ExCon
making billion pixel images

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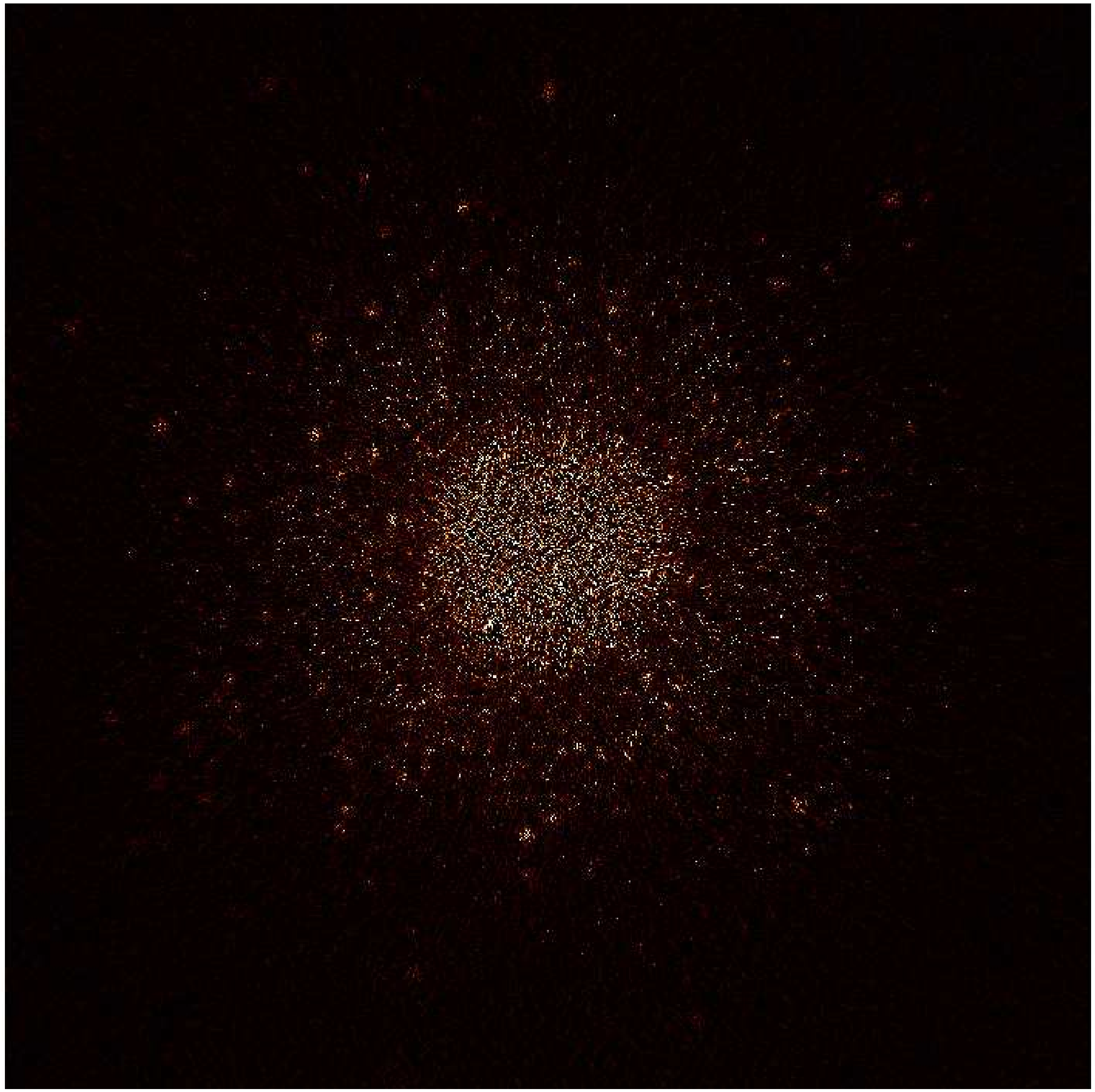
Widefield Imaging

Why?

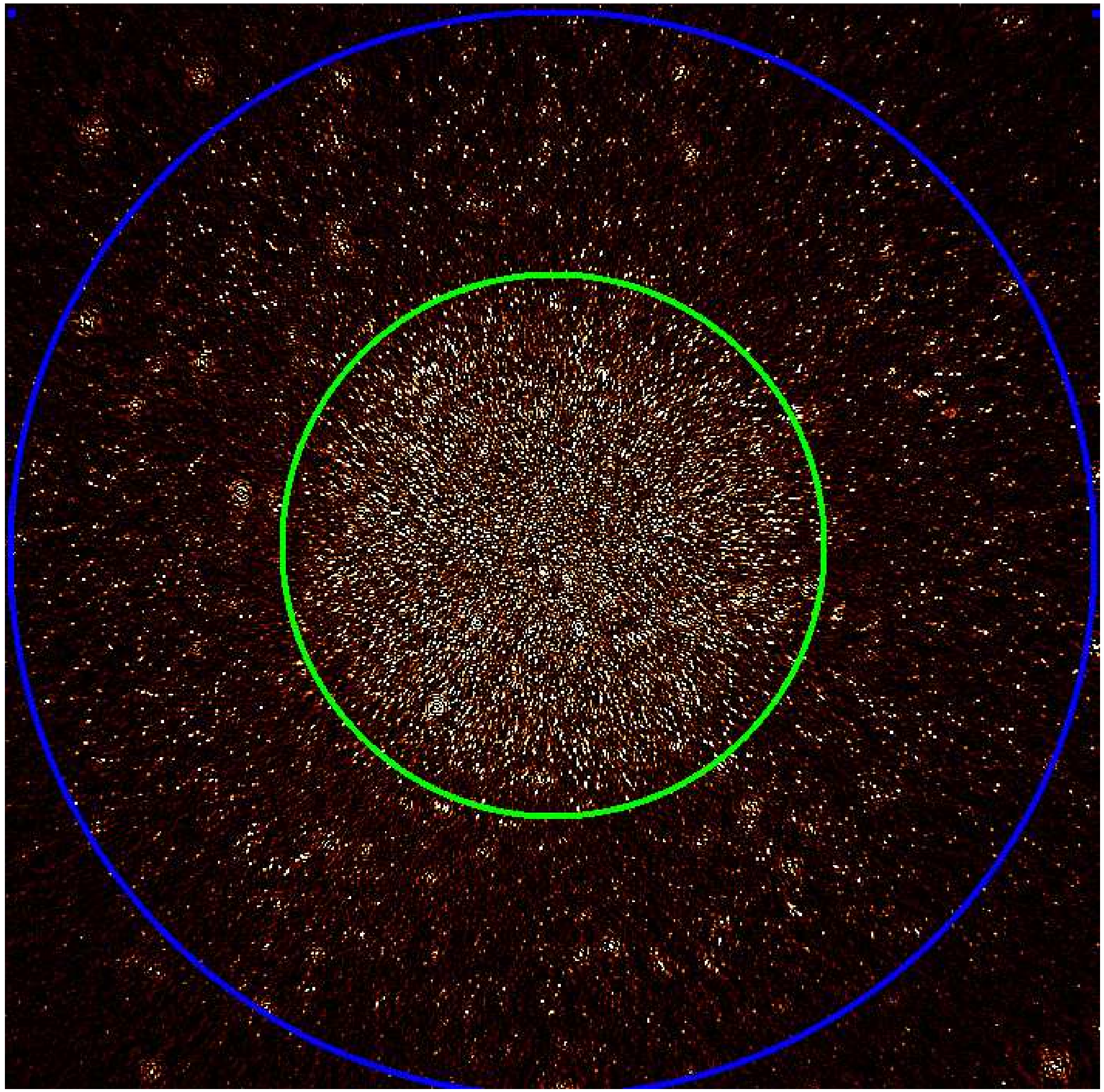
- Calibration down to noise needs a good sky model, covering the full sky [Bregman, 2012].
- Variable beam,ionosphere $\Rightarrow$ errors that vary across the sky.
- Wide beams $\Rightarrow$ thousands of sources.
- Many complex/extended sources.
- Sky model construction $\Rightarrow$ imaging a large field of view, with good enough resolution.
- Widefield calibration is affordable (SAGECal http://sagecal.sf.net/).
- Need to make billion pixel images (ExCon) $\Rightarrow$ computational problems and aliasing problems need to be addressed.

