

LOFAR Tied-Array All Sky Survey

An update on the survey for Pulsars
and Transients

Sally Cooper

University of Manchester

+ LOFAR Pulsar Working Group

MANCHESTER
1824

The University of Manchester

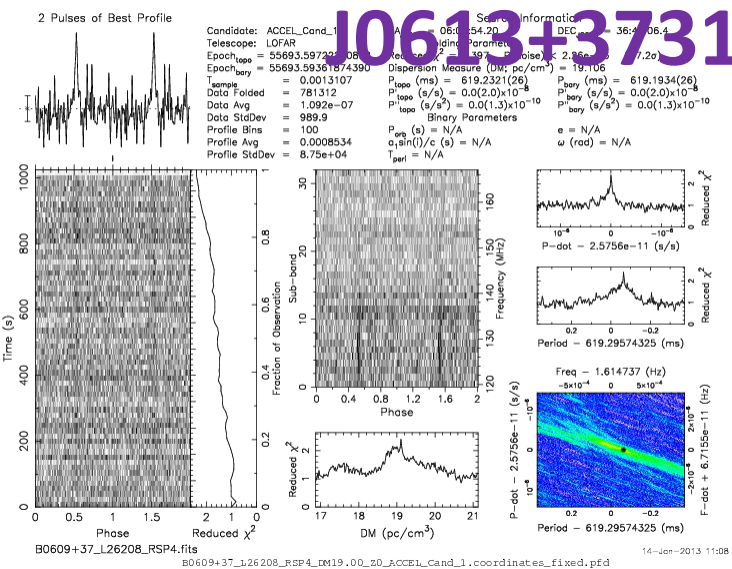
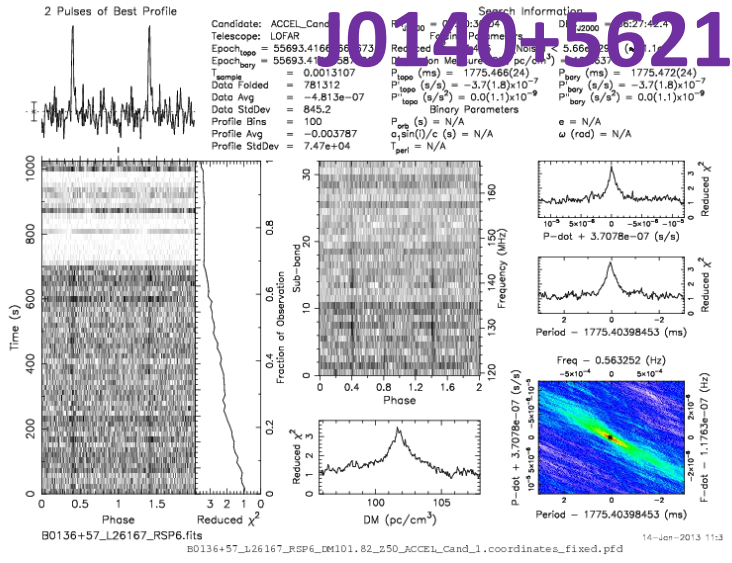


Science & Technology
Facilities Council

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Joris Verbiest	MPI für Radioastronomie
Patrick Weltevrede	University of Manchester
Kimón Zagkouris	University of Oxford

LOTAS Discoveries



The LOFAR pilot surveys for pulsars and fast radio transients
 T. Coenen 2014

LAST YEAR...

KAIRA Project @KairaProject · 8 Apr 2014

Sally Cooper announces #LOFAR has discovered two new pulsars. That's 4 total, with those from the commissioning team. #lofarscience2014

KAIRA Project @KairaProject · 8 Apr 2014

#LOFAR is using #machinelearning to teach the radio telescope processors to find new pulsars. #lofarscience2014 #bigdata #supercomputer

LOFAR Tied-Array All Sky Survey (LOTAAS)

All Northern sky

Pulsars and Transients

Started Dec 2012

Superterp HBA stations

3 sub array pointings (SAP)

