Identifying transient and variable sources in radio images

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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:
    \[ \eta_\nu = \frac{N}{N - 1} \left( \frac{\omega I^2}{\bar{\omega}} - \frac{\omega \bar{I}^2}{\bar{\omega}} \right) \]

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

See TraP documentation to see how these can be calculated in aggregated way from image to image.
Interacting with the TraP database: “Banana”
Developing tools to interact with the TraP database

- 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

Time since UTC 02:09:04 (minutes)

Hobbs et al. (2016)
• 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

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Array Elements</td>
<td>288 inverted V antennas</td>
</tr>
<tr>
<td>Freq. Range (MHz)</td>
<td>30-80</td>
</tr>
<tr>
<td>Field of View (sr)</td>
<td>π</td>
</tr>
<tr>
<td>Angular Resolution (arcmin)</td>
<td>60</td>
</tr>
<tr>
<td>Spectral Res. (kHz)</td>
<td>15</td>
</tr>
<tr>
<td>Temporal Res. (s)</td>
<td>1</td>
</tr>
<tr>
<td>Sensitivity (Jy)</td>
<td>40</td>
</tr>
</tbody>
</table>

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)
Reduced Weighted $\chi^2$

Variability Index

Bright sources - statistical flux errors very small, systematic errors dominating

Faint sources - likely imaging artefacts

Rowlinson et al. (2019)
Mining the databases with machine learning

Rowlinson et al. (2019)
Interpreting TraP results

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