Searching for Radio Transients

LOFAR Data School lecture 2026

Antonia Rowlinson

21st September 2026

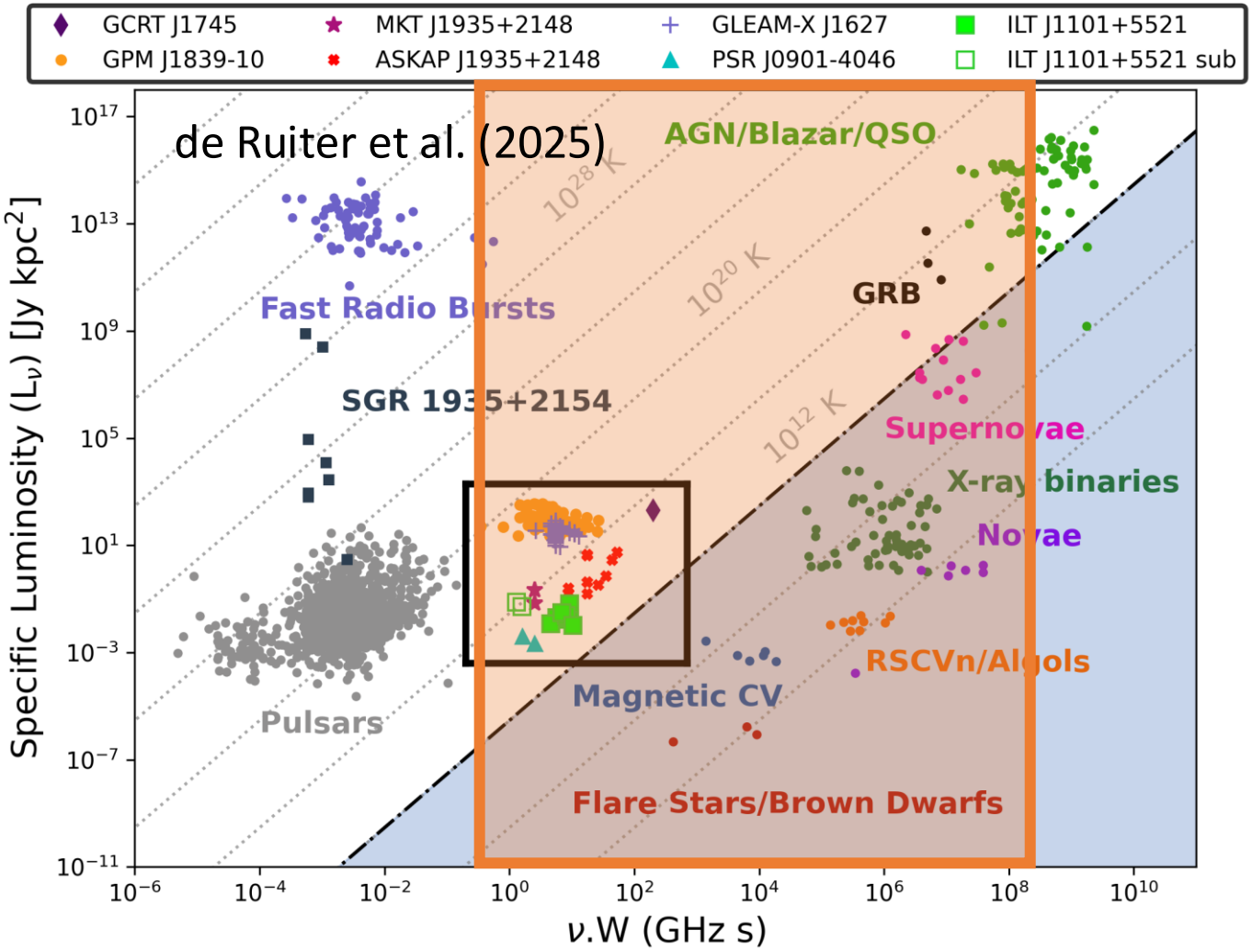
ANTON PANNEKOEK INSTITUTE

UNIVERSITEIT VAN AMSTERDAM

ASTRON
Netherlands Institute for Radio Astronomy

LOFAR

Transient Phase Space



LOFAR imaging transient search phase space

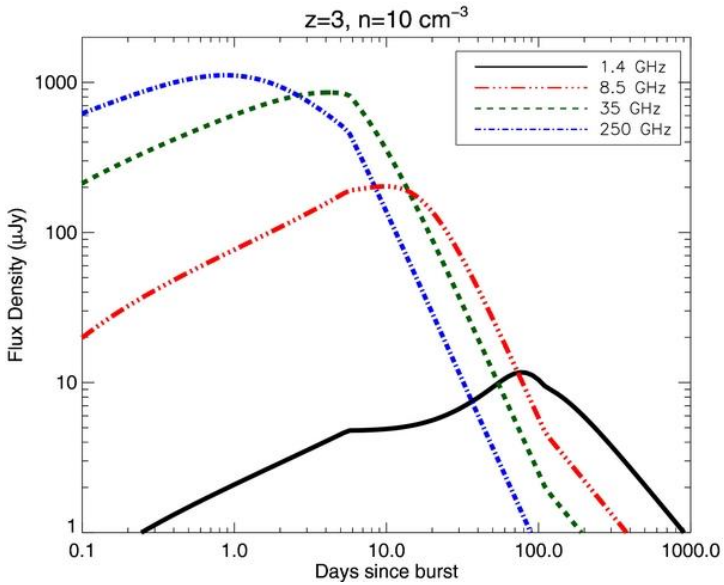
Two Categories of Emission

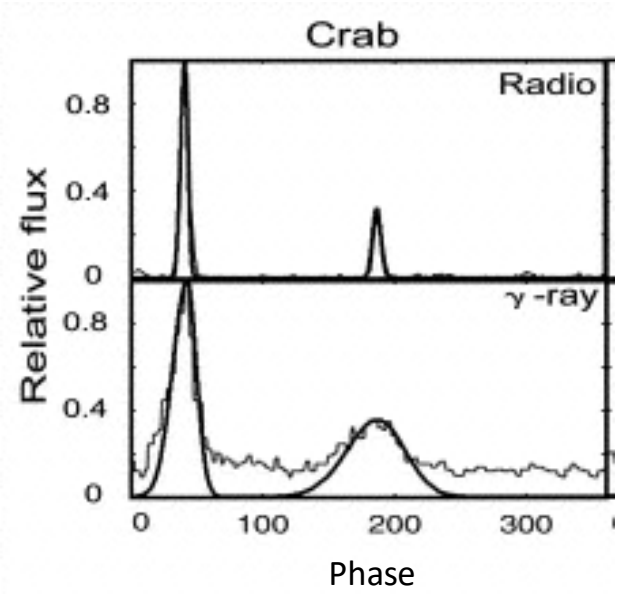
Incoherent

- Synchrotron 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





Transient and variable sources are point sources

Minimum emitting region size

Speed of light

Fastest variability timescale

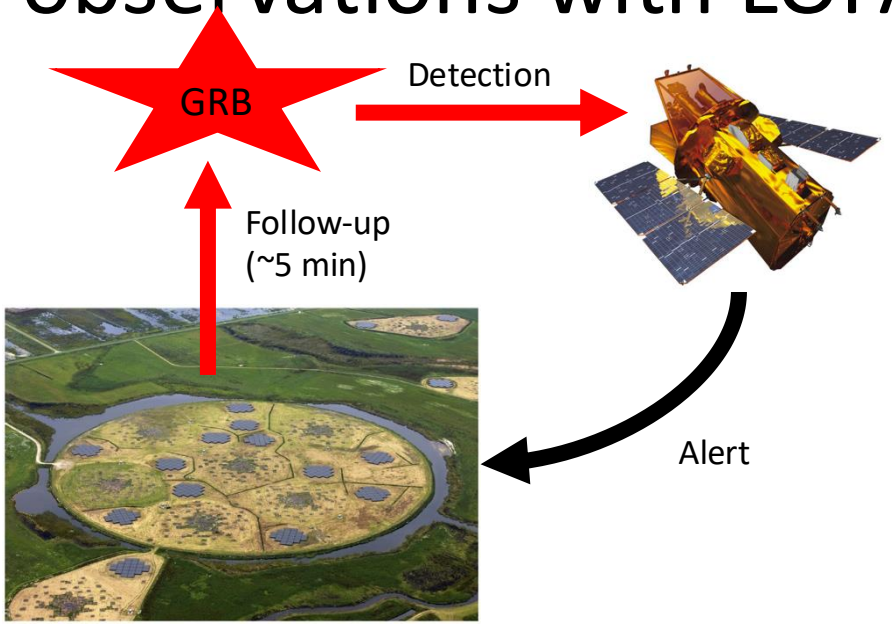
$$R \leq c \cdot \Delta t$$

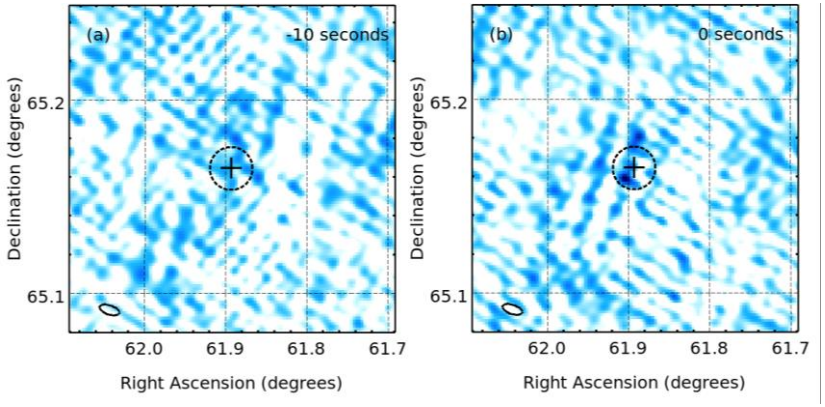
Minimum emitting region size $\ll$ Telescope resolution

(not always with VLBI observations)

