LOW-FREQUENCY EVOLUTION OF PULSAR PROFILES WITH LOFAR

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On behalf of the LOFAR Pulsar Working Group

ASTRON

LOFAR

PWG

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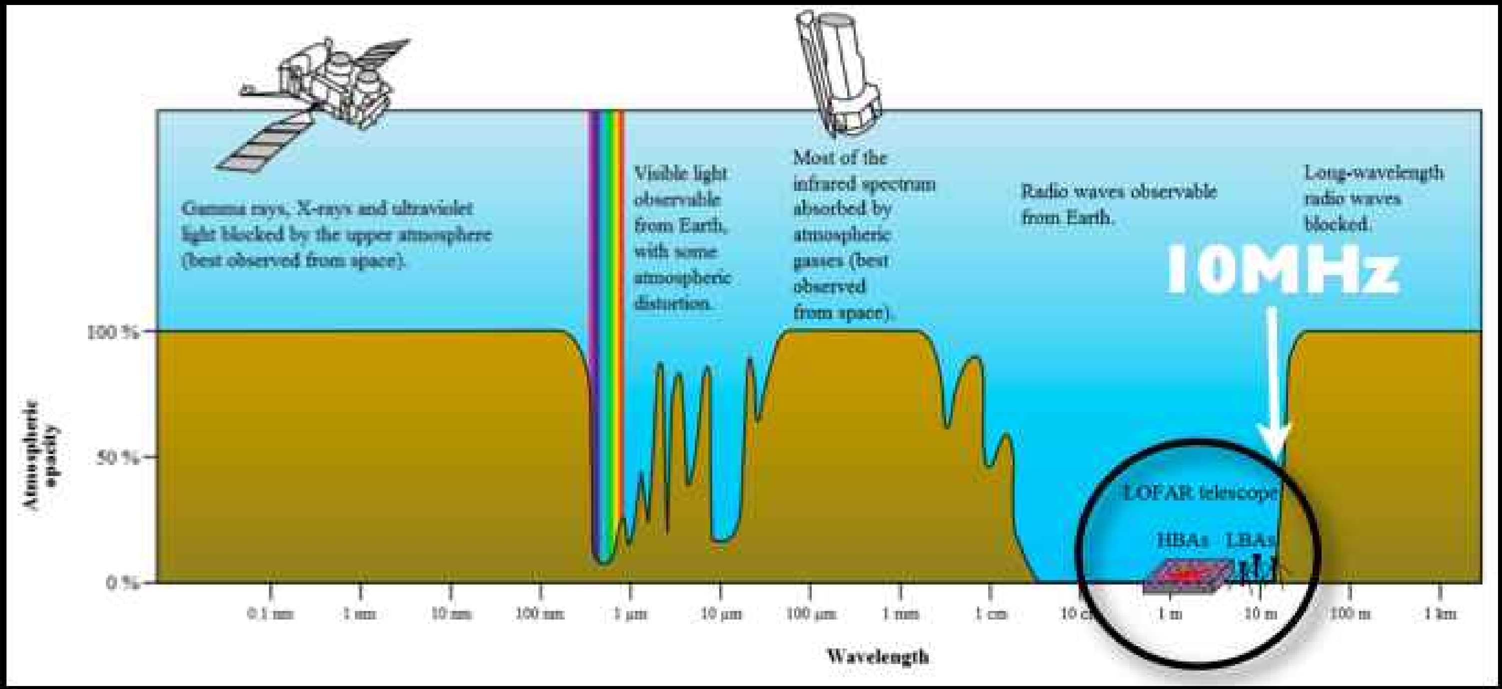
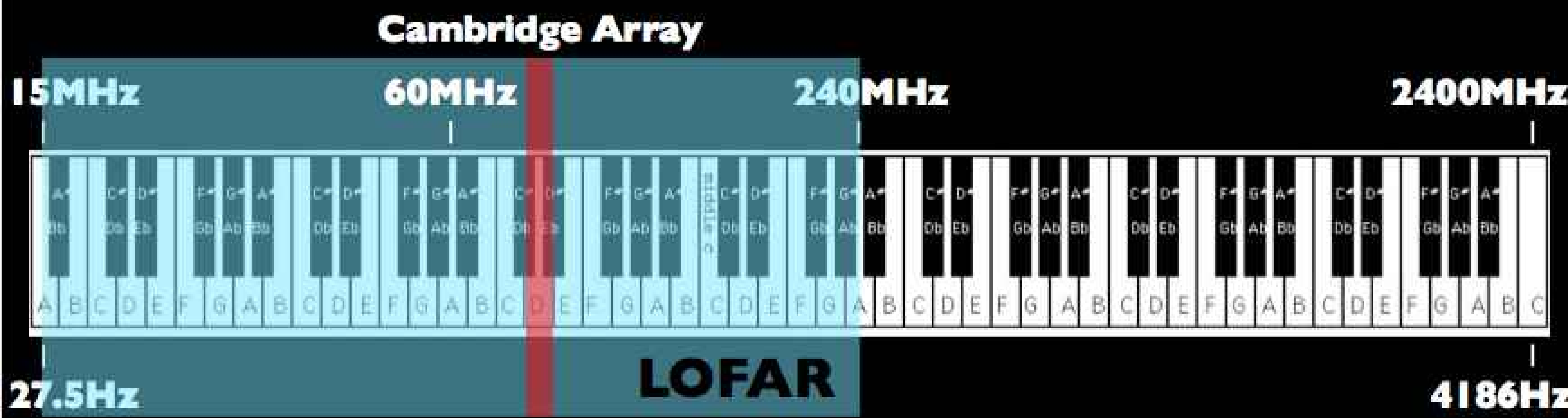
Joris Verbiest	MPI für Radioastronomie
Patrick Weltevrede	University of Manchester
Kimon Zagkouris	University of Oxford

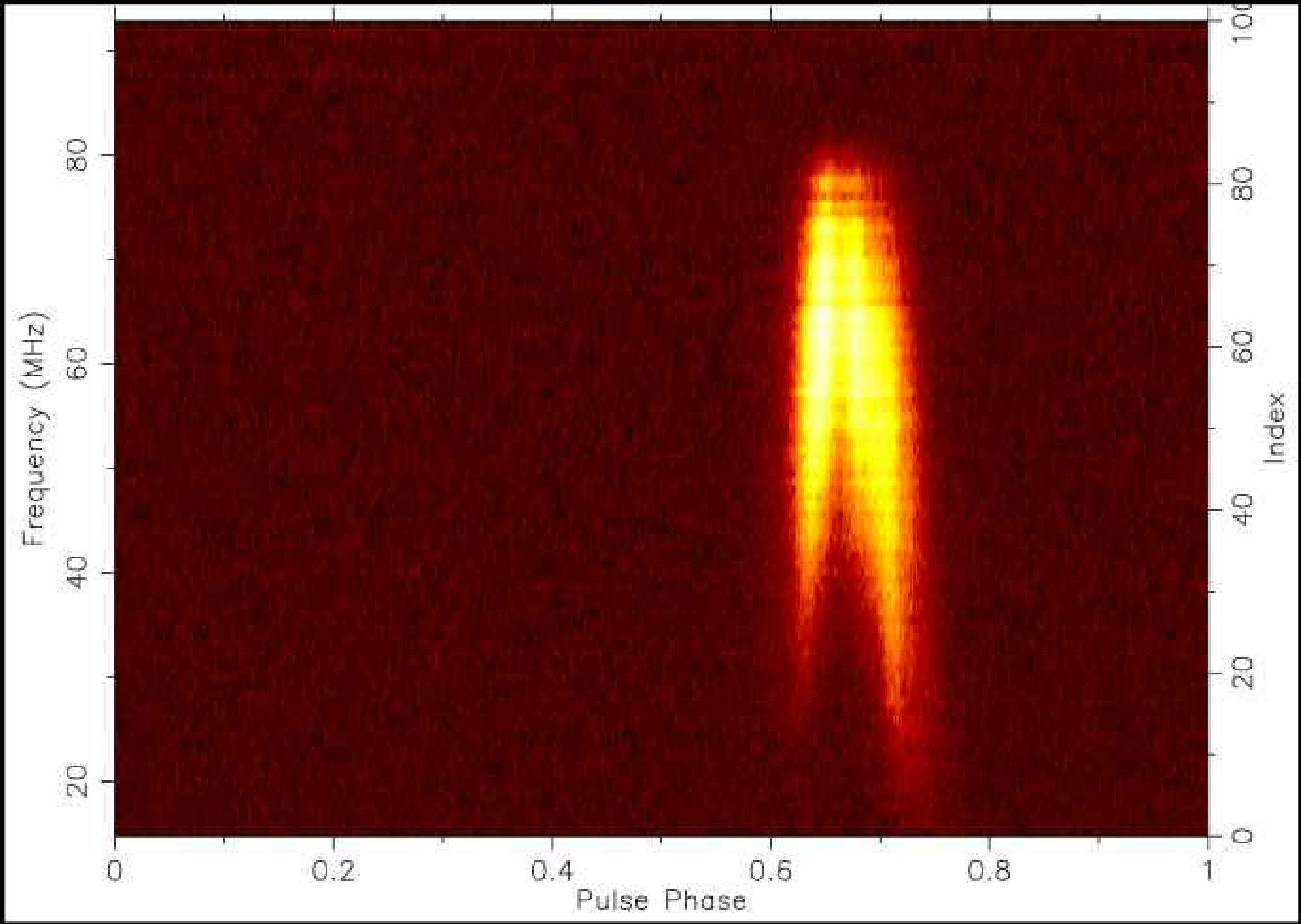
LOFAR's Enormous Frequency Range





LOFAR's Enormous Frequency Range

93MHz



15MHz

PSR B0809+74 detected down to 15MHz

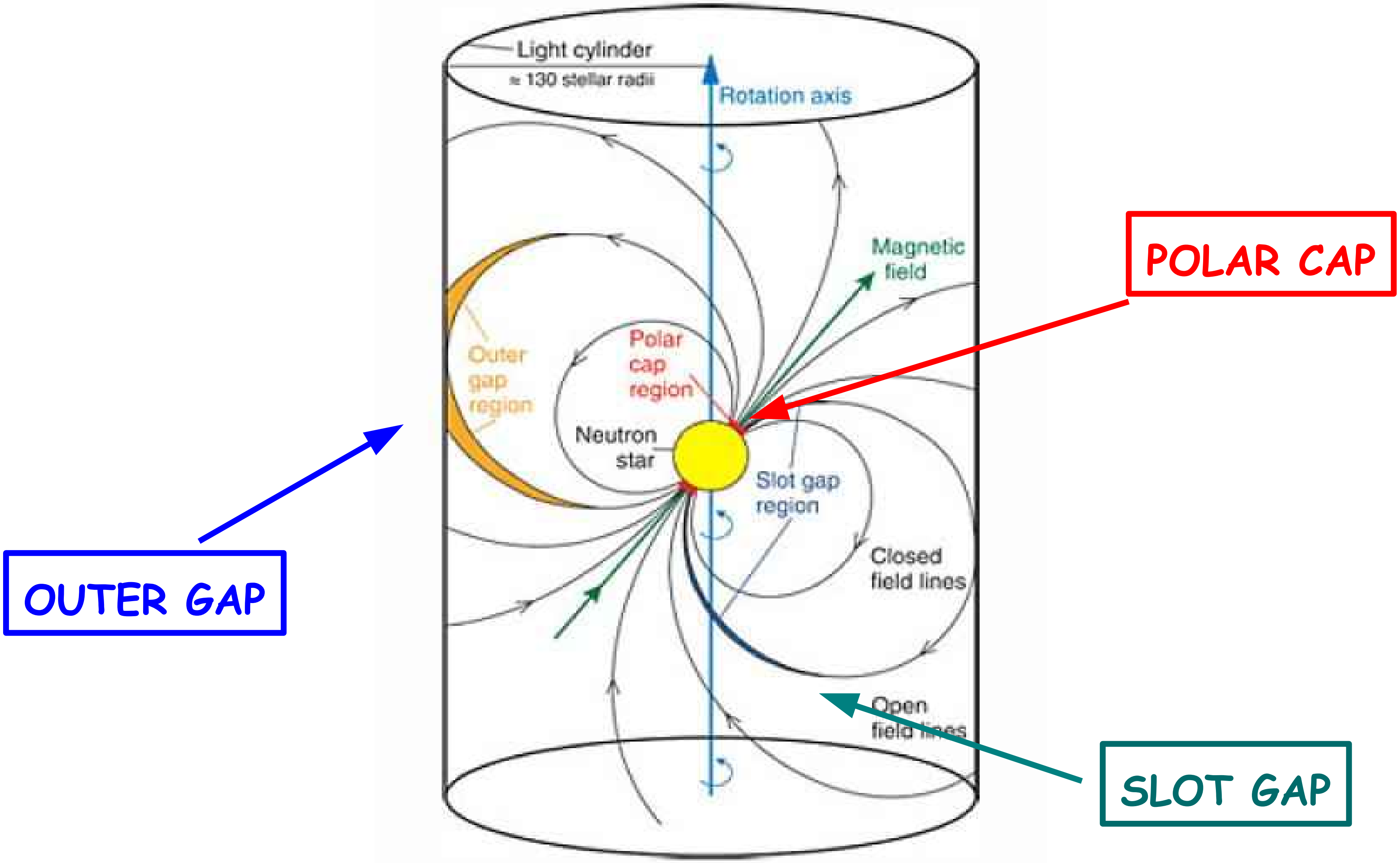
Observations with LOFAR - Advantages

Large fractional bandwidth (up to ~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.
<u>LOFAR is also capable of coherently dedispersing the data.</u>