Sources Outside the FOV



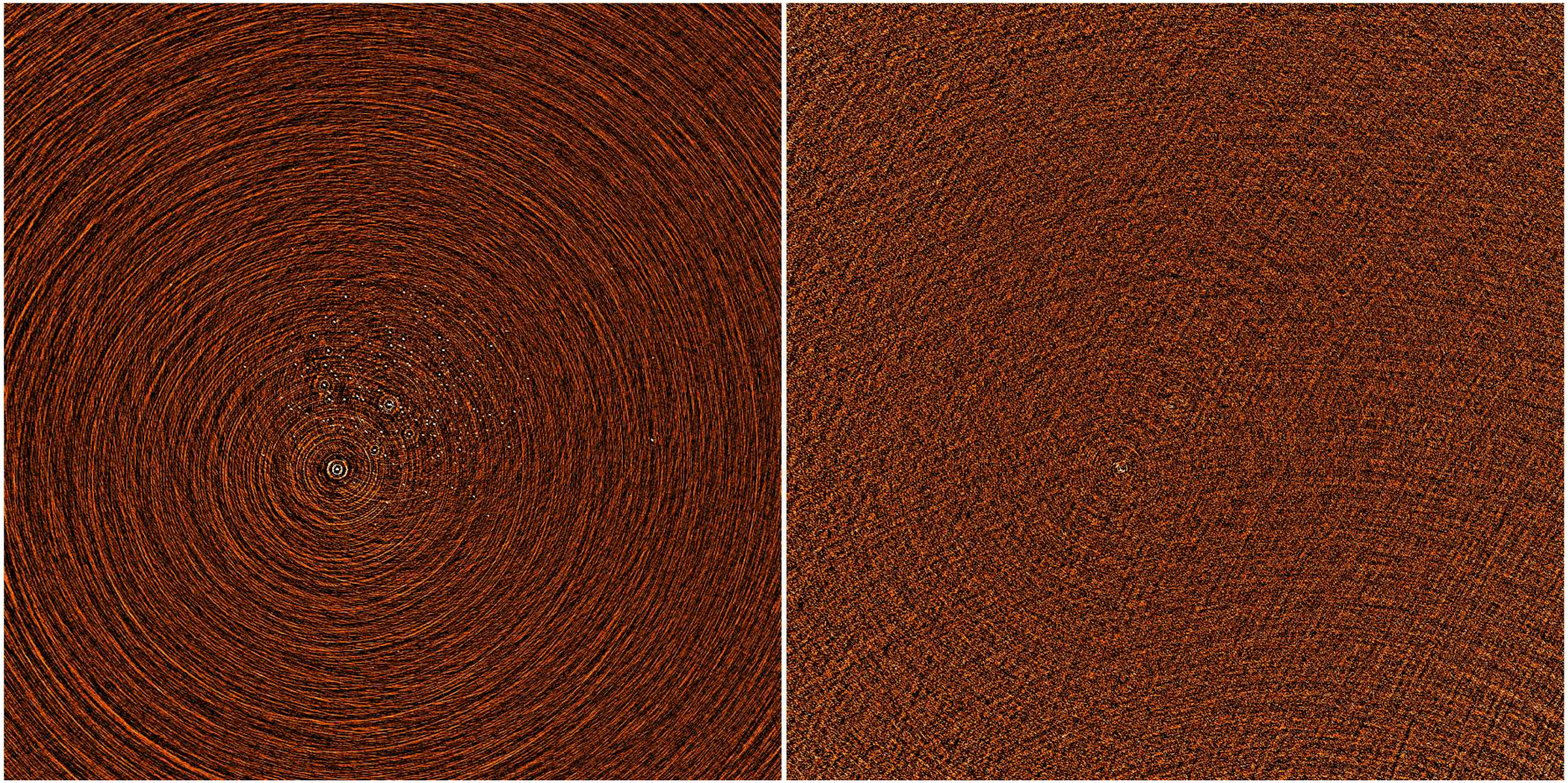
40×40 sq. deg. image, 150 MHz, $30 - 1000\lambda$, $3'$ PSF, 17 μJy

