Identifying transient and variable sources in radio images

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8th October 2019

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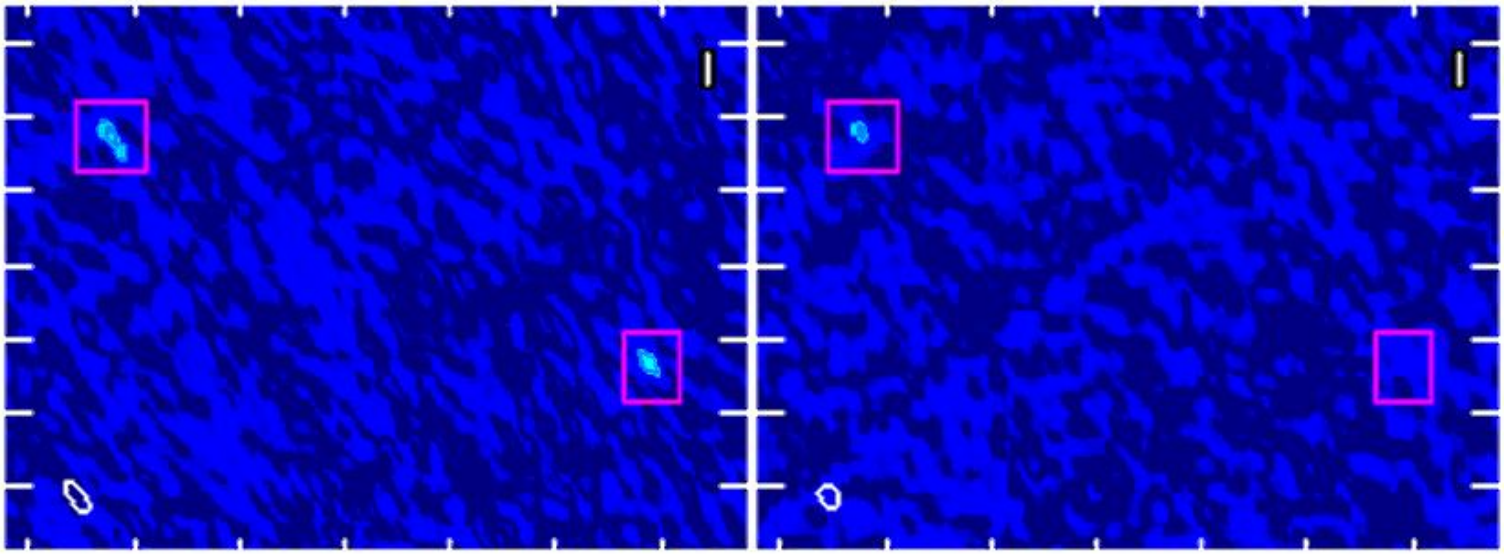
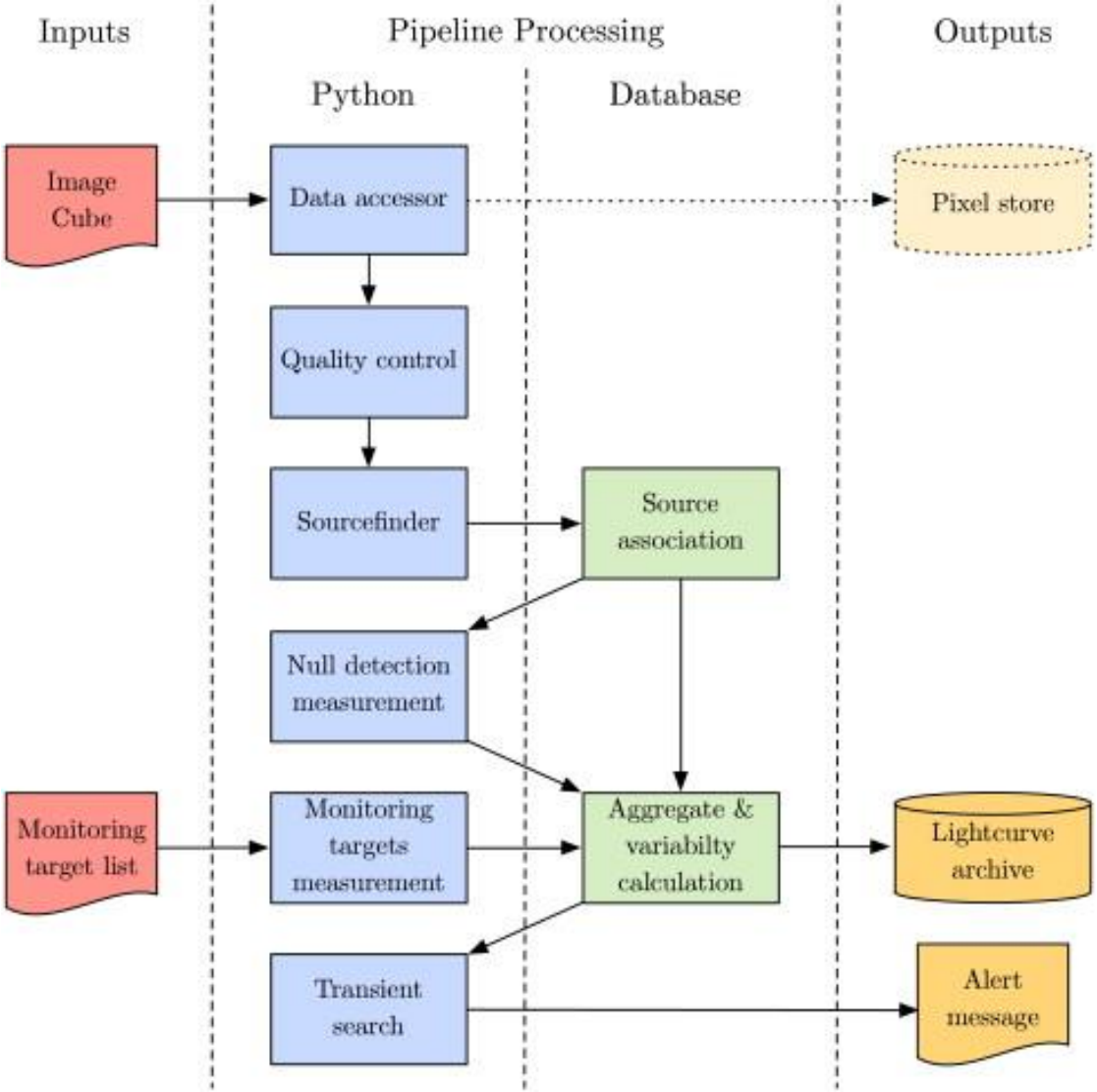
LOFAR

