Commensal radio transient searches using the TraP

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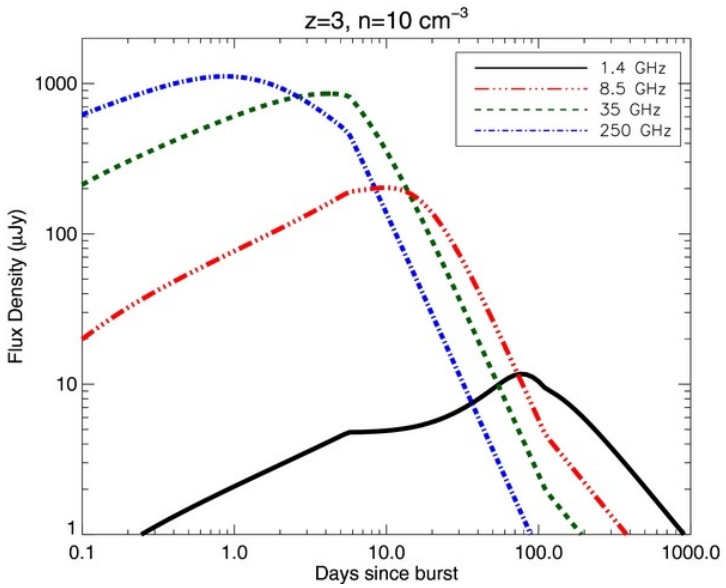
LOFAR

What are we looking for?

Two Catagories of Emission

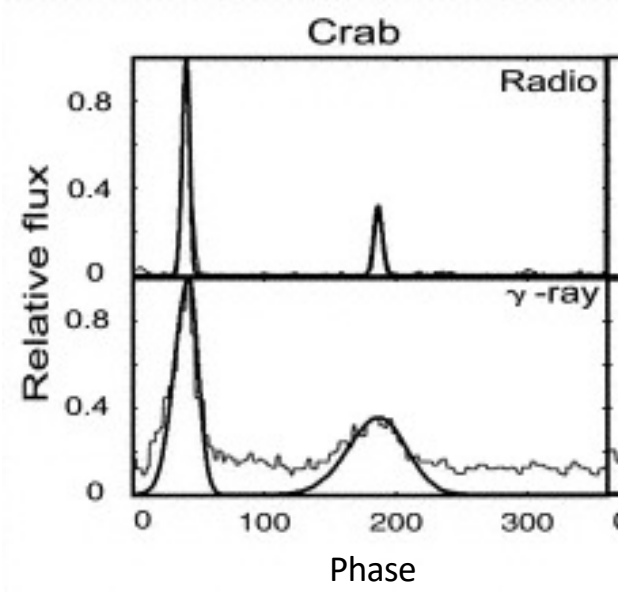
Incoherent

- Synchrotron afterglow or thermal sources
  - Slow and faint
- E.g. GRBs

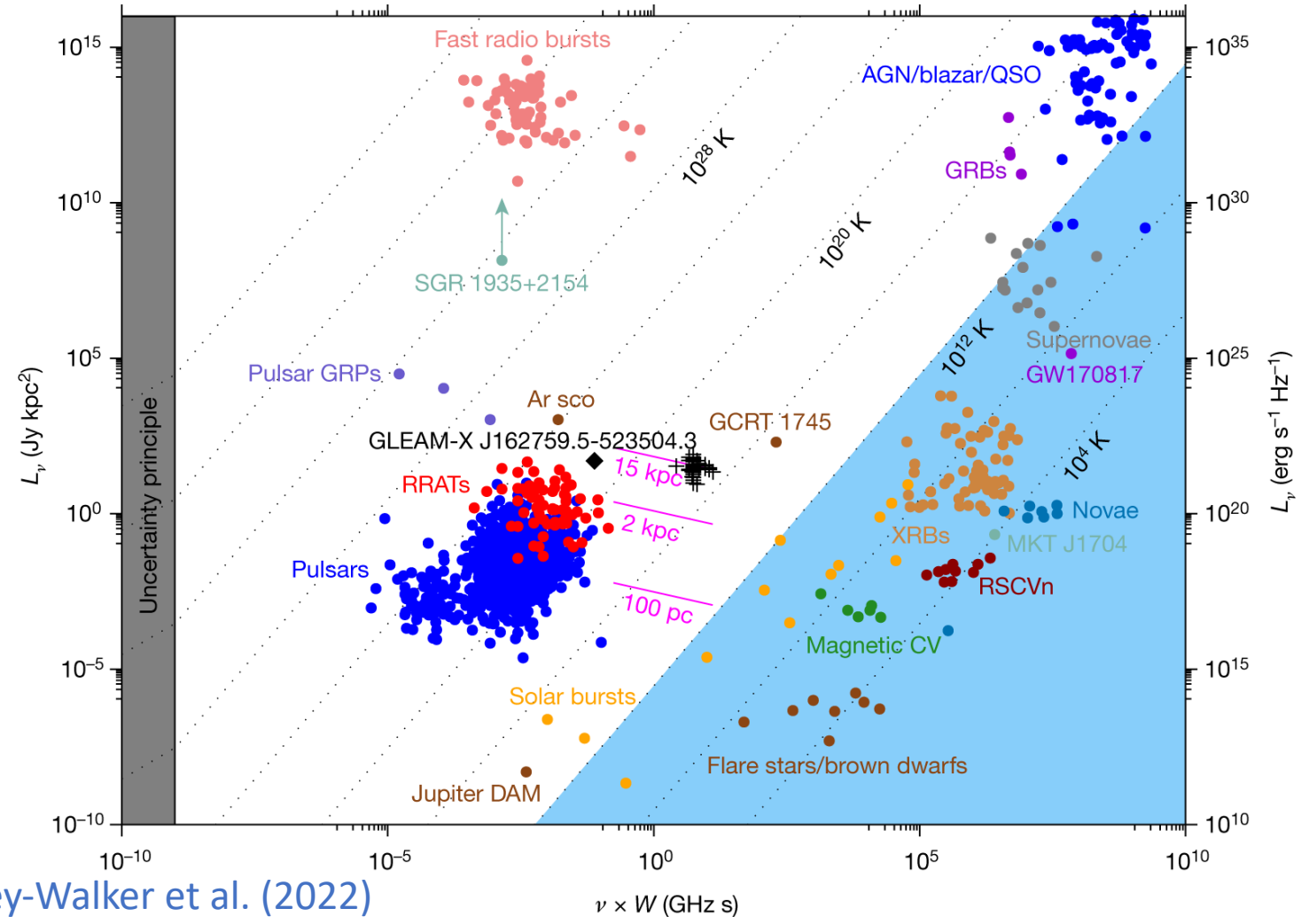


Coherent

- Electrons in emitting region emit in phase, e.g. MASER
- Fast variability and bright
- E.g. Pulsars