67 tied-array beams per SAP

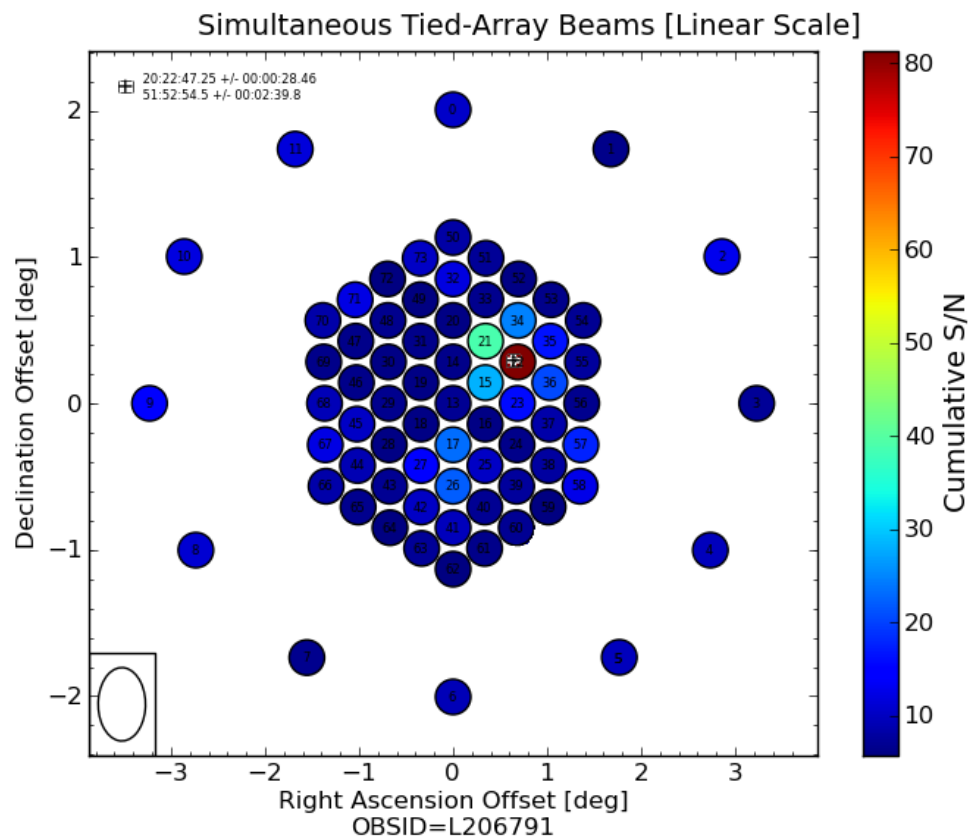
+12 TABs on known sources

119 – 151 MHz

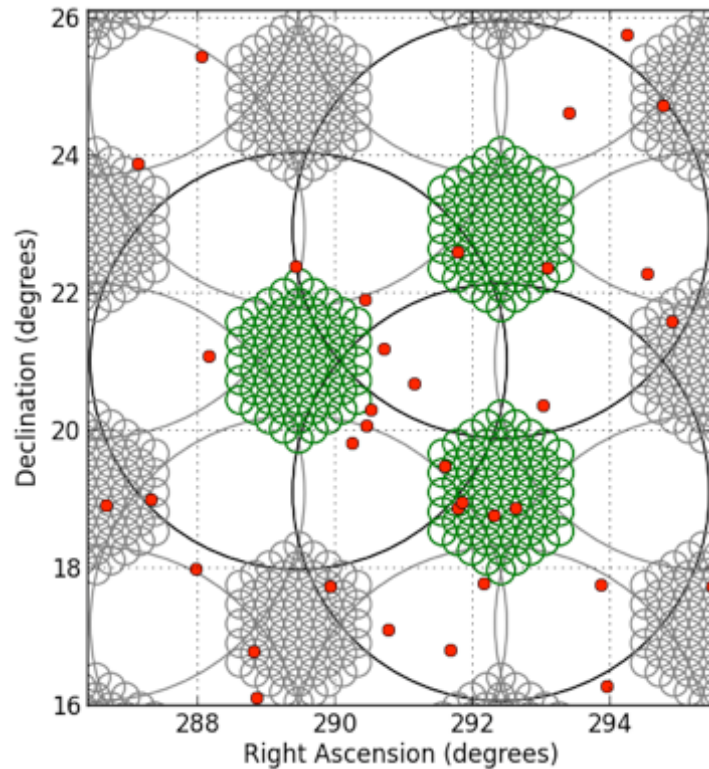
1 hour observations

0.49 ms sampling time

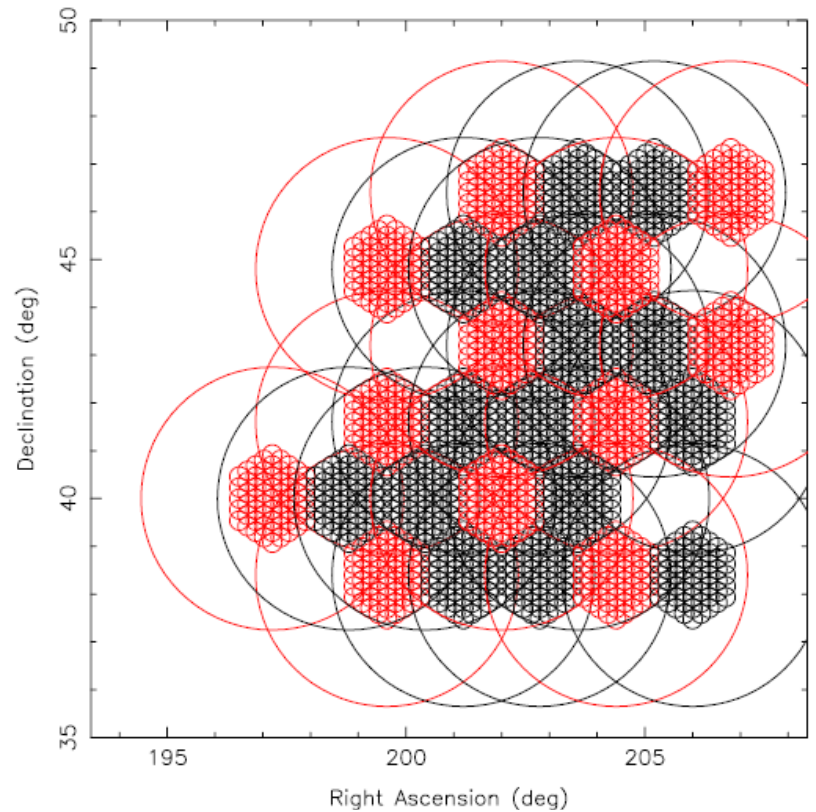
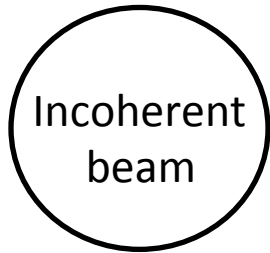
32 MHz bandwidth per SAP



LOTAAS Survey



- Known pulsars
- Tied-array beam



Multiple passes on sky:
3x with incoherent beams
1x full coverage tied-array beams

Cartesius

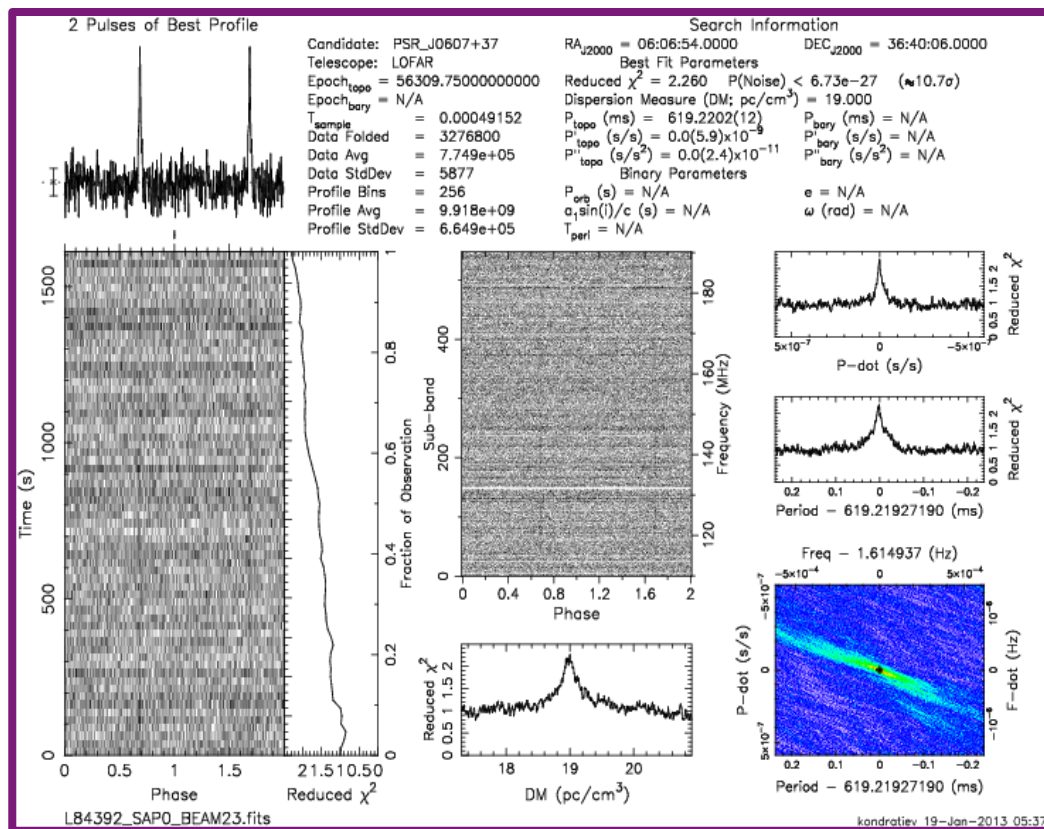
- 4 TB per pointing
- 1st year data was processed at Manchester but limited by download and processing power
- Cartesius is the Dutch National Supercomputer
- Granted 10 million CPU hours
- 500 nodes with 24 CPUs
- Download from LTA
- 5 hours to process single beam (periodicity + single pulse)
- 5 hours to process full pointing (maybe not in practice)