How to do a blind survey

- Many images as sensitive as possible on a given timescale
- Search through for anything that changes in the images
- Datasets typically have more than
  - 1,000 unique sources
  - 10,000 images
  - 100,000 individual source extractions



The LOFAR Transient Pipeline (TraP)



Swinbank et al. (2015)

Publicly available:
http://docs.transientskp.org
(Documentation)
https://github.com/transientskp/tkp
(Code)

Variability Parameters

- After each new data point is inserted into the database we calculate:
  - Variability Index:

$$V_\nu = \left(\frac{s}{\bar{I}} \right)$$

  - Weighted Chi-squared:

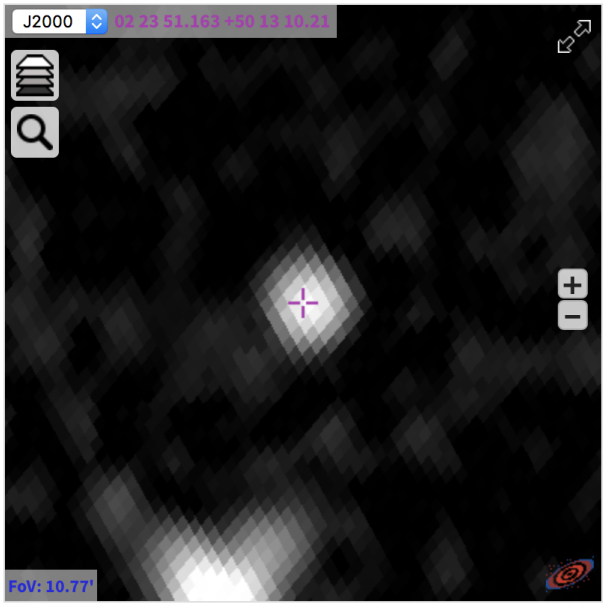
$$\eta_\nu = \frac{N}{N-1} \left(\overline{\omega I^2} - \frac{\overline{\omega I}^2}{\overline{\omega}} \right)$$

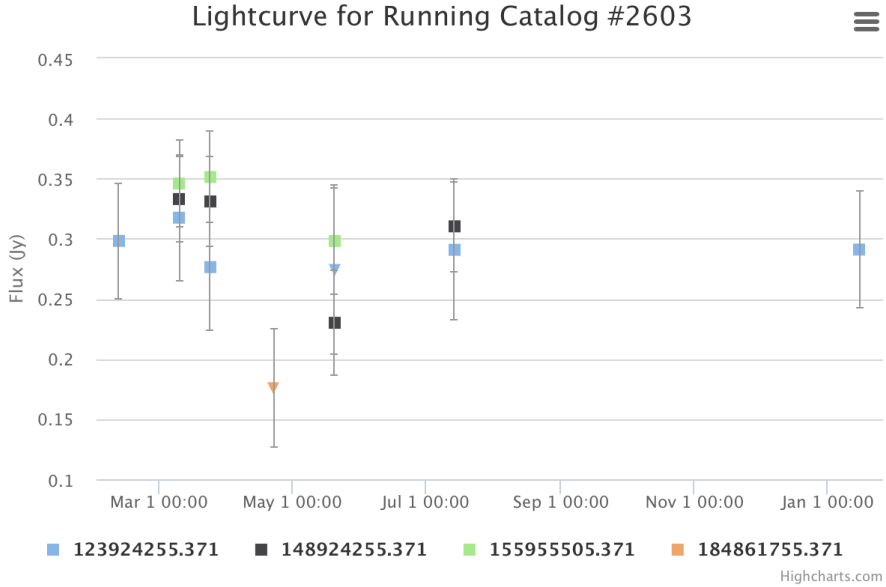
S = Unbiased standard deviation
I = Integrated flux
N = Number of datapoints

$$\omega = \frac{1}{e^2} = \frac{1}{(\text{Flux error})^2}$$

See TraP documentation to see how these can be calculated in aggregated way from image to image

Interacting with the TraP database: “Banana”





