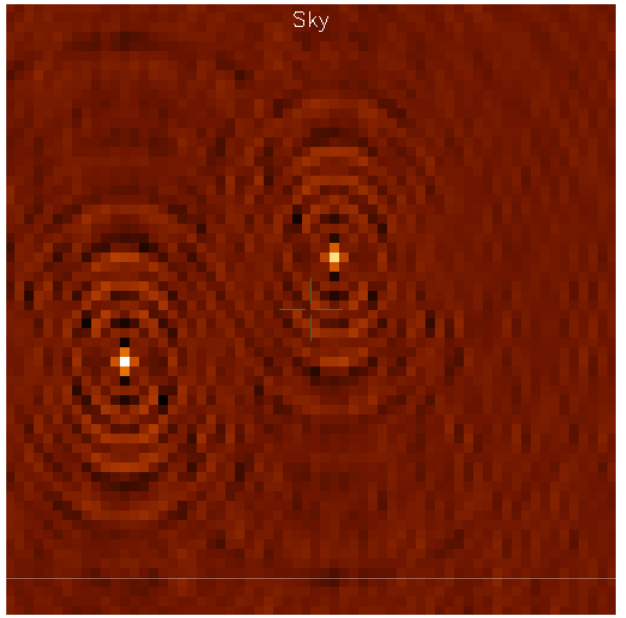
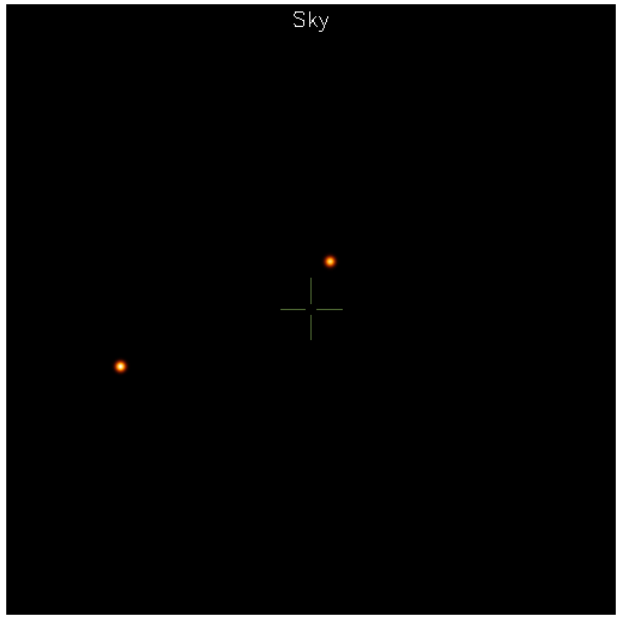
‘Deconvolution’.

- How can we go from
  - this
  - to this?

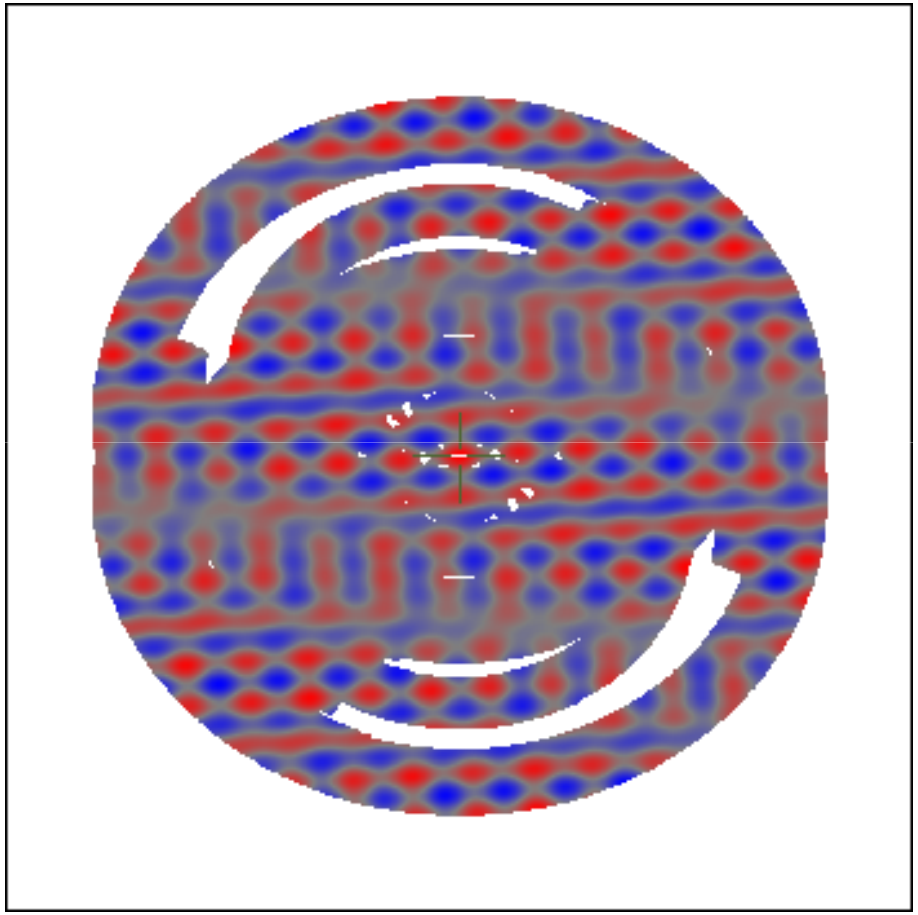


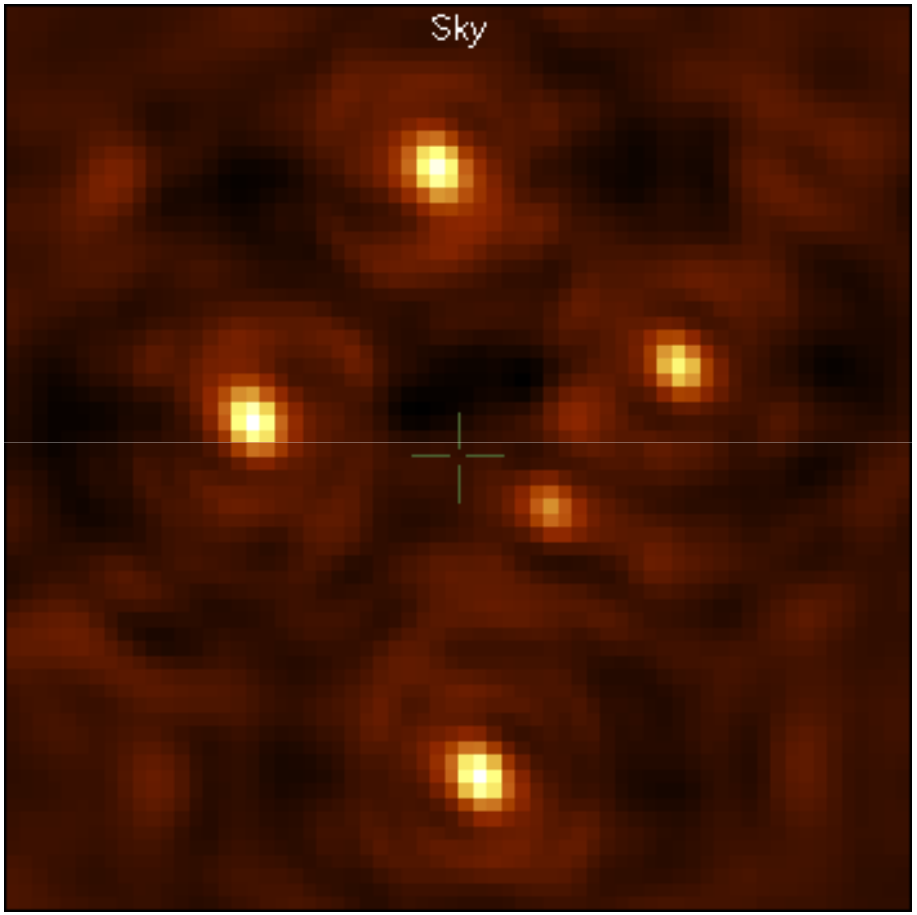


- Deconvolution in the sky plane implies interpolation or reconstruction of missing values in the UV plane.
- But we, the human observer, can look at the top image and just ‘know’ that it is 2 point sources on a blank field.

Looking again at the KAT-7 simulation.

Convolution =FT=> multiplication; so deconvolution =FT=> division?





But we would need to divide by zero. The information is simply no longer available. We say ‘deconvolve’ but what me must do is interpolate.

The CLEAN algorithm.

Högbom J A, Astron. Astrophys. Suppl. 15, 417 (1974)

1. Find the brightest pixel $\mathbf{r}_b$ in the dirty image.
2. Measure its brightness $D(\mathbf{r}_b)$.
3. Subtract $\lambda D(\mathbf{r}_b)B(\mathbf{r}\text{-}\mathbf{r}_b)$ from the image, where λ is a number in the approximate range 0.01 to 0.2.
4. Repeat until satisfied.

- The successive numbers $\lambda D(\mathbf{r}_b)$ are called clean components.

Further refinements have been added by Clark and later by Cotton and Schwab, but the essential nature of the algorithm remains the same.

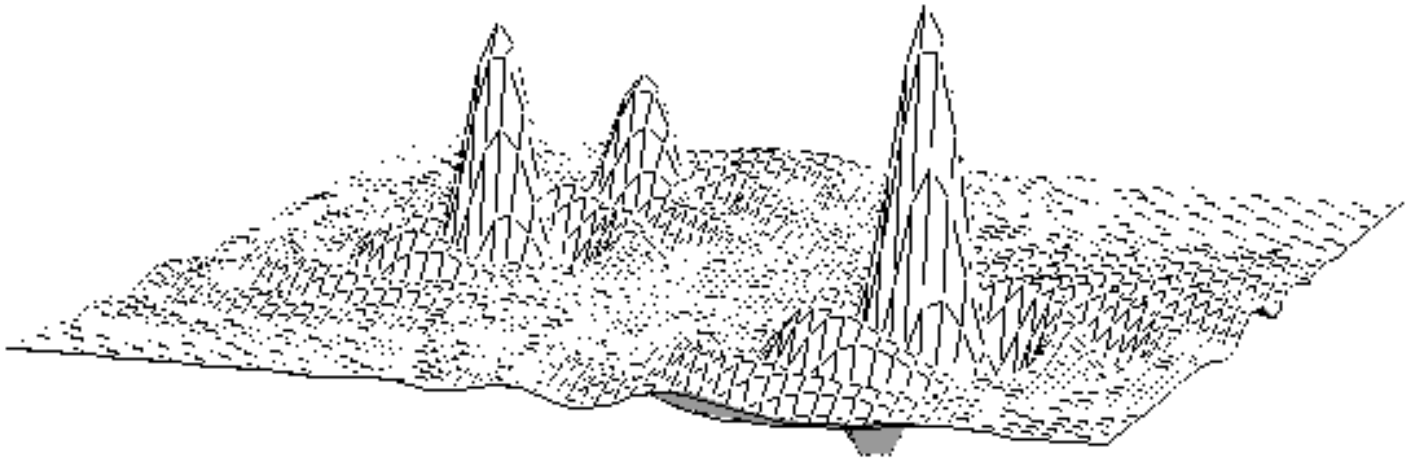
(It has only quite recently been placed on a sound mathematical footing.)

Problems:

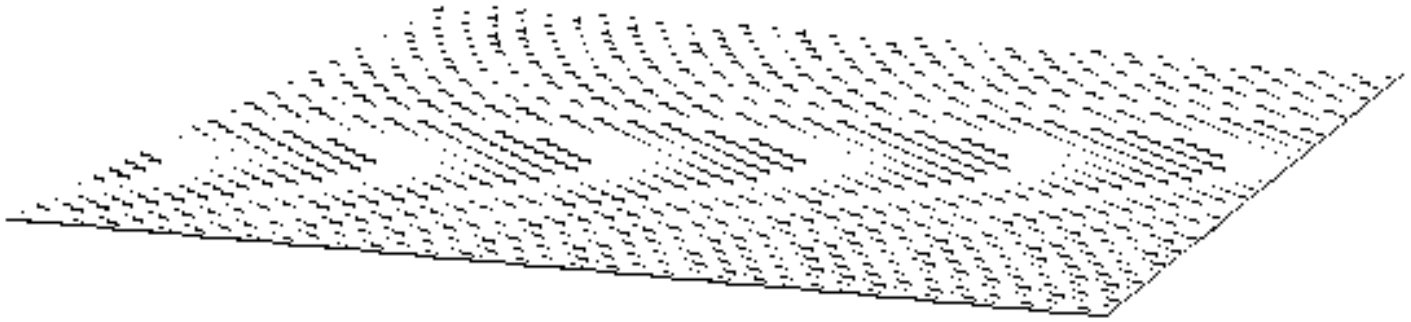
- CLEAN works best on point sources.
- Gridding means that dirty image is no longer quite the 'true' image convolved with the dirty beam.
- Difficult to know when to stop – cleaning is an art, not a science.
  - Underclean: you don't recover all the source flux.
  - Overclean: some of your 'clean components' will be noise.
    - You can usually tell when this has set in because your noise RMS will no longer decrease.