LOFAR as a transient follow-up machine

Automatically triggered rapid response observations with LOFAR



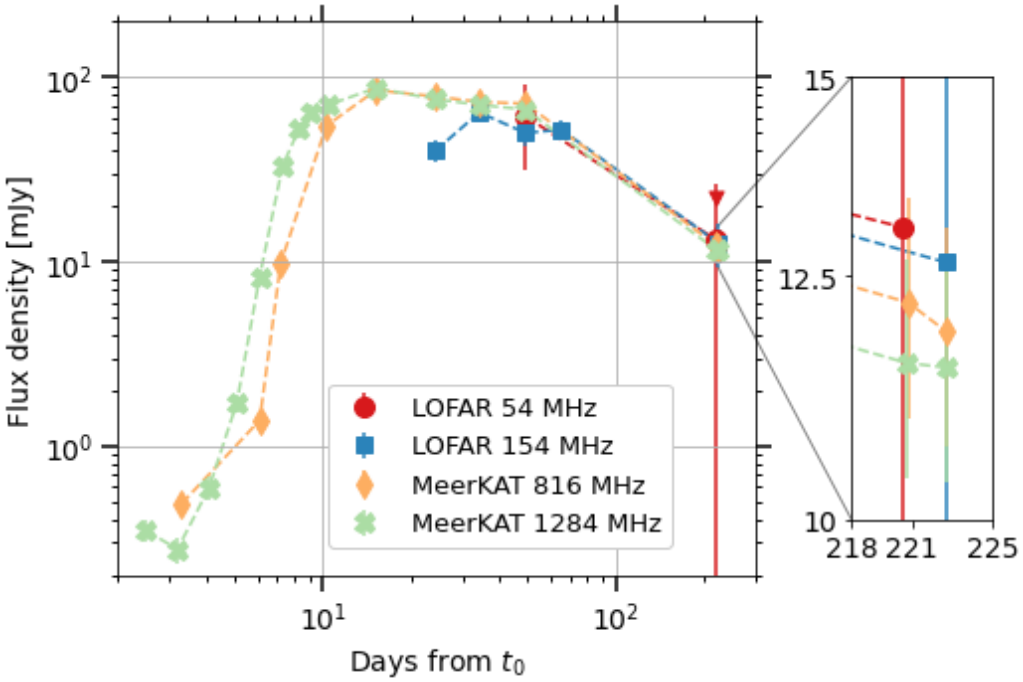


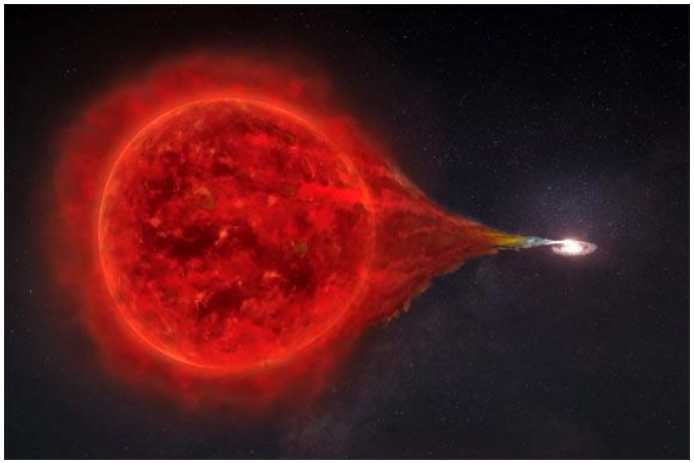
- Automatic rapid response capability available on LOFAR1 from November 2017
- Used to follow-up Gamma-Ray Bursts (GRBs) within 5 minutes of detection by the Niel Gehrels Swift Observatory
- Identified a candidate coherent transient following one GRB

e.g. Rowlinson et al. (2024)

LOFAR DDT imaging follow-up in co-ordination with MeerKAT

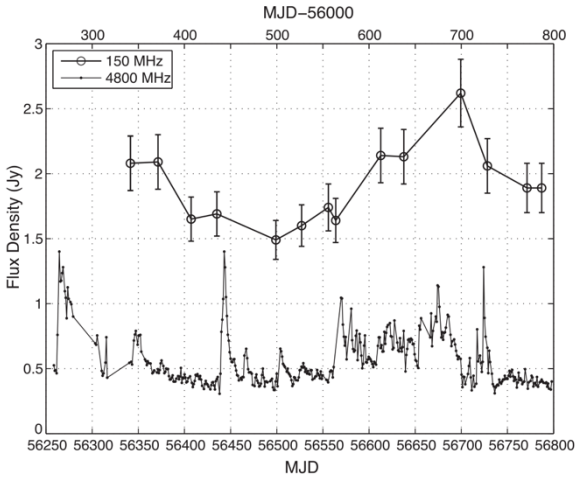
- RS Ophiuchi: a recurrent nova in outburst
- LOFAR1 and MeerKAT worked together to monitor the outburst
- Lowest frequency (54 MHz) detection of a recurrent nova to date
- These observations led to the identification of 2 emission components



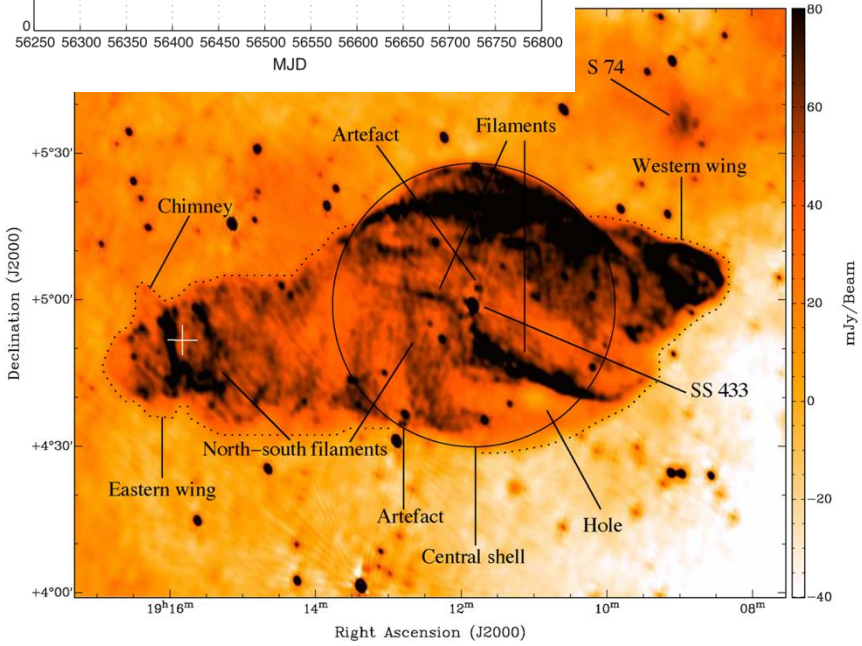


de Ruiter et al. (2023)

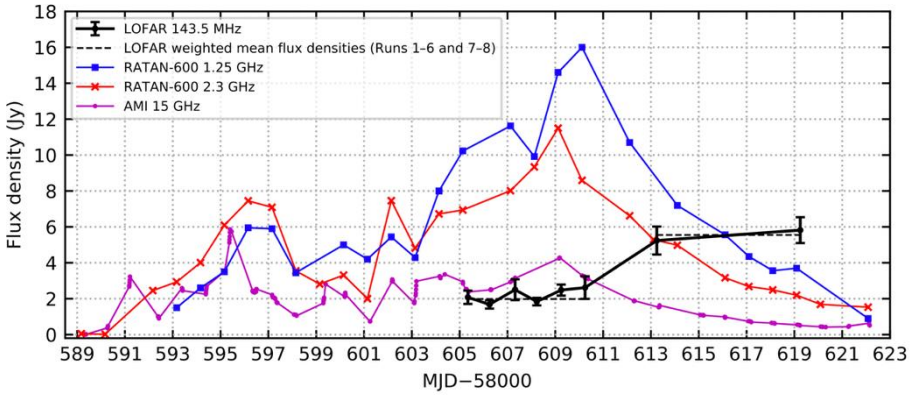
X-ray Binaries



SS433 & W50 with LOFAR
(Broderick et al. 2018)



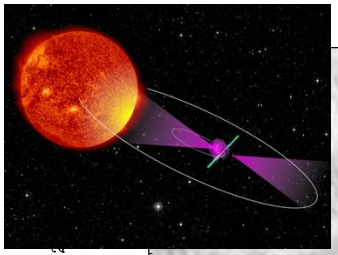
Cygnus X-3 variability
(Broderick et al. 2021)