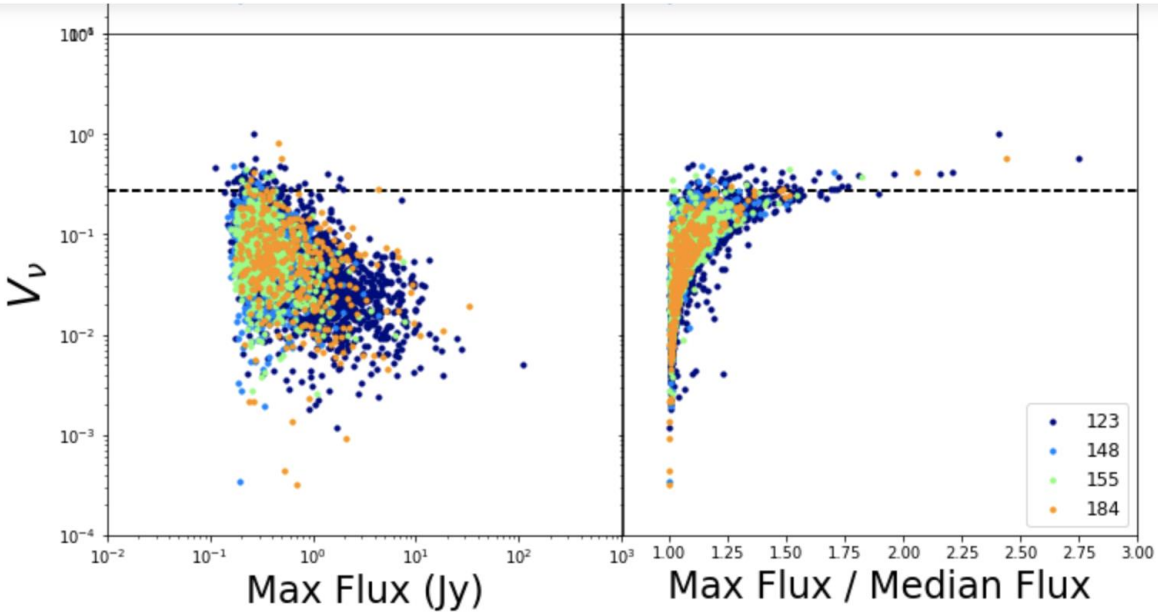
Position	(35.963°, 50.220°) ± (27.319″, 17.480″)	**Trigger source**	No
		Previous limits image	No
		# of datapoints	12
		Dataset	RSM
RA (hh:mm:ss.s)	$02^h\ 23^m\ 51.2^s$	**Number of forced fits**	0
Dec (dd:mm:ss.s)	+50° 13′ 10.2″	**Max int. flux (Jy)**	
New source	No	**Mean int. flux (Jy)**	
ηv	None	**Median int. flux (Jy)**	
Vv	None		
$\Sigma_{RMS_{min}}$	None		
$\Sigma_{RMS_{max}}$	None		
Skyregions	109		

Developing tools to interact with the TraP database

jupyter FilterVariables Last Checkpoint: 01/25/2017 (autosaved)

File Edit View Insert Cell Kernel Help

Code CellToolbar



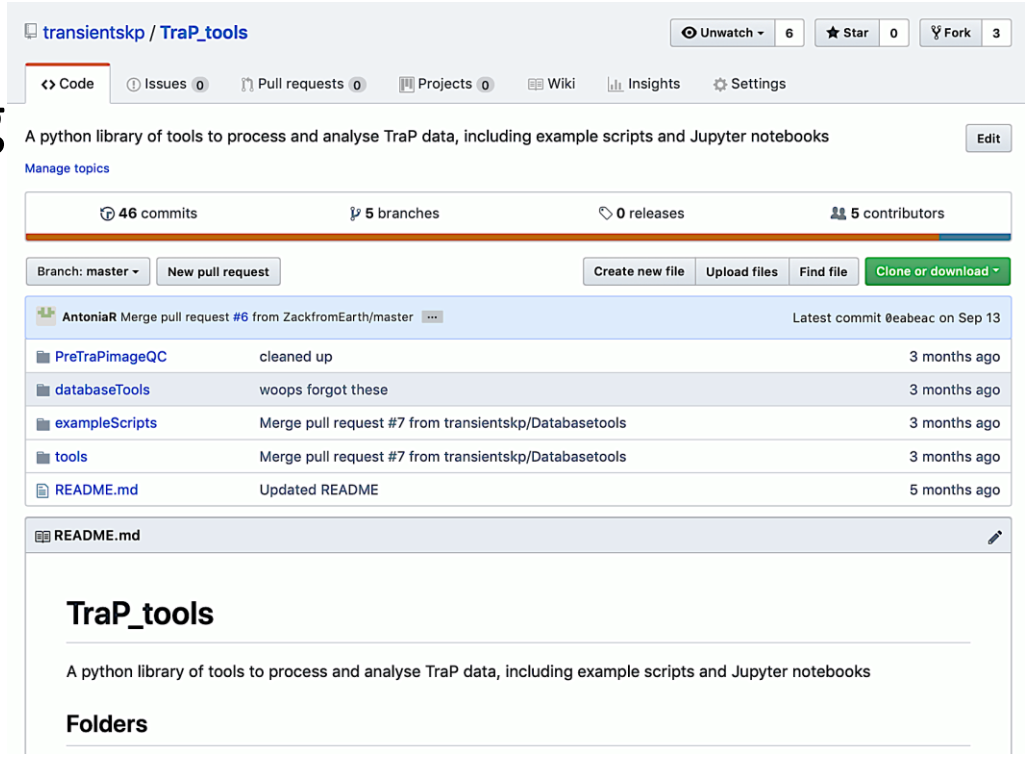

```
In [12]: tmp=[x[0] for x in plotdata if x[1]>10.**sigcutx and x[2]>10.**sigcuty and x[7]==None and x[6]>1]
IdTrans=[]
if len(tmp)>0:
    IdTrans=np.sort(np.unique(tmp), axis=0)
else:
    print "No Variables"
for a in IdTrans:
    print websiteURL+str(a)
```

```
http://banana.transientskp.org/r4/vlo_AR_R4/runningcatalog/1208
http://banana.transientskp.org/r4/vlo_AR_R4/runningcatalog/2893
```

- Jupyter Notebooks
- More flexibility for transient searches
- Enables direct interaction with the databases

TraP tools available

- Complex analysis now often completed using Jupyter Notebooks
- Using SQL alchemy to access TraP database
- Amsterdam team are making tools and example notebooks available
- Others welcome to contribute their scripts