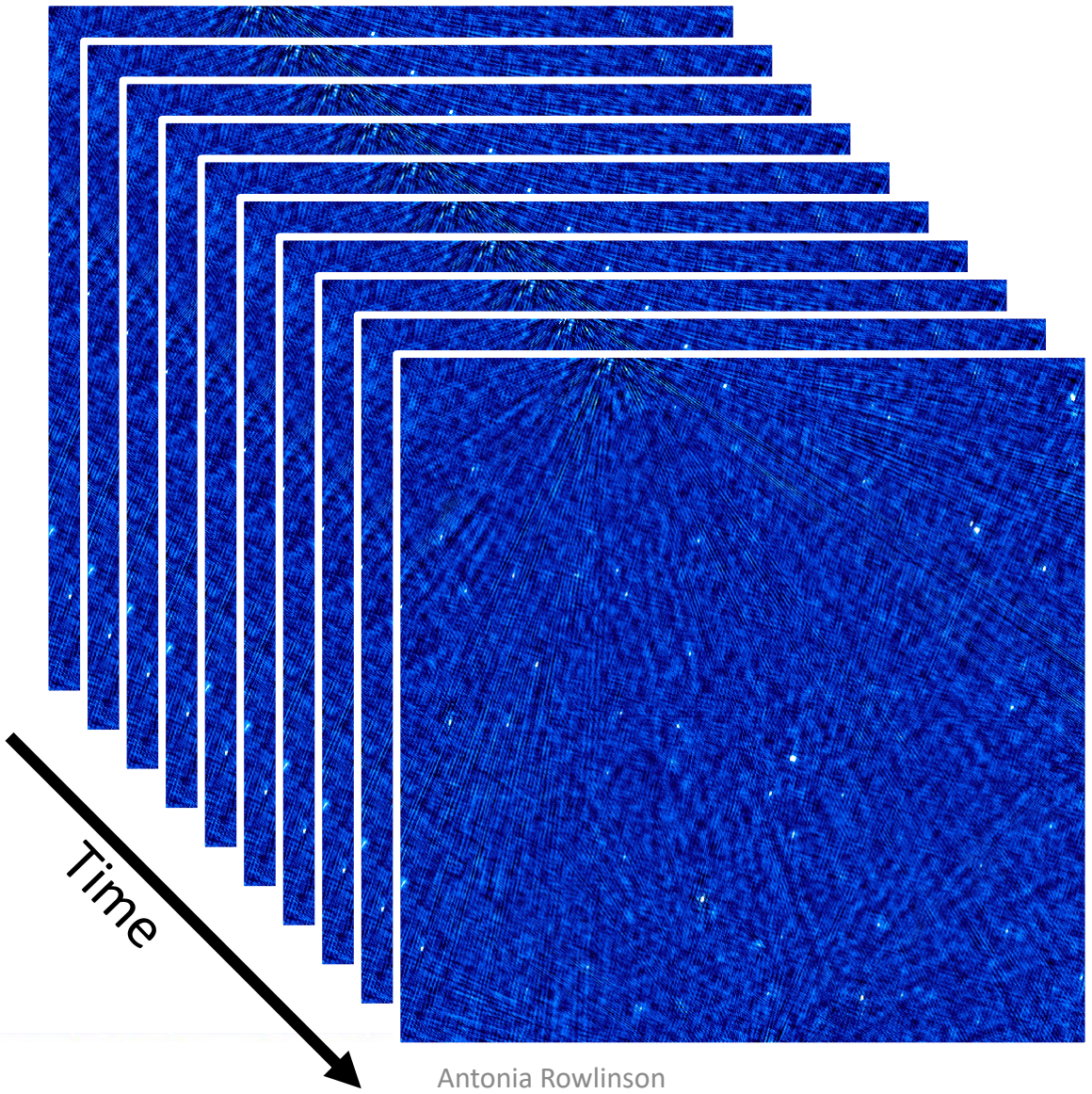


Radio transient populations

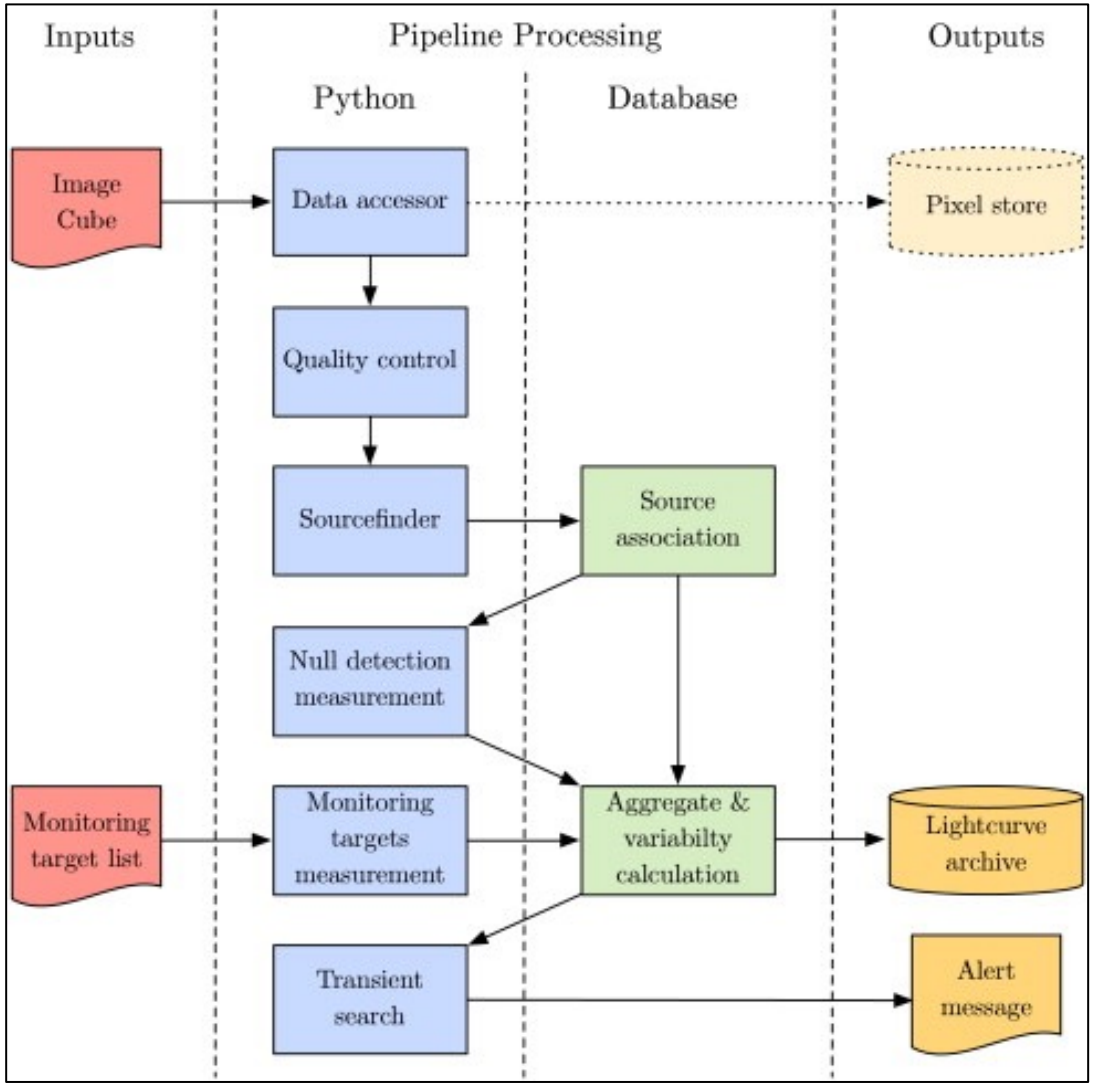


Hurley-Walker et al. (2022)

Searching for transients & variables



Transients Pipeline (TraP)



- Publicly available: https://github.com/transientskp/tkp
- Well documented: https://docs.transientskp.org
- Example tools for interacting with database and filtering strategies: https://github.com/transientskp/TraP_tools

Swinbank et al. (2015)

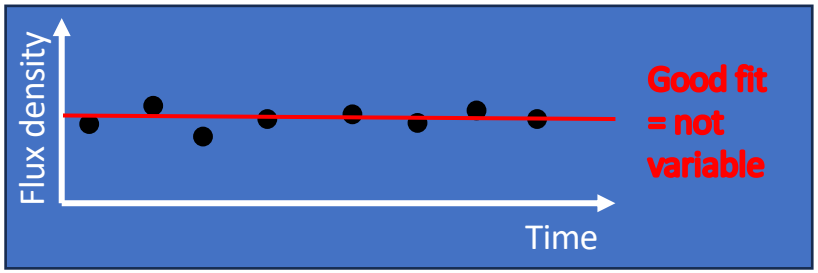
Variability parameters

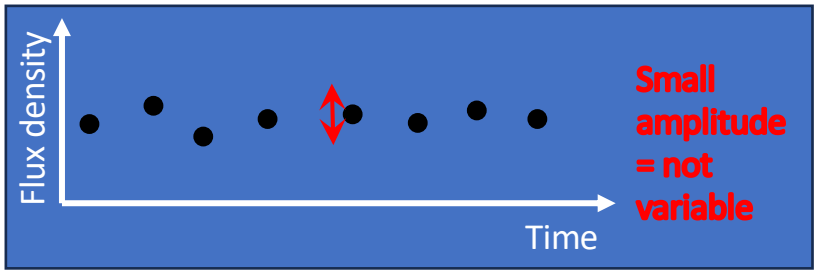
Reduced weighted $\chi 2$

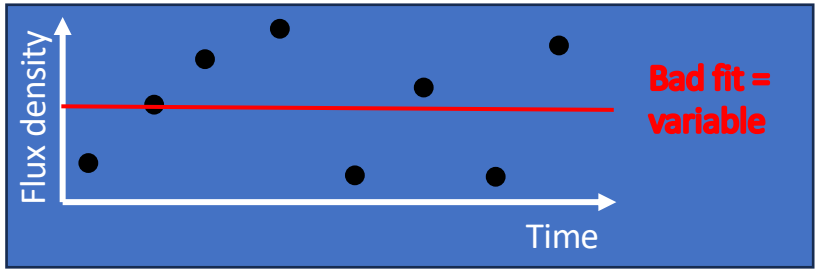
"How well the data fits to a horizontal line"

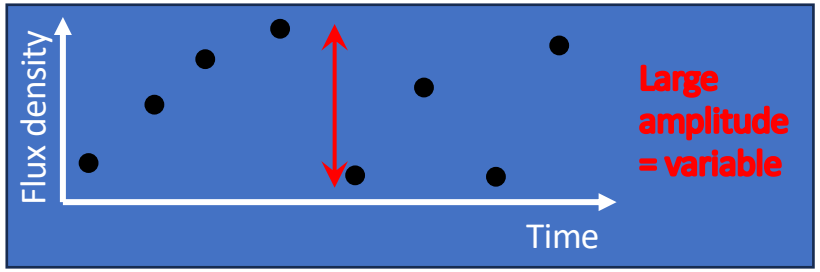
Coefficient of variation

"The amplitude of the change in flux density"







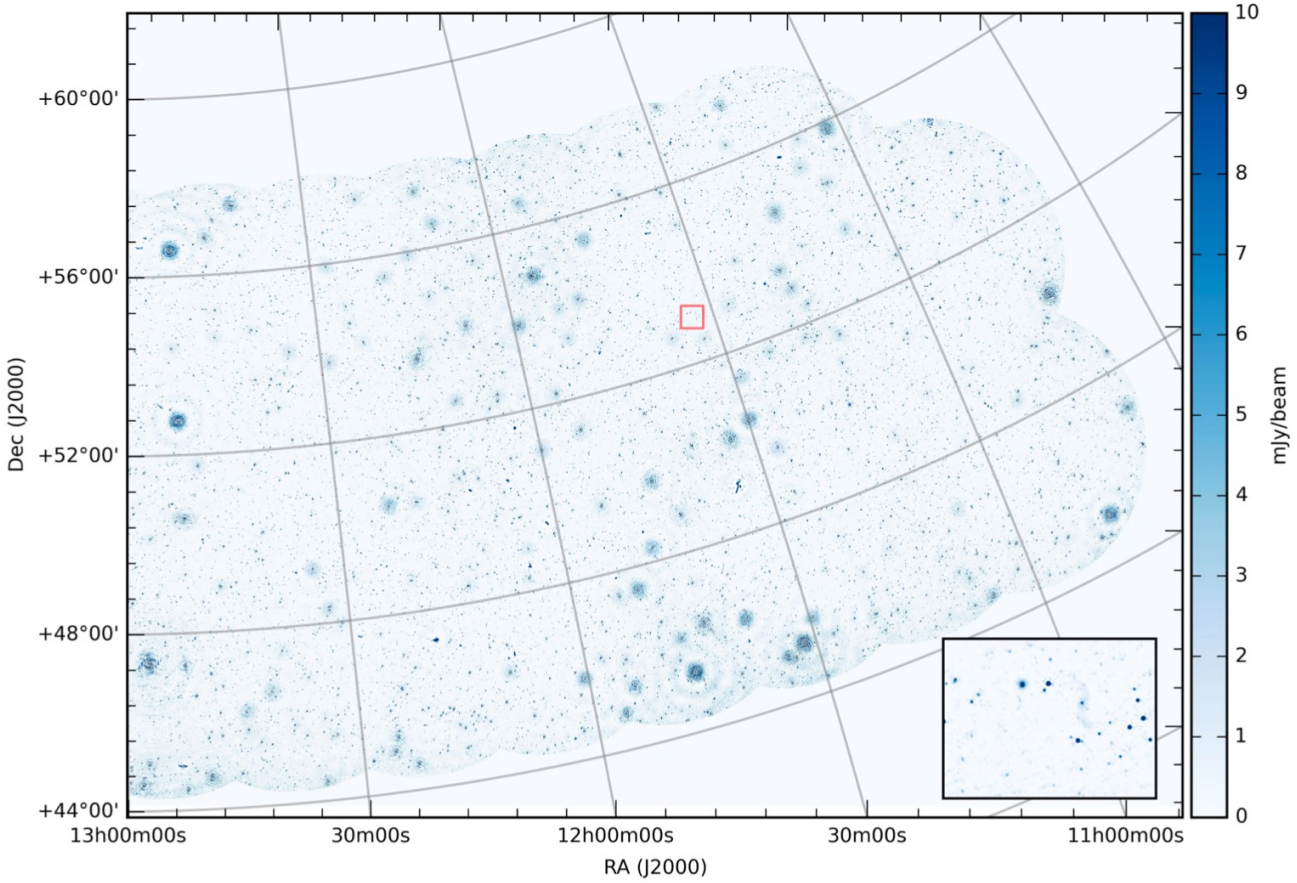


Demo

https://github.com/AntoniaR/TraP_filter_demo

Recent LOFAR results

The LoTSS Survey



LOFAR Two-meter Sky Survey

Shimwell et al. (2019)

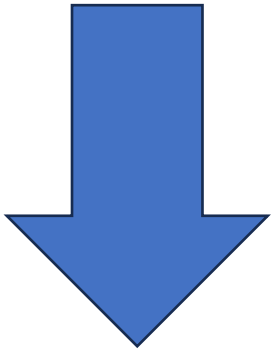
Pilot survey –
Kriek van de Meulen &
Zack Meyers

Main survey –
Iris de Ruiter
First 8% complete!

