Jan65 Nijmegen 2011

LOFAR: Pulsars and Transients

Ben Stappers / University of Manchester

on behalf of the LOFAR Pulsar Working Group, the TKP and the whole LOFAR team
(Hessels, van Leeuwen, Kramer, Karastergiou, Alexov, Hassall, Noutsos, Kondratiev, Weltevrede, et al.)

Observing pulsars and fast transients with LOFAR

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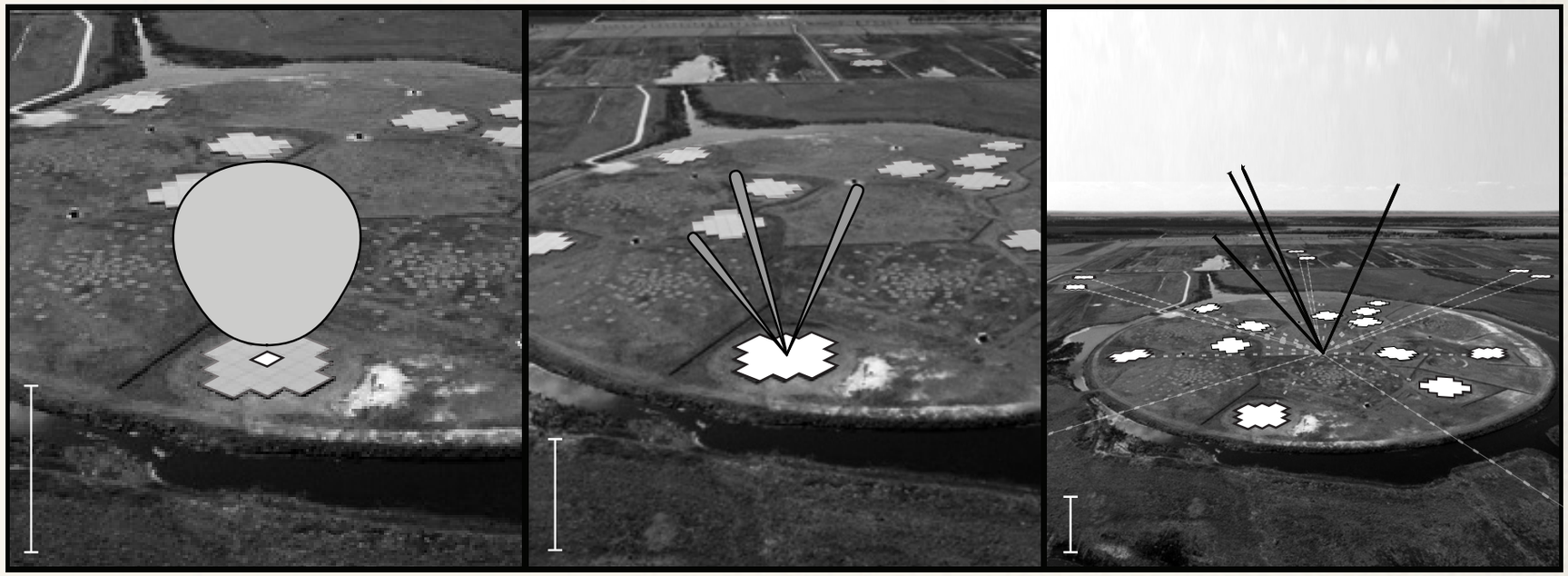
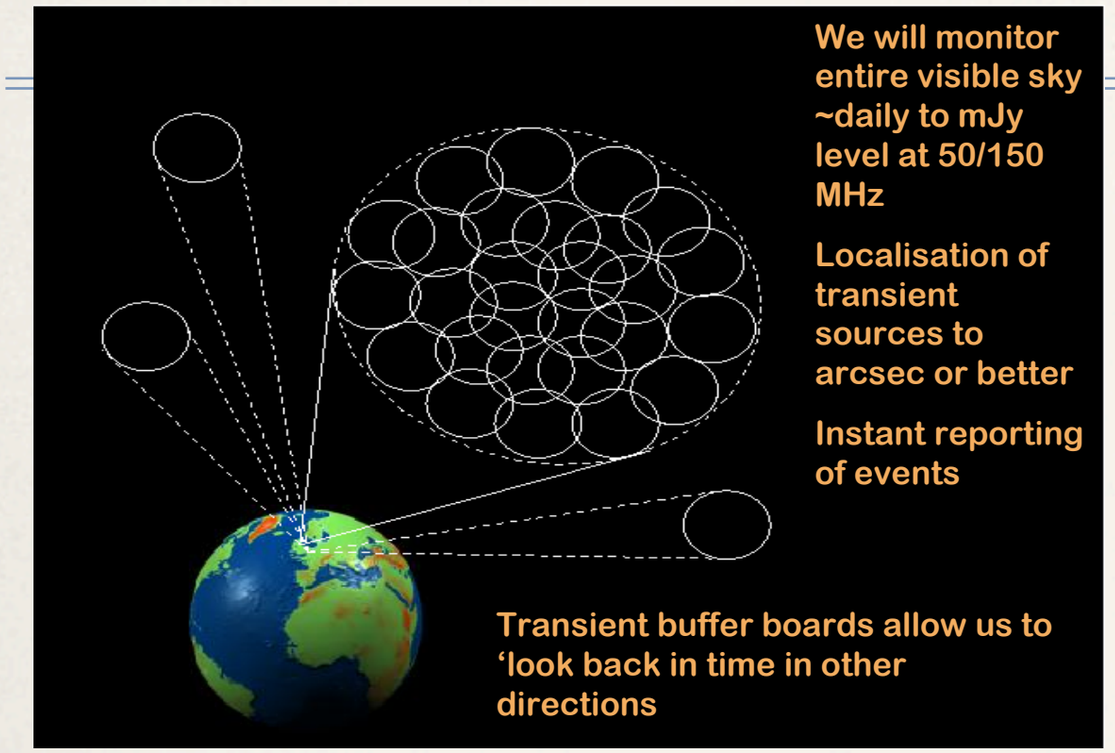
LOFAR: LOw Frequency ARray

