The LOFAR Transients Key Science Project: status and updates on image plane transients

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Jess Broderick[2], Benito Marcote[3], Antonia Rowlinson[4],
Tim Staley[2], Adam Stewart[2], Sara Turriziani[5]
and the LOFAR Transients Key Science Project

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LOFAR is detecting image-plane transient and variable sources

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Outline

- Methods to detect image-plane transients and to calculate transient surface density

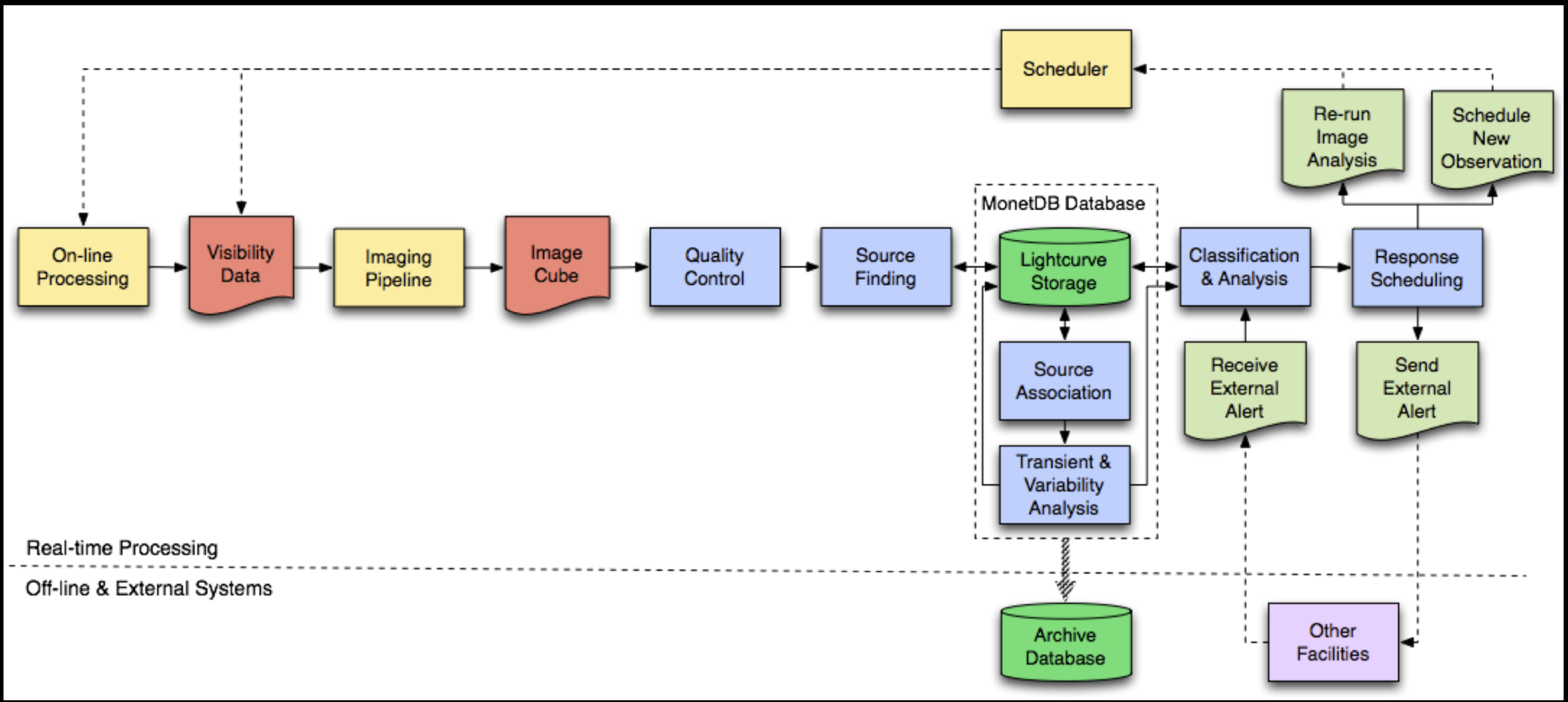
- Examples of detections of image-plane transient and variable sources

Transient Pipeline

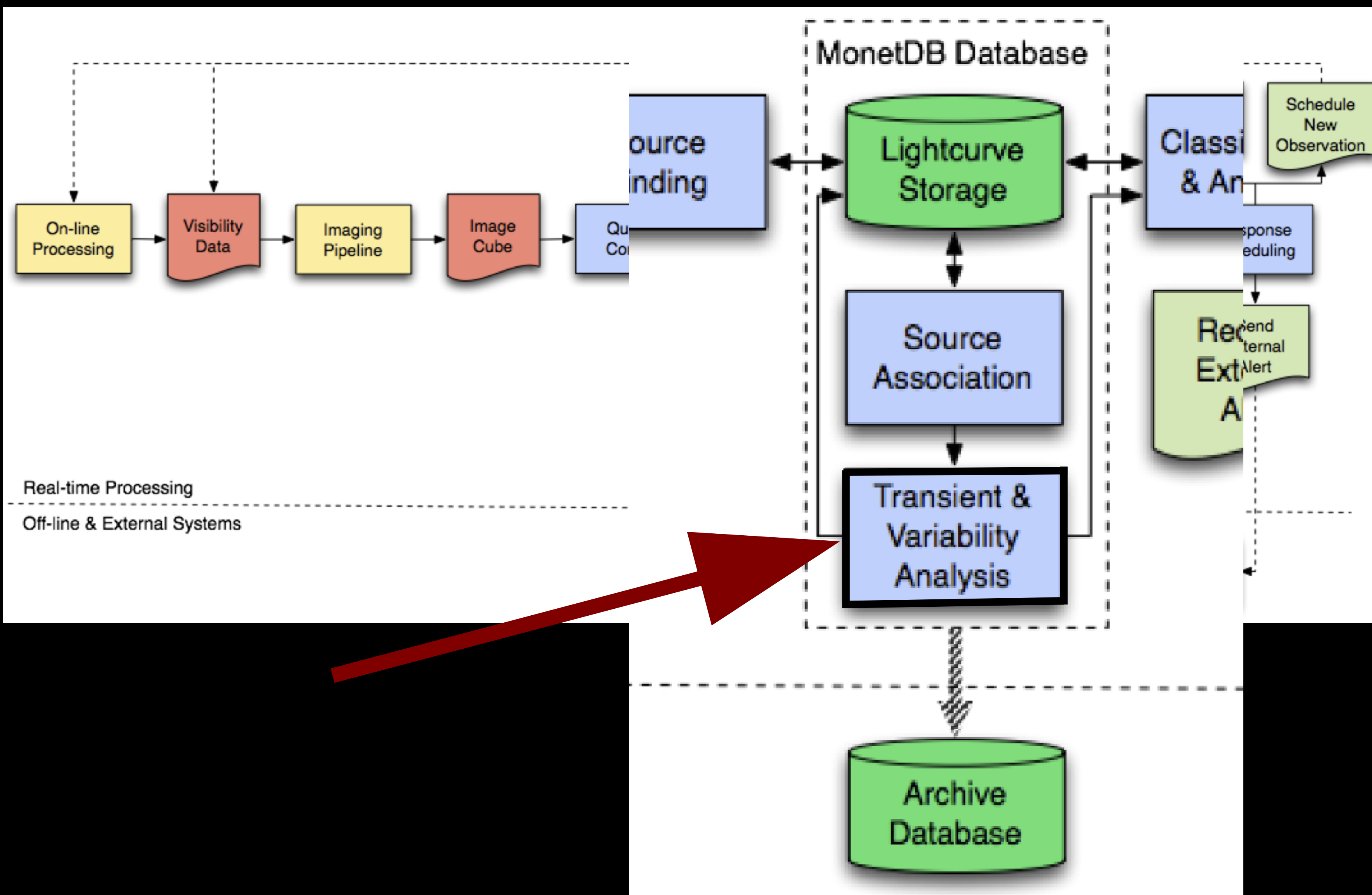
- Provides lightcurves catalogue, list of transients and variable sources for radio image stack in near real-time.
- Images can be multiple overlapping pointing, different wavebands, different integration times, etc.
- Web-based analysis interface (banana).

- Paper published (Swinbank et al., 2015)
- Open-source! (available on github)
- Used by multiple radio facilities.

