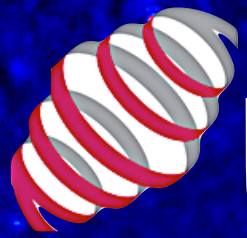

LOFAR Image Plane Transient Candidate

Found in the NCP Field by the TraP

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LOFAR Community Science Workshop - Amsterdam - 8-9 April 2014

four π sky

UNIVERSITY OF OXFORD

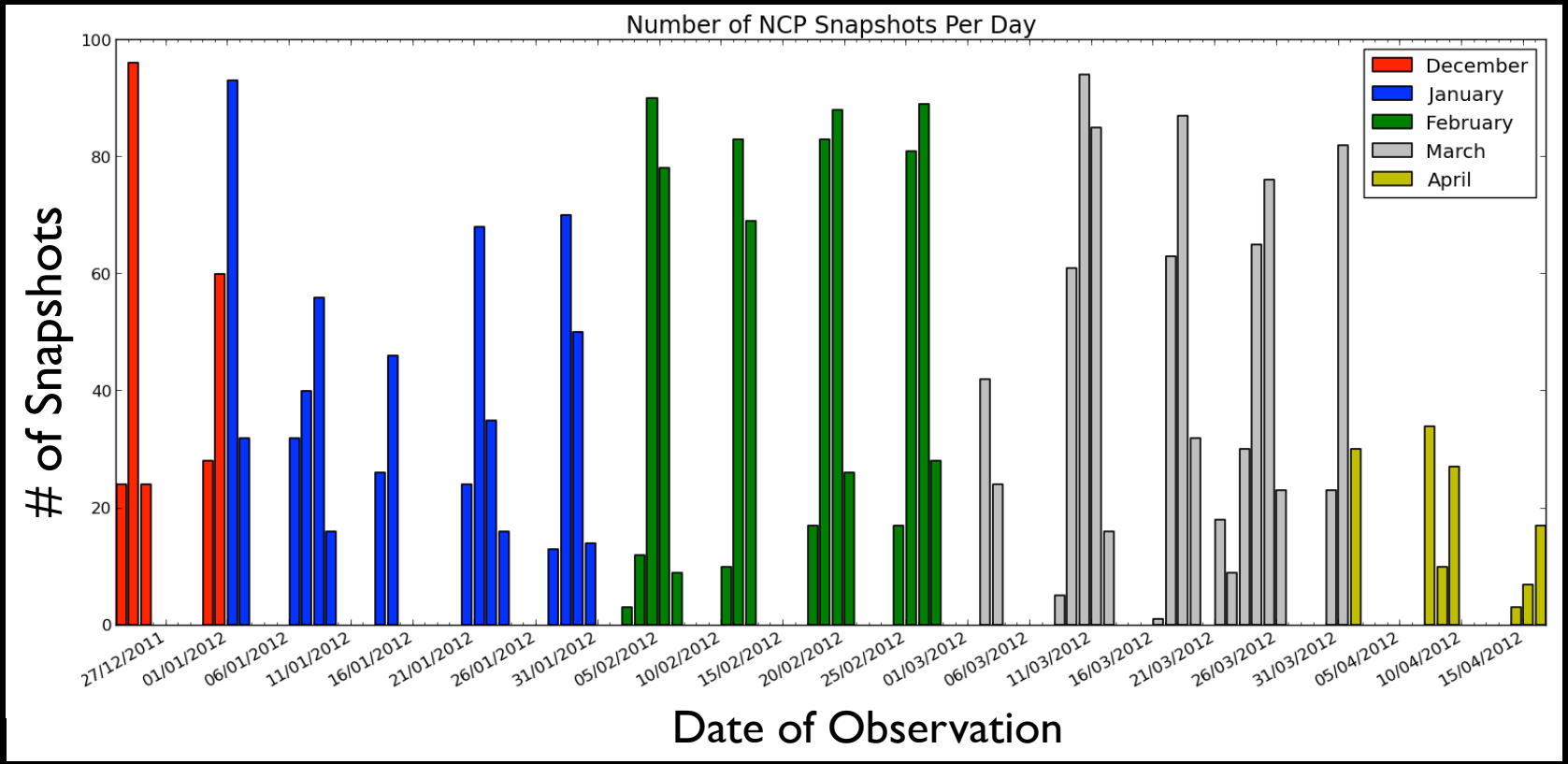
UNIVERSITY OF Southampton

MSSS-LBA NCP Monitoring Campaign

- Observed during the initial MSSS-LBA run in 2011/12.
- With each MSSS observation made, a single subband was placed on the North Celestial Pole.
- This amassed ~2600 NCP snapshots spread over 4 months.

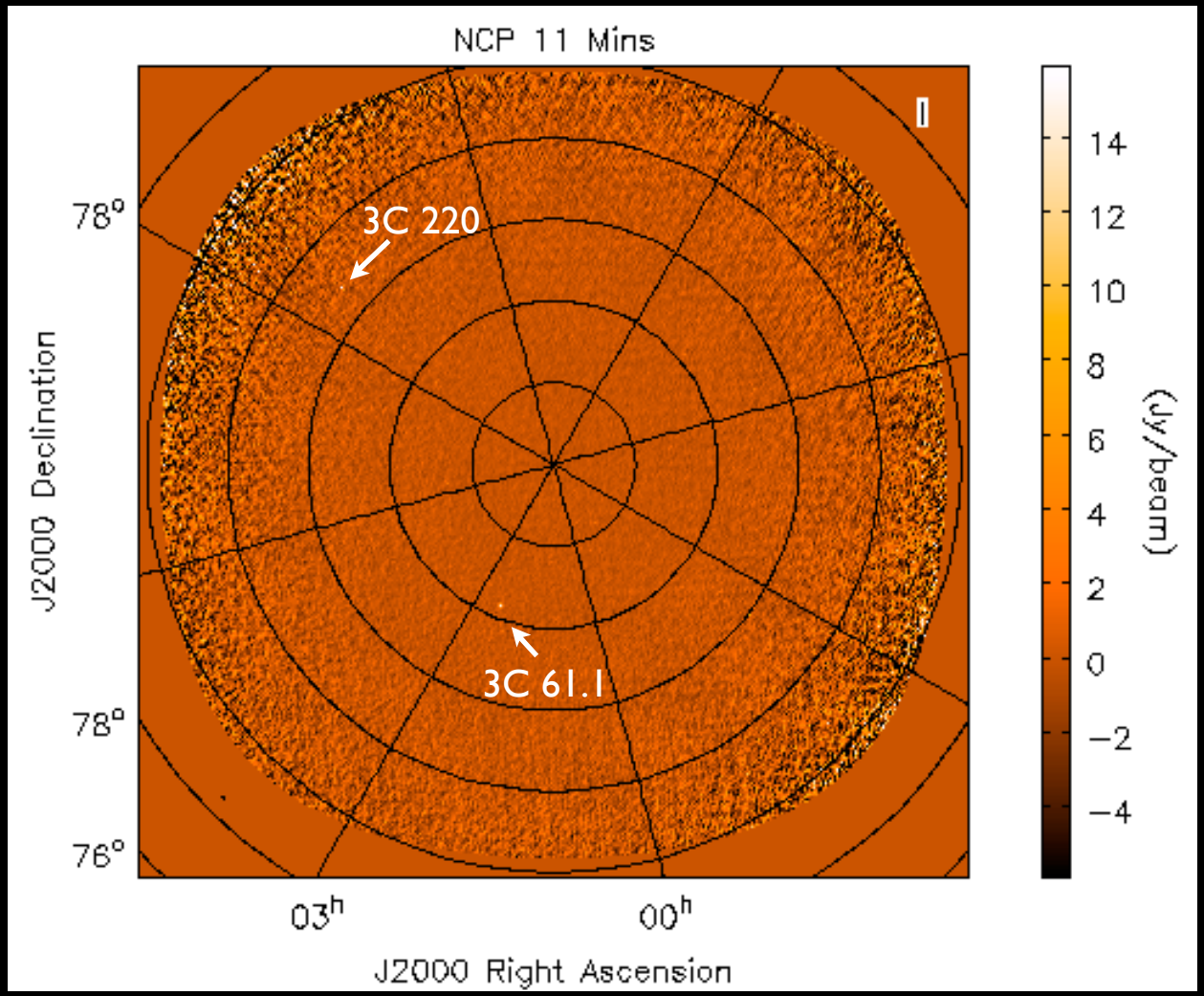
Beam 0	Target	L219+29
	Subbands	80
Beam 1	Target	L220+23
	Subbands	80
Beam 2	Target	3C295
	Subbands	80
Beam 3	Target	NCP
	Subbands	1