- Beautiful, well calibrated datasets covering much of Northern Sky (target is full sky)
- 8 hour calibrated observations for imaging in snapshots

Imaging on short timescales

- Radio imaging takes a long time!
- Analysing images containing many sources is slow

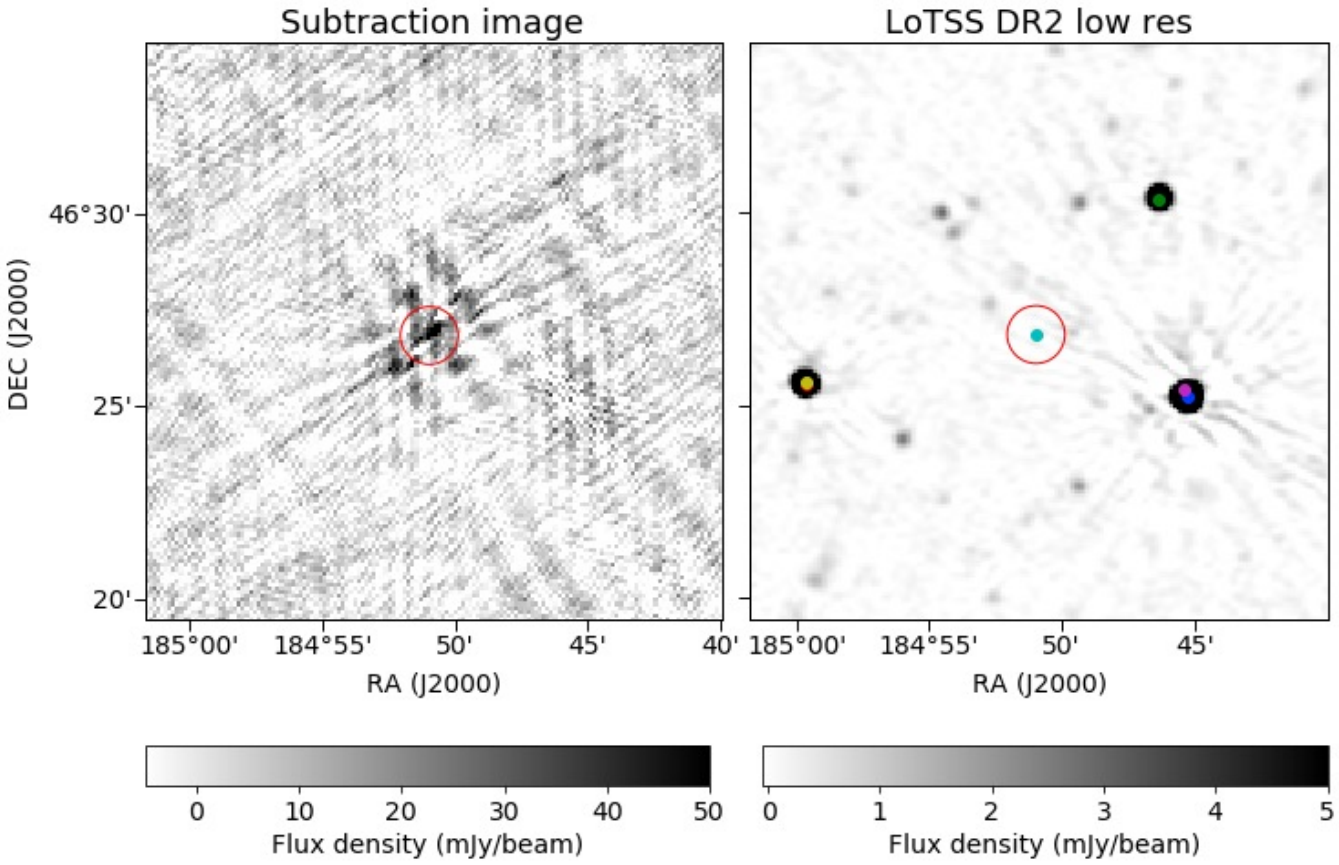


Subtraction imaging

- Images do not require cleaning or primary beam correction → very fast
- Very few sources to detect and monitor → increased speed in transient pipelines

de Ruiter, Meyers et al. (2023)
Fijma et al. (2023)

Subtraction imaging of LoTSS: simulated transients

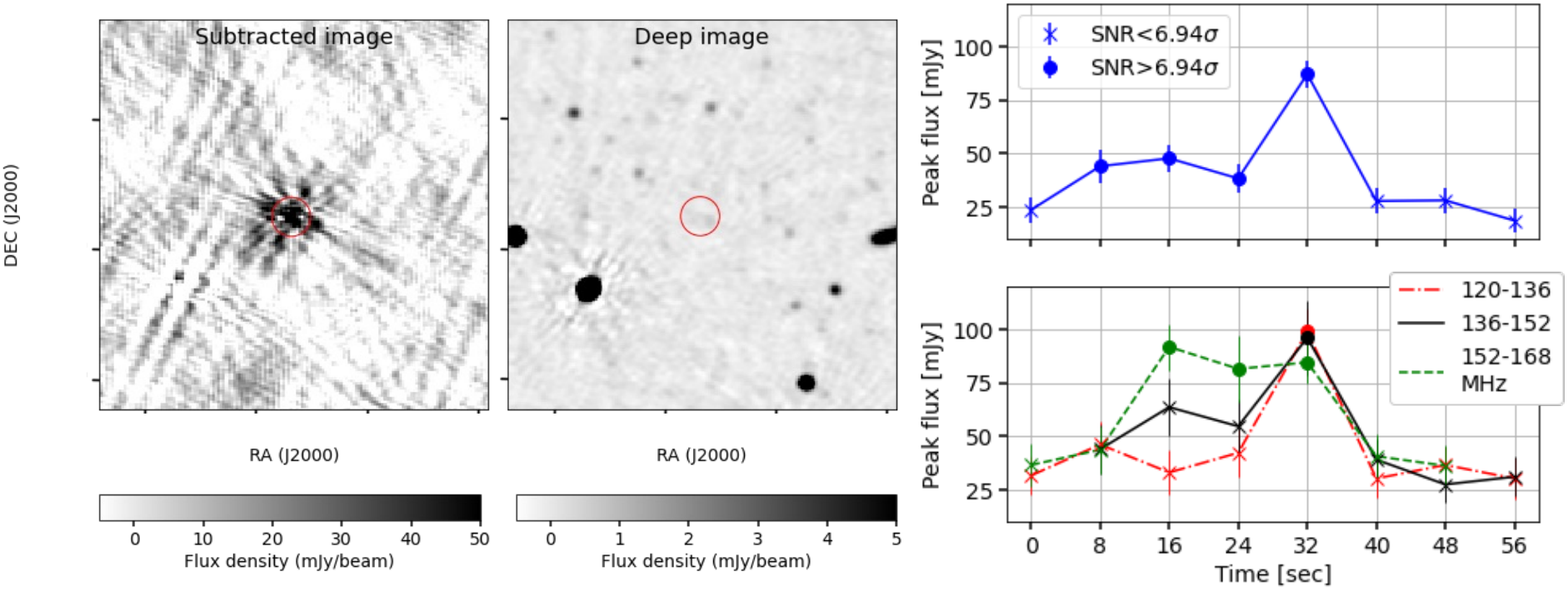


	Sensitivity (mJy)
1 hour	6 mJy
8 sec	130 mJy

- f_{int} = 105 mJy
- f_{int} = 72 mJy
- f_{int} = 407 mJy
- f_{int} = 12 mJy
- f_{int} = 10 mJy
- f_{int} = 250 mJy

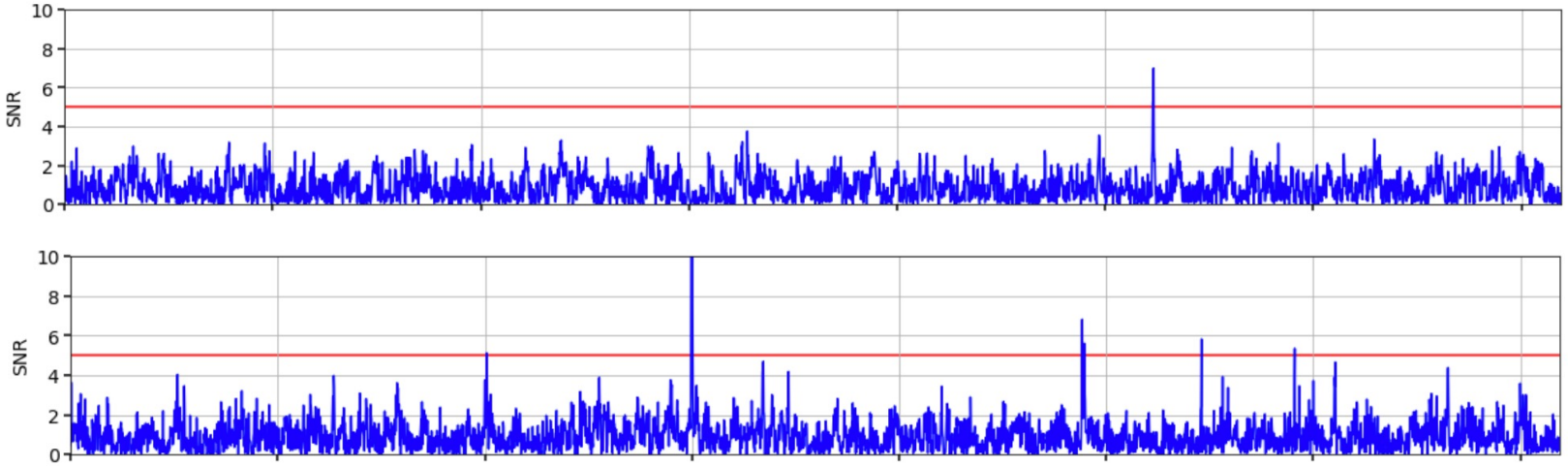
de Ruiter, Meyers et al. (2023)