CLEANing

Dirty image

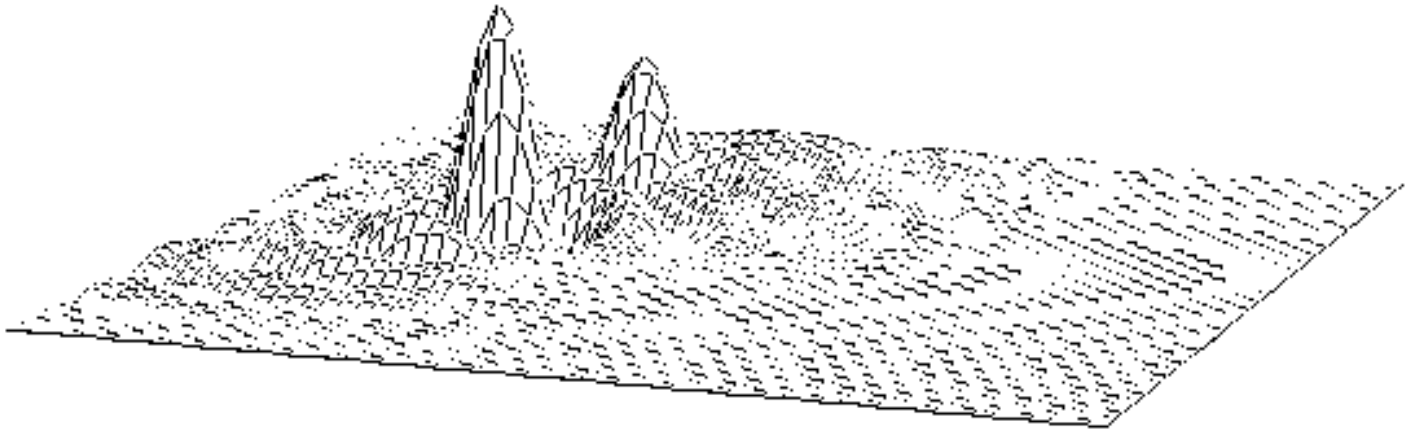


Cleaned image

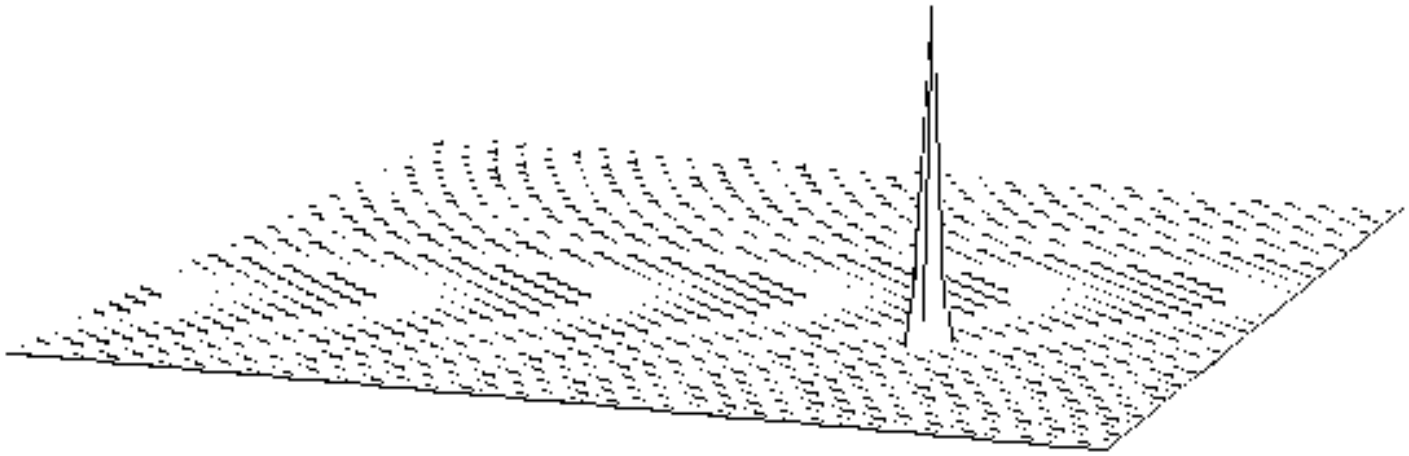


CLEANing

Dirty image

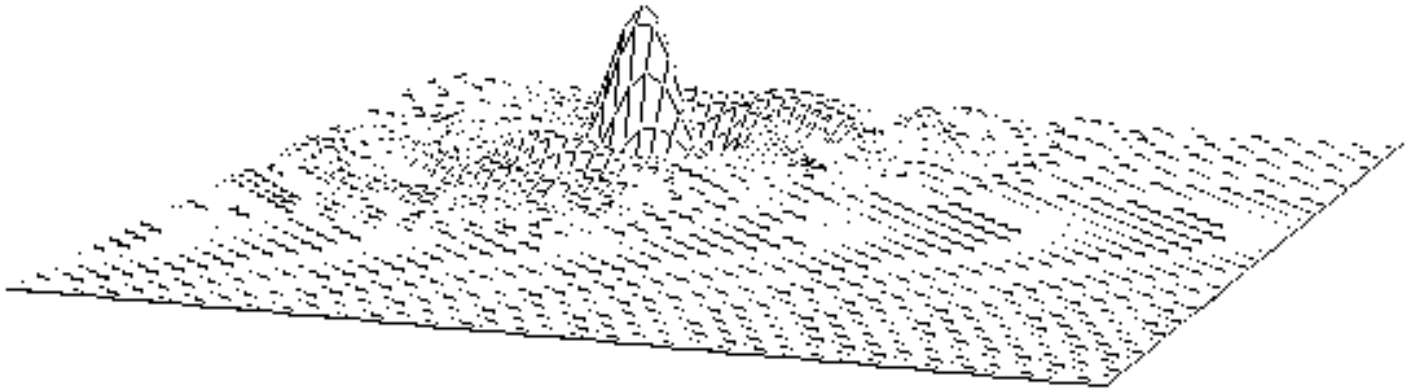


Cleaned image

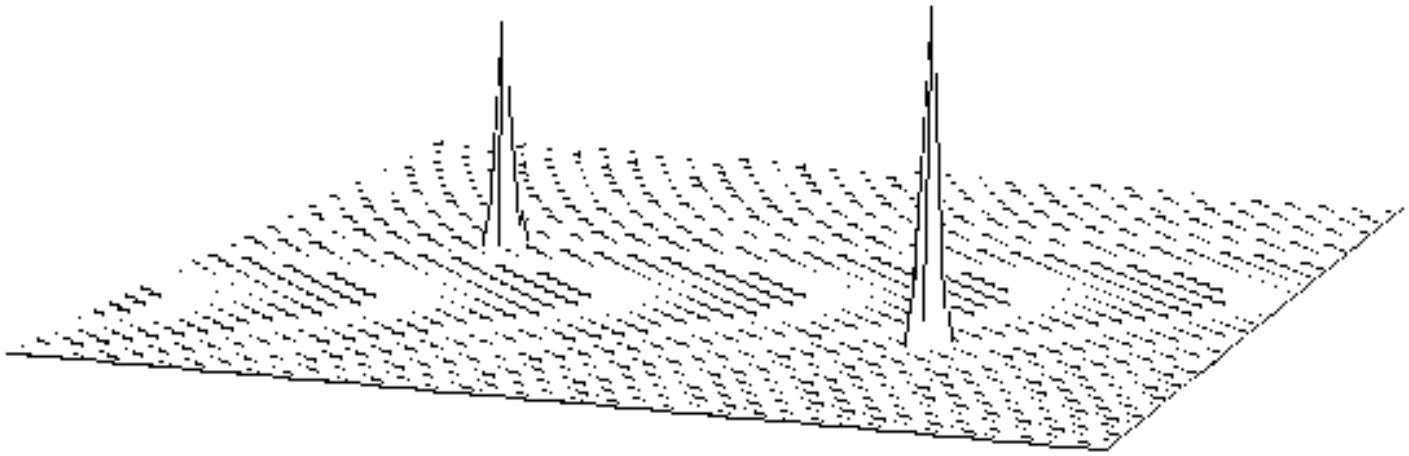


CLEANing

Dirty image

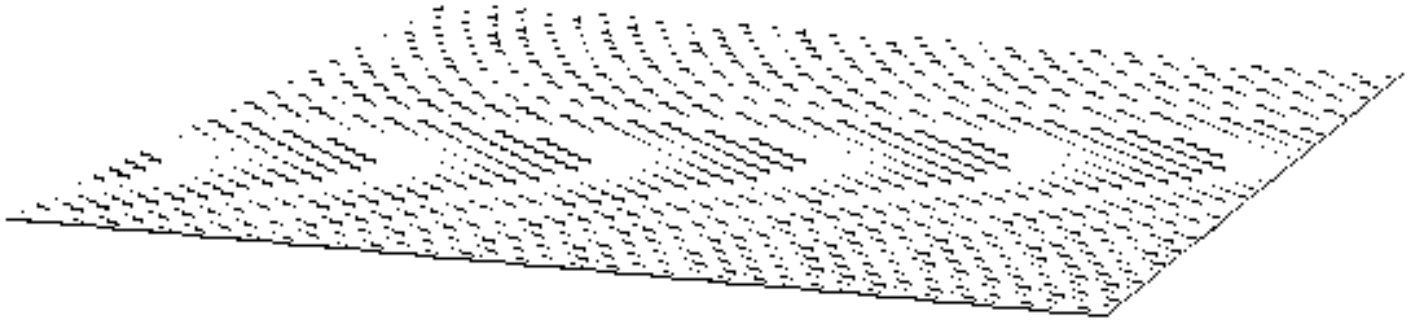


Cleaned image

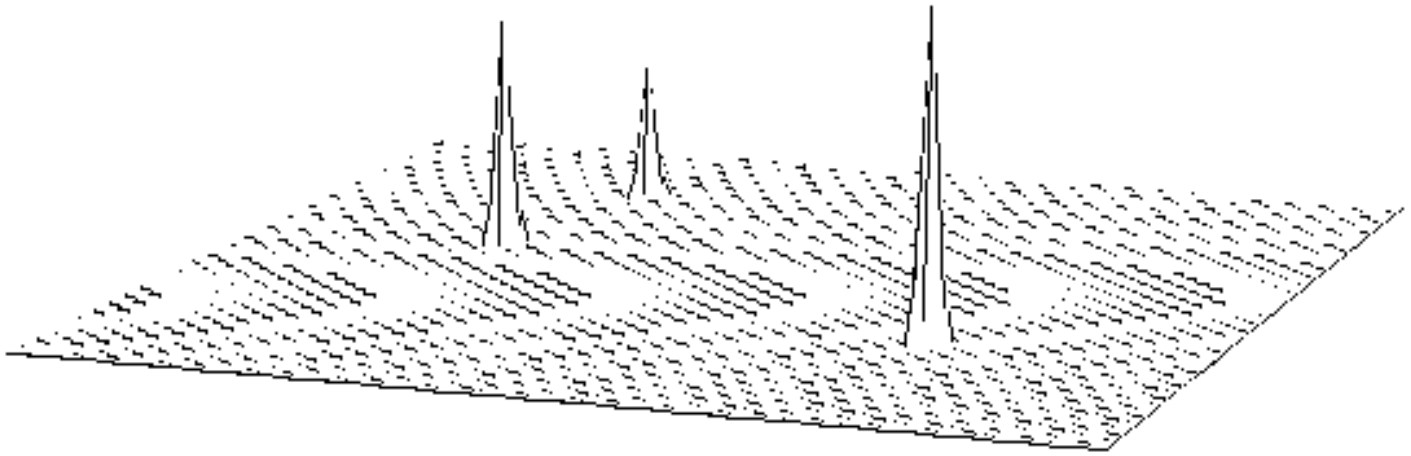


CLEANing

Dirty image



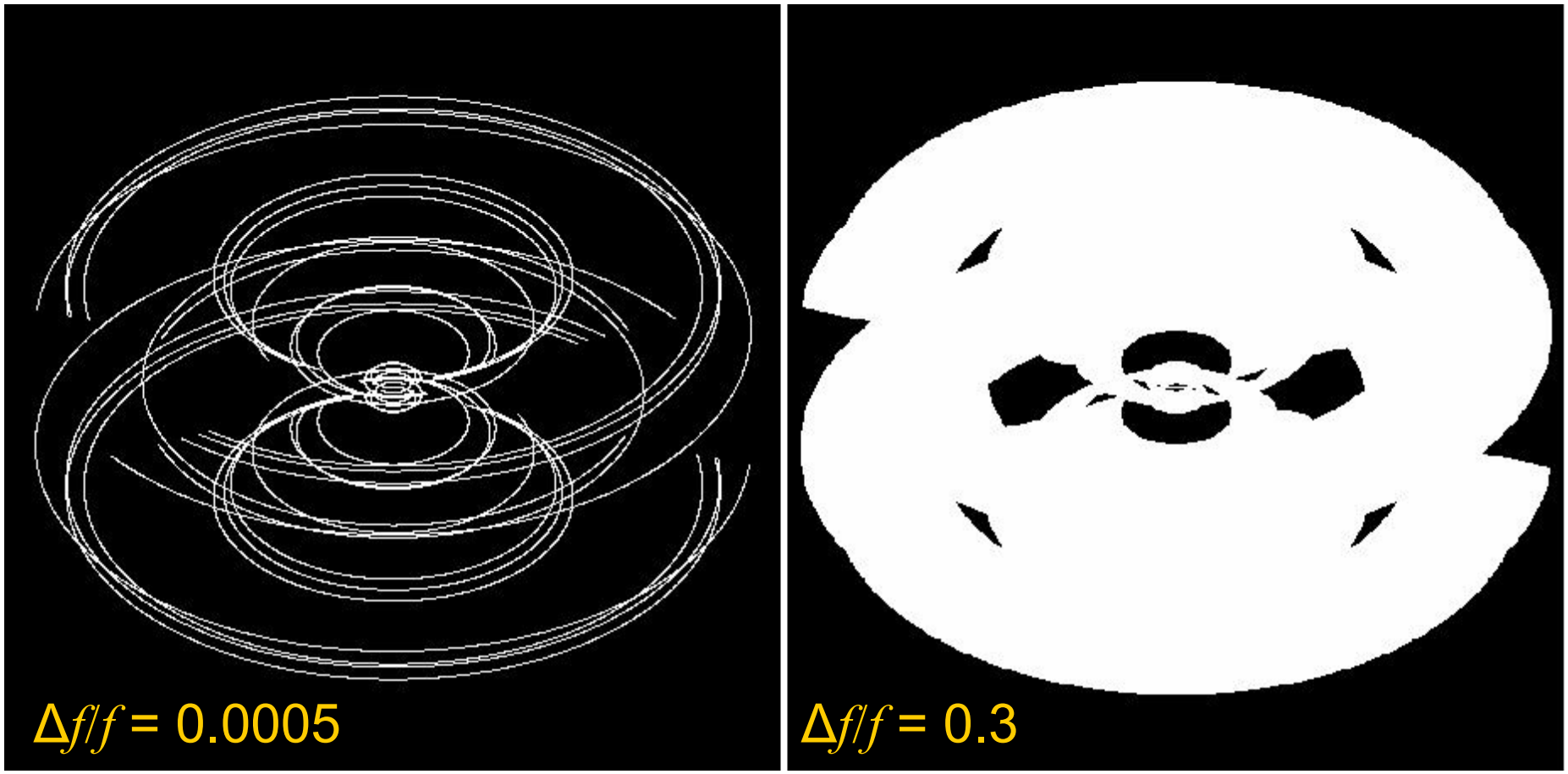
Cleaned image



Wide-band issues:

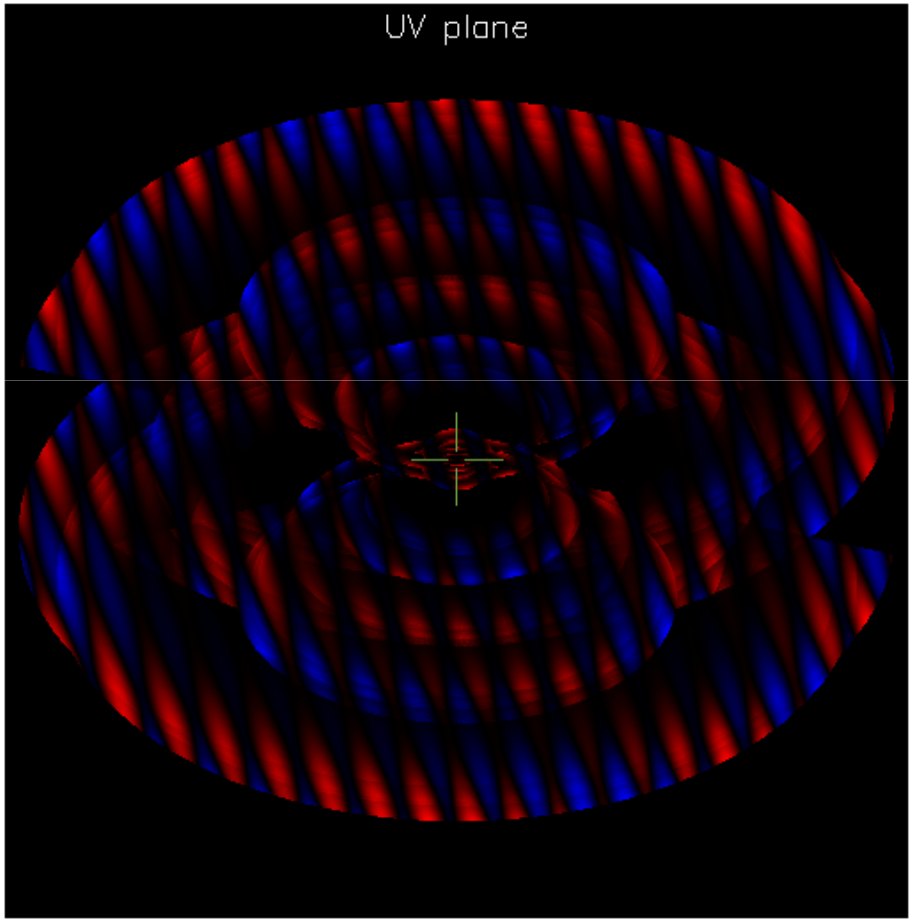
one can vastly increase the number of samples by extending the bandwidth.