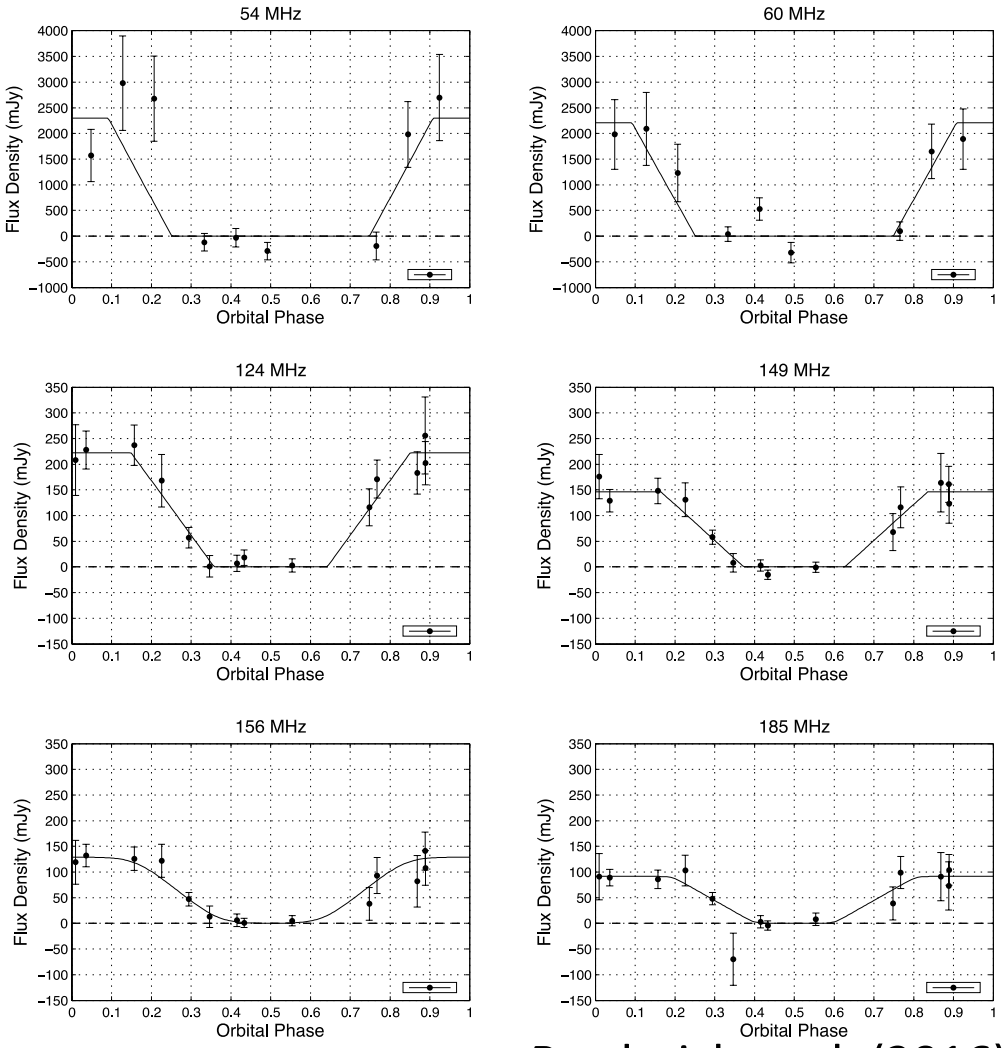


LOFAR as a transient detection machine

Tools and strategies for image plane searches for transient and variable sources

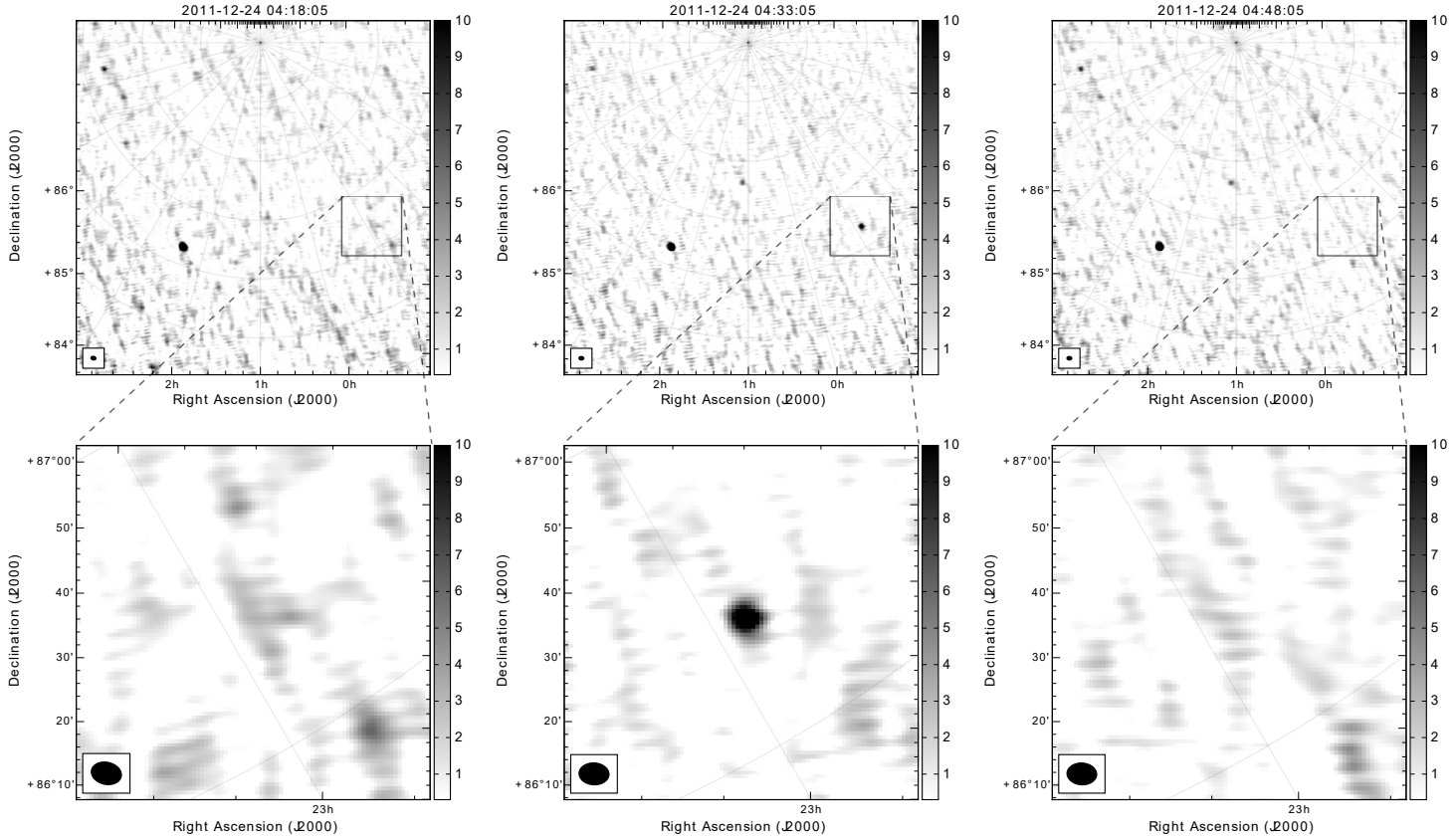
Redback pulsar J2215+5135





Broderick et al. (2016)

The first very low frequency radio transient

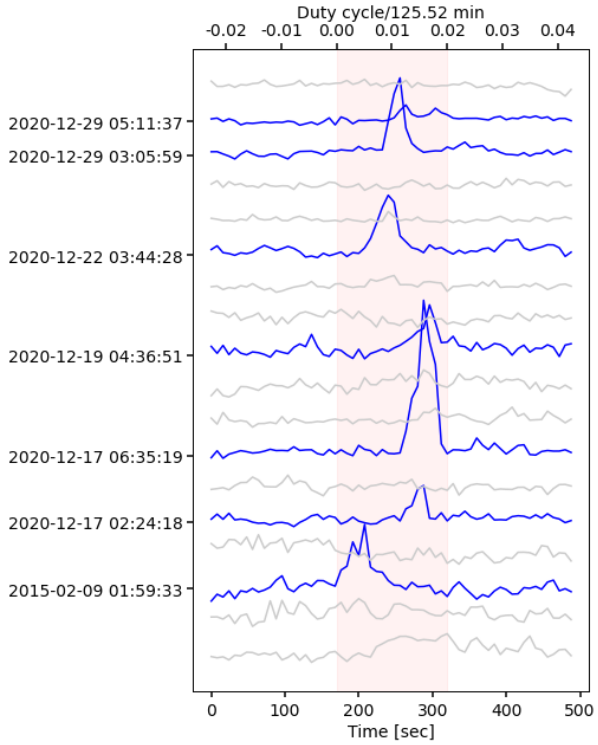


Frequency 57 MHz
Duration ~4 minutes

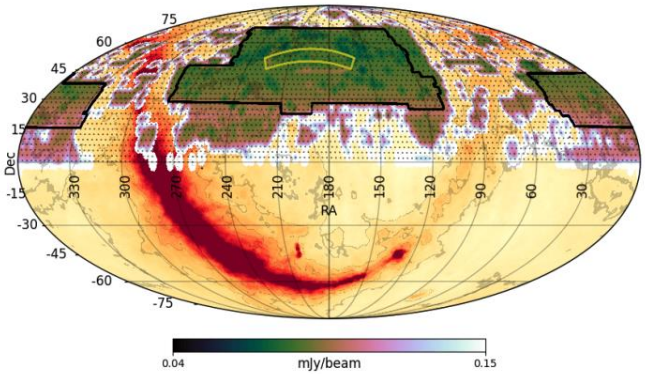
Stewart et al. (2016)

Archival searches: LoTSS

- LoTSS (Shimwell et al. 2019, 2022) provides great dataset for short snapshot transient search and yeilding cool results!



De Ruiter et al. (2024)







Iris de Ruiter
Jason Hessels
Tim Shimwell
Reshma Anna-Thomas
Sylvain Ranguin
Ines Pastor-Marazuela