Since Dec 2013

Current Status

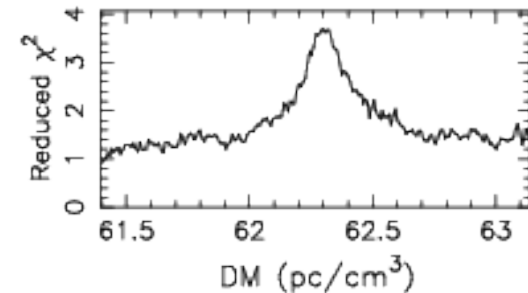
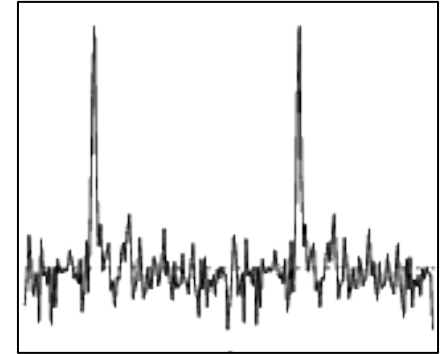
- 425 observed pointings out of the 650 in Pass A
- Processed 280 pointings (period + single pulse)
- 5 million candidates (PRESTO)
- Apply machine learning classifier
- 100+ known pulsar redetections



Candidate plot with known pulsar detection

ML Classifier

- 5 million candidates
- ~40 million total
- Too many to visually inspect
- Generate scores from pulse profile and DM-SNR curve
- Apply Decision Tree Classifier (VFDT)
- Used redetection of known pulsars plus first discovery pulsars as training set
- 6 more discoveries using classifier
- 2% positive predictions (100,000 viewed)

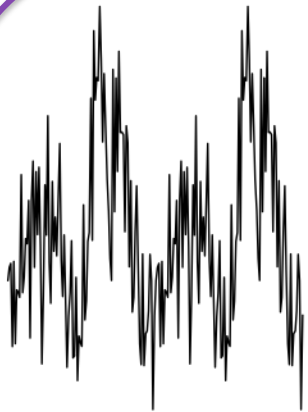


Lyon et al 2015

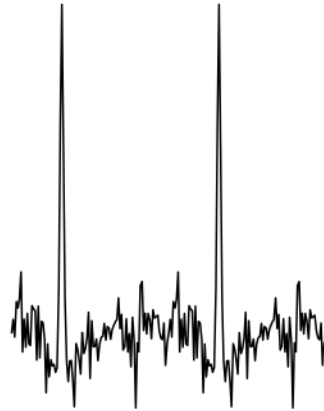
10 Pulsar Discoveries

*Discovered by eye

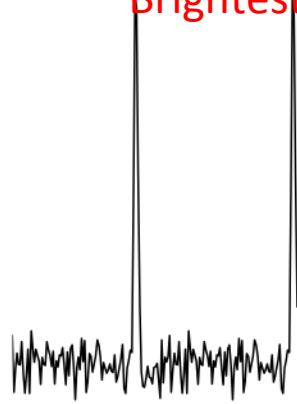
Brightest



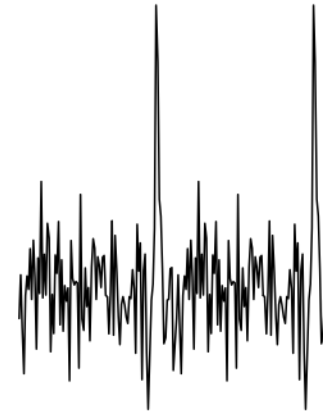
J1529+40*
P = 0.476 s
DM = 6.6
 σ = 13.6



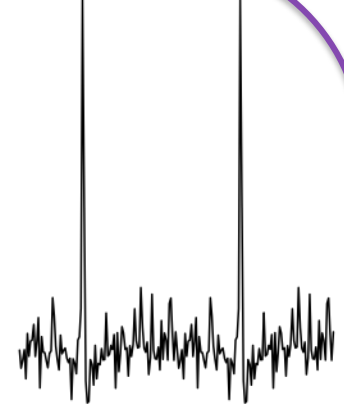
J0935+33*
P = 0.961 s
DM = 18.4
 σ = 19.6



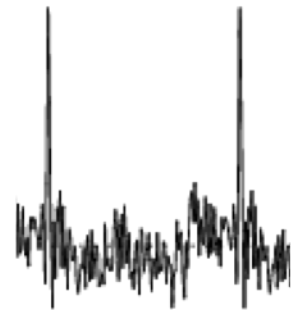
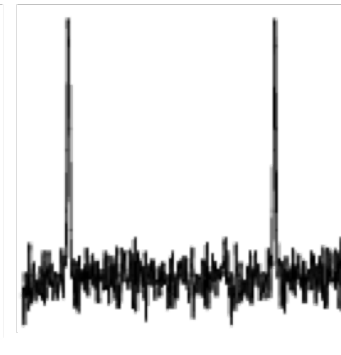
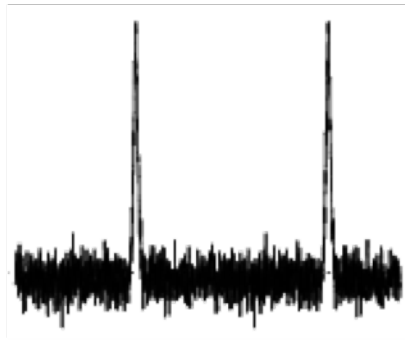
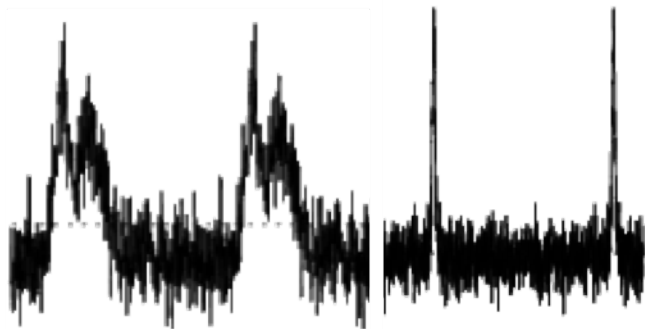
J2350+31*
P = 0.508 s
DM = 39.1
 σ = 33.8



