The NCP Transient

Found by the TraP

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LOFAR Transient Key Science Project Meeting - Jodrell Bank - 9-10 September 2014

four π sky

LOFAR

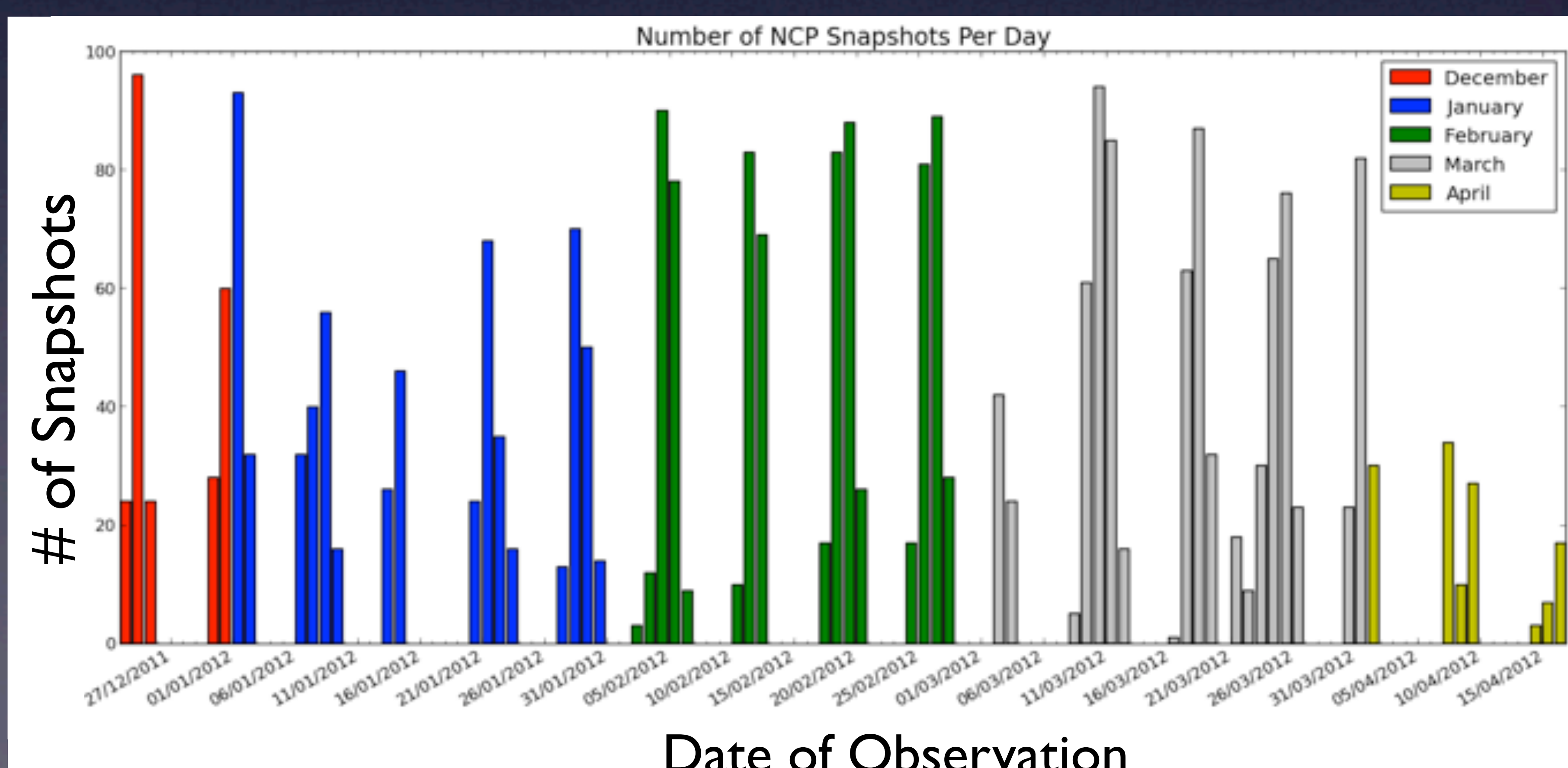
UNIVERSITY OF OXFORD

Brief Reminder of NCP Data

- Recorded simultaneously, using a single sub band, with the initial MSSS-LBA observing run in 2011-2012

- ~2600 snapshots.
- 11 minutes long
- At 60 MHz

- 200 kHz of bandwidth
- Snapshots 4 minutes apart when in sequence.
- MSSS calibrator is used to process the data.



General Results

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
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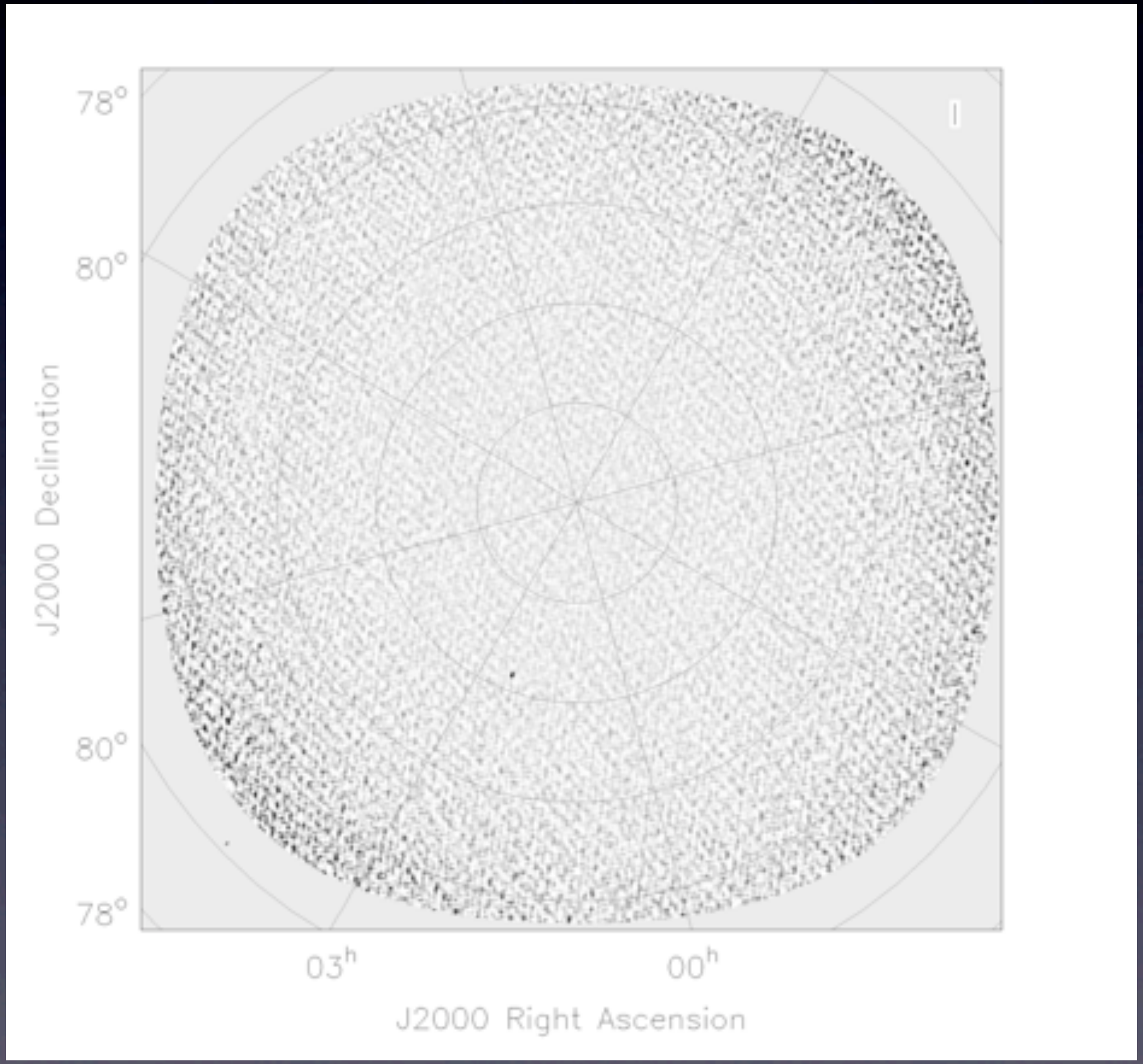

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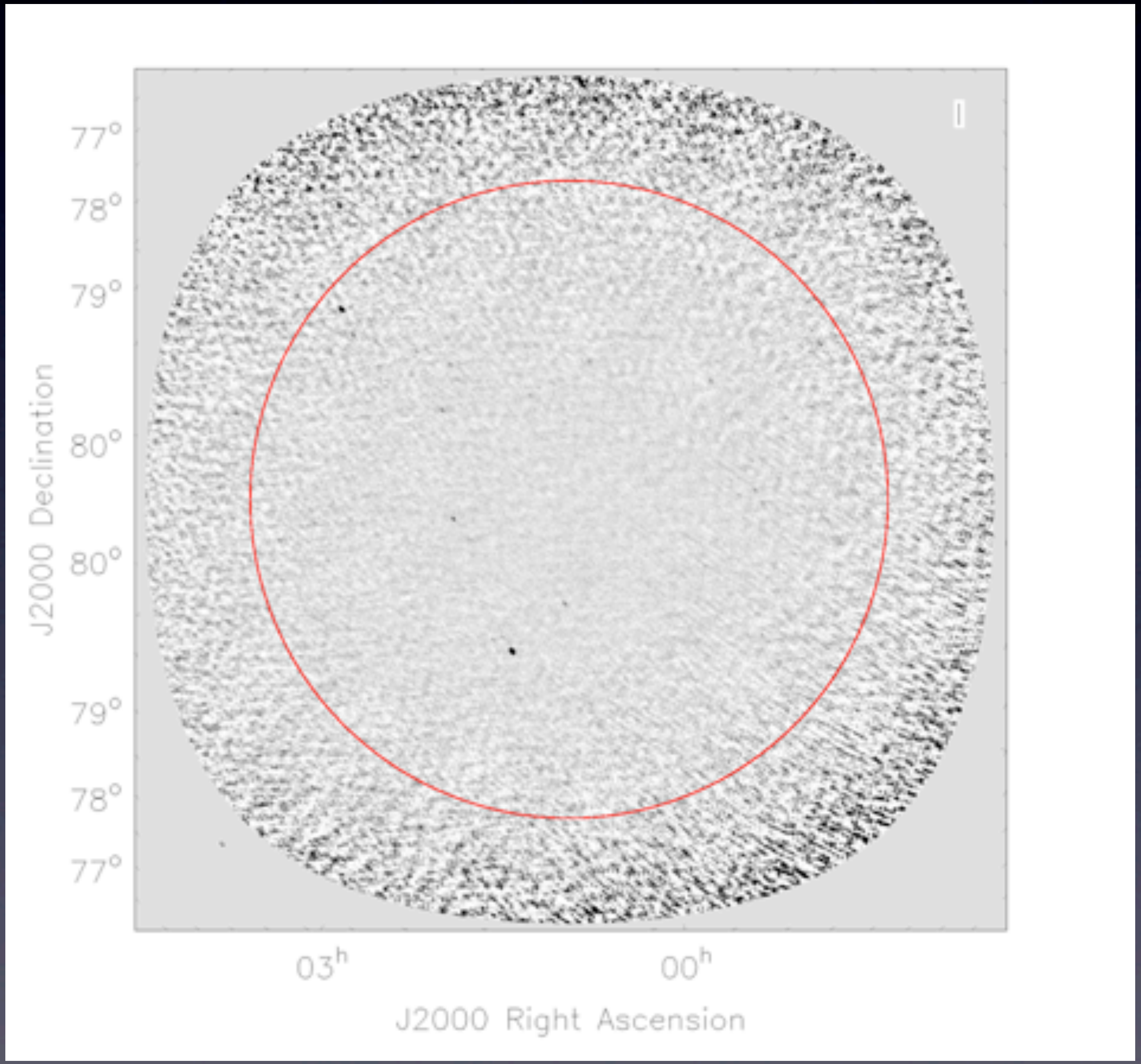