Transient surface density

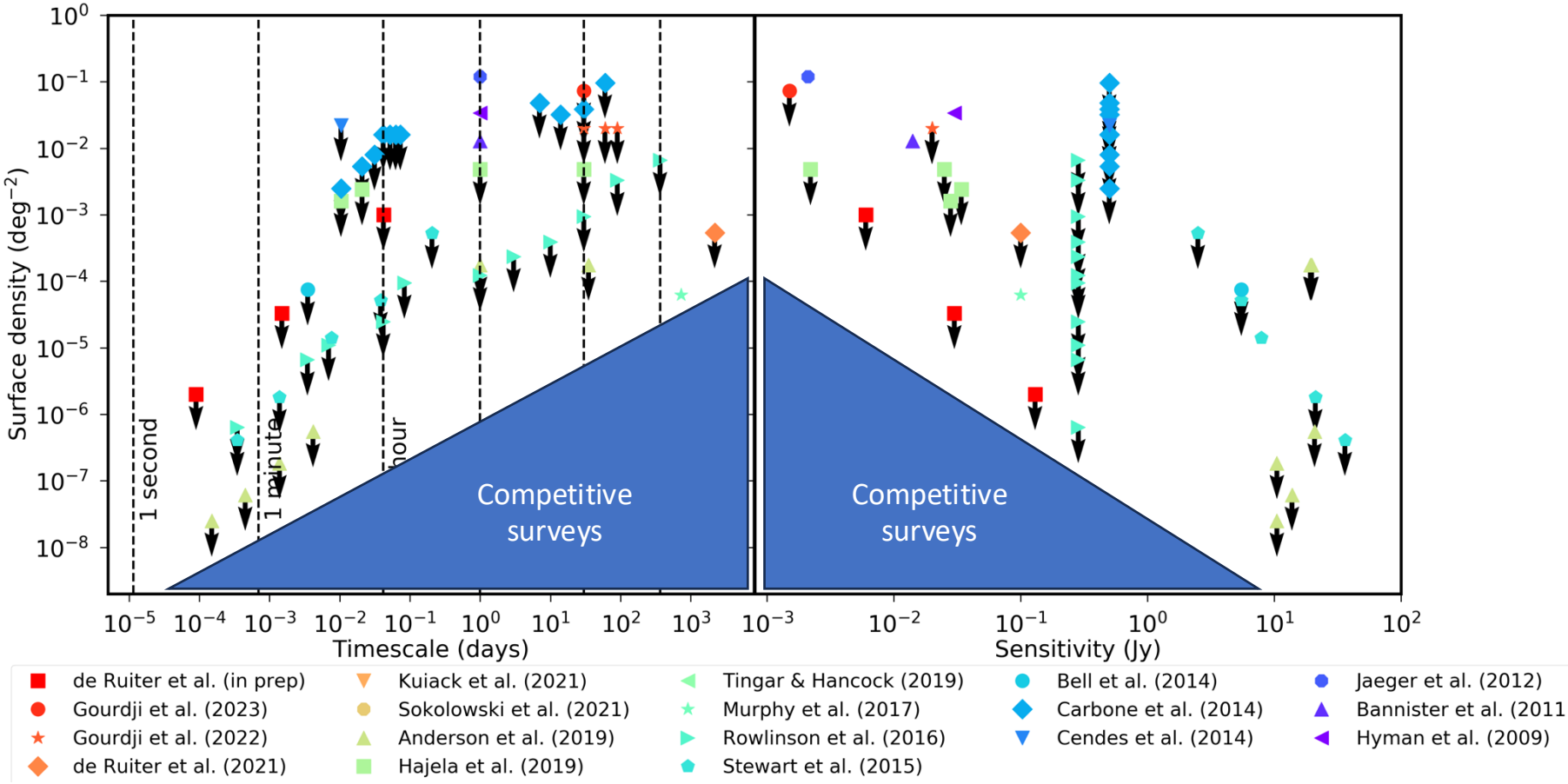
Number of transients per square degree

$$Surface\ density = \frac{Number\ of\ transients}{A\ (N-1)}$$

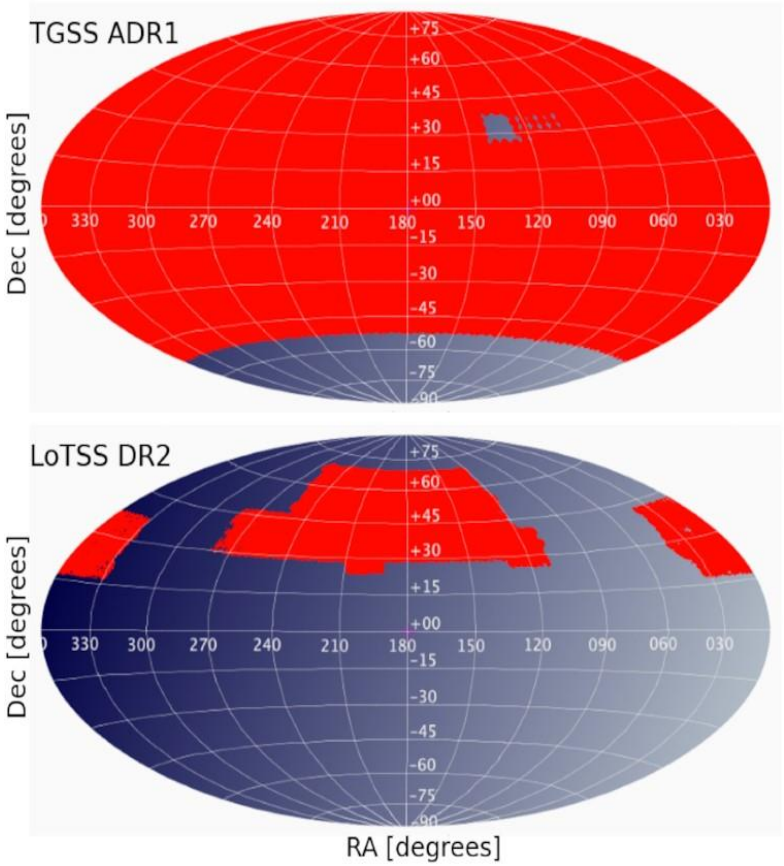
Area of 1 image

Number of images

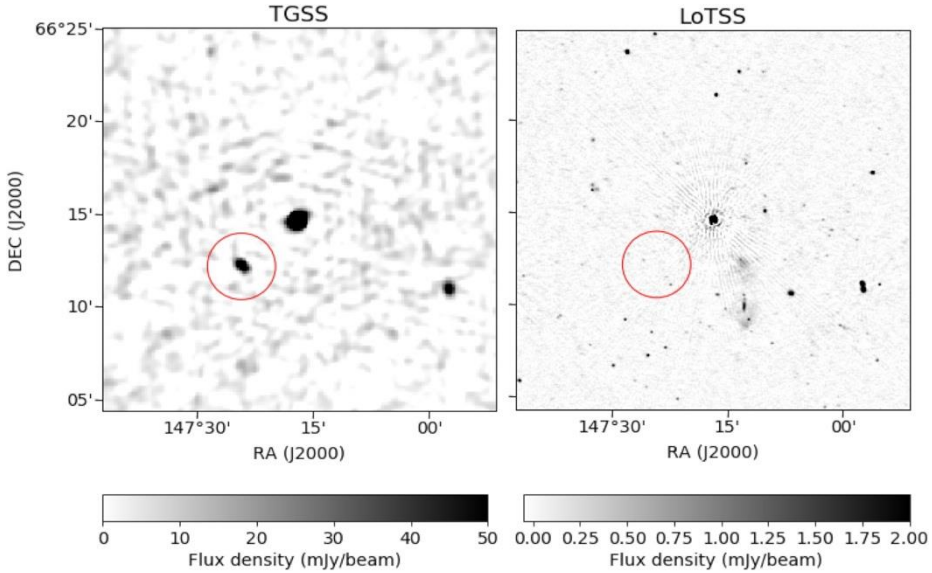
Transients Surveys < 1GHz



Simple transient survey – compare two deep images/catalogues



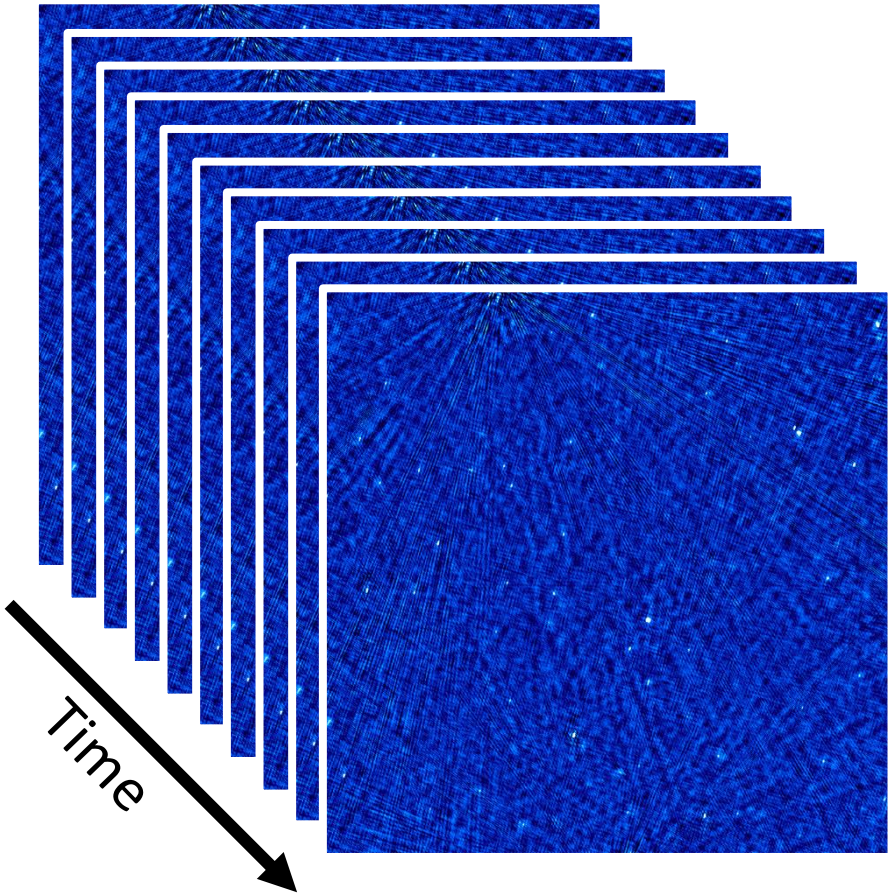
De Ruiter et al. (2021)



- ~ years timescale
- Be wary of imaging artefacts and different array configurations!

Imaging strategies

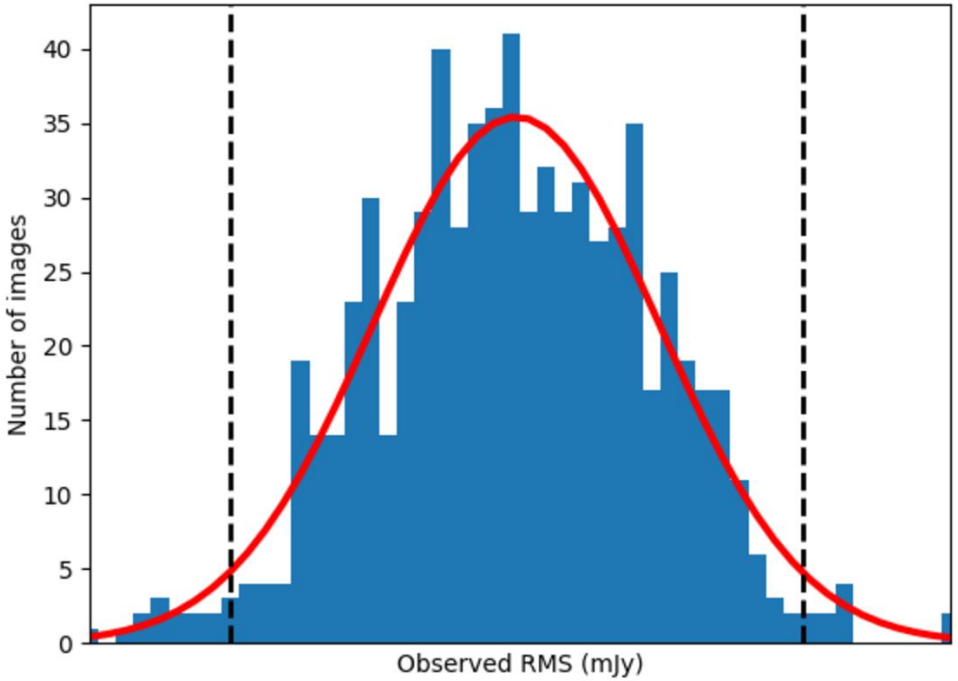
- Snapshot imaging in time and frequency
- Standard options for WSClean
  - -intervals
  - -intervals-out



https://wsclean.readthedocs.io/en/latest/snapshot_imaging.html

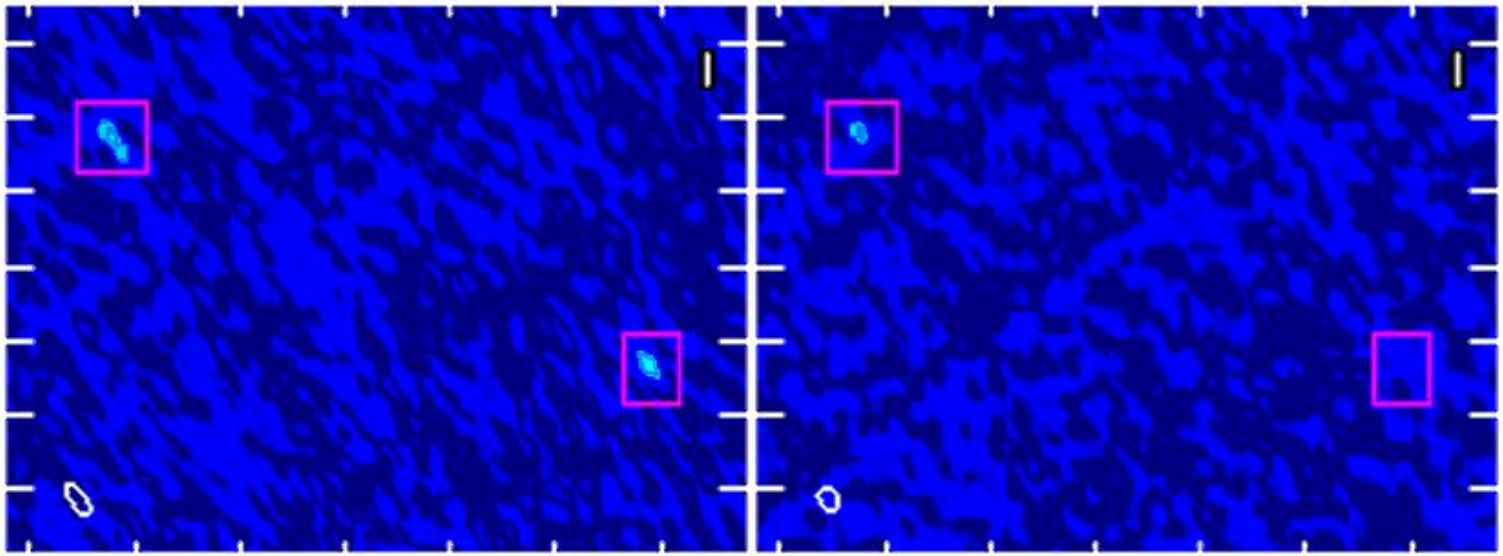
Imaging strategies

- Bad images in → many false positives
- Simple rms noise clipping is effective, throw away any images that are particularly noisy



Transients Pipeline (TraP)

- Simple in concept, challenge is in data volume and processing speed
- Datasets can have more than
  - 1,000 unique sources
  - 10,000 images
  - 100,000 individual source extractions