- Distributed in NL & EU
- 30 - 240 MHz
- LBA & HBA
- > 30000 dipoles
- 20 Core / 18 NL / >10 EU
- 2.5km / 100km / 1000km

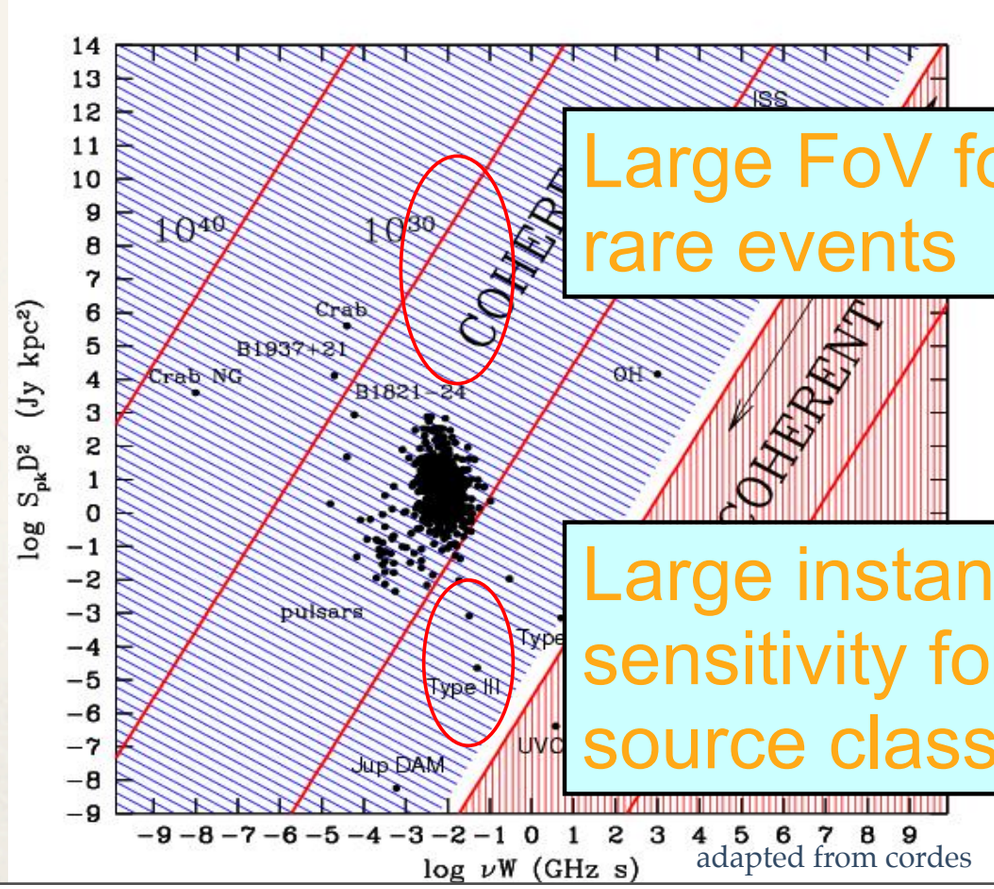


Transients Key Science Project

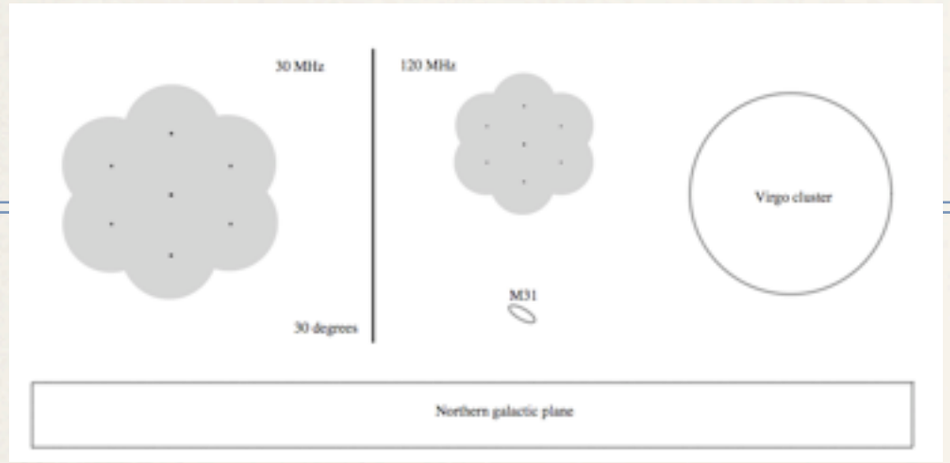
PIs: Fender, Wijers & Stappers