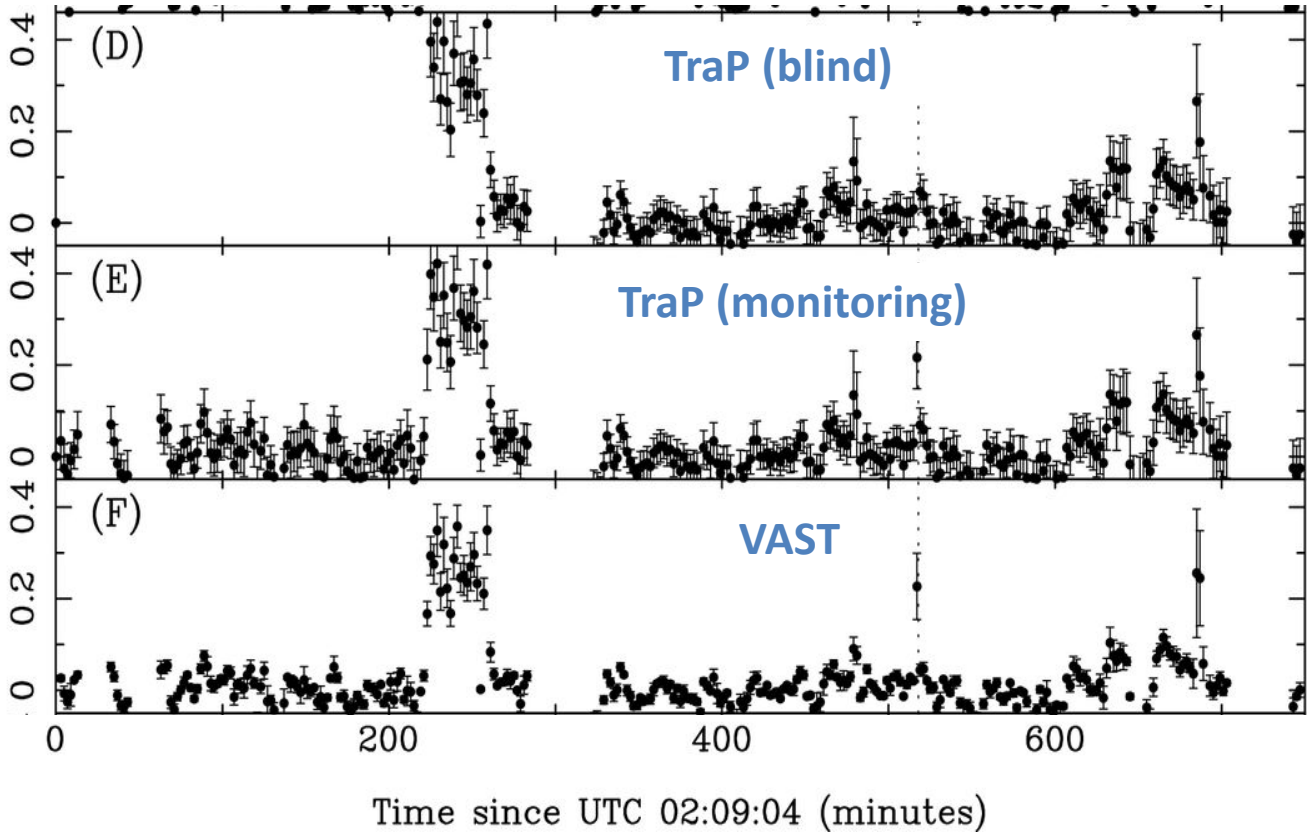


https://github.com/transientskp/TraP_tools

Thanks to: Mark Kuiack, Kriek van der Meulen, Zack Meyers, Kelly Gourdji, Bart Scheers