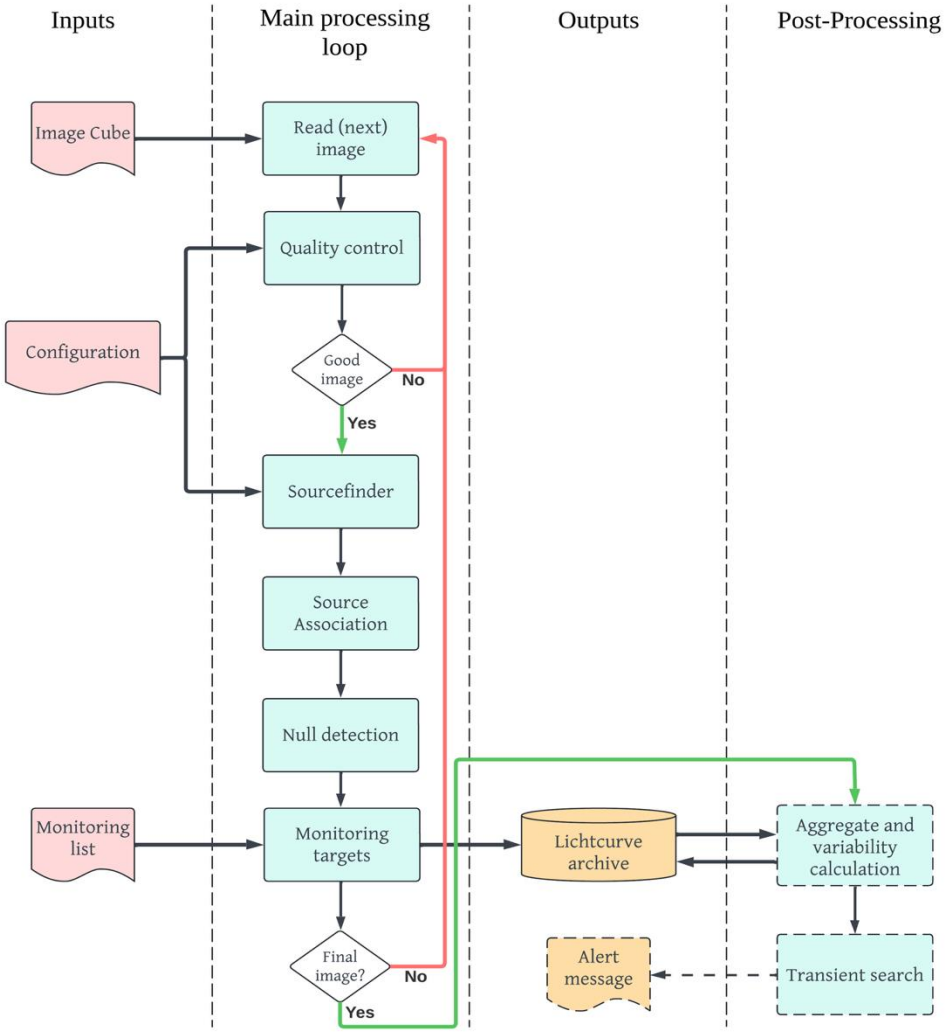


LOFAR2.0: TraP2.0

- TraP2.0 is one of LOFAR2.0 supported pipelines
- Based on original TraP (Swinbank et al. 2015)
- Runs automatically on SDC but can also be used offline
- LINC output image will be automatically ingested by TraP
- Pip installable



Timo Millenaar &
Team Rapthor



https://transients-pipeline.readthedocs.io/en/latest/

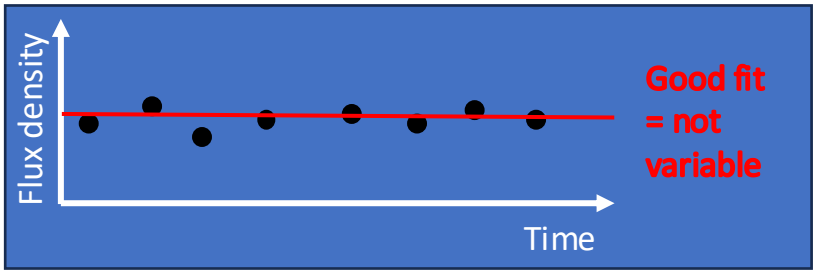
Variability parameters

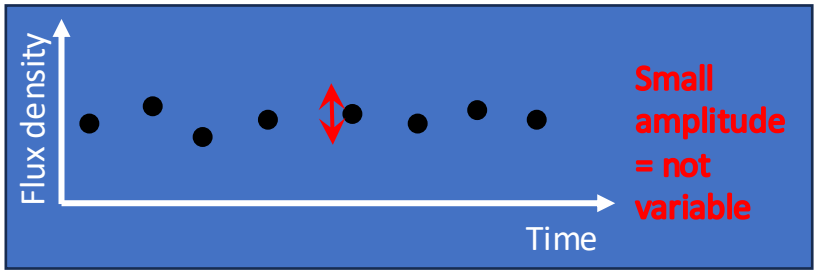
Reduced weighted $\chi 2$

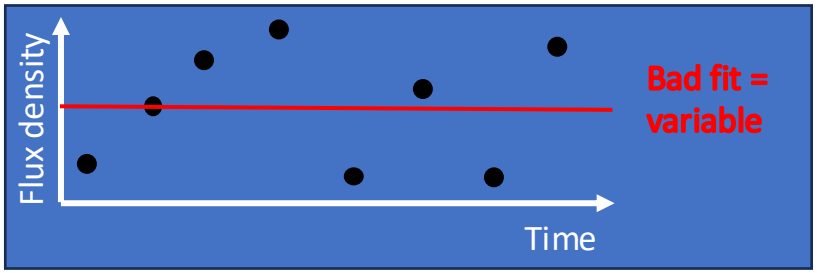
"How well the data fits to a horizontal line"

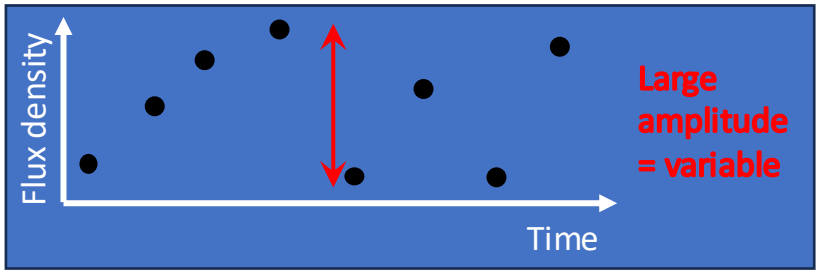
Coefficient of variation

"The amplitude of the change in flux density"