msss.astron.nl



MSSS-LBA NCP Monitoring Campaign

- Processed exactly the same as MSSS-LBA data.
- Including using MSSS calibrators for amplitude calibration and using gsm.py model.
- Each observation:
  - Is 11 minutes long
  - At 60 MHz
  - Has 200 kHz of bandwidth
  - When in sequence observations are 4 minutes apart.
  - Typical snapshot rms ~ 400 mJy

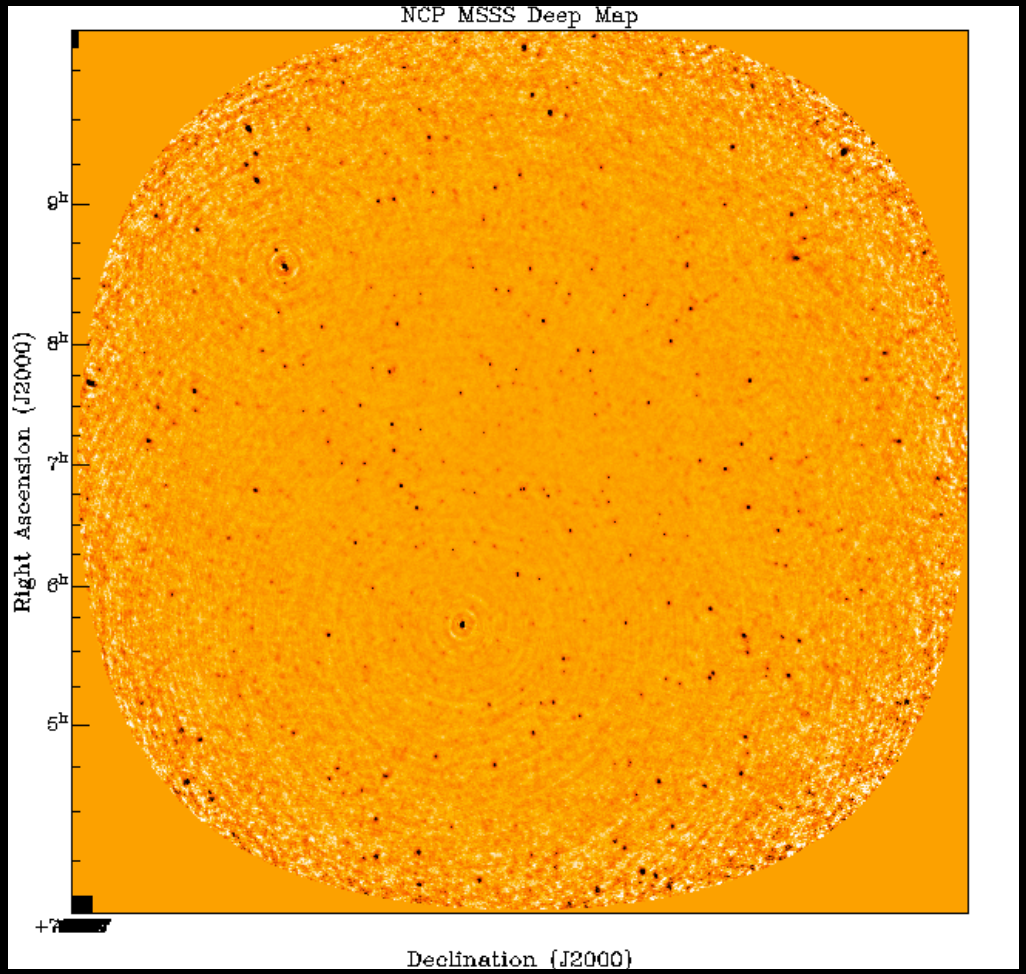


Typically 220 x 130 arcsec (50 BPA) 10 km baselines

Transient Search

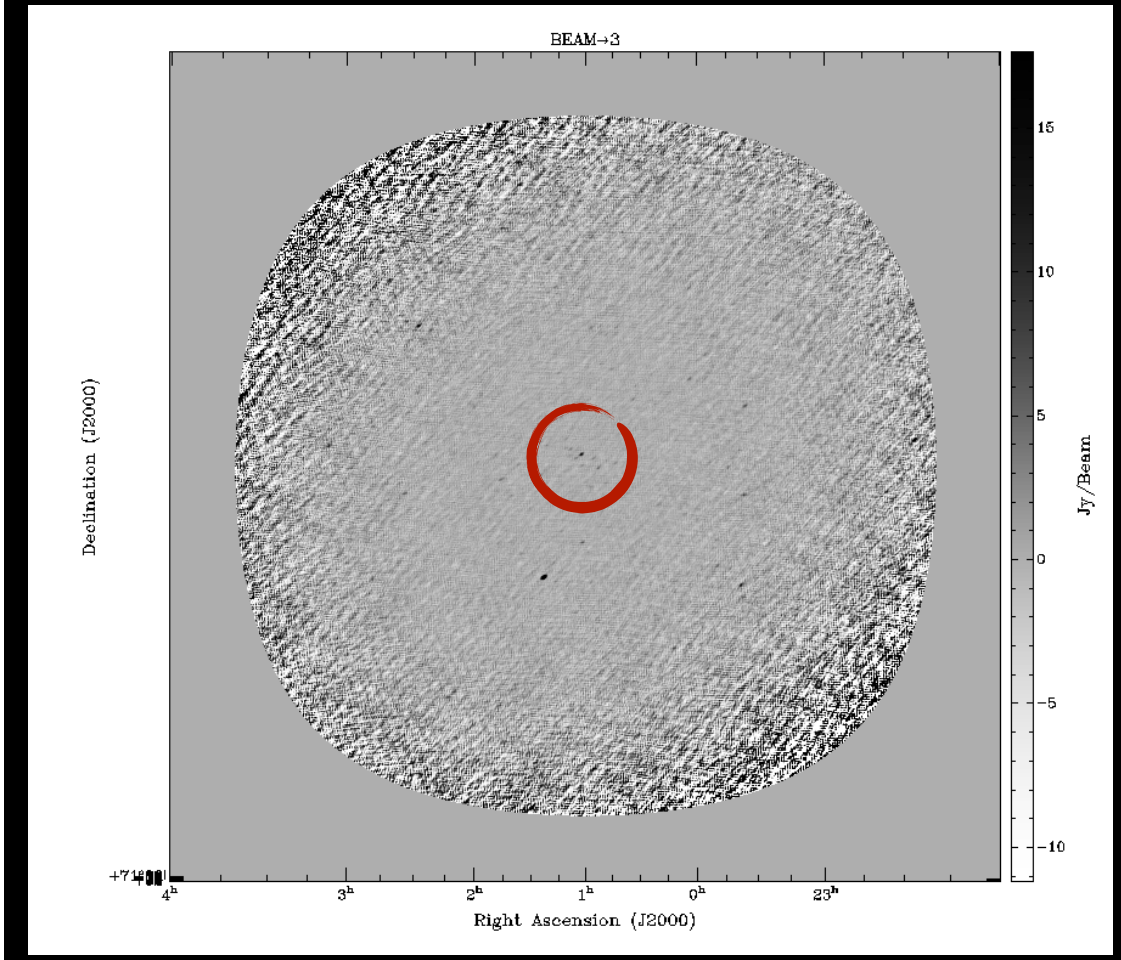
- Time-scales of low-frequency transient population unknown.
- Hence data was split or combined to create various time-scales at which to search for transients.