Pulsar Magnetosphere



Building the Model

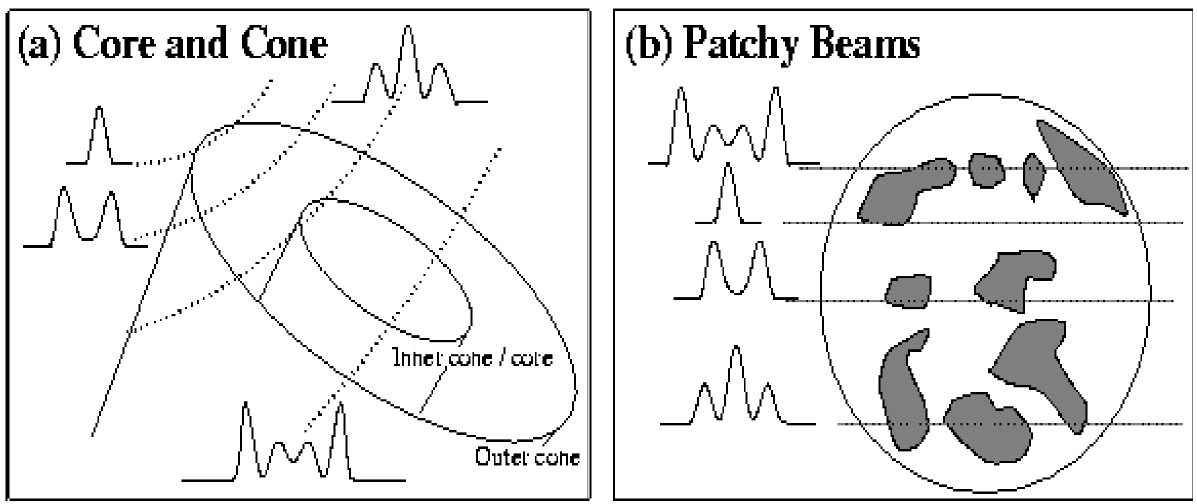
Height vs Longitude

Conal components

CORE - CONE vs PATCHY

Single profiles

Patches



Rankin 1983+ Lyne & Manchester 1988

Period-width dependance

Complex profs = complex PA

RFM

Building the Model

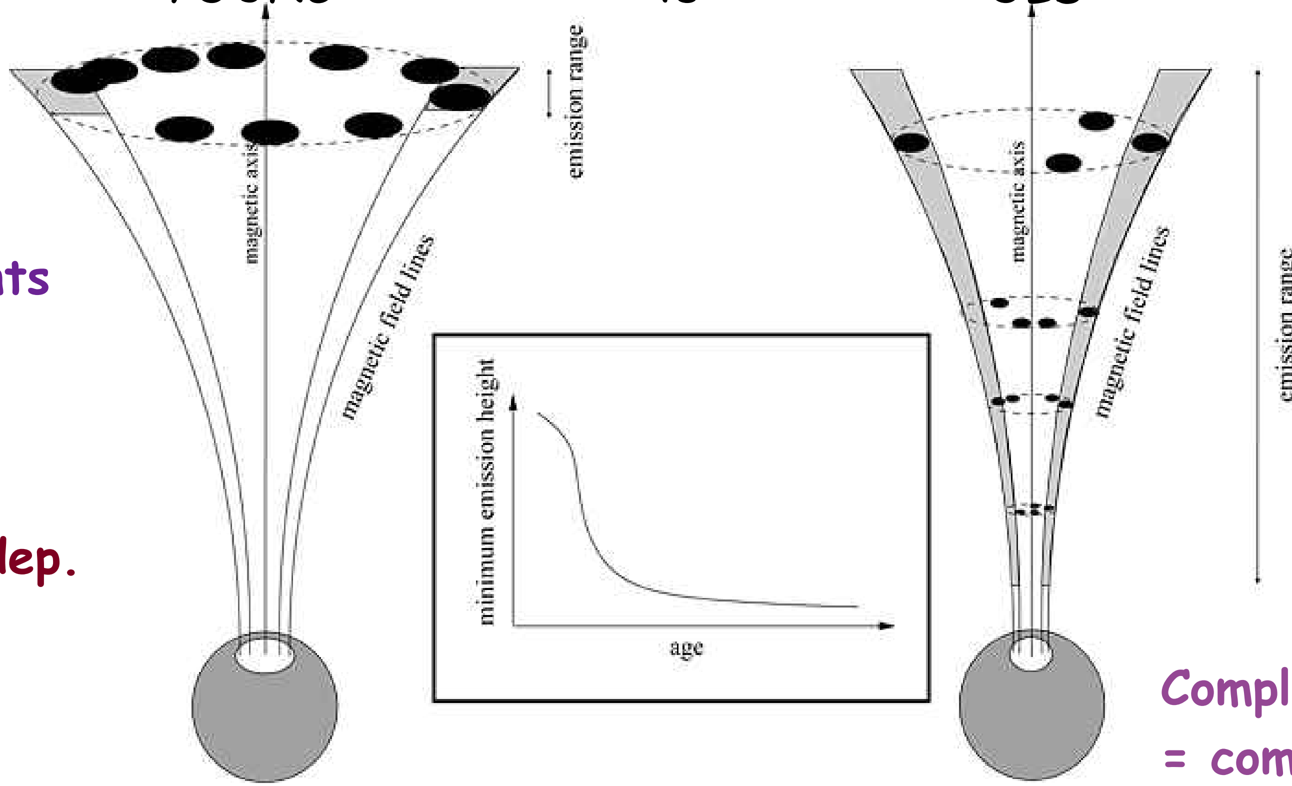
Single profiles

Conal components

Period-width dep.

Height vs Longitude

YOUNG vs OLD



Simple young

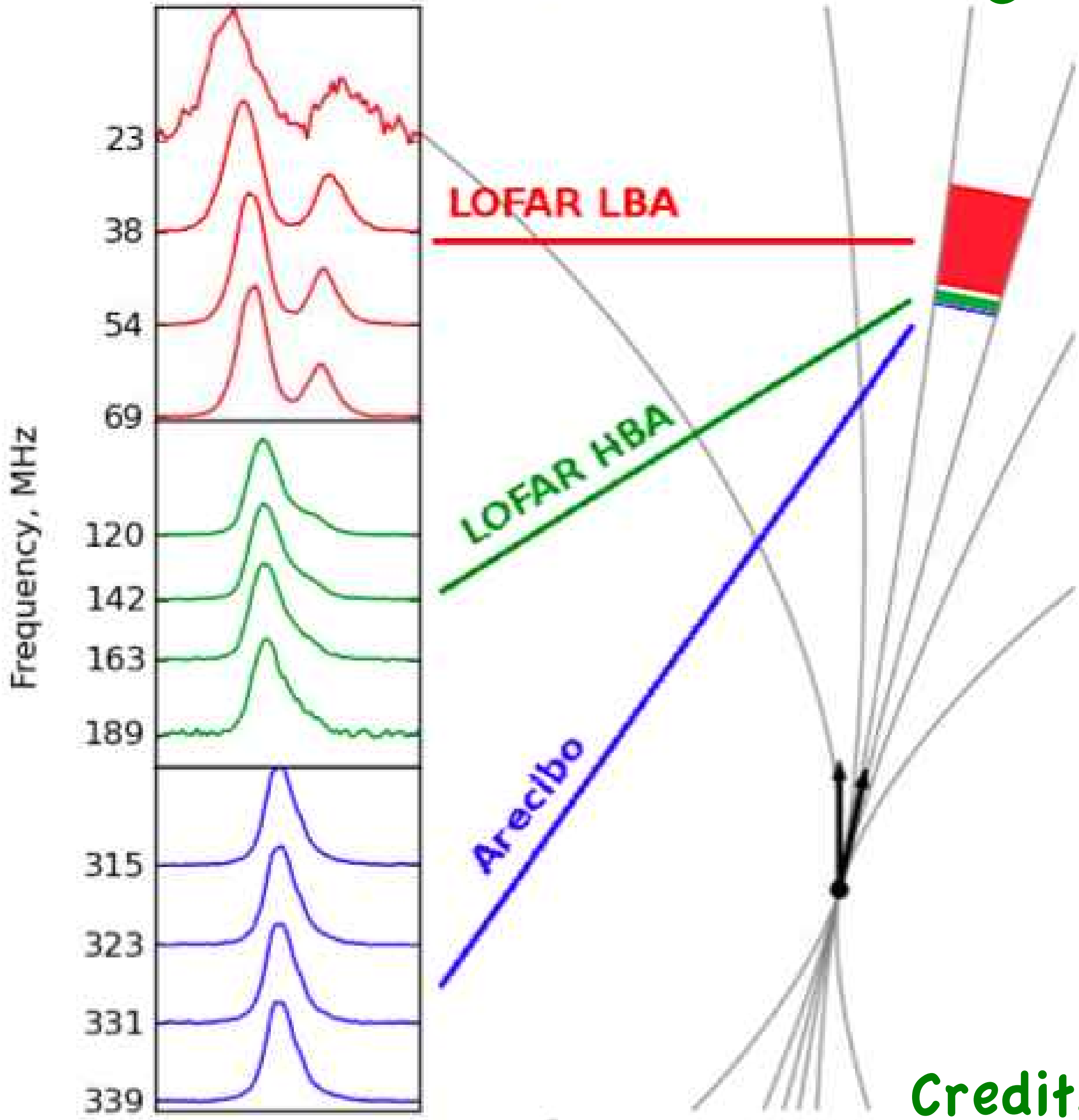
Patches

RFM

Complex profs
= complex PA

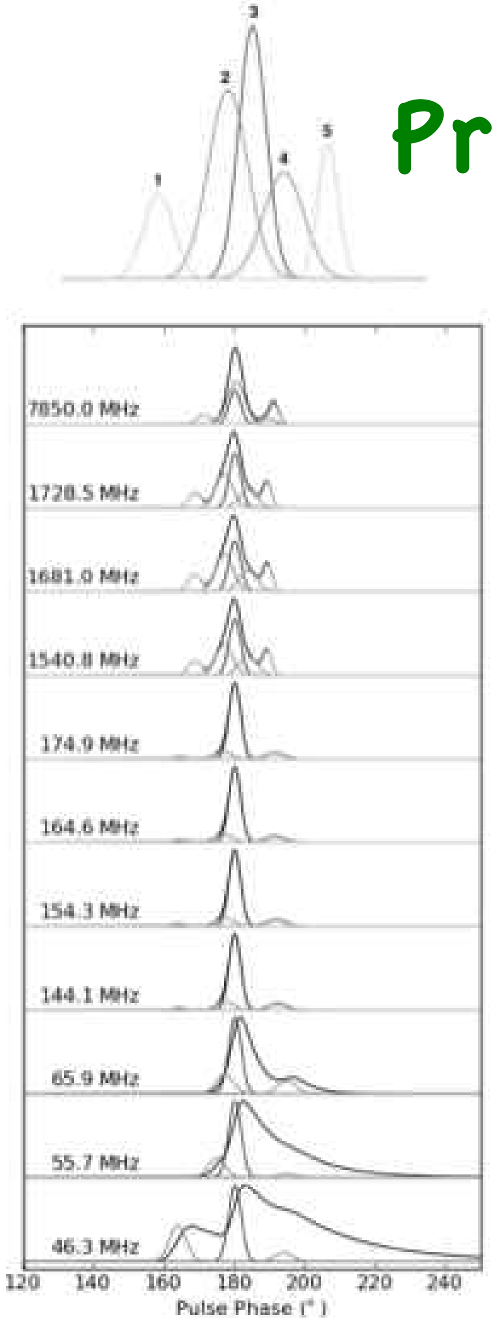
Karastergiou & Johnston 2007

Pulsar Emission Regions



Credits: Anna Bilous

Profile evolution



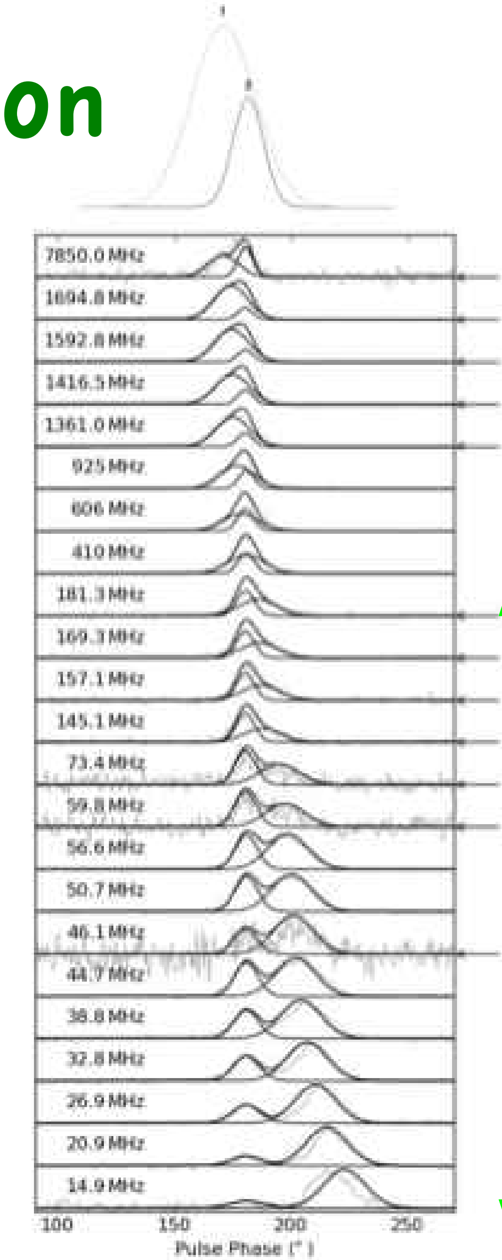
LOFAR bands

B0329+54

extrinsic effects

Hassall et al. 2012

intrinsic effects



LOFAR bands

B0809+74

LOFAR Observations:

HBA observations

<u>SUPERTERP</u>

120 – 167 MHz

240 subbands

17 minutes

LBA observations

<u>FULL CORE</u>

25 pulsars

15 – 61 MHz

57 minutes

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

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LBA observations

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25 pulsars

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HBA observa

SUPERTERP

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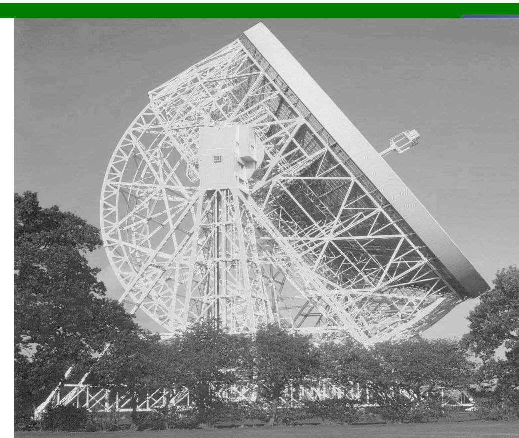
240 subbands

17 minutes

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

+ WSRT @ 300MHz

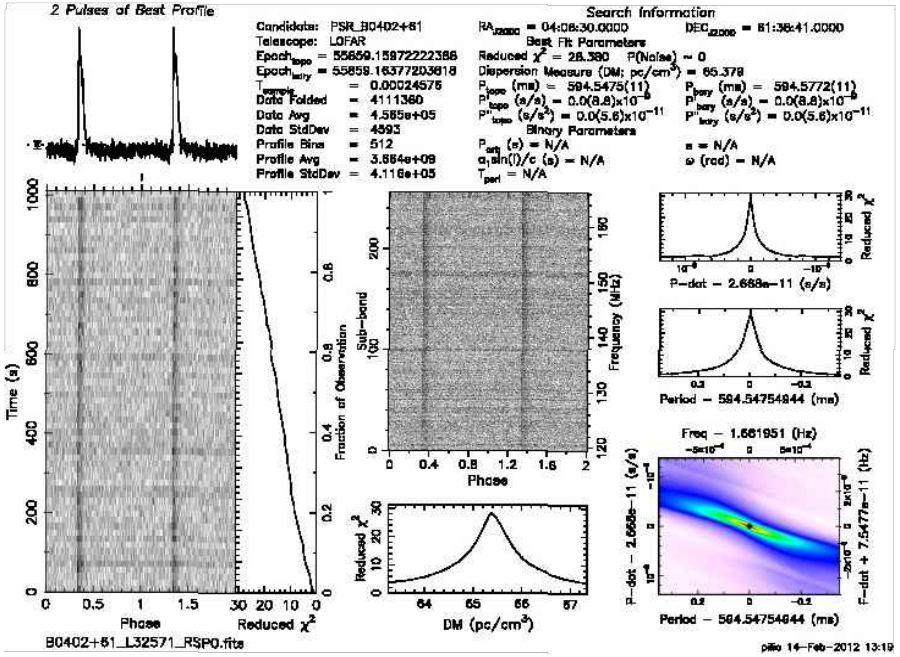
+ Lovell @ 1.5 GHz

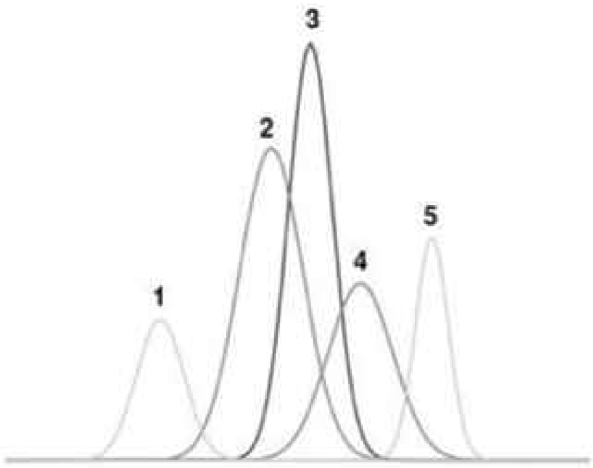


Observations with LOFAR - Analysis

psrfits format data obtained from the initial HDF5 format

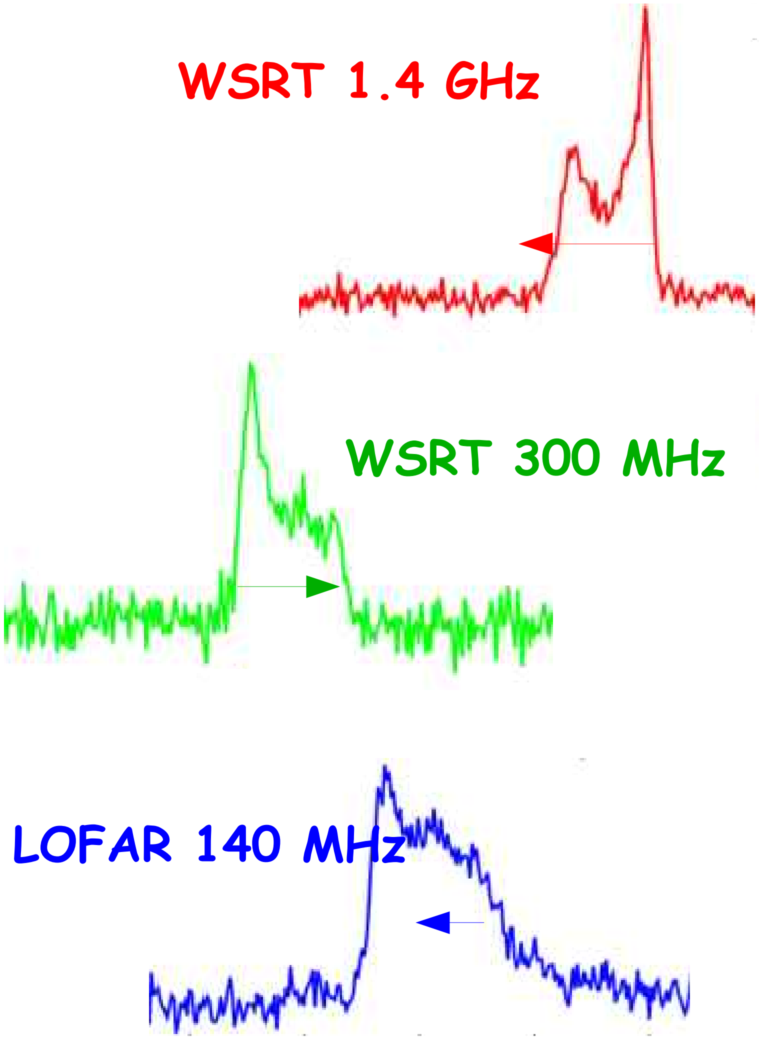
Dedispersion and folding using the **prepfold** tool from presto and an accurate rotational **ephemeris**