Transient Pipeline



Transient Pipeline



Variability parameters

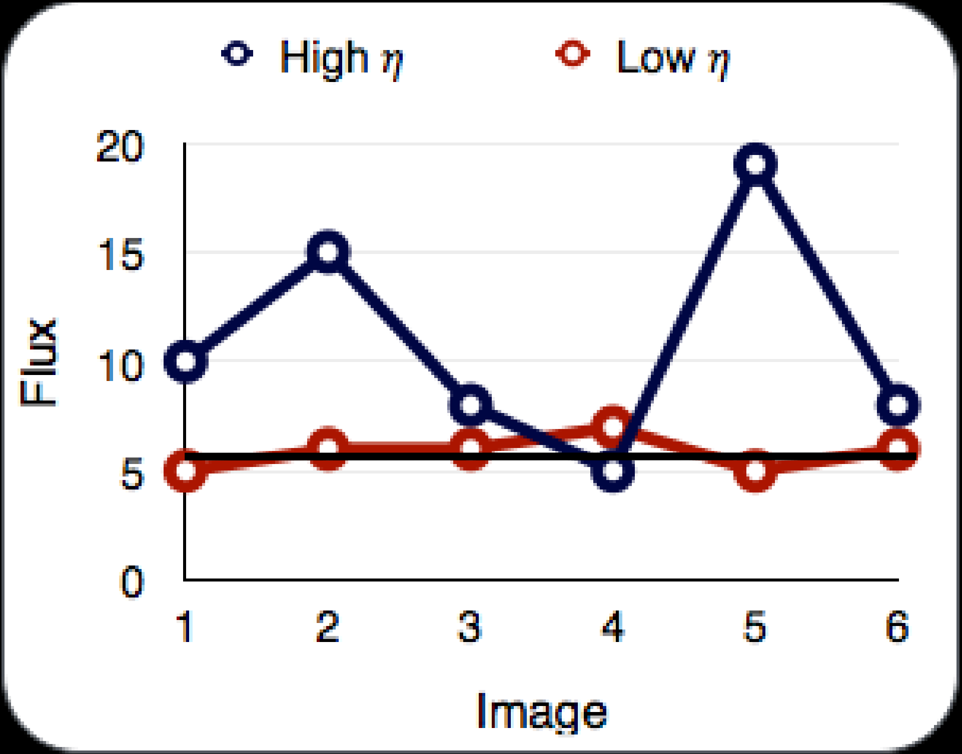
Weighted χ^2 of a fit to a constant flux:

$$\eta_\nu = \frac{N}{N-1}\left(\overline{\omega I^2} - \frac{\overline{\omega I}^2}{\overline{\omega}}\right)$$

S = Unbiased standard deviation
I = Integrated flux
N = Number of datapoints
$\omega = \frac{1}{e^2} = \frac{1}{(\text{Flux error})^2}$

Variability index:

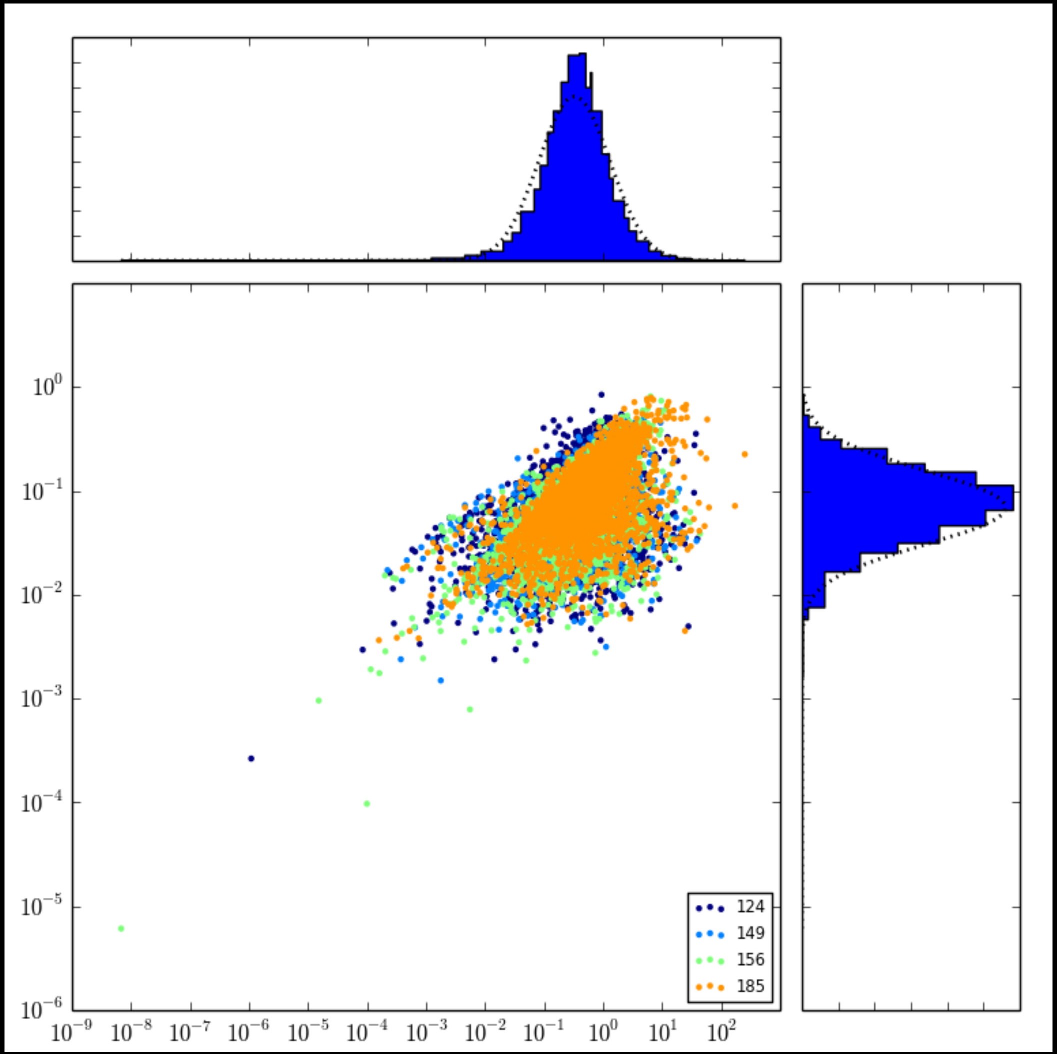
$$V_\nu = \left(\frac{S}{\overline{I}}\right)$$



Radio Sky Monitor sources - constant

- Radio Sky Monitor Sources
- Gaussian distributions

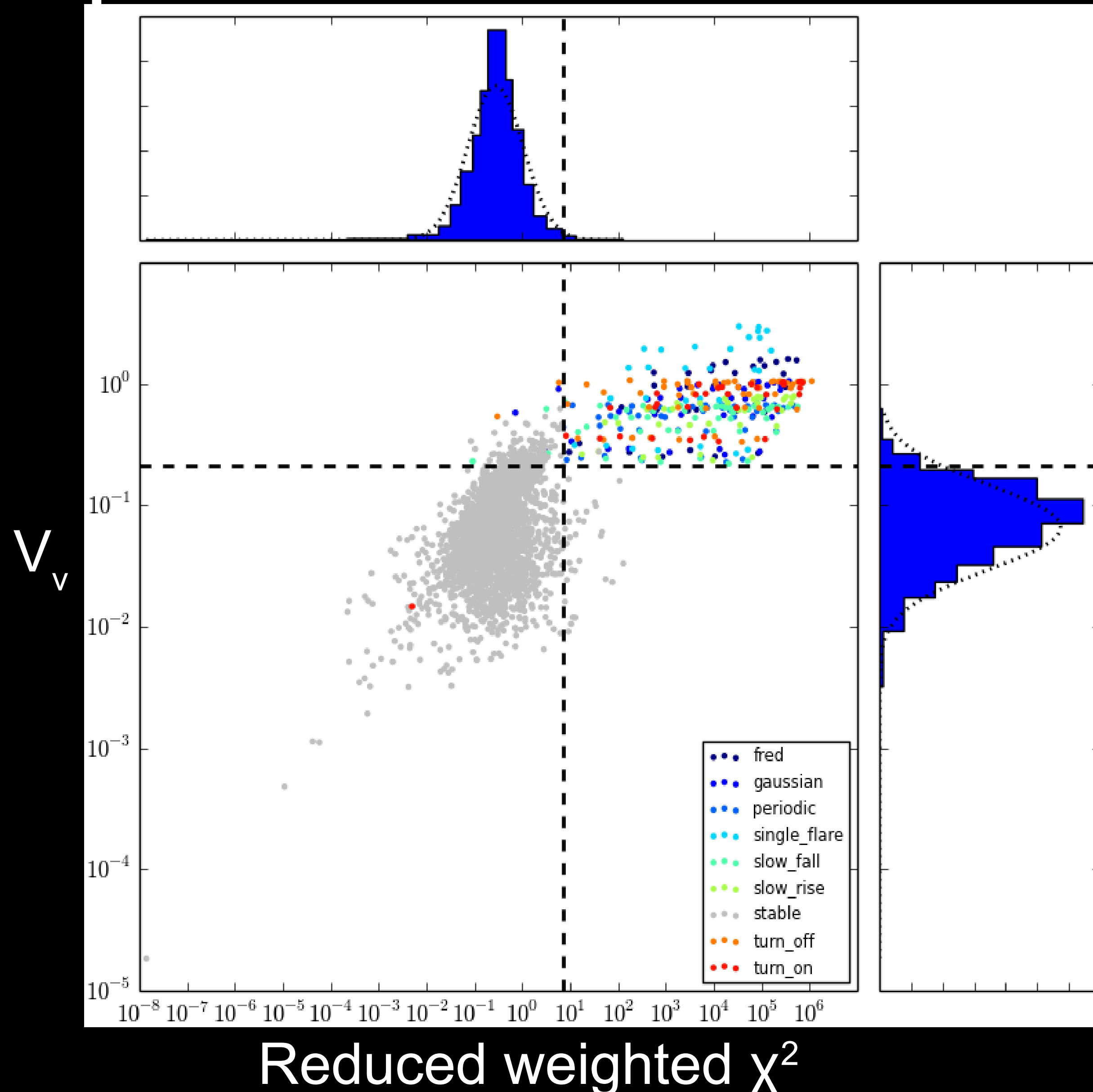
V_ν



Reduced weighted χ^2

How do transients behave in this space?