Main FOV



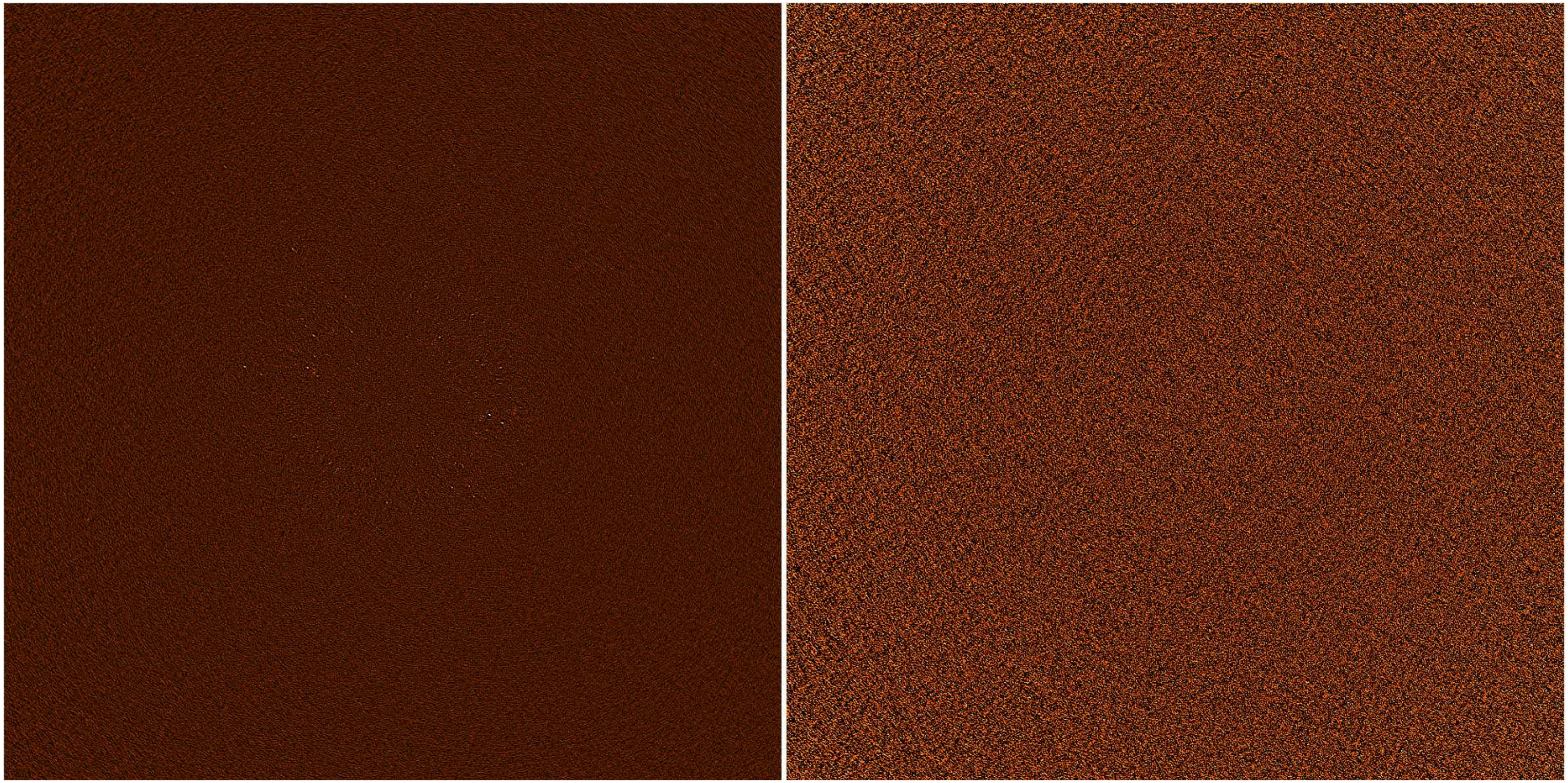
First null 10 deg. diameter, second null 20 deg. diameter, $30 - 1000\lambda$
uniform weights, $3'$ PSF, 60 μJy

Before SAGECal



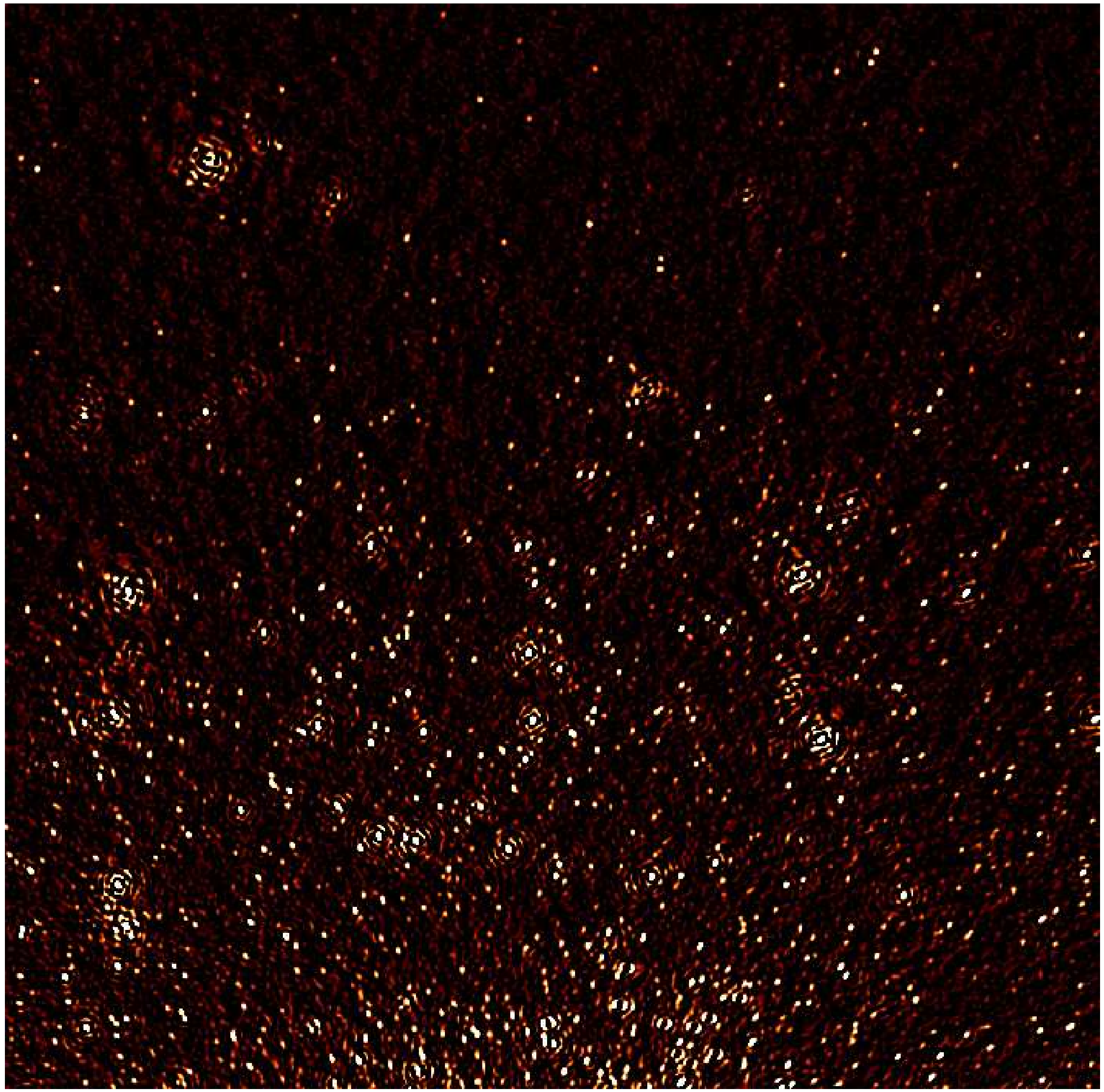
Stokes I (left) Stokes Q (right) showing sidelobes from CasA and CygA