175 deg^2 Search Area

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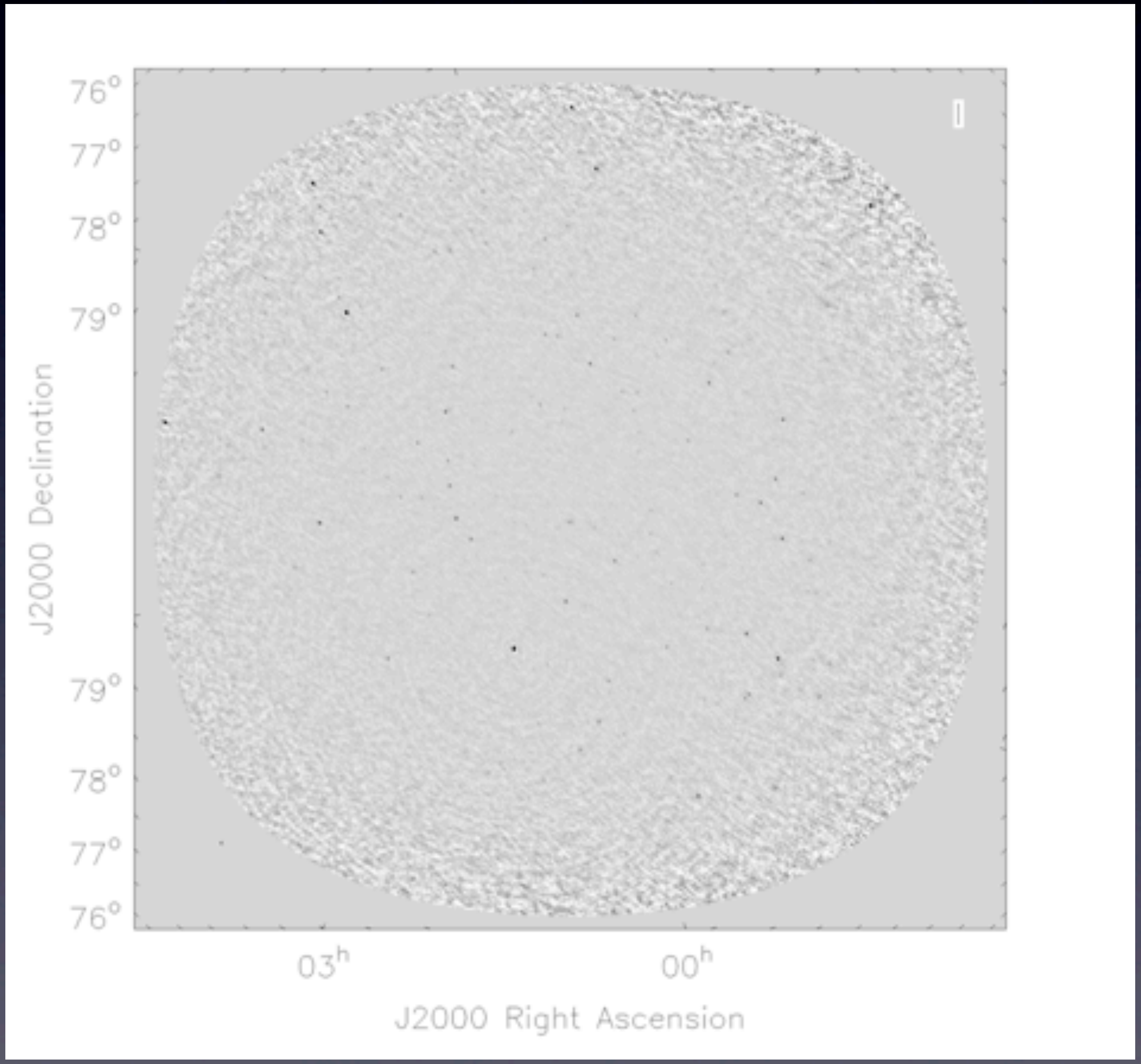

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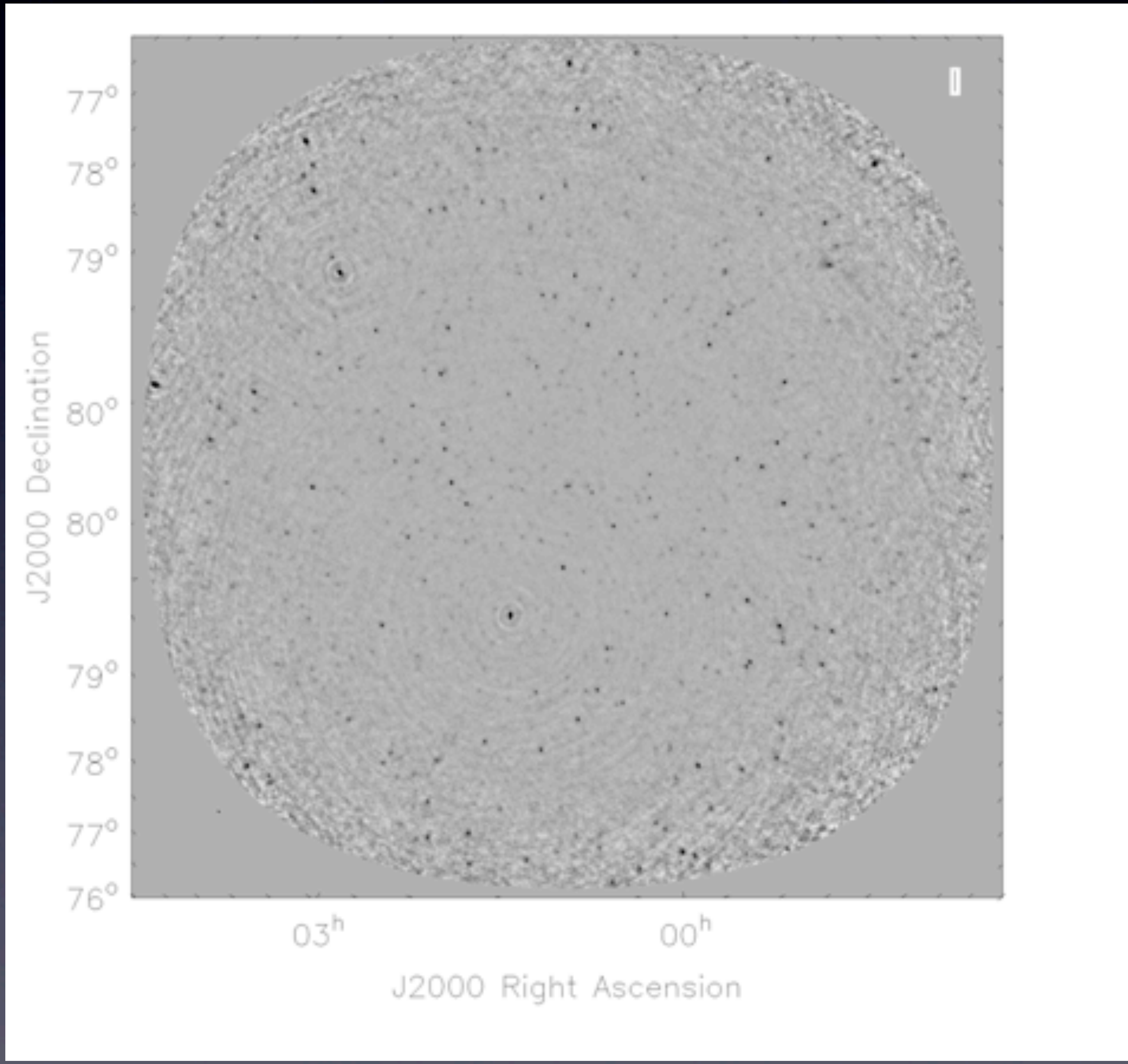

Deep map
(Averaged 297 min images)

General Results

Searched Using the TraP

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No transients

No transients

9 candidates

No variables or transients

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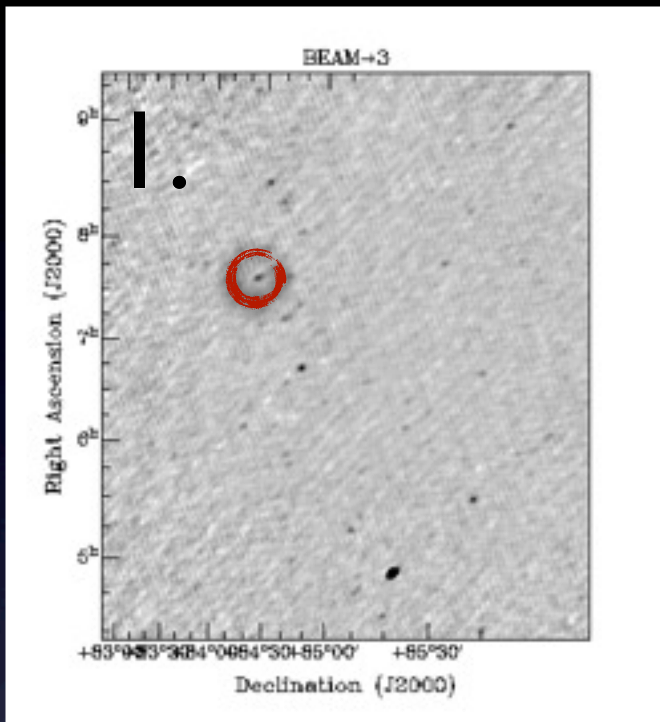
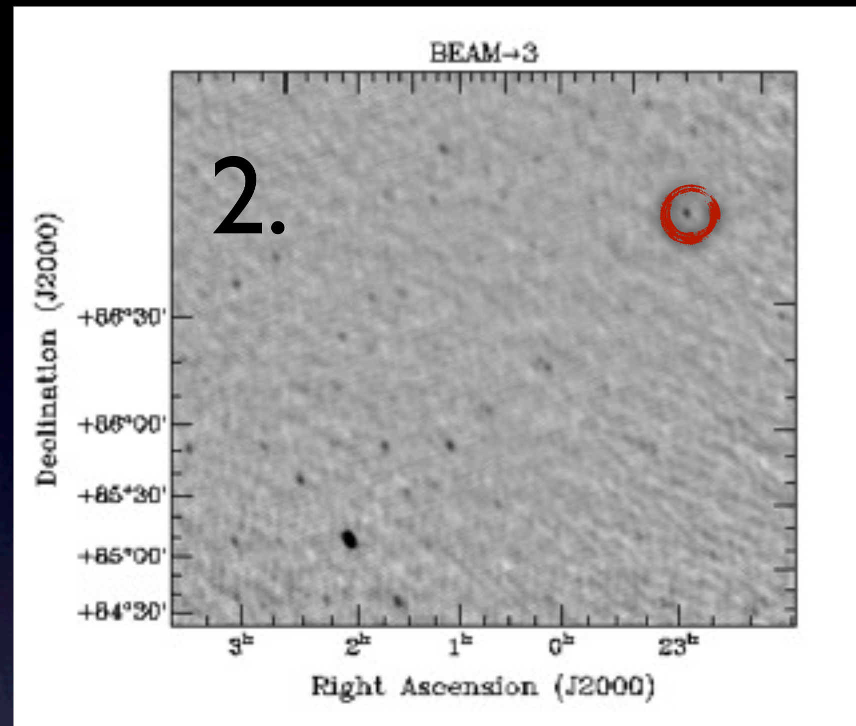
Other NCP Transient Candidates