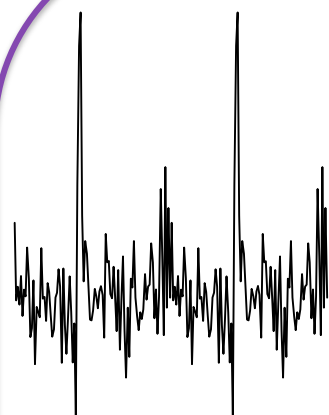
J1809+17*
P = 2.066 s
DM = 47.0
 σ = 9.3



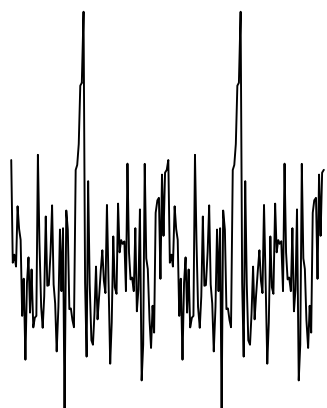
J0317+13
P = 1.974 s
DM = 12.9
 σ = 17.6



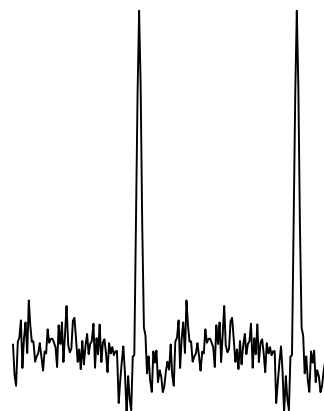
10 Pulsar Discoveries



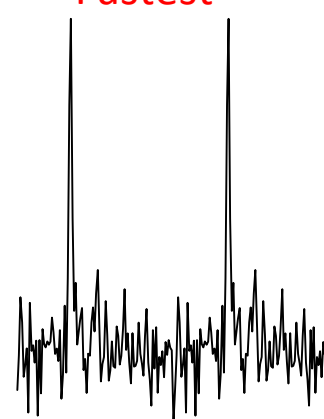
J0305+11
P = 0.862
DM = 27.8
 σ = 8.9



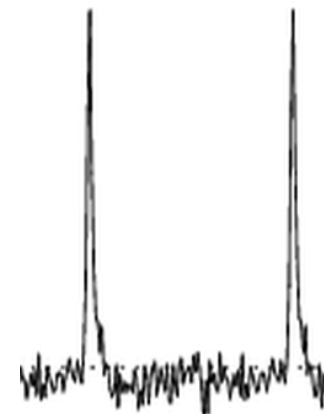
J2057+21
P = 1.116 s
DM = 73.6
 σ = 5.8



J2336-01
P = 1.029 s
DM = 19.6
 σ = 31.5

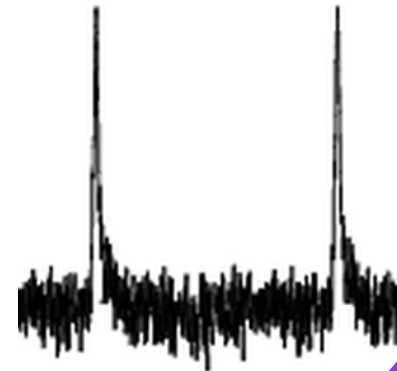
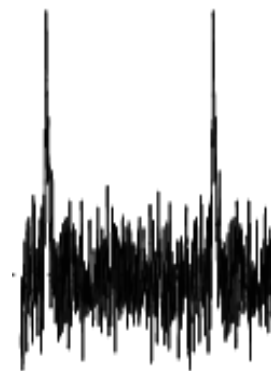
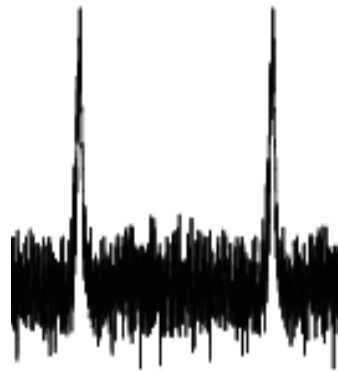
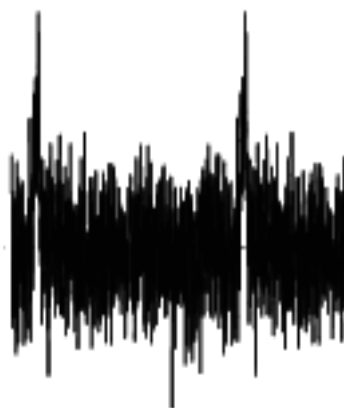
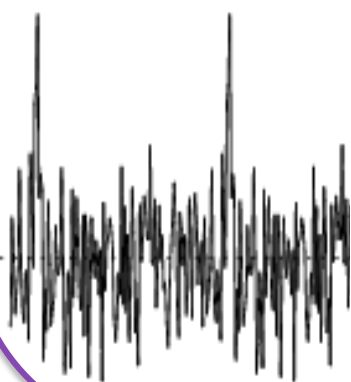


J1814+22
P = 0.253 s
DM = 62.3
 σ = 11.8

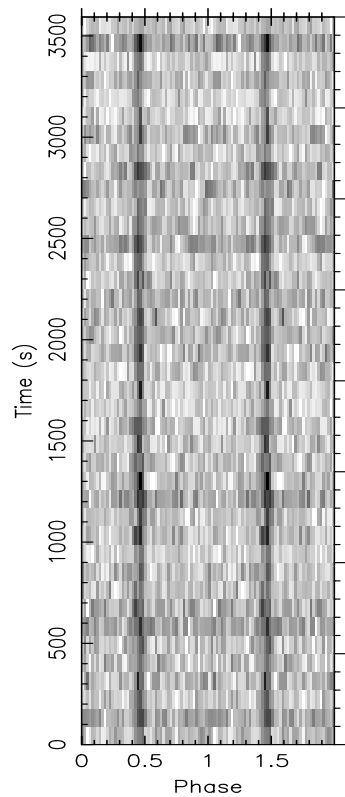
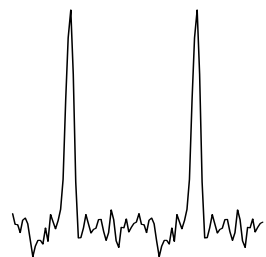


J2305+31
P = 0.341 s
DM = 46.1
 σ = 29.4

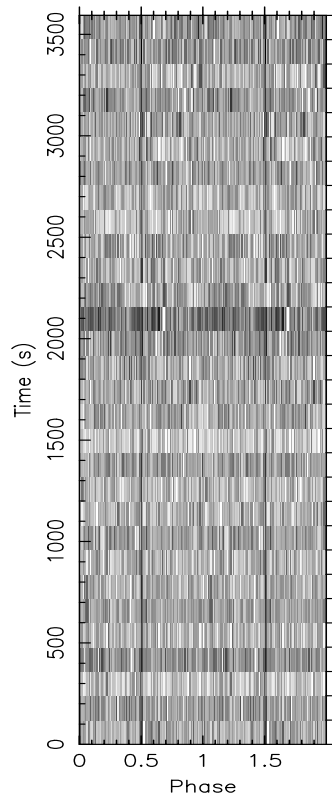
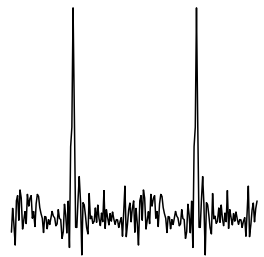
Fastest