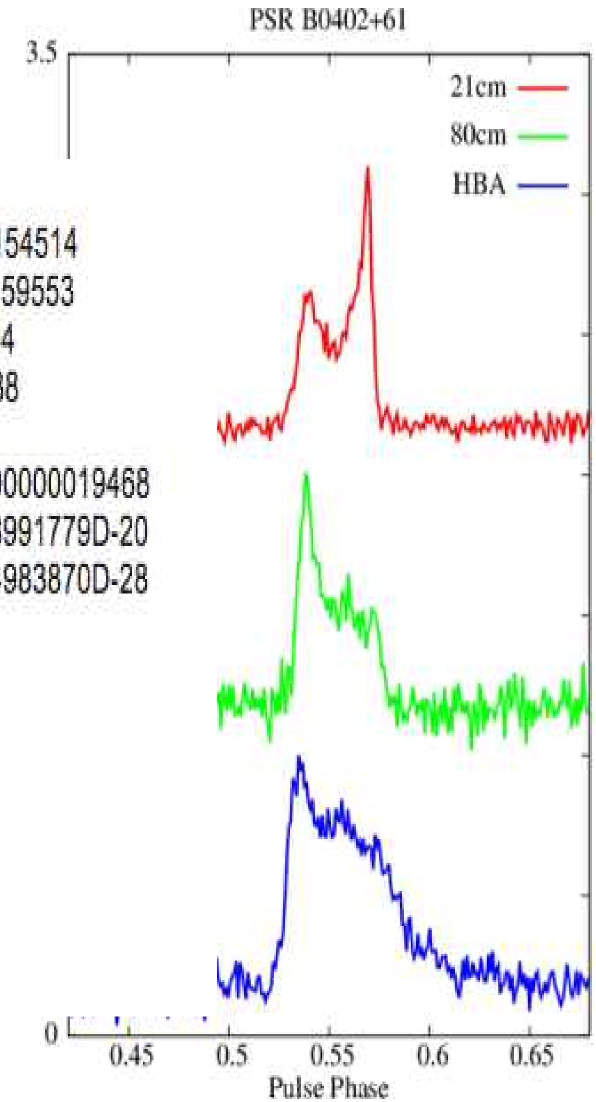


Multi-gaussian fit to the profiles in a number of frequency bands

Observations with LOFAR - Alignment

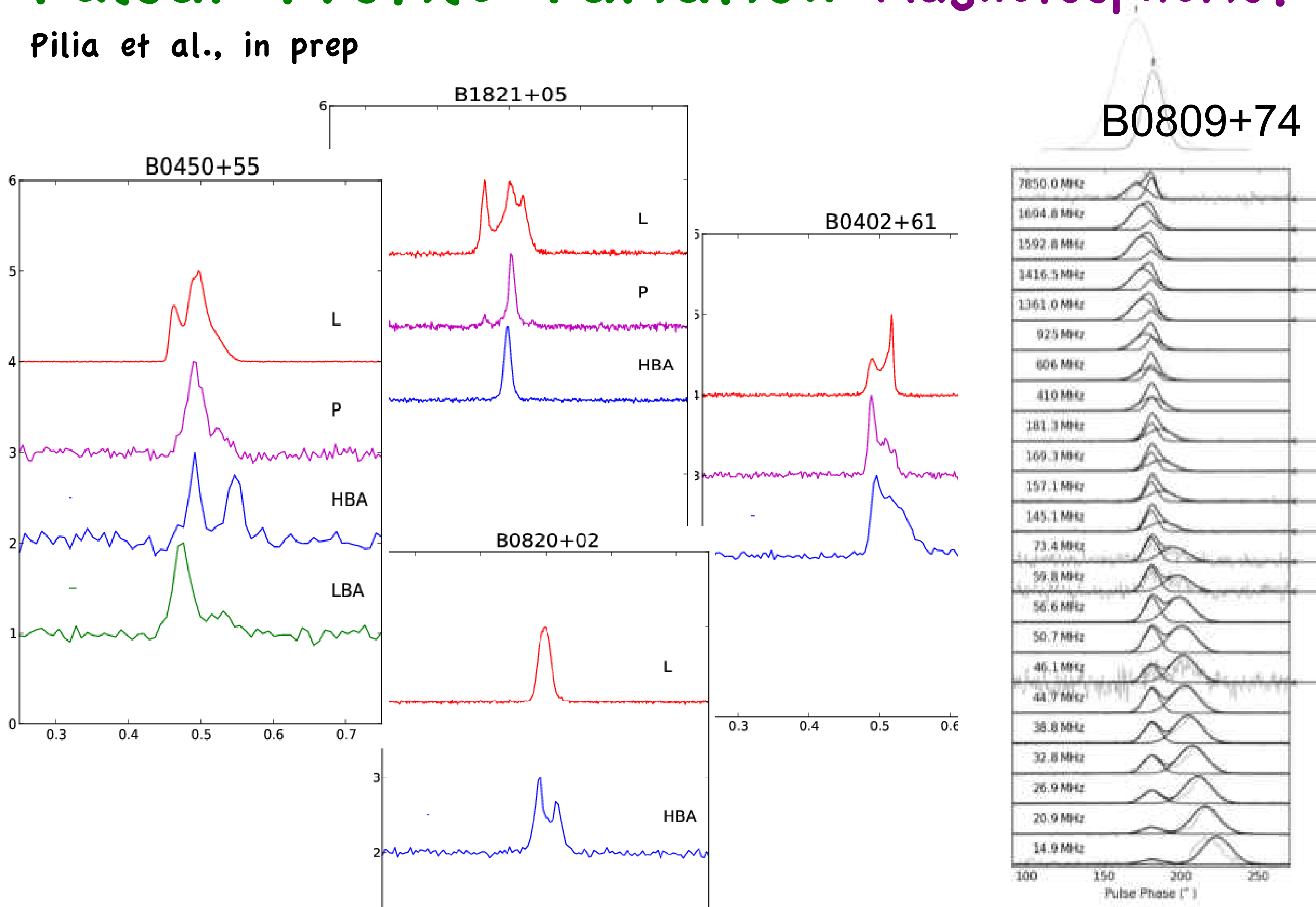


PSR	0402+61		
RAJ	04:06:29.86781532	0	0.00154514
DECJ	61:38:40.2807886	0	0.0159553
PMRA	113.9046	0	2.7164
PMDEC	52.2482	0	4.2388
POSEPOCH	49876.0000		
F0	1.6818673177083718	0	0.0000000000019468
F1	-1.576508166061D-14	0	3.794388991779D-20
F2	-1.557870025896D-28	0	2.995224983870D-28
PEPOCH	55981.999999		
START	52874.476		
FINISH	55974.070		
DM	65.303000		
EPHEM	DE200		
CLK	UNCORR		
NTOA	263		
TRES	1795.98		

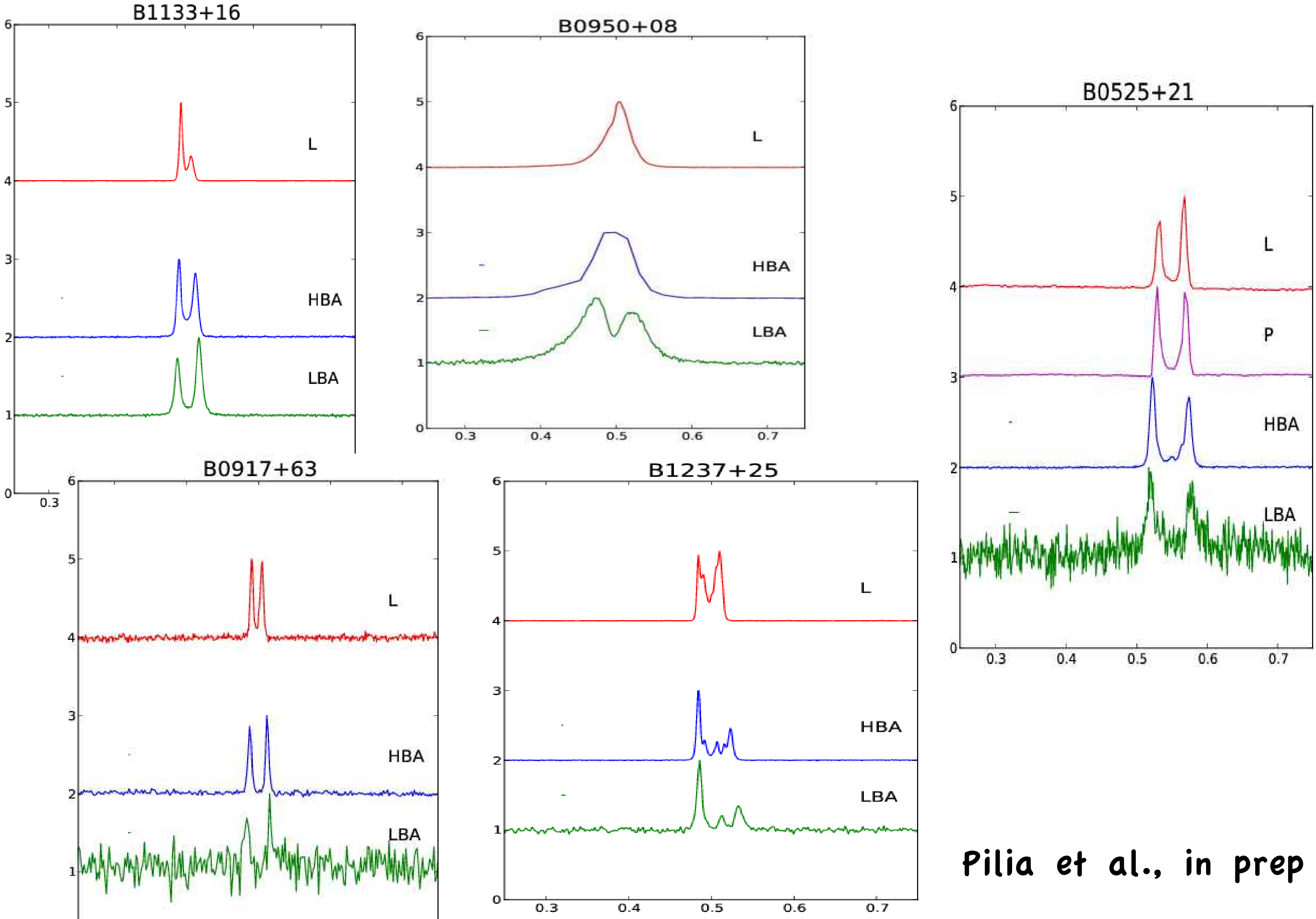


Pulsar Profile Variation-Magnetospheric?