After SAGECal



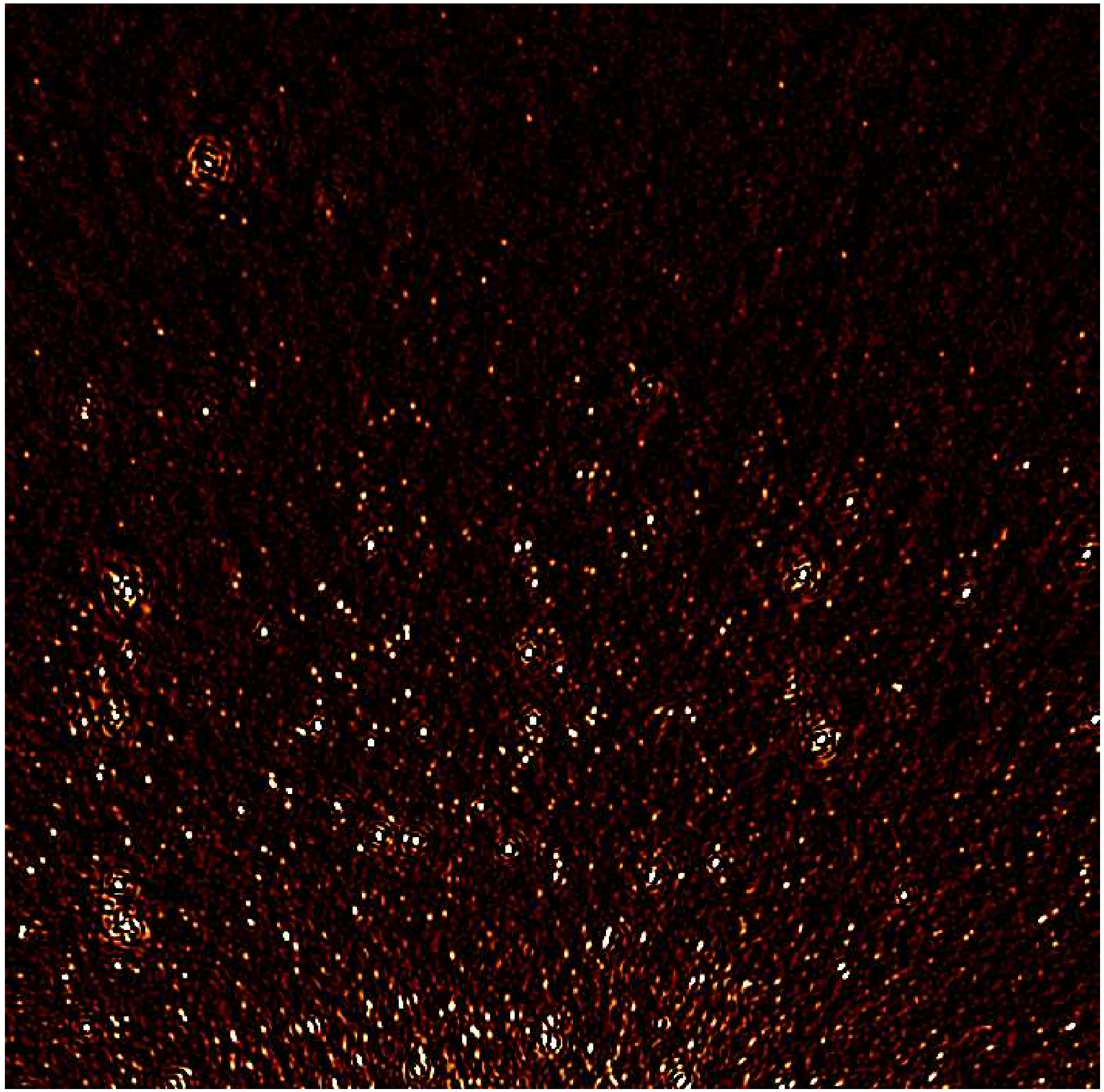
Stokes I (left) Stokes Q (right), after subtraction of 11,000 sources