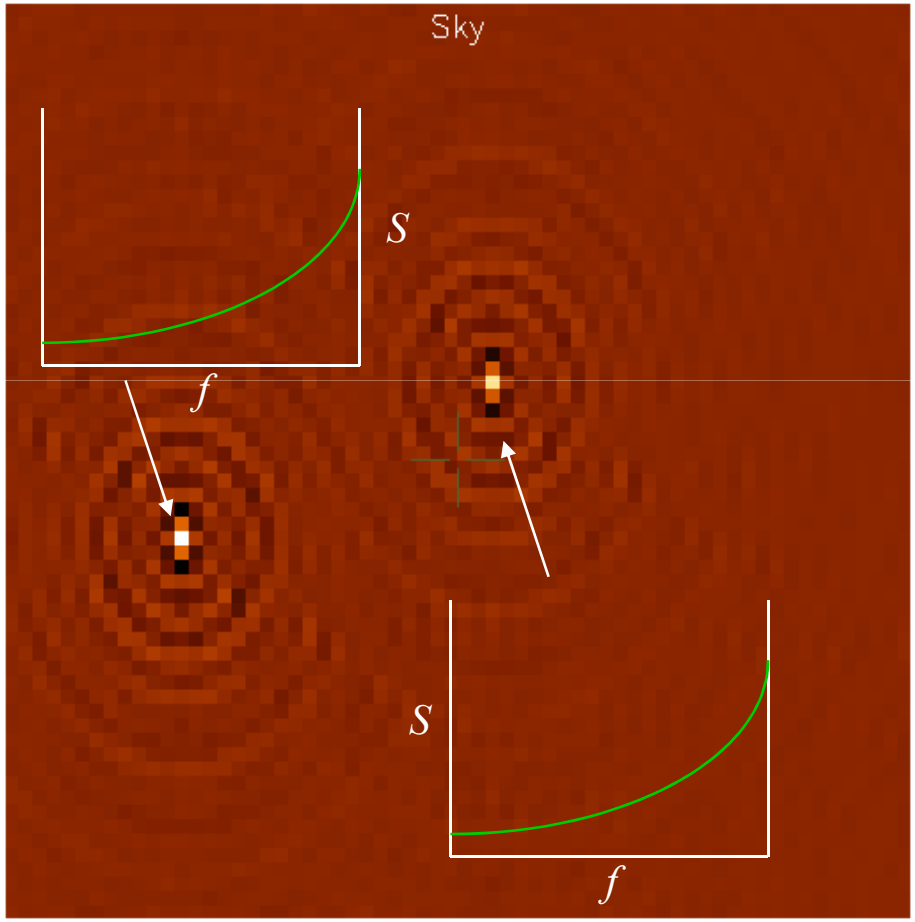
Simulated (e)MERLIN UV samples, δ=+35°



Description of the problem: an example.

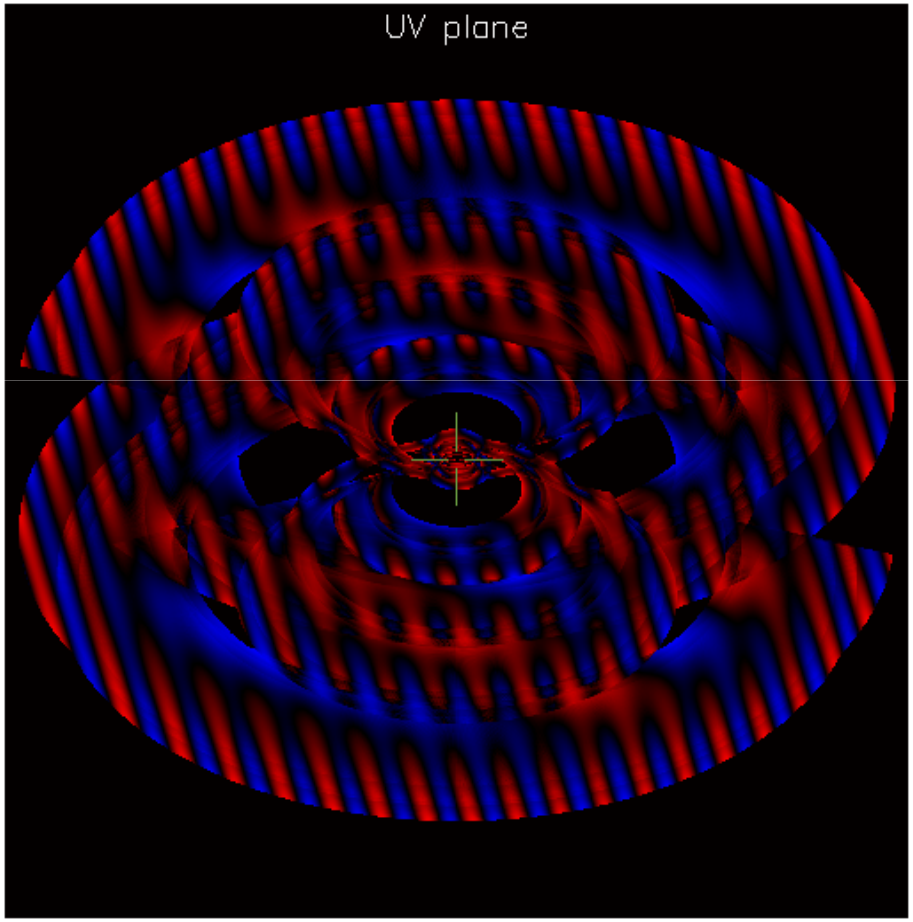
If both point sources have identical spectra, there *is* no problem.

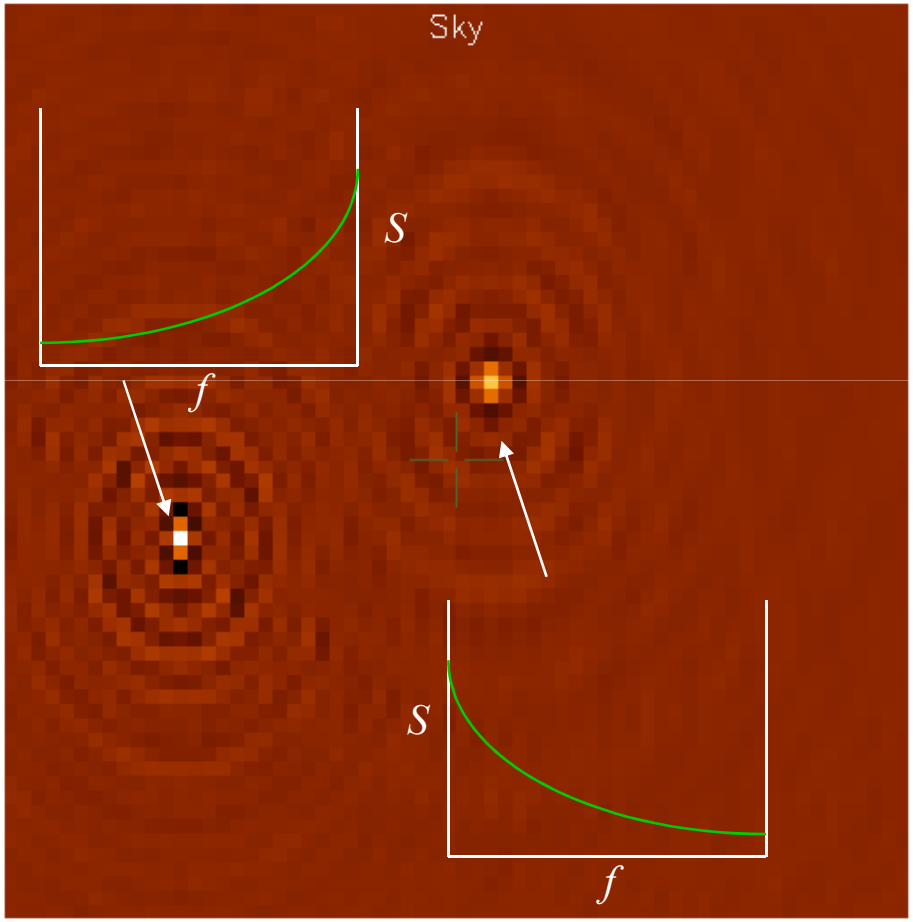




Description of the problem: an example.

More realistic: different spectra:





This will **not** clean away.

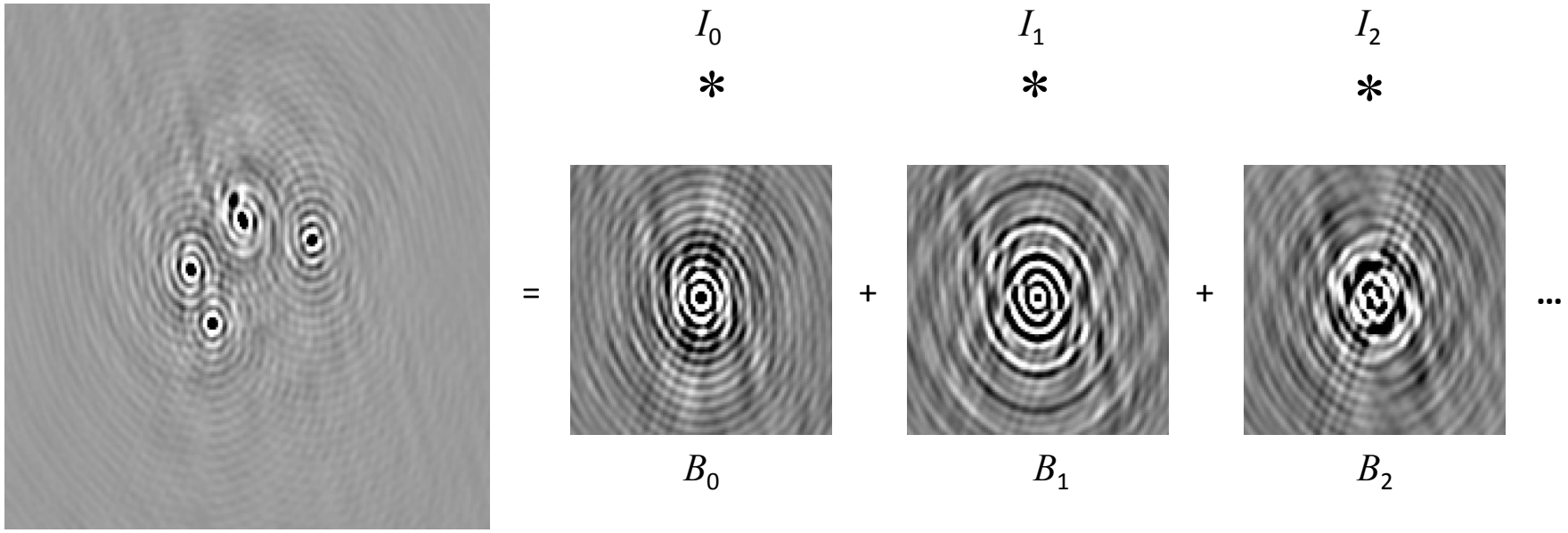
Parallel CLEAN for wide-band observations.

Conway J E, Cornwell T J & Wilkinson P N, MNRAS 246, 490 (1990)

Decomposed the dirty image as a sum of convolutions.

Sault R J & Wieringa M H, A&A Suppl. Ser. 108, 585 (1994)

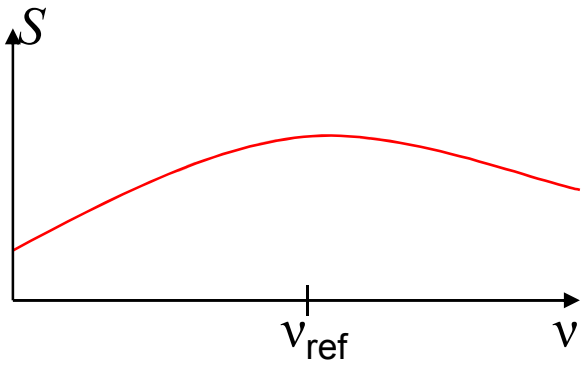
Described the parallel CLEAN algorithm.



Dirty image D

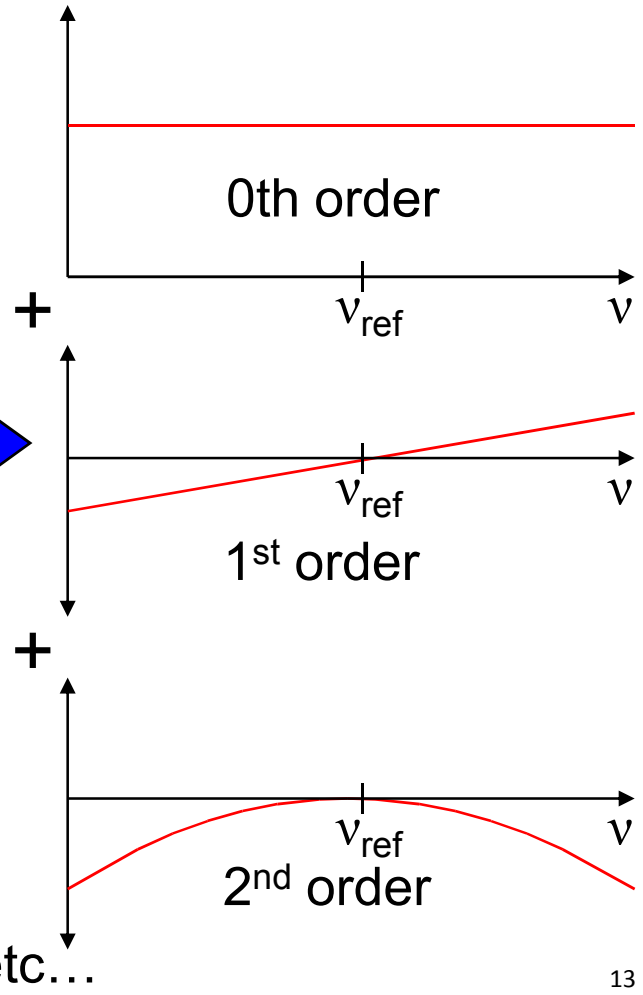
The Sault-Wieringa algorithm:

- The basic idea is to construct a number of dirty beams from components of a Taylor expansion of the spectrum.