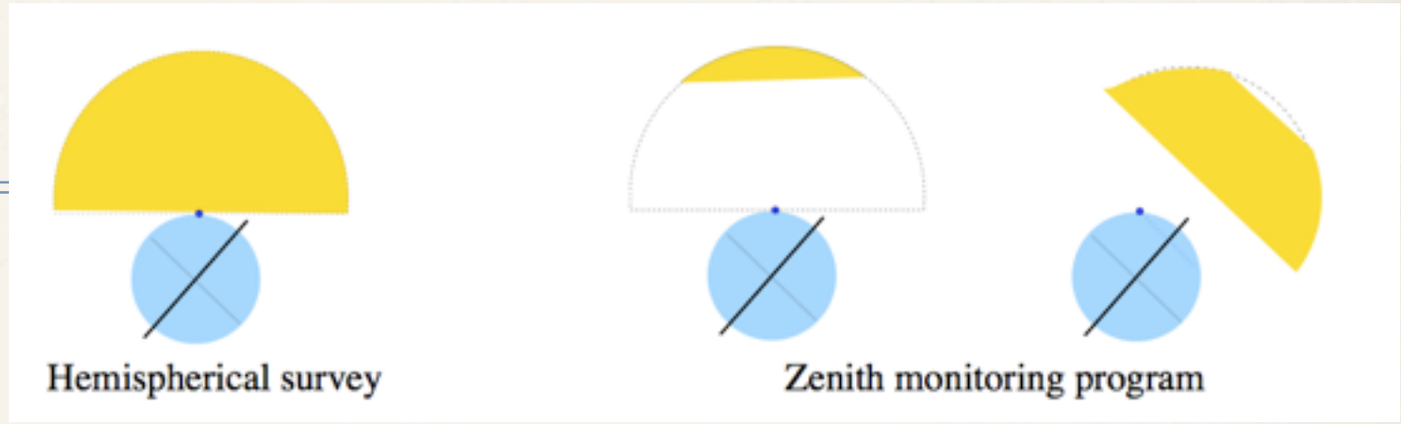


All Sky Monitor



FoV & Observing Modes



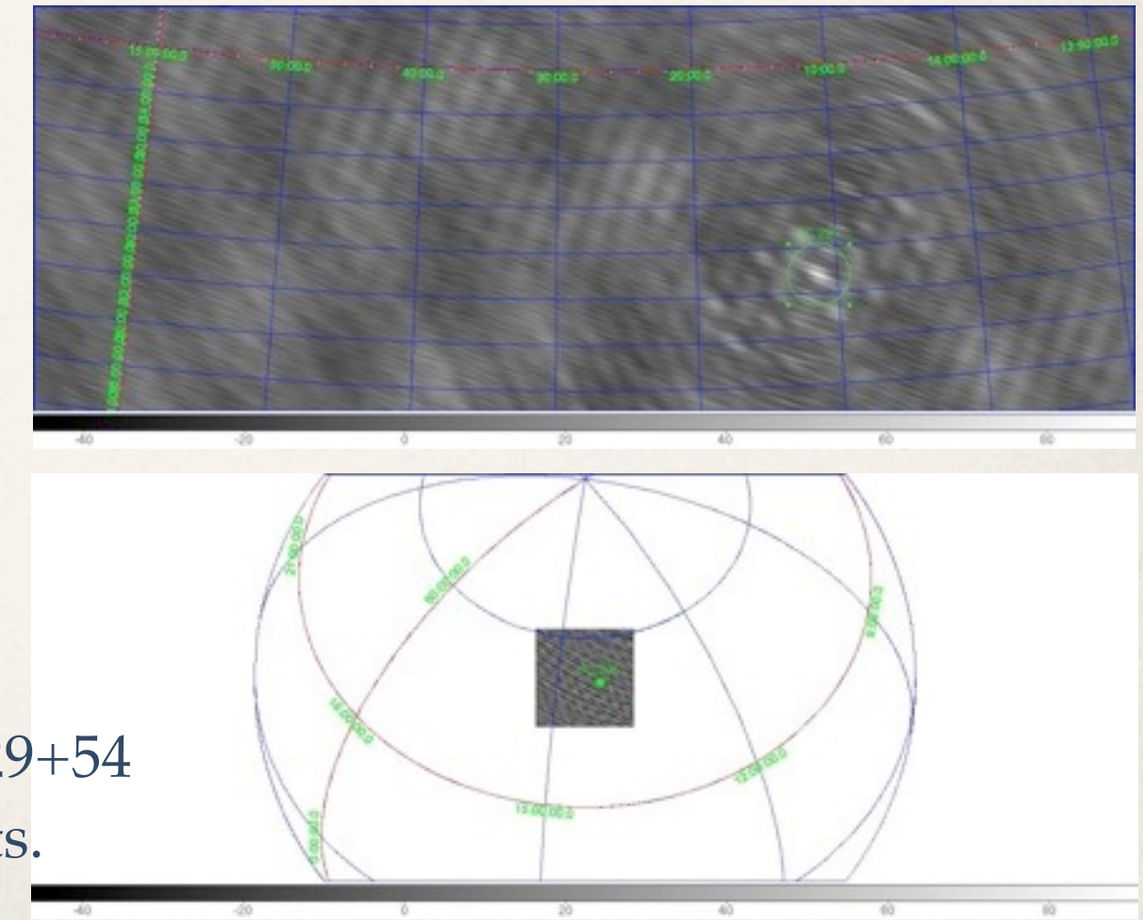


Dedicated observing and commensurate

- First zenith monitoring couple months ago
- Observed for 24 hours to get a full scan
- One field has bright source 3C295 in it
- Single sub band at about 150 MHz
- 25 degrees FoV in single pointing

Commissioning

- Follow up LIGO events
- Multiple (~10) observations of field of PSR B0329+54
- Observations of recent SS433 and Crab outbursts.