Subtraction imaging of LoTSS: Detected transient source



de Ruiter, Meyers et al. (2023)

Seconds to minutes - transient (LoTSS)



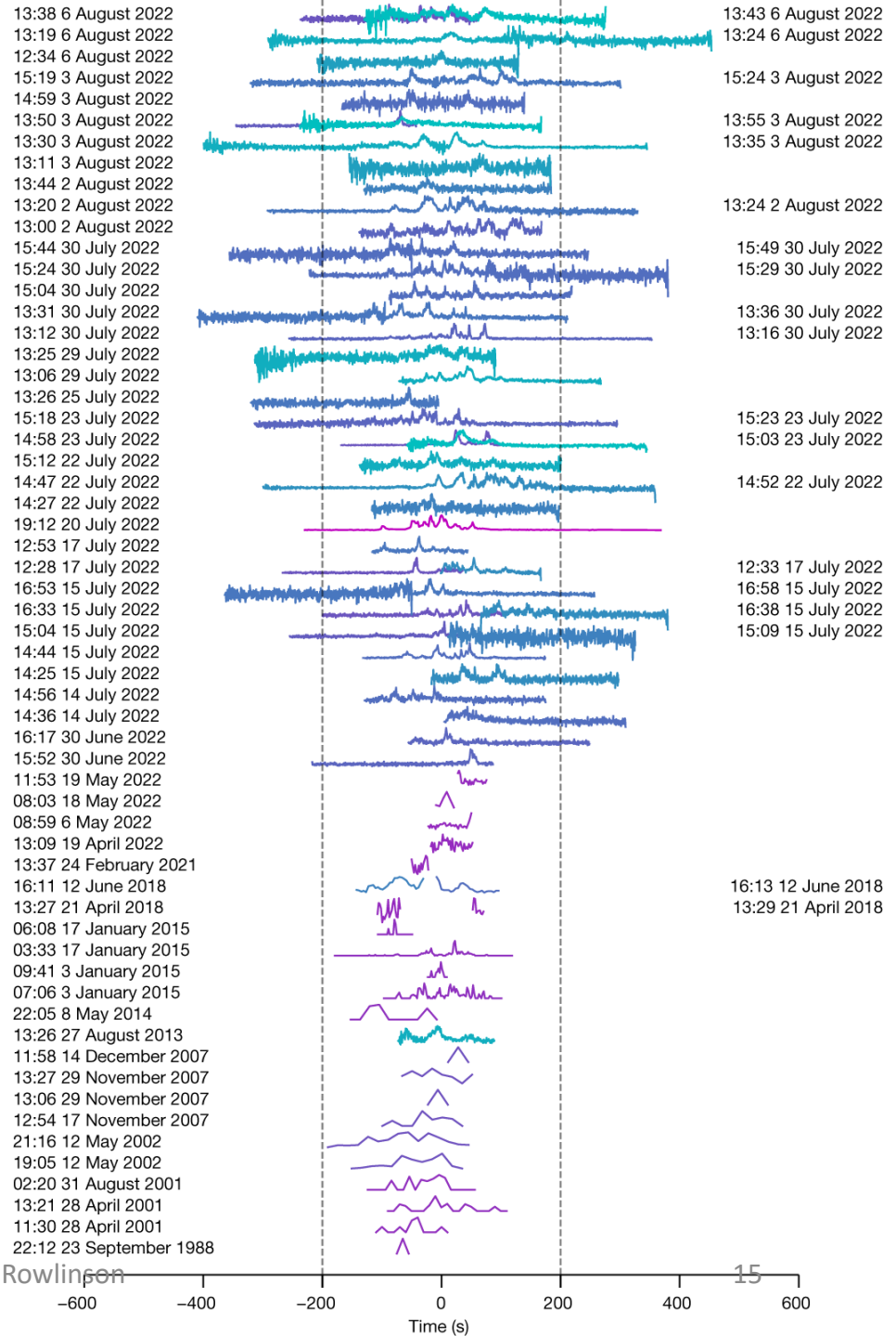
5 years

- Flares seen in several other LOFAR observations
- Not on the Galactic Plane
- Periodicity ~few hours
- Follow-up observations ongoing

de Ruiter et al. (in prep)

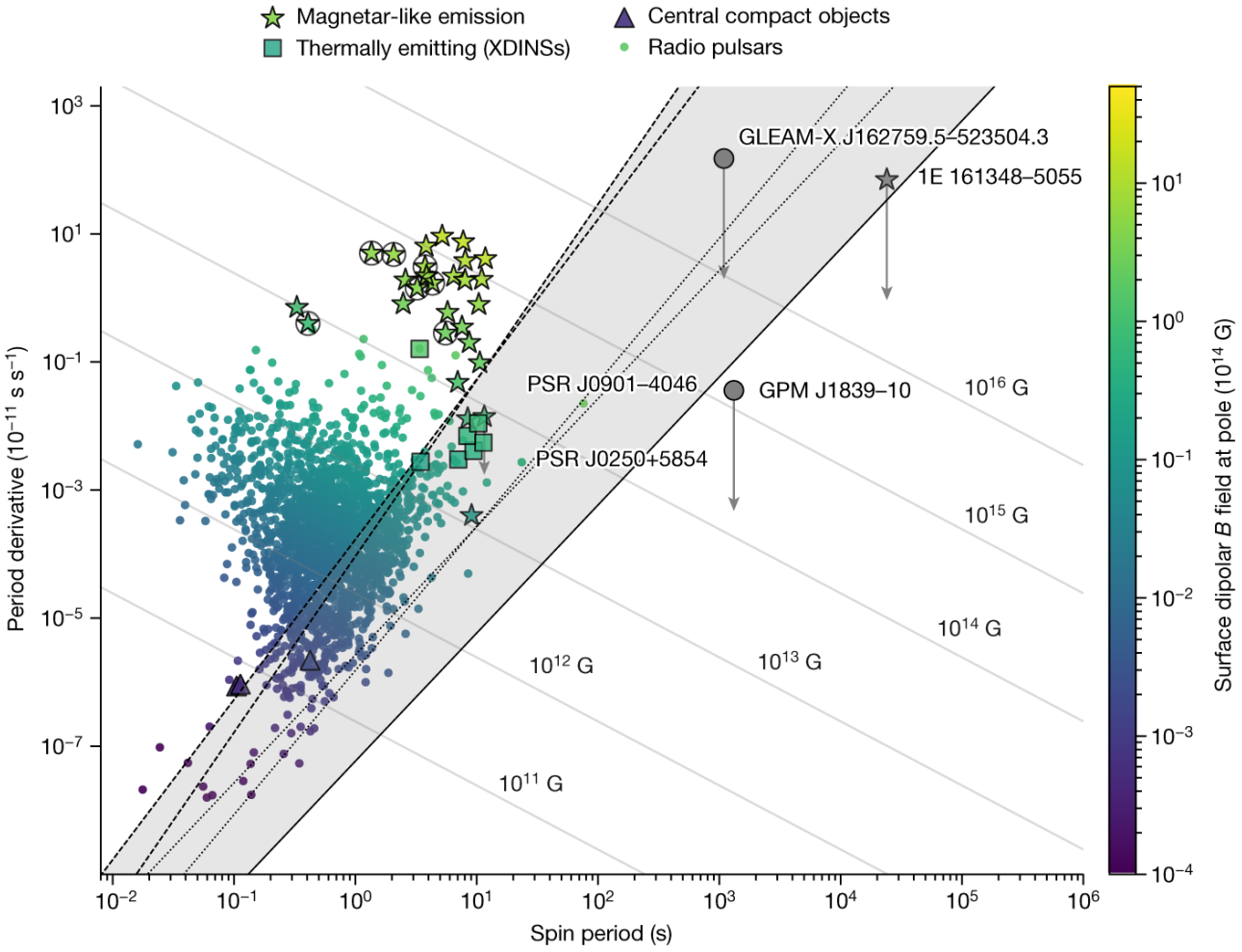
What could this source be?

- 2 similar sources seen by the MWA on the Galactic plane
- Long periodicies of 18 and 21 minutes (rotation or orbit?)
- One only active for a short time the other for 30 years…



Hurley-Walker et al. (2022, 2023)

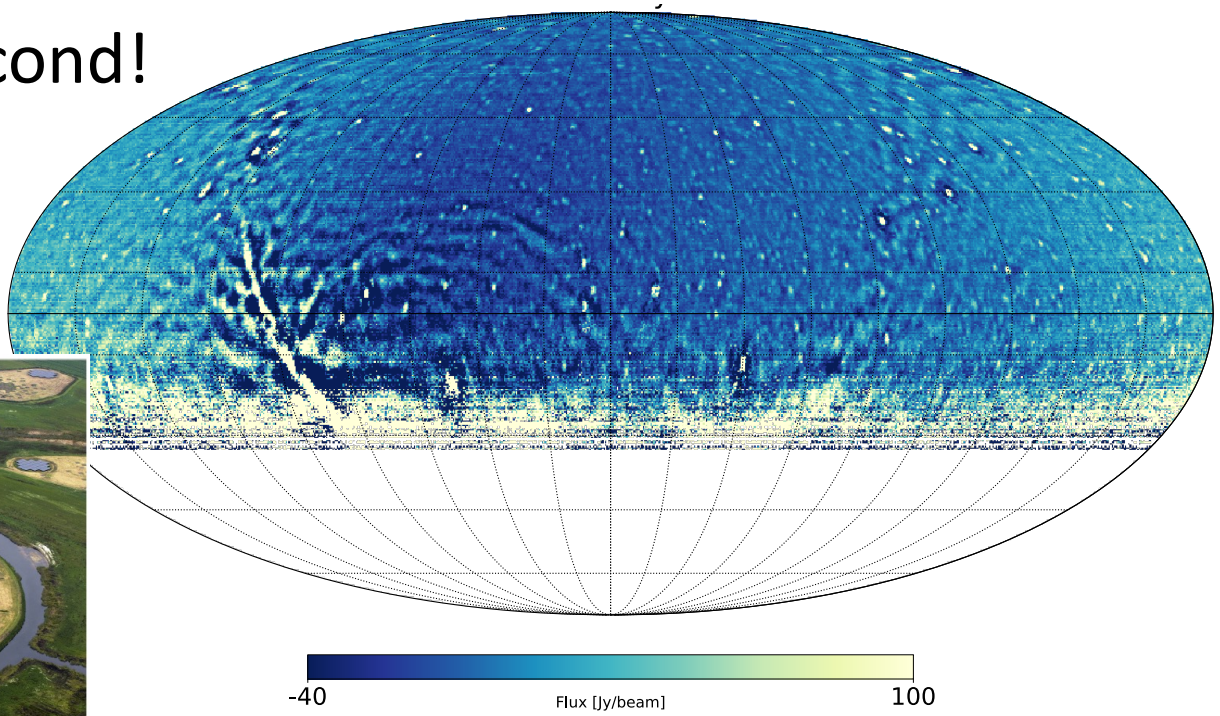
What could this source be? Magnetar, white dwarf… ?