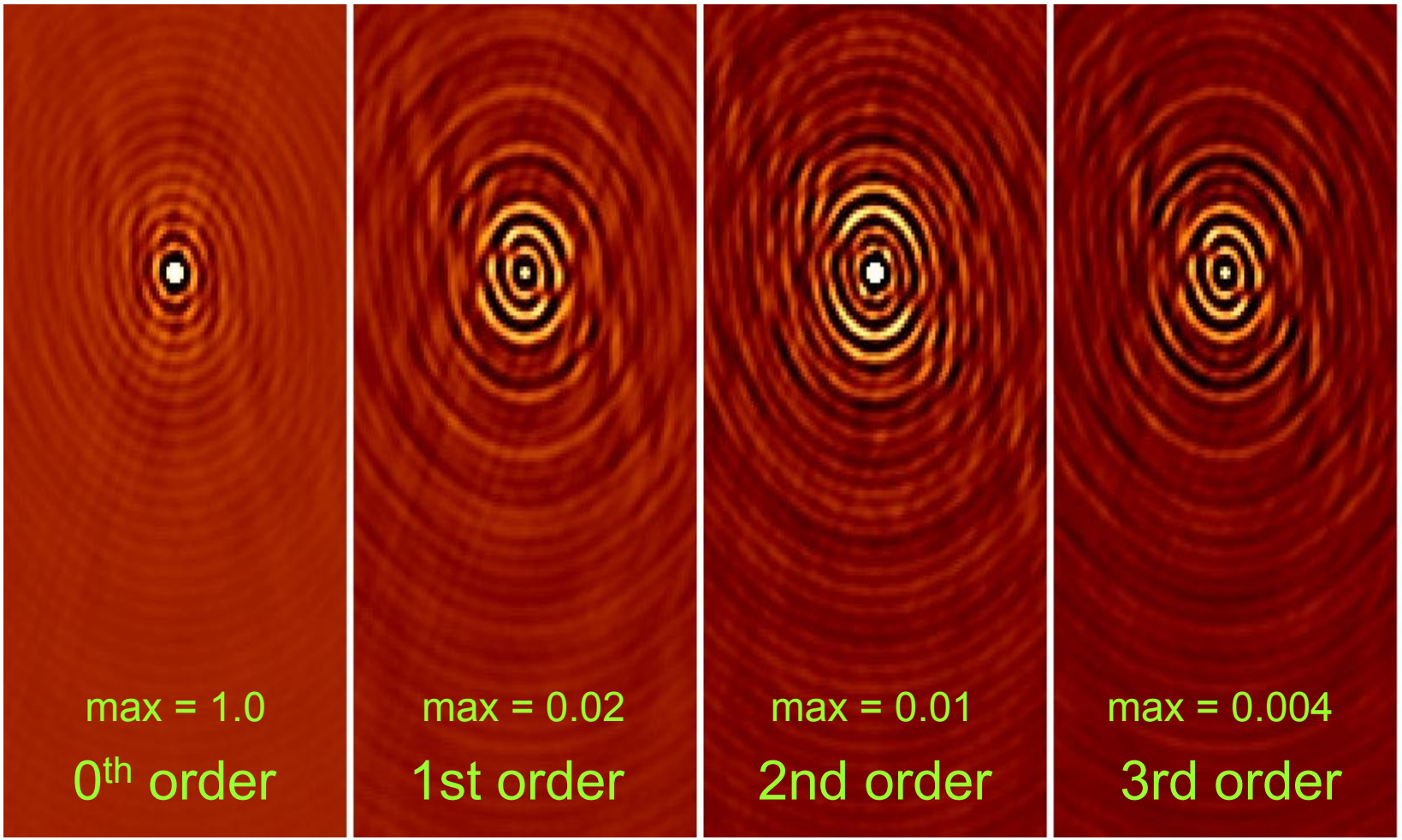


A source spectrum:

Taylor expansion

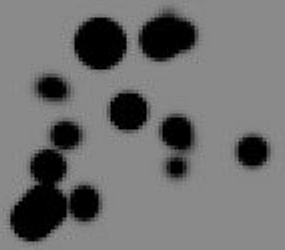


Taylor-term beams



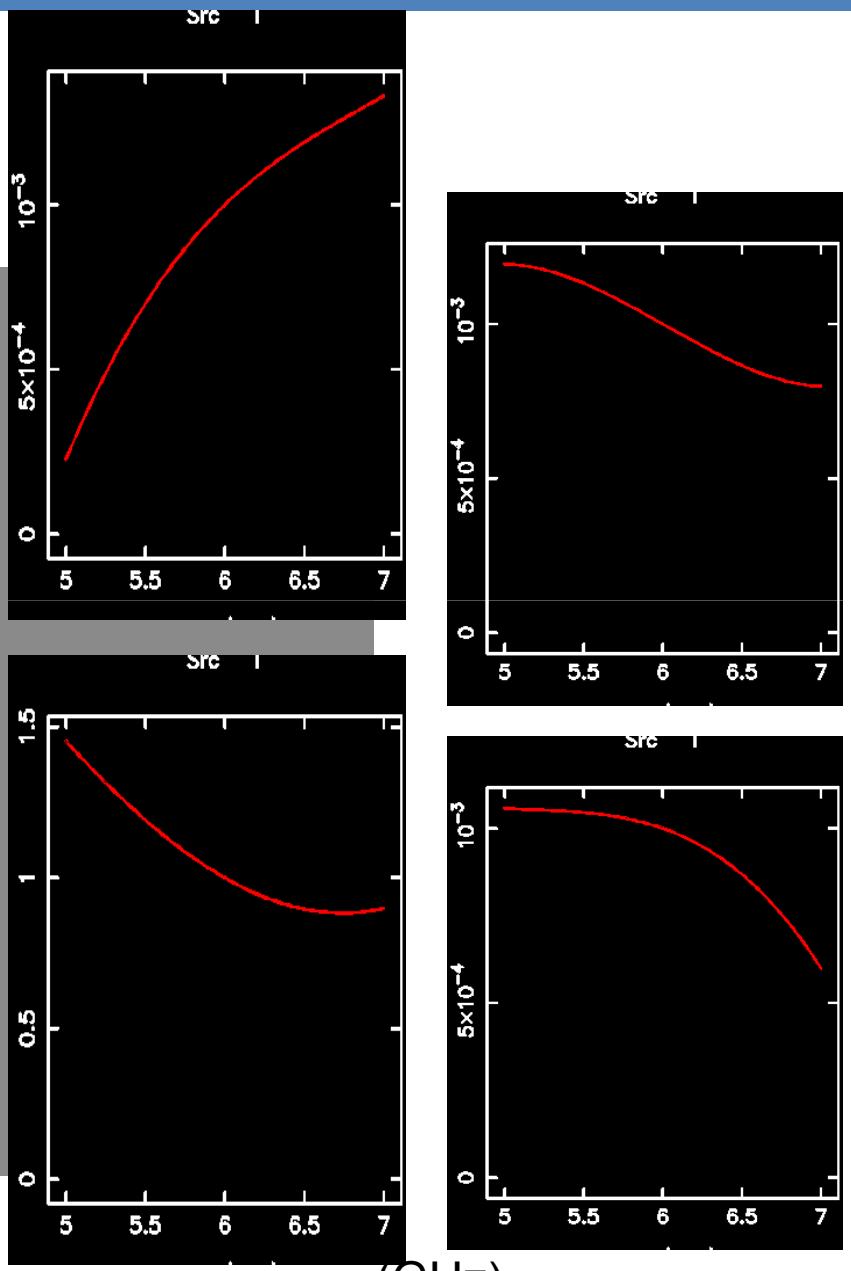
A simulation to test this:

19 point sources
from 0.001 to 1 Jy

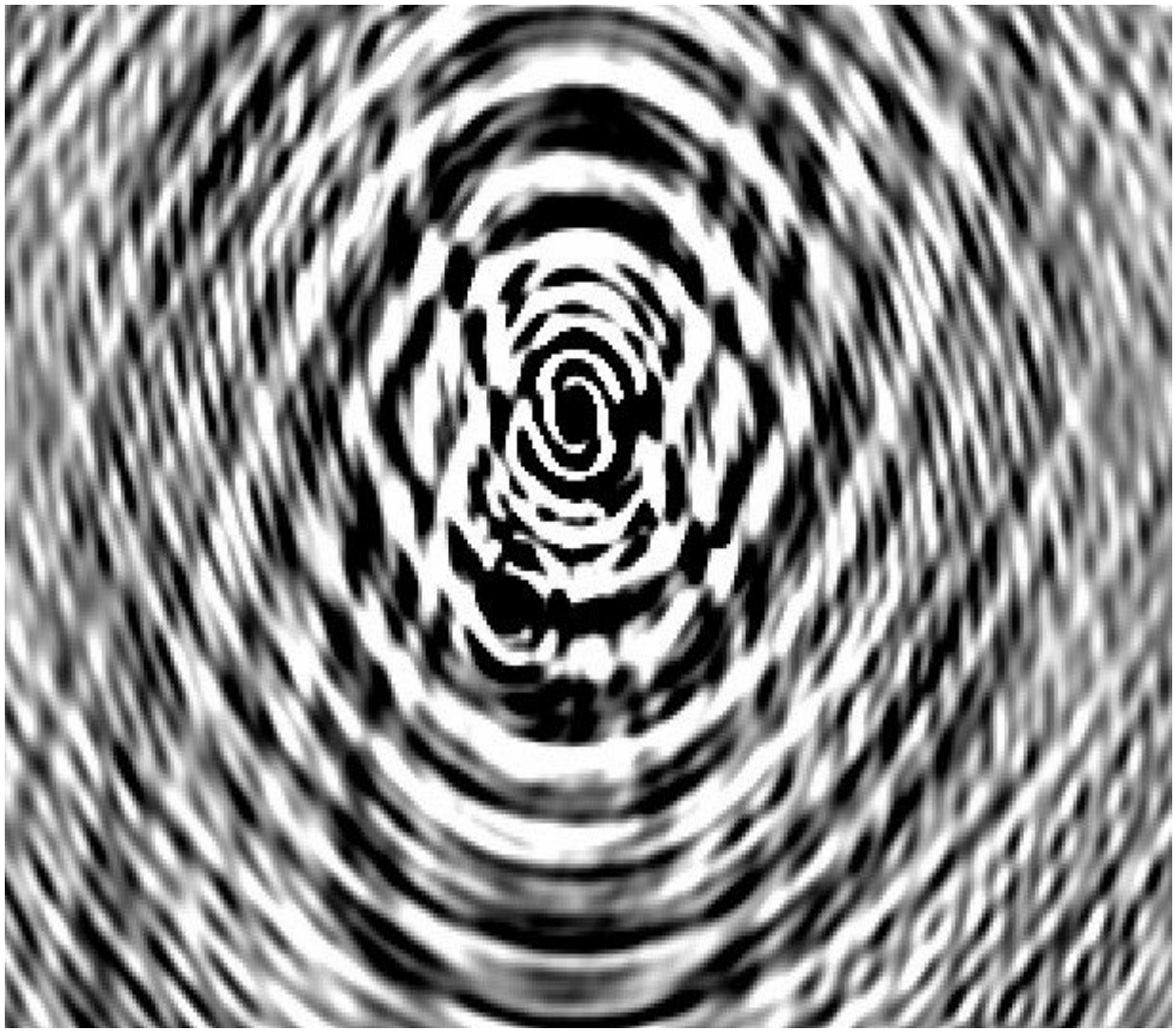


Spectra: cubics, with
random coefficients.

eg

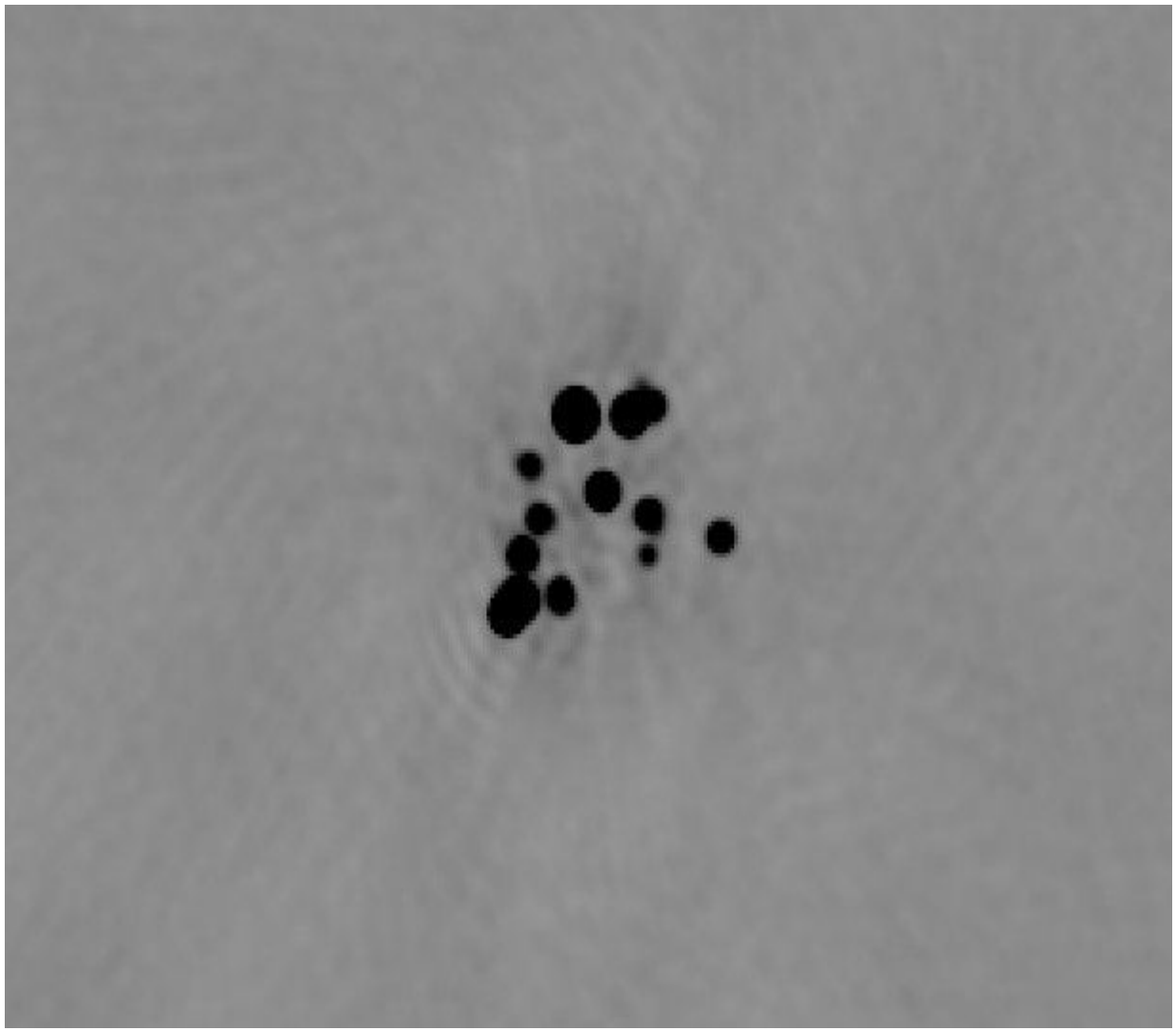


Alternate cleaning:
(i) 1000 cycles of standard clean



…not good.

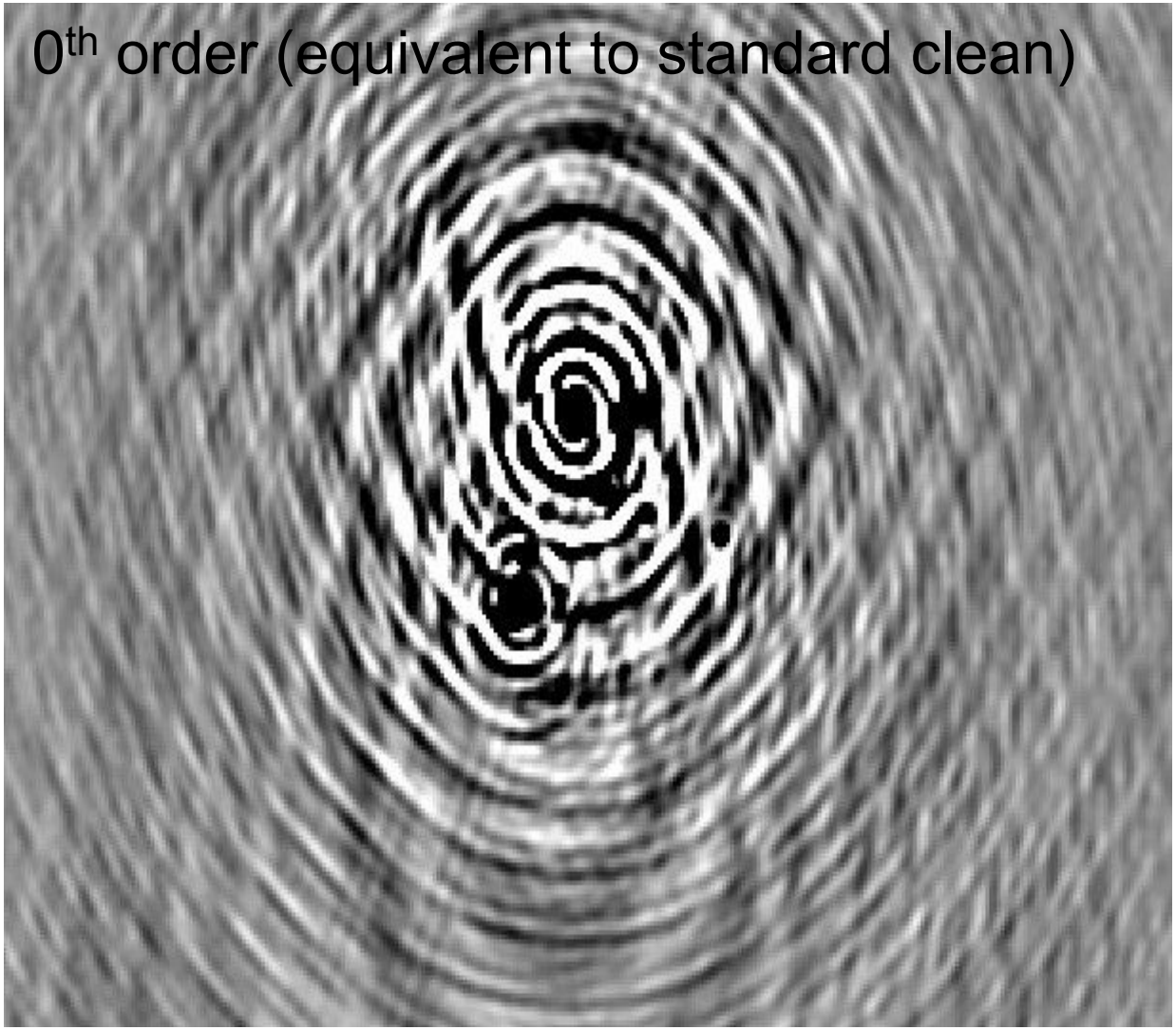
Alternate cleaning:
(ii) each spectral channel cleaned, then co-added.