Sources Outside the FOV



5×5 sq. deg. image, 11 000 sources subtracted using SAGECal

Sources Outside the FOV

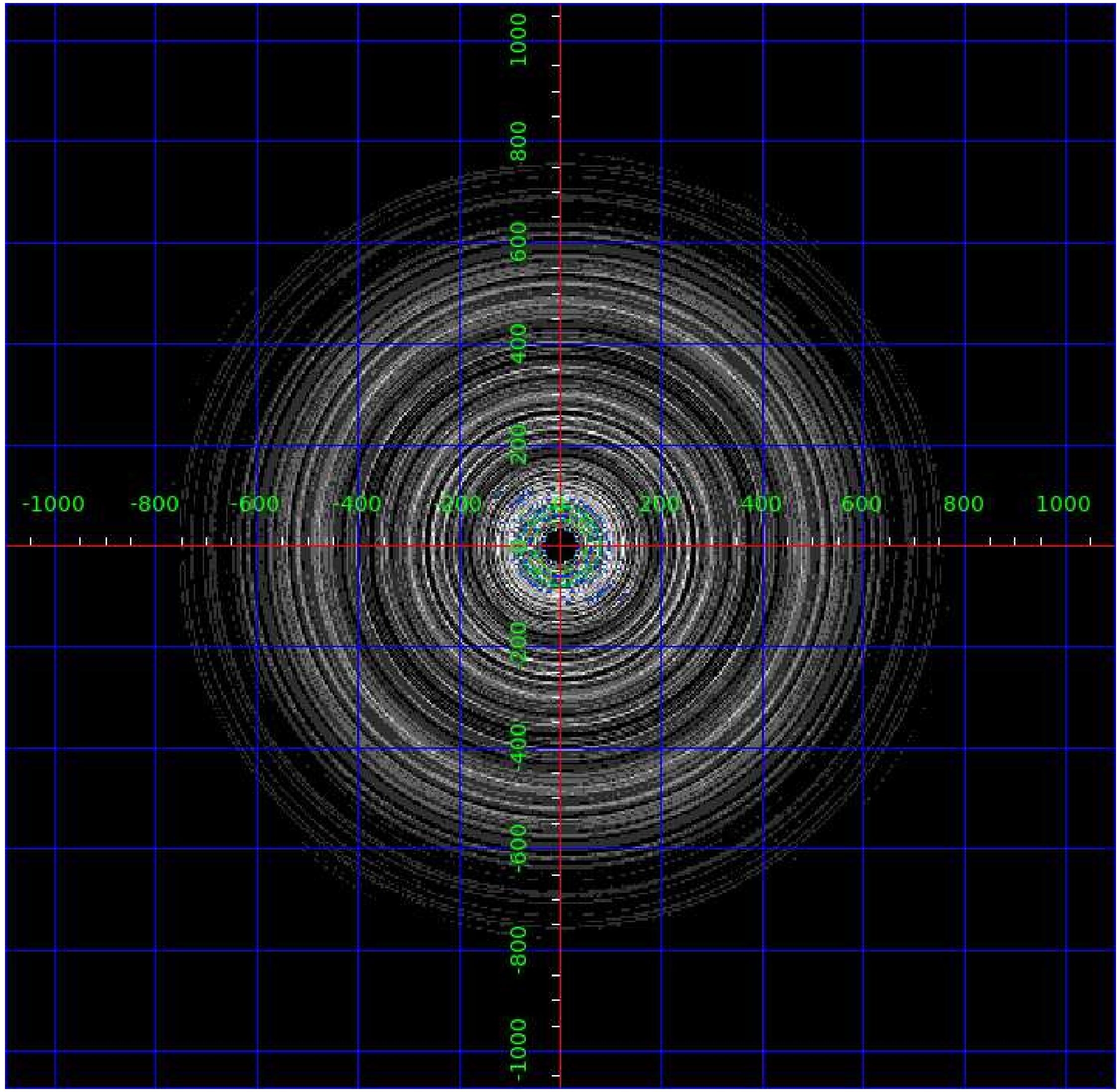


5×5 sq. deg. image, 15 000 sources subtracted using SAGECal

ExCon

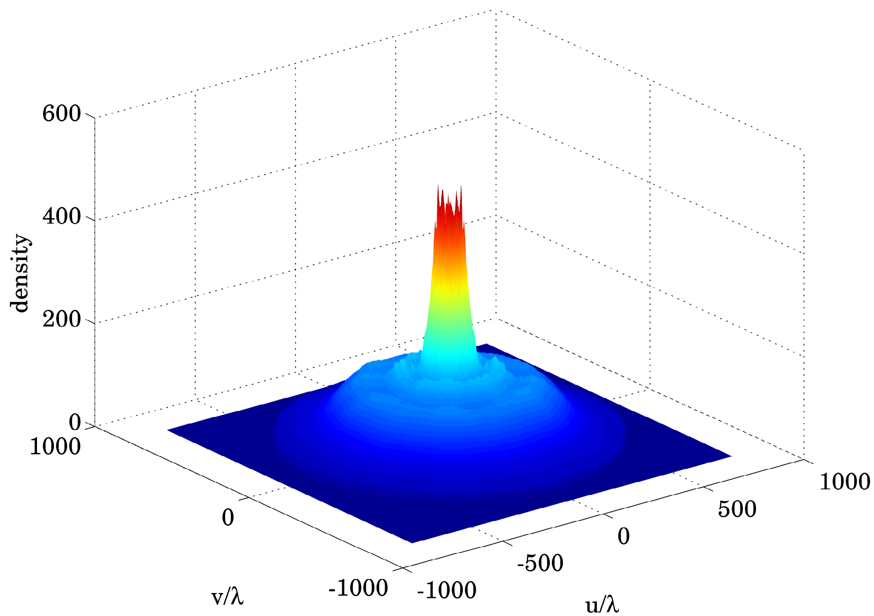
- Question: Who makes billion $ dirty images? Answer: ExCon.
- All aspects of imaging completely reimplemented.
- Weighting: new schemes for sampling density compensation.
- W-projection and W-snapshots with GPU acceleration.
- Convolutional kernel calculation: exact, not using polynomial approximation. PSWF bandwidth/support variable.
- FFT: out-of-core FFT using disk/distributed memory.
- Output: images, gridded data: tailored to EoR data processing and fast snapshot imaging.
- In making small dirty images, actually faster than CASA. No performance differences in in-core and out-of-core FFT.
- Can make much bigger images than CASA, NOT using a supercomputer ($\sim$ 12 GB memory).