Hurley-Walker et al. (2022, 2023)

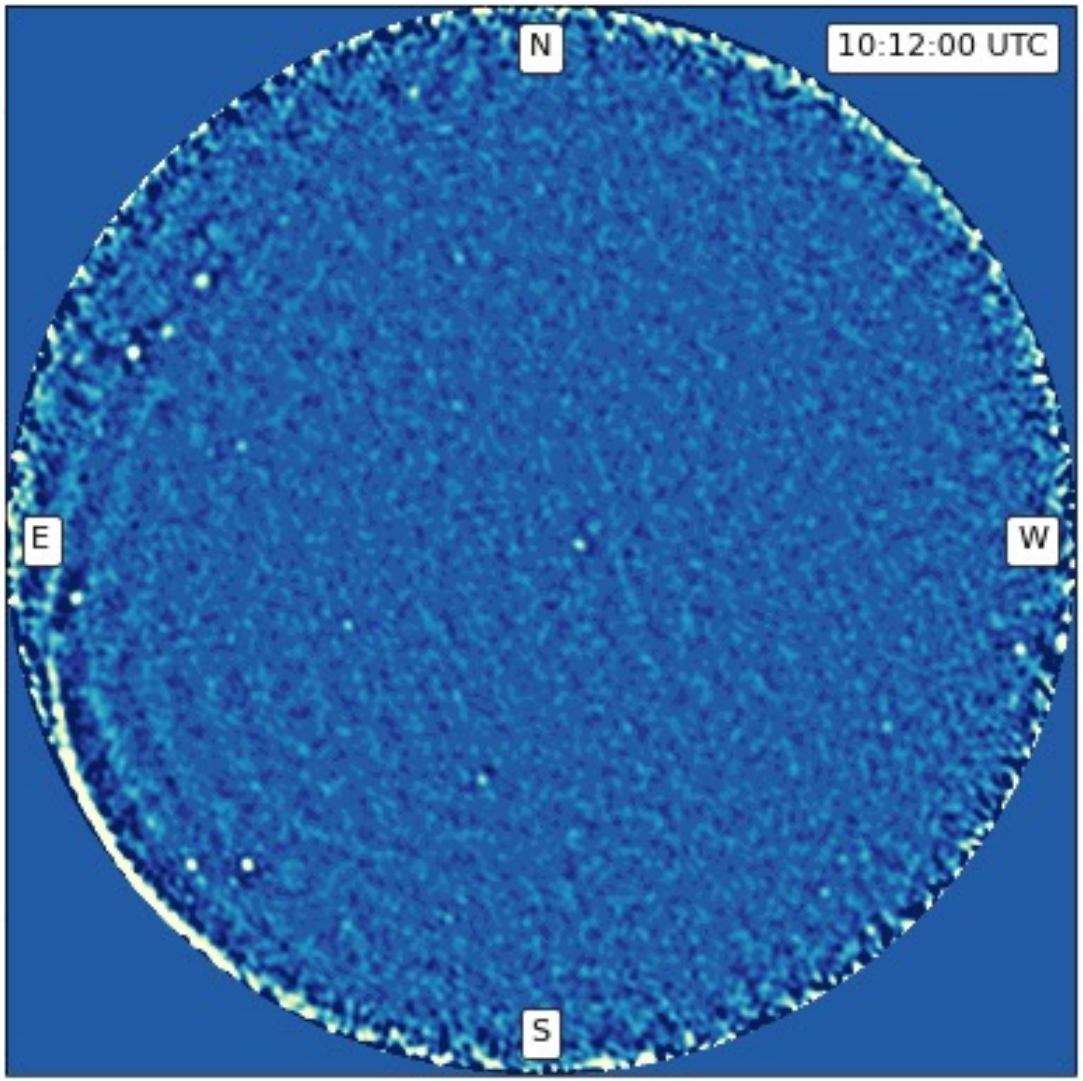
The AARTFAAC Sky

- AARTFAAC uses the central 6-12 stations of LOFAR
- Sees whole visible sky
- 1 image per second!



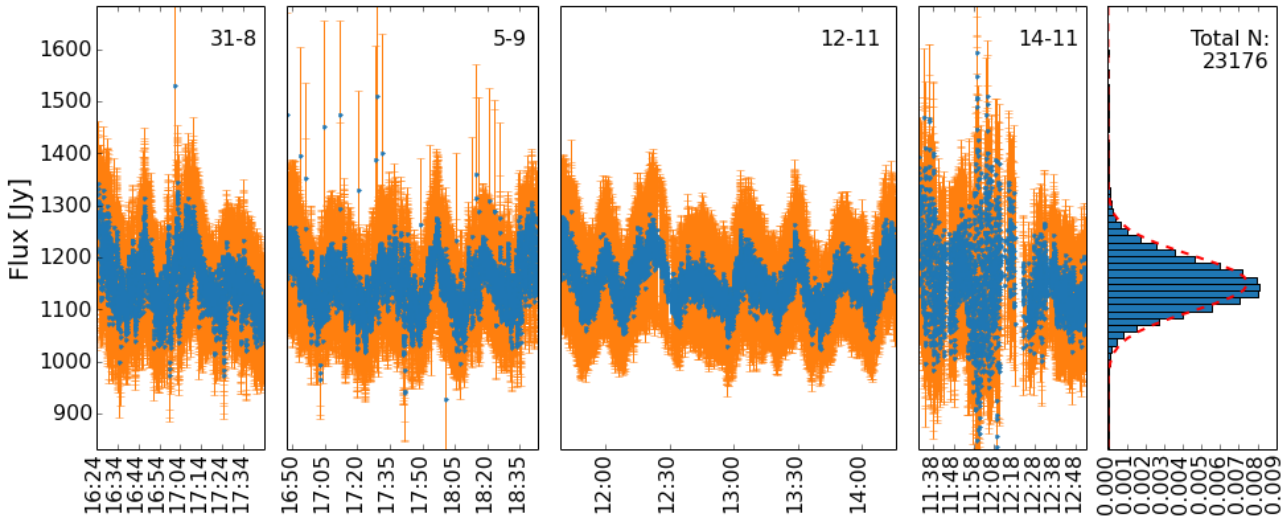
Whole sky integrated image
Kuiack et al. (2019)