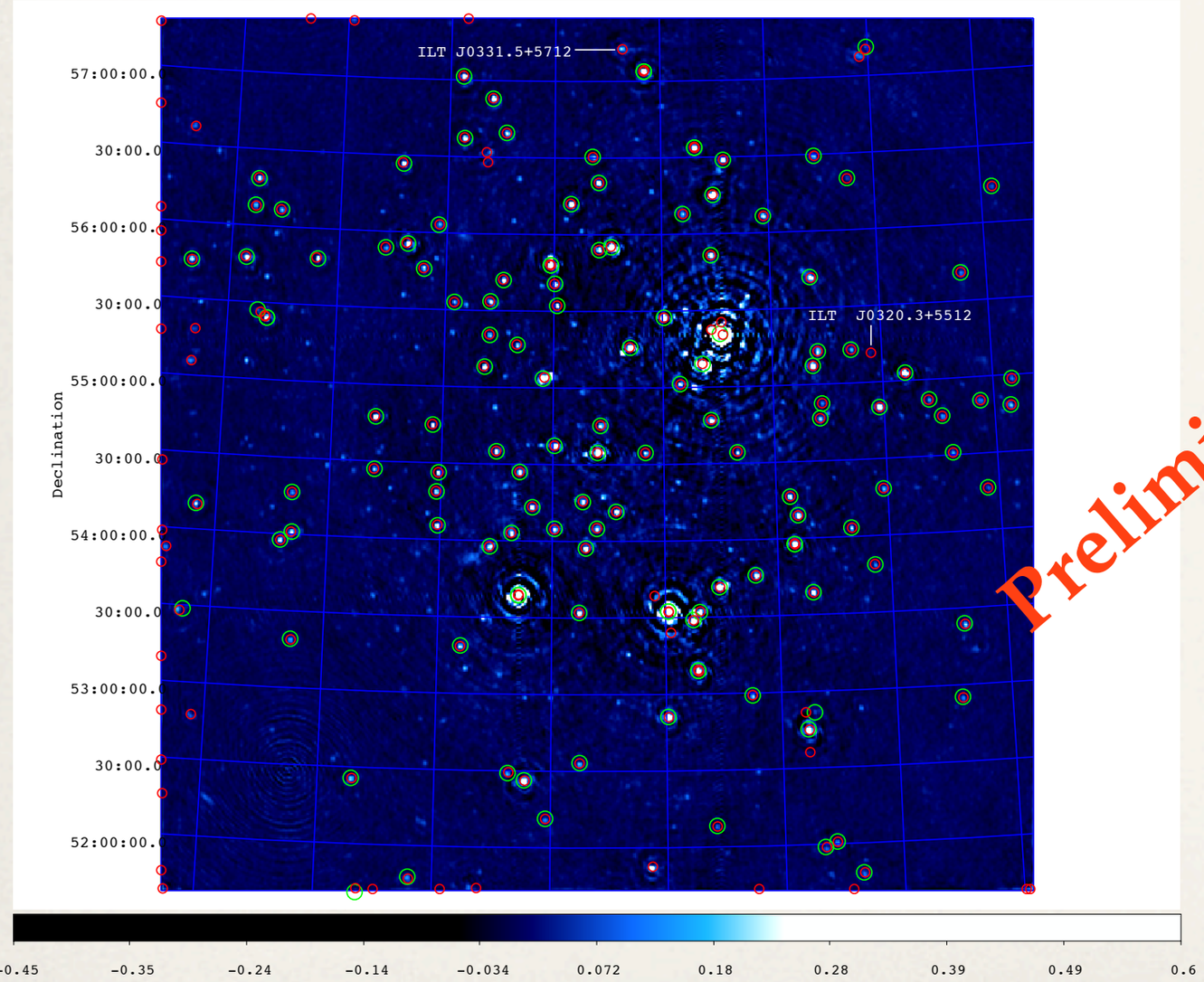


3C 295

Transients Pipeline

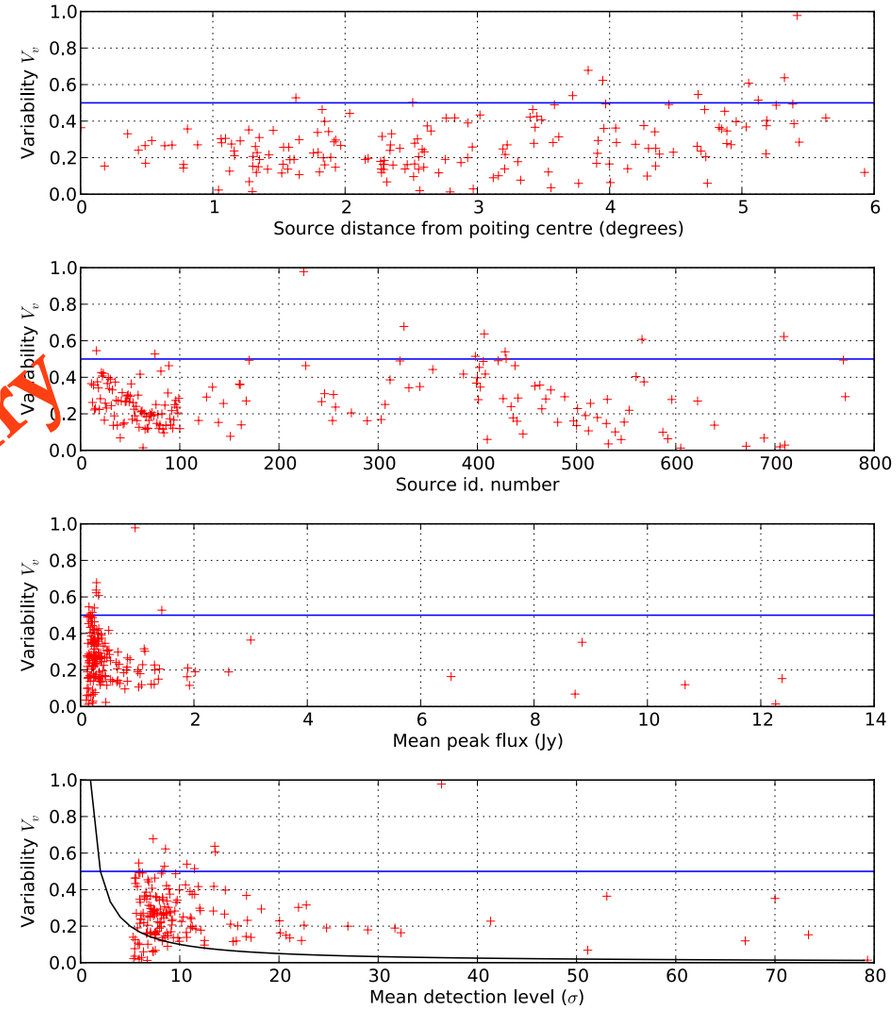
Bell, Fender, Broderick, Swinbank, Rol, & TKP

Field of PSR B0329+54



LOFAR HBA detections (red) overlaid on WENSS

Variability Index



Standard pipeline products

Preliminary

Calibration still being perfected

Why LOFAR for Pulsars/Fast Transients?

ν_{sky} ~ 10 - 300 MHz

Advantages

- Steep spectral indices?
- Only visible at low frequency?
- Low-DM sources distinguishable from RFI.
- Large field of view / dwell times (high F.O.M.).
- Respond to high-frequency triggers (DM delay).

Disadvantages

- Scattering $\nu^{-4.4}$
- *Many* dispersion trials (ν^{-2}).
- Lower effective time resolution.
- Ionosphere.

Why LOFAR for Pulsars/Fast Transients?

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- Steep spectral indices?
- Only visible at low frequency?
- Low-DM [illegible] visible [illegible]
- [illegible] well times [illegible].
- Respond to high-frequency triggers (DM delay).

More luminous, different behaviour

Disadvantages

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- re.