Time Scale	# Epochs	Mean Sensitivity	Typical # Sources (10σ)
30 secs	41340	2.3 Jy	1
2 Mins	9262	1.35 Jy	2
11 mins	1897	0.41 Jy	25
55 Mins	328	0.3 Jy	40
297 Mins	32	0.14 Jy	60



Deepest Map ~ 35 mJy rms

Simulating a Transient

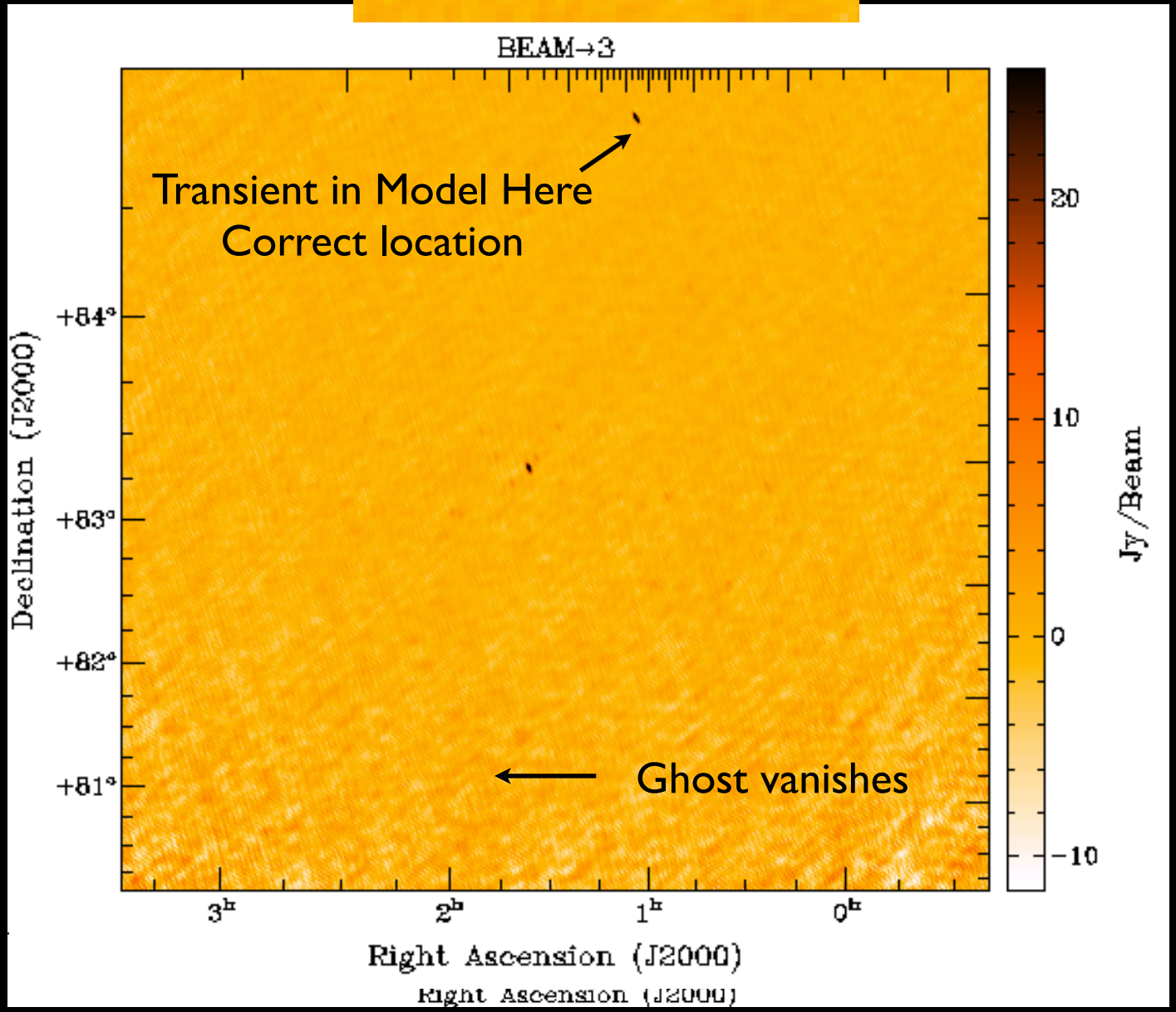


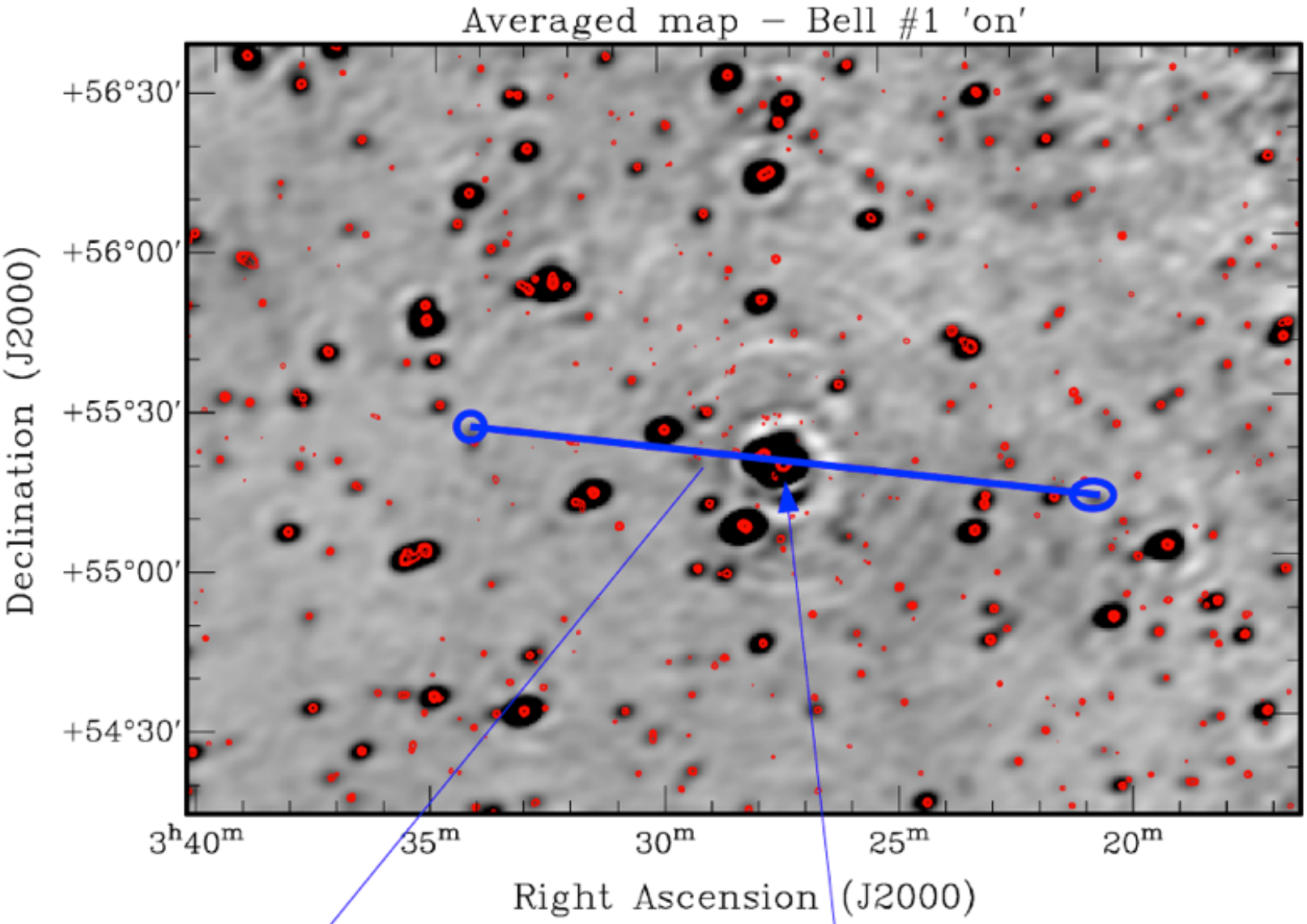
30 Jy Source inserted

- General aim was to test whether a transient would be seen with the reduction method.
- How did this particular data react?
- Any brightness of transient.
- Transient inserted into pre-processed data before being reduced through MSSS pipeline.
- Using calibrator gain solutions to insert - ideally want field phase solutions but proved difficult to merge and use gains table.