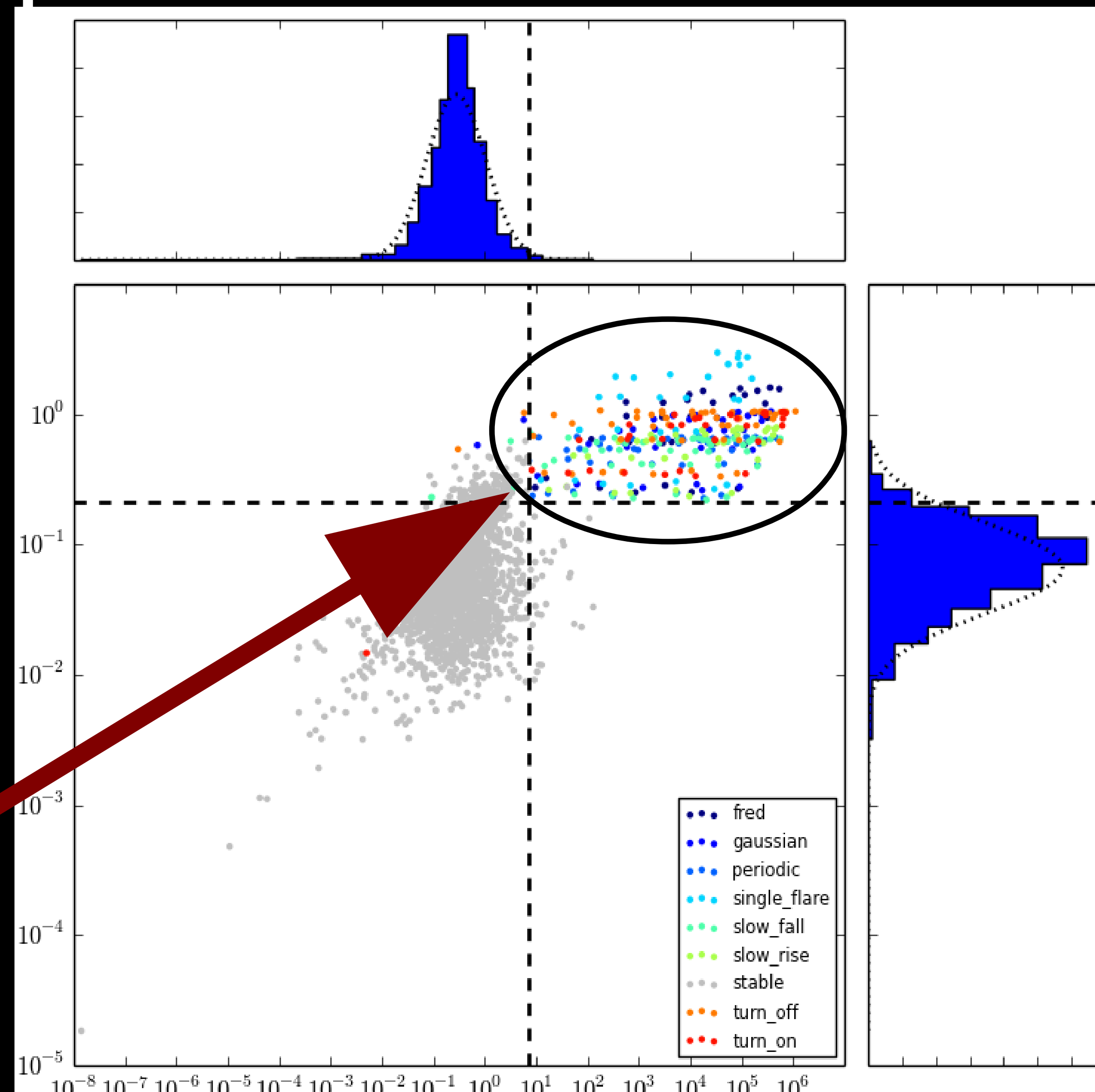
- 440 transient and variable sources with different lightcurve shapes and fluxes
- 55 different combinations of max flux and quiescent flux for each type of transient source



How do transients behave in this space?

- 440 transient and variable sources with different lightcurve shapes and fluxes
- 55 different combinations of max flux and quiescent flux for each type of transient source
- **Separated by straight lines**