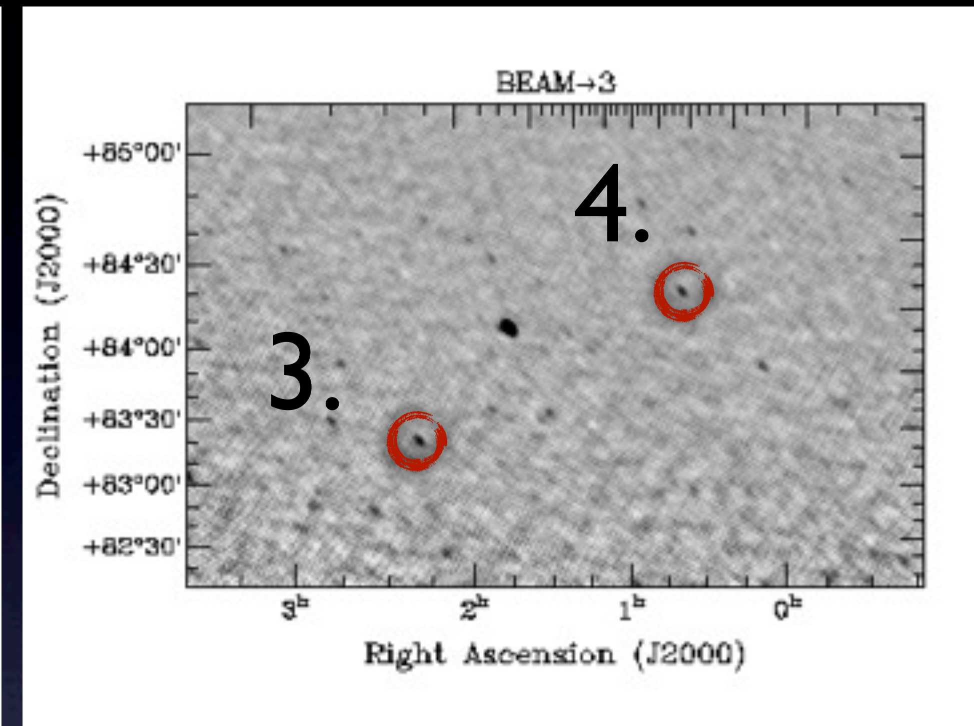
- 8 more to be precise at similar fluxes of the initial source found 4 - 8 Jy
- Series of tests devised to determine authenticity.



