LOW-FREQUENCY EVOLUTION OF PULSAR PROFILES WITH LOFAR

MAURA PILIA
On behalf of the LOFAR Pulsar Working Group
### LOFAR Pulsar Working Group

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<td>Joris Verbiest</td>
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<td>Patrick Weltevrede</td>
<td>University of Manchester</td>
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<tr>
<td>Kimon Zagkouris</td>
<td>University of Oxford</td>
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LOFAR’s Enormous Frequency Range

PSR B0809+74 detected down to 15MHz
Observations with LOFAR - Advantages

Large fractional bandwidth (up to \( \sim 80 \) MHz) can be recorded at any time allows for continuous studies of the evolution, as opposed to studies via a number of widely separated narrow bands:

**CONTINUOUS FREQUENCY COVERAGE**

Ability to track sources:
- an adequate number of pulses can be collected in a single observing session rather than having to combine several short observations

Excellent frequency and time resolution necessary for properly dedispersing the pulses as well as resolving narrow features in the profile.

LOFAR is also capable of coherently dedispersing the data.
Pulsar Magnetosphere

- **Outer Gap**
- **Polar Cap**
- **Slot Gap**
Building the Model

Conal components

CORE - CONE vs PATCHY

Single profiles

Height vs Longitude

Patches

CORE - CONE

(a) Core and Cone

(b) Patchy Beams

Rankin 1983+

Lyne & Manchester 1988

Period-width dependance

Complex profs = complex PA

RFM
Building the Model

- Single profiles
- Conal components
- Period-width dep.
- Height vs Longitude

Karastergiou & Johnston 2007
Pulsar Emission Regions

Credits: Anna Bilous
Profile evolution

Hassall et al. 2012

extrinsic effects

intrinsic effects

B0329+54

B0809+74
LOFAR Observations:

HBA observations

SUPERTERP
120 – 167 MHz
240 subbands
17 minutes

LBA observations

FULL CORE
25 pulsars
15 – 61 MHz
57 minutes

Using the full core has allowed to go a factor 4x deeper!
LOFAR Observations:

HBA observations
- SUPERTERP
  - 120 – 167 MHz
  - 240 subbands
  - 17 minutes

LBA observations
- FULL CORE
  - 25 pulsars
  - 15 – 61 MHz
  - 57 minutes

Using the full core has allowed to go a factor 4x deeper!

+ WSRT @ 300MHz
+ Lovell @ 1.5 GHz
Observations with LOFAR - Analysis

psrfits format data obtained from the initial HDF5 format

Dedispersion and folding using the prepfold tool from presto and an accurate rotational ephemeris

Multi-gaussian fit to the profiles in a number of frequency bands
Observations with LOFAR - Alignment

WSRT 1.4 GHz

WSRT 300 MHz

LOFAR 140 MHz

PSR B0402+61

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</table>
Pulsar Profile Variation - Magnetospheric?

Pilia et al., in prep
Pulsar Profile Variation - Widening

Pilia et al., in prep
Pulsar Profile Variation –

External Effects

DM smearing

Scattering

Pilia et al., in prep
Pulsar Profile Variation - Single pulses

B0329+54
Radius to Frequency Mapping (RFM)

Hassall et al. 2012, A&A
• Cold-dispersion law good to 1/100,000

• For PSR B1133+16 all radio frequencies come from a region $\Delta R < 59$ km in altitude below 110 km from NS surface (0.2% of the light cylinder)
RFM – Peaks Separation

We calculated, in the case of multiple peaks pulsars, the separation of the two most prominent peaks as it evolves with frequency.

B0525+21

Pilia et al., in prep
For all pulsars, where possible, we calculated the width of the profile at the 10% level of the full width of the outer components of the profile. This gives an indication on the opening of the cone of the emission.

\[ \text{Index} = -0.1 \]

Pilia et al., in prep
RFM - Comparison with the models - Rankin's Groups for Multiple Peaks

Pilia et al., in prep
Profile Evolution – Peaks Ratio

B1133+16

P2/P1

Preliminary

Pilia et al., in prep
The broadening at low radio frequency is caused by the separation of the individual beams of the two propagation modes, and the depolarization at high frequency results from the merger of their orthogonal polarizations.
In total, we have obtained high-quality polarisation profiles at 150 MHz, for 20 pulsars.
Interstellar Scattering

Only down to 140 MHz!
Frequency Scaling of Scattering

Preliminary

Kimon Zagouris
Not all pulsars that were expected to be scattered in LOFAR data actually are...
Evolution for MSPs?

Careful modelling of the evolution will aid in precision timing: creation of 2D (frequency and phase) analytic templates.
LOFAR Tied-Array All-Sky Survey (LOTAAS)

- ~2x more sensitive than LOTAS (coh. pilot survey)
- ~2x more sensitive than LPPS (incoh. pilot survey)
LOFAR Pulsar Discoveries

LOTAAS Survey

<table>
<thead>
<tr>
<th>PSR</th>
<th>Period (ms)</th>
<th>Distance (pc)</th>
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<td>J0140+56</td>
<td>1775</td>
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<td>J2350+31</td>
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Summary and Conclusions

We are completing the analysis of 100 PSRs

- Intrinsic variations in the profiles (variation of the height of emission, sites of the emission)
- Extrinsic variations in the profiles (ISM)

Opportunity to go much deeper

- Full core
- Coherent dedispersion
- 80 MHz band
Summary and Conclusions

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Opportunity to go much deeper

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THANK YOU!
Pulsar Spectra

B1541+09

Flux (mJy)

Frequency (MHz)

Credits: Tom Hassall
Spectra

120 pulsars total

PSR B0943+10

Period: 1.098 s
DM: 15.32 pc cm^-3

No obvious difference between normal pulsars and MSPs

Hassall et al. 2014, in prep.
Spectral Index Distribution

Fig. 3: A histogram of the high-frequency spectral indices of all of the pulsars in our sample. The black line shows slow pulsars, and the grey area shows MSPs. The mean of the distributions are both at $-1.9$, the median is $-1.9/-1.6$ for slow and MSPs respectively, and the standard deviations 0.4/0.9.

Hassall et al. 2014, in prep
Fig. 3: A histogram of the high-frequency spectral indices of all of the pulsars in our sample. The black line shows slow pulsars, and the grey area shows MSPs. The mean of the distributions are both at $-1.9$, the median is $-1.9/-1.6$ for slow and MSPs respectively, and the standard deviations $0.4/0.9$. 

Malofeev 1996
LOFAR Tied-Array Multi-Beam

See Mol & Romein 2011 for multi-beam tied-array benchmarking results
LOTAAS
Single Pointing

First SKA-like pulsar survey

222 beams per pointing

Extra-galactic burst per 10hr observing?