AARTFAAC-6 in operation



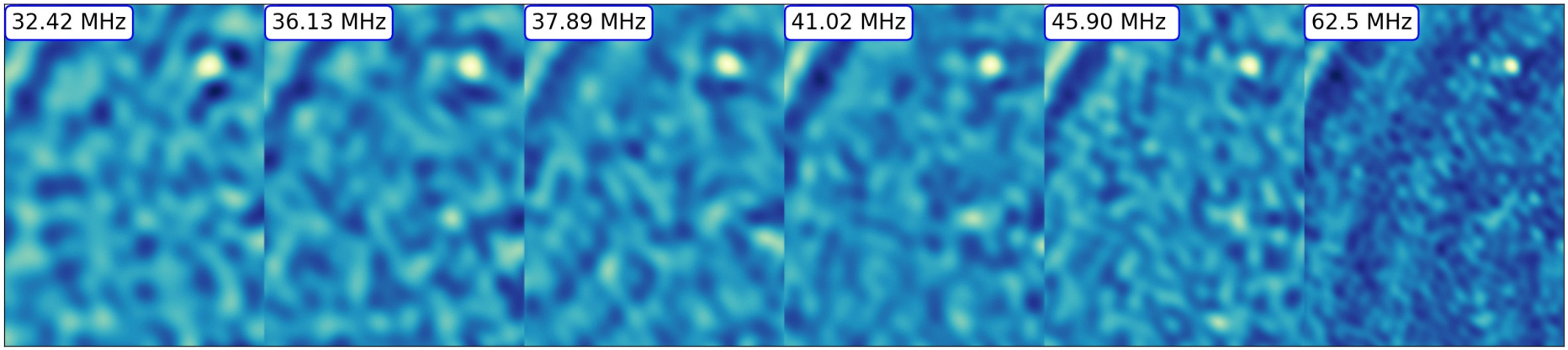
Credit: Mark Kuiack

The variable AARTFAAC Sky



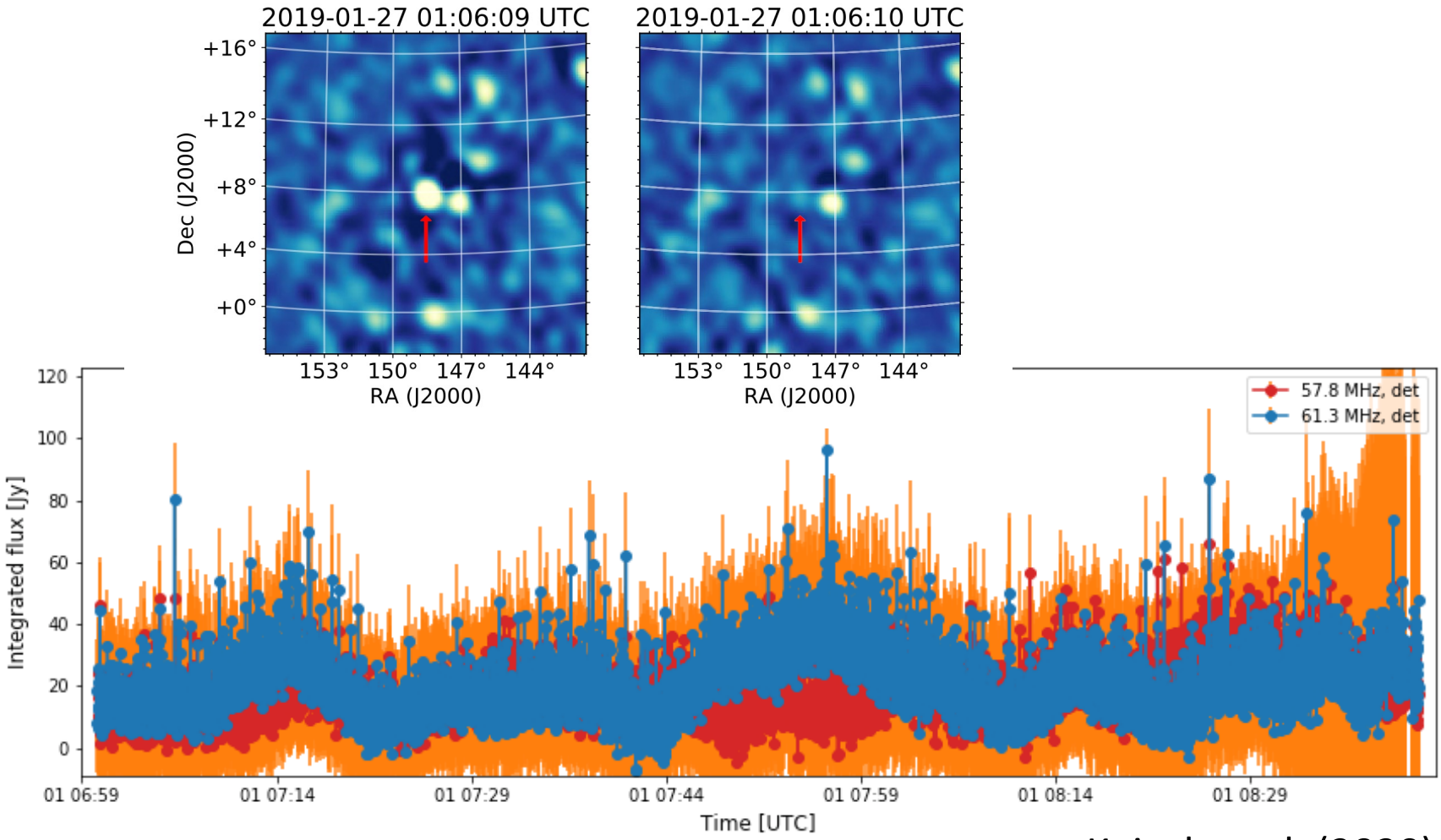
Long timescale lightcurve of Hercules A showing scintillation

Multi-wavelength detection of a Perseid meteor fireball



Credit: Mark Kuiack

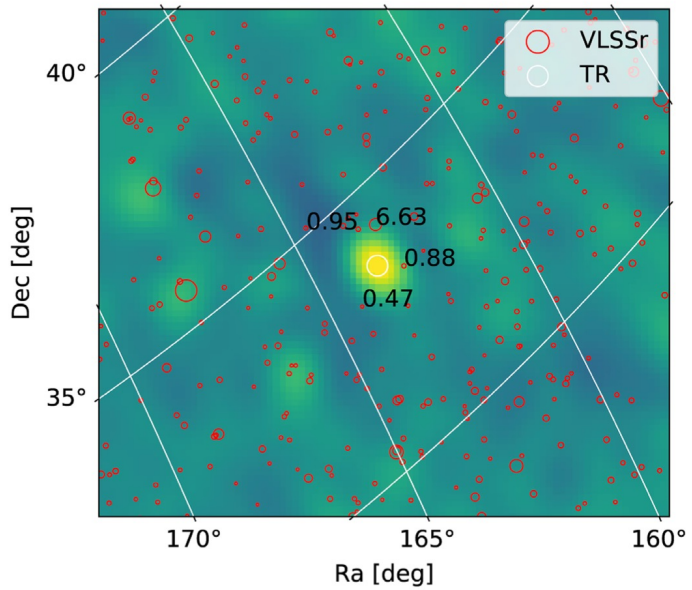
Giant Pulses from PSR B0950+08

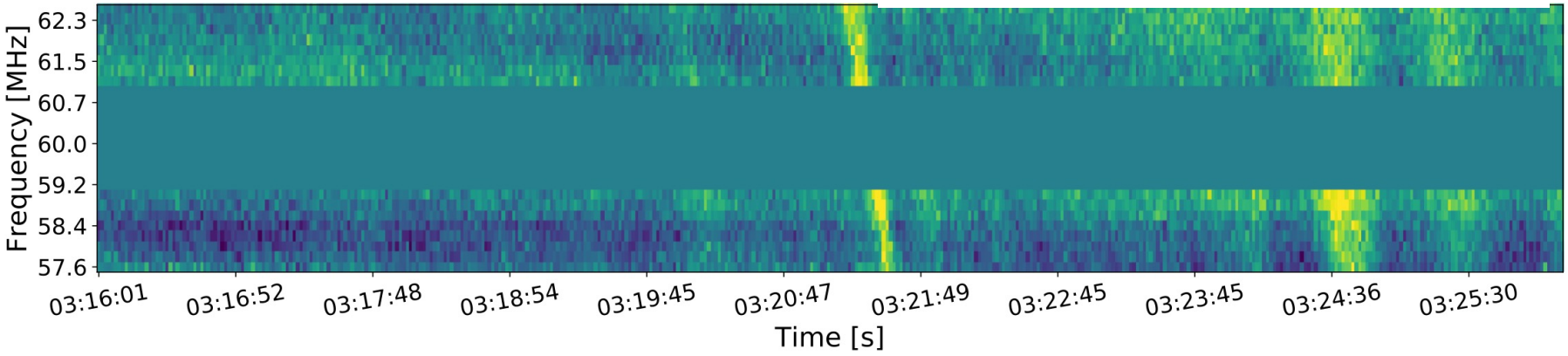


Kuiack et al. (2020)

AARTFAAC dispersed transients

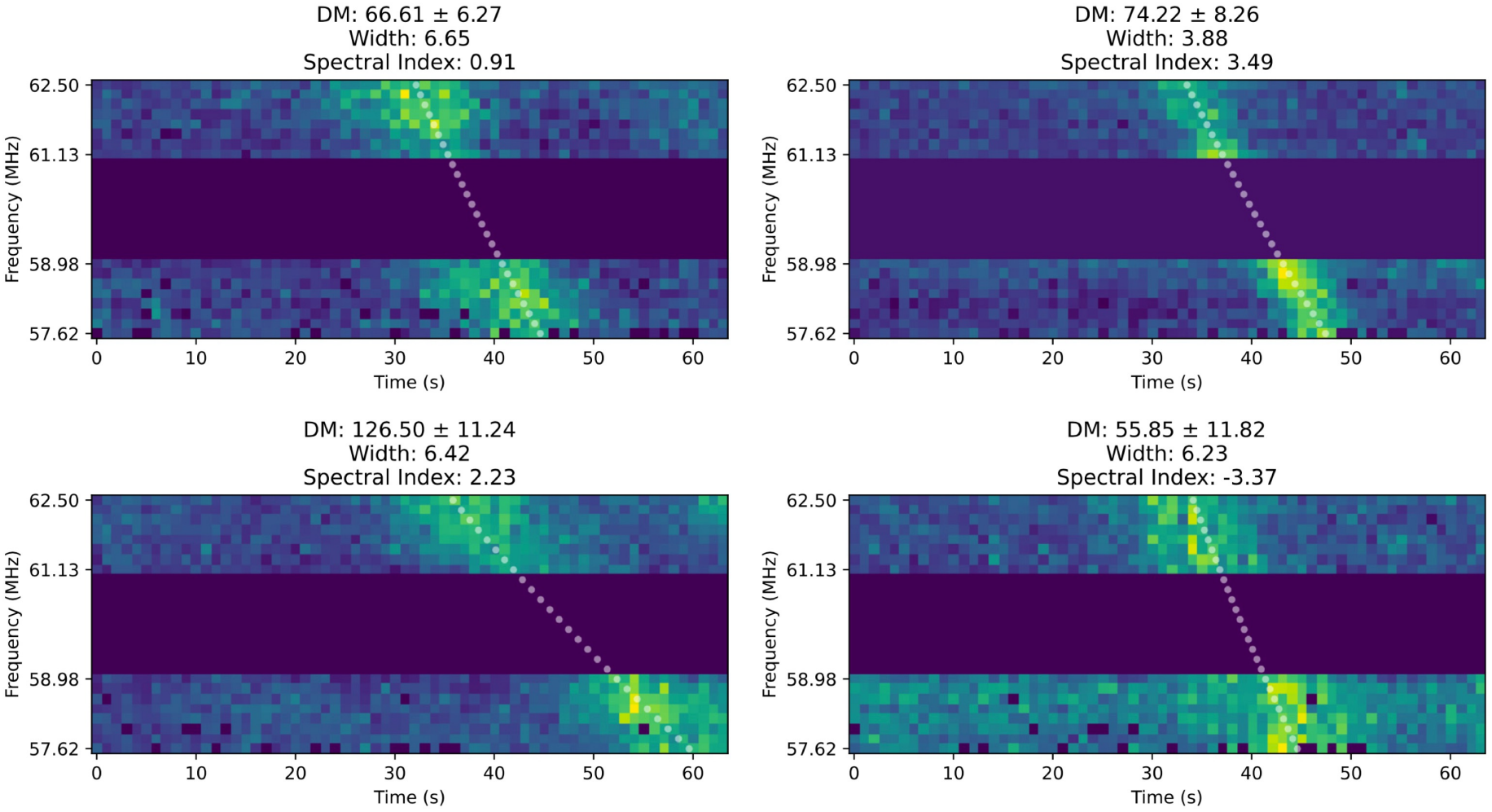
- 545 hours of data
- 60 MHz
- 7.7 second, 80 Jy flare
- Consistent with being dispersed with a DM of 73 pc cm^-3





Kuiack et al. (2021)