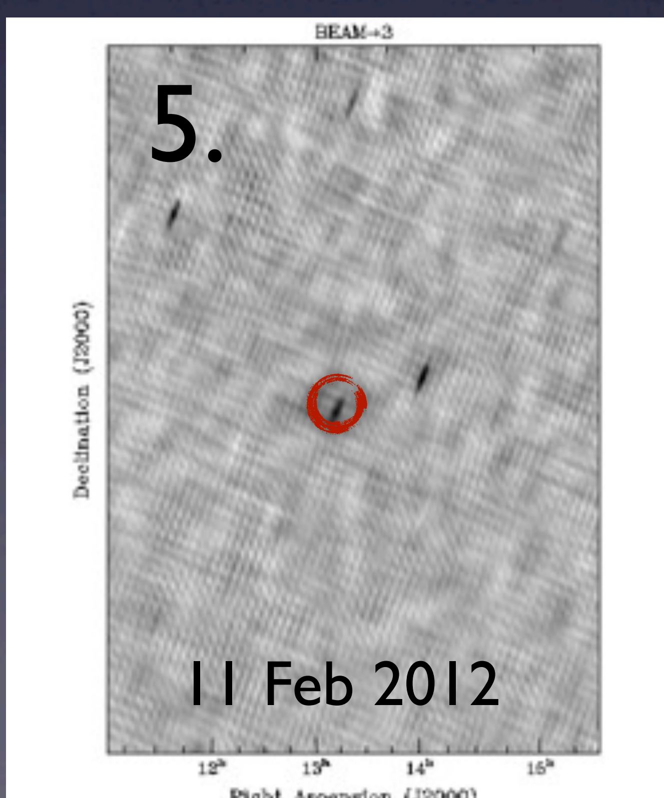
1 Jan 2012

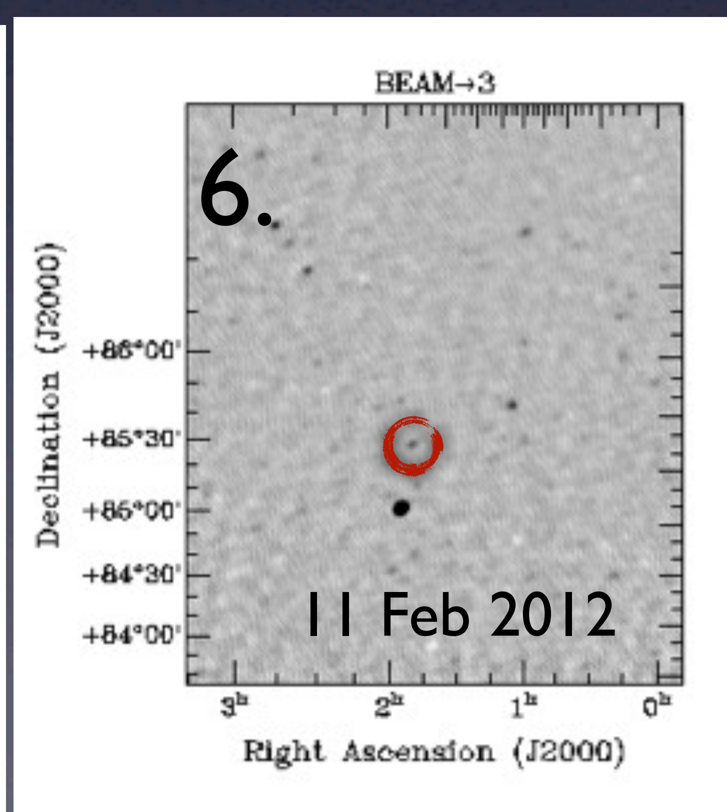


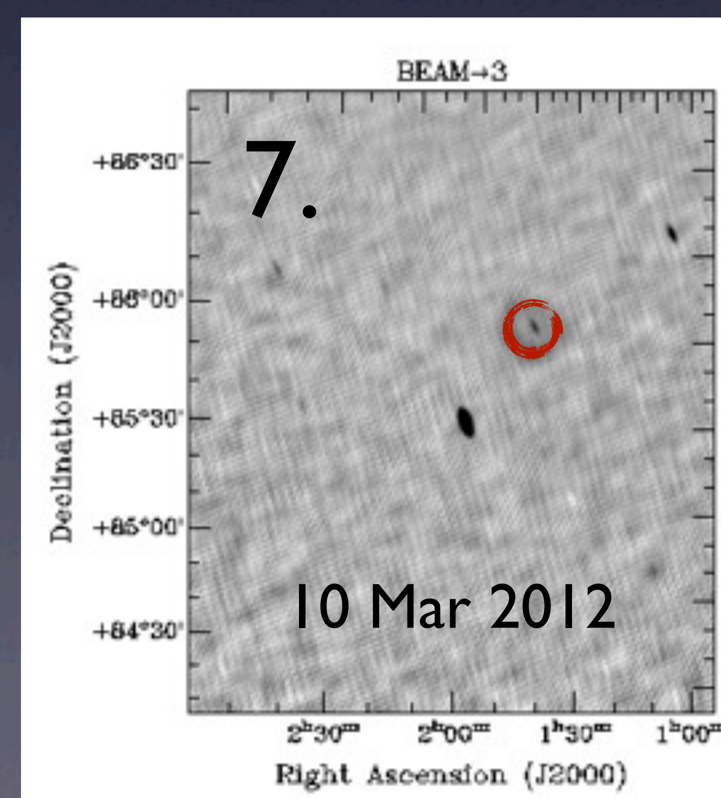
2 Jan 2012

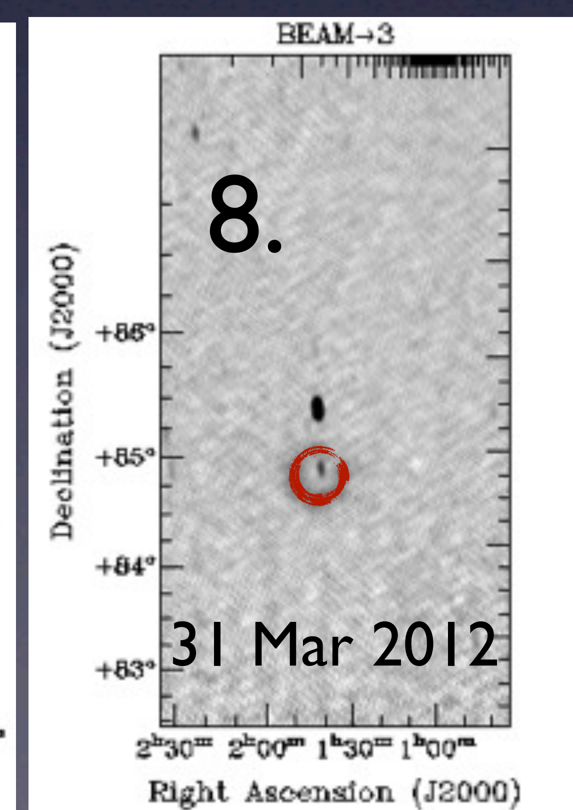


21 Jan 2012









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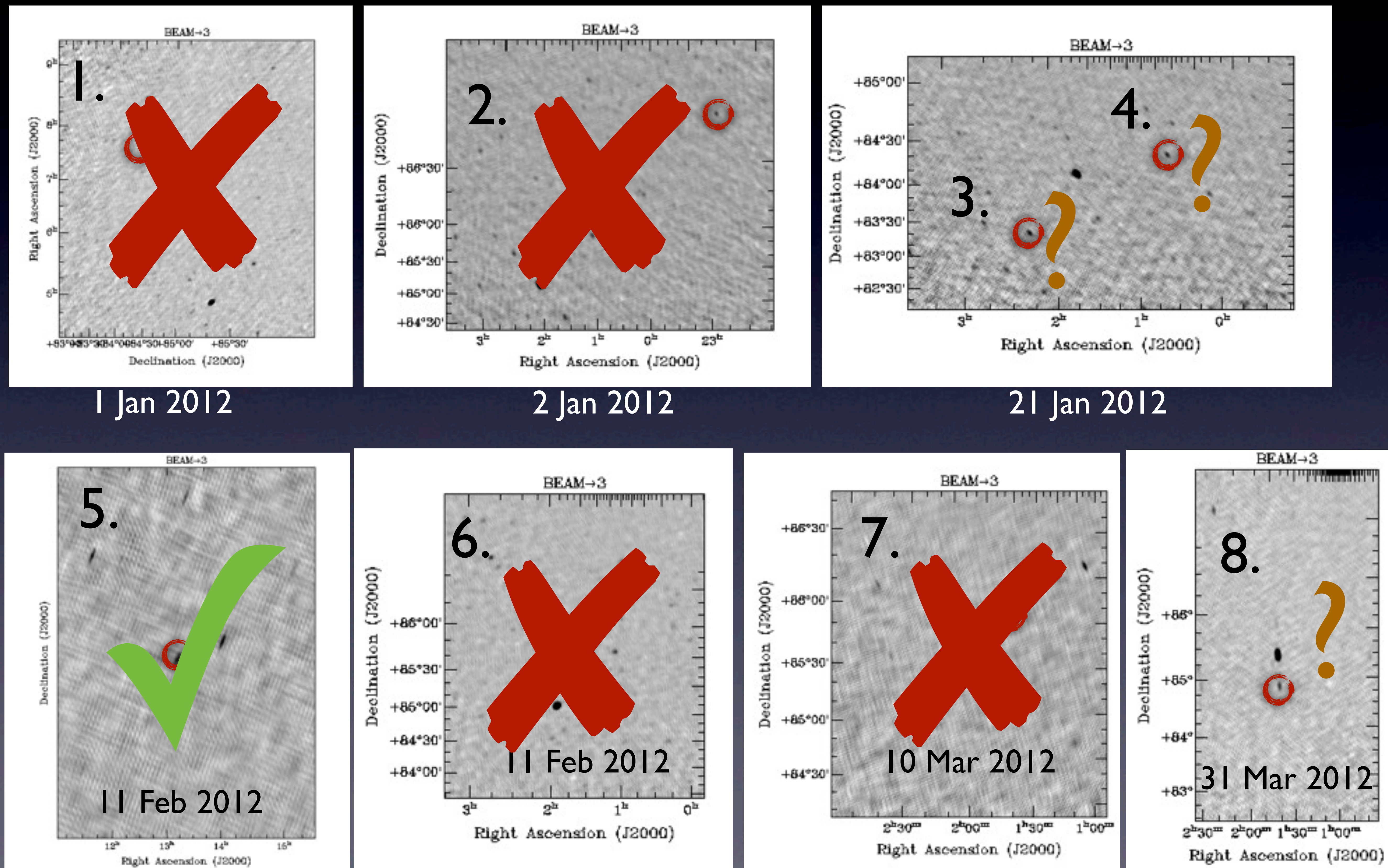
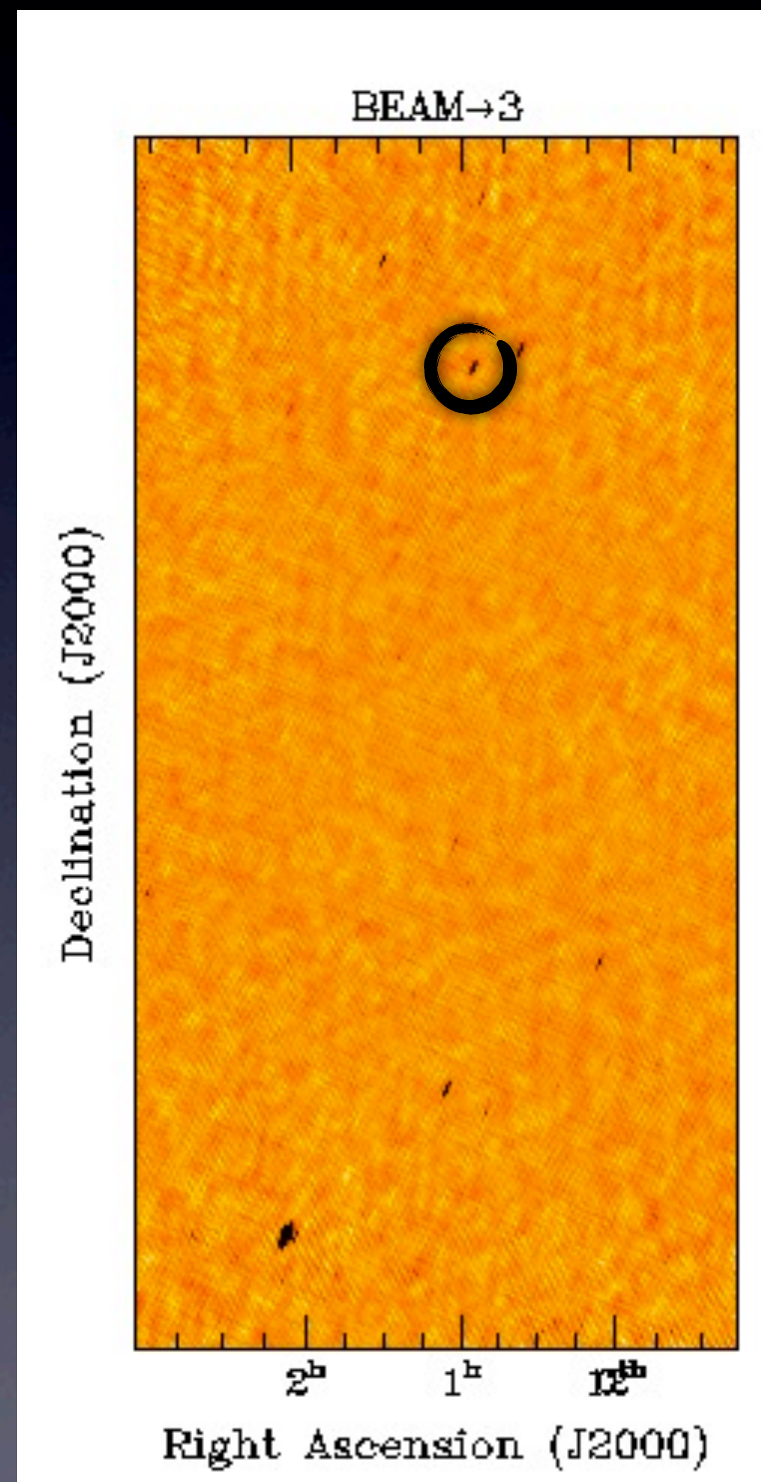
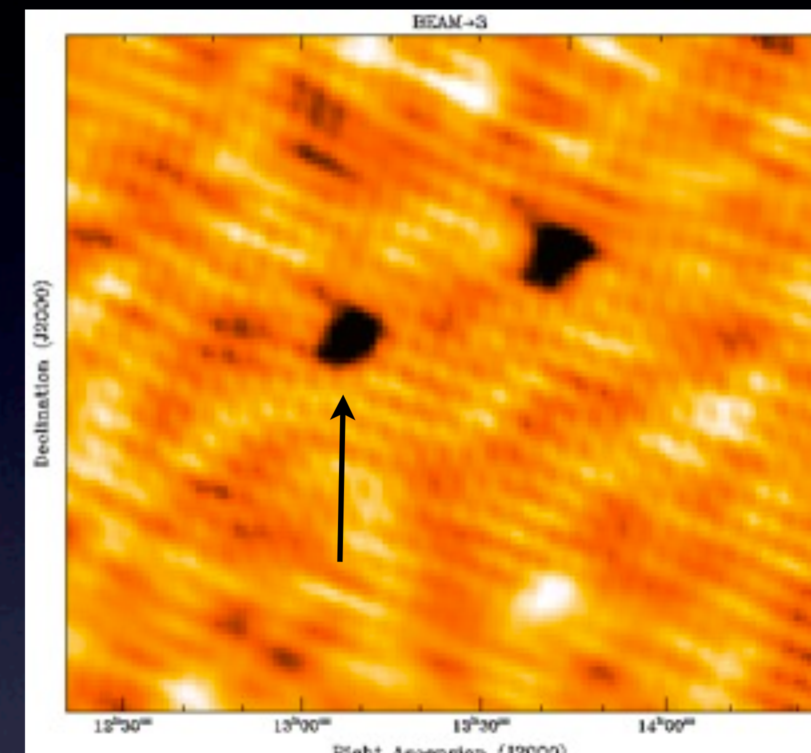
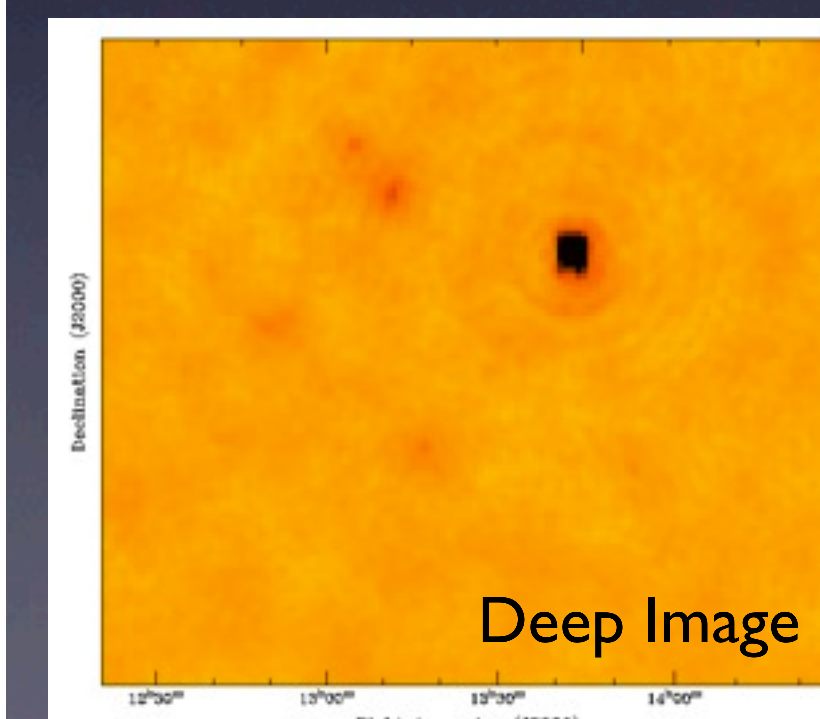


Candidate #5

- The only other candidate which was not effected by any test.
- Because of this, one further test was to enter a component into the sky model.
- However it remained unresponsive even to the model.
- So while slightly doubtful because of this, there is no other hard evidence to rule it out.