- Assuming transient survives demixing, flagging etc

Ghost?

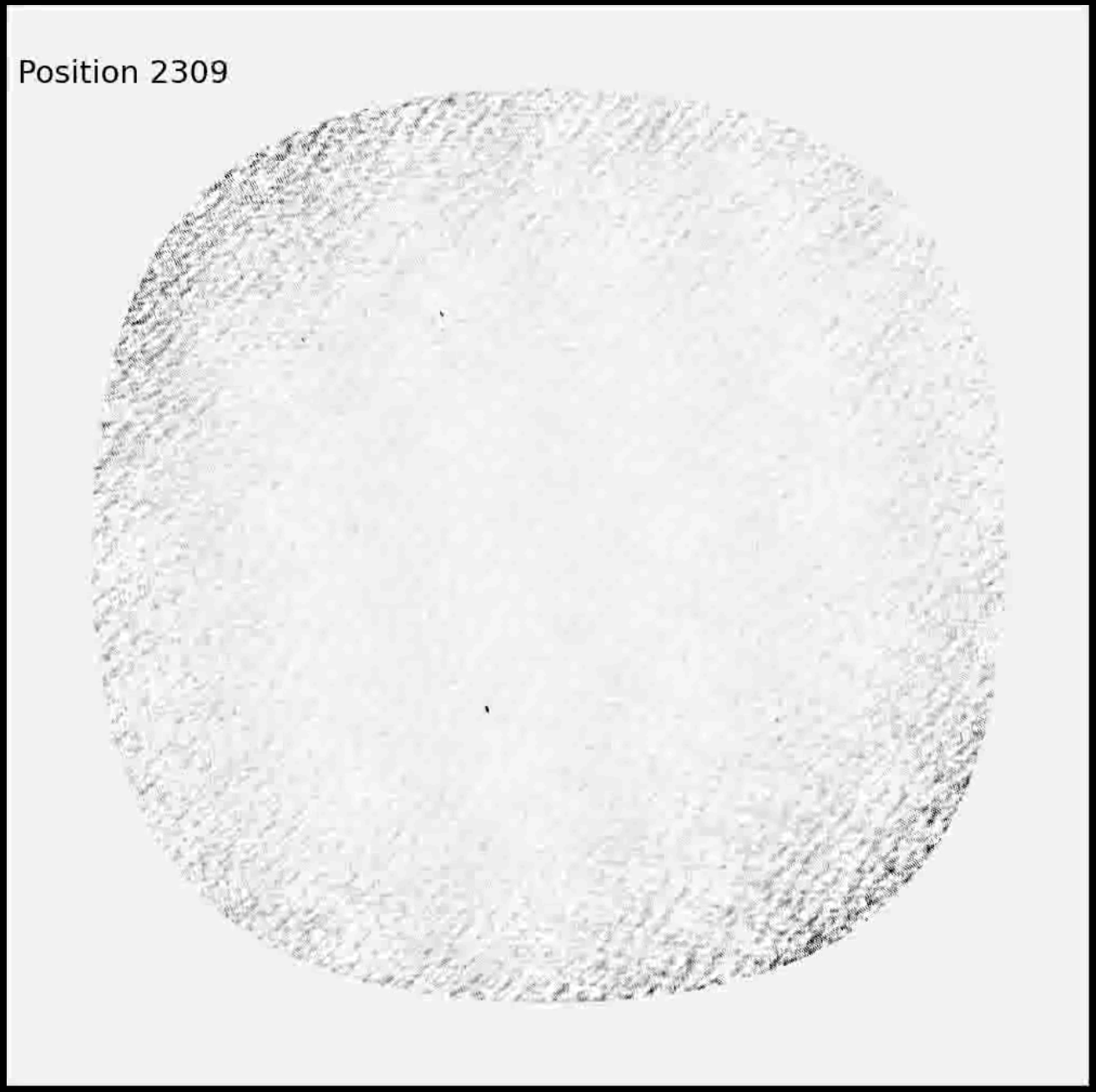
- A mirrored source appears when the transient was bright 50 - 80 Jy
- Opposite 3C 61.1 - the brightest source in the field.
- Ghost is brighter, roughly 60 - 20 Jy (in 80 Jy case)
- Flux would seem to be split between ghost and 'real source'.
- Ghost would vanish if correct source was entered in the sky model.
- A similar situation as the Bell#1 transient candidate.




Averaged map – Bell #1 'on'
+56°30′
+56°00′
+55°30′
+55°00′
+54°30′
Declination (J2000)
3h40m
35m
30m
25m
20m
Right Ascension (J2000)
1.96 deg separation
3C 86 (z not known)
exactly at the midpoint!