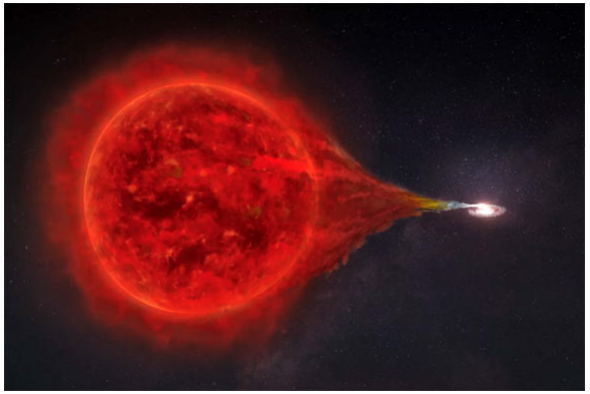
AARTFAAC dispersed transients

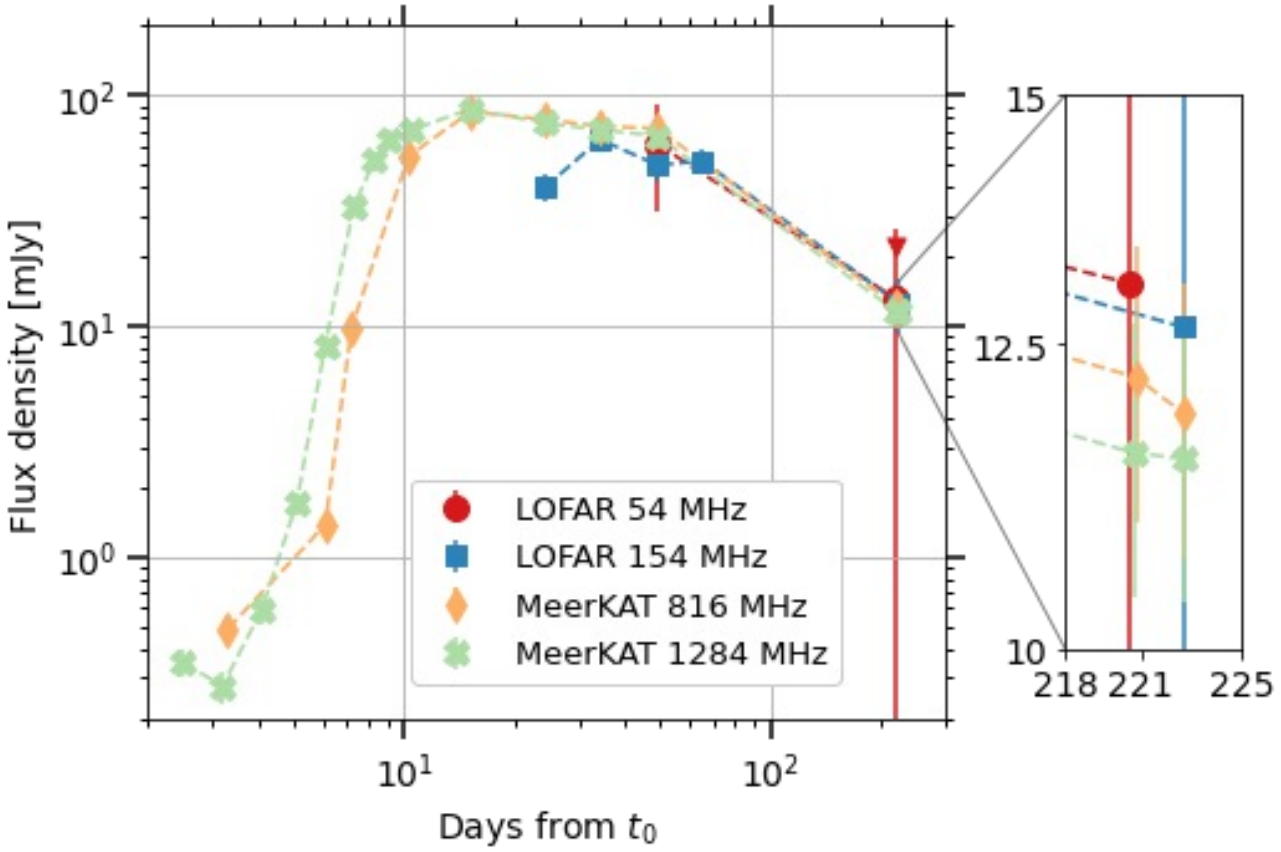


Ruhe et al. (2021)

RS Ophiuchi:
A recurrent nova in outburst

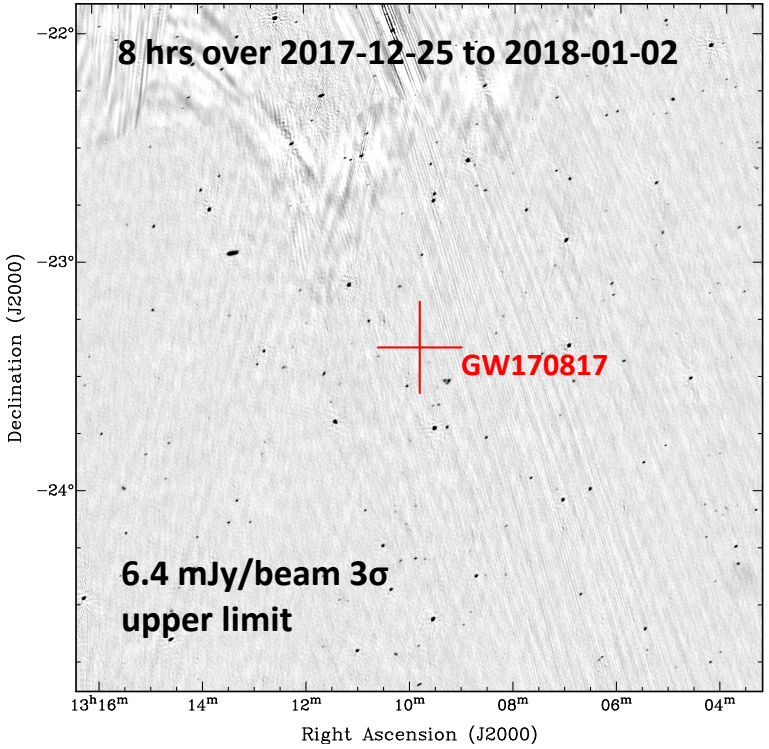
Lowest frequency detection of a recurrent nova to date

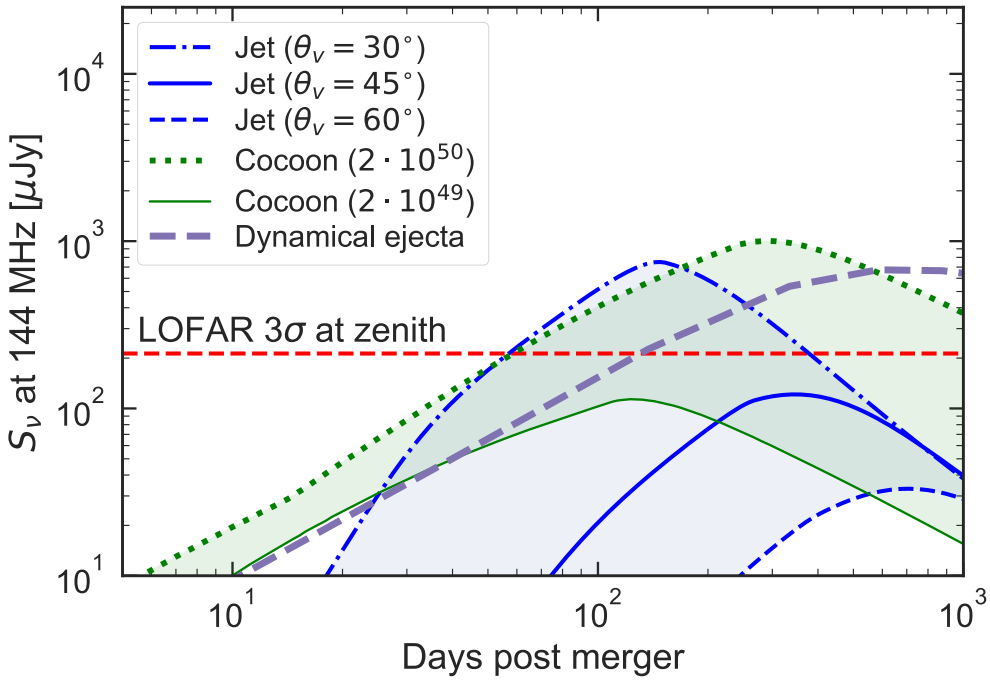




de Ruiter et al. (2023)

GW 170817 follow-up with LOFAR



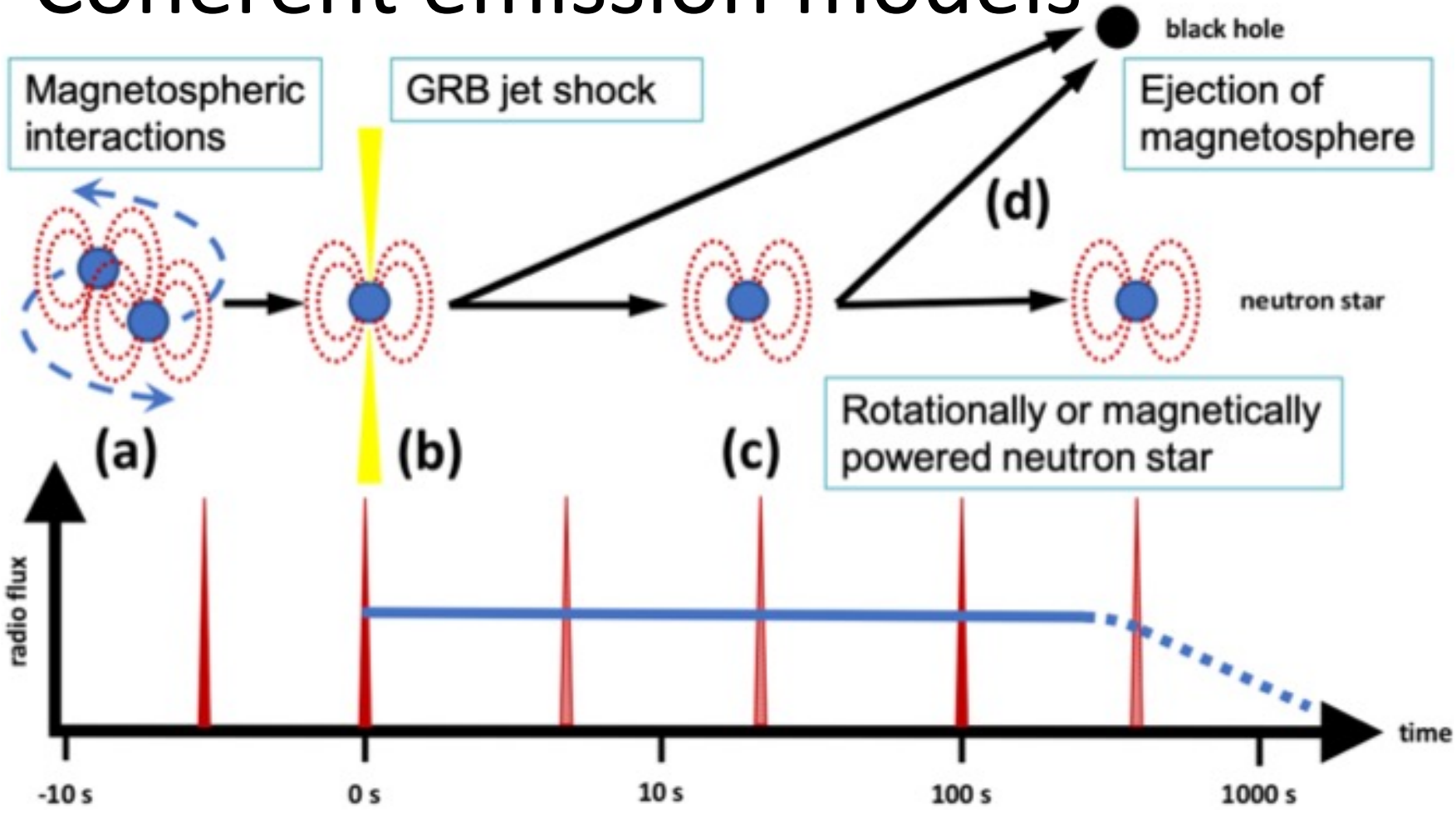


The deepest image ever made at very southerly declinations with LOFAR

Max elevation ~13.7 deg

Broderick et al. (2020)