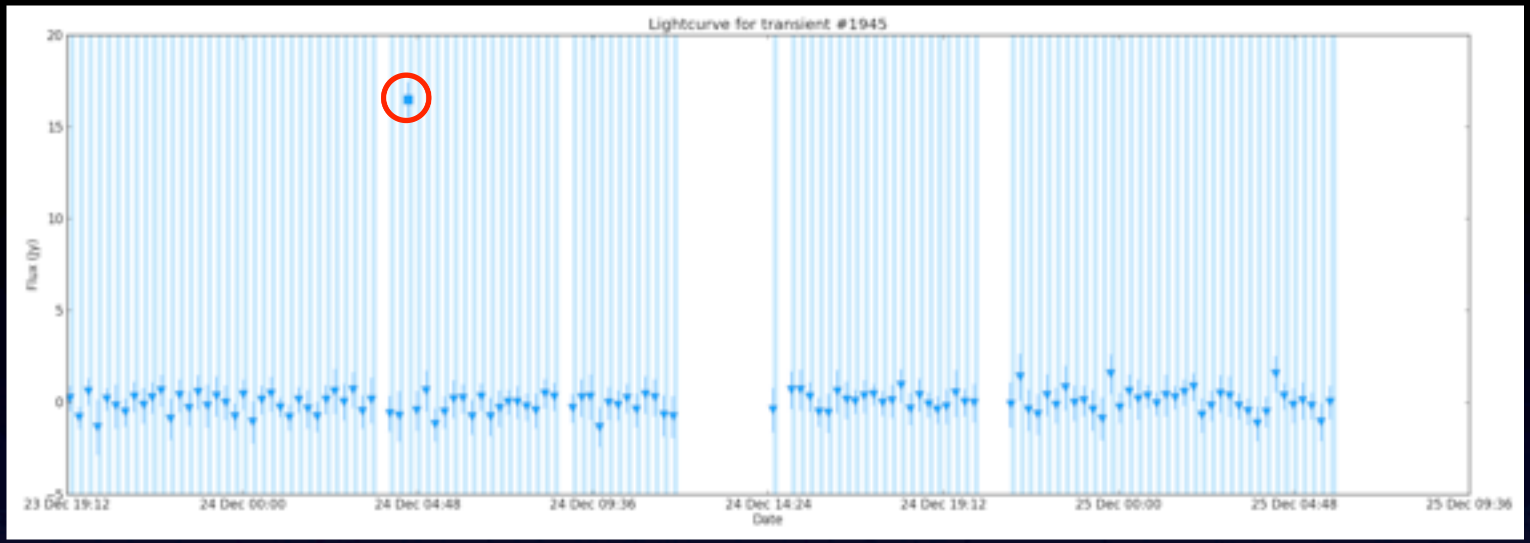


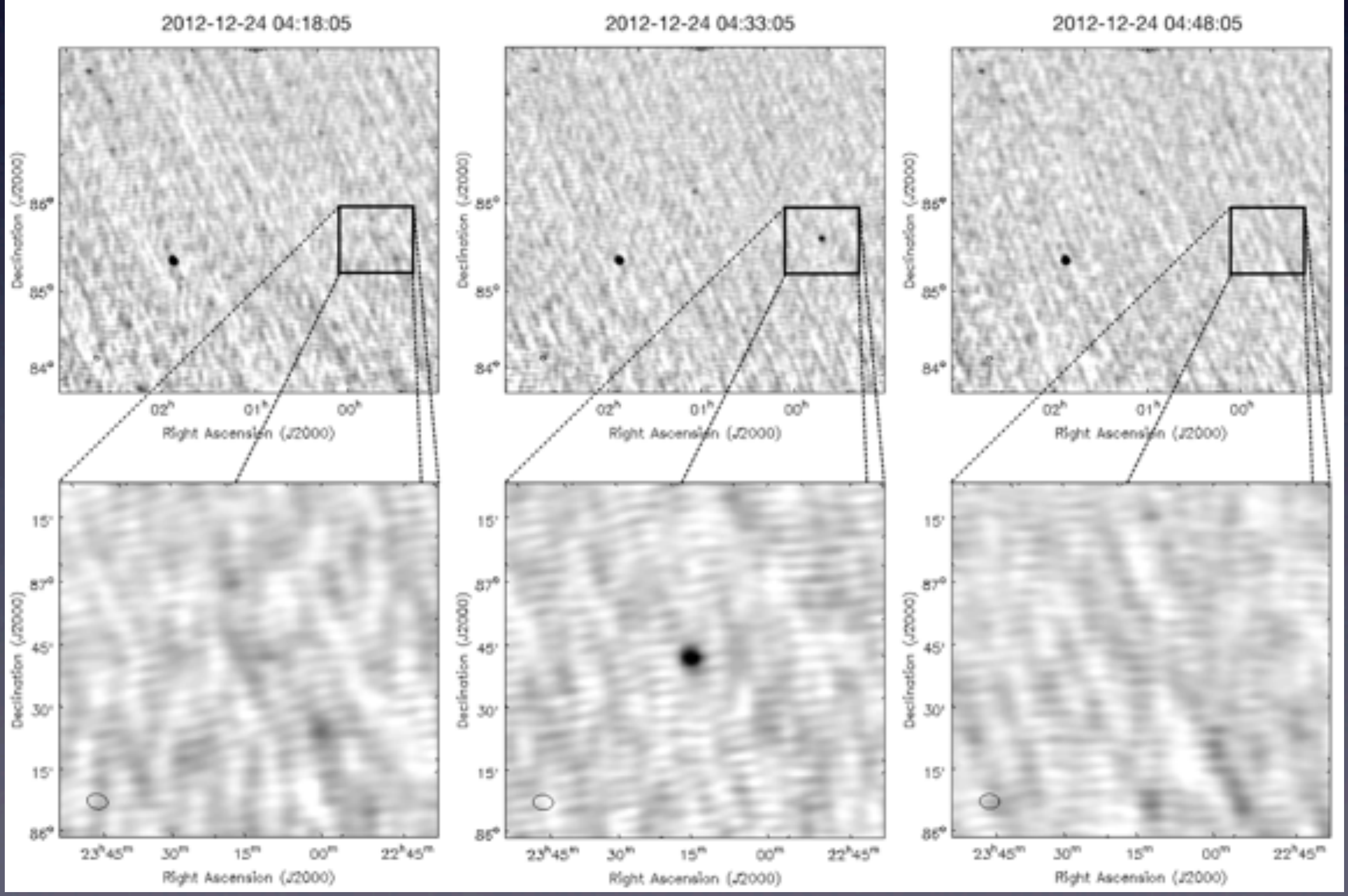




The Transient

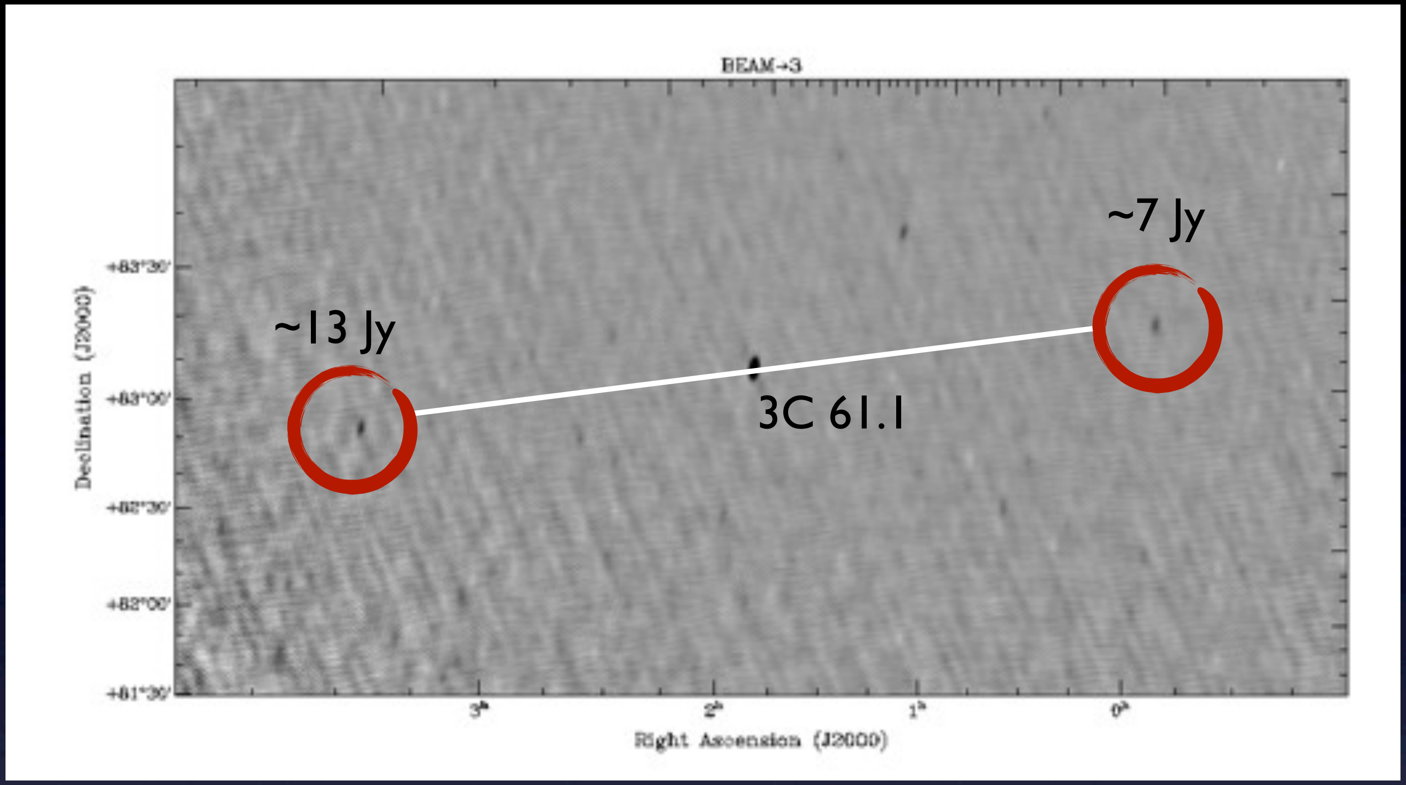
- Single event, never repeated.
- On for **11 minutes** (19 mins max with dead-time).
- Observations at **60 MHz**.
- Brightness around **15 - 25 Jy/beam**, difficult to accurately state.
- No source at location in previous radio surveys: VLSS, WENSS and NVSS.
- No source at location in high-energy surveys.
- Rate of 1/2538 day^{-1} deg^{-1}.