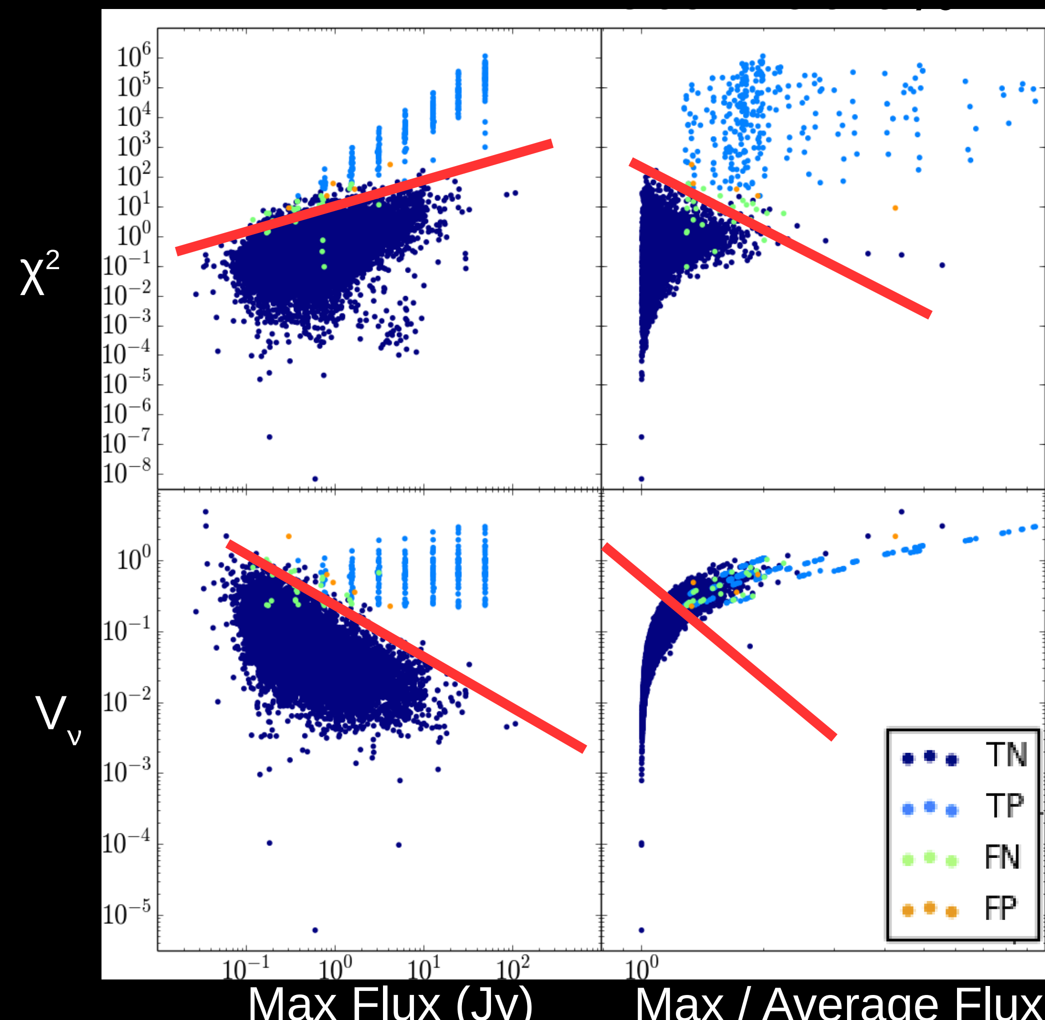
V_v



Reduced weighted χ^2

4D space: more accurate

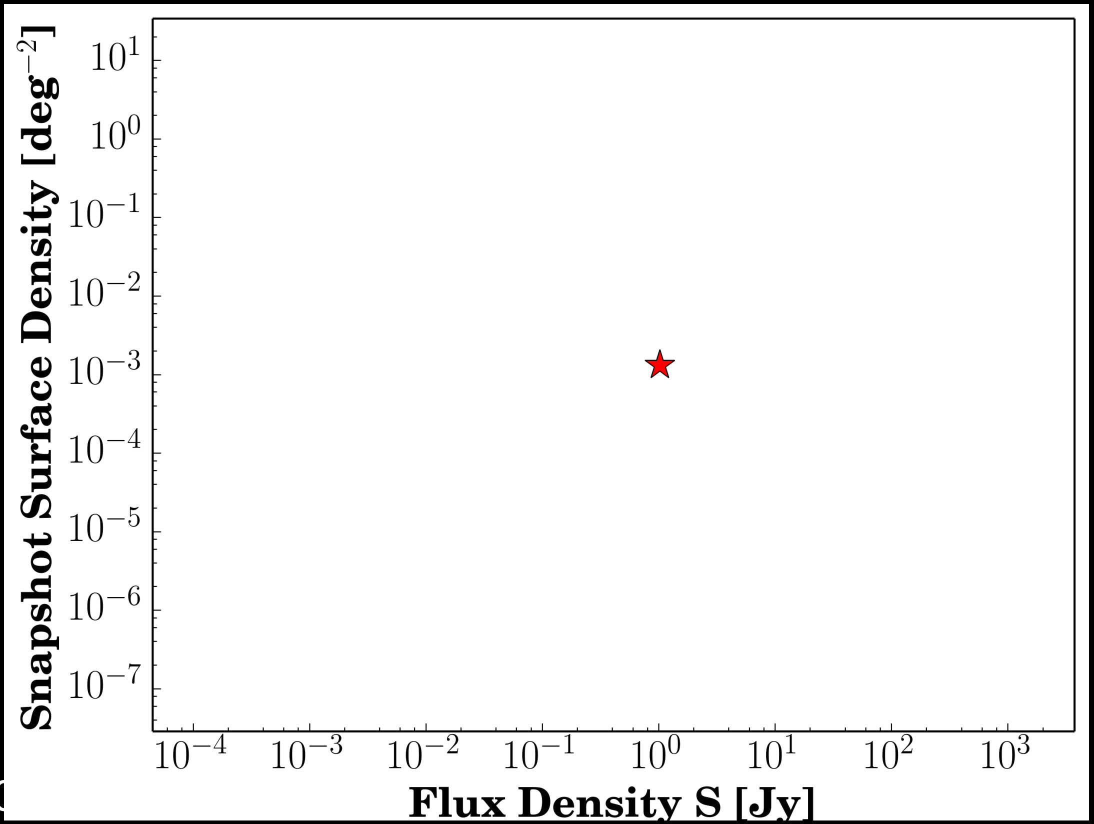
- 4d space:
  - Reduced weighted
  - Variability index
  - Max Flux
  - Max / Average Flux
- Variable and non-variable sources separated by a straight line in N-dimensions
- Supervised machine learning technique
- Training requires labeled data



Rowlinson et al., in prep.

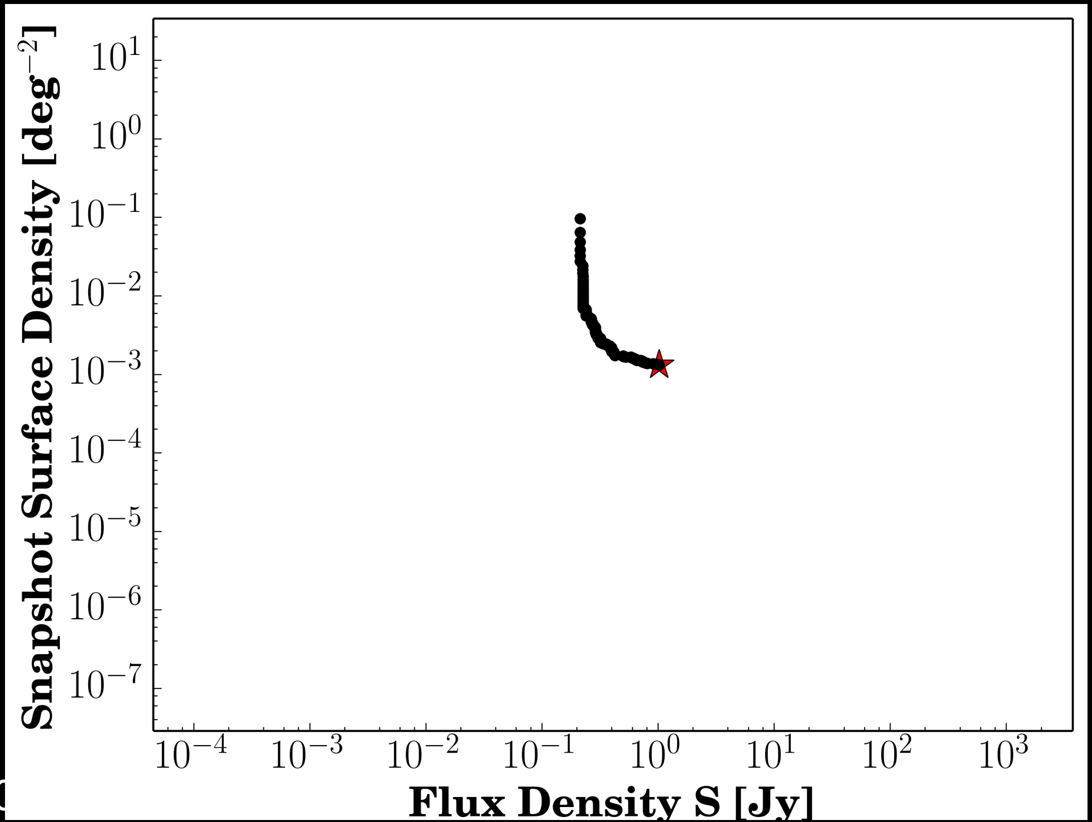
Non detections

- **Literature: out of the whole dataset derive one upper limit**
- Applied to a LOFAR survey of 4 fields, for a total of 63 snapshots of 11 minutes each.



Non detections

- Literature: out of the whole dataset derive one upper limit
- **We can eliminate the worst image and calculate a new method – iteratively**
- Applied to a LOFAR survey of 4 fields, for a total of 63 snapshots of 11 minutes each.