Bell #1

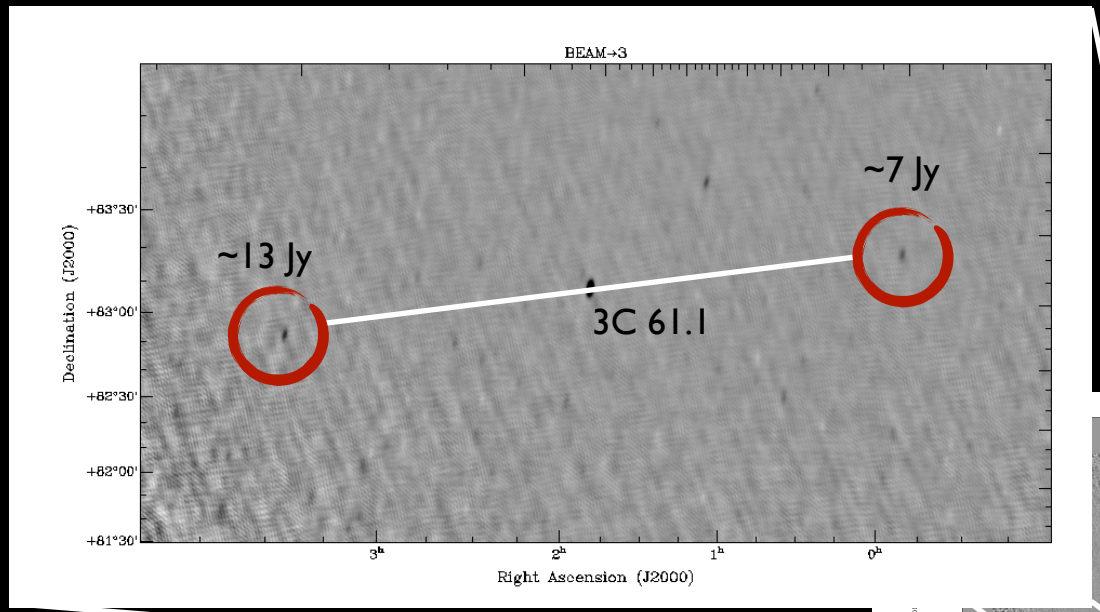
Ghosts Not Limited to One Location

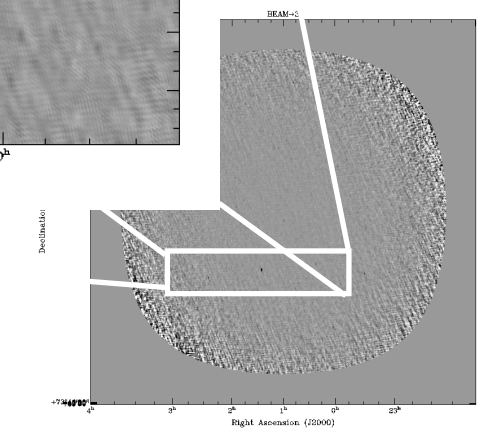


- At first we were worried that there was a special distance such as Bell #1 that would scale with frequency.
- Sampling the whole field reveals ghosts can be created in various locations.
- Each frame in the movie is inserting the simulated transient at a different location.
- In the NCP cases tested it seems to be concentrated to the right-hand side of 3C 61.1

TraP Discovered a Similar Event

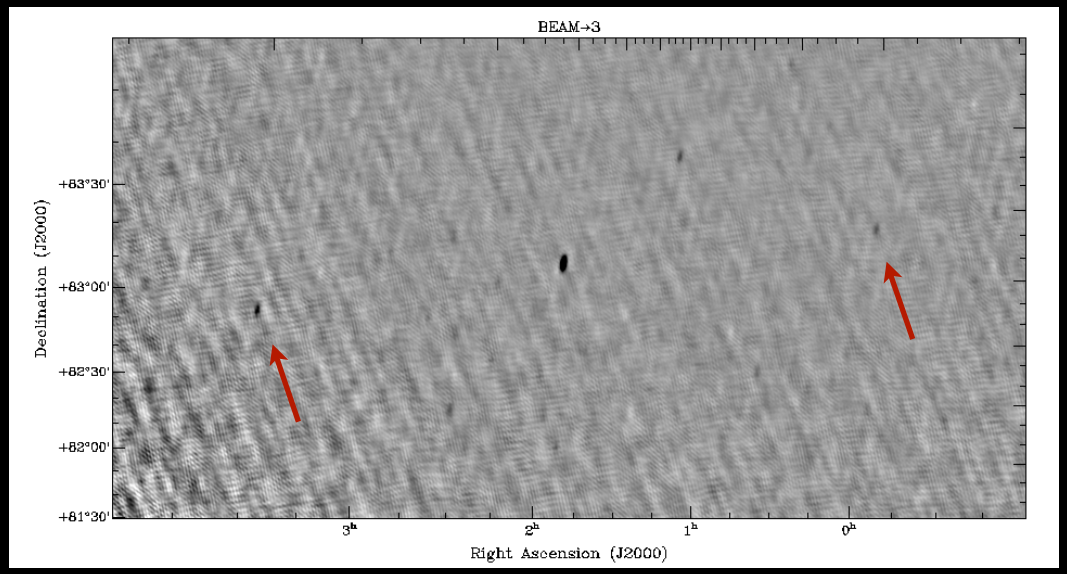
- An object only seen once and never again.
- Extracted by TraP with a flux of 7.5 Jy.
- Snapshot taken on December 24th 2011 at 04:33.
- On closer inspection it was also accompanied by a ghost source mirrored across from 3C 61.1 - just like the simulations.
- Ghost not picked up due to higher noise in the outer region.
- Proceeded to experiment with the sky model as with the simulations.





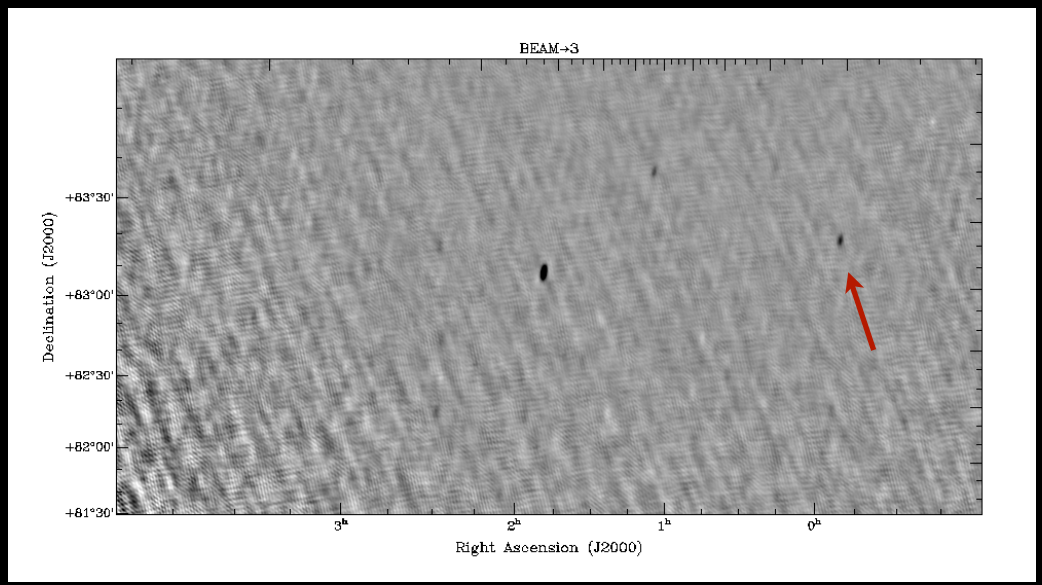
Transient in the Sky Model

- As in simulations, a source was placed in the sky model in each position.