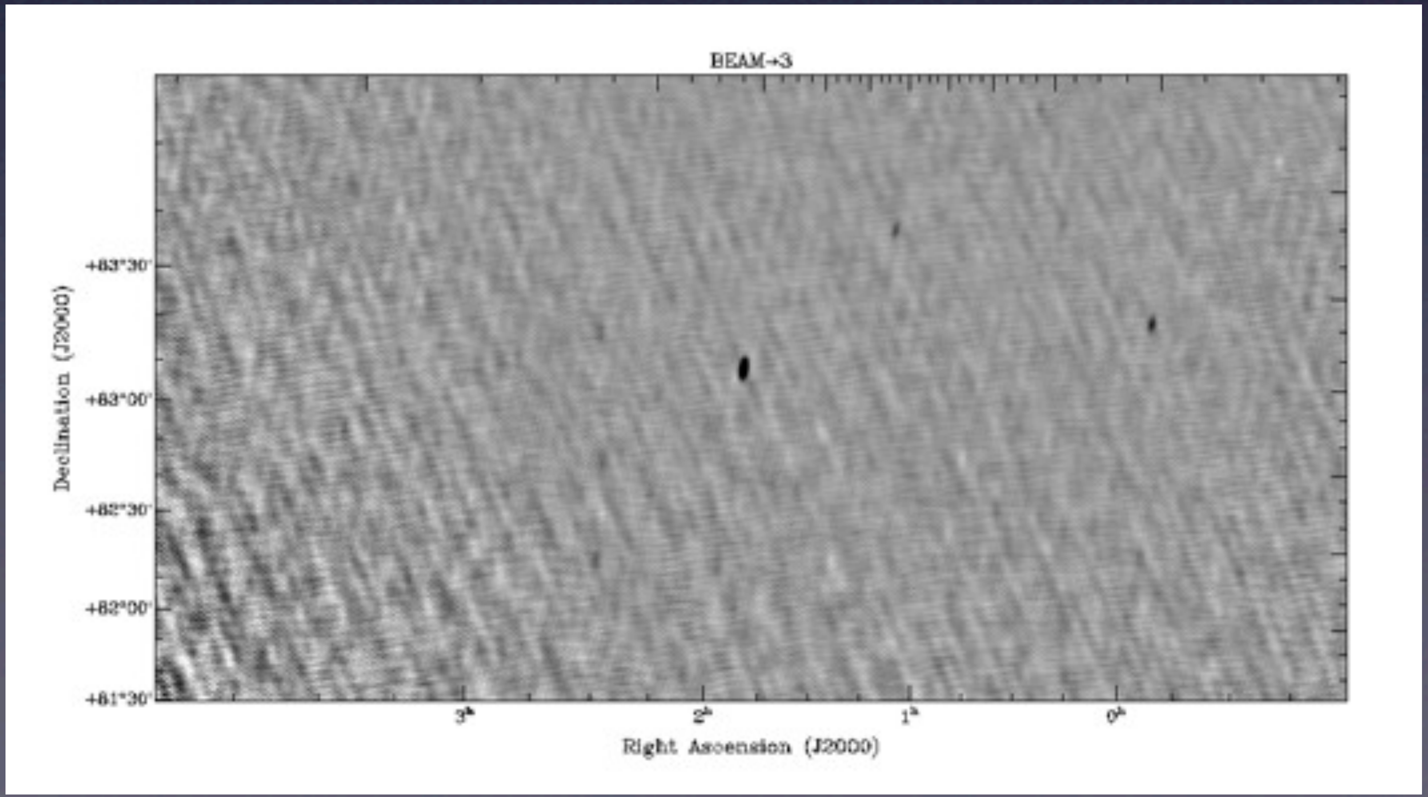




The Transient Ghost

- Only candidate to also show a ‘ghost’ source.
- Artefact linked to an incomplete sky model when processing.
- Inserting the transient into the sky model, at the correct location causes ghost to vanish.
- Also seen in simulations of transients.
- Still the exact reasoning behind their appearance is unknown.
- u-v coverage?





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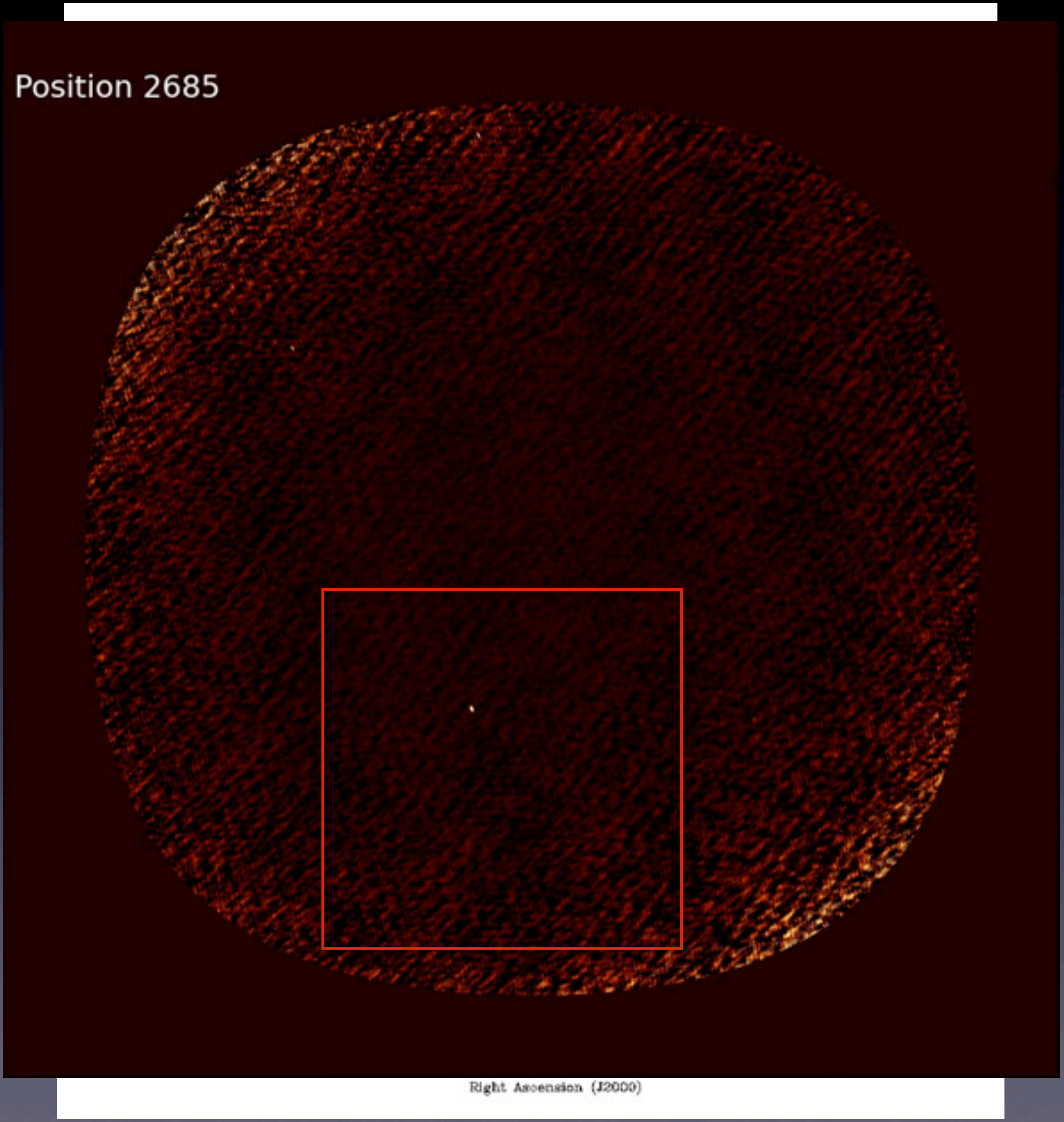
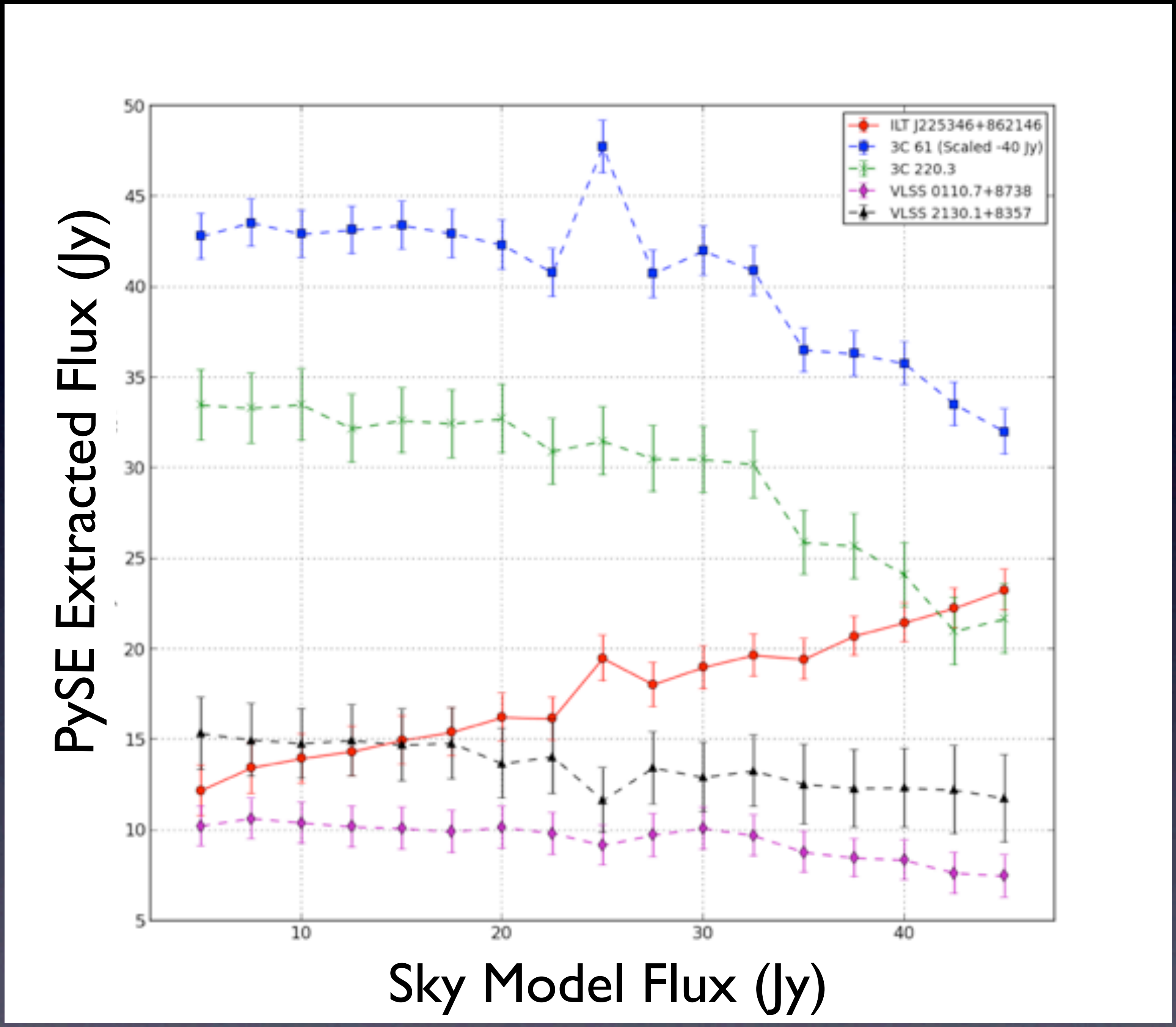
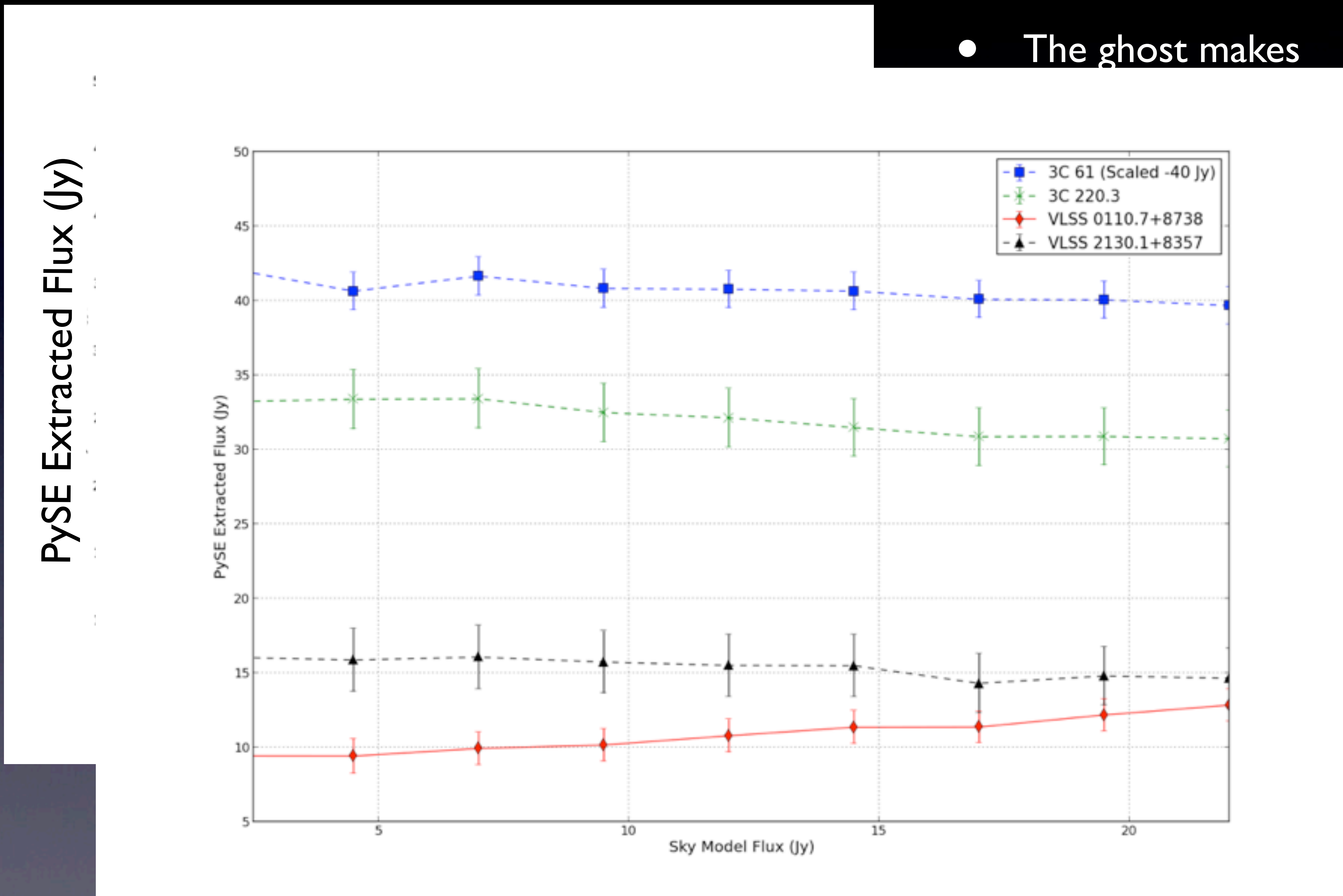