Pilia et al., in prep



Pulsar Profile Variation – Widening

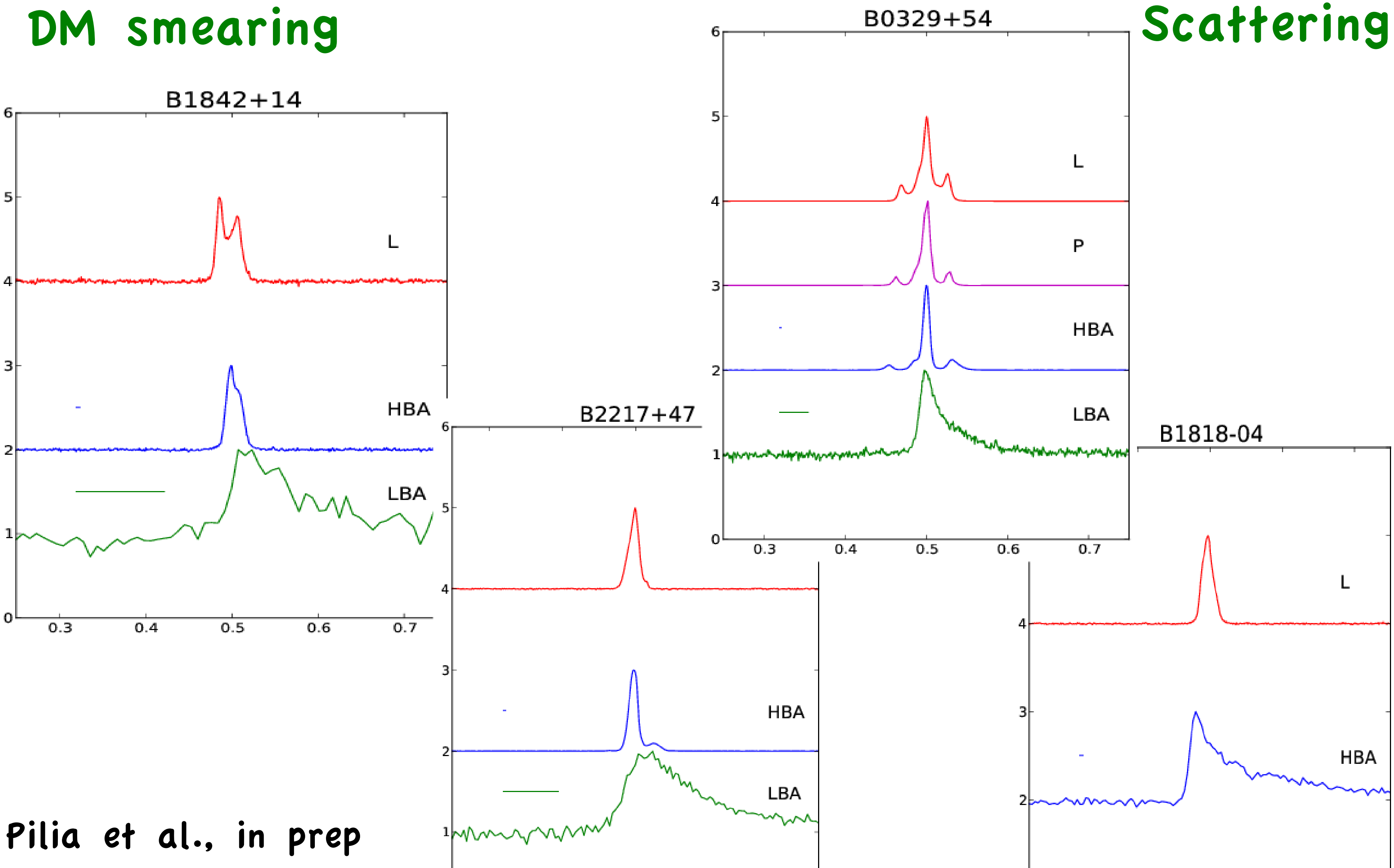


Pilia et al., in prep

Pulsar Profile Variation – External Effects

DM smearing

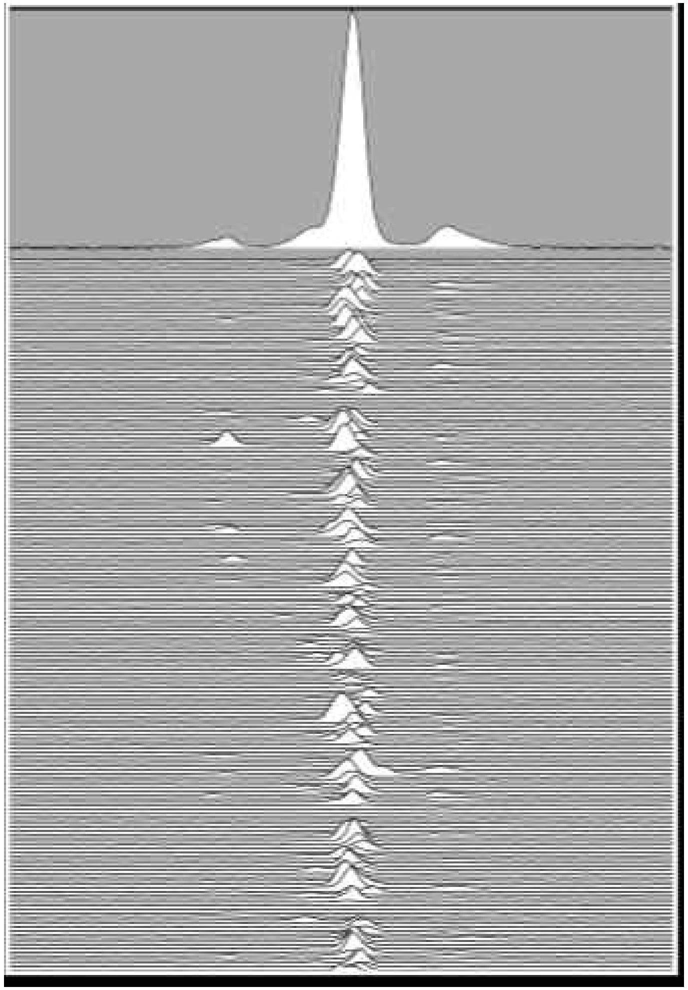
Scattering



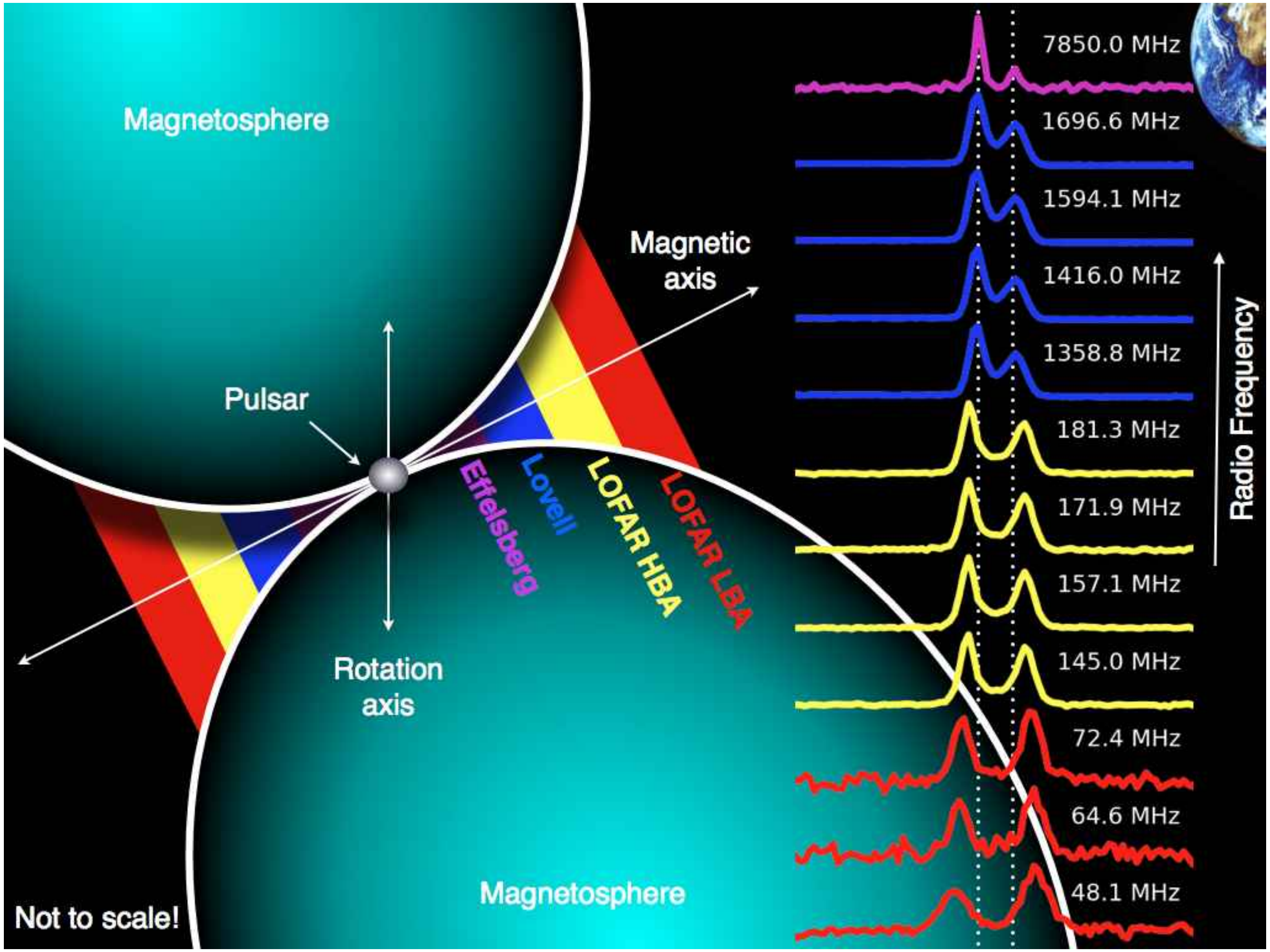
Pilia et al., in prep

Pulsar Profile Variation - Single pulses

B0329+54

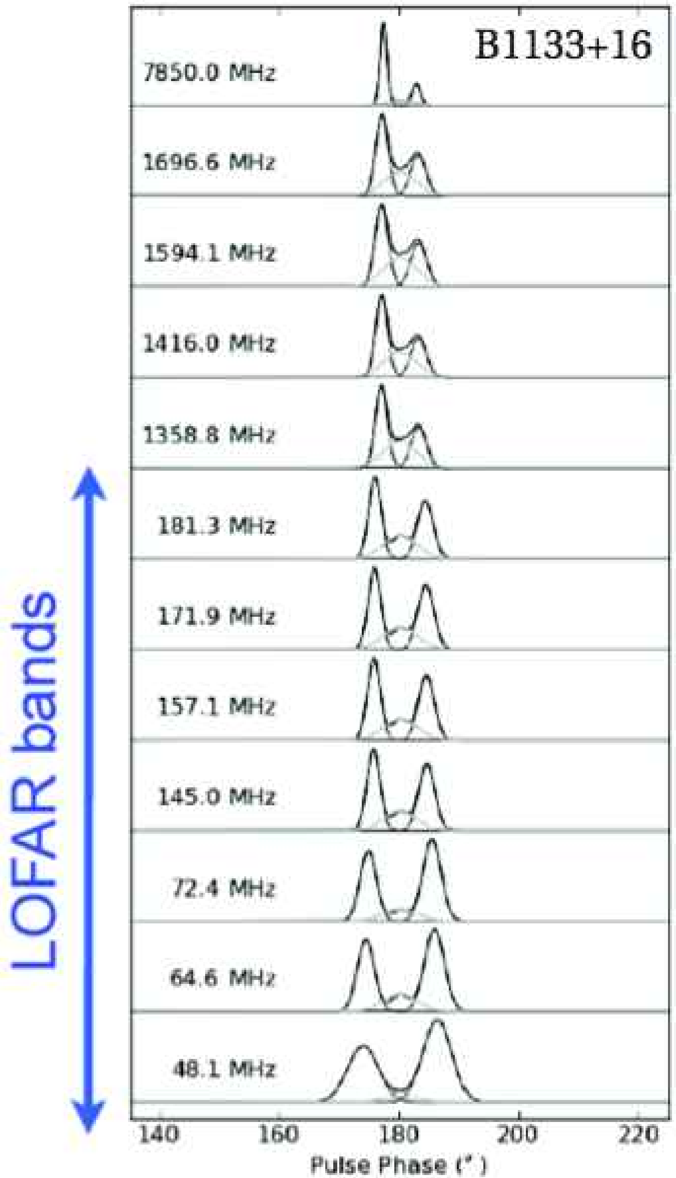


Radius to Frequency Mapping (RFM)



Hassall et al. 2012, A&A

DM vs Profile variations

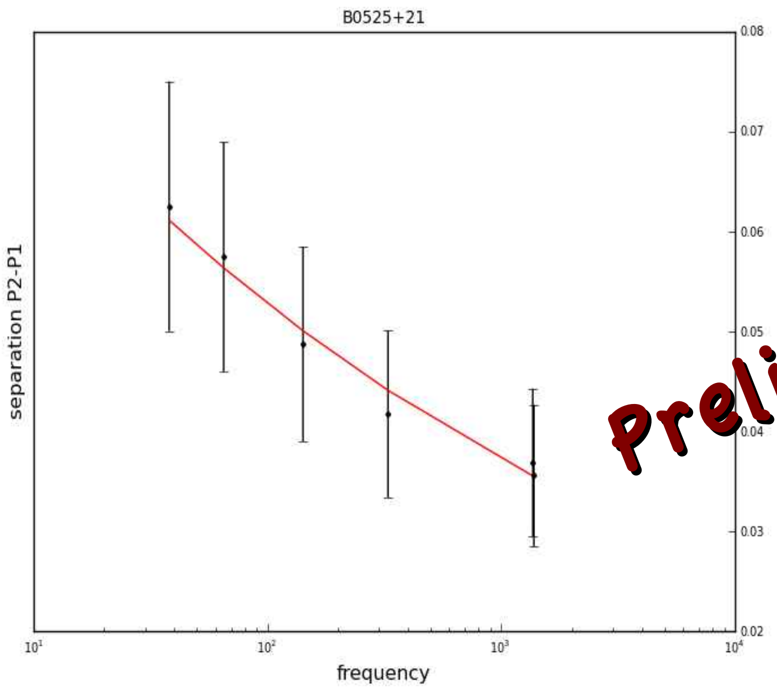


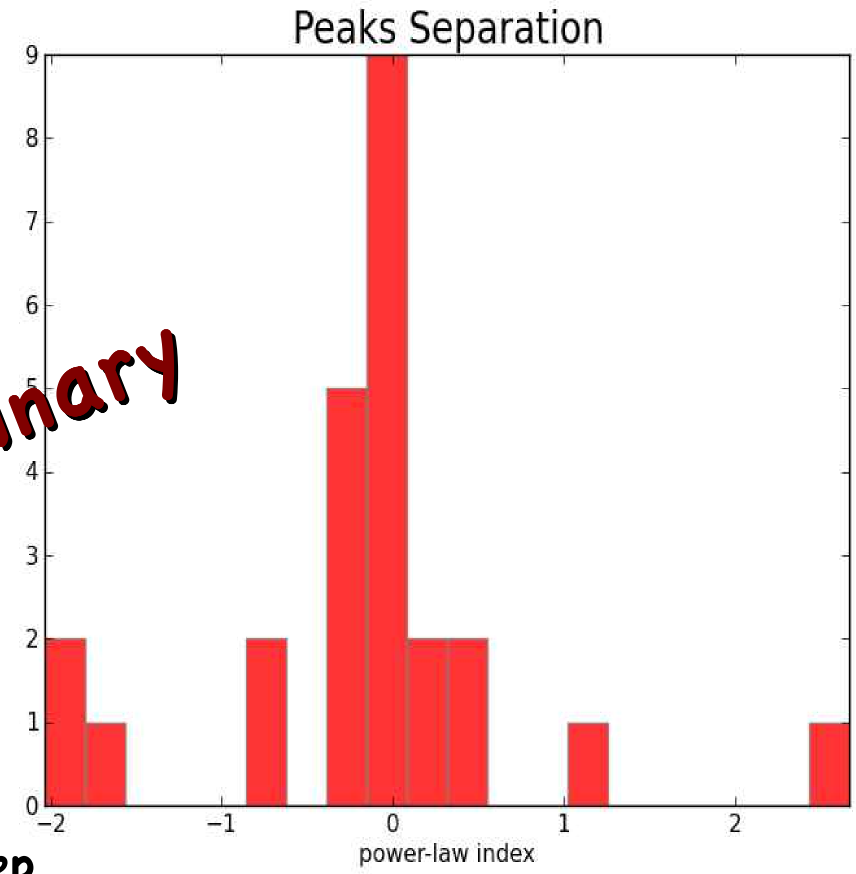
- Cold-dispersion law good to 1/100,000
- For PSR B1133+16 all radio frequencies come from a region ΔR < 59 km in altitude below 110 km from NS surface (0.2% of the light cylinder)

Hassall et al. 2012

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.





Preliminary

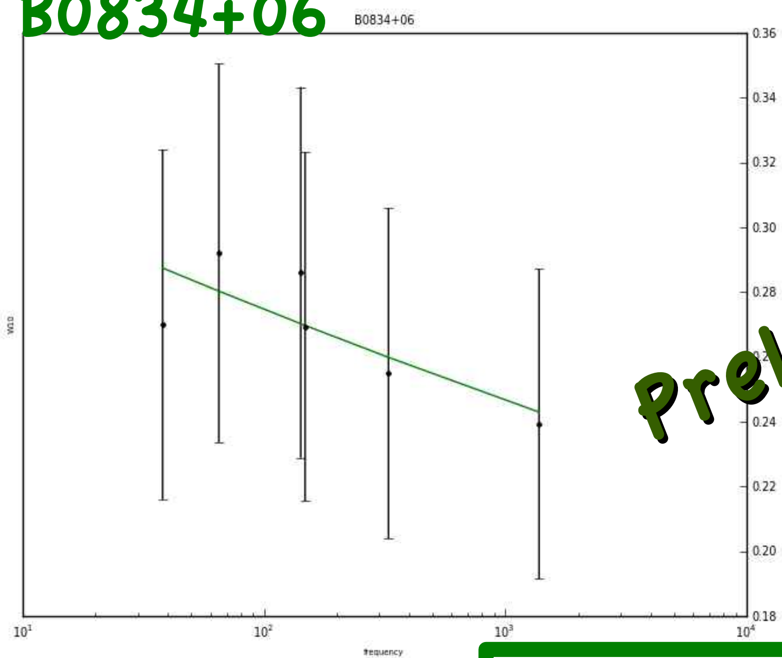
B0525+21

Pilia et al., in prep

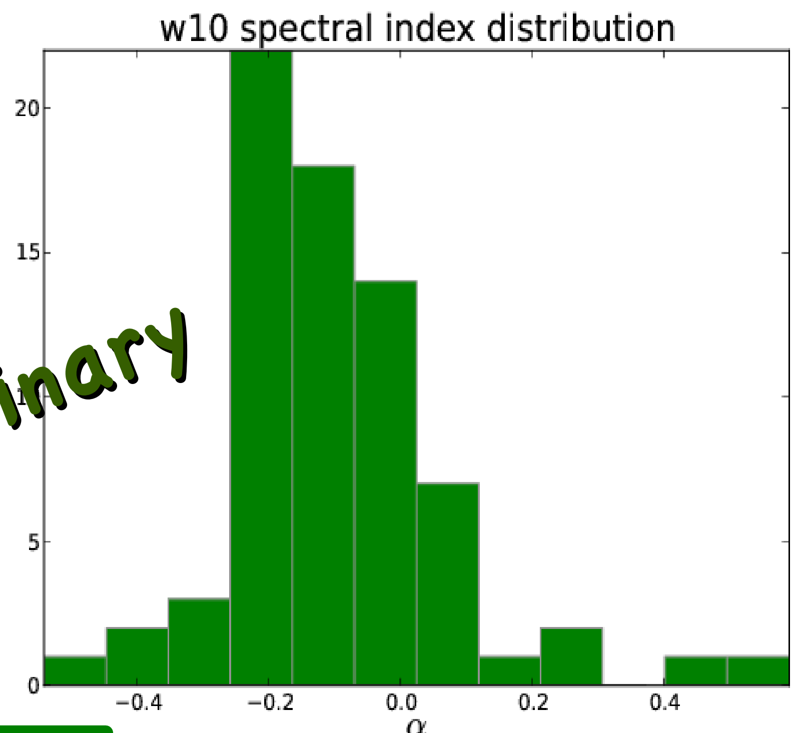
RFM - Width of the Pulse Profile

For all pulsars, were 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.