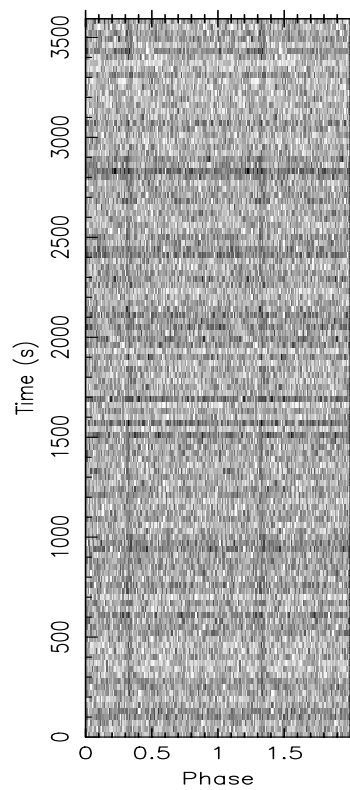
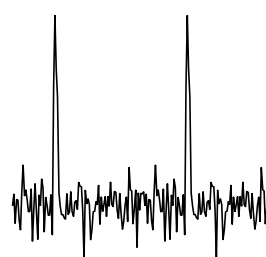
GBNCC independent discoveries



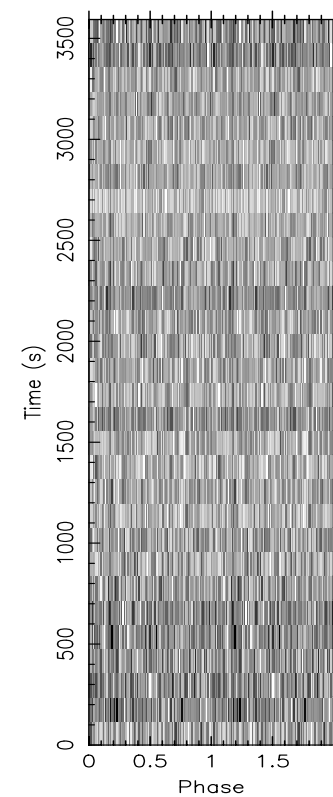
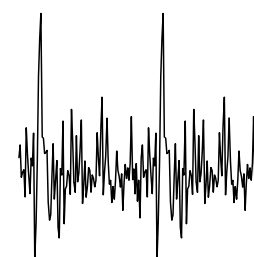
J0216+52