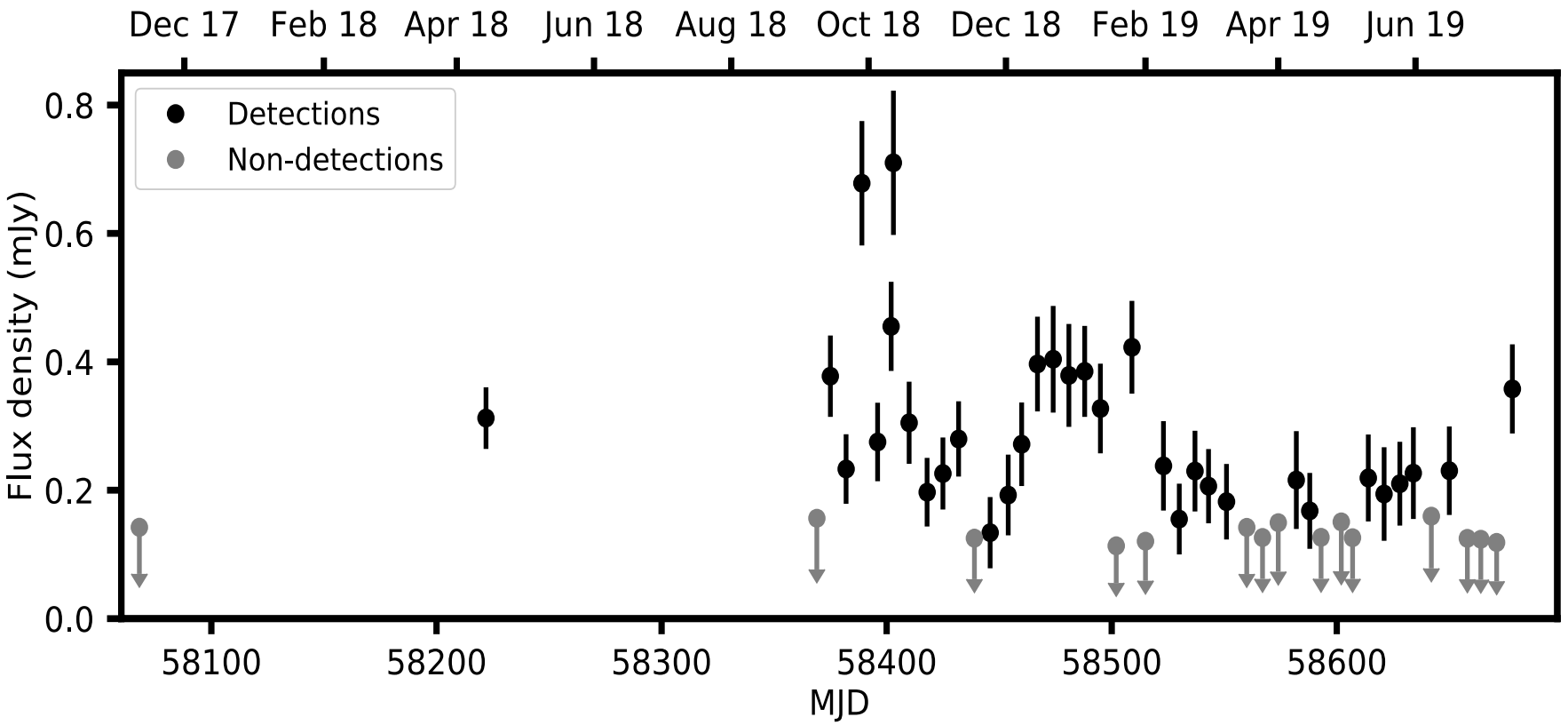
TraP Successes

- Already used with
  - LOFAR
  - AARTFAAC
  - MWA
  - AMI
  - VLA
  - ATCA
  - ASKAP/BETA
  - MeerKAT



Hobbs et al. (2016)

First MeerKAT Transient



- The radio light curve of MKT J170456.2-482100, the first blindly detected MeerKAT transient. This transient is coincident with a K-type sub-giant star.

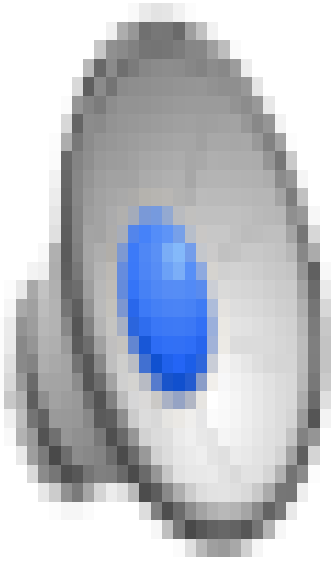
Driessen et al. (submitted)

AARTFAAC

a real-time transient machine using LOFAR

	AARTFAAC
	
Array Elements	288 inverted V antennas
Freq. Range (MHz)	30-80
Field of View (sr)	π
Angular Resolution (arcmin)	60
Spectral Res. (kHz)	15
Temporal Res. (s)	1
Sensitivity (Jy)	40

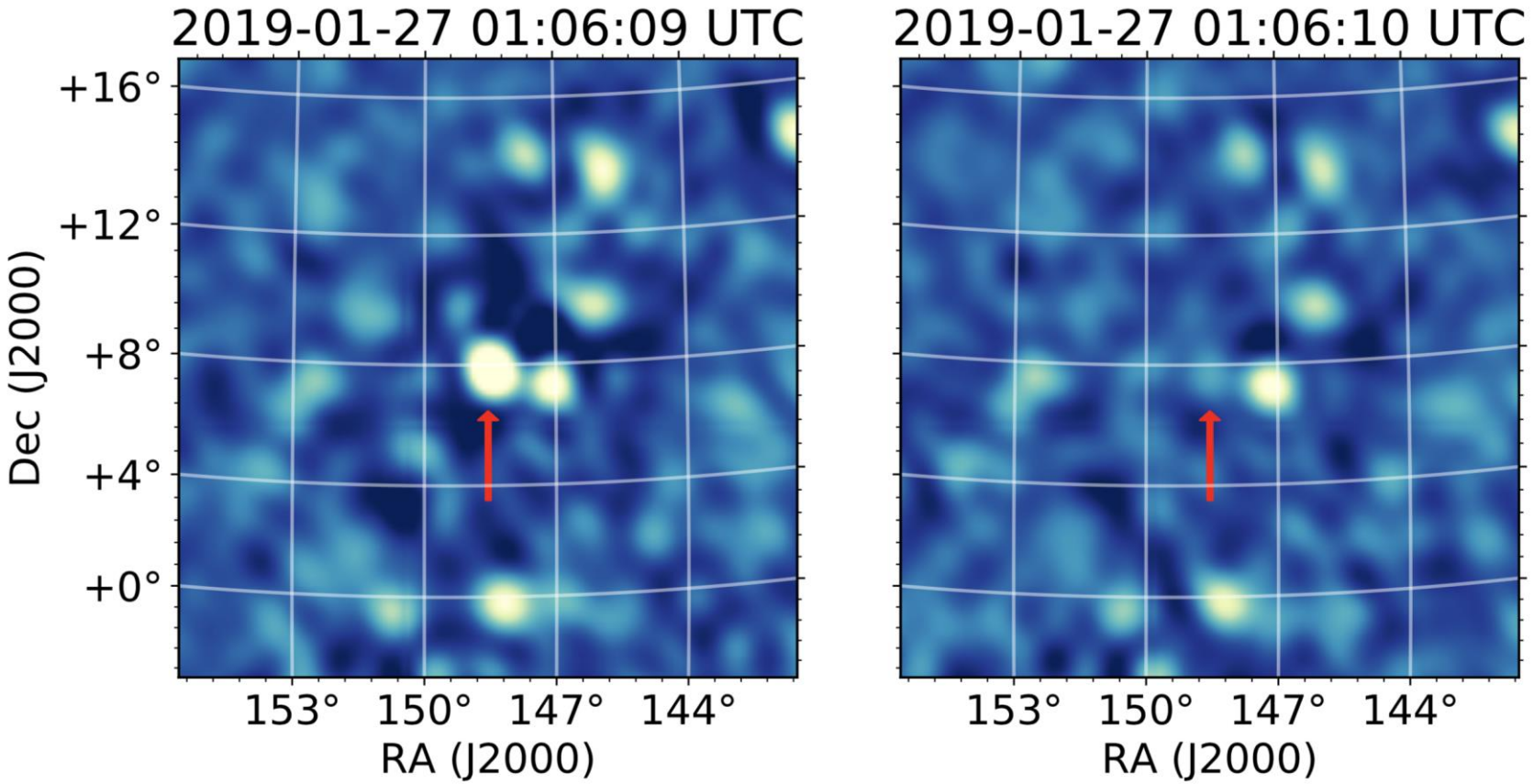
Prasad et al. (2014, 2016)