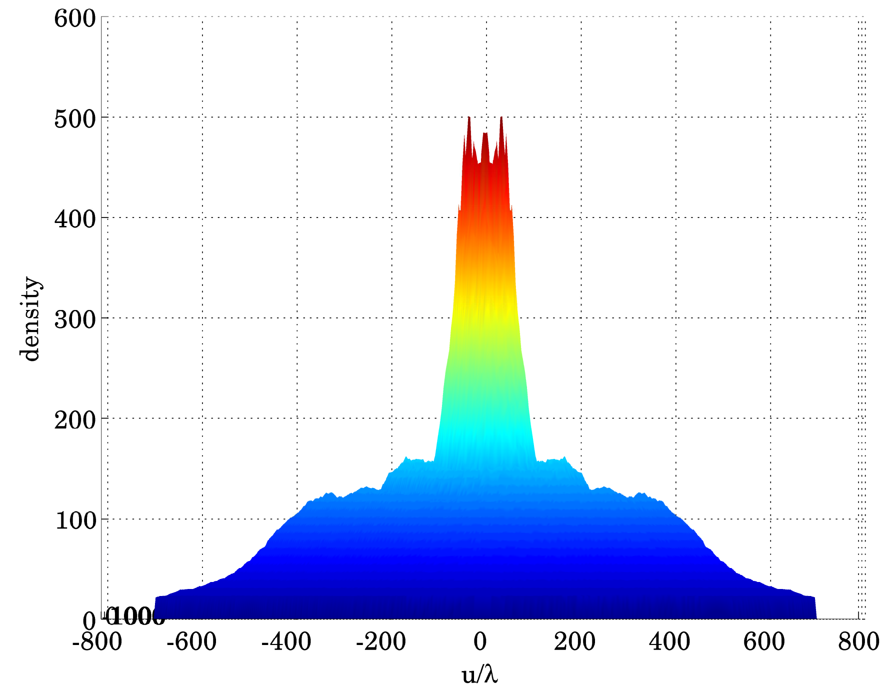
Sampling Density



uv sampling density for one frequency

Average Sampling Density

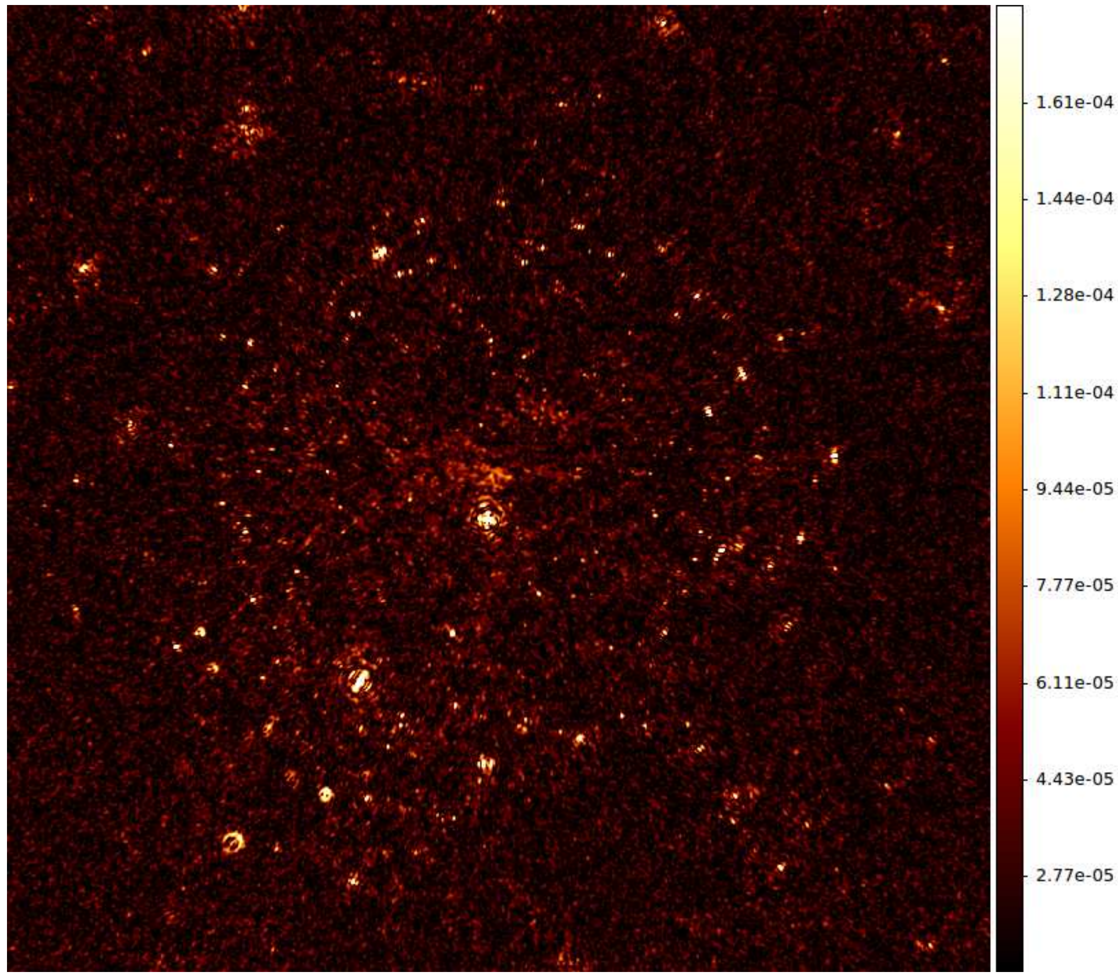




Average uv sampling density for full bandwidth 115-185 MHz

Important note: Filled uv plane $\neq$ no sidelobe variation.

Weak Diffuse Foregrounds



$f(x)$ diffuse forground, $g(x)$ PSF, image $f(x) \otimes g(x)$. $f(x)$ is very weak, but can we select $g(x)$ to enhance $f(x)$?