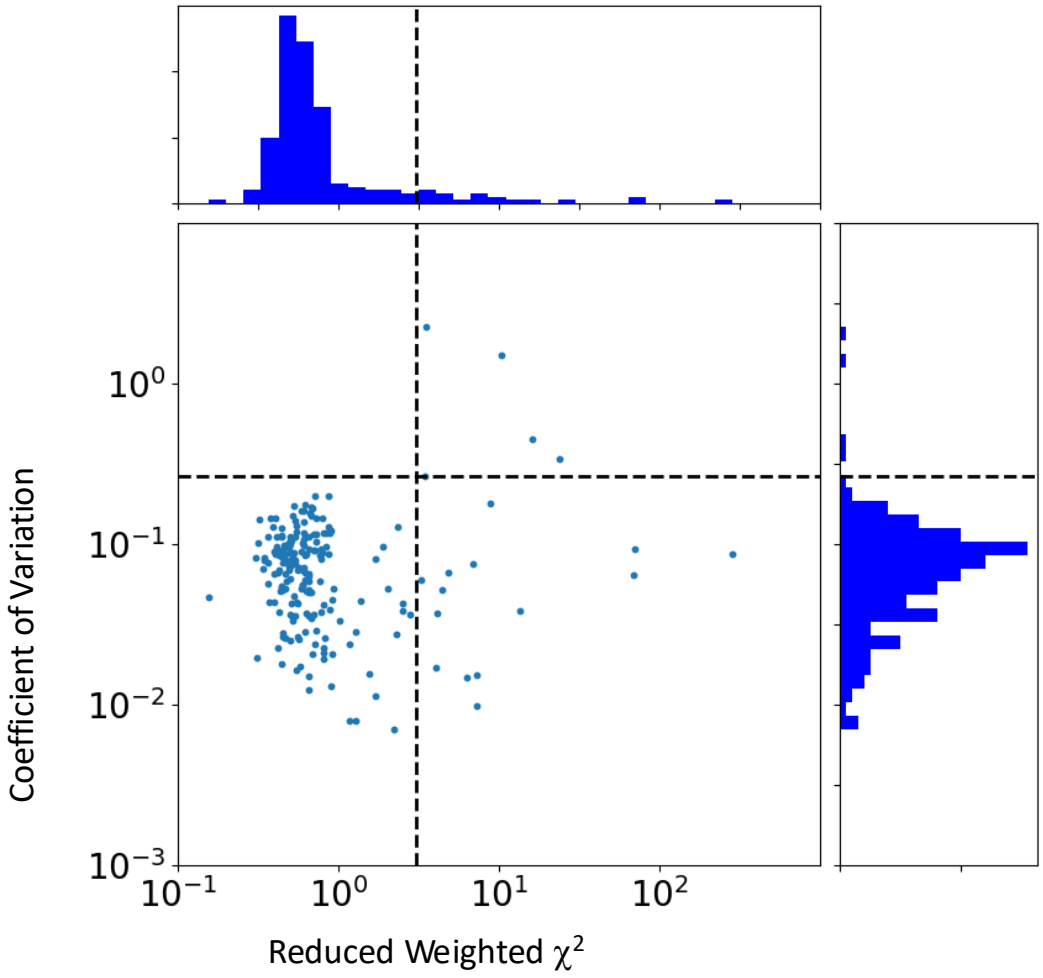
CAVEAT

Extended sources can look variable

Remove extended sources before analysis where possible

Our team is working on strategies for this

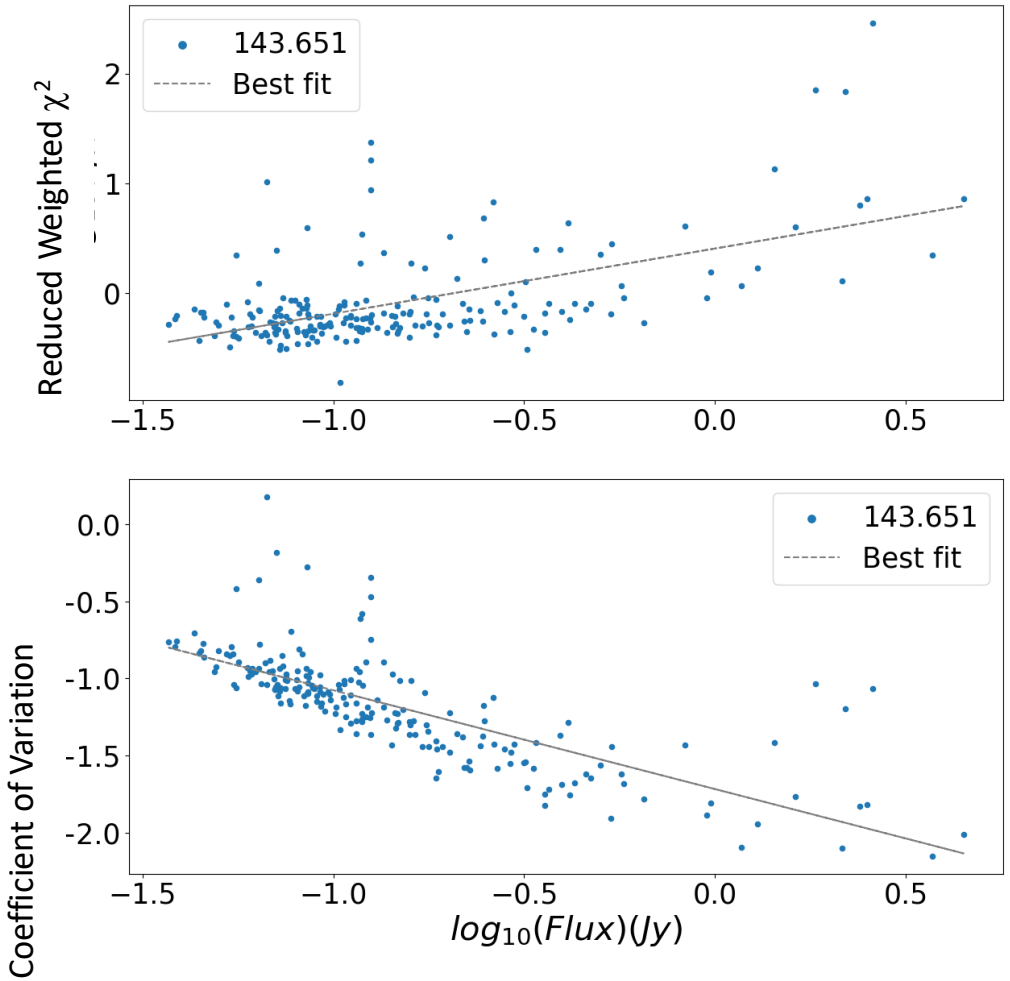
Finding variable sources

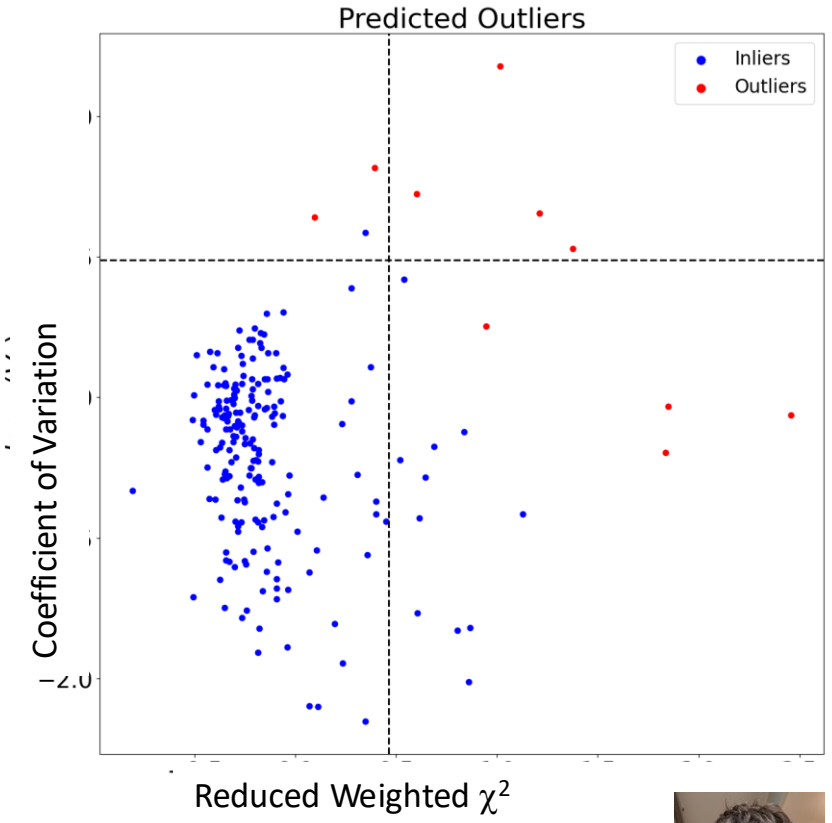


- Light curves are created by the LOFAR Transients Pipeline (TraP)
- Variability parameters are calculated
- Outliers are transient and variable sources
- But… there are systemmatic errors

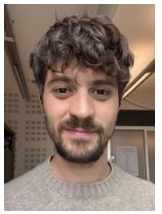
Swinbank et al. (2015)

Developing new search methods

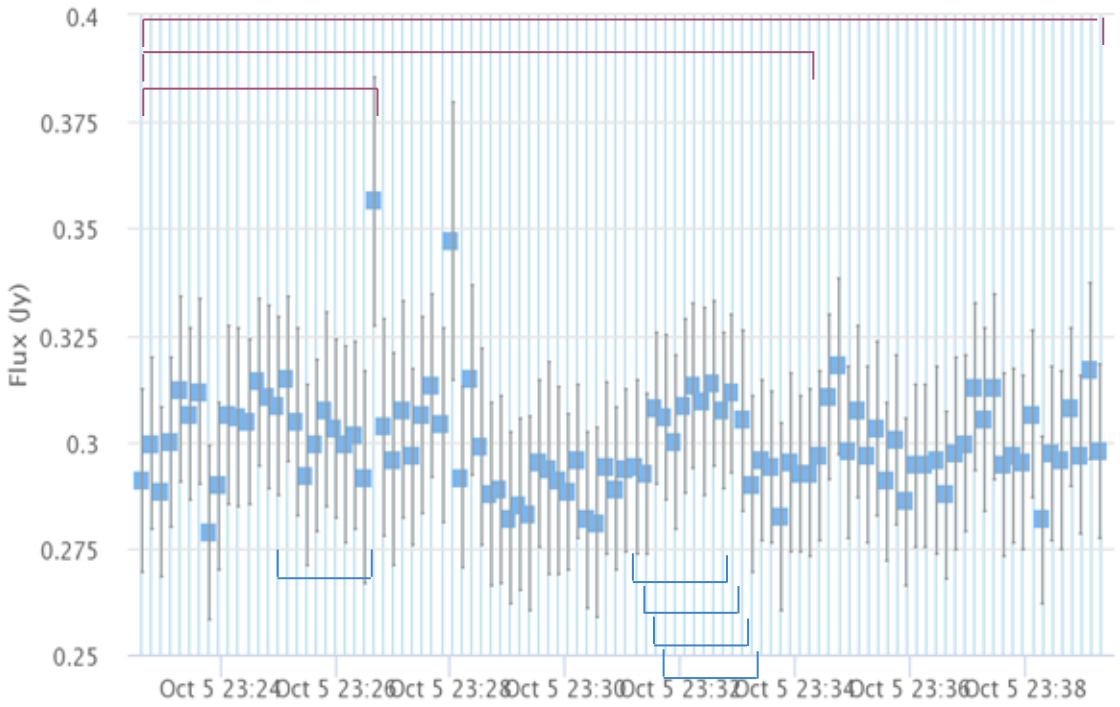




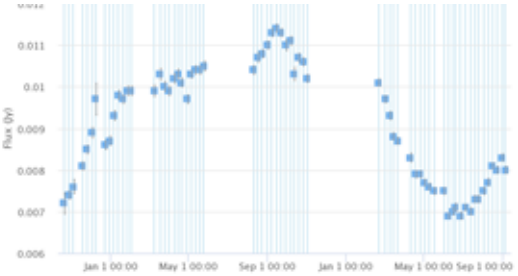
Ruggero Valdata
Valdata et al. (in prep)



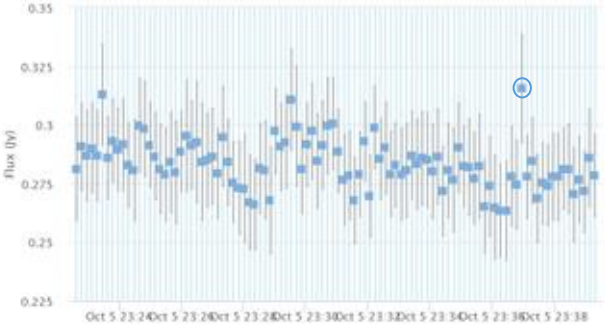
Developing new search methods



Standard variability parameters

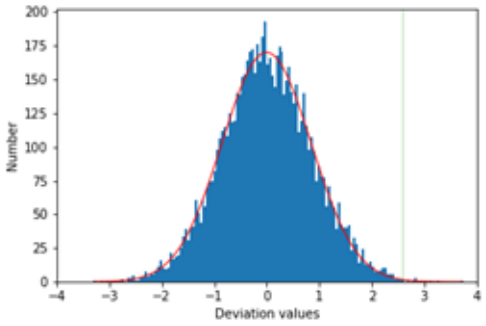


Moving Average



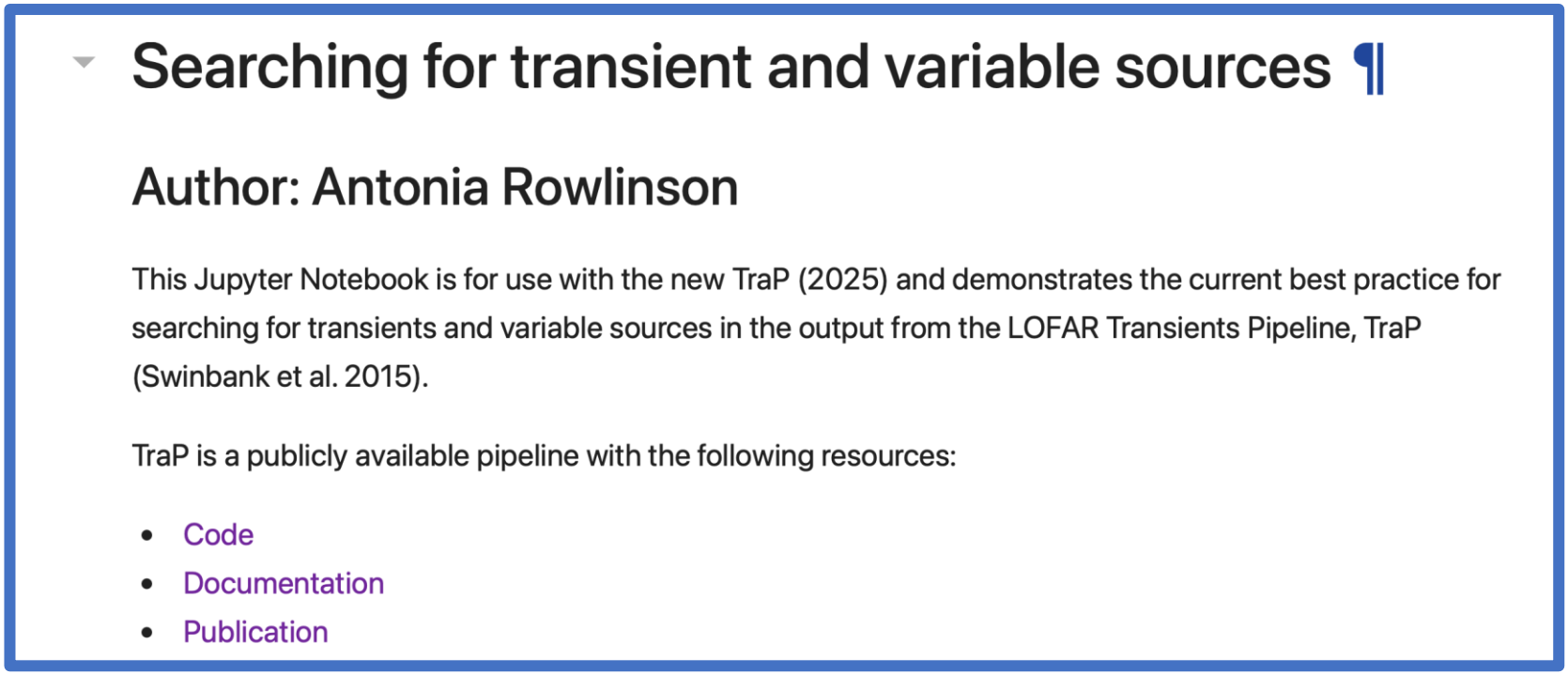
$$MA_i = \sum_{j=1}^{WINDOW_SIZE} \frac{f_{int,[i-j]}}{WINDOW_SIZE}$$

$$\Delta_i = (f_{int,i} - MA_i) \Big/ \sigma_f,$$



Credit: Sander Heimans

TraP Tutorial
Jupyter Notebook



Searching for transient and variable sources ¶

Author: Antonia Rowlinson

This Jupyter Notebook is for use with the new TraP (2025) and demonstrates the current best practice for searching for transients and variable sources in the output from the LOFAR Transients Pipeline, TraP (Swinbank et al. 2015).