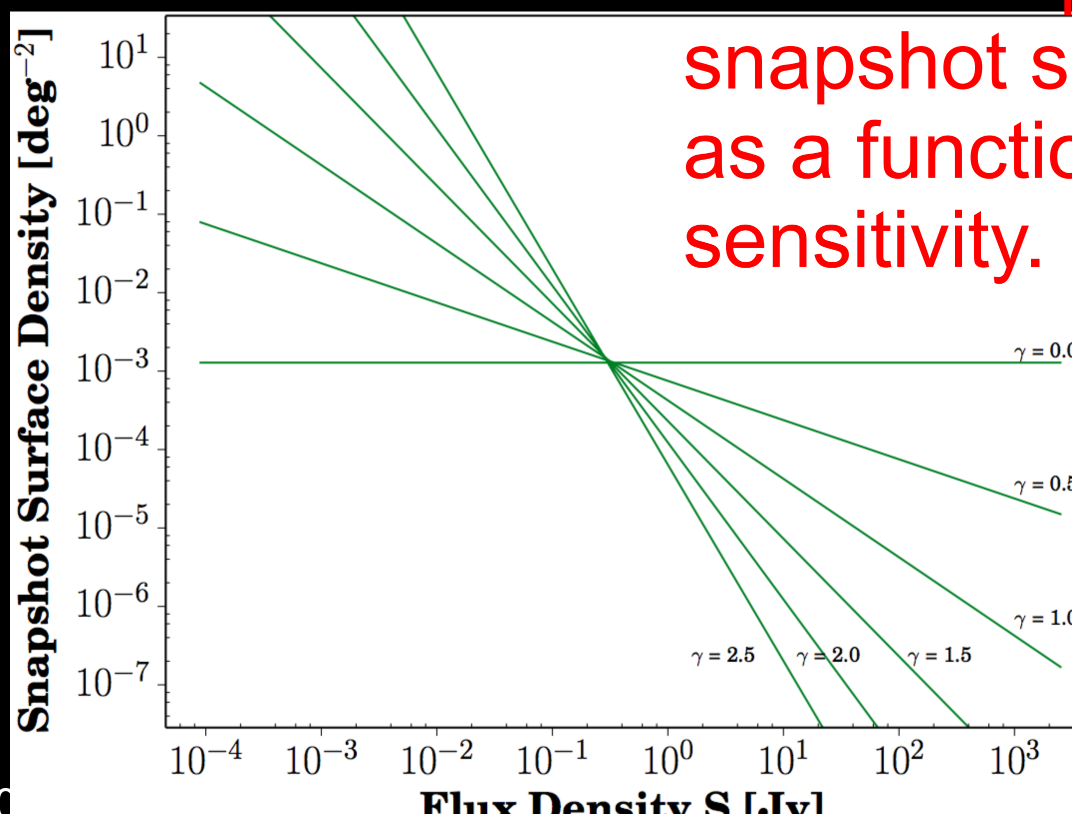


Non detections

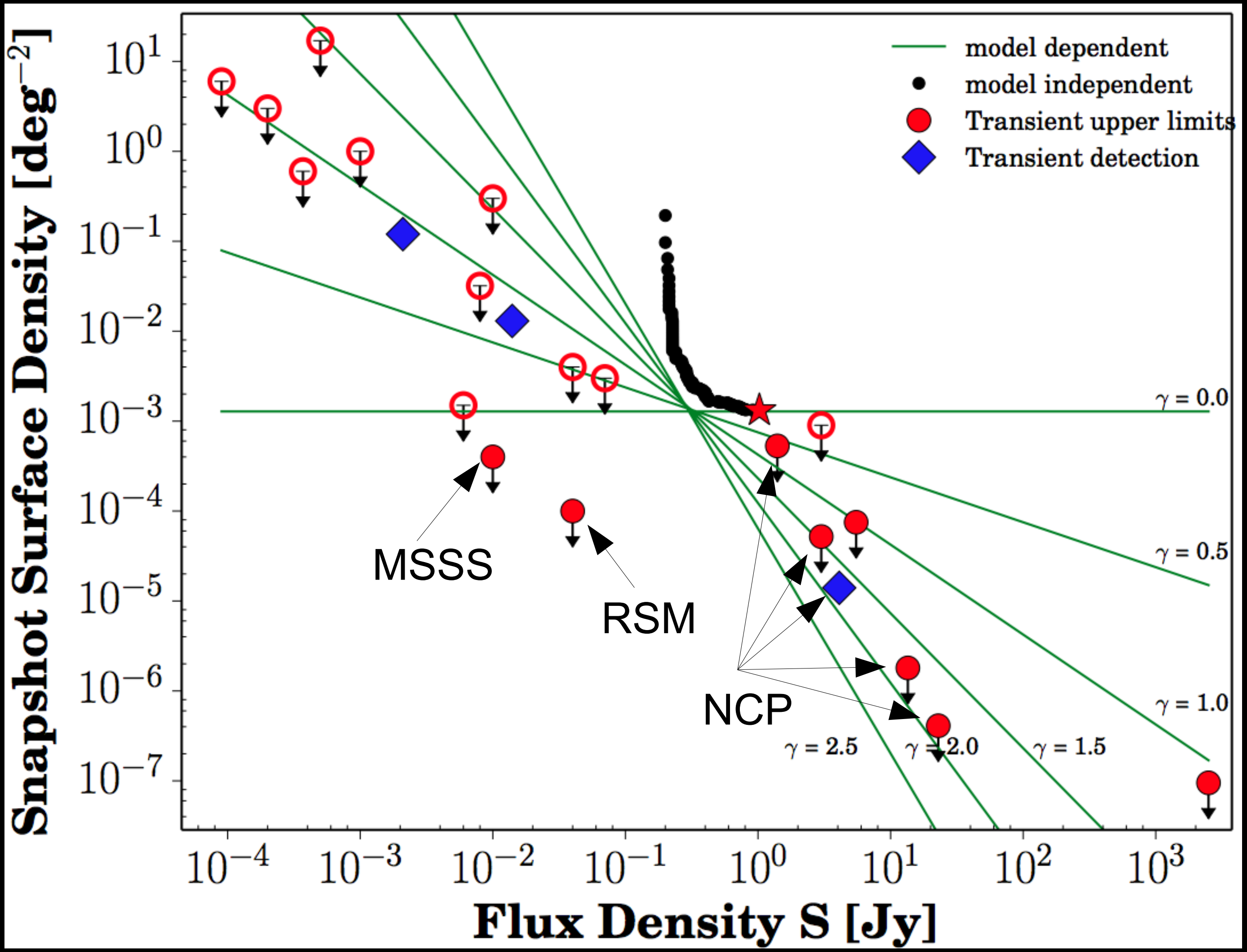
- Literature: out of the whole dataset derive one upper limit
- We can eliminate the worst image and calculate a new method – iteratively
- **We can assume a power-law distribution in flux for the transients and calculate the u.l.**

- Applied to a LOFAR survey of 4 fields, for a total of 63 snapshots of 11 minutes each.

We can express the snapshot surface density as a function of the sensitivity.