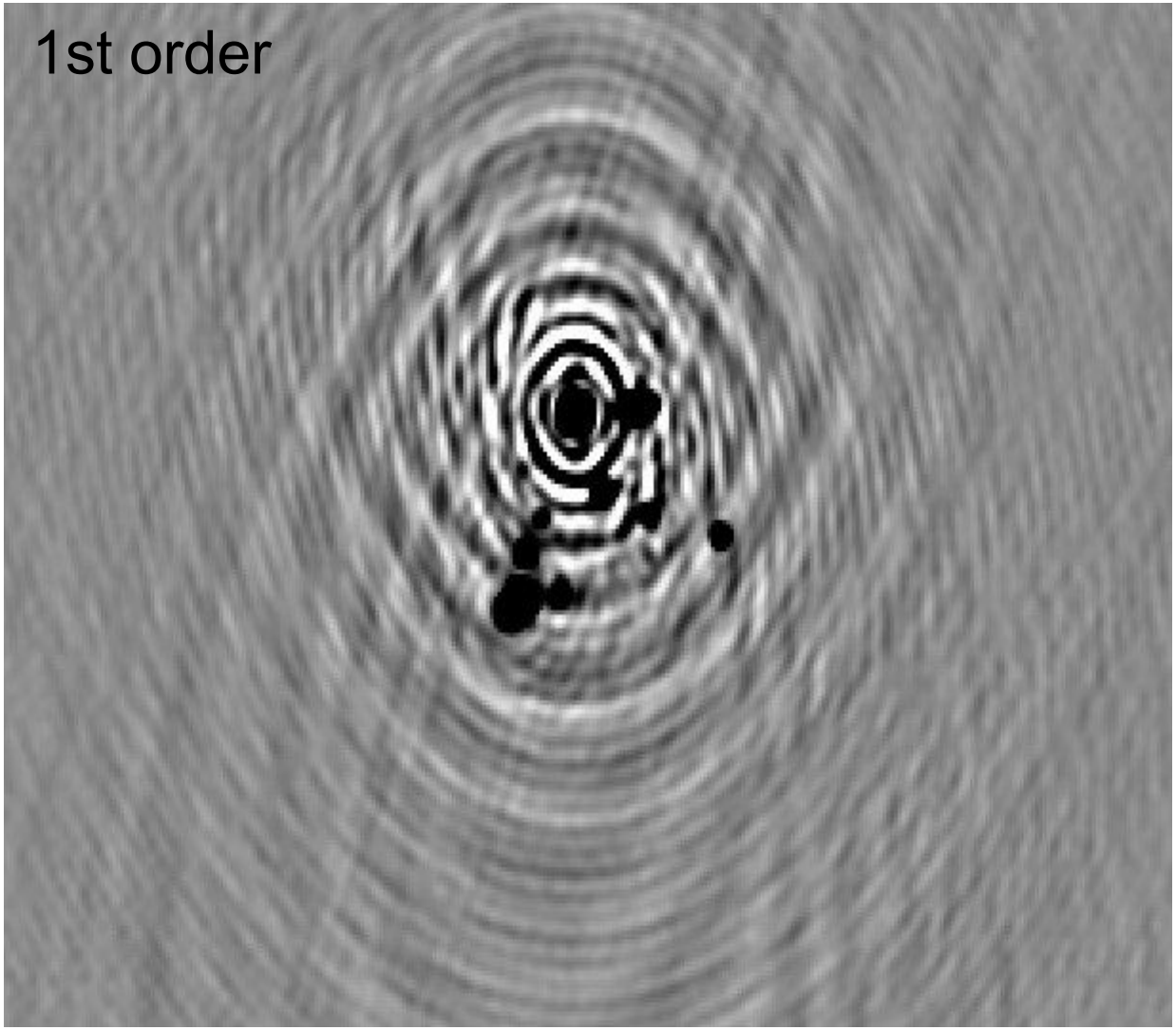
…pretty good, but do we lose faint sources?

S-W clean to various orders

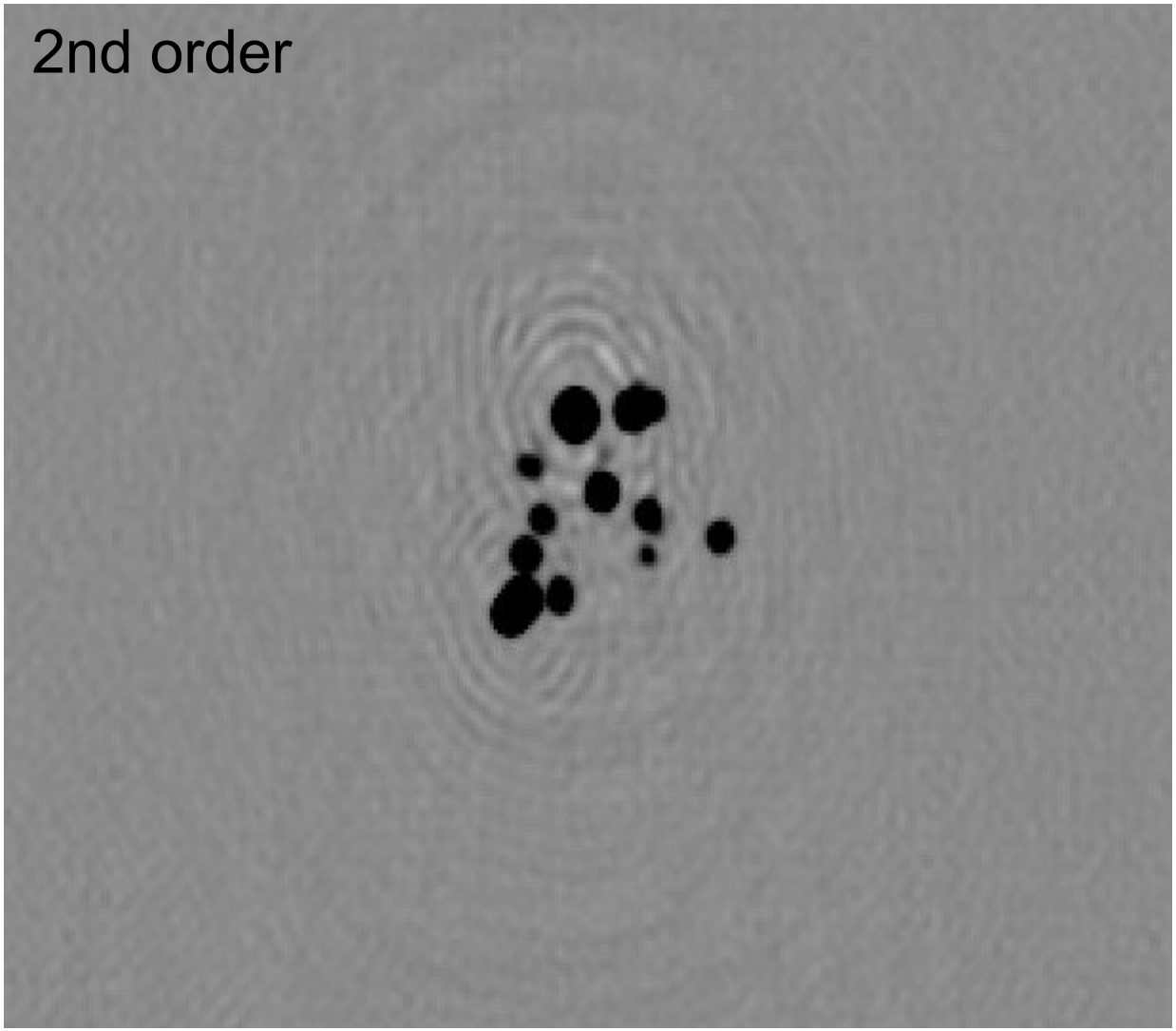
(All 1000 cycles with gain (λ) = 0.1)



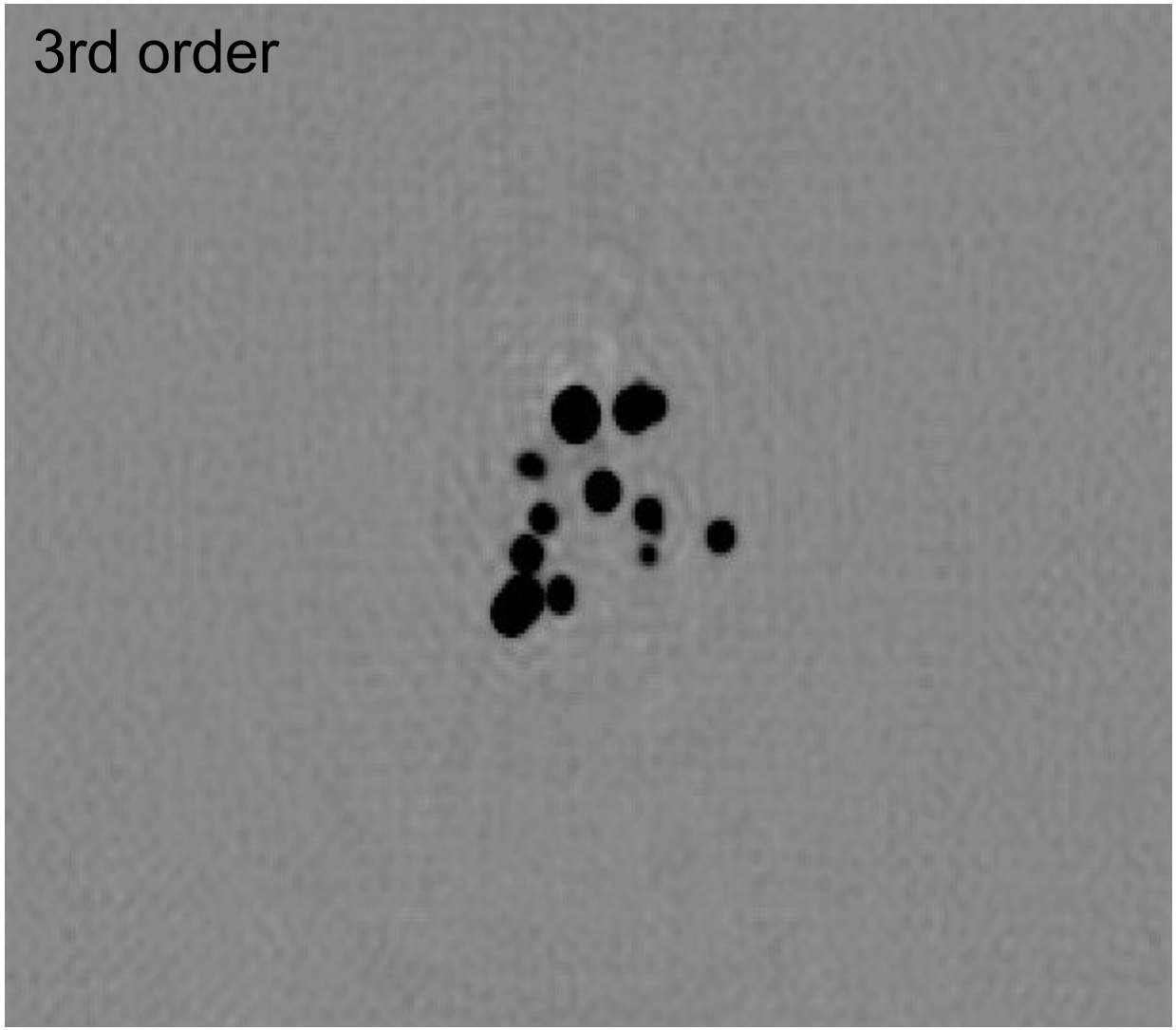
S-W clean to various orders



S-W clean to various orders



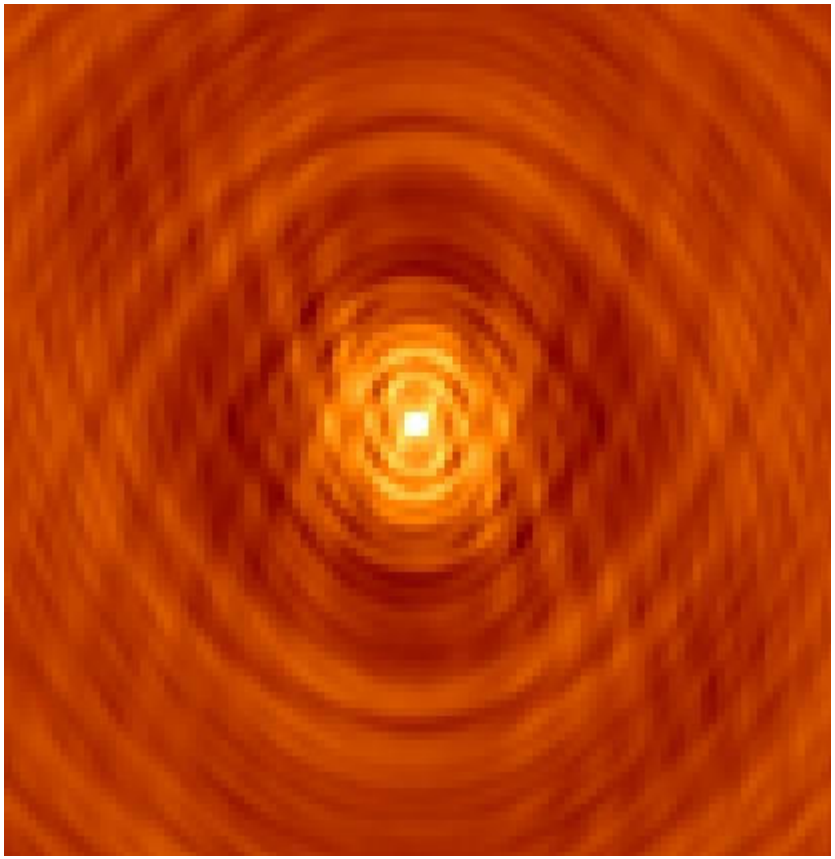
S-W clean to various orders



Not much left but numerical noise.