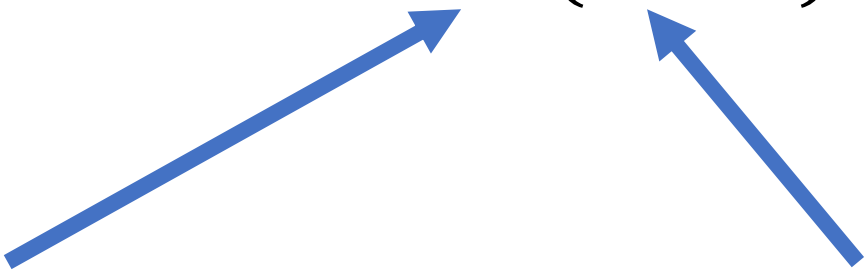
TraP is a publicly available pipeline with the following resources:

- Code
- Documentation
- Publication

- https://github.com/AntoniaR/TraP_filter_demo

Getting more transients or deeper constraints…

$$Surface\ density = \frac{Number\ of\ transients}{A\ (N-1)}$$

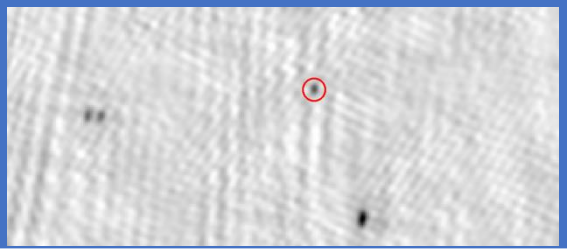
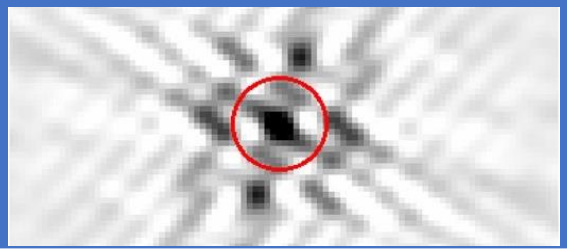


Bigger field of view
e.g. AARTFAAC

Many more images
e.g. larger datasets

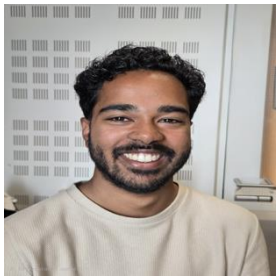
Both ways to get deeper transient surveys have their challenges

Faster snapshot imaging

Standard Imaging	Subtraction Imaging
	
Images contain sources	Sources are subtracted from the visibilities before imaging
Cleaned and primary beam correction	No cleaning and no primary beam correction
e.g. Rowlinson et al. (2016)	e.g. de Ruiter et al. (2024)
1 LoTSS field takes 500 hours DR1 has 58 fields → entire NL PhD contract	15 hours per field

LATTES

LOFAR Archival Transient Trapping and Extraction Suite



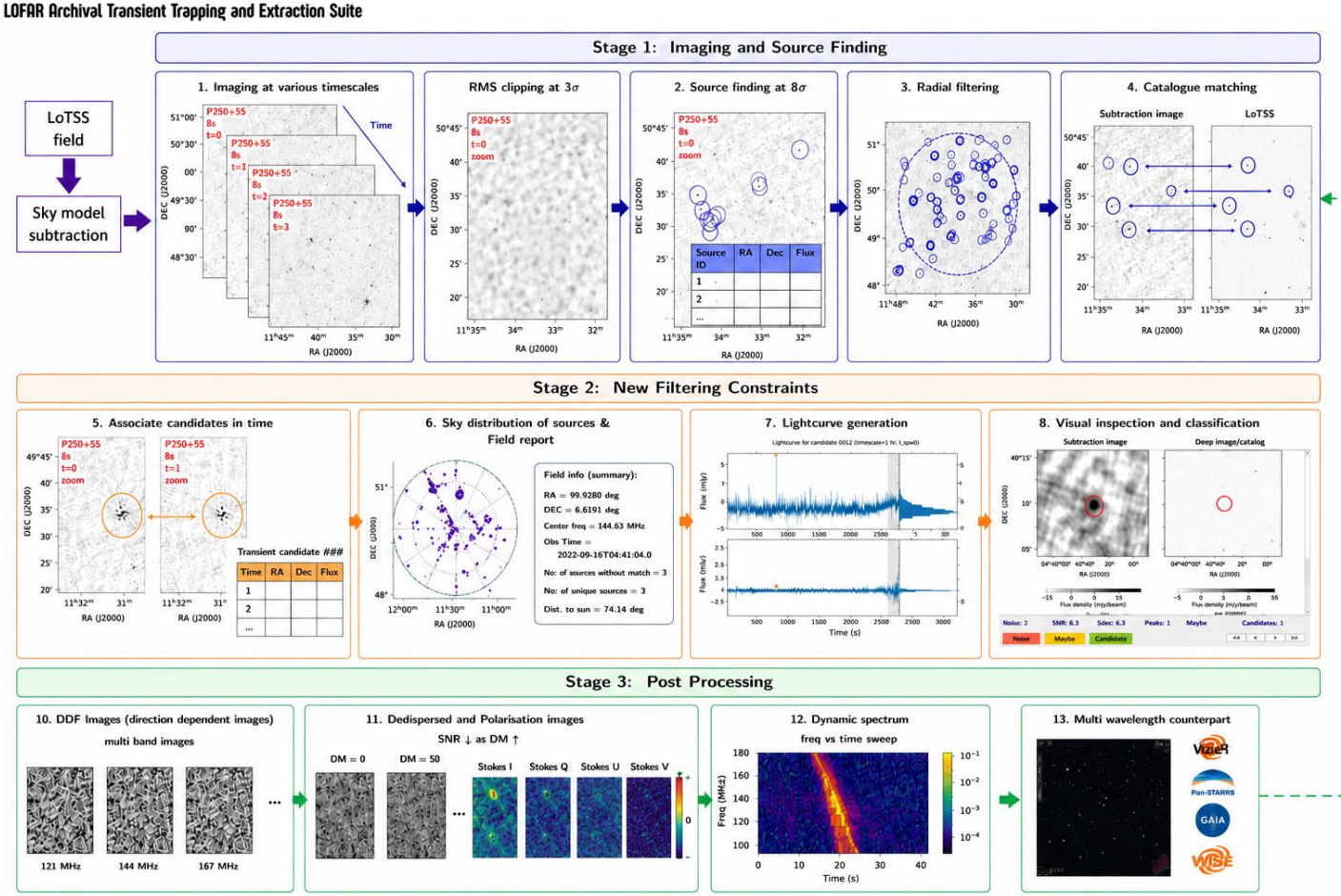
Sylvain Ranguin



Reshma Anna-Thomas



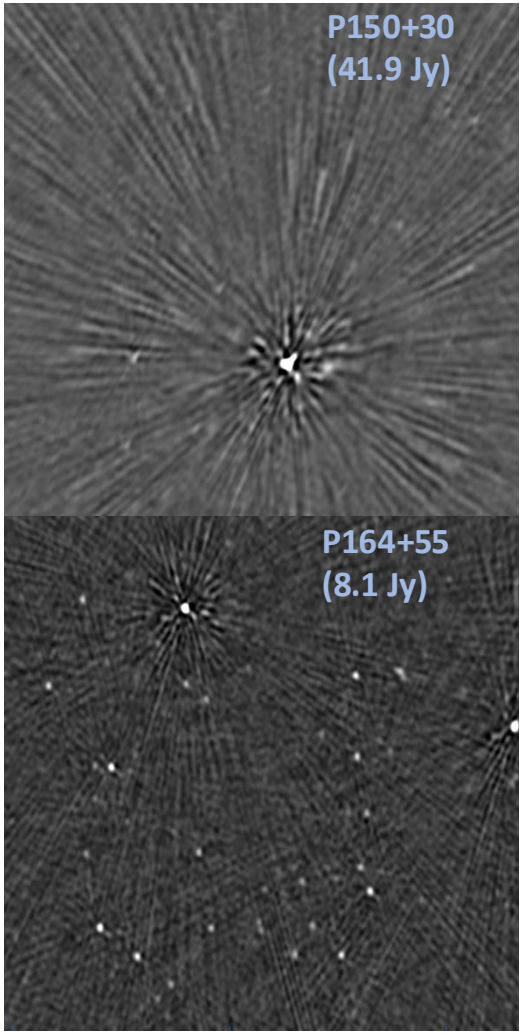
Inés Pastor-Marazuela



Based on de Ruiter et al. (2024)

Ranguin et al. (in prep)