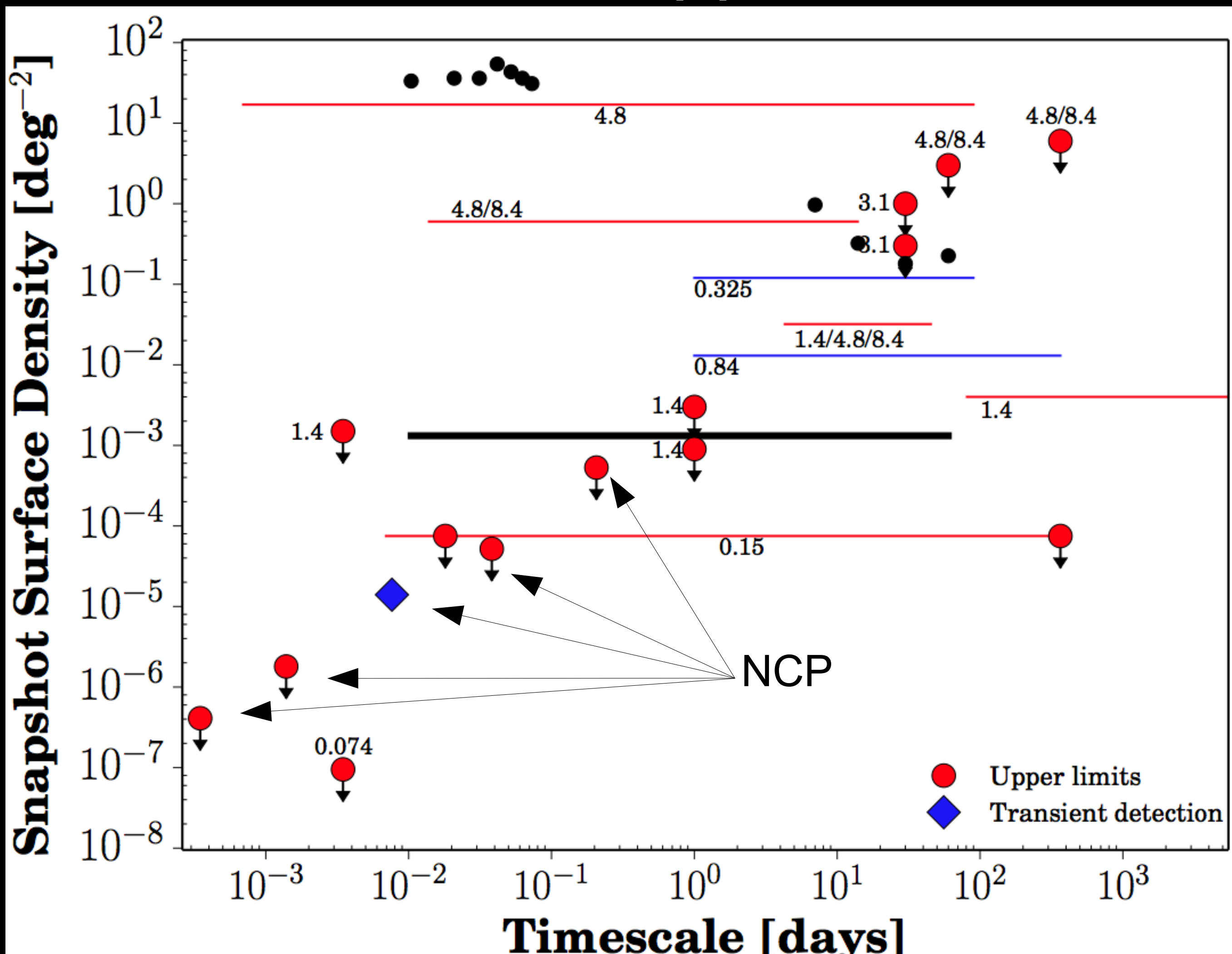
Non detections



Carbone et al. 2015, submitted to MNRAS

Timescales

- Calculate transient upper limit vs Timescale



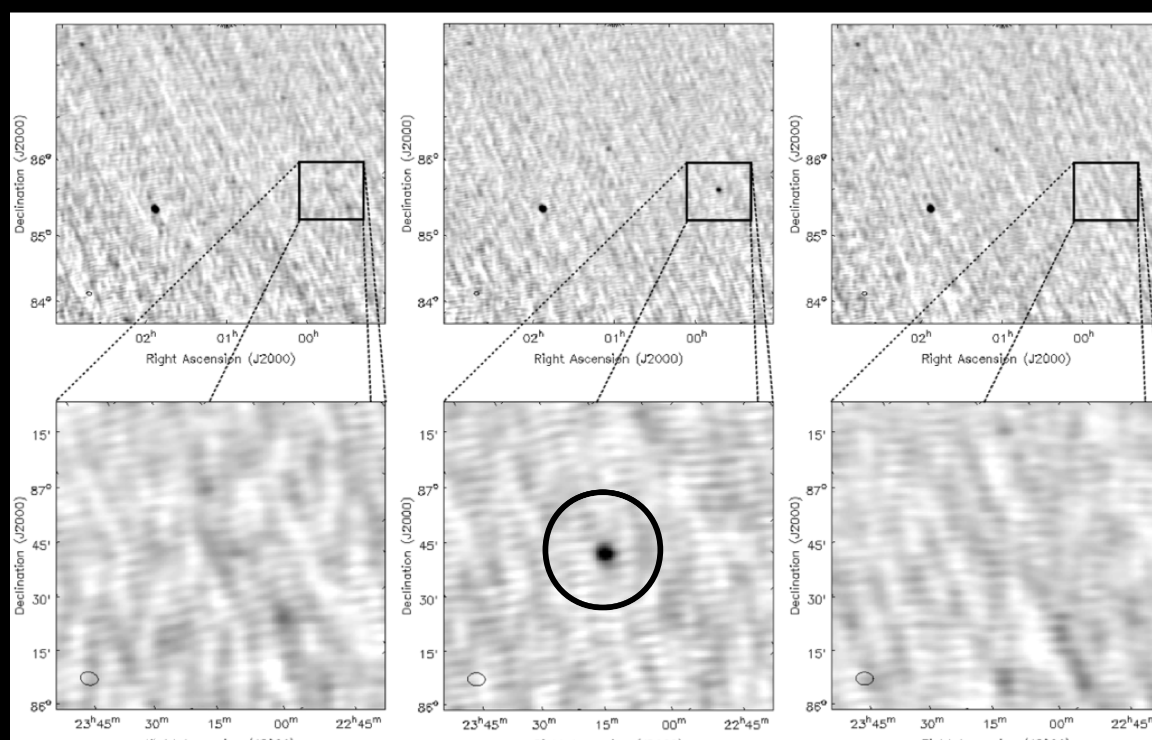
Carbone et al. 2015, submitted to MNRAS

Dario Carbone, Assen – 02/06/2015

LOFAR is detecting image-plane transient and variable sources

Adam's transient

- NCP monitoring project during MSSS-LBA
- Transient seen in one, 11 min snapshot at 60 MHz
- Brightness of 15-20 Jy
- Passed exhaustive validity tests
- No counterpart at higher frequencies
- At present the origin is unknown - attempt to find more events, using data from Cycles 2 & 3.
- Paper about to be submitted

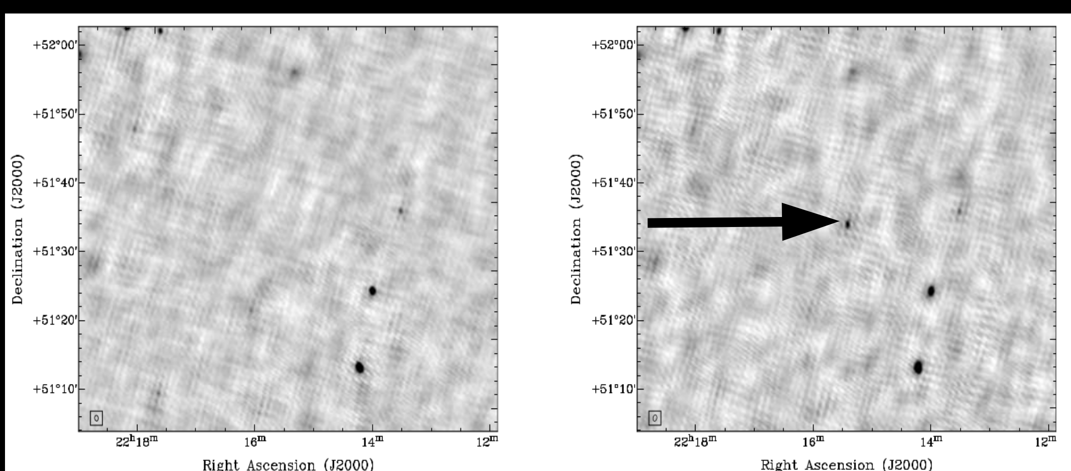


Stewart et al., in prep.

PSR J2251+5135
An eclipsing redback pulsar in the RSM

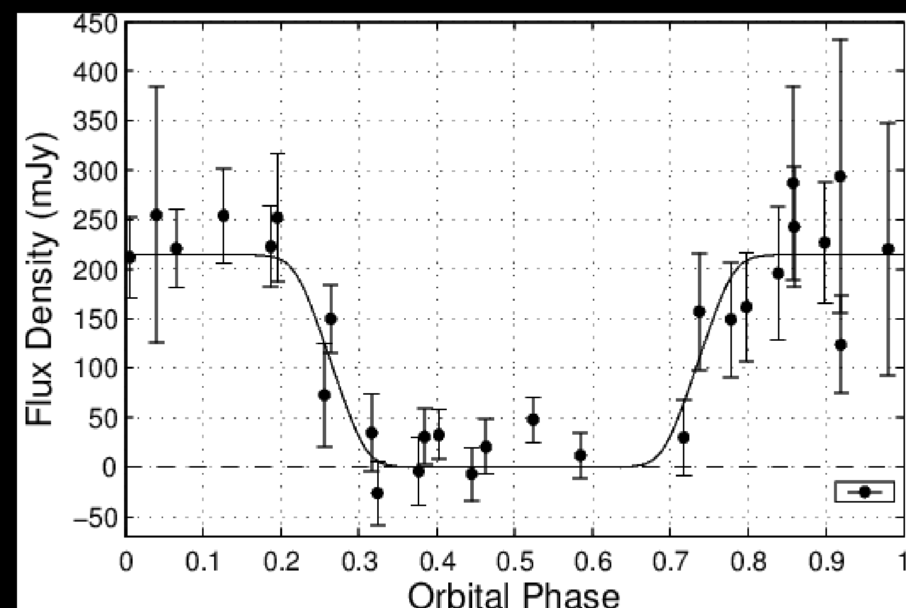
- Variable image-plane source first spotted by eye, but also picked up by the TraP.

124 MHz observations



2013 February 10

2014 January 15



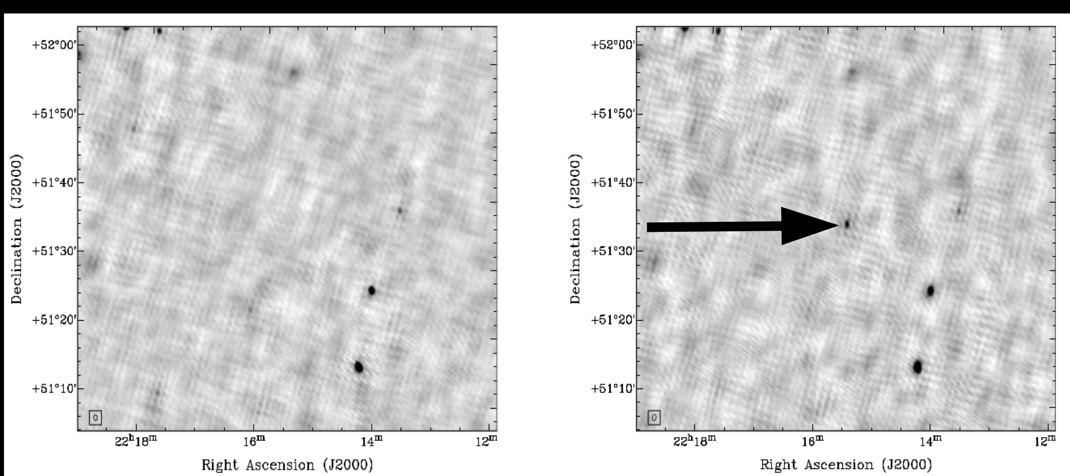
Full RSM dataset (e.g. 28 x 11 min images) → eclipses observed

Dario Carbone, Assen – 02/06/2015

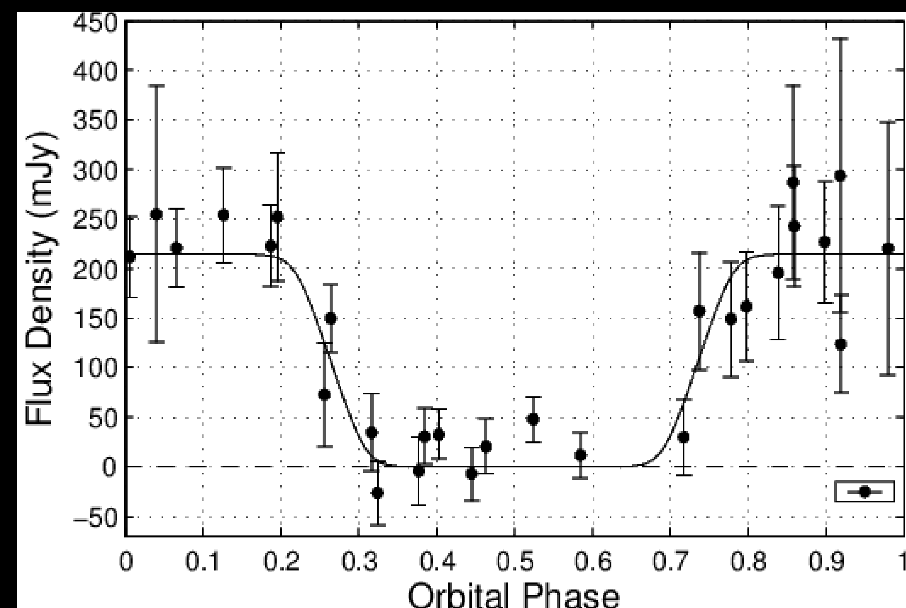
PSR J2251+5135
An eclipsing redback pulsar in the RSM

- Variable image-plane source first spotted by eye, but also picked up by the TraP.
- Position coincident with PSR J2215+5135 (Hessels et al. 2011).Discovered at 350 MHz with the GBT (survey of faint, unidentified *Fermi* gamma-ray sources).
- Paper submitted to MNRAS (Broderick et al.).