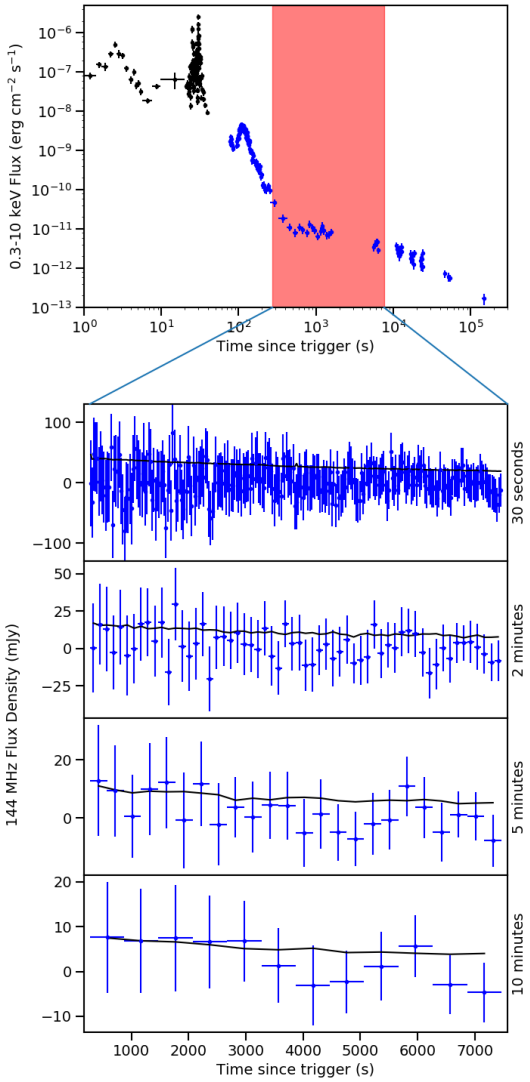
Coherent emission models



Rowlinson & Anderson 2019. See also Gourdji et al. 2020 for overview of these models and comparison to some localised FRBs

Rapid response with LOFAR

- Responds to GRBs within 4.5 minutes – speed improvements expected with new scheduler and LOFAR 2.0
- Deepest limits on coherent radio emission from gamma-ray bursts at early times to date

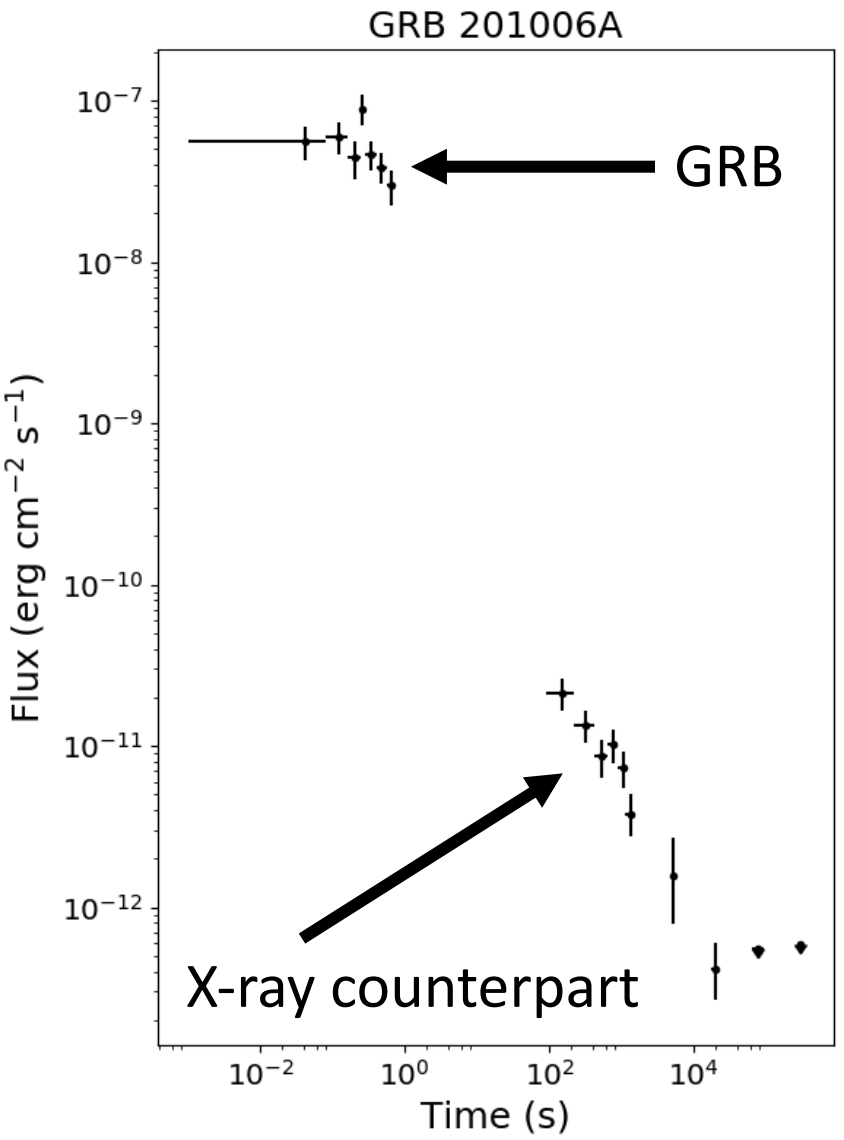


Rowlinson et al. (2019)

GRB 201006A

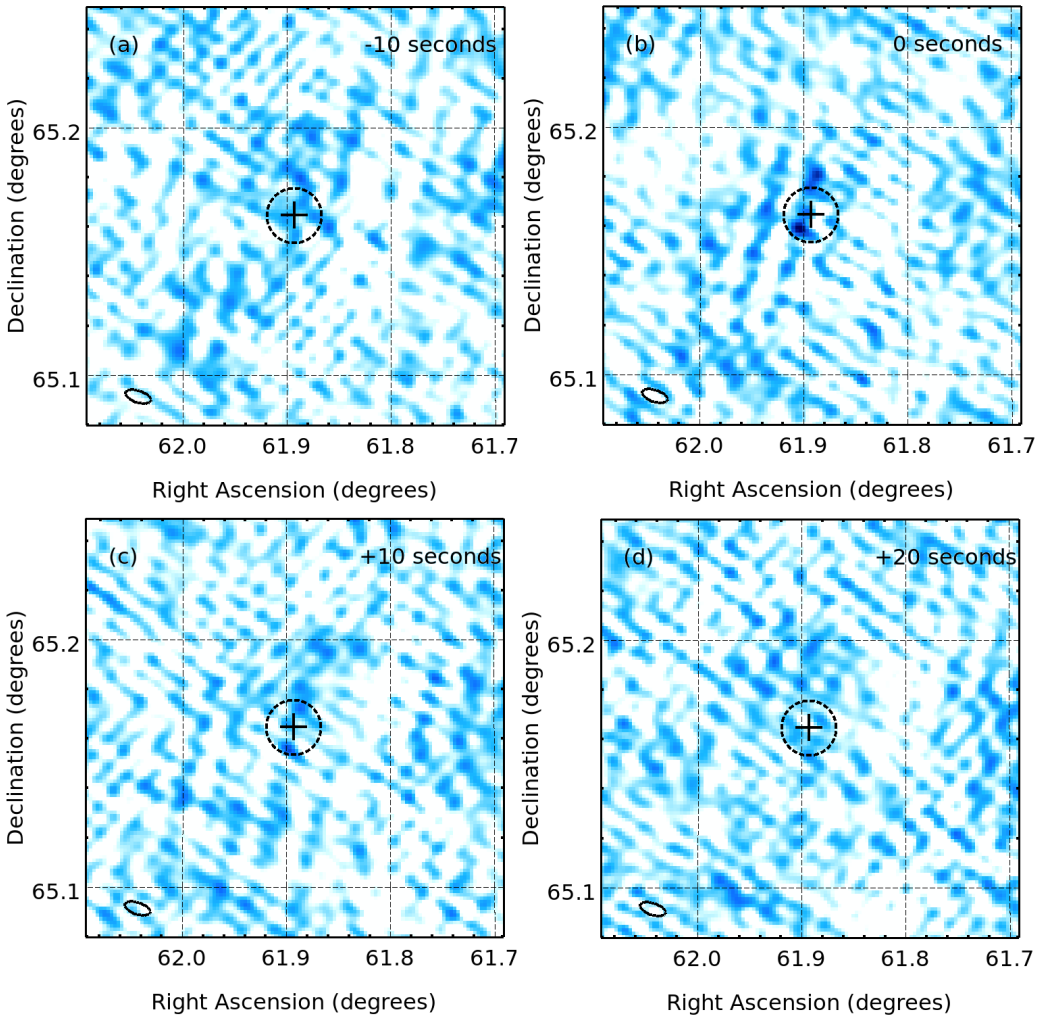
- Detected by Swift
- Duration ~0.5 seconds
- 2 hour LOFAR observation started 4.75 minutes after GRB

Rowlinson et al. (2023)



Detection of candidate source

- Sky model subtracted from visibilities
- Imaged in 10 second snapshots
- 5.6σ detection at 76.6 minutes after GRB
- Flux density of 47 ± 14 mJy
- Note slight offset from X-ray position – probability of occurring by chance 0.5%



Rowlinson et al. (2023)

Summary

- Outlined key strategies and tools to conduct searches for transient and variable objects in radio data

- Presented some of the recent key results with LOFAR