Image Weighting

- Natural weights: high SNR, high sidelobes; Uniform weights: low SNR, low sidelobes; Briggs weights: between uniform and natural weights.
- What we want: high SNR, low sidelobe variation over all frequencies and all epochs.
- Iterative weighting: [Pipe & Menon, 1999],[Yatawatta, 2014].
- $W(k)$: weights, $C(k)$: convolution kernel, $w(x)$ and $c(x)$ their FT. Gridded weights are $W(k) \otimes C(k)$, and FT of this is similar to the PSF. Given an a priori function $g(x)$ we want $w(x)c(x) \approx g(x)$. Convolve both sides with $w(x)$

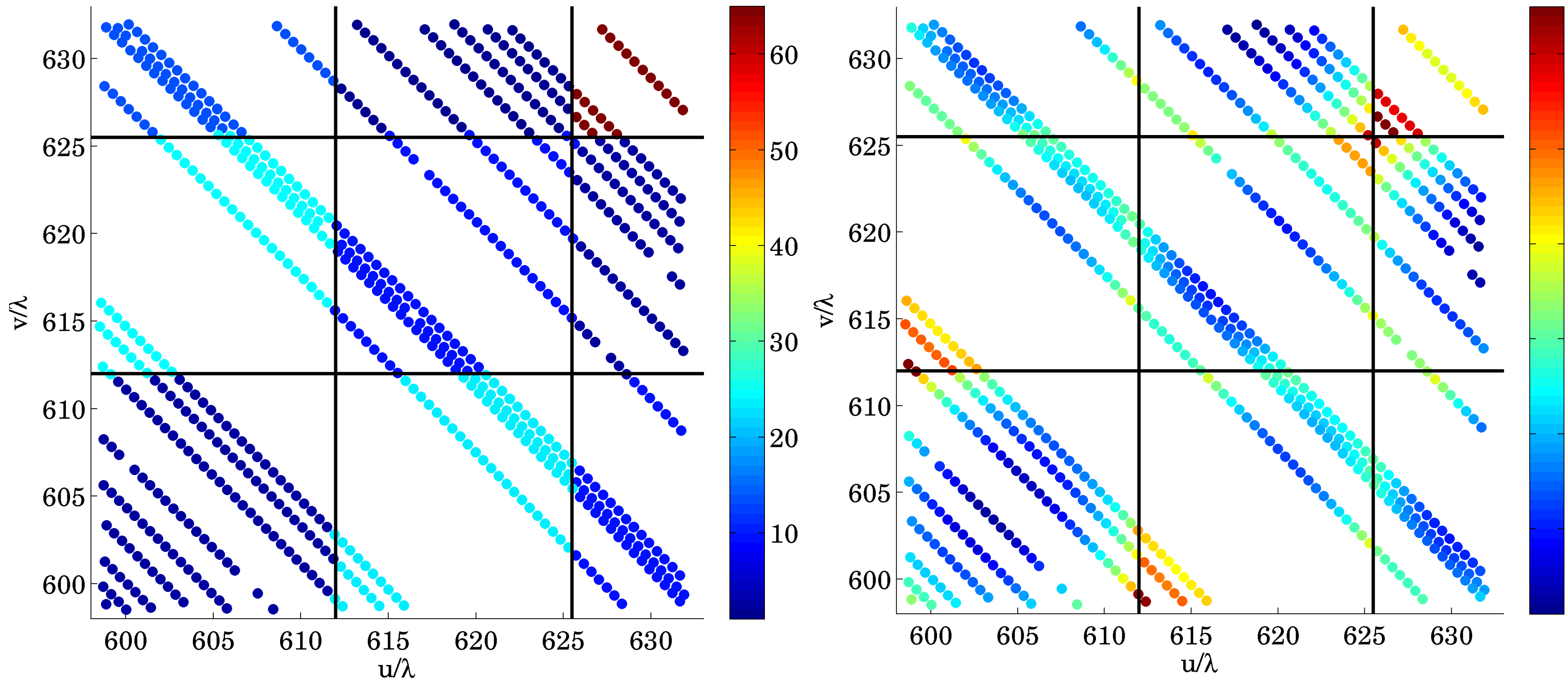
  $$w(x) \otimes (w(x)c(x)) \approx w(x) \otimes g(x) \quad W(k)(W(k) \otimes C(k)) \approx W(k)G(k)$$

  Both $W(k), C(k)$ positive real,

  $$W^{i+1}(k) \leftarrow \frac{W^i(k)G(k)}{(W^i(k) \otimes C(k))}$$

  which gives $W(k)$ to make the PSF as much as close to $g(x)$.

Example



(left) Uniform weights (right) Iterative weights with $g(x) \approx \delta(x)$. Weights follow 1 / sampling density

We can select $g(x)$ to maximize SNR.

