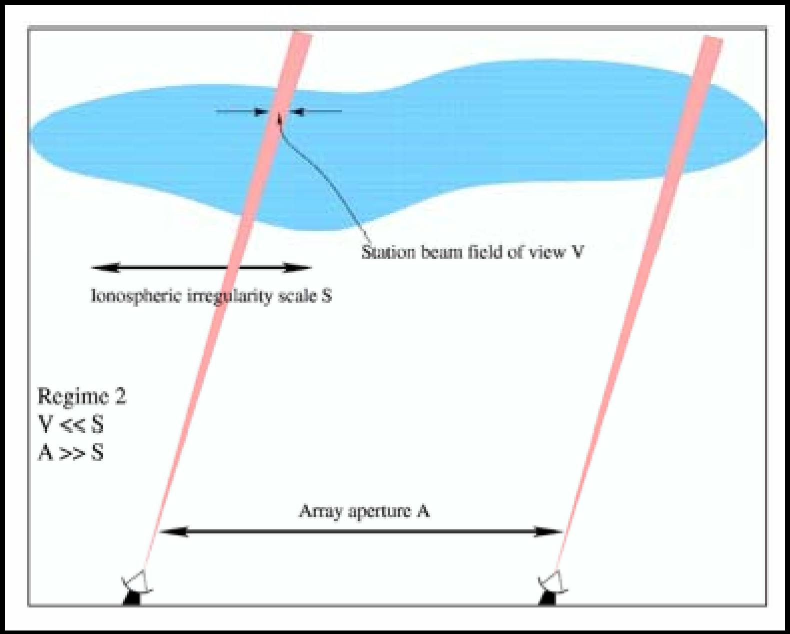
Predicting Sky Model visibilities with the UVBrick and forward application of DDE's.



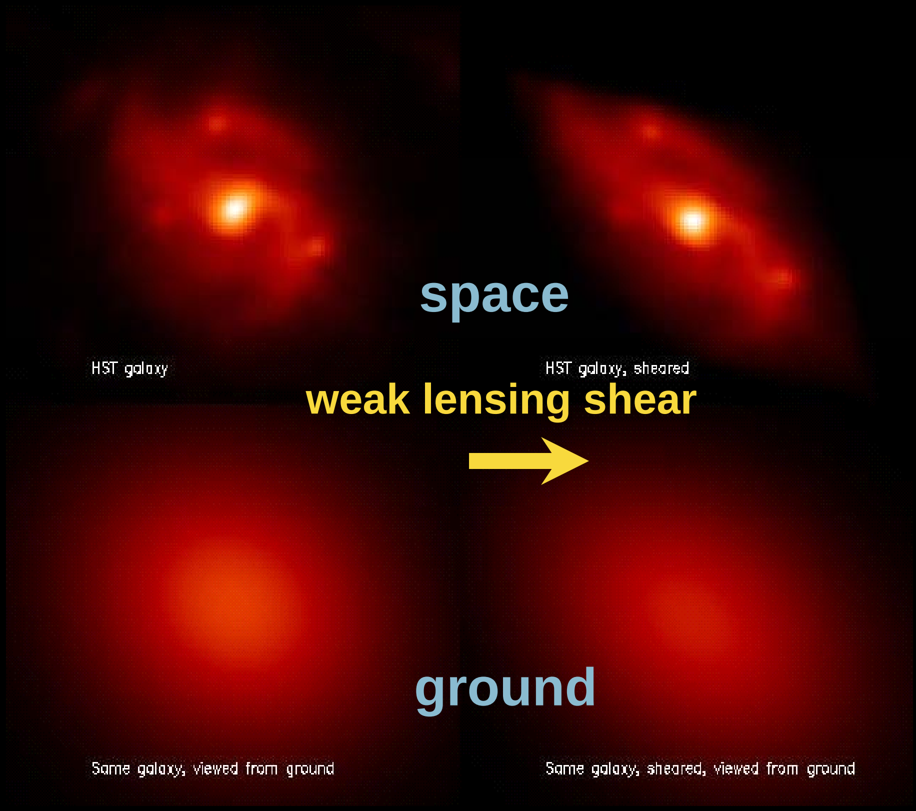
Filipe B. Abdalla

UCL

Outline

- Original motivation
- Gridding and degridding
- Simulations with the Brick
- Data: 3C83/84 (preliminary) with the Brick
- DDE's with the brick and the next steps...

Original motivation:
Shear Data: Optical
Ground and Space and Radio?



I am not a radio astronomer (at least I don't think I am one yet!!!) and most of this is work in progress so any comments are much welcome!!

Original motivation was to check if weak lensing was possible with radio data

Typical cosmic shear is ~ 1%, and must be measured with high accuracy

Along the way, discussion with Oleg, Jan, Tony and others (thanks to all of them) it became apparent that this could also be useful generally for calibration, inc DDE's, fast simulations, etc…

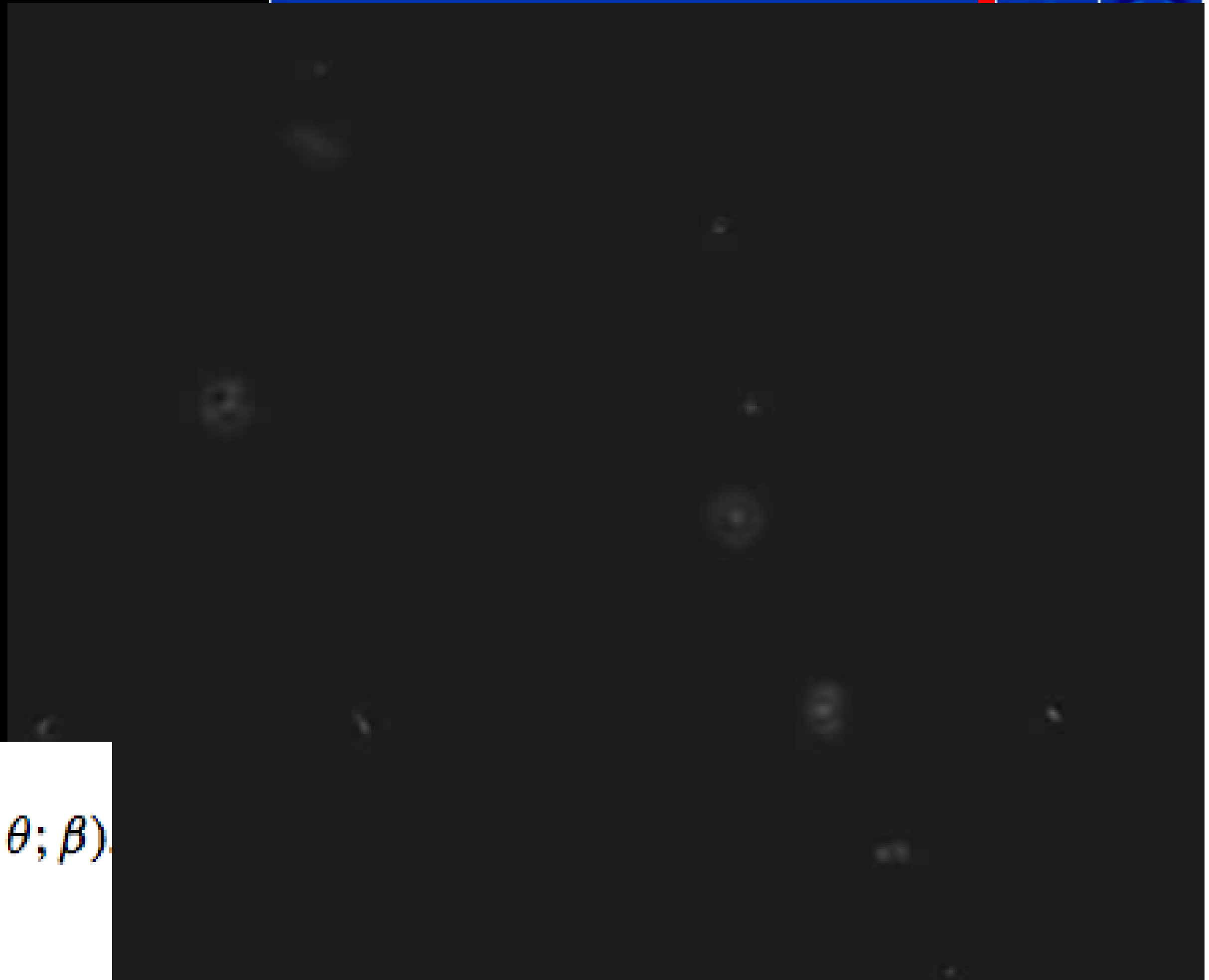
Shapelets for simulation:

Refregier 2003, Refregier & Bacon 2003,
Massey & Refregier 2005

Complete orthogonal basis functions

Capture all shape information of an object

Simple and analytic form for convolution and shear



$$f(r,\theta) = \sum_{n=0}^{\infty} \sum_{m=-n}^{n} f_{n,m} \chi_{n,m}(r,\theta;\beta)$$

$$f_{n,m} = \iint_{\mathbb{R}} f(r,\theta)\, \chi_{n,m}(r,\theta;\beta)\, r\, \mathrm{d}r\, \mathrm{d}\theta$$

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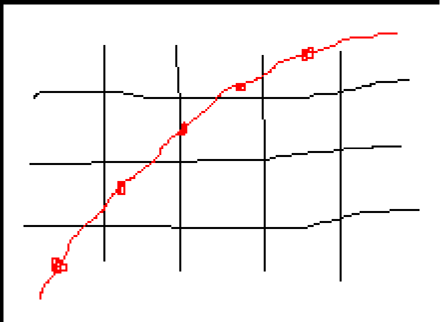
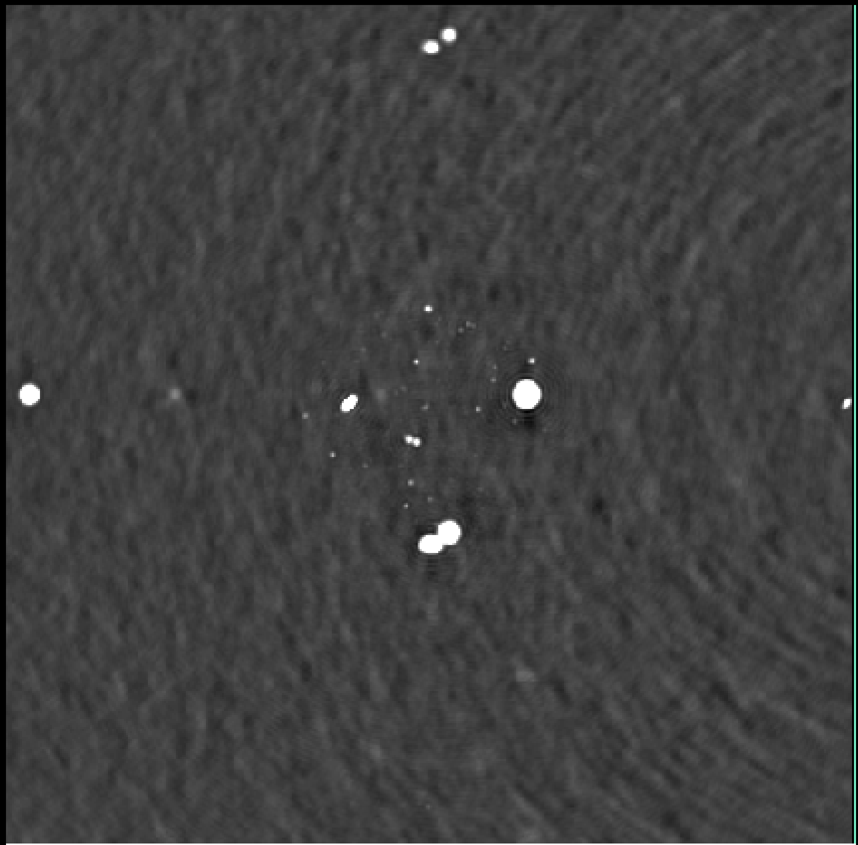
Gridding and degridding

MAP PLANE		VISIBILITY PLANE
$f(\vec{x})$ True Sky	$\Longrightarrow$	$V(u,v)$ Visibilities
$f * s$ DFT Map	$\xleftarrow{\text{DFT}}$	$\downarrow$ VS Sampled Visibilities
$(f * s)c$		$\downarrow$ $VS * C$ Convolved Visibilities
$((f * s)c) * \text{III}$ Gridding Correction	$\xleftarrow{\text{FFT}}$	$\downarrow$ $(VS * C)\text{III}$ Gridded Convolved Visibilities
$\downarrow$ $h((f * s)c)\text{III}$ Gridding Corrected Dirty Map		$h = 1/\mathcal{F}(c)$

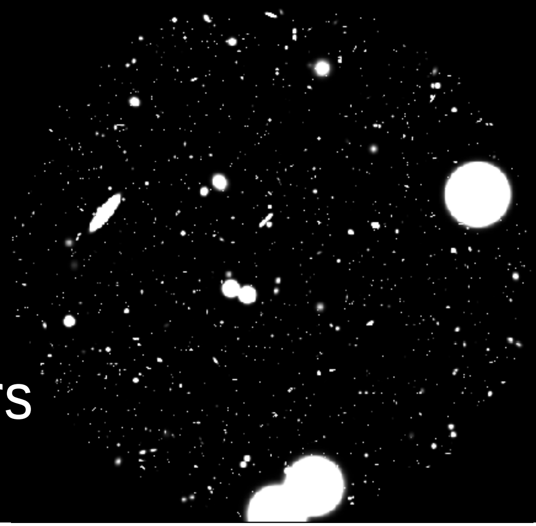
- UVBrick is flipping an image into the UV plane: the inverse of imaging.
- Step zero: a Fourier transform
- Step one: interpolation of UV data points (but interpolation is a convolution) -> image plane corrections
- Step two: correction DFT $\neq$ FFT (padding) and correction in the image plane…
- In practice, there are padding factors as well



UVBrick background:



- Used here are convolution functions spheroid functions (not the most accurate solution to the problem!!!) (padding)
- Within MeqTrees framework all other directional independent effects (DIE) can be included.
- Not everything the final Brick will do. Hopefully!!!
- In the side image this shows the effect of not using the correct degriding, i.e. using interpolation in the UV plane.