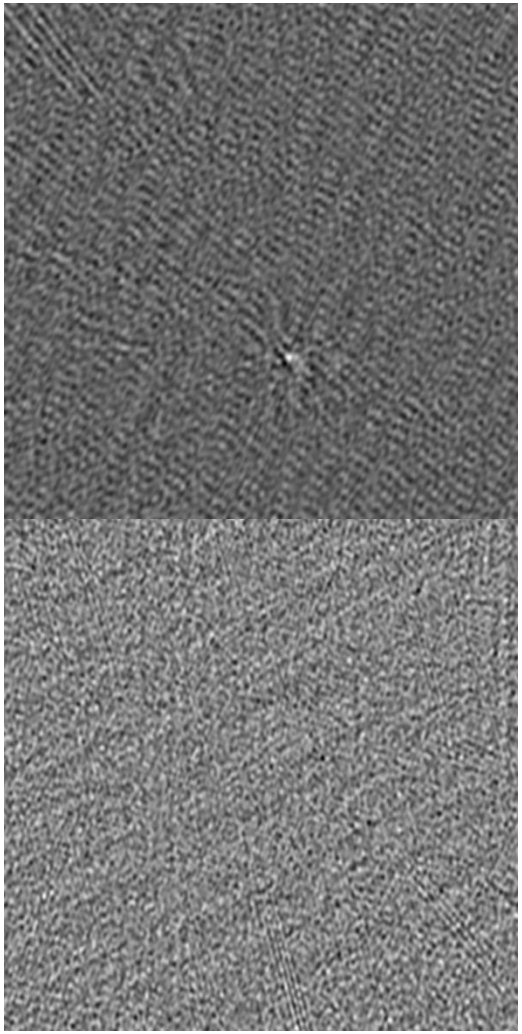
LOFAR2.0: Even faster imaging



Trialled with LoTSS data

8 second images with **no** Calibration

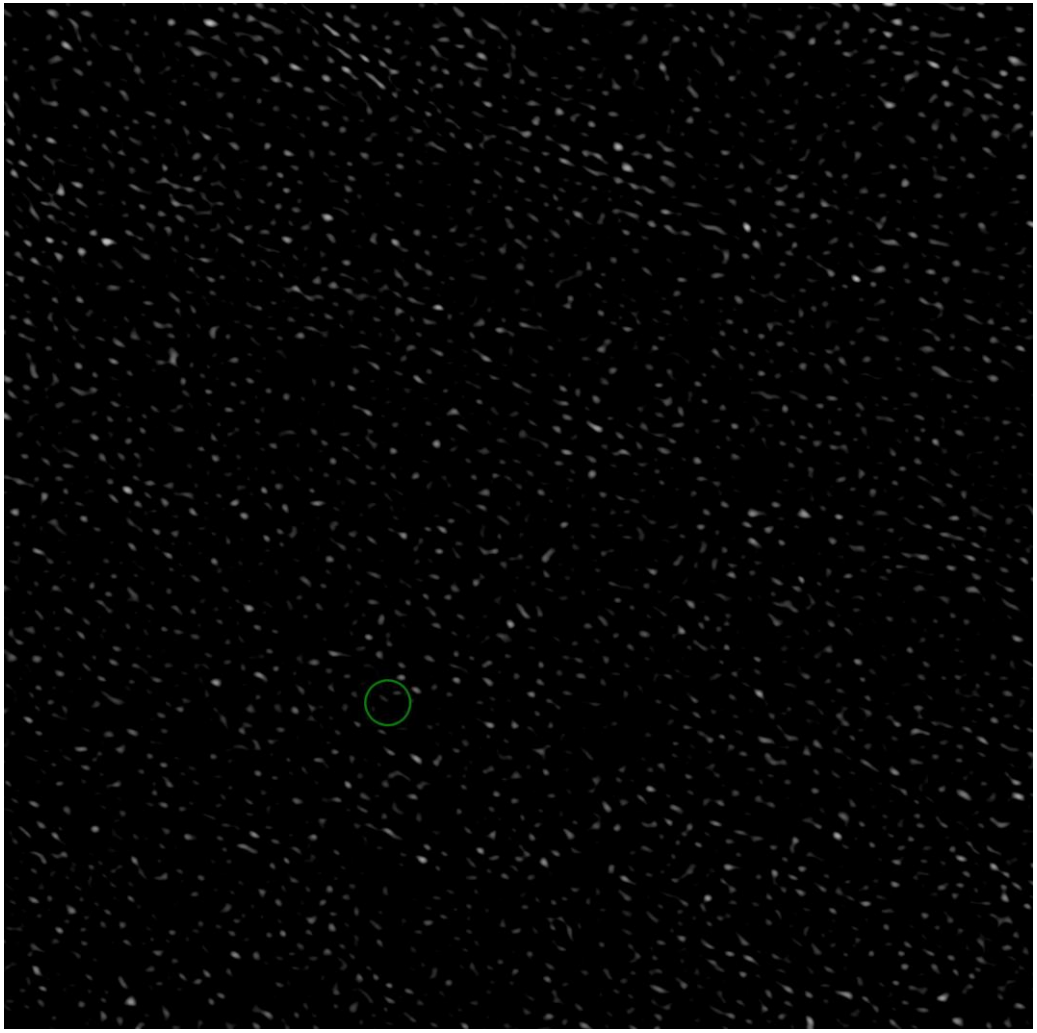
Subtract consecutive images





Lars Zwaan
Jason Hessels

LOFAR2.0: Even faster imaging



Goal:

- Run in real time on LOFAR2.0 data
- Run on EuroFlash cluster
  (PI: Jason Hessels)



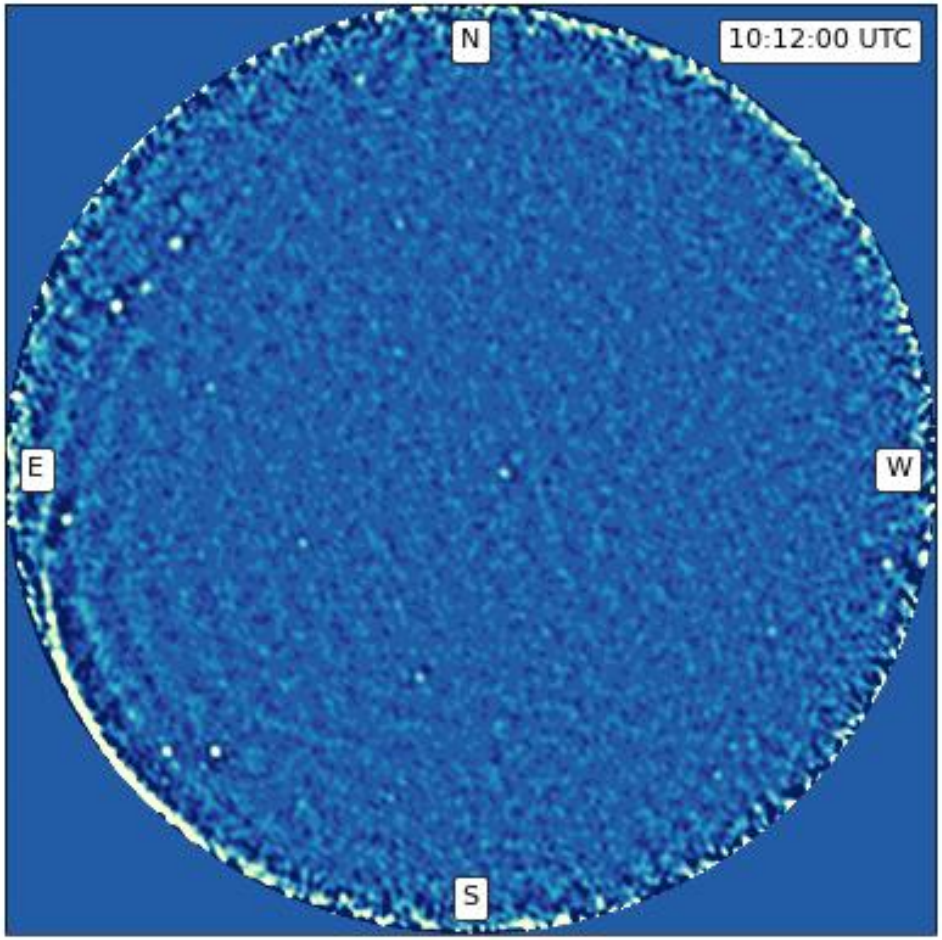
First time low frequency radio transients will be detected in real time!



Zwaan et al. (in prep)

Increasing the field of view





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



PI: Ralph Wijers

Credit: Mark Kuiack

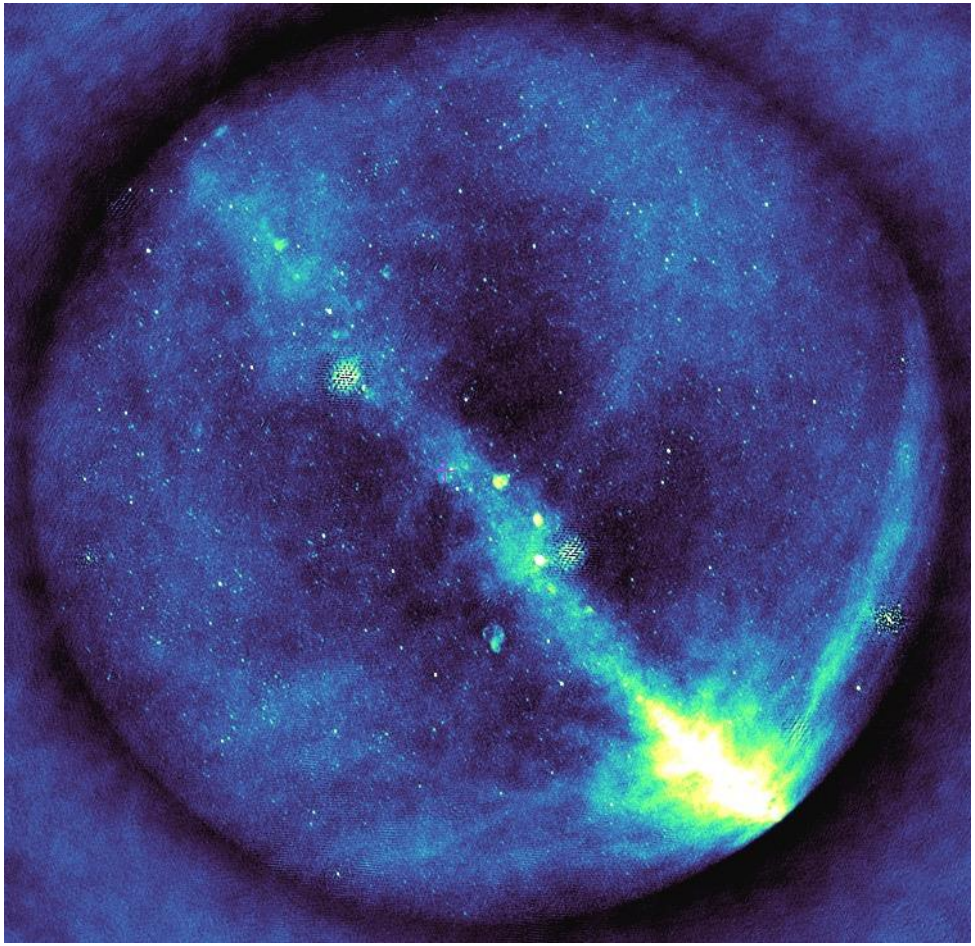
AARTFAAC2.0: Design

Funded by the European Union
European Research Council
Established by the European Commission

- 30 MHz bandwidth
- 1 Jy confusion limit
- ~30’ resolution
- 12 stations
- Operational whenever LOFAR2.0 is turned on
- 12 hour buffer to save visibilities (200+ TB)



Thanks to:
Arno Schoenmakers and many others at ASTRON



Credit: Aleksander Shulevski

Online mid 2027!

Automated Searches with LOFAR2.0



Publicly available on LOFAR Science Data Centre

Direction independent calibration

Cleaned deep image

Subtract sky model from visibilities

Light curve database

Transients Pipeline (TraP)

8 second subtraction images

Summary

- LOFAR is a powerful transients machine
- Follow-up of multi-messenger transients via standard proposals/DDTs and analyse as needed
- Rapid response mode available
- Transient surveys used to find new transient and variable sources:
  - Design survey to match your target transient population and/or target unexplored regions
  - Imaging strategy important (standard versus subtraction) as often compute and/or storage limited
  - Pipelines exist to find sources in the images
  - Range of techniques to analyse the source possible following detection
  - Light curve database will be available from LOFAR2.0

Any Questions?