Time-varying sources:

Source constant in time



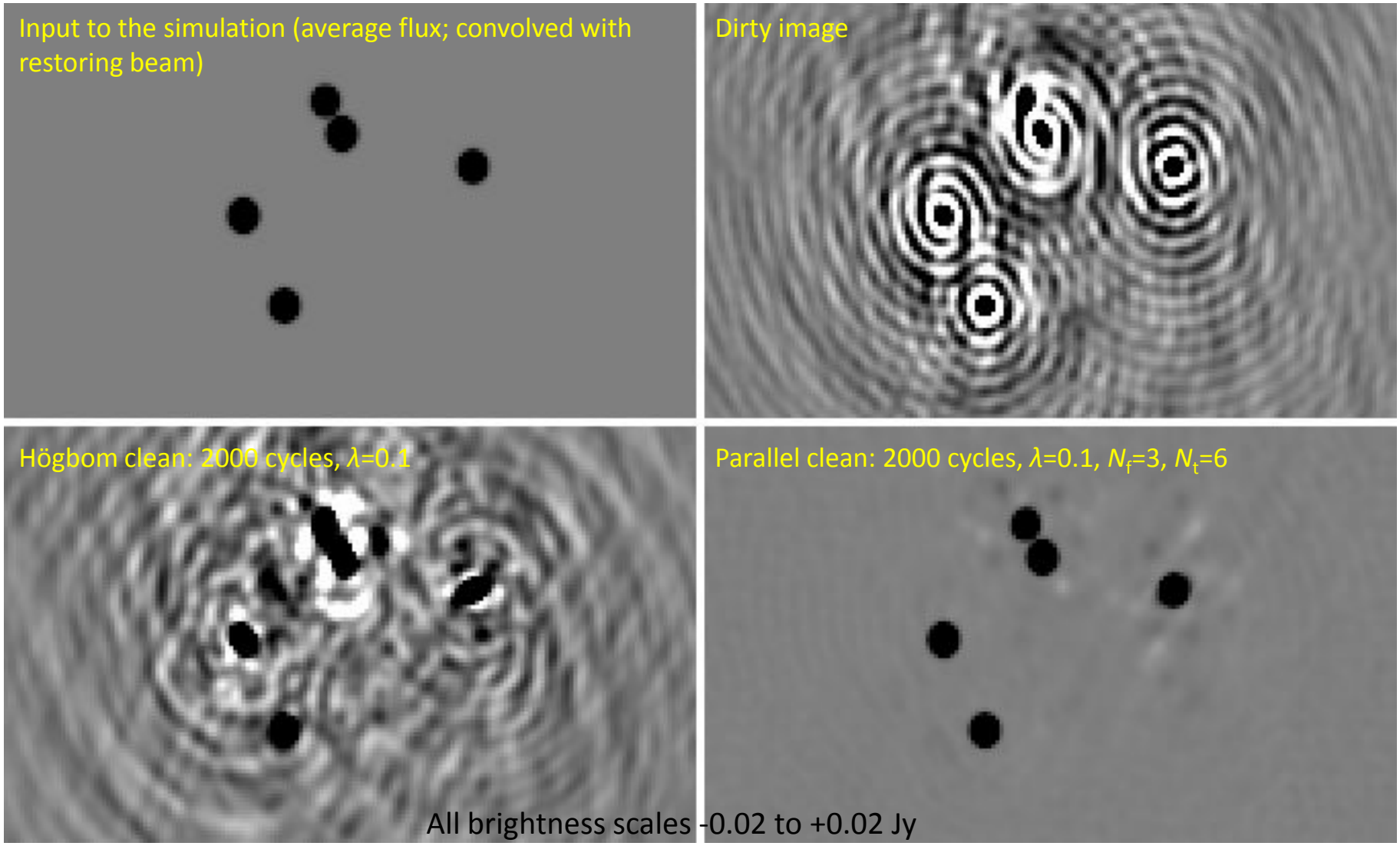
Source flux varying with time



Time-varying sources:

Stewart I M, Fenech D M & Muxlow T W B, A&A 535, A81.

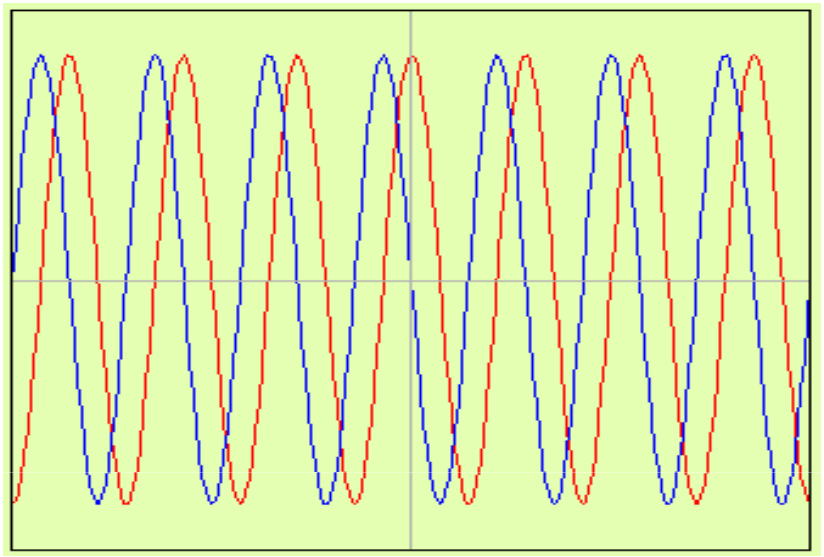
5 sources, all ~1 Jy, varying in both flux and spectral index by ~x10.



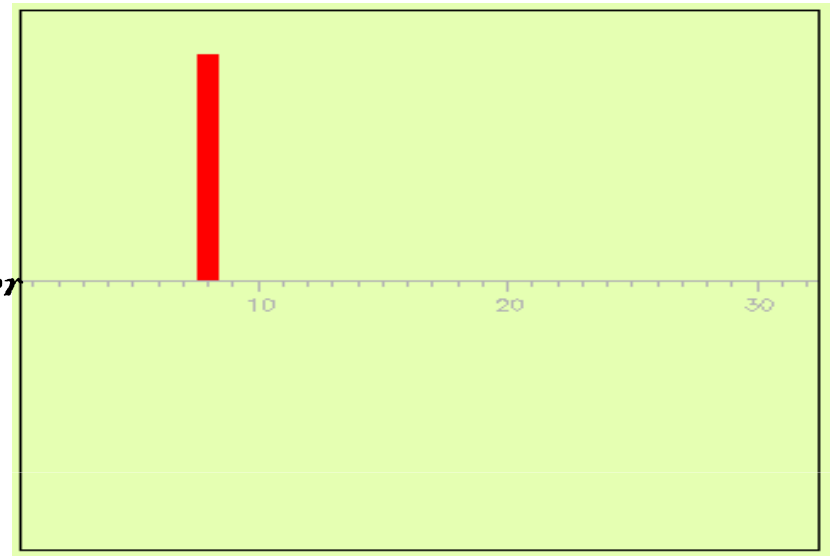
Off-pixel-centre sources

U-V ‘plane’

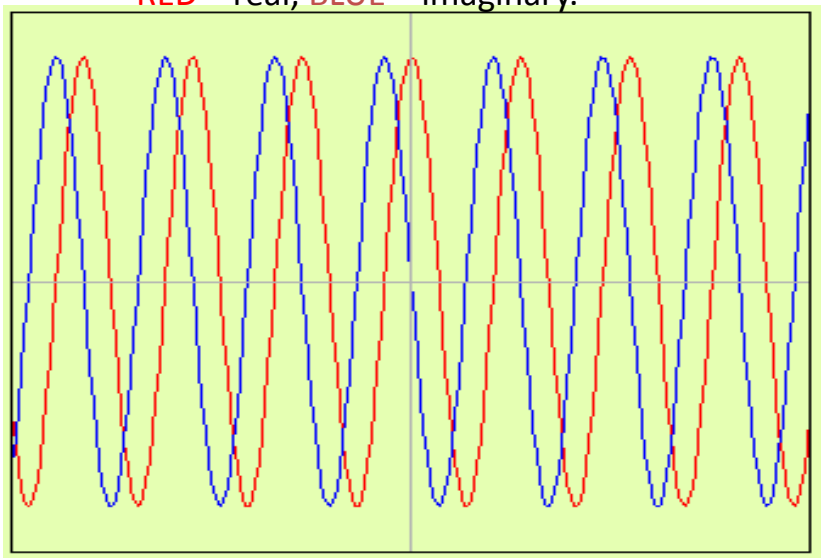
‘Sky’



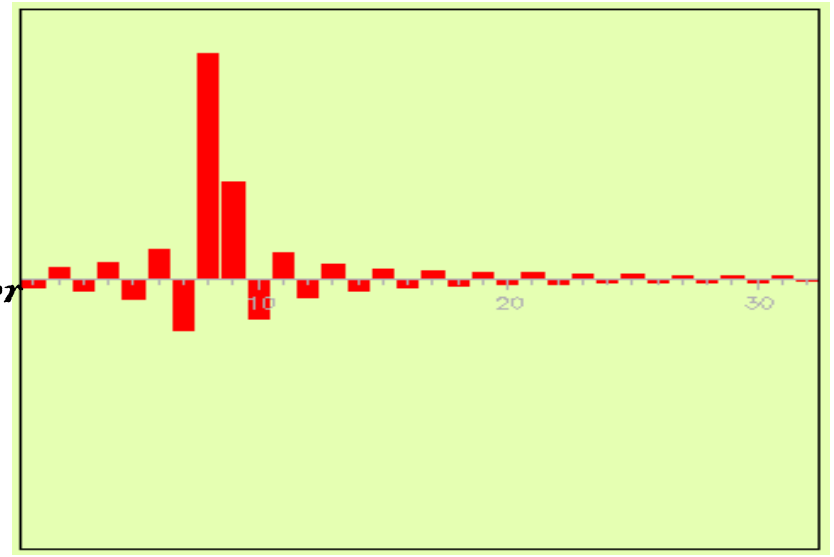
Fourier



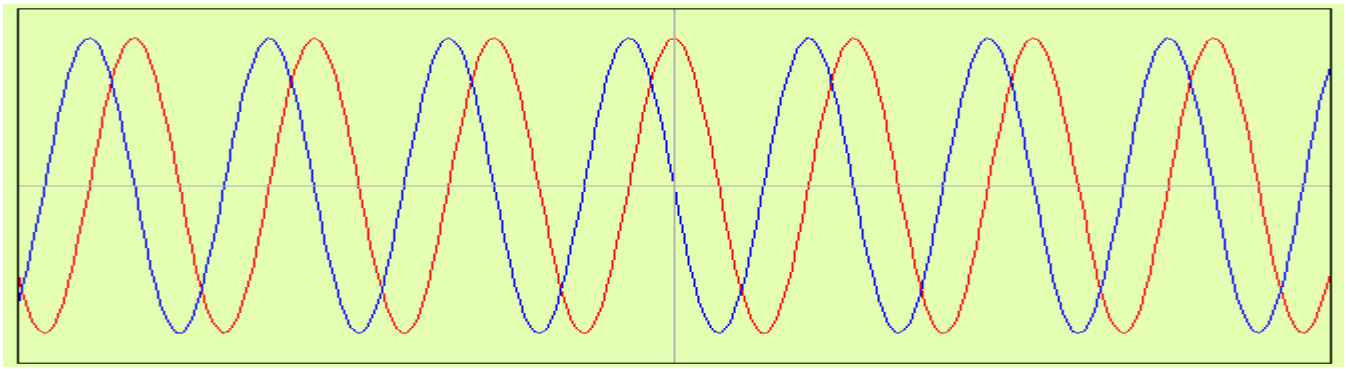
RED = real, BLUE = imaginary.



Fourier

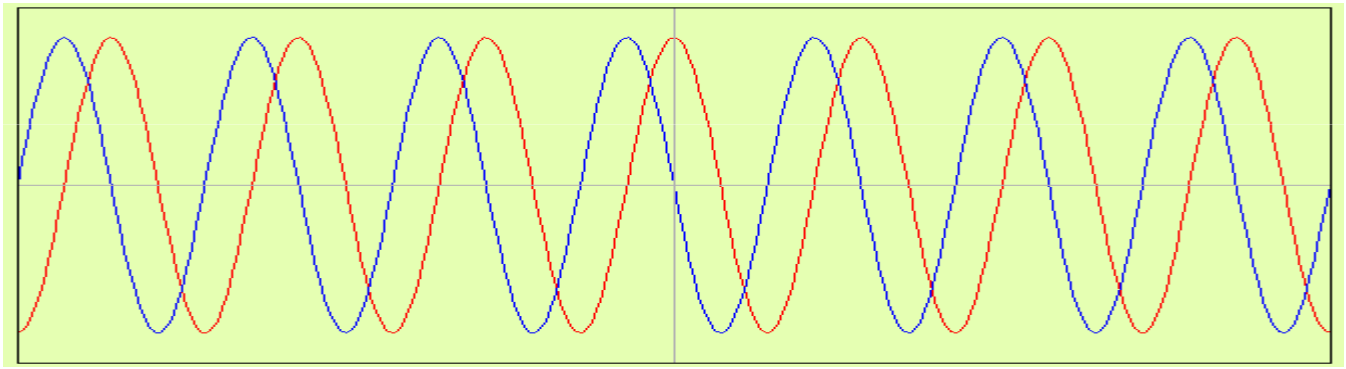


Off-pixel-centre sources



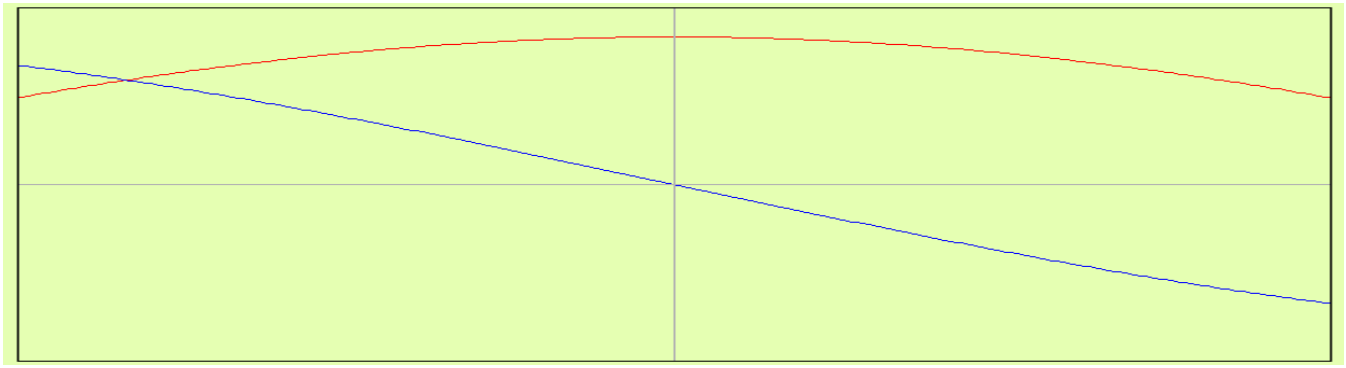
$$\exp\left(-2\pi i[n+f]\frac{t}{T}\right)$$

=



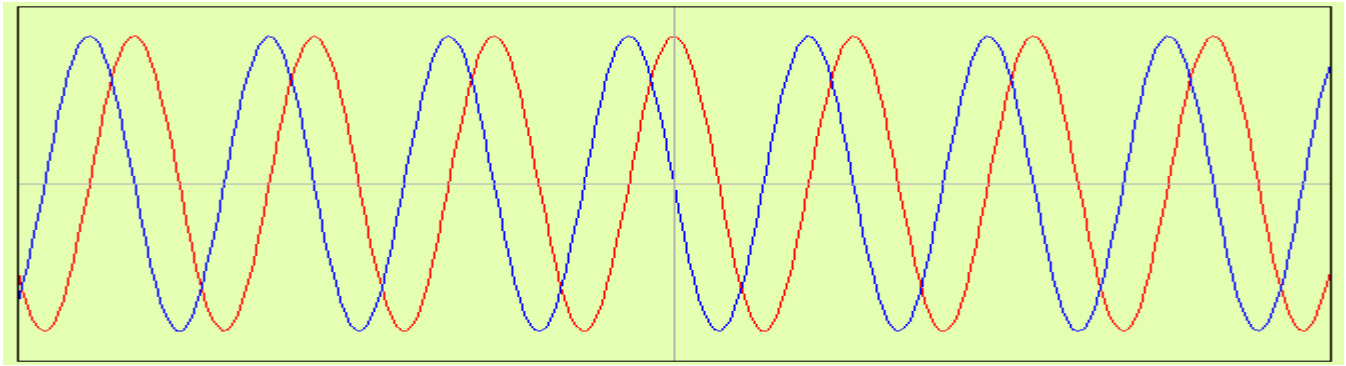
$$\exp\left(-2\pi i n\frac{t}{T}\right)$$