The Transient Flux



- The ghost makes determining the correct flux a little tricky.
- Can easily control the flux by altering the sky model.
- Believe that the flux is somewhere in the region of 15 - 25 Jy.
- After this range other sources in the field start to become severely effected.
- Can also test the same method with real sources.

The Transient Flux



- The ghost makes

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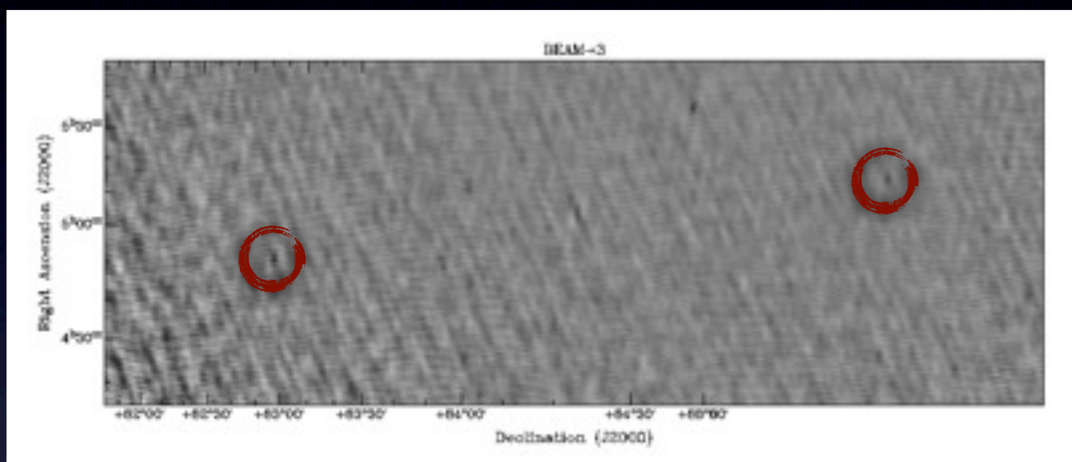
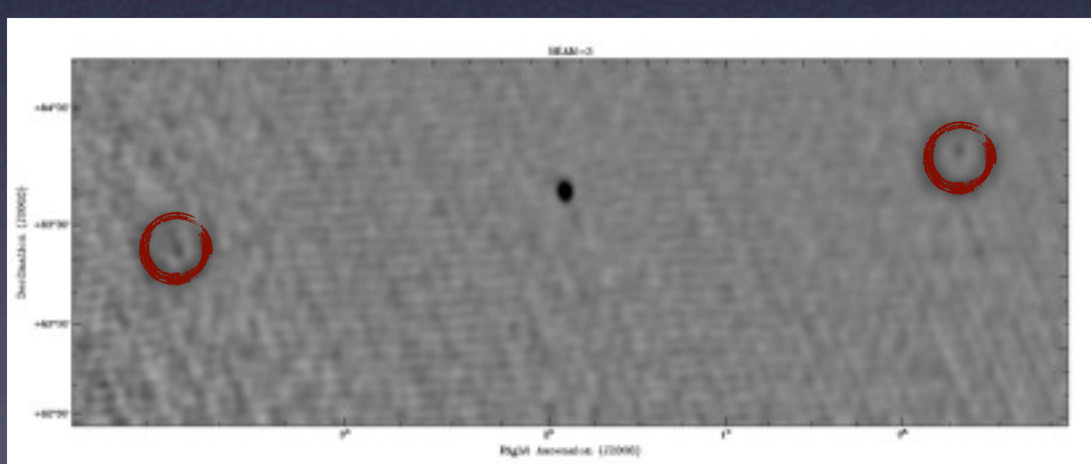
Is it an Artefact?

- 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 is it?
Incoherent Emission

- Firstly lets assume an incoherent emission process.
- Can calculate a rough distance estimate assuming that the brightness temperature is at the limit for un-beamed synchrotron radiation - 10^{12} K (Readhead 1994).
- Use the Rayleigh-Jeans law:

$$d^2 = \frac{2k_B\nu^2\Delta t^2 T_{\mathrm{Bmax}}}{\Delta F}$$

  with v = 60 MHz, ΔF = 20 Jy and Δt = 11 & 19 mins
- This gives a distance range of 15.1 - 26.0 pc.
- Flare star?

Flare Star?

- Most relevant previous observations of flare stars at low frequencies come from using the UTR-2 telescope in Ukraine.
- Boiko et al. (2012) observed AD Leonis (4.9 pc) and EV Lacertae (5.1 pc) at frequencies of 16.5 - 33 MHz.
- With AD Leonis they detected 167 bursts over two months with a flux range of 10 - 50 Jy - consistent with the flux seen with the NCP transient.
- But...

Flare Star?

- The average duration of the bursts are 2 - 12 seconds - much shorter than the NCP burst.
- A period of outbursts lasting 11 minutes perhaps?
- Would also expect to see other events in different epochs not just a single event.
- Lack of possible counterpart in optical follow up and high energy catalogues also worrying.
- Superflares such as those described in Notsu et al. (2013) could offer an explanation.

Boiko et al. (2012)

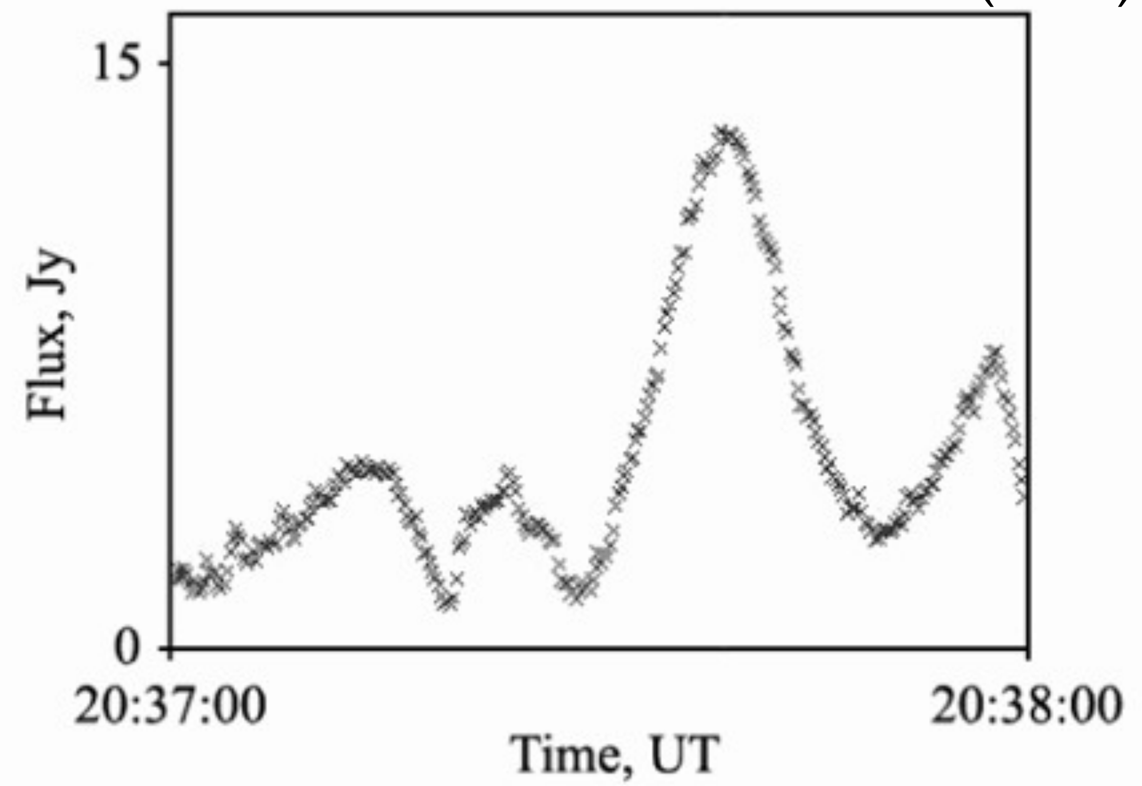


Fig. 2: The time profile of AD Leo burst (20:37:39 UT) at 24 MHz.

Coherent - FRB?