B0834+06



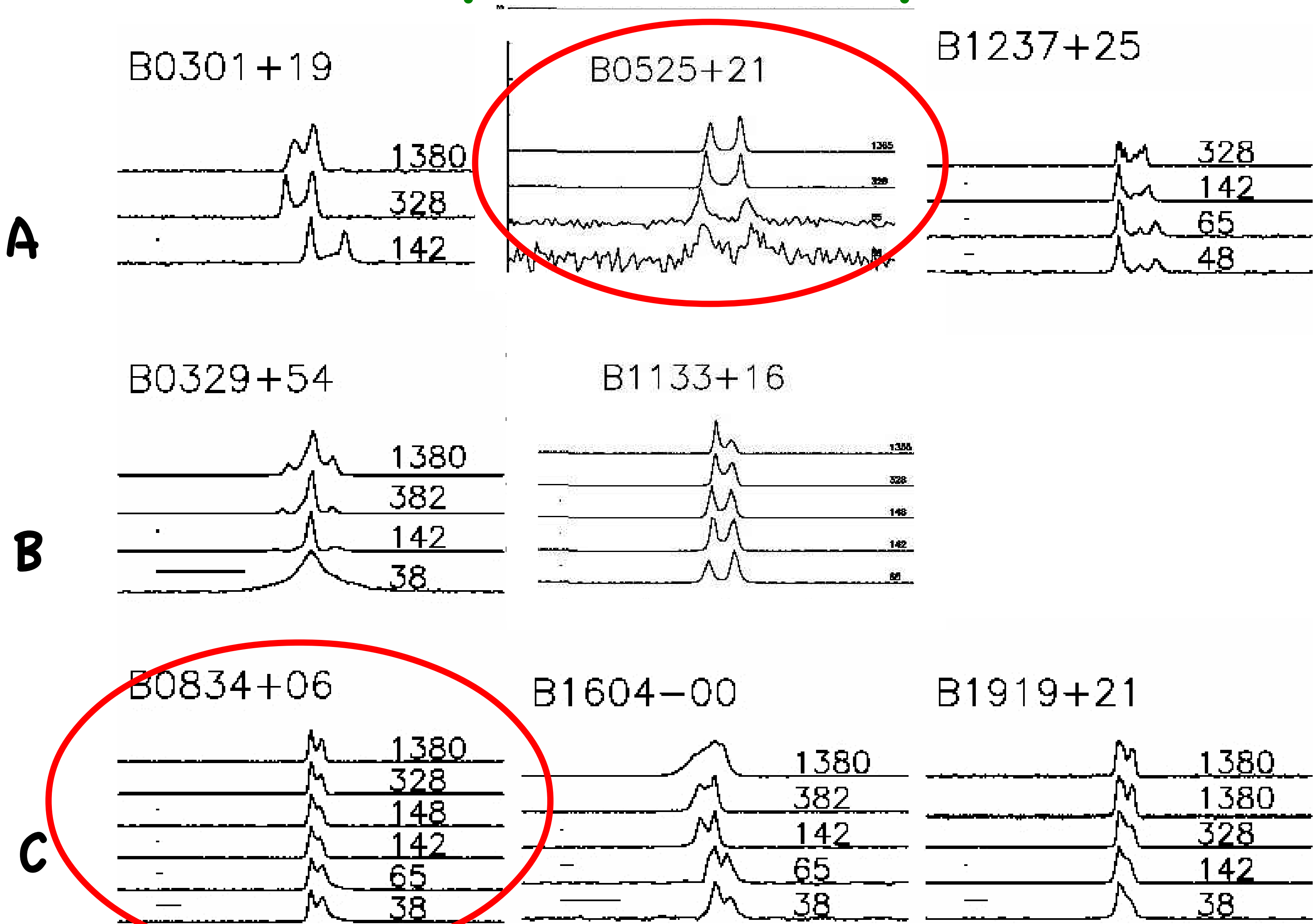
Preliminary



Index = -0.1

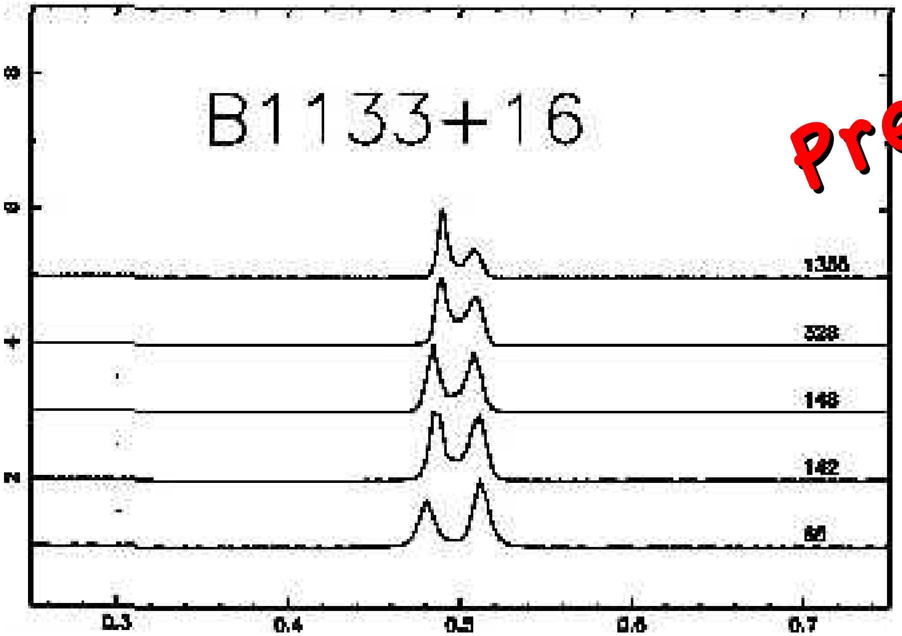
Pilia et al., in prep

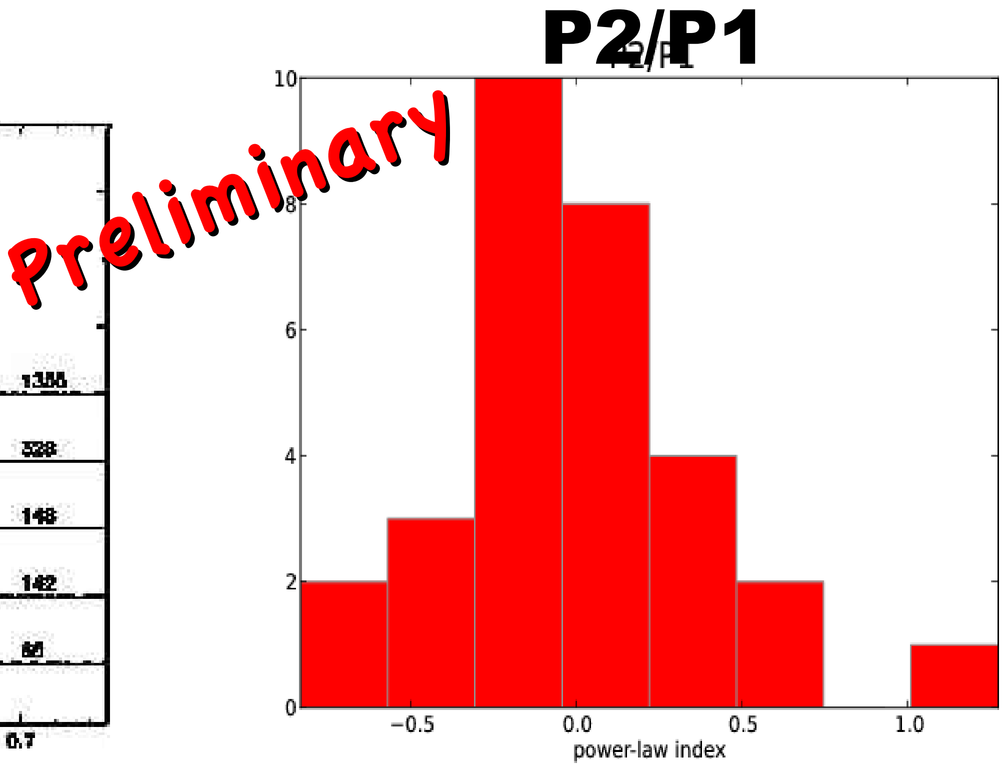
RFM - Comparison with the models - Rankin's Groups for Multiple Peaks



Pilia et al., in prep

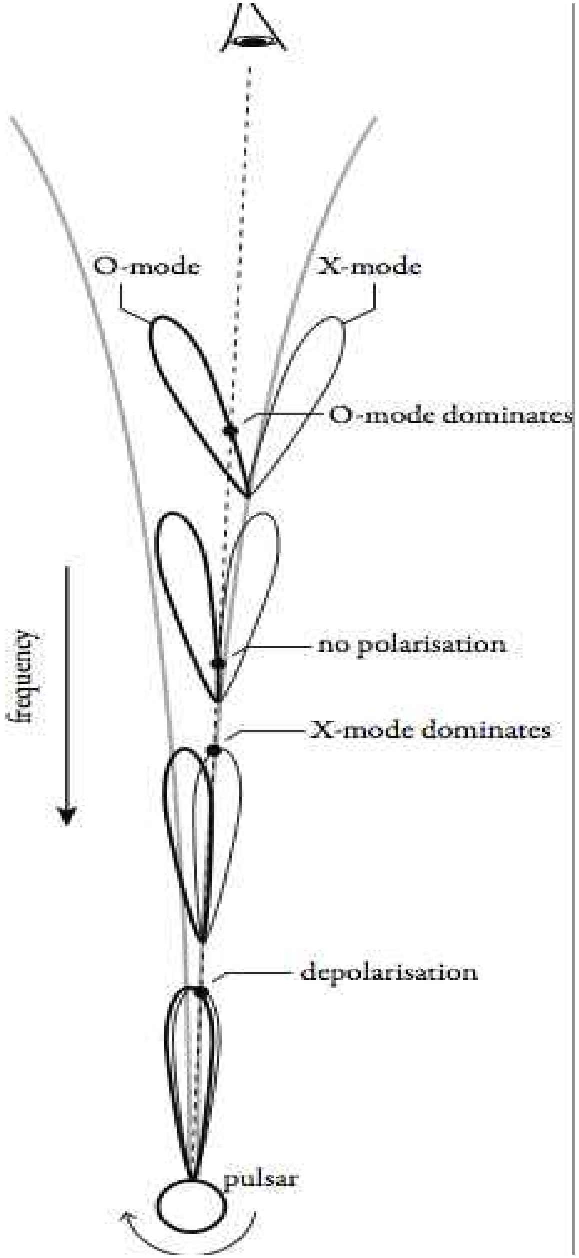
Profile Evolution - Peaks Ratio





Pilia et al., in prep

Birefringence

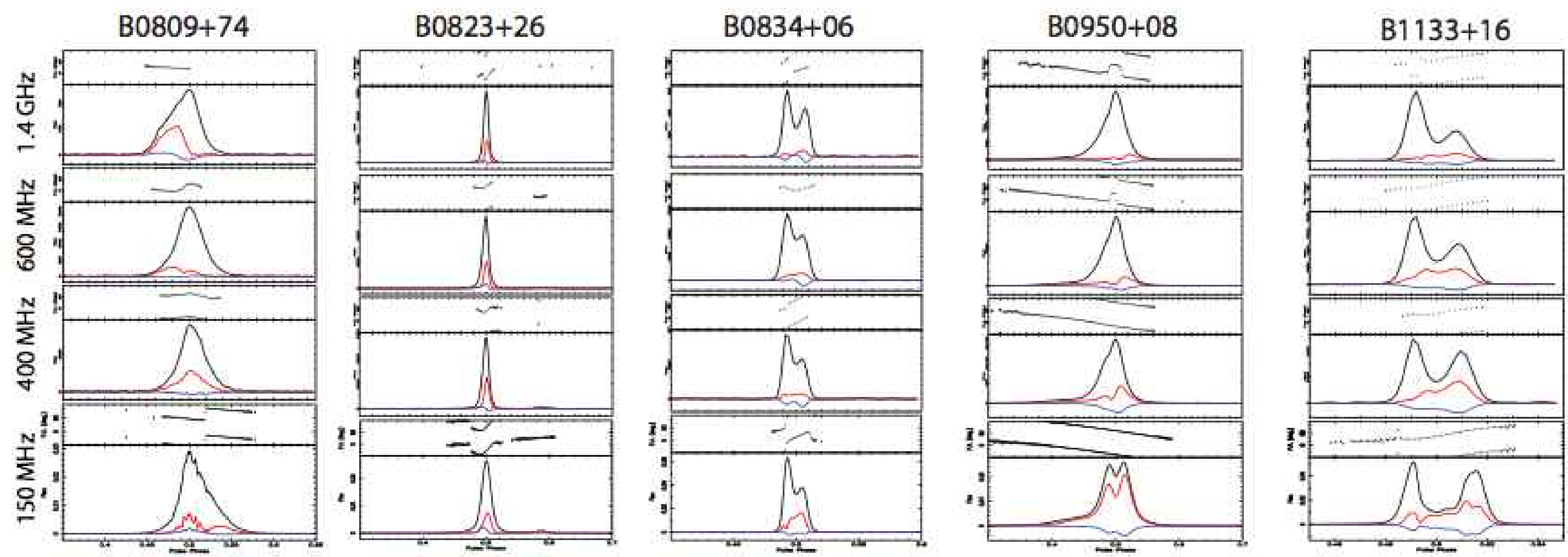


The broadening at low radio frequency is caused by the separation of
the individual beams of the two propagation modes, and the depolarization at high frequency results
from the merger of their orthogonal polarizations.

Credits: Aris Noutsos

Polarization Profiles

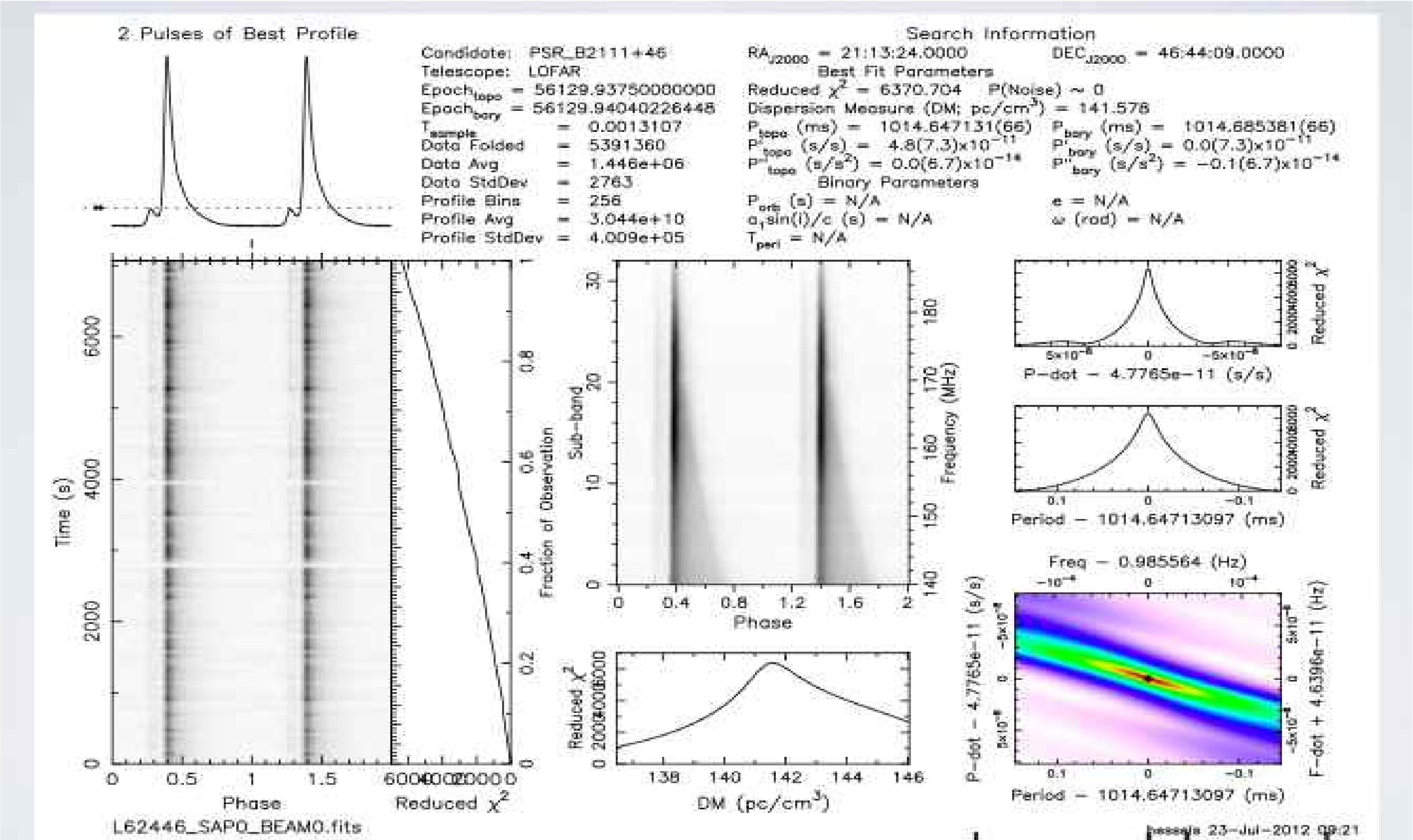
In total, we have obtained high-quality polarisation profiles at 150 MHz, for 20 pulsars.