J1815+55

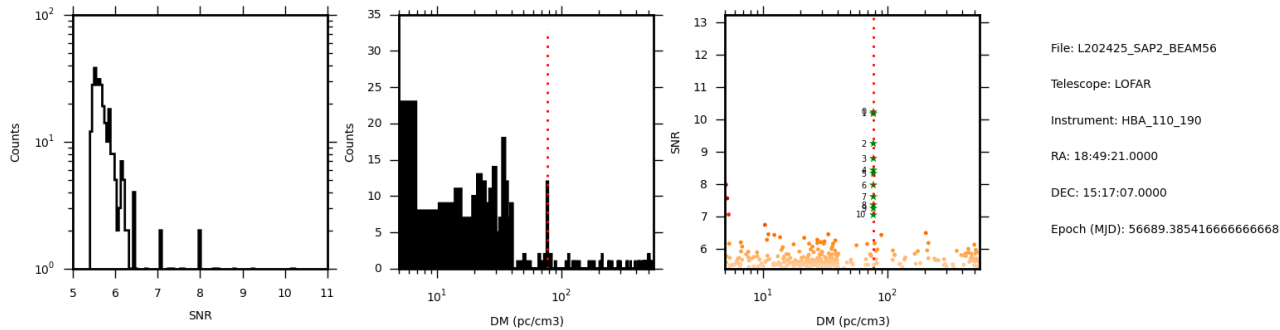


J1800+50

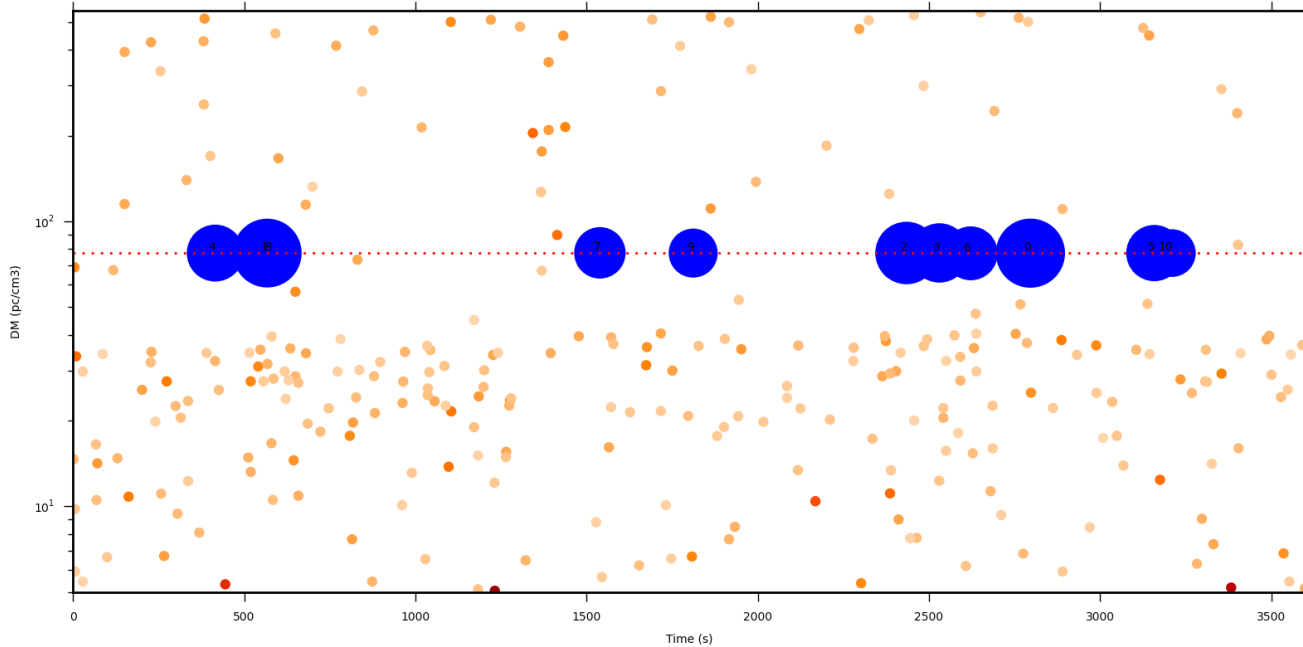


J2001+42

RRAT J1849+15 Discovery



J1849+15
Period = 2.233 seconds
DM = 77.4 pc/cm²

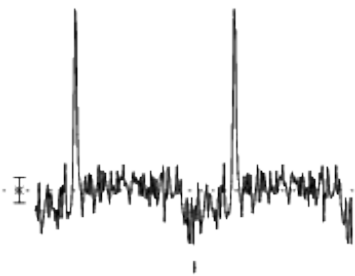


Daniele Michilli

Single Pulse Analysis

Confirmation of J1849+15

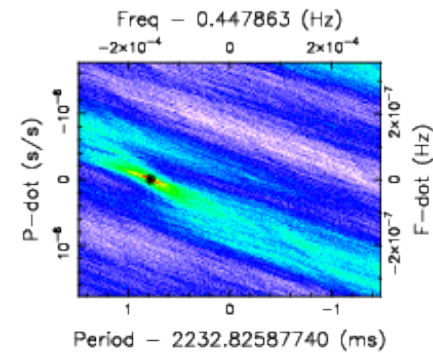
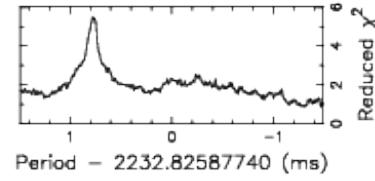
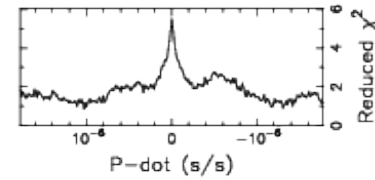
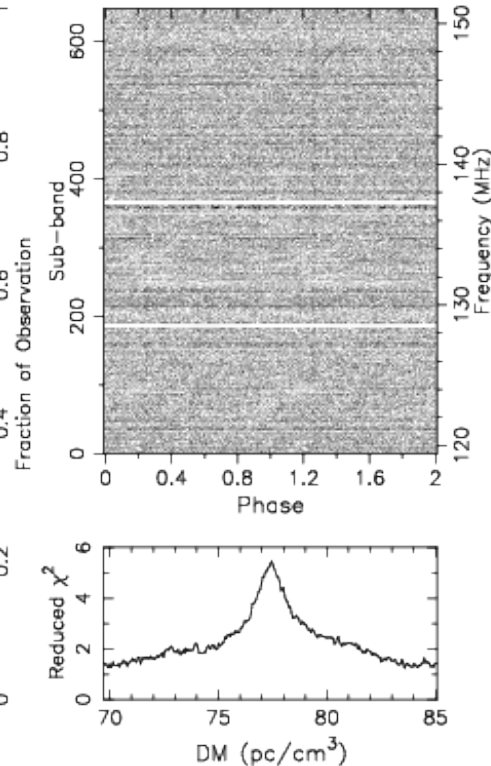
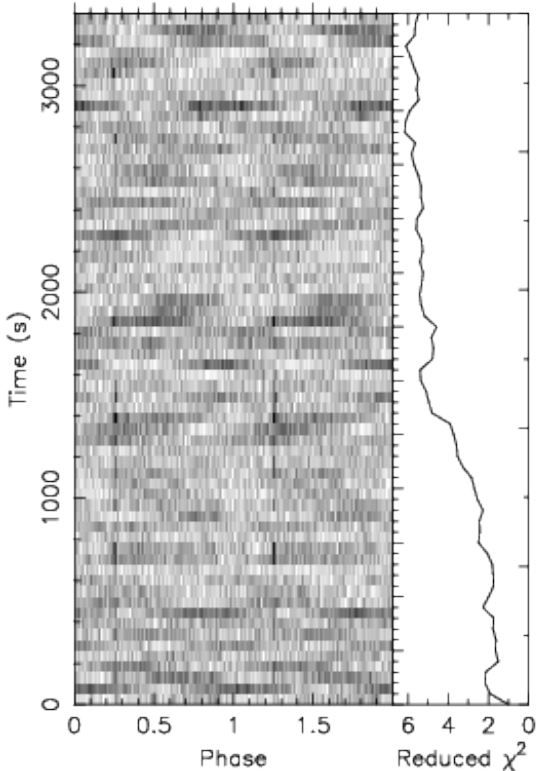
2 Pulses of Best Profile



Candidate: PSR_J1849+15
 Telescope: LOFAR
 Epoch_{topo} = 57121.21666666667
 Epoch_{bary} = N/A
 T_{sample} = 0.00049152
 Data Folded = 6815744
 Data Avg = 3.061e+05
 Data StdDev = 3621
 Profile Bins = 128
 Profile Avg = 1.629e+10
 Profile StdDev = 8.356e+05

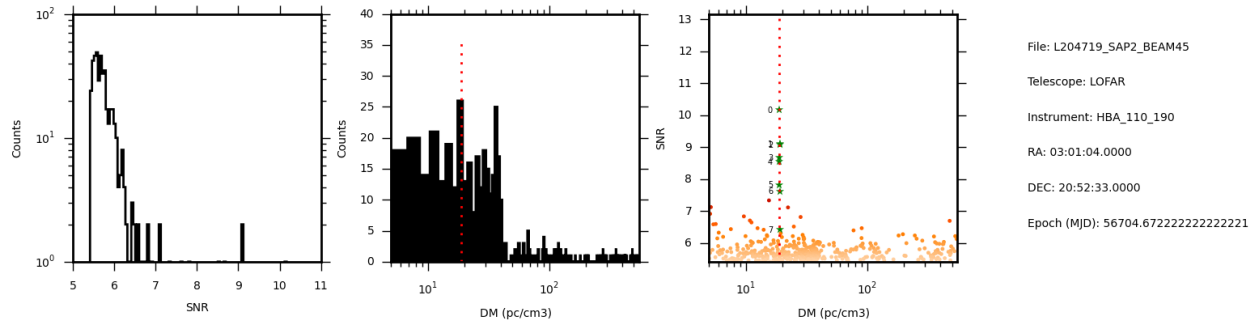
Search Information
 RA_{J2000} = 18:48:56.0000 DEC_{J2000} = 15:17:07.0000
 Best Fit Parameters
 Reduced χ^2 = 5.472 P(Noise) < 3.97e-79 ($\approx 18.8\sigma$)
 Dispersion Measure (DM; pc/cm³) = 77.460
 P_{topo} (ms) = 2233.605(12) P_{bary} (ms) = N/A
 P $\dot{}$ _{topo} (s/s) = 0.0(2.8)x10⁻⁸ P $\dot{}$ _{bary} (s/s) = N/A
 P $\ddot{}$ _{topo} (s/s²) = 0.0(5.4)x10⁻¹¹ P $\ddot{}$ _{bary} (s/s²) = N/A
 Binary Parameters
 P_{orb} (s) = N/A e = N/A
 a₁sin(i)/c (s) = N/A ω (rad) = N/A
 T_{perl} = N/A