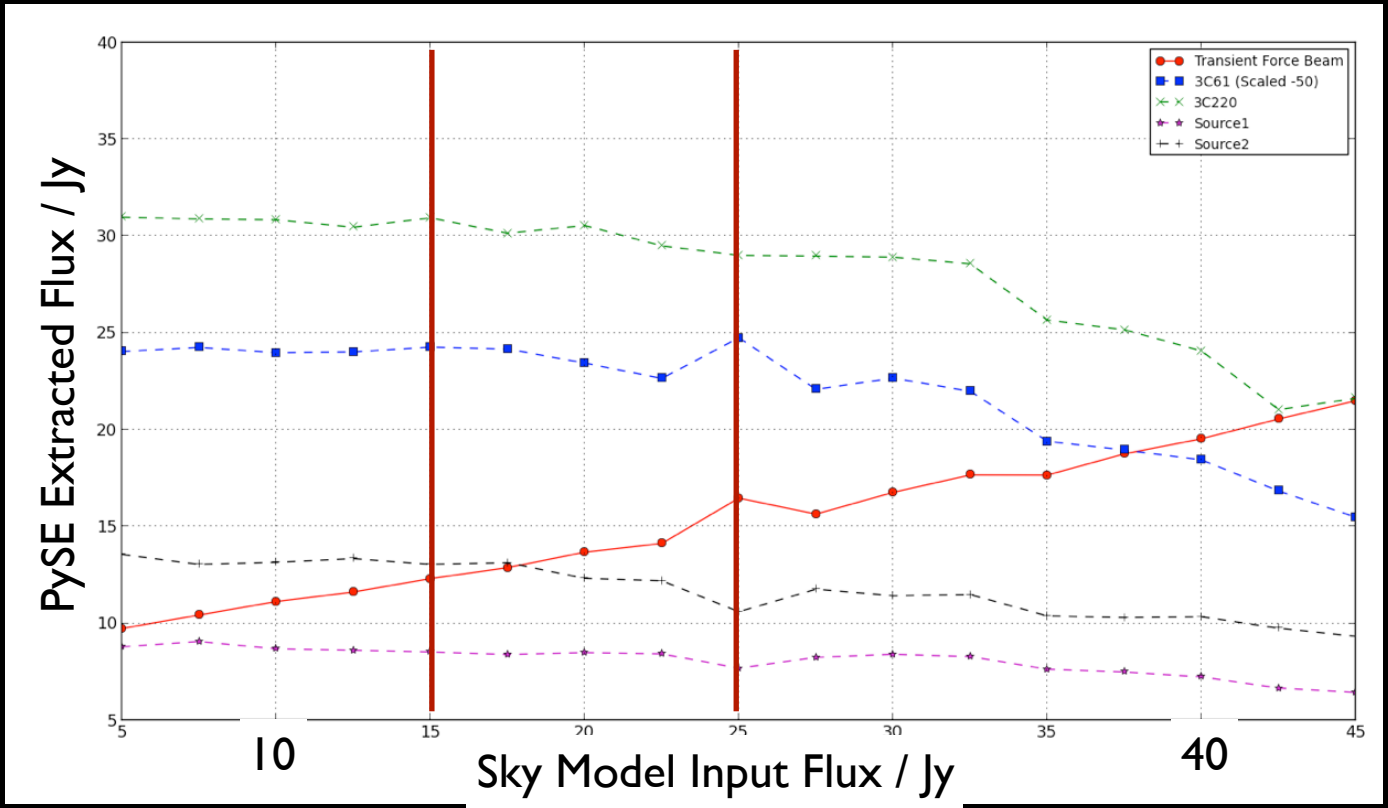
- Here a 20 Jy source in the 'ghost' position (left)
- Both sources still clearly visible.

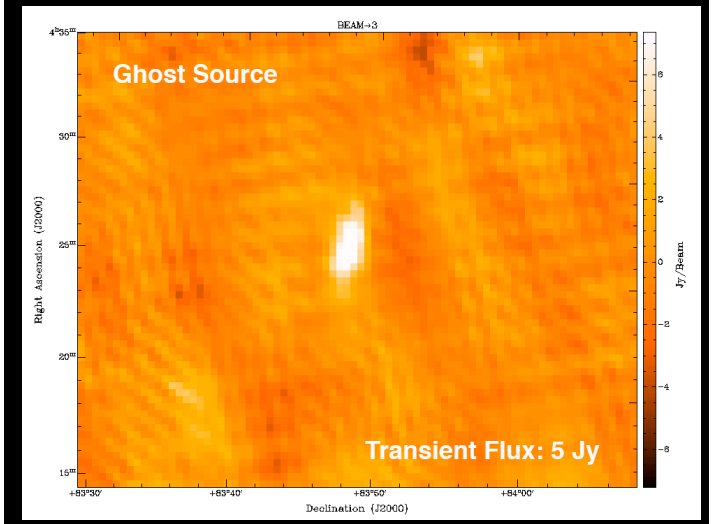
- Now place a 20 Jy source in the 'source' position (right)
- The ghost source is drastically reduced in brightness if not vanished.
- Leads us to conclude that this is most likely the 'real' source



What about the Flux?

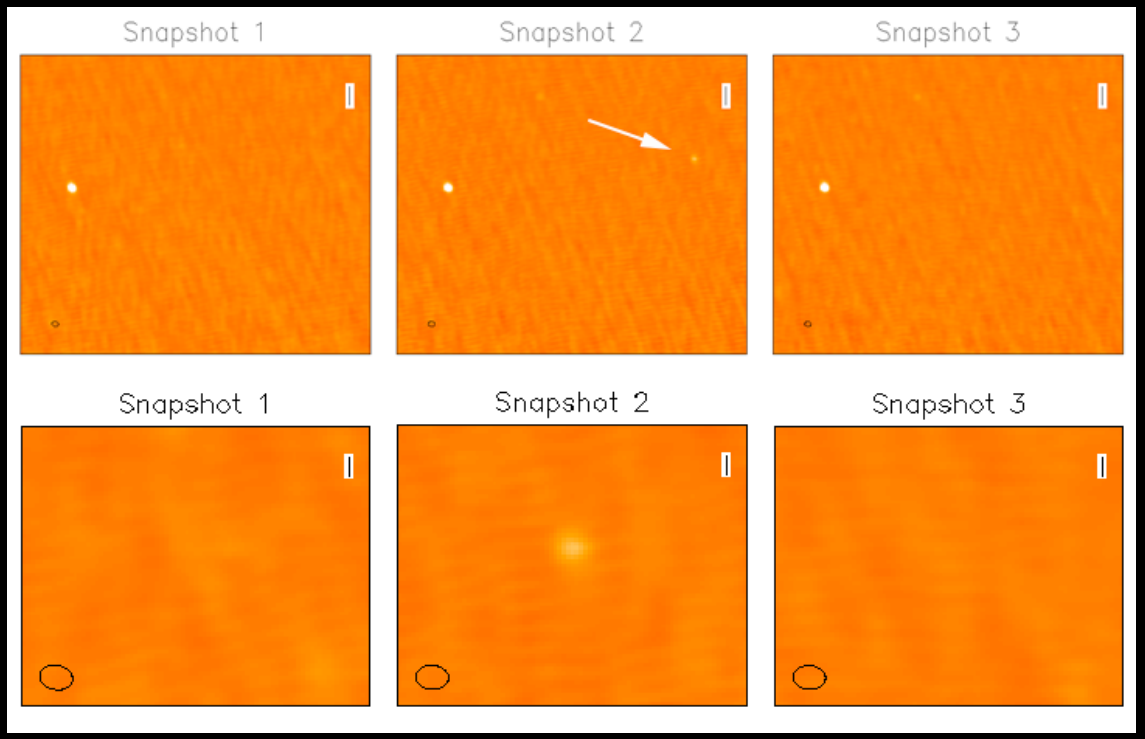
- Attempted to get a better estimate of the flux by entering the transient into the sky model at different flux levels, from 5 Jy -> 45 Jy.
- Monitor surrounding sources fluxes for clue as to when correct flux is used.
- Other sources seem to lose flux when passing the 17.5 Jy range.
- Odd spike feature at ~25 Jy which also effects other sources.
- Source flux perhaps lies in the range where other sources begin to be affected. 20 +/- 5 Jy ?