Preliminary

Aris Noutsos

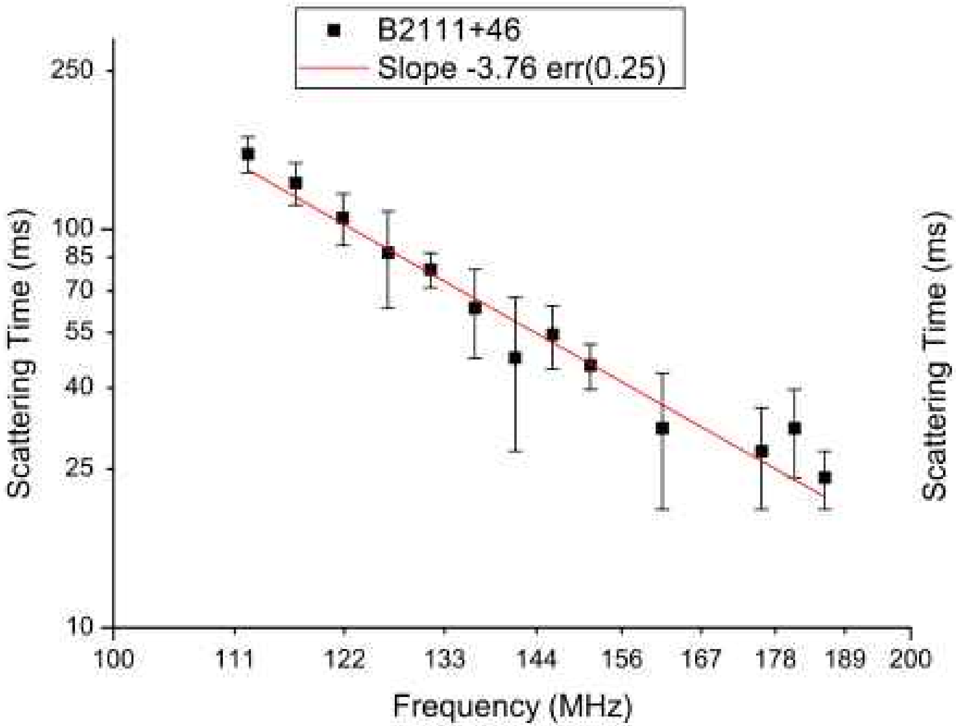
Interstellar Scattering

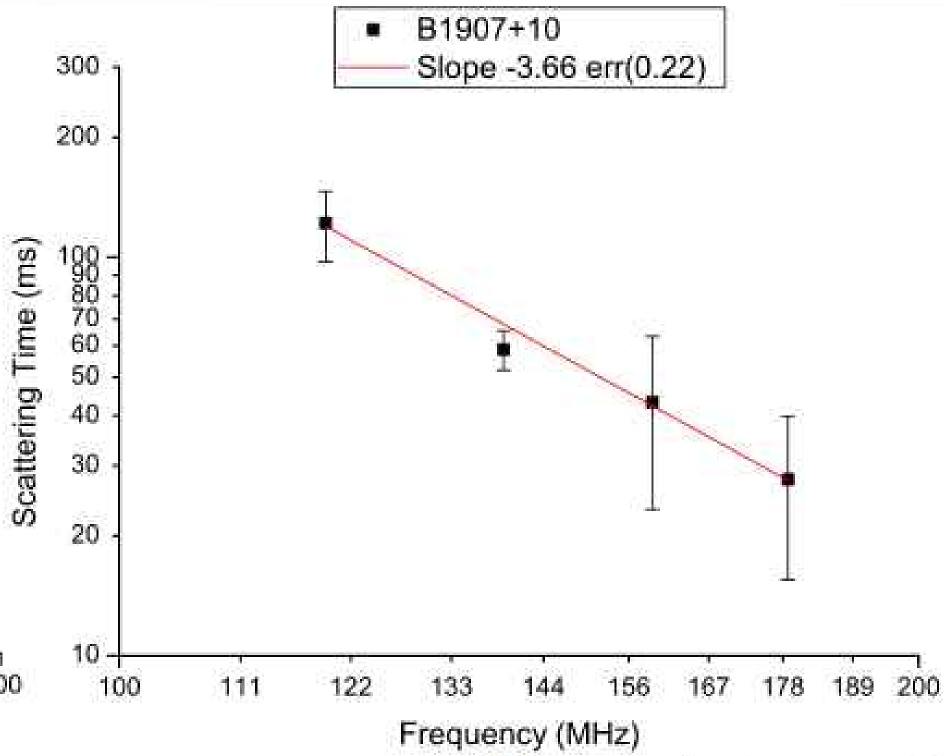


Only down to 140 MHz!

Jason Hessels

Frequency Scaling of Scattering

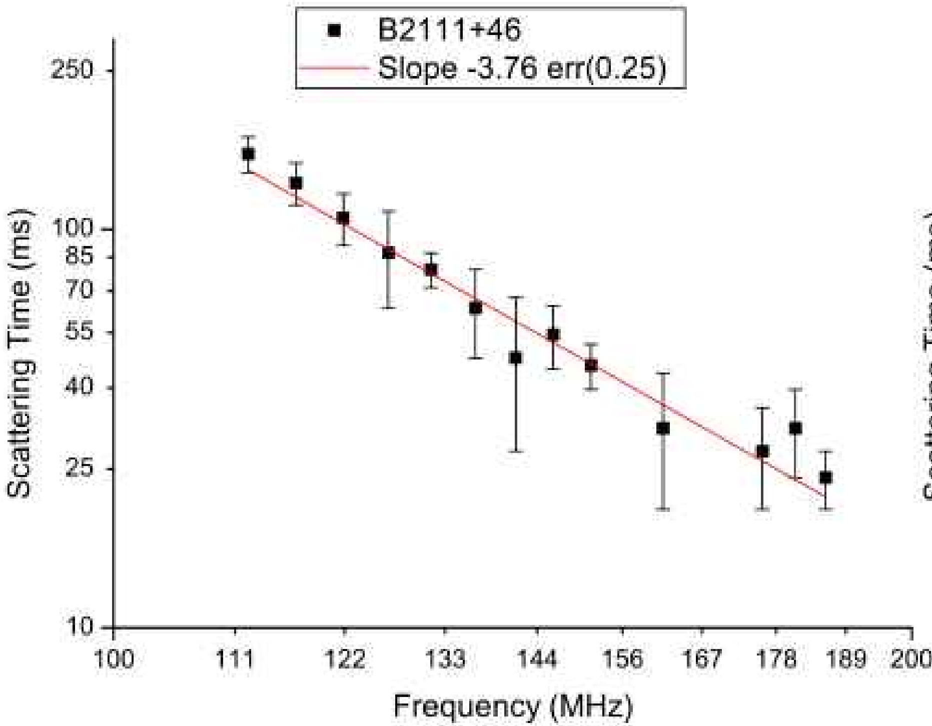


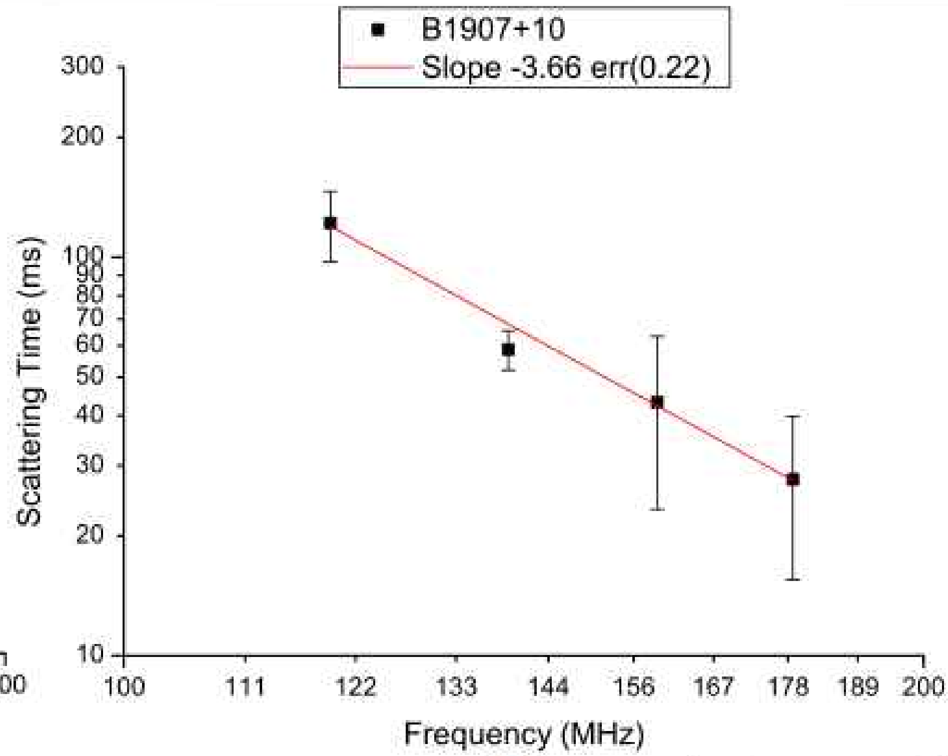


Preliminary

Kimon Zagouris

Frequency Scaling of Scattering





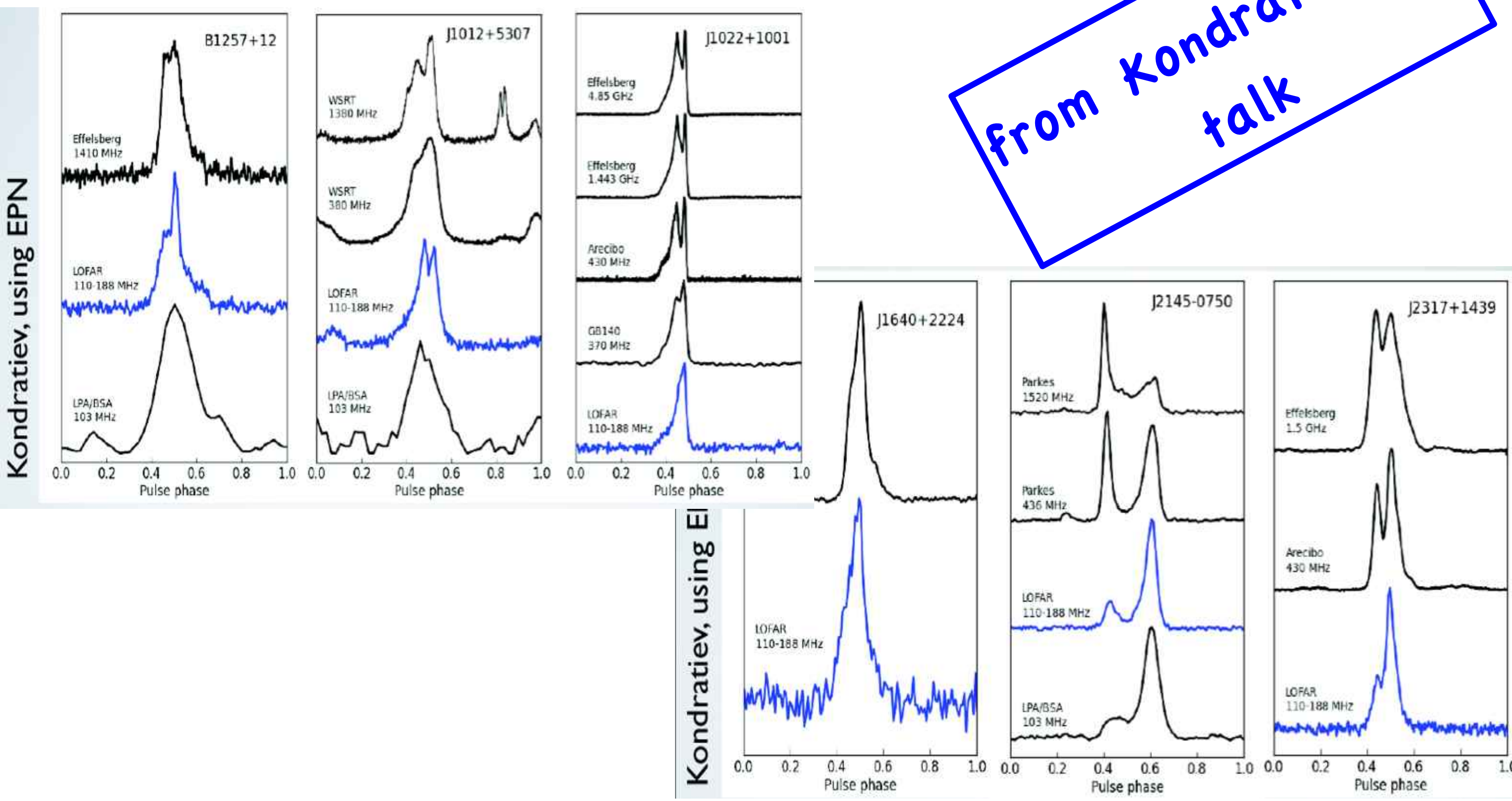
Preliminary

Kimon Zagouris

Not all pulsars that were expected to be scattered in LOFAR data actually are

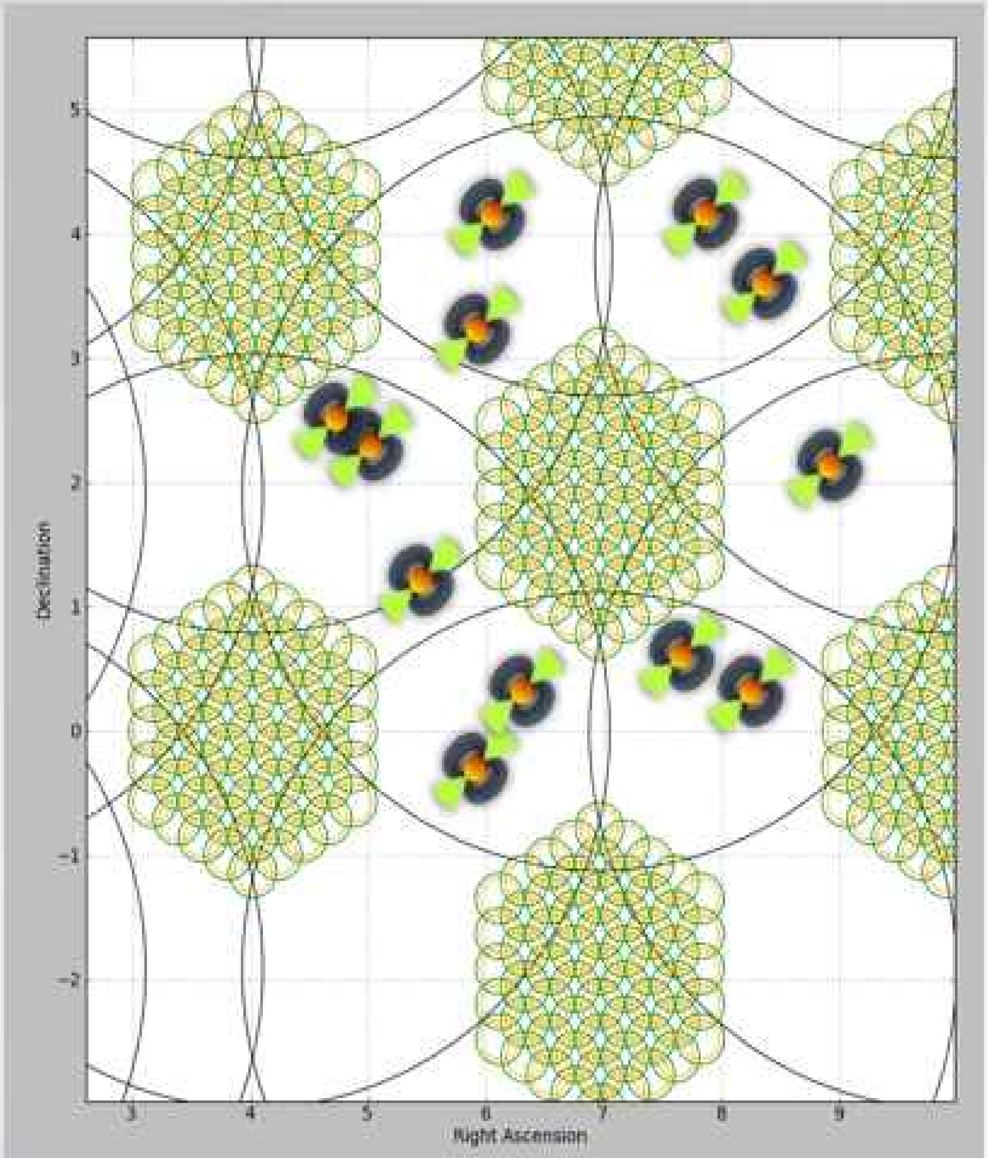
Evolution for MSPs?