Credit: Mark Kuiack

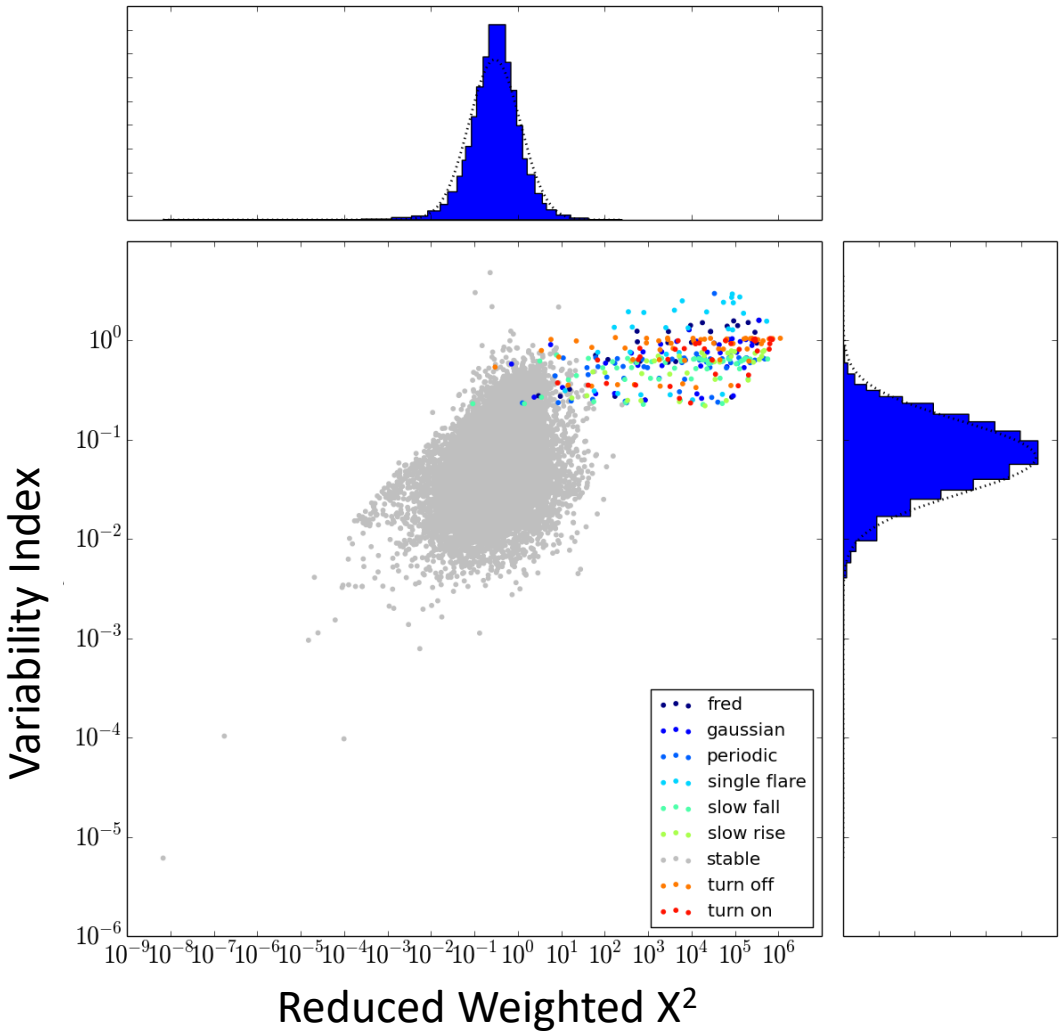
See also poster P10.35 by Aleksander Shulevski