Source didn't show up
 in original periodicity
 search



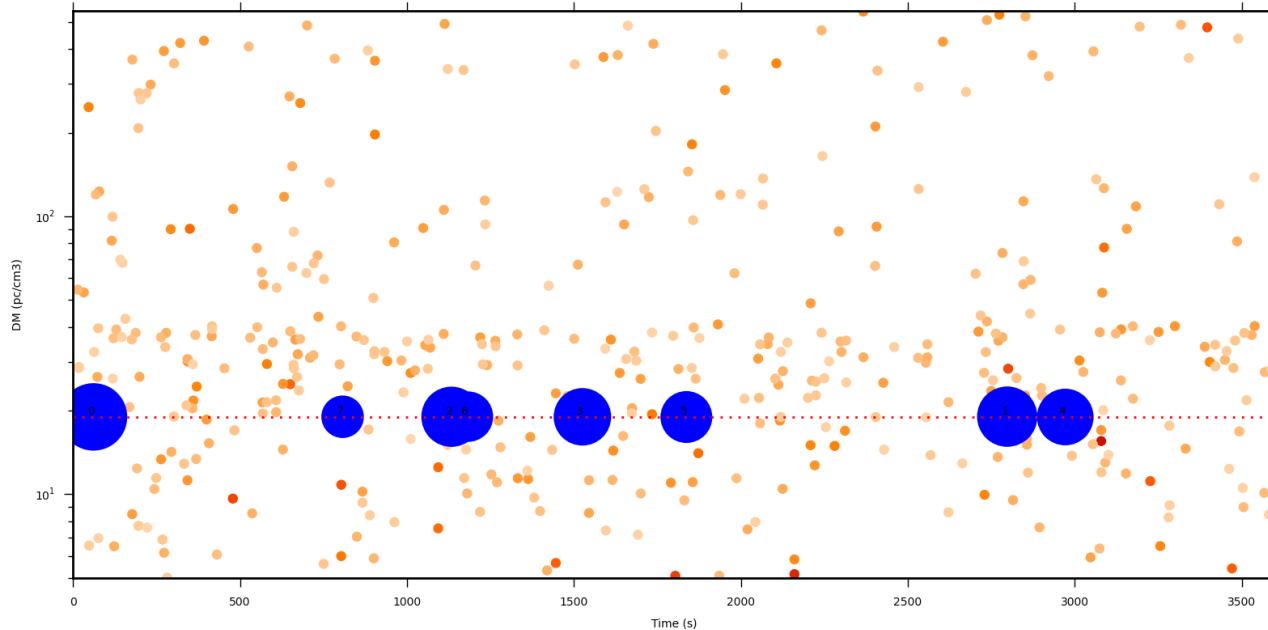
Observed with
 LOVELL @ 1400MHz

RRAT J0301+20 Discovery



File: L204719_SAP2_BEAM45
Telescope: LOFAR
Instrument: HBA_110_190
RA: 03:01:04.0000
DEC: 20:52:33.0000
Epoch (MJD): 56704.67222222222221

J0301+20
Period = 1.207 seconds
DM = 19.0 pc/cm²



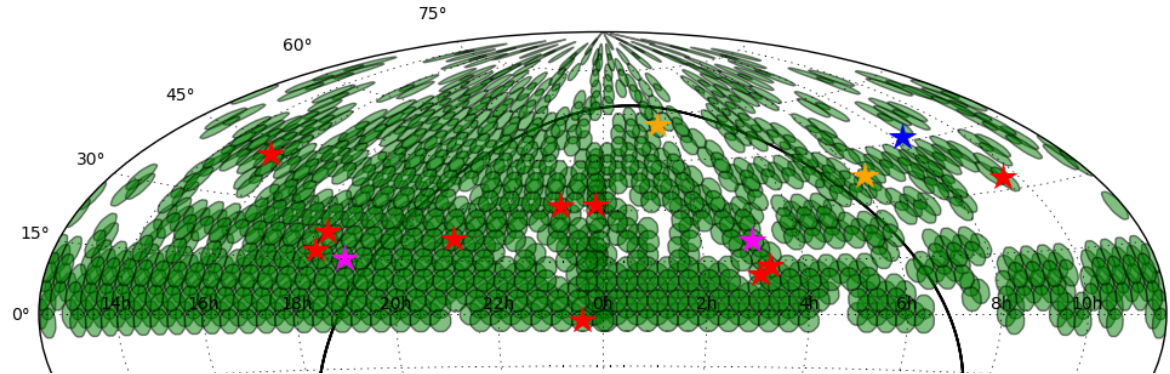
Cartesius System Failure

- Project area on Lustre filesystem
- First failure: 23 March 2015
- Second Failure: 17 April 2015
- Imposed maximum file number quota
- Many files lost (total 10 – 15 % of results)
- Restoration Job – Sotiris Sanidas
- 2 month delay
- Total stop in processing
- New more efficient pipeline
- Back up and running soon!

Observed Pointings

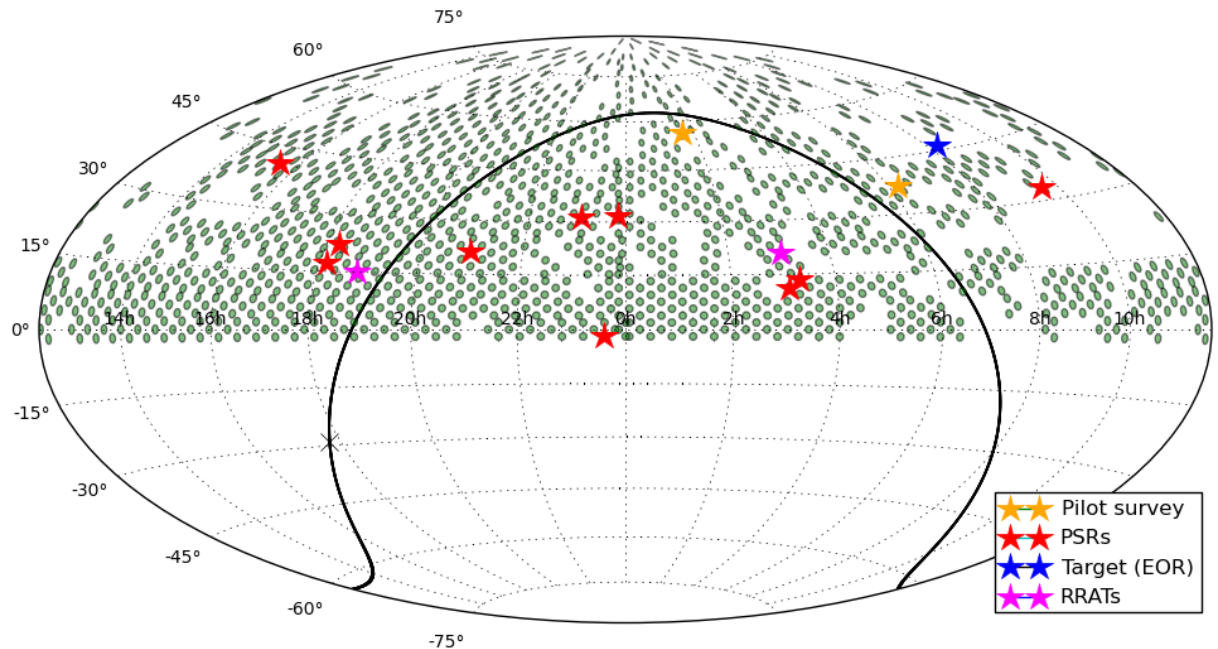
Incoherent beams

Sensitivity of SAP is lower
Only 1 discovery was also
seen in the SAP as well
as the TAB