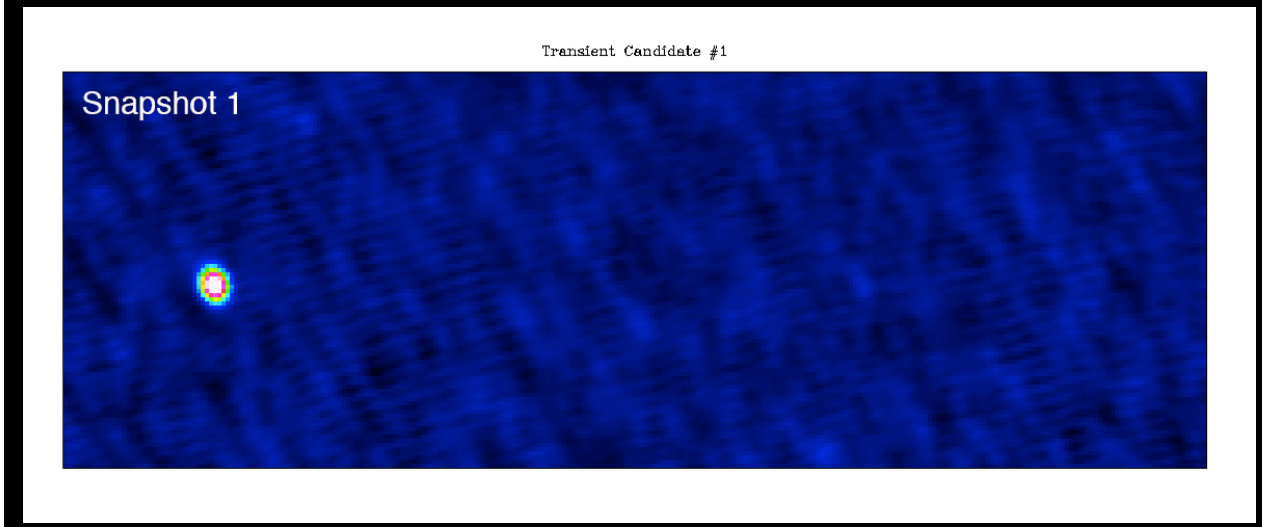




Ghost source disappears as flux increases

Transient in Other Surrounding Snapshots Model

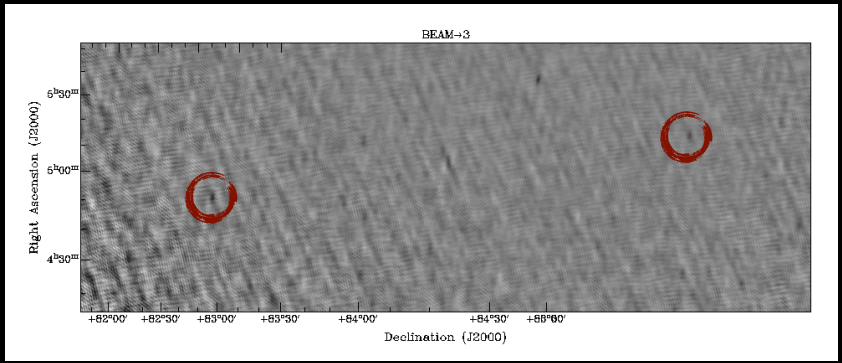




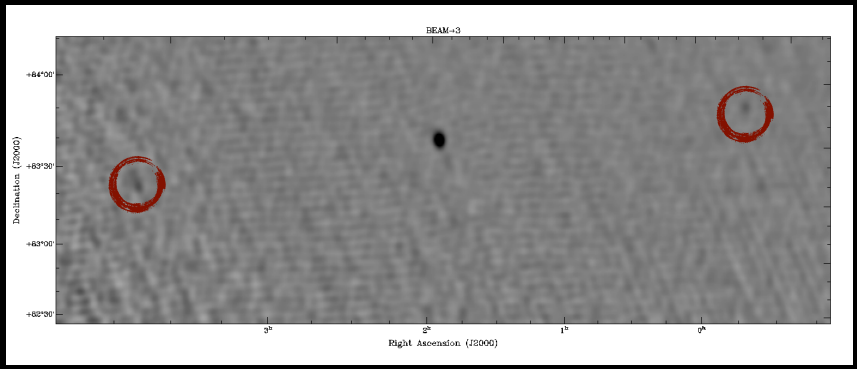
- Source seemed very sensitive to a model component being entered at it's location.
- Process the surrounding 4 observations with the transient IN the sky model.
- The source appears strongly only in the original snapshot where it was discovered.
- I.e. putting the source in the model of the other snapshots does not create a source at that point.

Is it an Artefact?

- Tried numerous methods to remove or at least greatly effect the transient source (or ghost)



Subtract 3C 61.1

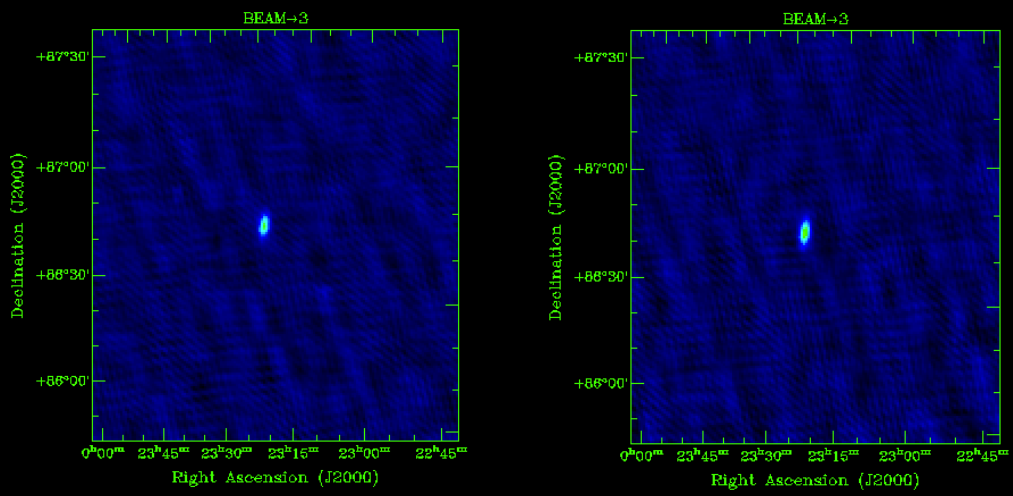


Different weighting scheme (here natural)

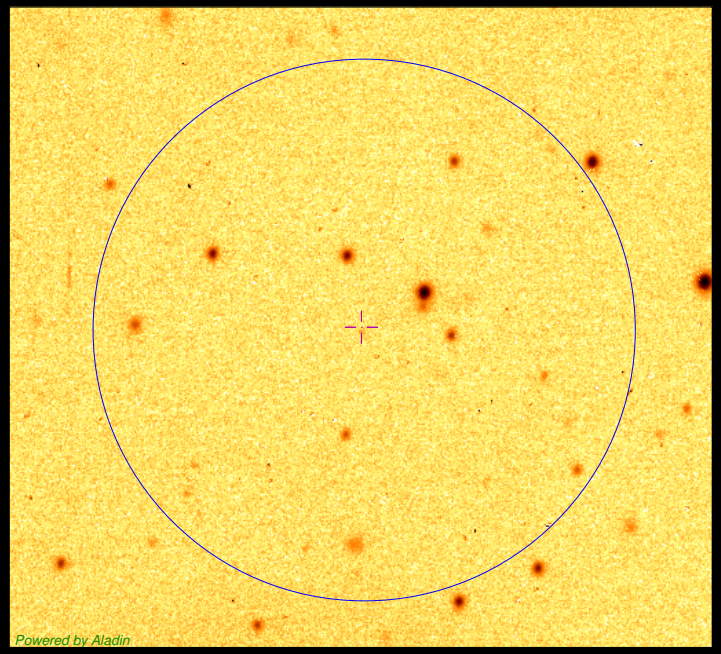
- Imaged using Calibrator gains only.
- In dirty image.
- Subtracting 3C61.1
- A second round of flagging both AOFlagger and manually, had no effect.
- Also checked for possible narrow-band rfi by splitting bandwidth in half - source present in both.
- Imaging using different weighting and baseline selections
- Different time compression before processing. 10s -> 13s
- Checked other observations at the same LST - no hint of source.
- Removing possible bad stations by manual judgement had no effect on the source.
- Imaged with CASA (as oppose to AWimager)
- No evidence of data corruption in measurement set.
- Phase center shift to transient position - still present.
- Peeling 3C 61.1 and using solutions with the transient in and out the model. Very strong when in.
- It survived all these tests where somewhat similar candidates failed.