from Kondratiev's talk



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)

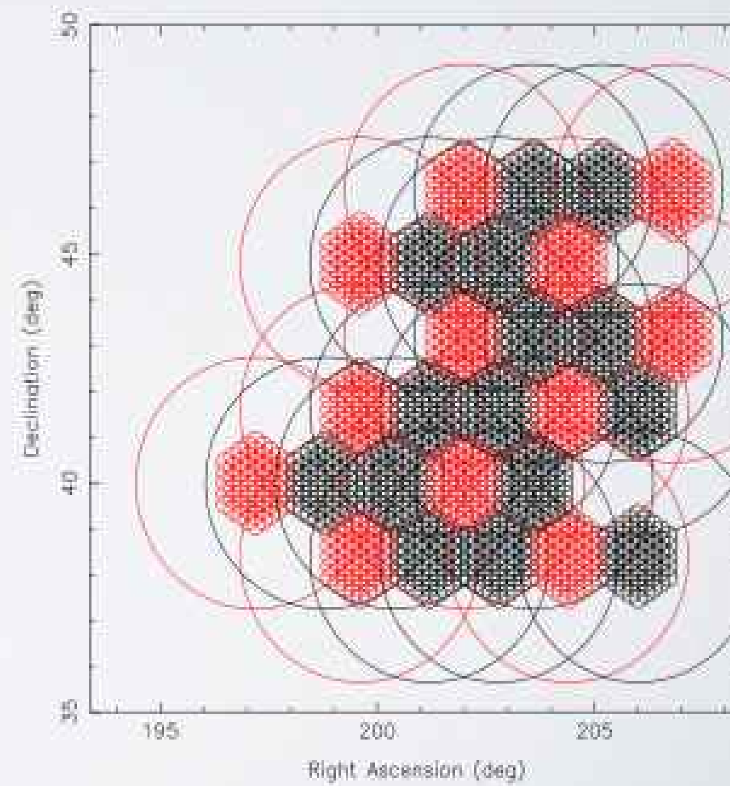


- ~2x more sensitive than LOTAS

(coh. pilot survey)

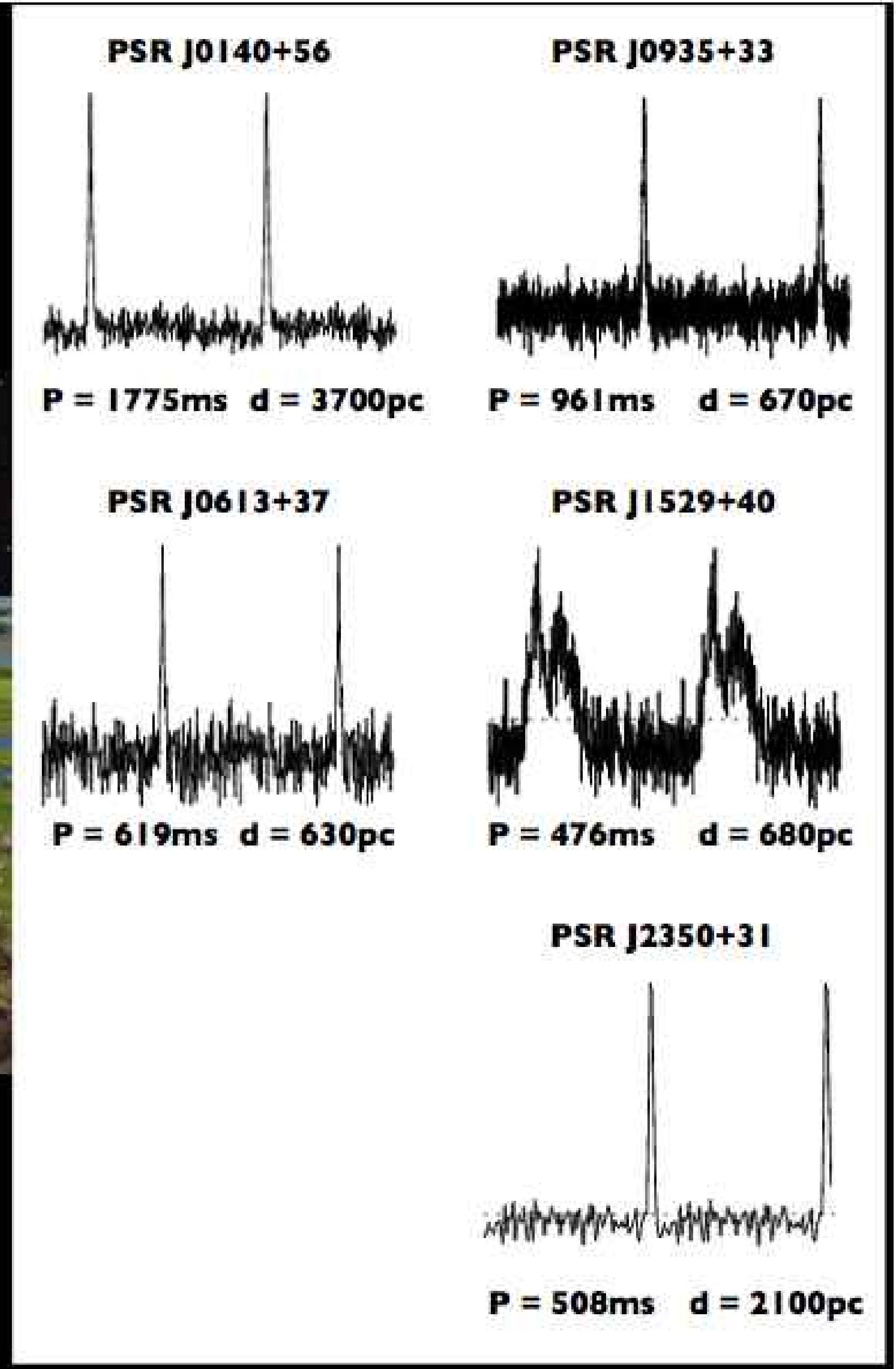
- ~2x more sensitive than LPPS

(incoh. pilot survey)



LOFAR Pulsar Discoveries

LOTAAS Survey



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

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Opportunity to go much deeper

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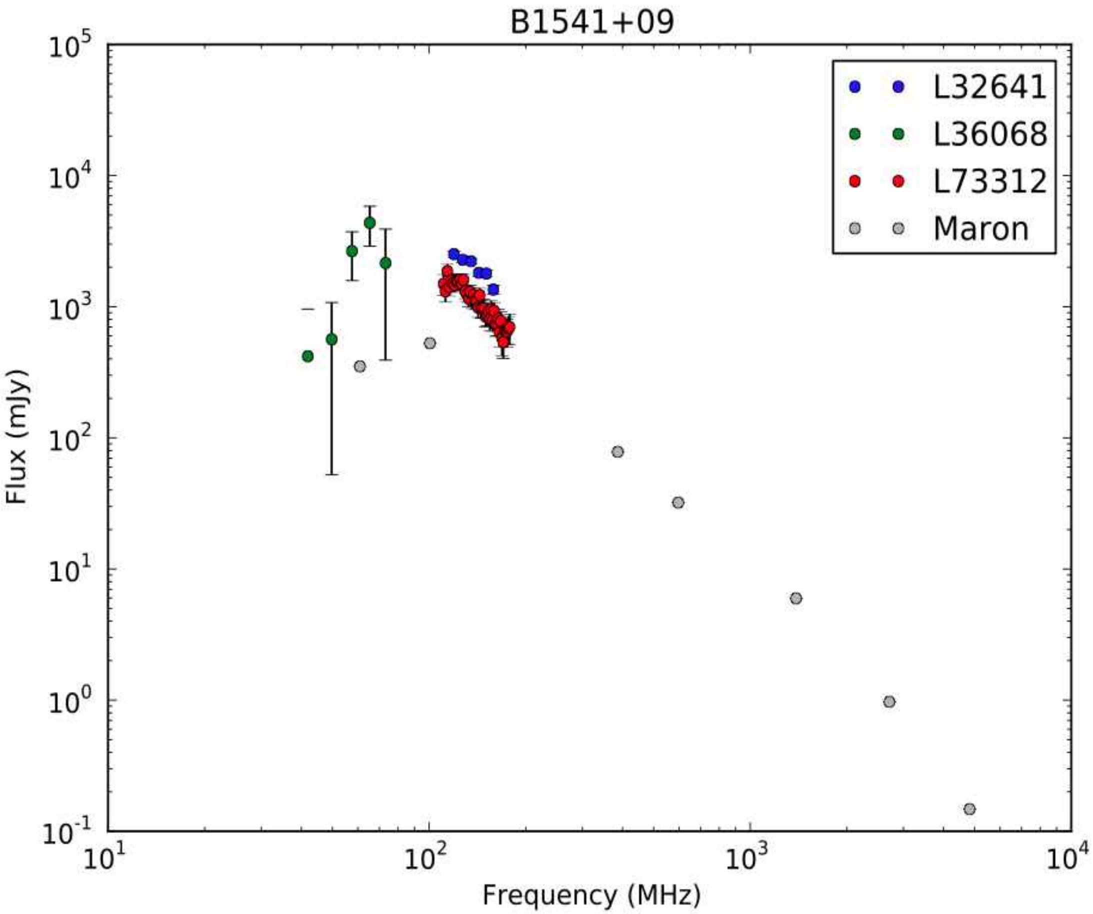
THANK YOU!