Apologies to the Black belt radio astronomers in the room if this is too simple

Why an UVBrick?

- UVBrick is flipping an image into the UV plane
- First reason is to simulate extended sources -> complementary to shapelets (hence the weak lensing original motivation!!!)
- Second is that is faster than doing one DFT per simulated object as they are all treated simultaneously in the FFT
- Scalings:

  Direct simulations: scales as the number of sources

  Brick: scales with baselines if degridding is limit

  Brick: scales as resolution^2 if FFT is limit
- Small overhead of convolution (support used is 4*4 so 16 operation convolution) remember this for the DDE case…

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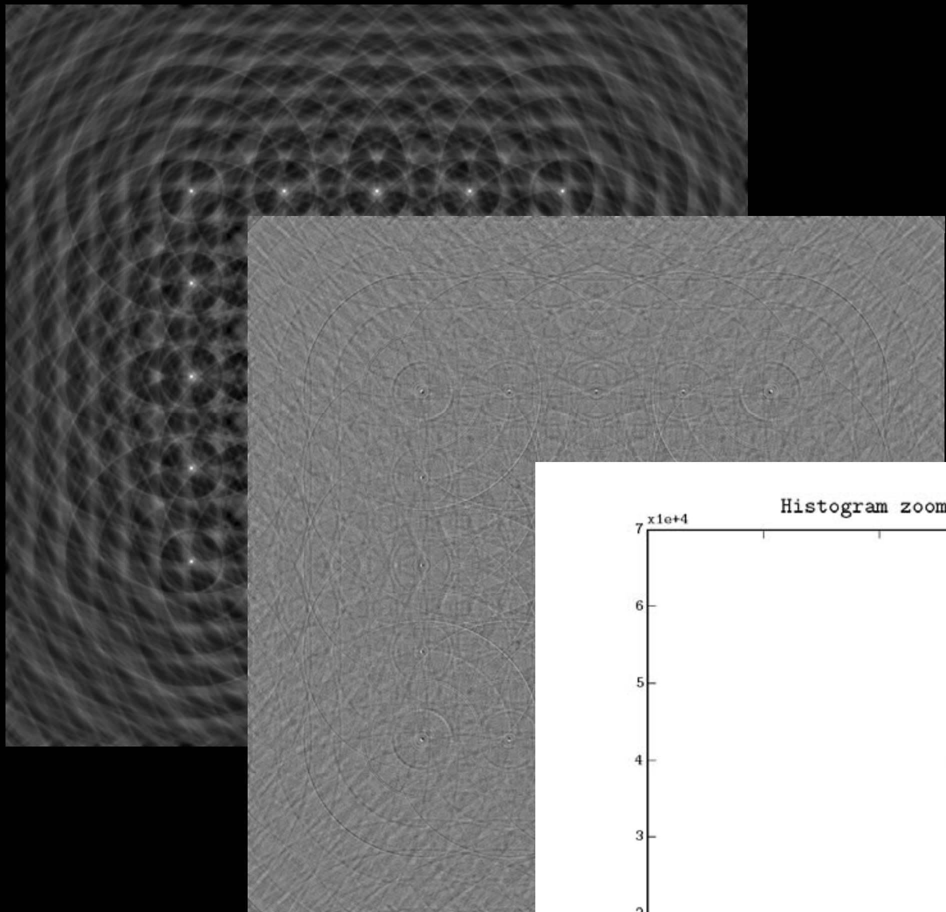
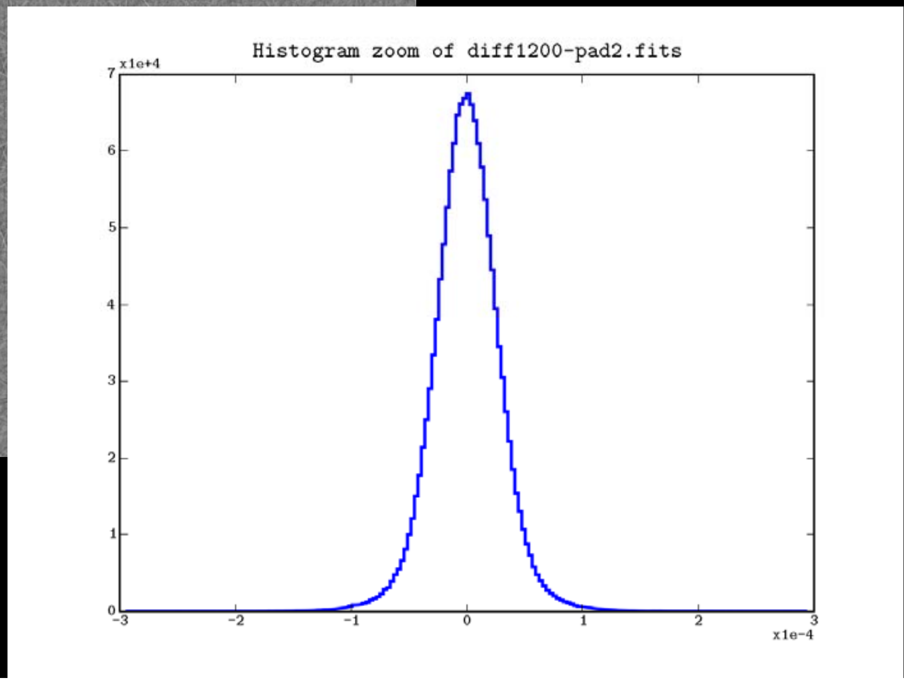
UVBrick accuracy:

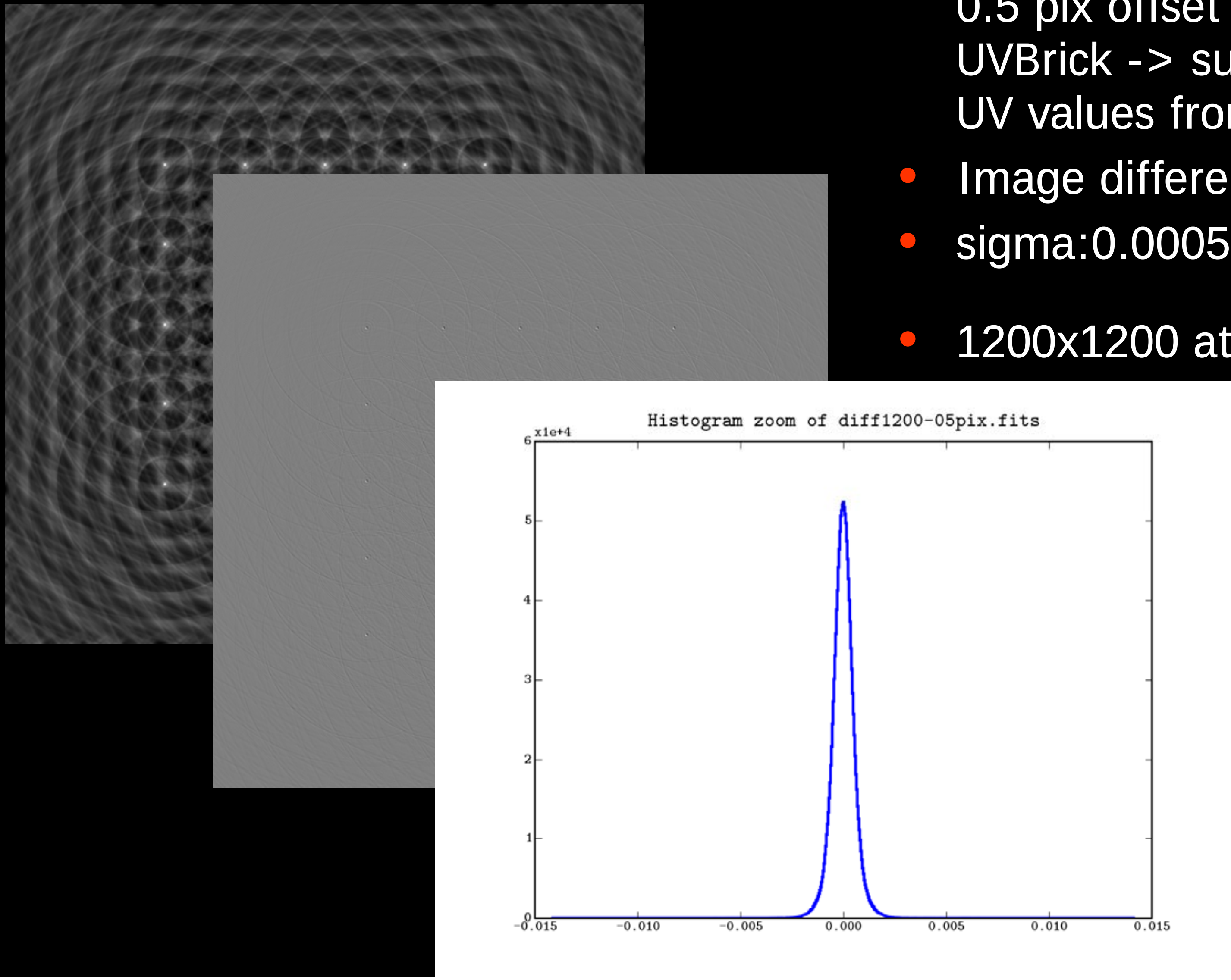
- Simulate a grid of points with DFT's -> fill MS
- Simulate the same points with the UVBrick -> subtract the UV values from MS.
- Image difference.
- sigma:3.02036e-05
- 1200x1200 at 120'





UVBrick accuracy:

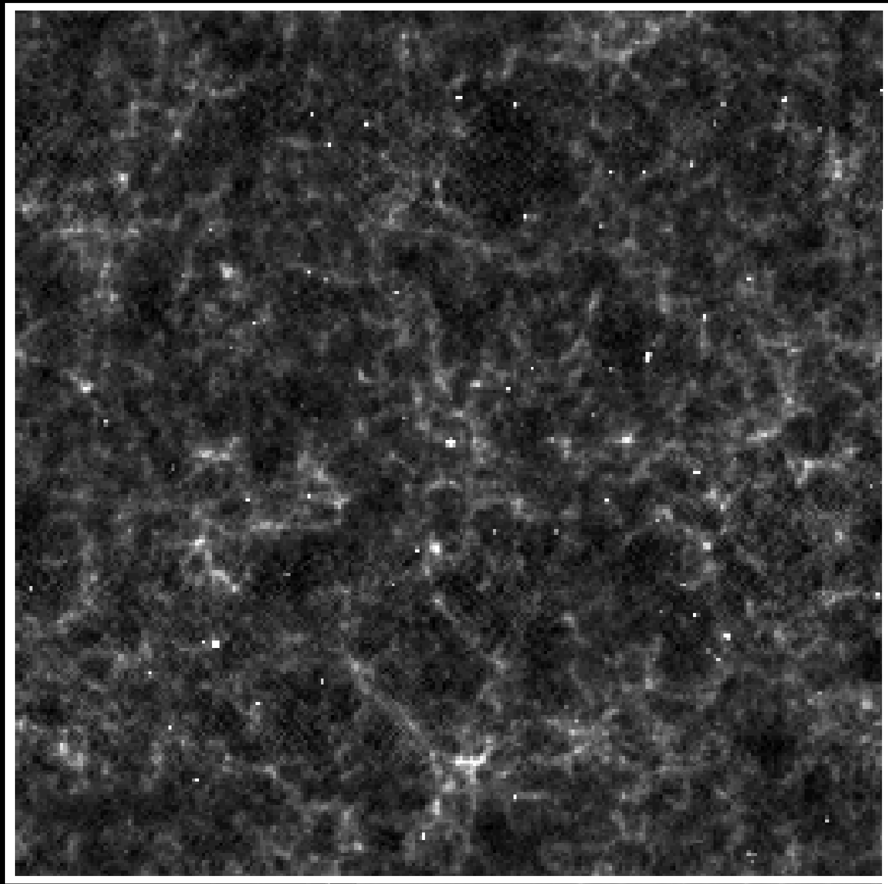
- Simulate a grid of points with DFT's -> fill MS
- Simulate the same points 0.5 pix offset with the UVBrick -> subtract the UV values from MS.
- Image difference.
- sigma:0.000555845
- 1200x1200 at 120'