124 MHz observations

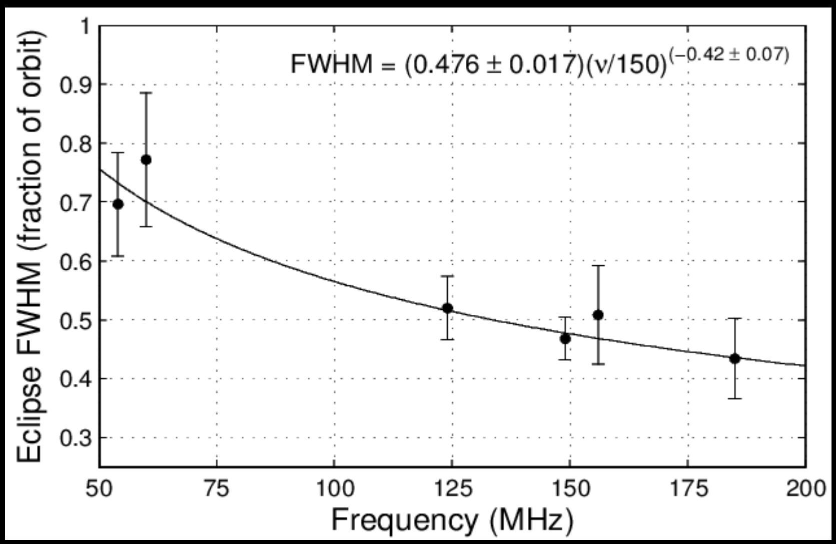


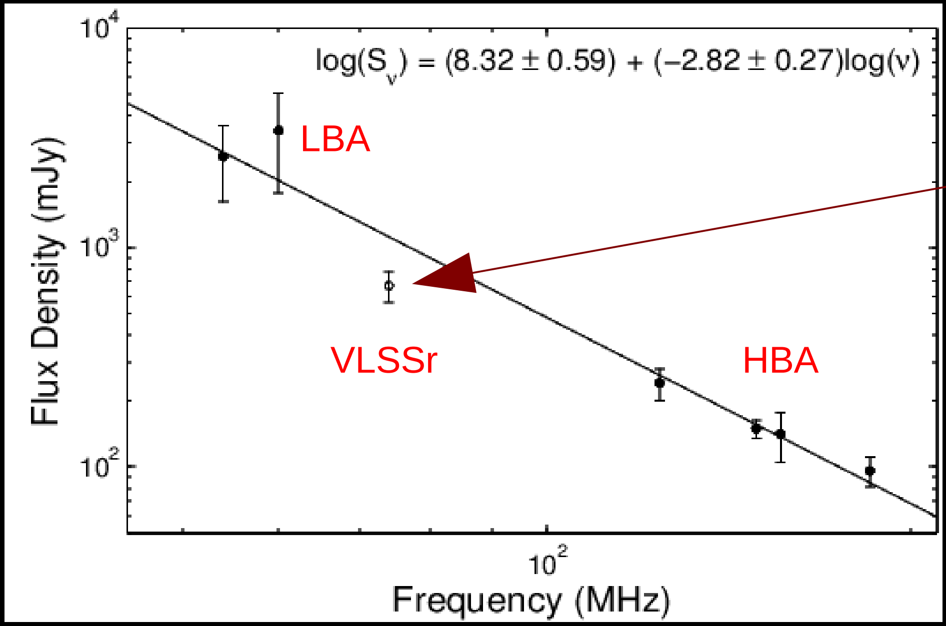
2013 February 10 — 2014 January 15



Full RSM dataset (e.g. 28 x 11 min images) → eclipses observed

Eclipse is longer at lower frequencies





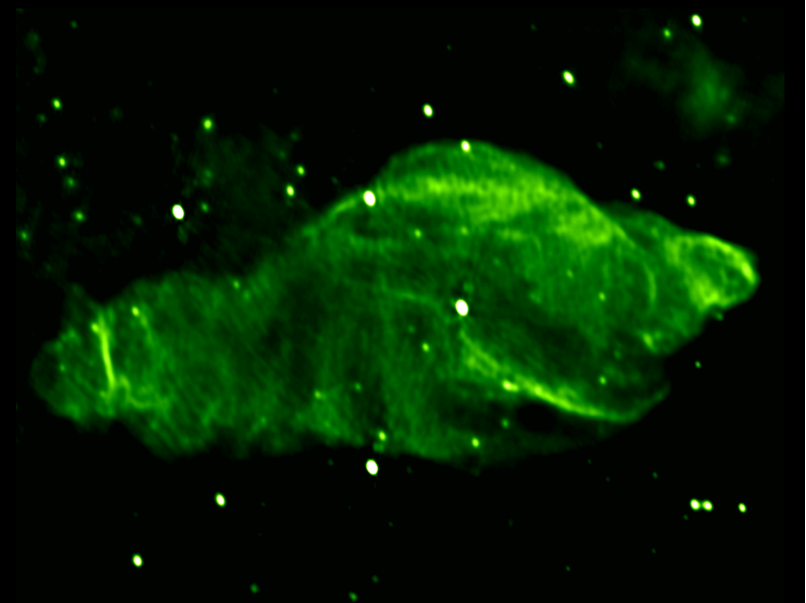
- ~ $\nu^{-0.4}$ dependence
- We could have had a much finer orbital phase resolution, using beamformed data. (also relevant to FRB detections; e.g. see Hassall, Keane & Fender 2013).

- Very steep radio spectrum (~ $\nu^{-2.8}$).

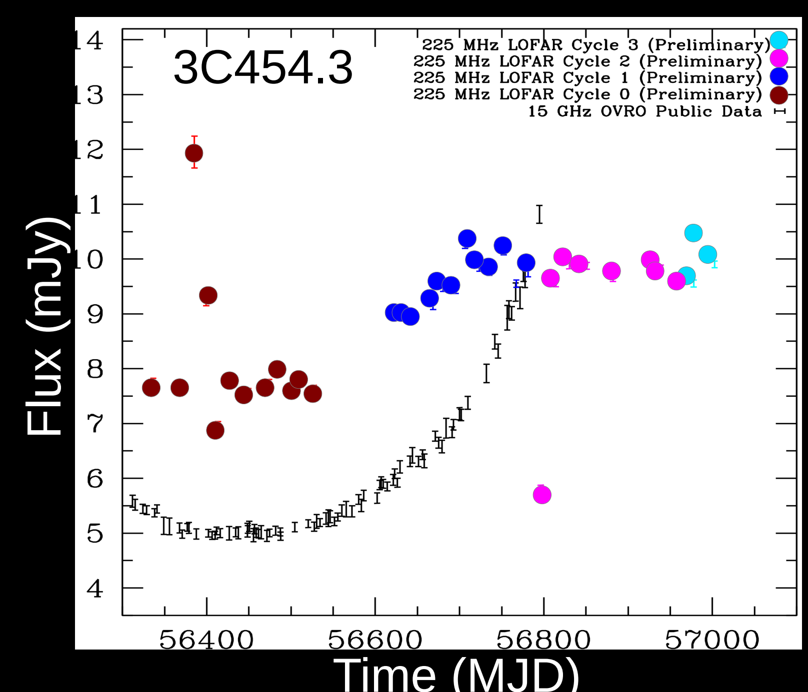
74 MHz VLSSr data point from observations where PSR J2251+5135 is partially eclipsed

TKP Jets Working Group

- SS 433 paper to be submitted very soon (Broderick et al.).
- GRS 1915+105; marginal detection (~20-30 mJy).
- Searches for 'missing' SNRs (Anderson, Lizancos, Broderick et al. in prep.).
- LOFAR HBA + KAT-7 1.4 GHz (Broderick, Rushton et al. in prep.)

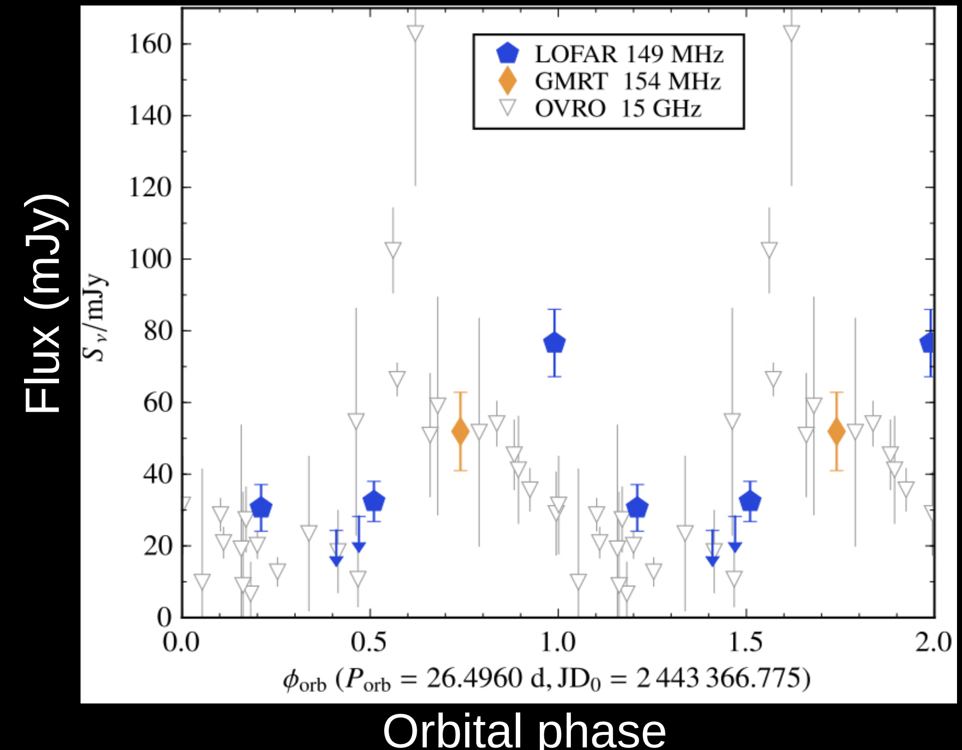


- Blazar monitoring: sources strongly variable at GHz-frequency.
- LOFAR: smooth behaviour; trends on timescales of months
- Turriziani et al. 2015