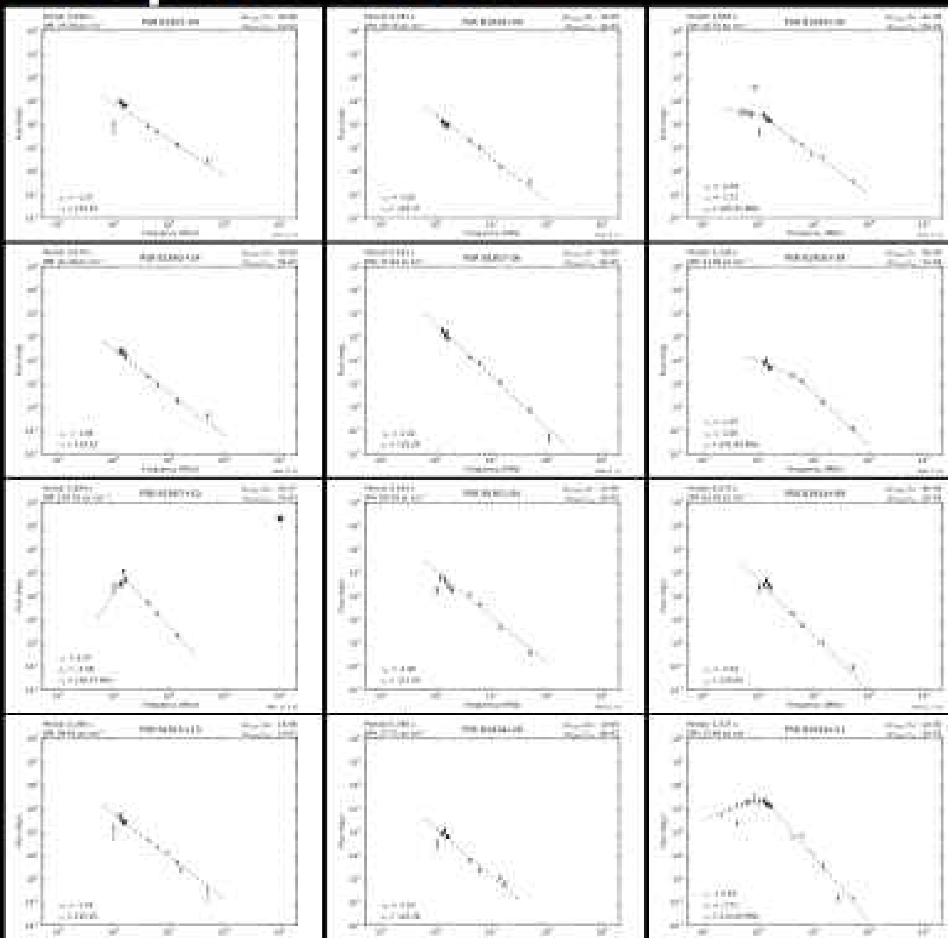
Pulsar Spectra



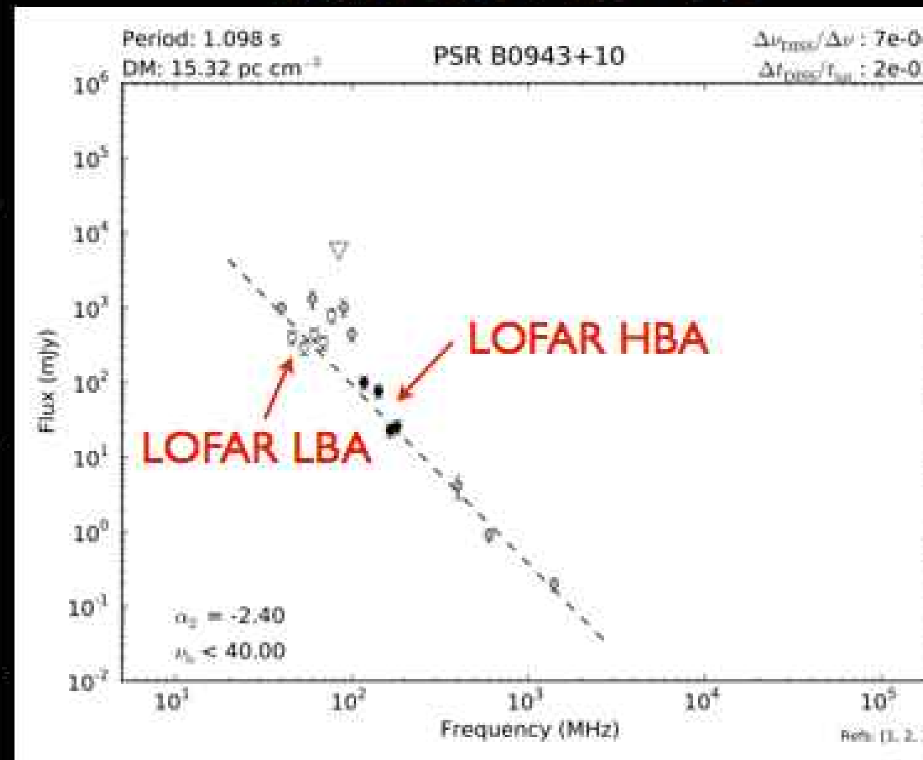
Credits: Tom Hassall

Spectra

120 pulsars total



PSR B0943+10



No obvious difference between normal pulsars and MSPs

Hassall et al. 2014, *in prep.*

Spectral Index Distribution

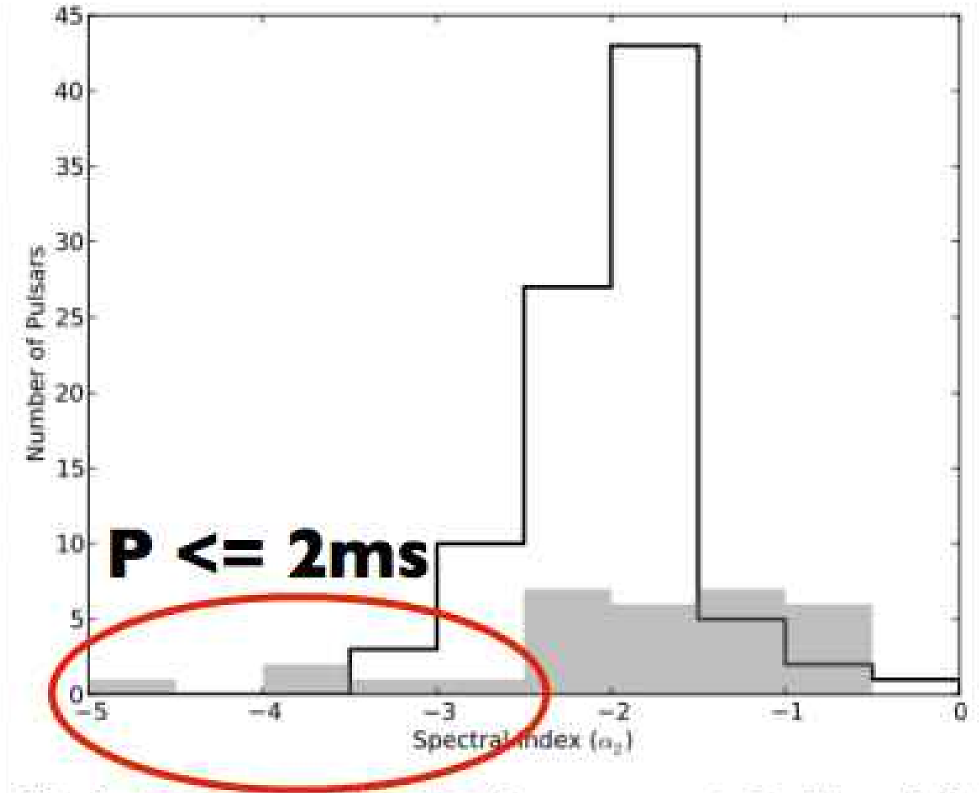


Fig. 3: A histogram of the high-frequency spectral indices of all of the pulsars in our sample. The black line shows slow pulsars, and the grey area shows MSPs. The mean of the distributions are both at −1.9, the median is −1.9/−1.6 for slow and MSPs respectively, and the standard deviations 0.4/0.9.

Hassall et al. 2014, in prep

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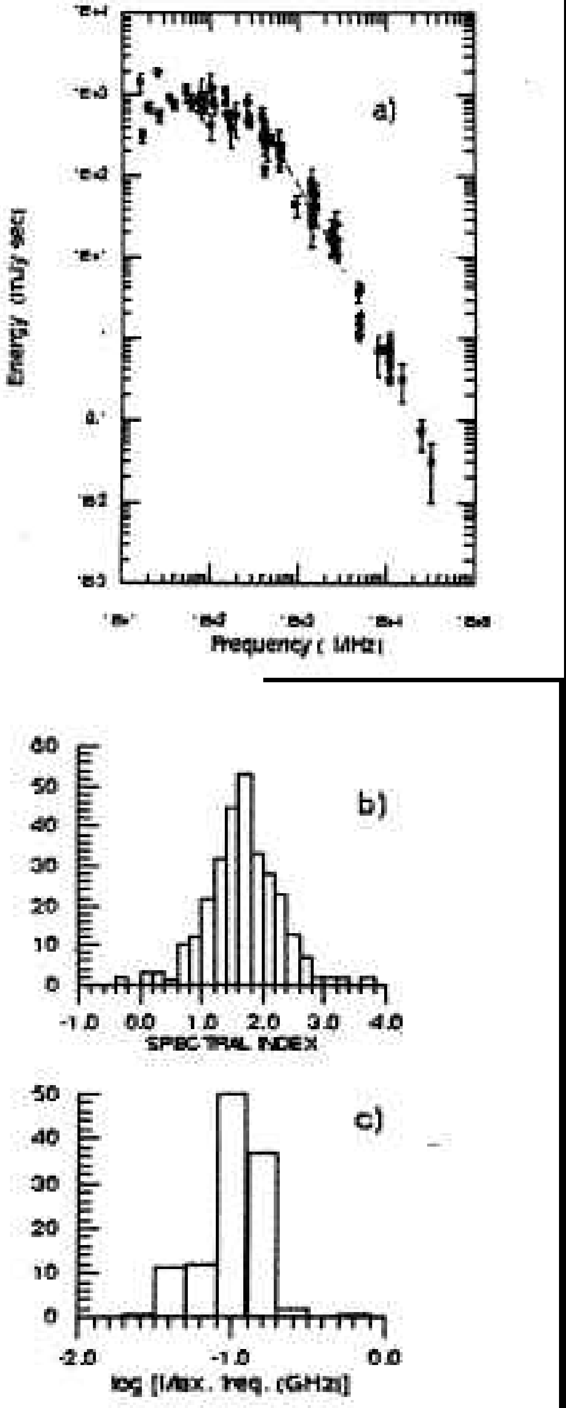

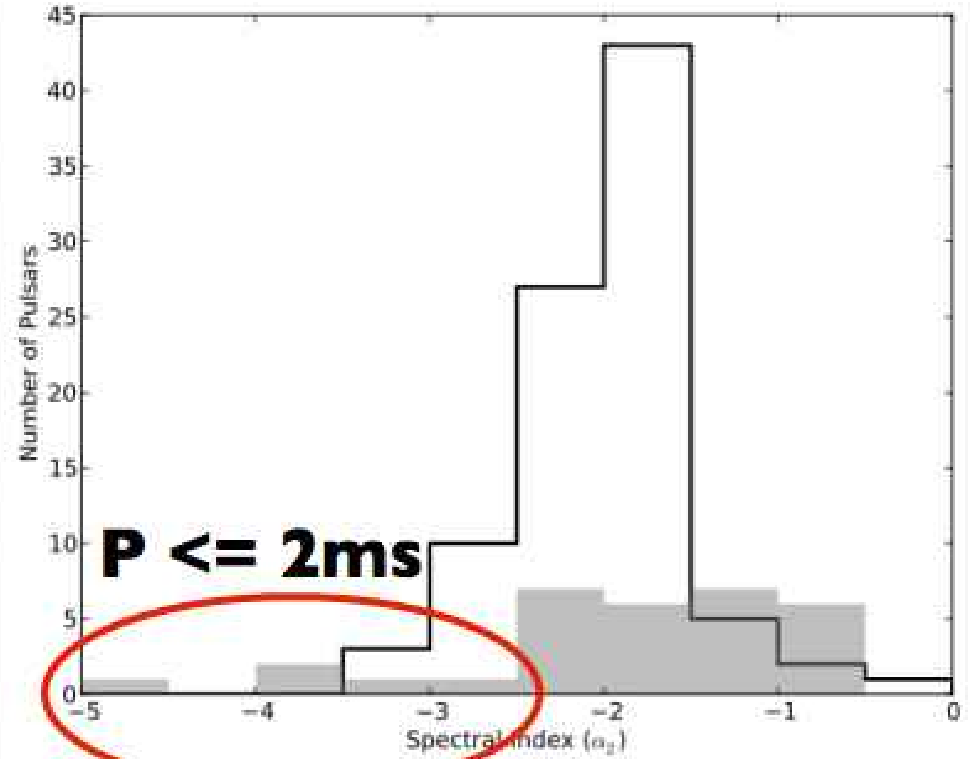

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Malofeev 1996

Hassall et al. 20

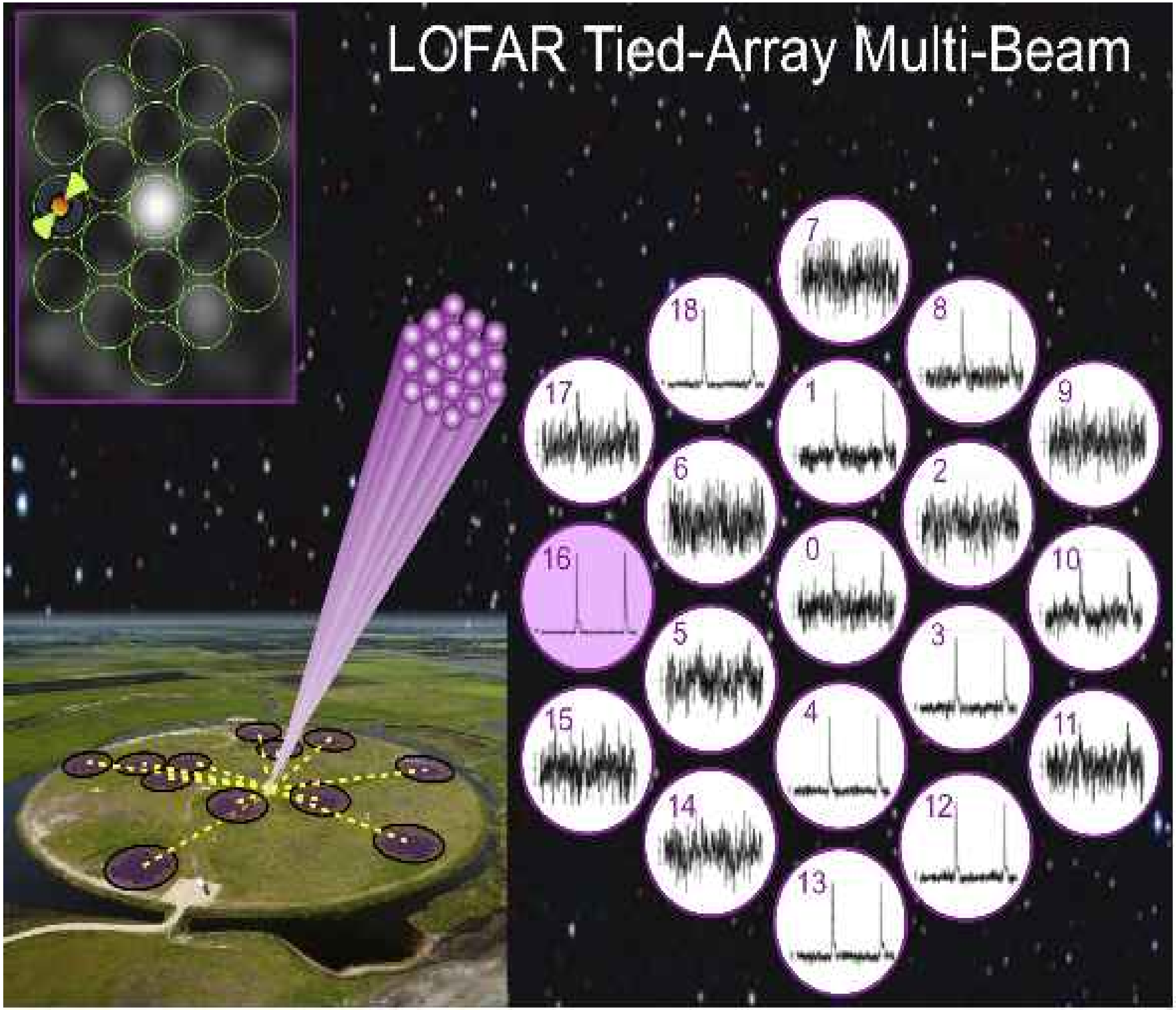
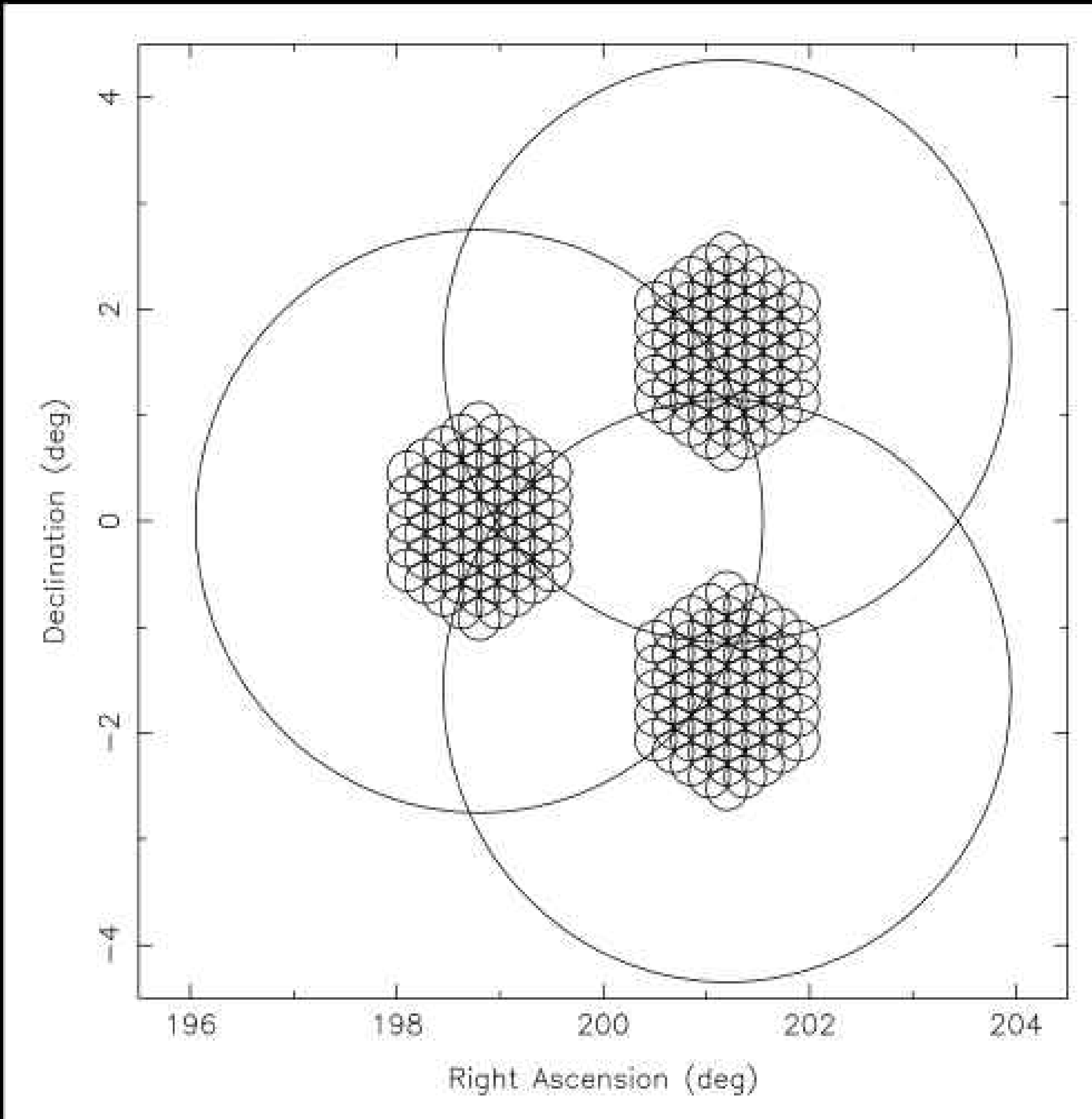


Image credit:
Hessels
Stappers
Scaife

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

Hessels et al., in prep.



LOTAAS Single Pointing

First SKA-like pulsar survey

1 Extra-galactic burst per 10hr observing?

222 beams per pointing