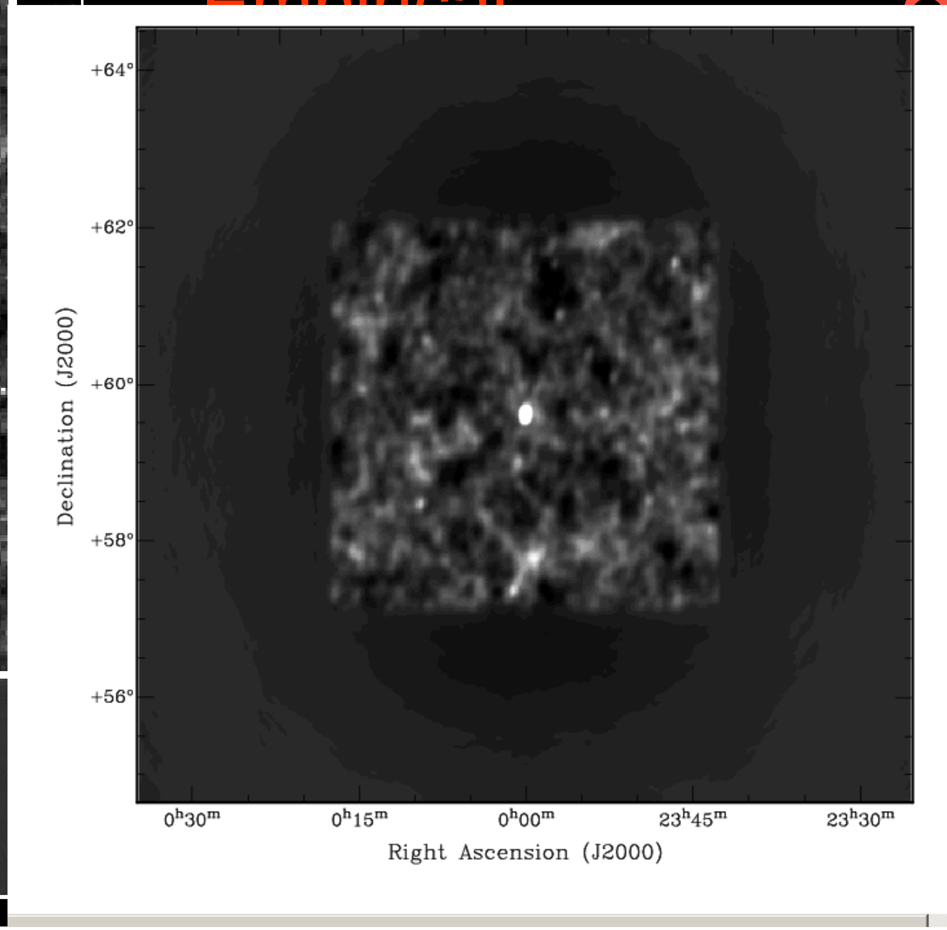
What does this mean?

- When simulating or using the brick to make a sky model:
- Simulate the brighter sources with DFT's they are not many as they are bright
- Simulate the fainter remembering there is a 'dynamic range' introduced by the brick.
- This error is a function of convolution functions and the resolution.
- I.e. if you want to simulate sources over 6 orders of magnitude and the gridding errors are 1e-4 then the top two orders have to be simulated with DFT's the bottom 4 magnitudes can be done with the Brick.
- Warning: can always increase resolution but the limit is the convolution functions. Better convolution functions than the ones used are claimed to exist…
- Compared to shapelets, the brick is preferable:
  - Many more and/or much more extended sources/emission
  - Fainter sources
- Compared to shapelets, the brick is less preferable:
  - Compact bright extended sources

UVBrick simulations at work:



Design requirements of the Semi-Empirical

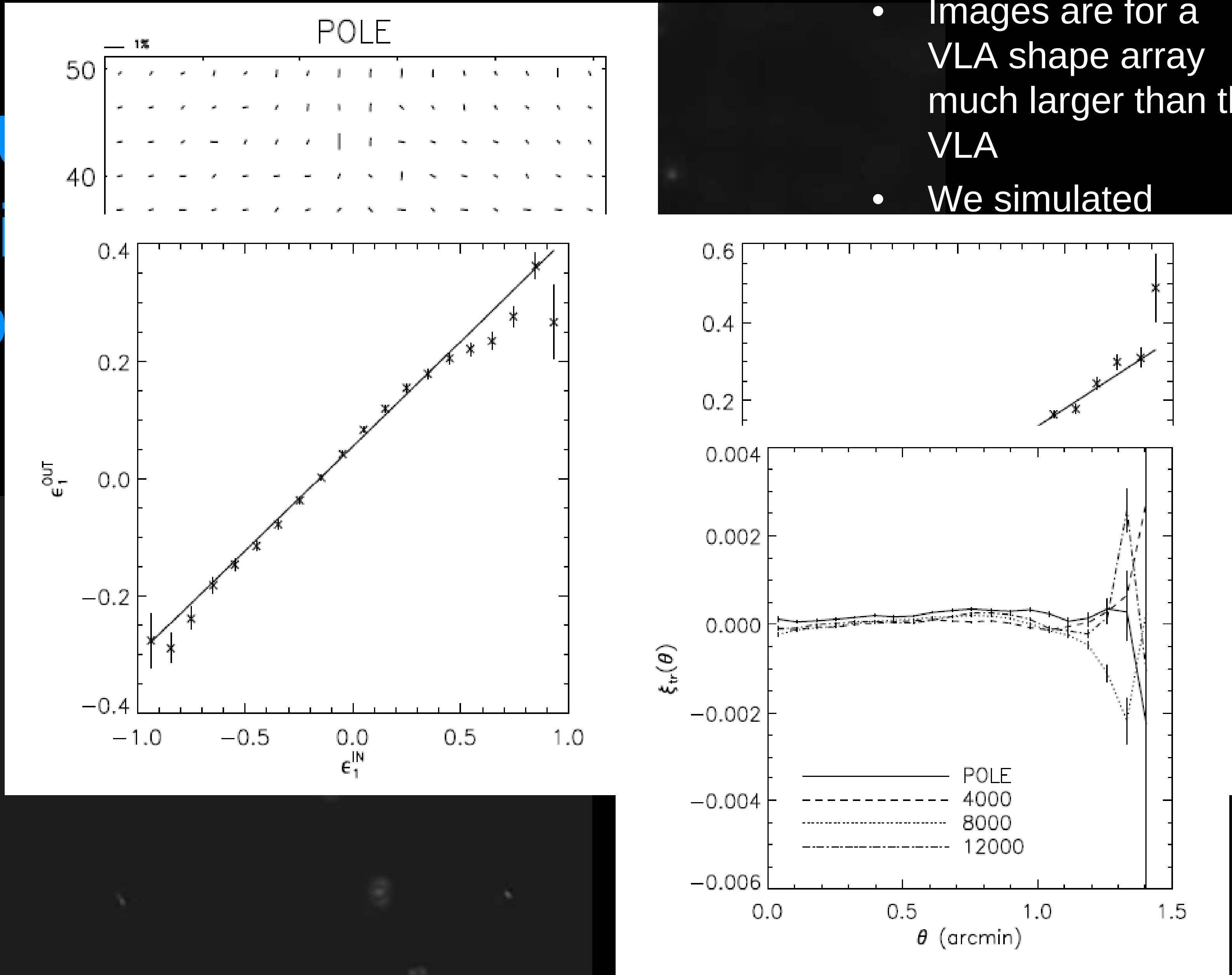


LOFAR sim for the EoR from Panos

U

si

fo



- Images are for a VLA shape array much larger than the VLA
- We simulated

Pattel, Abdalla, Bacon and others (in prep)