X



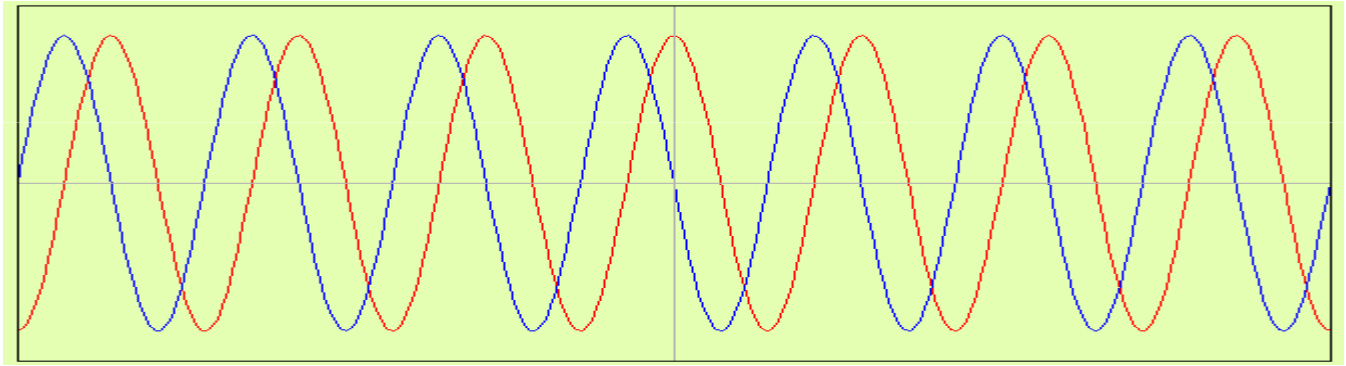
$$\exp\left(-2\pi i f\frac{t}{T}\right)$$

Off-pixel-centre sources



$$\exp\left(-2\pi i\left[n+f\right]\frac{t}{T}\right)$$

≈



$$\exp\left(-2\pi i n\frac{t}{T}\right)$$

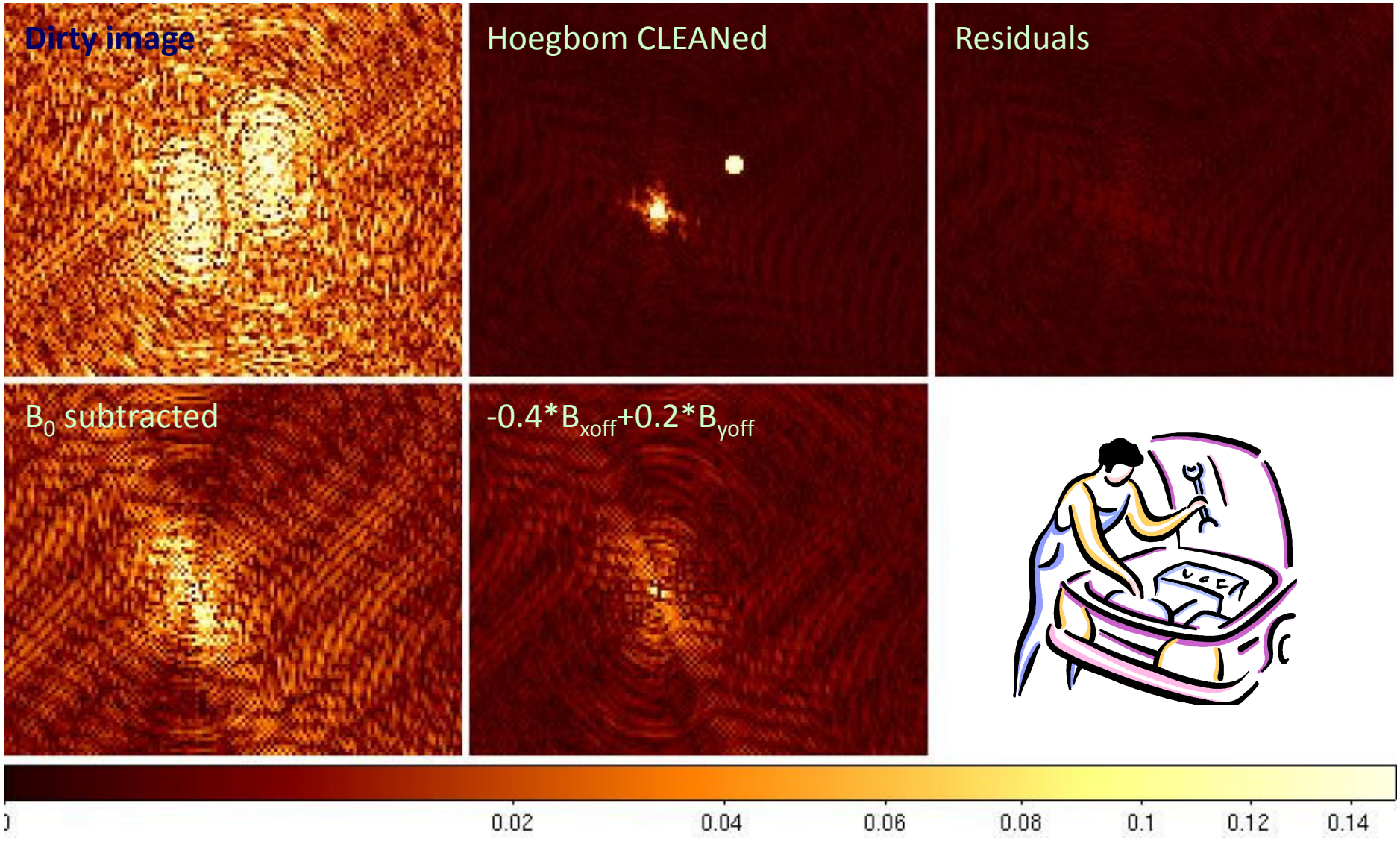
X



$$1-2\pi i f\frac{t}{T}$$

Off-pixel-centre sources

Lower left source at ($m\Delta x$-0.4, $n\Delta y$+0.2):



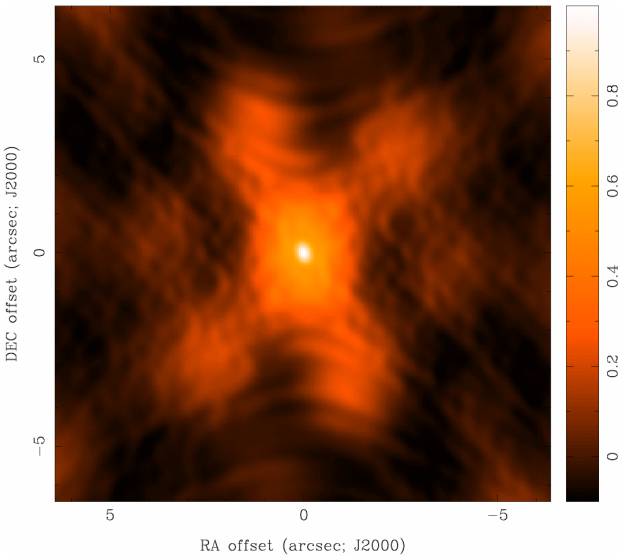
The remaining slides are borrowed from

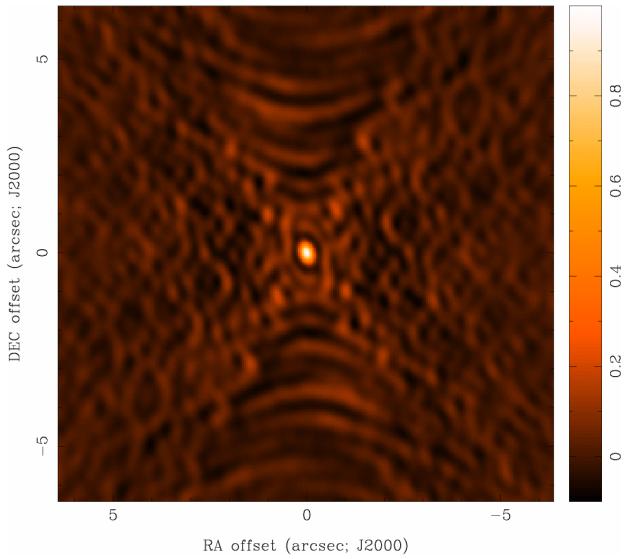
http://www.aoc.nrao.edu/events/synthesis/2010/lectures/wilner_synthesis10.ppt

Weighting and Tapering: Noise

Natural
0.77x0.62

σ=1.0



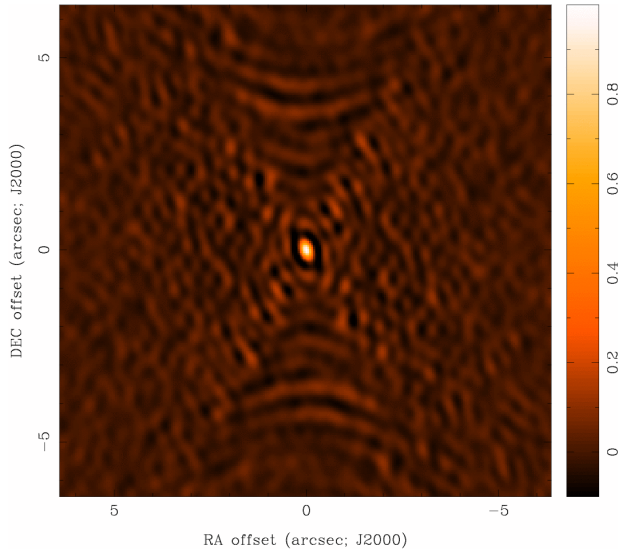


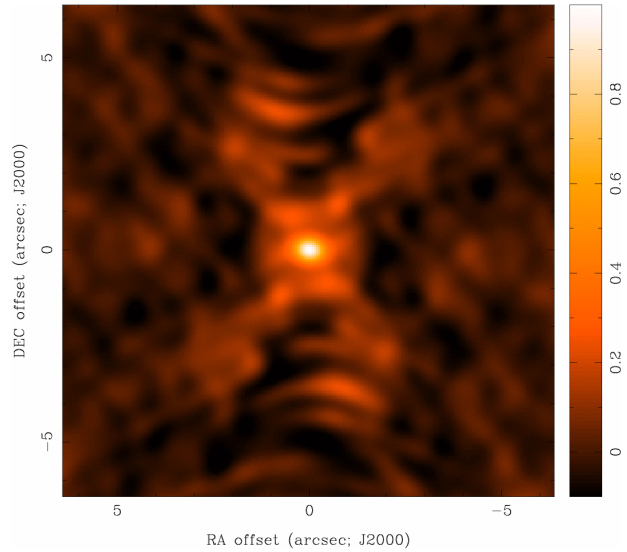
Robust 0
0.41x0.36

σ=1.6

Uniform
0.39x0.31

σ=3.7





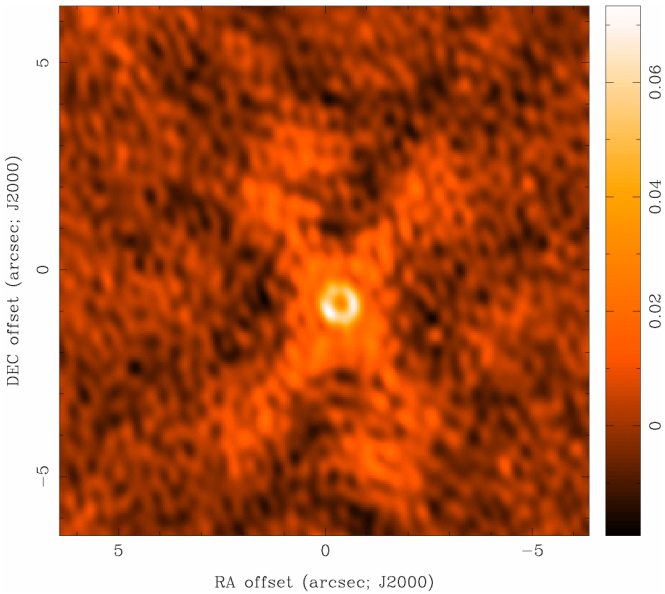
Robust 0
+ Taper
0.77x0.62

σ=1.7

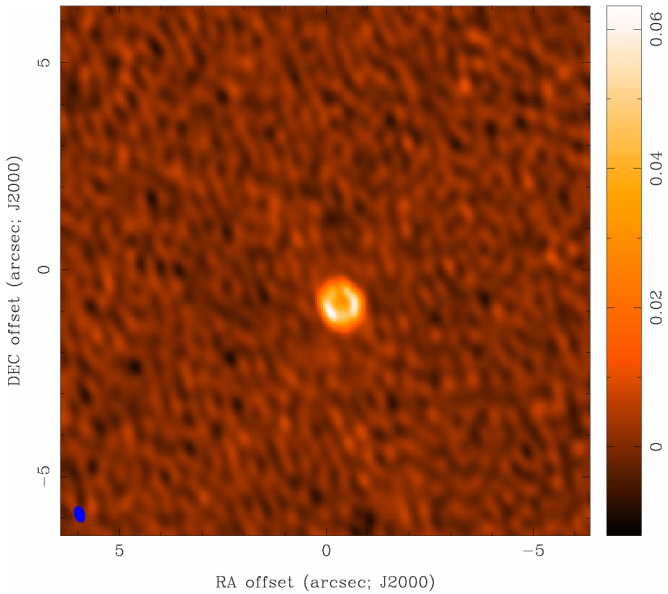
Deconvolution

- difficult to do science on dirty image
- deconvolve b(x,y) from $T^D(x,y)$ to recover T(x,y)
- information is missing, so be careful!
  (there's noise, too)

dirty image



"CLEAN" image



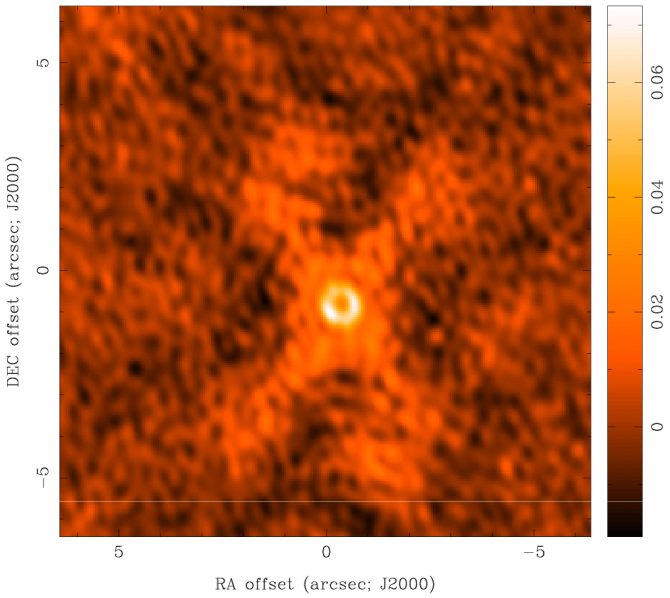
Deconvolution Algorithms

- most common algorithms in radio astronomy
  - CLEAN (Högbom 1974)
    - *a priori* assumption: T(x,y) is a collection of point sources
    - variants for computational efficiency, extended structure
  - Maximum Entropy (Gull and Skilling 1983)
    - *a priori* assumption: T(x,y) is smooth and positive
    - vast literature about the deep meaning of entropy (Bayesian)
  - hybrid approaches of these can be effective

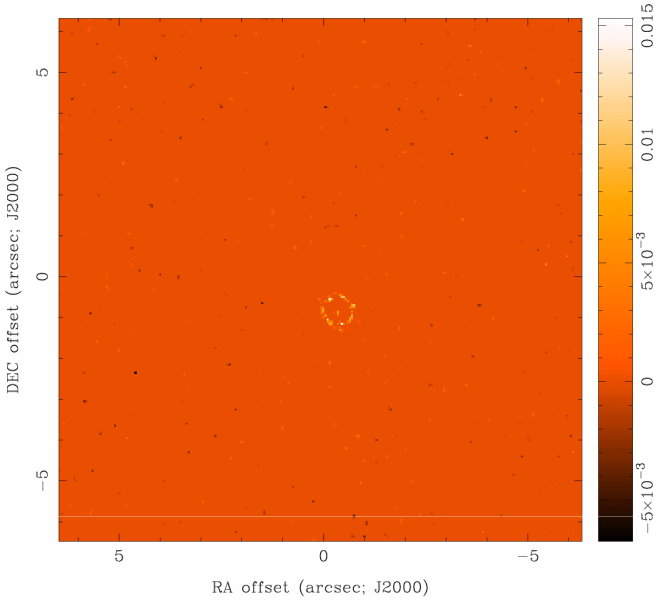
- deconvolution requires knowledge of beam shape and image noise properties (usually OK for aperture synthesis)
  - atmospheric seeing can modify effective beam shape
  - deconvolution process can modify image noise properties