AARTFAAC: detection of extreme giant pulses from a pulsar



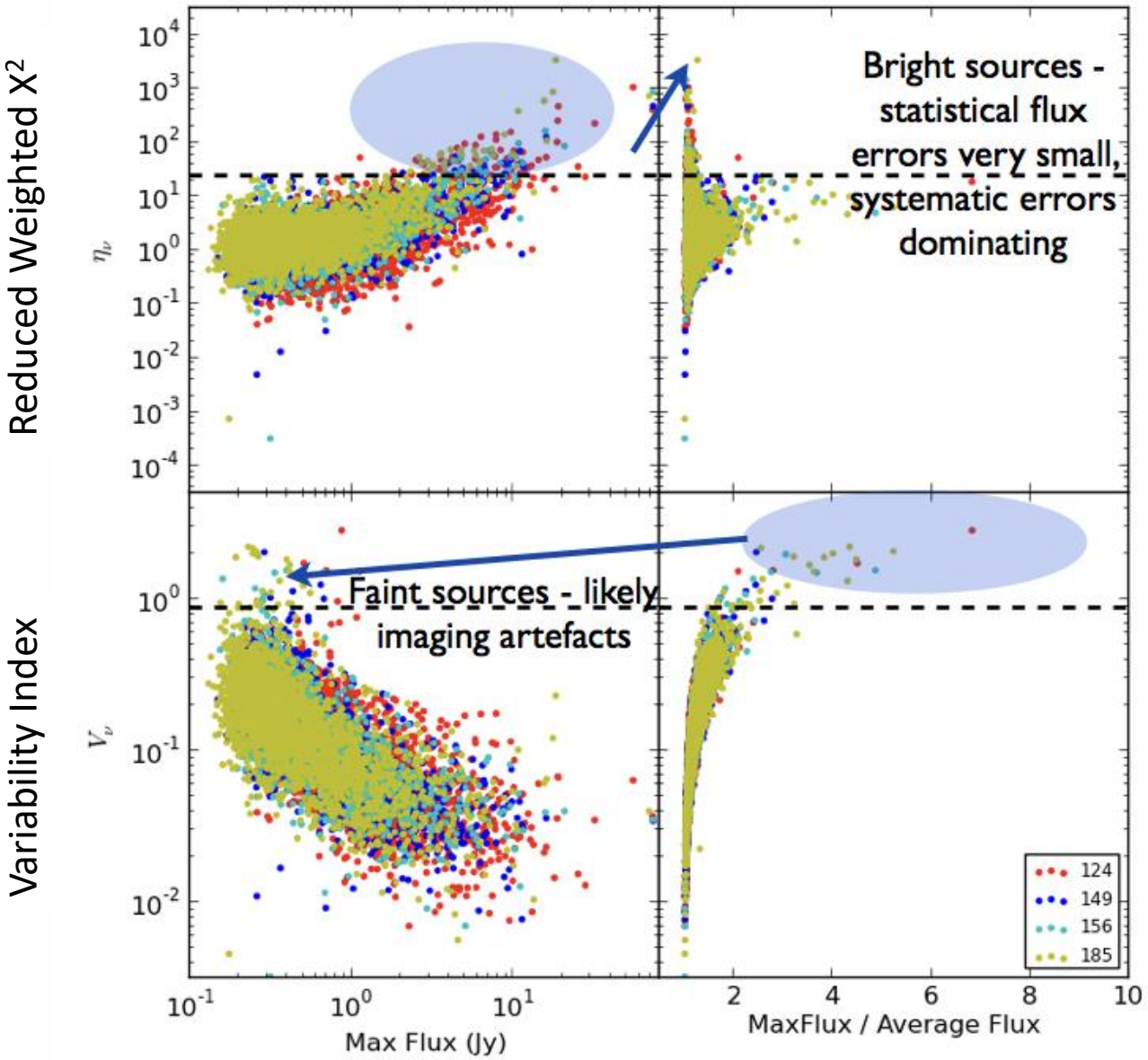
Kuiack et al. (submitted)

Interpreting TraP results



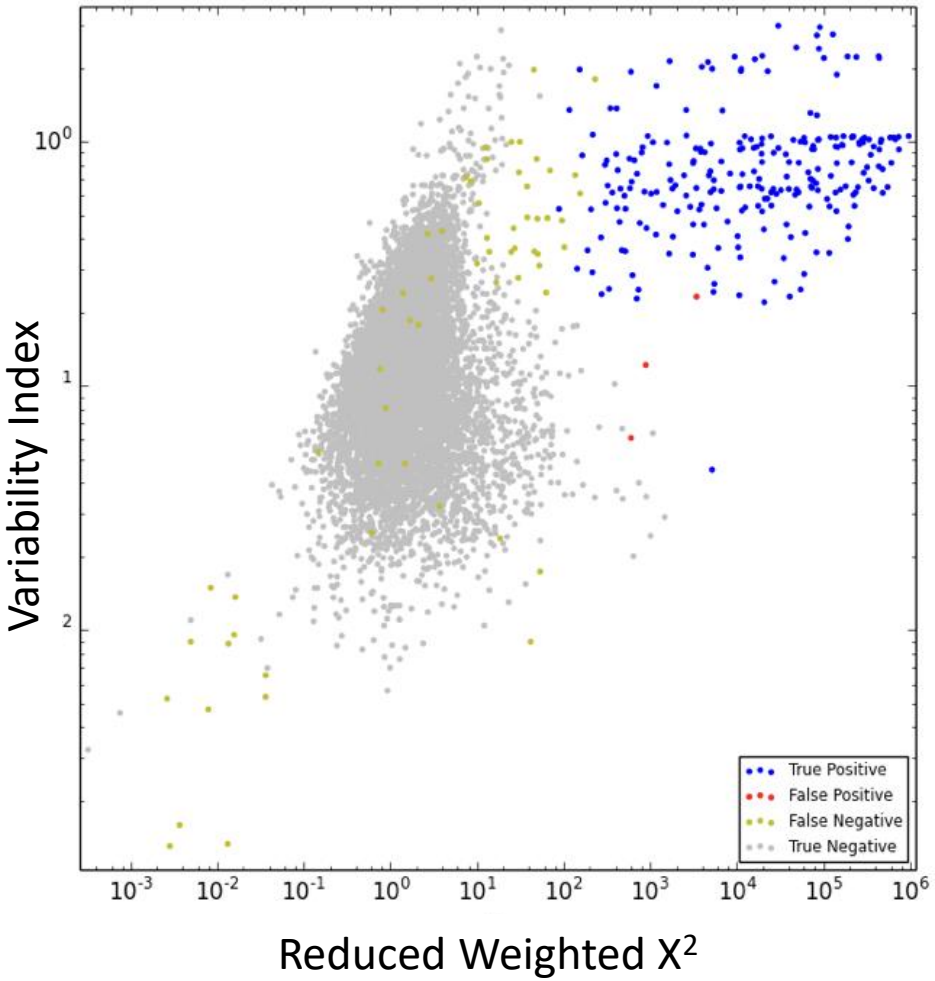
- TraP stores variability parameters for all sources in a database
- Using machine learning strategies we can identify transient and variable sources