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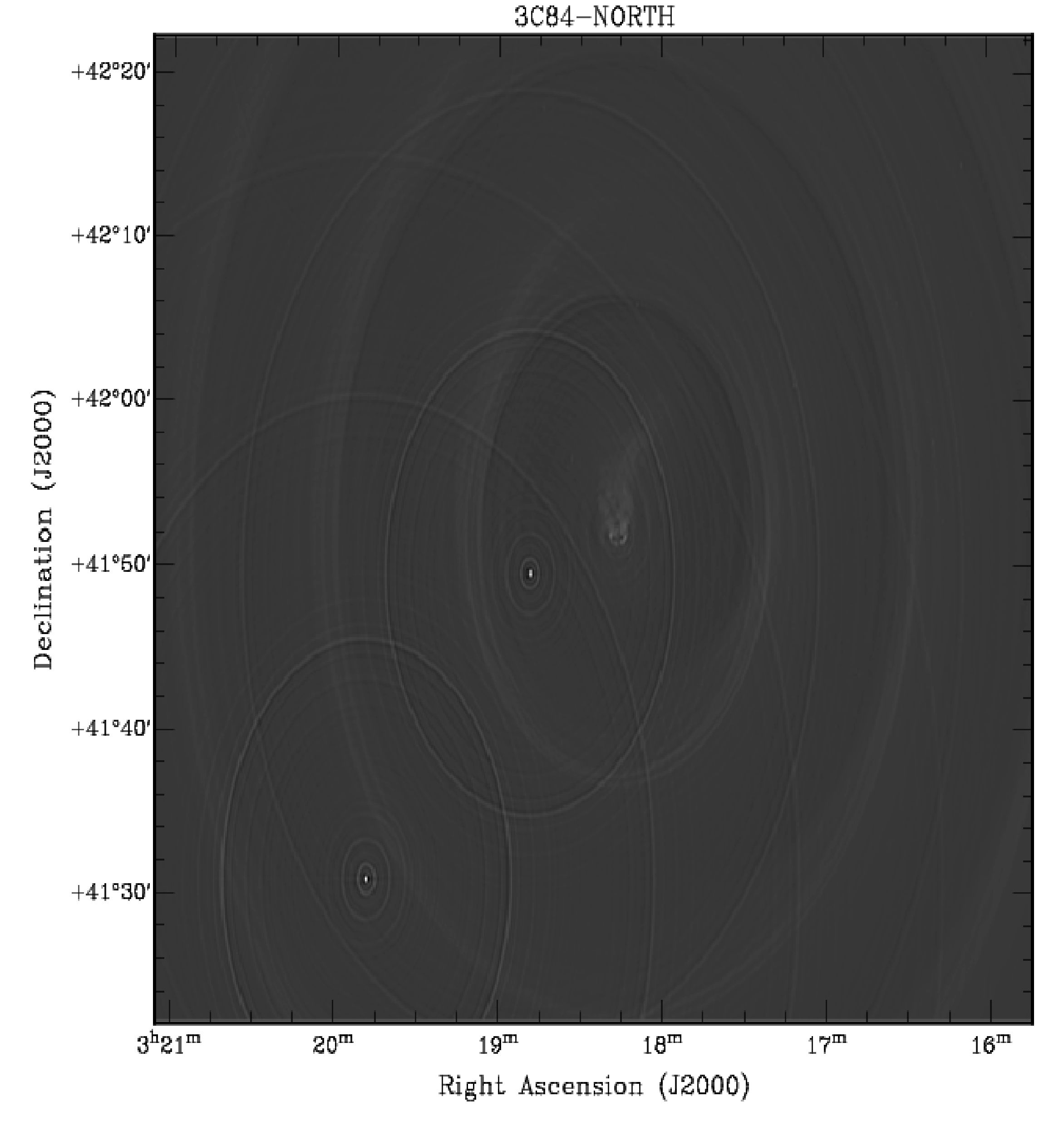
3C84 the field:

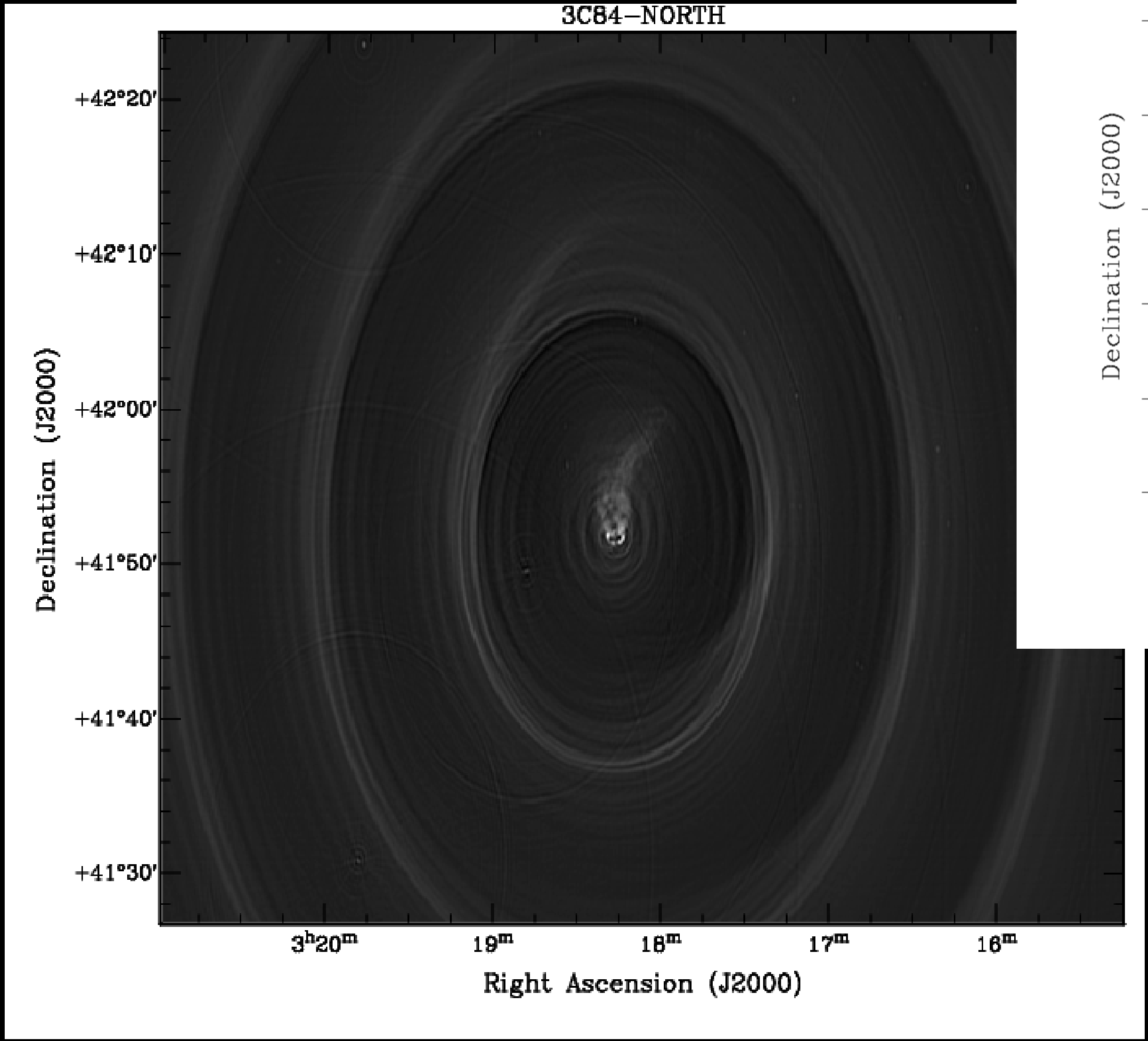
- 3 main sources: extended source, 20 Jy source and 0.5 Jy source. Off centre All have similar apparent fluxes given positions.
- 20 Jy source very polarised, extended source has some polarisation.