CLEAN

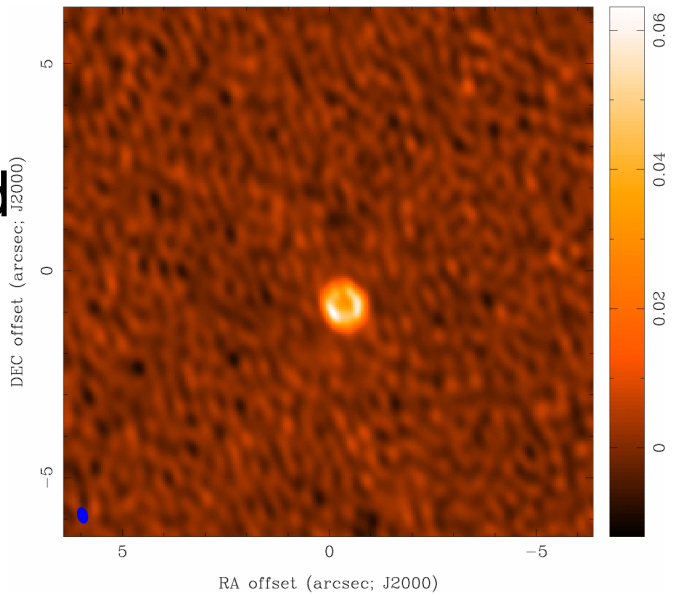
$T^D(x,y)$



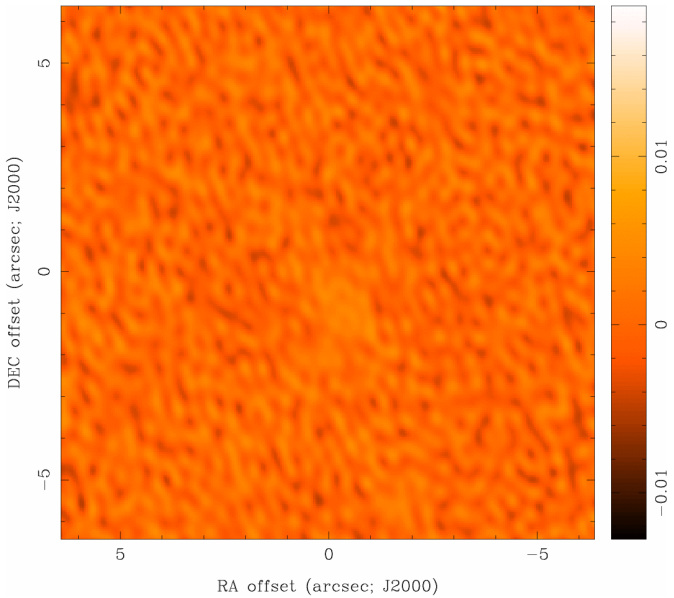
CLEAN model



restored image

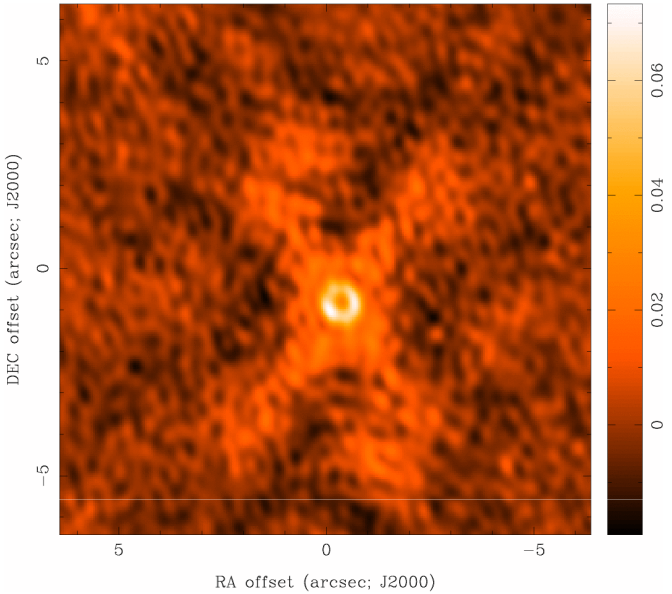


residual map

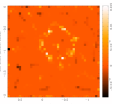


CLEAN with Box

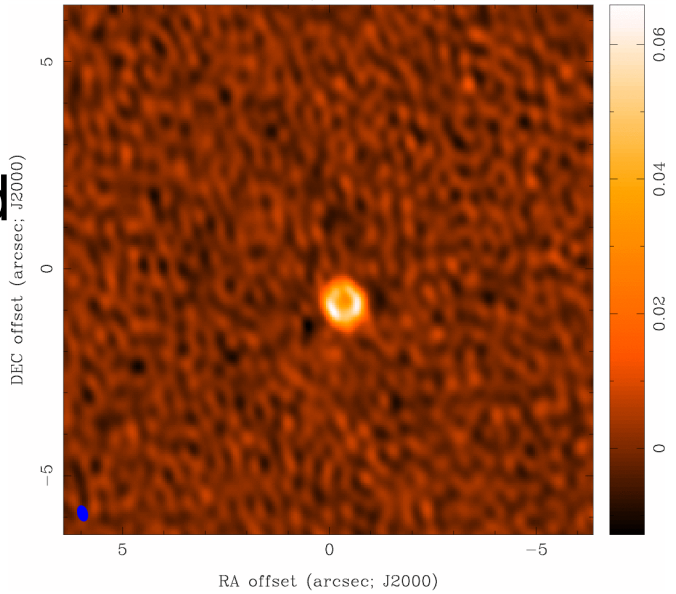
$T^D(x,y)$



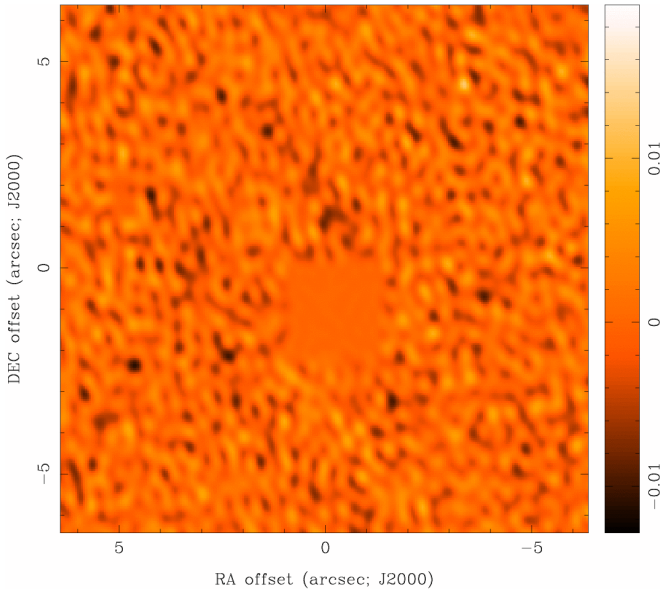
CLEAN model



restored image



residual map



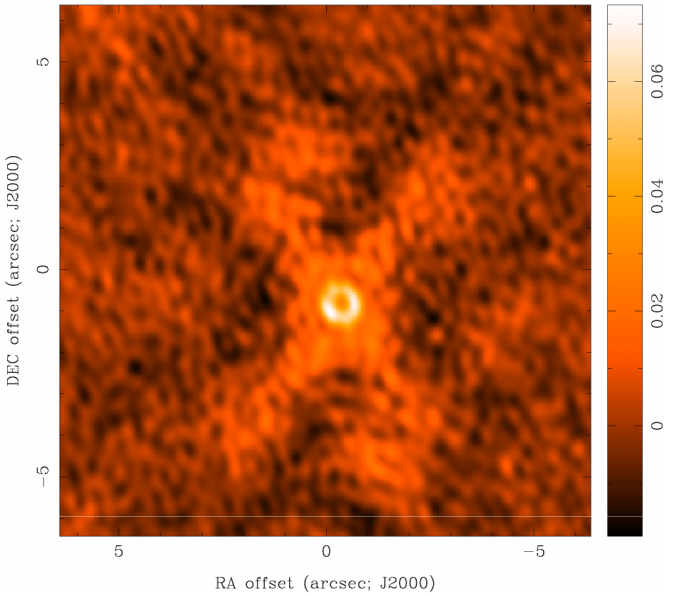
Maximum Entropy Algorithm (cont)

- easy to include *a priori* information with default image
  - flat default best only if nothing known (or nothing observed!)
- straightforward to generalize χ^2 to combine different observations/telescopes and obtain optimal image
- many measures of "entropy" available
  - replace log with cosh $\rightarrow$ "emptiness" (does not enforce positivity)

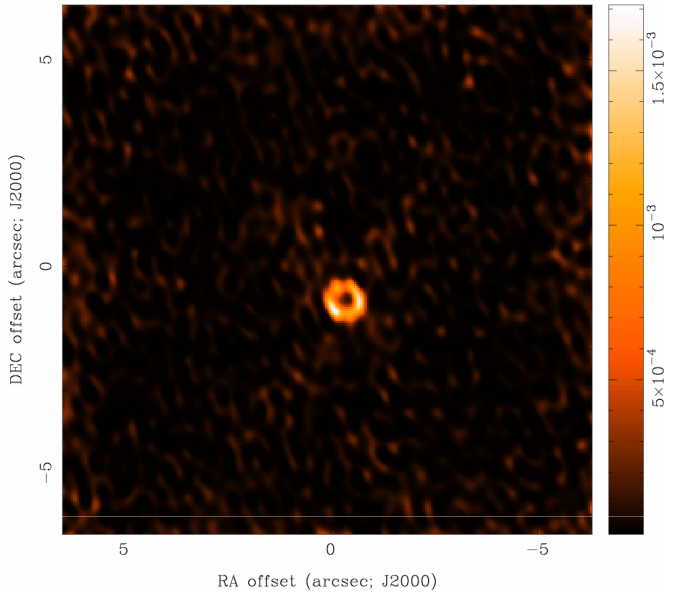
- less robust and harder to drive than CLEAN
- works well on smooth, extended emission
- trouble with point source sidelobes
- no noise estimate possible from image

Maximum Entropy

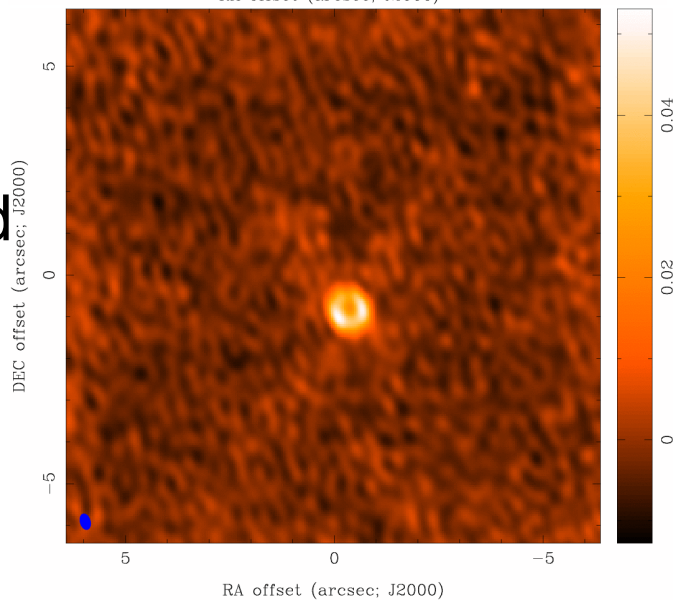
$T^D(x,y)$



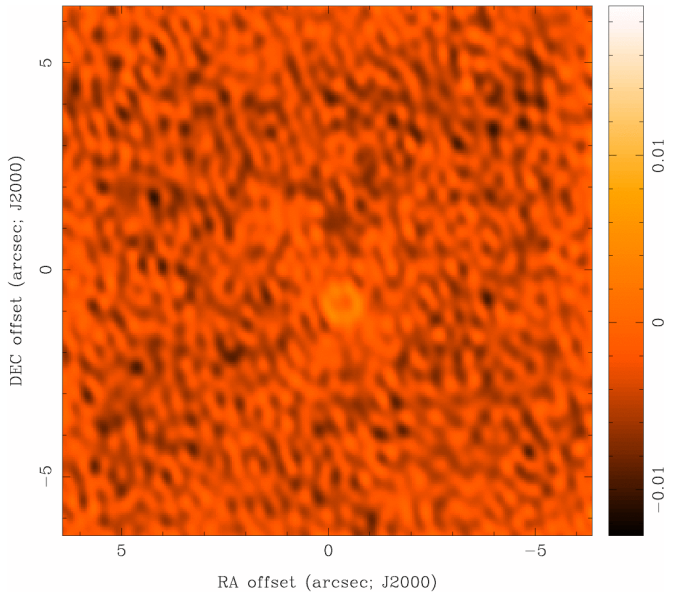
MAXEN model



restored image

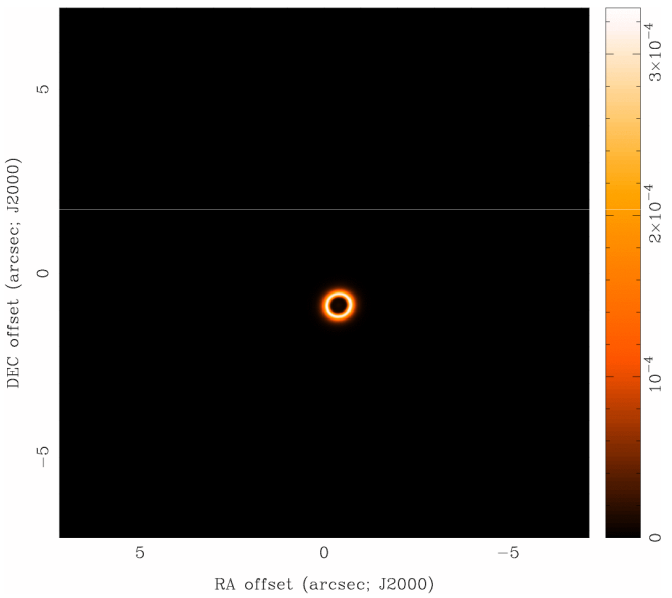


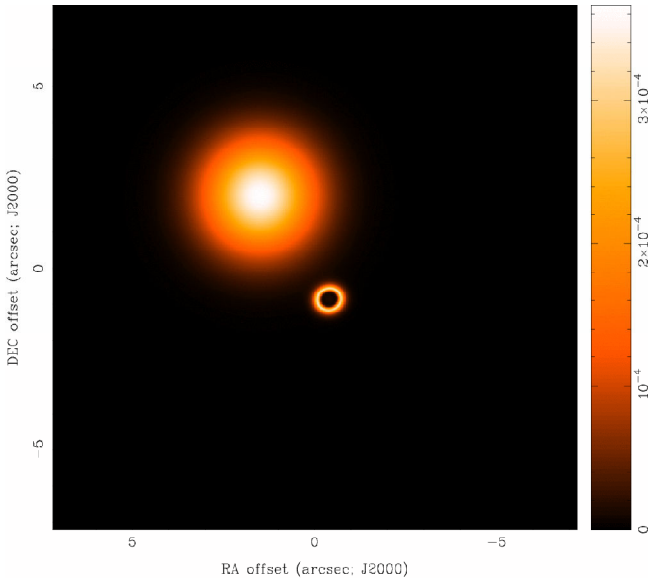
residual map



Missing Short Spacings

Do the visibilities in the example discriminate between these models of the sky brightness distribution, T(x,y)?





Yes… but only on baselines shorter than ~100 kλ.

Missing Short Spacings: Demonstration