Billion Pixel Image

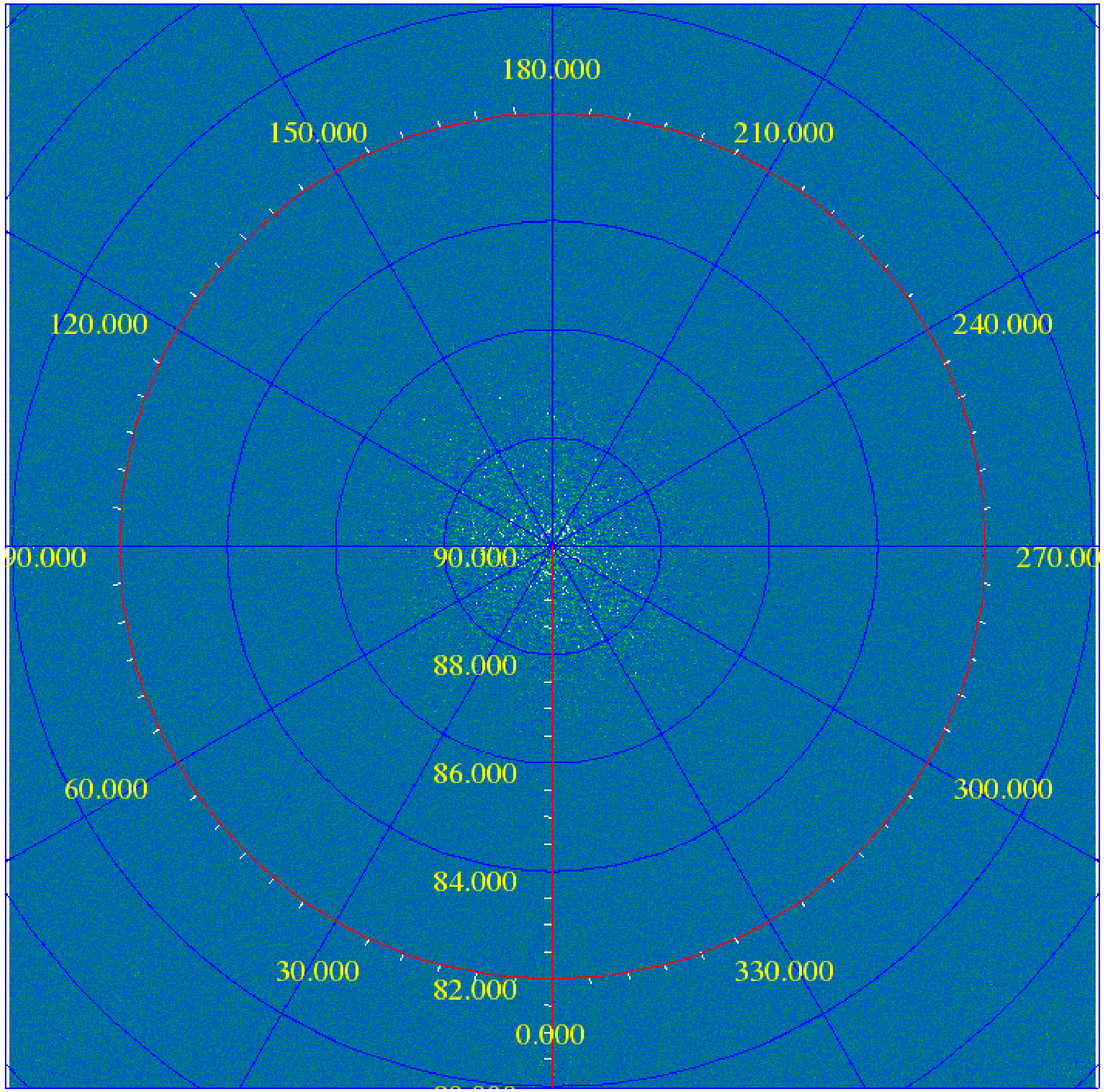
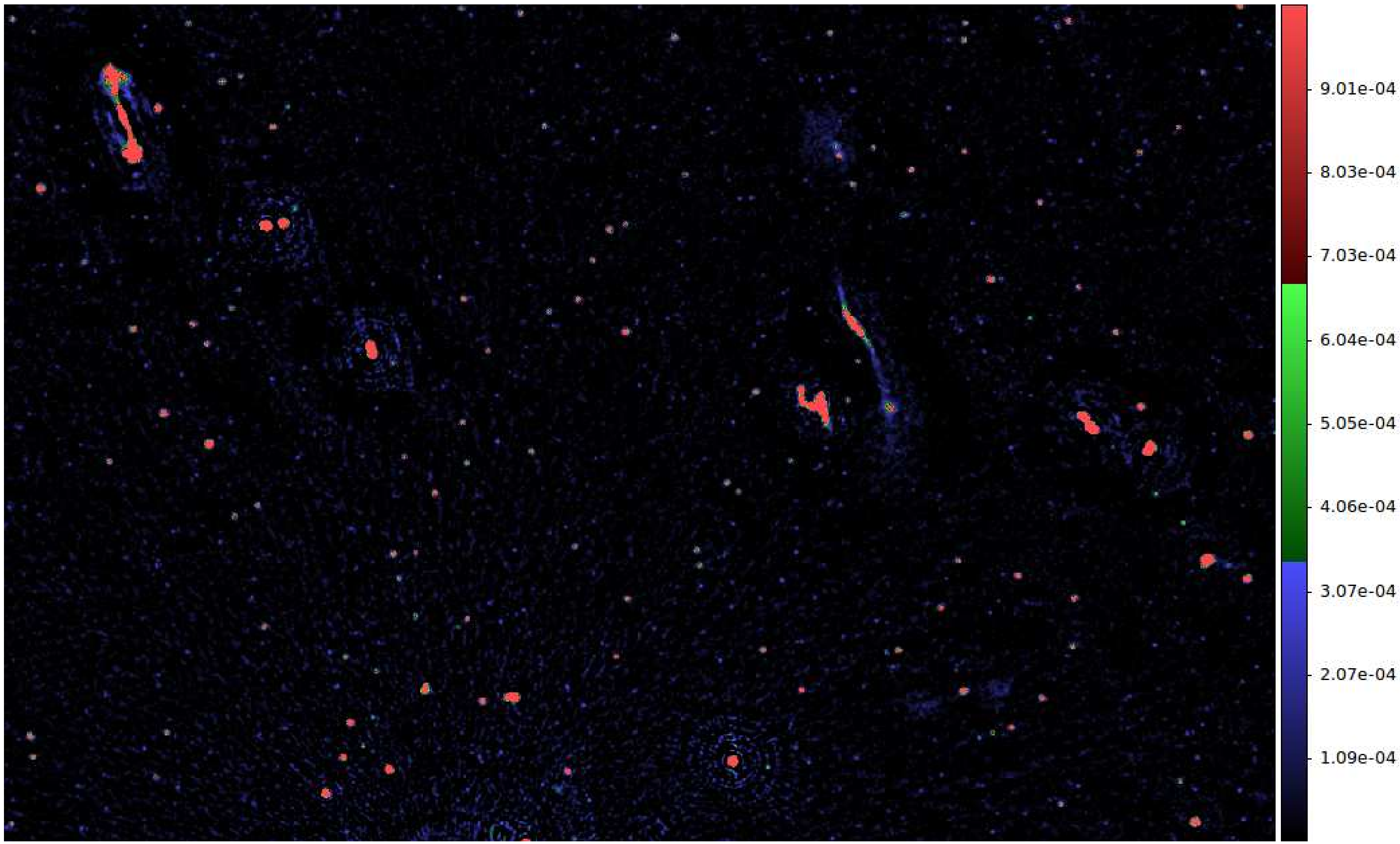


Image with $>$ 1 billion pixels, 36 000$\times$36 000, made in an average computer with 12 GB memory.

Deep Image with ExCon



Small area the NCP at 150 MHz, 2$''$ pixels, 30$\sim$17 μJy noise, 200 hrs data, dynamic range $>$ 150 000