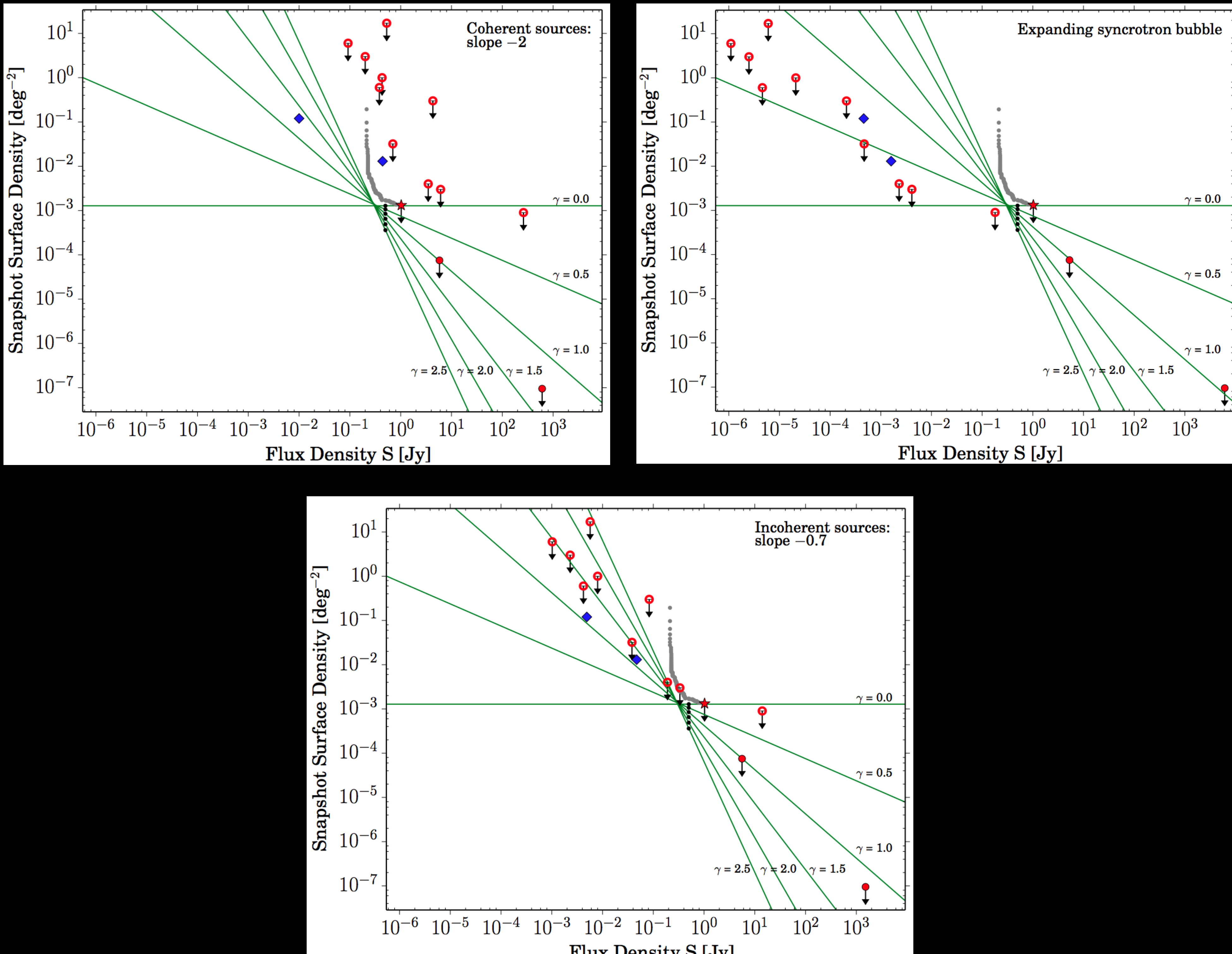
The gamma-ray binary LS I +61 303

- High Mass X-ray Binary
- Orbitally modulated emission from radio to TeV energies.
- At GHz frequencies the radio lightcurve shows an outburst per orbital cycle.
- LOFAR lightcurve: outbursts are not clear and phase delay with respect to 15 GHz observations.
- Paper accepted (Marcote et al.)



LOFAR is detecting image-plane transient and variable sources

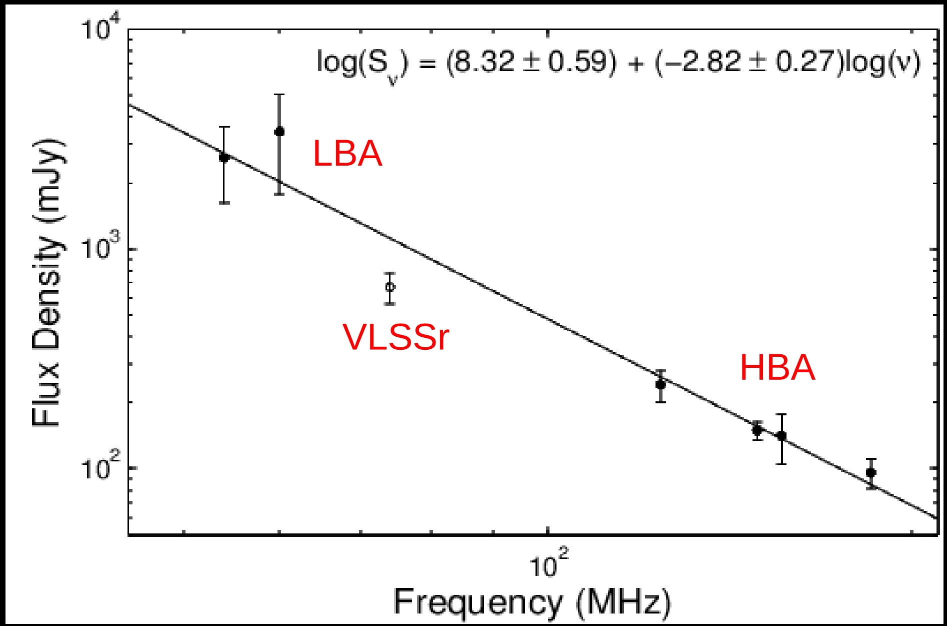
END



Coherent sources:
slope −2
Expanding syncrotron bubble
Incoherent sources:
slope −0.7
γ = 0.0
γ = 0.5
γ = 1.0
γ = 1.5
γ = 2.0
γ = 2.5
Snapshot Surface Density [deg^{-2}]
Flux Density S [Jy]

Survey	Sensitivity (mJy)	ρ (deg^{-2})	t_{char}	ν (GHz)
This work	> 500	< 0.001	minutes - months	0.150
Bell et al. 2011	> 8	< 0.032	4.3 - 45.3 days	8.4, 4.8 and 1.4
Gal-Yam et al. 2006	> 6	$< 1.5 \cdot 10^{-3}$	-	1.4
Croft et al. 2010	> 40	< 0.004	81 days - 15 years	1.4
Bower et al. 2007	> 0.09	< 6	1 year	8.4 and 4.8
Bower et al 2010(A)	> 1	< 1	1 month	3.1
Bower et al 2010(B)	> 10	< 0.3	1 month	3.1
Bower & Saul 2010(A)	> 70	< 0.003	1 day	1.4
Bower & Saul 2010(B)	> 3000	$< 9 \cdot 10^{-4}$	1 day	1.4
Lazio et al. 2010	$> 2.5 \cdot 10^{6}$	$< 9.5 \cdot 10^{-8}$	5 minutes	0.0738
Bell et al. 2014	> 5500	$< 7.5 \cdot 10^{-5}$	minutes - year[1]	0.154
Alexander et al. 2014	> 0.5	< 17	minutes - months	4.9
Bannister et al. 2011	14	$1.3 \cdot 10^{-2}$	days - years	0.843
Bower et al. 2007	0.37	1.5 ± 0.4	20 minutes - week	8.4 and 4.8
Bower et al. 2007	0.20	2	2 months	8.4 and 4.8
Jaeger et al. 2012	2.1	0.12	1 day - 3 months	0.325

Why is this interesting?



Very steep radio spectrum. 74 MHz VLSSr data point from observations where PSR J2251+5135 is partially eclipsed → explains discrepancy

* Most robust approach for future work: simultaneous image-plane and beamformed observations (also relevant to FRB detections; e.g. see Hassall, Keane & Fender 2013).