What do we know? What is it?

- Duration of 11 mins.  ?
  - When dataset split in half or thirds, the source is still present in each half/third.
  - Flux seemingly steady between two halves.
- Also not present in snapshots before or after. Combing next two also nothing.
- Bright at ~ 25 +/- 5 Jy (though tricky to pin down)
- Would suggest a naive rate of 1 / 2537 day^{-1} deg^{-2} with Δt = 11 mins, 4 Jy limit (10σ TraP selection)



Transient set split in half (in model)

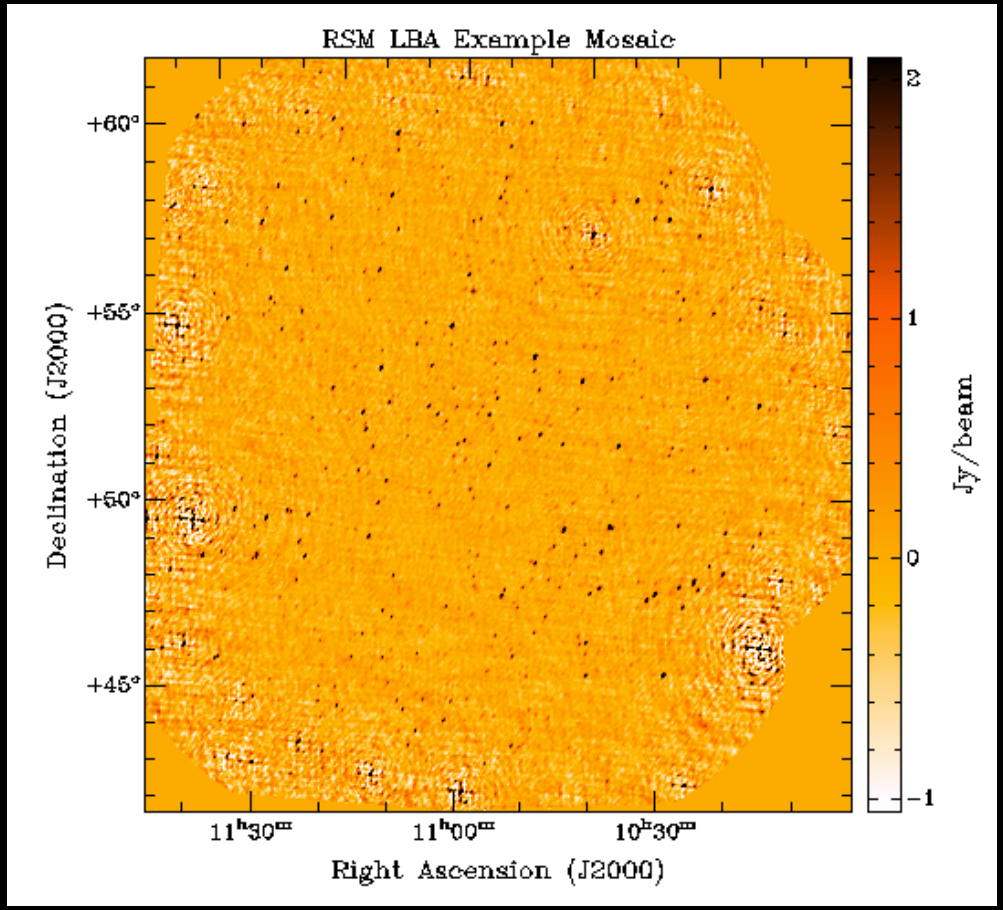


Stacked optical r' band image taken with LT gets to r' ~ 22.5

- Localisation to ~120" (10 km baselines).
- No source present in the EoR deep NCP map.
- Or other radio catalogues such as VLSS, WENSS etc.
- Flare star? - Optical data of the region obtained with the Liverpool Telescope (LT).
- ~20 sources in error box - none show strong variability on any time-scales.
- 6 stars show high proper-motion but none are classed as an M-Dwarf.
- Just beginning to consider what physical phenomena it could be related to.

Conclusions & Future Prospects

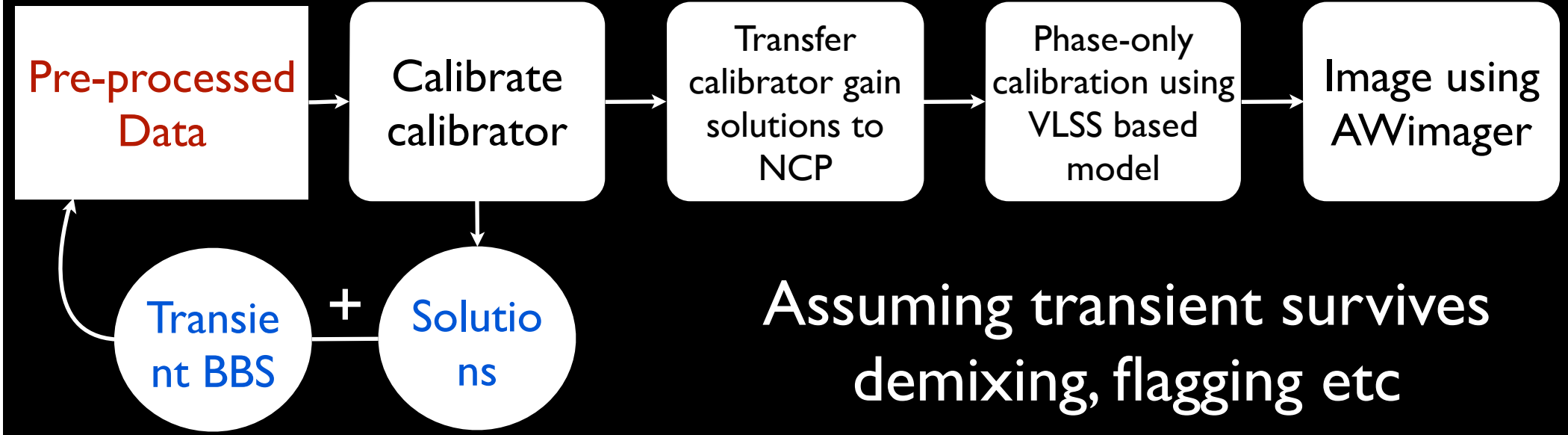
- A transient detection treated with caution.
- While some features seem concerning, the source persists through many tests and checks.
- Unfortunately lack of other data means we may never be 100% certain.
- If real - Radio Sky Monitor Zenith scan observations should detect more similar events. (At least 1).
- Continuation of MSSS-LBA will potentially offer more epochs with a better setup (eg more BW).
- Future observations, with better understanding, will answer whether this is a real potential hint at the low frequency transient sky.



LBA RSM Pointing

Inserting a Transient

- Aim was to test whether a transient would be seen with the reduction method.
- Any brightness of transient.
- Transient inserted into pre-processed data before being reduced through MSSS pipeline.
- Using calibrator gain solutions to insert - ideally want field phase solutions but proved difficult to merge and use table.



Assuming transient survives demixing, flagging etc

PSF Example