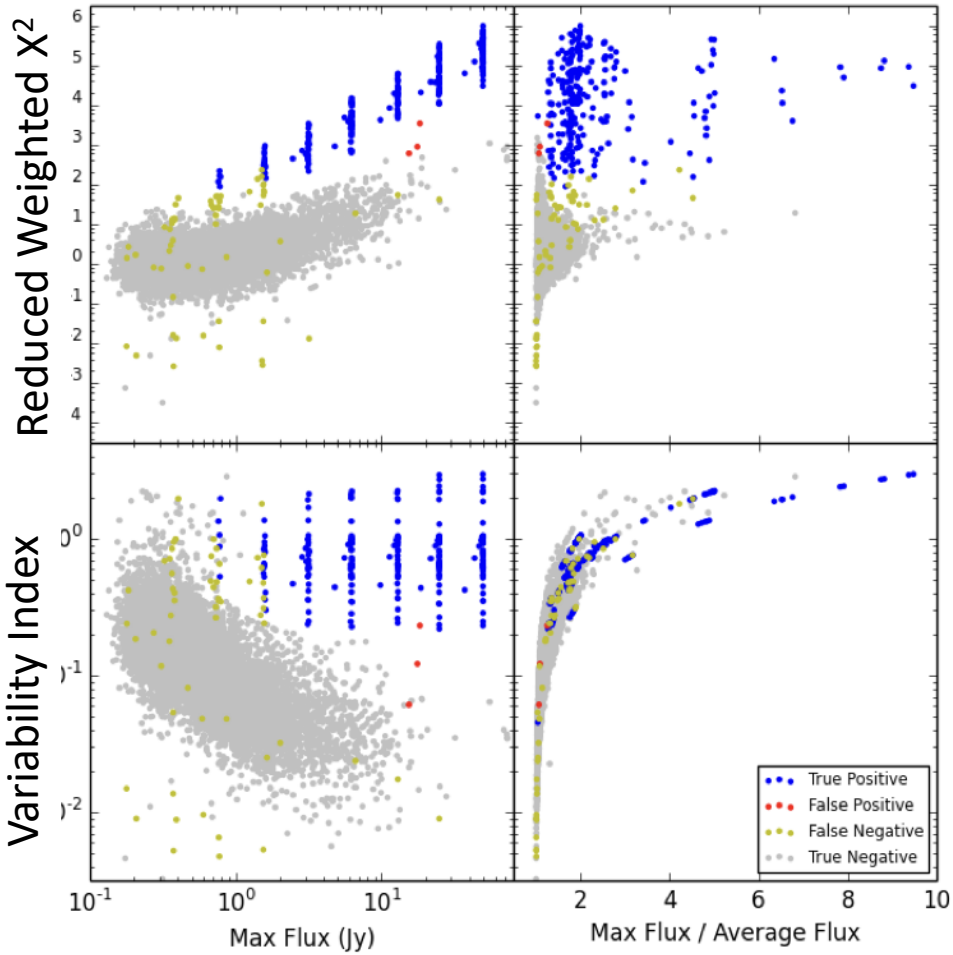
Rowlinson et al. (2019, A&C)



Rowlinson et al. (2019)

Mining the databases with machine learning





Rowlinson et al. (2019)

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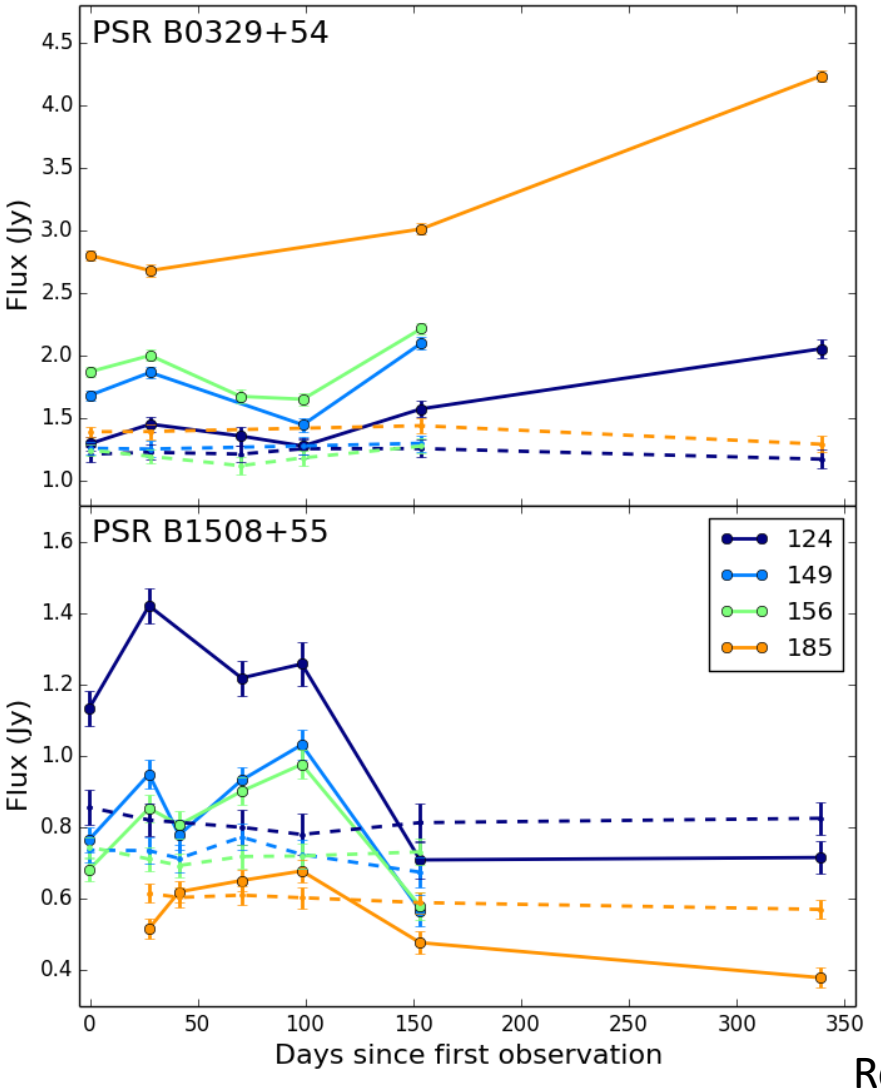

Rowlinson et al. (2019)

Conclusions

- TraP is a radio transient detection pipeline that is the only one of its kind that is publicly available
- A number of successes and already used with many current state of the art radio facilities
- Long term plans:
  - Expand capability for next generation surveys
  - Make databases publicly available
  - Implement machine learning algorithms
  - Publish real-time alerts