Tied-array beams

Sparse coverage
Fill in the gaps on
2nd and 3rd pass



Timing new pulsars

LOFAR

J0140+56
J0613+37
J1529+40
J0935+33
J2350+31
J1809+17
J0317+13
J0305+11
J2057+21
J2336-01
J1814+22
J2305+31

2x RRATs

International stations Chilbolton, German, Nancay

J0935+33
J1529+40
J1814+22
J2336-01
J2350+31
J2305+31

Lovell @ 1400 MHz

J1529+40
J1814+22
J2305+31
J0613+37
J0140+56

+RRAT

Anything interesting?

J2305+31 seems to show high variability in SNR

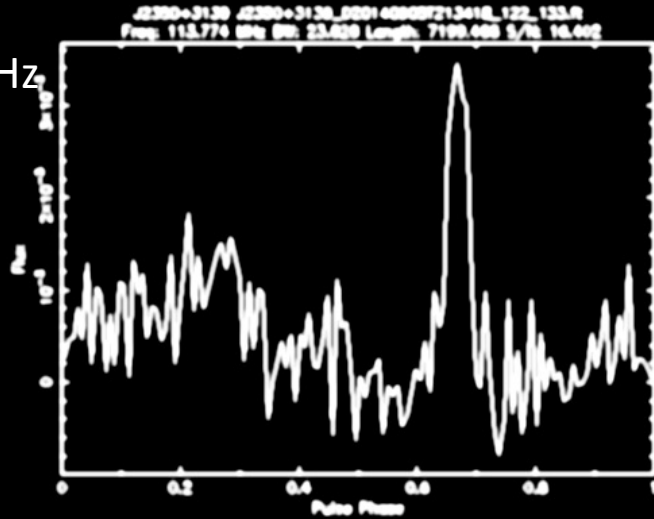
Those with measured pdots all fall in the centre of the 'normal' cluster of pulsars on the p-pdot diagram

Steep spectrum? Tried all pulsars with Lovell but not all of them are visible at 1400 MHz

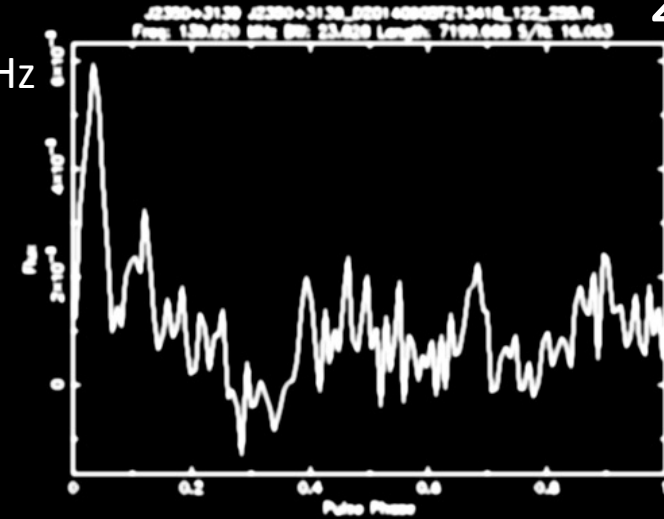
International Stations

Nançay
J2350+31
2 hours

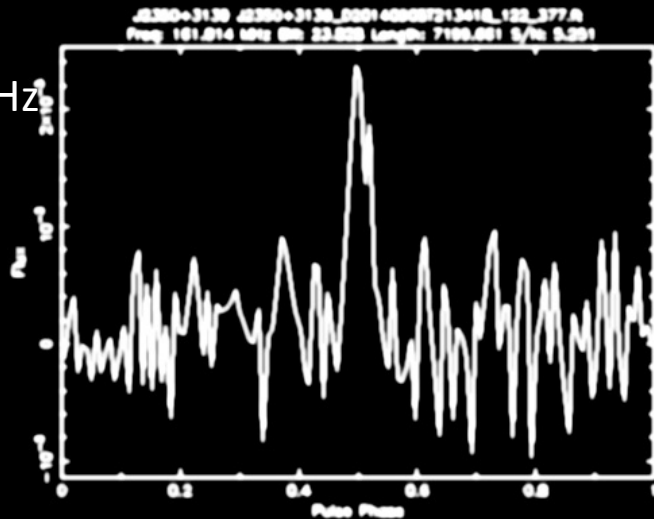
113 MHz



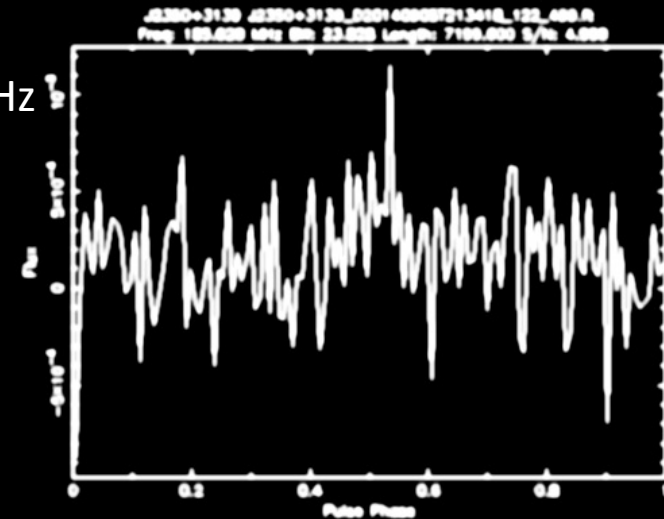
138 MHz



161 MHz



185 MHz



Summary

- LOFAR has made a total of 15 new pulsar discoveries
 - 2 from commissioning surveys
 - 10 from LOTAAS periodicity (Cooper)
 - 2 RRATs from LOTAAS single pulse analysis (Michilli)
 - 1 discovery from targeted (Kondratiev)
- 5+ million periodicity candidates
- Machine Learning classifier 2% positive predictions
- New single pulse search analysis: Daniele Michilli
- Timing with central LOFAR, Lovell at 1.4 GHz and Int'l stations
- Discovery webpage <http://www.astron.nl/lotaas>

Thank you!