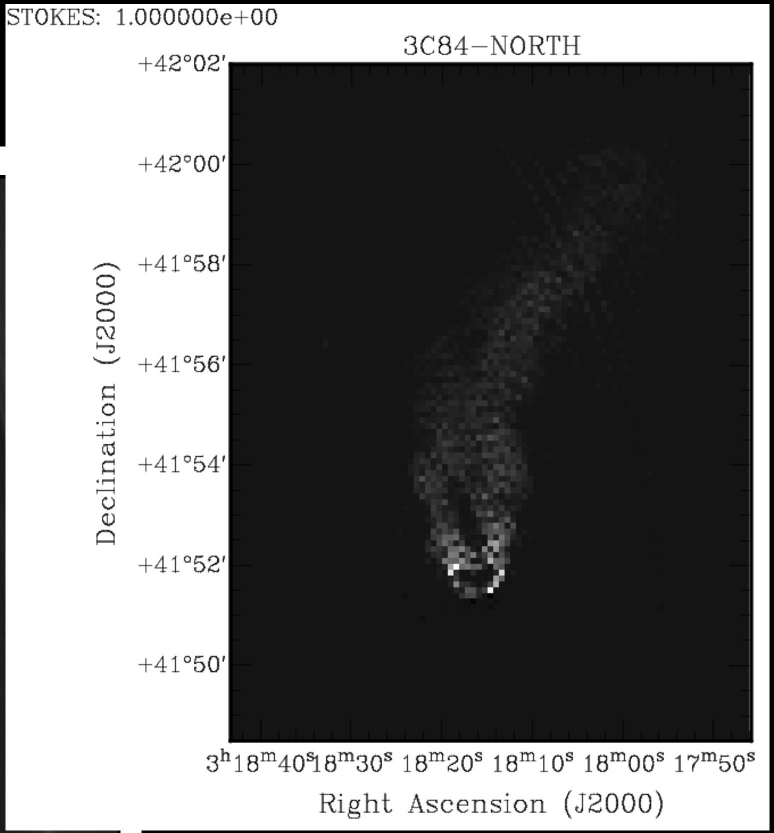


3C84 the field

- Didnt have a good sky model in the beginning...
- Solve for G Jones, dE jones for the furthest source (also for the closest one now), IG and source fluxes.
- Determined source positions from calibrated images and recalibrated, then iterated building up a model and recalibrating for the extended source.
- Harder problem because the solutions are mixed...

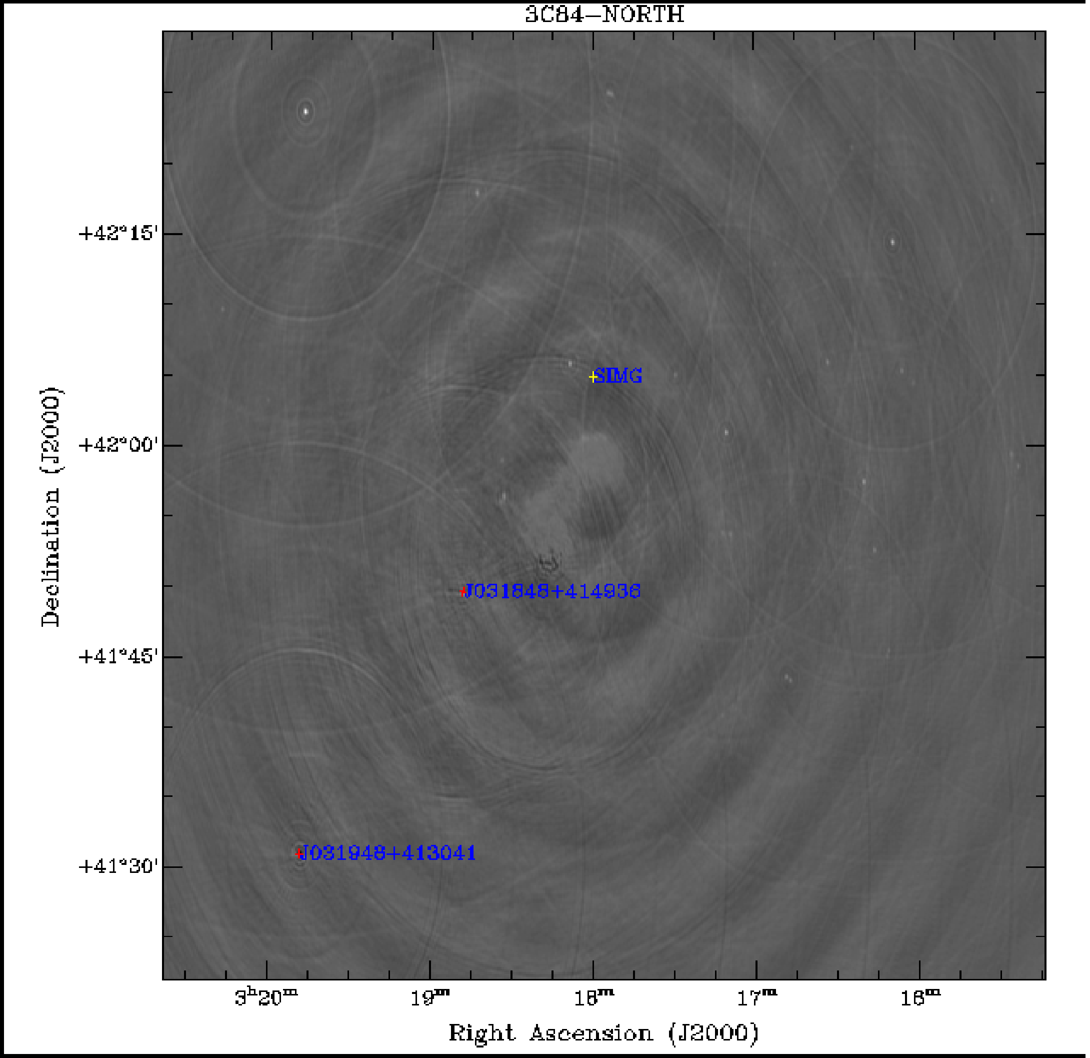
Calibrated field:





Residual map (not the final one):

- Extended source still there at ~per cent
- This is not the final map, used only one configuration of WSRT so cleaning was introducing some errors.
- Doing the analysis with more configurations atm.
- Use other clean algorithms…
- This proves the concept that the Brick can be used for calibration as well, the question is to what accuracy?



