perfect decomposition can be achieved with just 2 beams: the usual dirty beam for one, and a beam constructed from the entire light curve of the data for the other. Each pixel of the dirty image must be a combination of these two.

A single ~1 Jy, variable source surrounded by faint diffuse emission.



Sub-pixel cleaning (1D example).

Data: $y(x) = S(x)\cdot[A\cos(2\pi[n+f]x/X + \varphi) + y'(x)]$;
n is integer, f in [-0.5,0.5].

The 'beams':

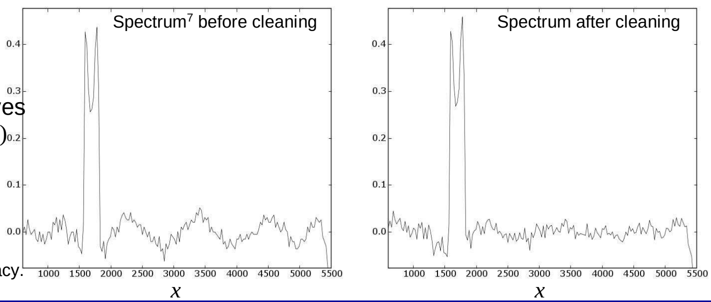
$B_0 = \mathfrak{F}\{S(x)/2\}$
$B_1 = \mathfrak{F}\{\pi i x/X\, S(x)\}$

Fourier transforming gives

$\mathfrak{F}\{y\}=\delta(\omega-n)*Ae^{i\varphi}(B_0+fB_1)$
$+\mathfrak{F}\{Sy'\}$

A, f and φ are easily recovered after Sault-Wieringa processing.

Higher orders ➔ greater accuracy.



1: Högbom J A 1974, Astron. Astrophys. Suppl. 15, 417
2: Schwab F R 1984, Ap. J. 89, 1076
3: Conway J E, Cornwell T J & Wilkinson P N 1990, MNRAS 246, 490
4: Sault R & Wieringa M H 1994, A&A Suppl. Ser. 108, 585
5: Stewart I M, Fenech D M, Muxlow T B M & Rushton A 2009, in preparation
6: Stewart I M 2009, in preparation
7: Schröder A C, private communication.

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