- If the signal is dominated by scattering then imaging surveys can be sensitive to FRBs.
- Taking the bursts reported in Thornton et al. (2013), we can compare how these bursts would appear at 60 MHz to the NCP transient.
- Assuming the events could be dominated by scattering, we can use the relation:

$$\tau_{sc}(\nu) \propto \nu^{\gamma}$$

to calculate the new durations. (γ=-4)

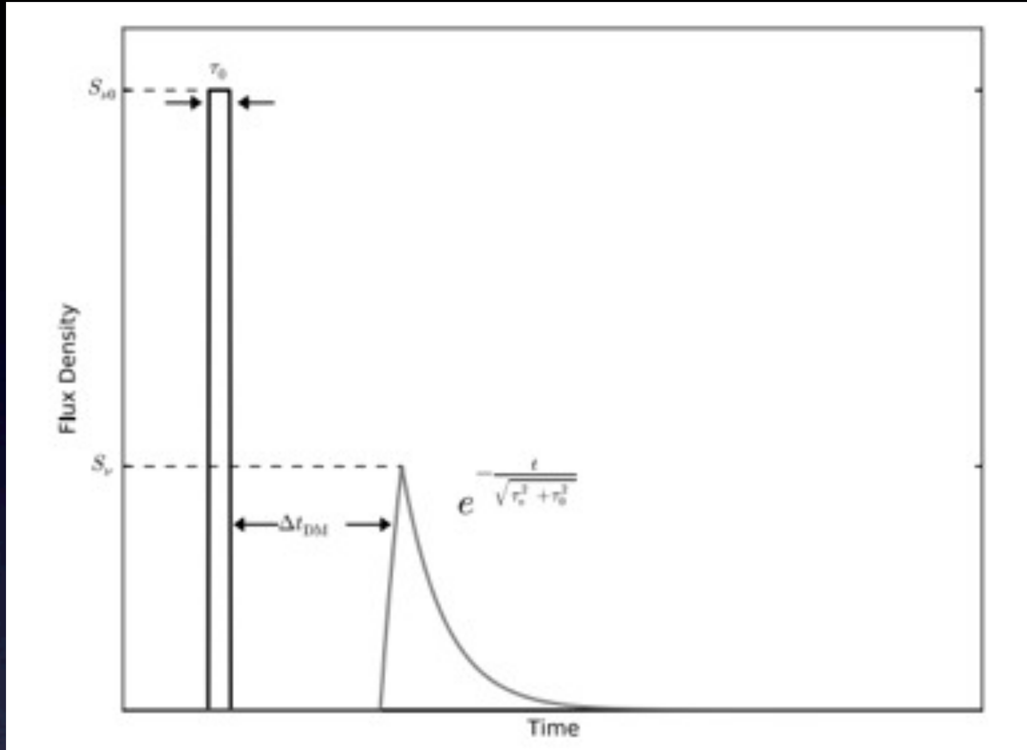


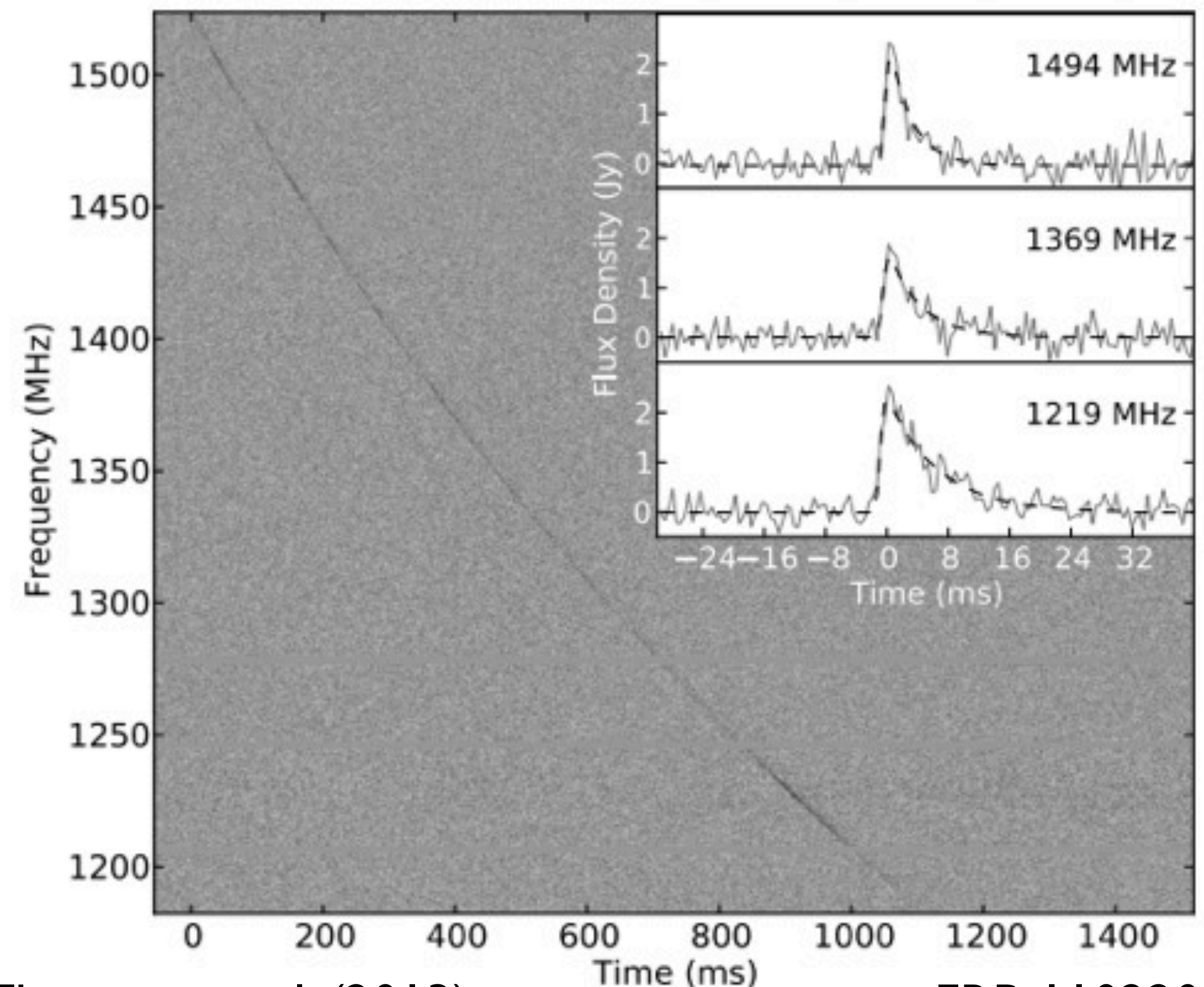
Figure 1. A boxcar pulse with initial pulse density $S_{\nu 0}$ (black line) is scatter broadened by the interstellar medium. Its peak flux density is reduced to S_{ν} and its profile changes (grey line), increasing the pulse width to $\sim \sqrt{\tau_0^2 + \tau_s^2}$.

	FRB 110220	FRB 110627	FRB 110703	FRB 120127	ILT J225346+862146
Observed width at 1.3 GHz (ms)	5.5	< 1.1	< 4.1	< 0.9	-
Scattered observed width at 60 MHz (s)	1212	< 242	< 903	< 198	900

- The NCP transient duration actually fits in quite well with the estimated scattering times.
- But...

Coherent - FRB?

- If we look at the Fluence of the bursts it's inconsistent with known FRBs.
- Fluence (Jy ms) = F x τ (Flux x duration)
- Assume fluence is conserved with scattering and ignore all dispersion effects.
- Eg. the fluence of the Thornton burst FRB 110220 was **8 Jy ms** at 1.3 GHz.



Thornton et al. (2013) FRB 110220

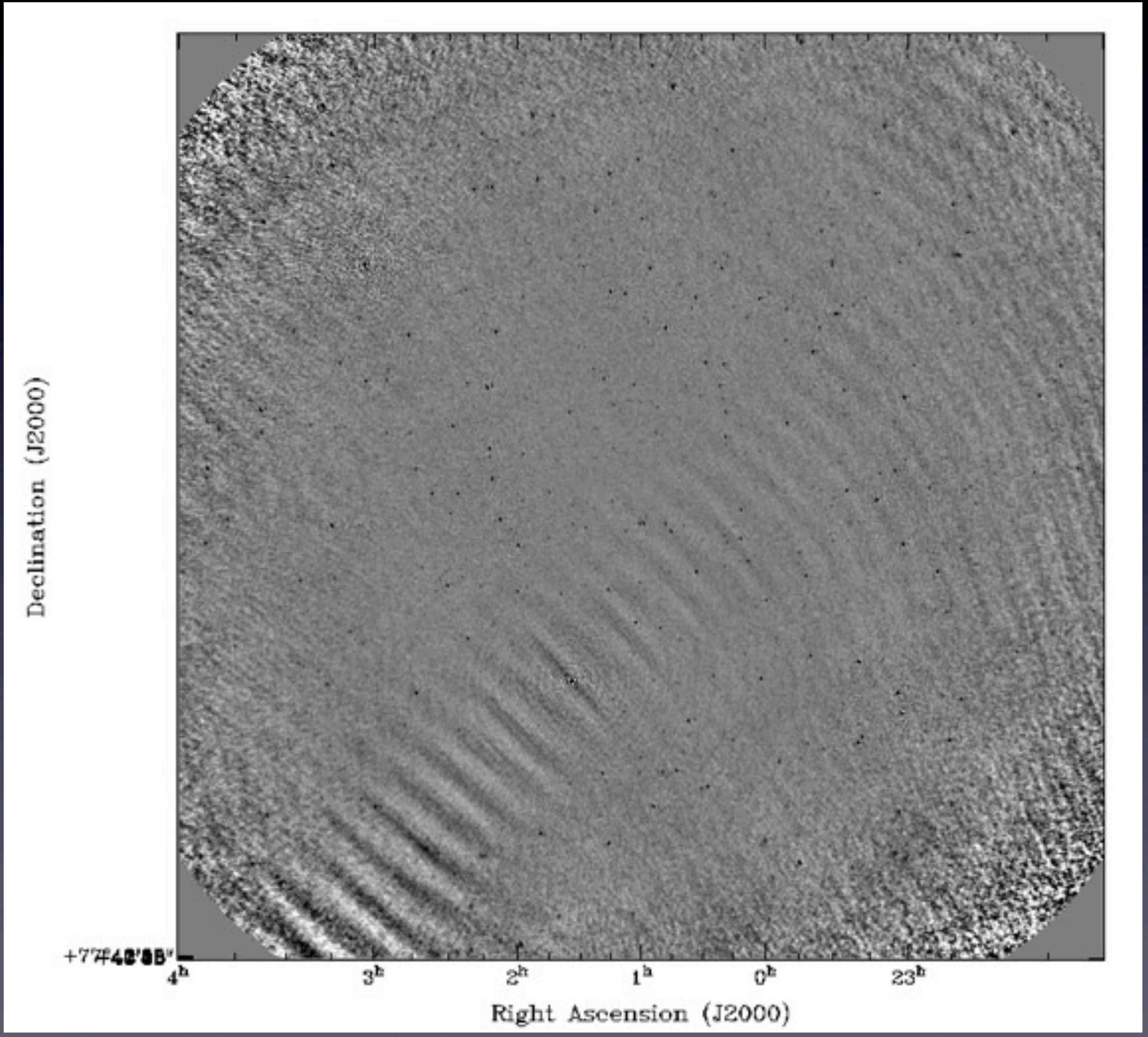
Coherent - FRB?

- For the NCP burst the fluence is 20 Jy x 9×10^5 ms = **1.8×10^7 Jy ms**
- If the spectral index **(α) = 0** then we directly compare this to the Thornton burst - **much** larger than 8 Jy ms.
- Taking **α=-2** the NCP transient becomes 0.04 Jy but the fluence is still much larger
- For the NCP transient **to 'fit'** with the Thornton (Lorimer) FRBs then α would need to = **-4.7 (-3.6)**.
- Basically, the NCP transient is far brighter than any other known FRBs.
- Spectral Index of FRB population not very well defined at this time.

α	**Fluence Jy ms**
0	1.8×10^7
-2	36,000
-4.7	8

Attempts to Find More

- During cycle 2 the NCP will be observed for a total of 35 hours using full LBA bandwidth.
- Assuming a bandwidth improvement of $\sqrt{244}$ the expected rate should be 6.2 events.
- There should be at least one new event in the data.



Conclusions

- The final conclusion is that with the data available, there is no obvious reason to not believe the transient.
- It does not seem to be completely consistent with a flare star or FRB.
- These were seen as the two most likely origins of the transient due to characteristics and no catalogue matches (radio + high energy).
- Full bandwidth observations of the NCP are on-going with around 20 hours of data recorded (though yet to be looked at).
- A detection of at least 1 other event is expected.