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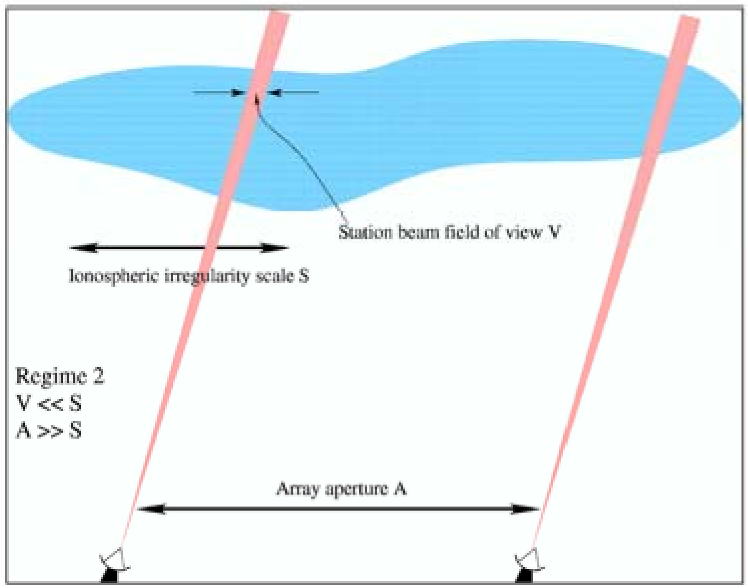
Back to the Measurement Equation

$$V_{pq} = J_p B J_q^{\dagger}$$

- *uv-plane effects* apply to all directions (i.e. all sources) equally
  - e.g. receiver gain
- *image-plane effects* depend on direction
  - e.g. ionosphere
- *source coherency* is (in a sense) intrinsic.
- Given that there is a small convolution in the brick this could handle DDE in principle if the kernel is small.

$$V_{pq} = J_{pn} \cdots J_{p2} J_{p1} B J_{q1}^{\dagger} J_{q2}^{\dagger} \cdots J_{qm}^{\dagger}$$



The ME a bit more in detail now…

$$V_{pq} = J_p\left(\iint_{lm} K_p E_p B E^\dagger K_q^\dagger \frac{\mathrm{d}l\mathrm{d}m}{n}\right) J_q^\dagger$$

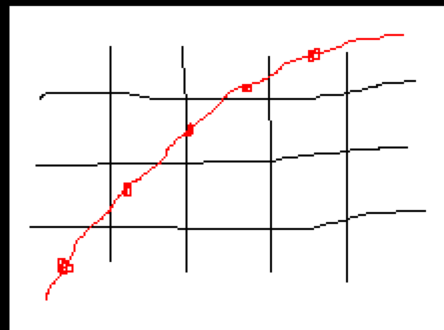
$$V_{pq} = J_p \mathcal{F}(E_p B E^\dagger) J_q^\dagger$$

$$\mathcal{F}(E_p B E^\dagger) = \mathcal{F}(E_p) \circ X \circ \mathcal{F}(E_q^\dagger)$$

$$\downarrow$$
$$h((f * s)c)\mathrm{III}$$
Gridding Corrected Dirty Map

- Here E depends on l and m say
- If the kernel of convolution is the small, this can be done in the last step of convolution when we use the UVBrick to predict visibilities… i.e. change c without changing h… Oleg calls this the Bhatnagar approach…

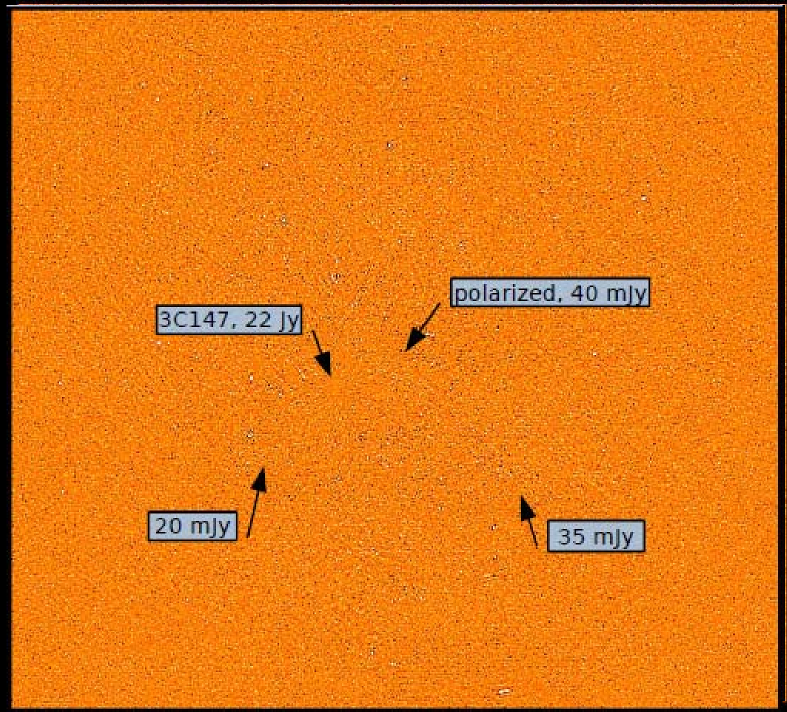
$$c \rightarrow c \circ \mathcal{F}(E_p) \circ \mathcal{F}(E_q^\dagger)$$



Why is this interesting?

- Can fit for a model ionosphere for the entire image, for example…
- Can use the selfcal solutions to guide the main solution for the image.
- Is general as it applies to any image plane effect in principle.
- Should be not much slower than making a simulation with the main Brick if the kernels are small…
- Scales as how big your kernel is compared to c squared plus computing each kernel convolution (might be the limiting step if one convolution needed for each time step for instance…)

$$Z(l, m) = e^{-i\xi(l,m)}$$



Borrowed from one of Oleg's tutorials for delta E solutions for none, 5 then 10 sources

Conclusions: the next steps

- Reminder of the UVBrick: qualities and drawbacks.
- Brick with DIEs exist in MeqTrees and can be used.
- UVBrick used for calibration as well as simulation. Script is very simple in the repository, just need to specify: A MS, an image, padding factors…
- Brick with DDEs does not exist… yet…
- Hopefully, this could be a way of dealing with DDEs in an efficient way both in simulation and calibration…
- Comments, suggestions, concerns about this method are very welcome…