

LOFAR Tied Array All-sky Survey (LOTAAS) Periodicity Search for Pulsars

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LOTAAS Team

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Collaborator

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LOTAAS

- All northern sky survey for pulsars, RRATs and fast transients.
- 12 HBA sub-stations of superterp
- Observing freqeuncies 119-151 MHz, 12 kHz channels.
- Sampling time 492 µs.
- 1 hour dwell time.



Field of View (FoV)

- 222 beams per pointing First SKA-like pulsar survey
 - ▶ 3 sub-array pointings (SAP), incoherent beams (IB), 30 deg² FoV
 - ▶ 183 tied-array beams (TAB), 61 per SAP, 9 deg² FoV
 - 12 free TAB per SAP, known sources within SAP or "random"





Sky Coverage



- 3 passes of 651 pointings required to cover the northern sky with TABs
- Pass A completed (survey area covered by IBs)



Sky Coverage



- 612/651 pointings completed in Pass B
- ~10 observations/week



Data Processing

- Cartesius (SURFsara) 1500 nodes (24 cores, 64 GB RAM)
- Dedispersion of DM 0-500 pc cm⁻³
- Fourier-based periodicity searches
- Single pulse searches (see Michilli)
- ~3 hours processing time/ beam/node





Periodicity Candidates

- ~20,000 periodicity candidates per pointing — expecting 40 million candidates for the whole survey
- Machine Learning (ML) classifier to choose the best candidate
- First ML classifier by Lyon et al. 2016
 - 8 features from pulse profile & DM curve
 - Very Fast Decision Tree (VFDT) binary classifier
 - ~500 candidates per pointing
- But less effective with pulsars with wide pulse profile





Periodicity Candidates — Important Bits

- A. Pulse profile
- B. Time against pulse phase
- C. Sub-band against pulse phase
- D. DM curve





New ML Classifier — New Features

- 8 features from Lyon et al. + 12 new features
- 8 features from time against pulse phase & sub-band against pulse phase
 - correlation coefficient between each band & pulse profile
 - calculate statistics from coefficients
- 4 new features from DM curve
 - alternate method to calculate the statistics

 $\mu = \frac{1}{n}\sum_{i=1}^n y_i$

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (y_i - \mu)^2}{n}}$$

$$s = \frac{\frac{1}{n} \sum_{i=1}^{n} (y_i - \mu)^3}{\sigma^3}$$

$$k = \frac{\frac{1}{n} \sum_{i=1}^{n} (y_i - \mu)^4}{\sigma^4} - 3$$

Features from Lyon et al. — mean, standard deviation, skewness & kurtosis Tan et al. 2017, in prep.



New ML Classifier — New Features

- 8 features from Lyon et al. + 12 new features
- 8 features pulse phas pulse phas

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- calcula coefficients
- 4 new features from DM curve
 - alternate method to calculate the statistics

Alternate method to calculate mean, standard deviation, skewness & kurtosis

 $\mu = \frac{\sum xy}{\sum y}$





$$k = \frac{\frac{\sum (x-\mu)^4 y}{\sum y}}{\sigma^4} - 3$$



New ML Classifier — RFI class

- Separate known RFI instances from other non-pulsars (noise)
- 3 class classifier





New ML Classifier — Ensemble Classifier

- 5 VFDT classifiers with 5 different training datasets
- Pulsar class 5 different detection (if possible) of 295 unique pulsars in each training set
- Noise and RFI class 5 sets of 600 noise and 100 RFI instances sampled from a pool of 1267 noise and 150 RFI instances with replacement
- Ensemble classifier candidate is pulsar if 3 or more VFDT classifiers said so



New ML Classifier — Performance

- Improved performance
 - Pulsar recall rate from 96.2% to 98.7%
 - False positive rate from 2.5% to 1% — 60% reduction in candidates
- More importantly, able to identify pulsars with wide pulse profile, amongst other previously misclassified pulsars





LOTAAS Discoveries

- 53 pulsars discovered via periodicity searches
- 5 RRATs from single pulse searches (Michilli)
- 1 from targeted search (Kondratiev)

LOTAAS Overview Paper + 50 first discoveries Sanidas et al. 2017, in prep.

	J0039+35 P=536 ms DM=53	J0115+63 P=521 ms DM=63	J0121+14 P=1388 ms DM=17	J0302+22 P=1207 ms DM=18	J0305+11 P=861 ms DM=27
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LOTAAS Discoveries

- Timing of new pulsars by LOFAR
- Only ~half detected & timed by Lovell (1.4 GHz)
 — steep spectrum

LOTAAS Overview Paper + 50 first discoveries Sanidas et al. 2017, in prep.

J0039+35 P=536 ms DM=53	J0115+63 P=521 ms DM=63	J0121+14 P=1388 ms DM=17	J0302+22 P=1207 ms DM=18	J0305+11 P=861 ms DM=27
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LOTAAS Discoveries — J1658+36

- 1st LOTAAS binary
- 33 ms period
- DM ~3 pc cm⁻³
- ~3.0 days orbit
- Minimum companion mass ~0.87 M_{Sun}
- Not detected by Lovell at 1.4 GHz & 300 MHz





- New LOTAAS v2.0 pipeline (Sanidas)
 - various improvement (~30% performance increase)
 - to be deployed during summer
- Higher time resolution
 - reducing sampling time to 246 μs or 164 μs
- Expanding survey coverage to $\delta = -10$
- Adding Fast Folding Algorithm (FFA) to search pipeline (Morello)
 - FFA more sensitive to long period pulsar and/or pulsars with small duty cycle



Conclusion

- LOTAAS is the deepest low-frequency pulsar survey ever performed
- New ML classifier implemented to periodicity search pipeline
- 54 pulsars + 5 RRATs found so far expect ~100 new discoveries by end of survey