Propagation effects in the ISM are stronger

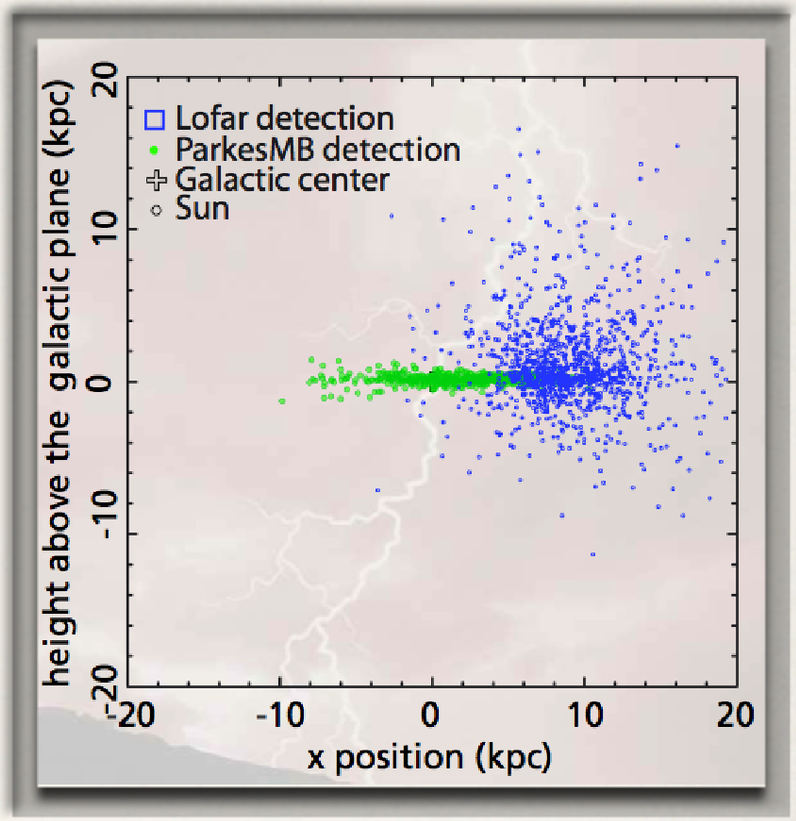
Single Pulses, Timing & ISM

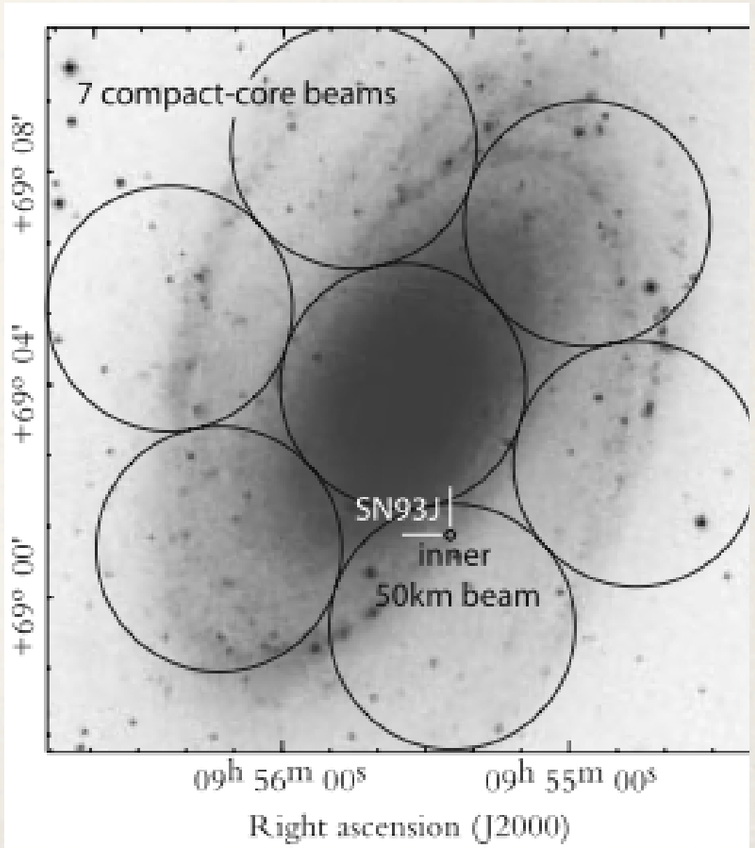
- **Fundamentally linked to the complex, but vital to understand, emission mechanism.**
- Modulation effects like microstructure are deeper.
- Strong linear polarisation seen in single pulses
- Changes happen rapidly in this range
- Spectral turnover -- correlates with emission properties?

- Can get single pulses from large number of MSPs (currently only a couple)!
- **HBAs detect single pulses from more than 1/2 or all known pulsars in LBAs something like 1/3!**
- **Wide BW spectra, simultaneously and often to get any variability**
- Monitor pulsars over wide frequency range to get changes in dispersion measure/ scattering - related to precision timing at high frequencies, absolute time alignment
- Can efficiently time many pulsars with multi-beaming, commensurate observing -- gives important links to high energy observations and GW observatories.

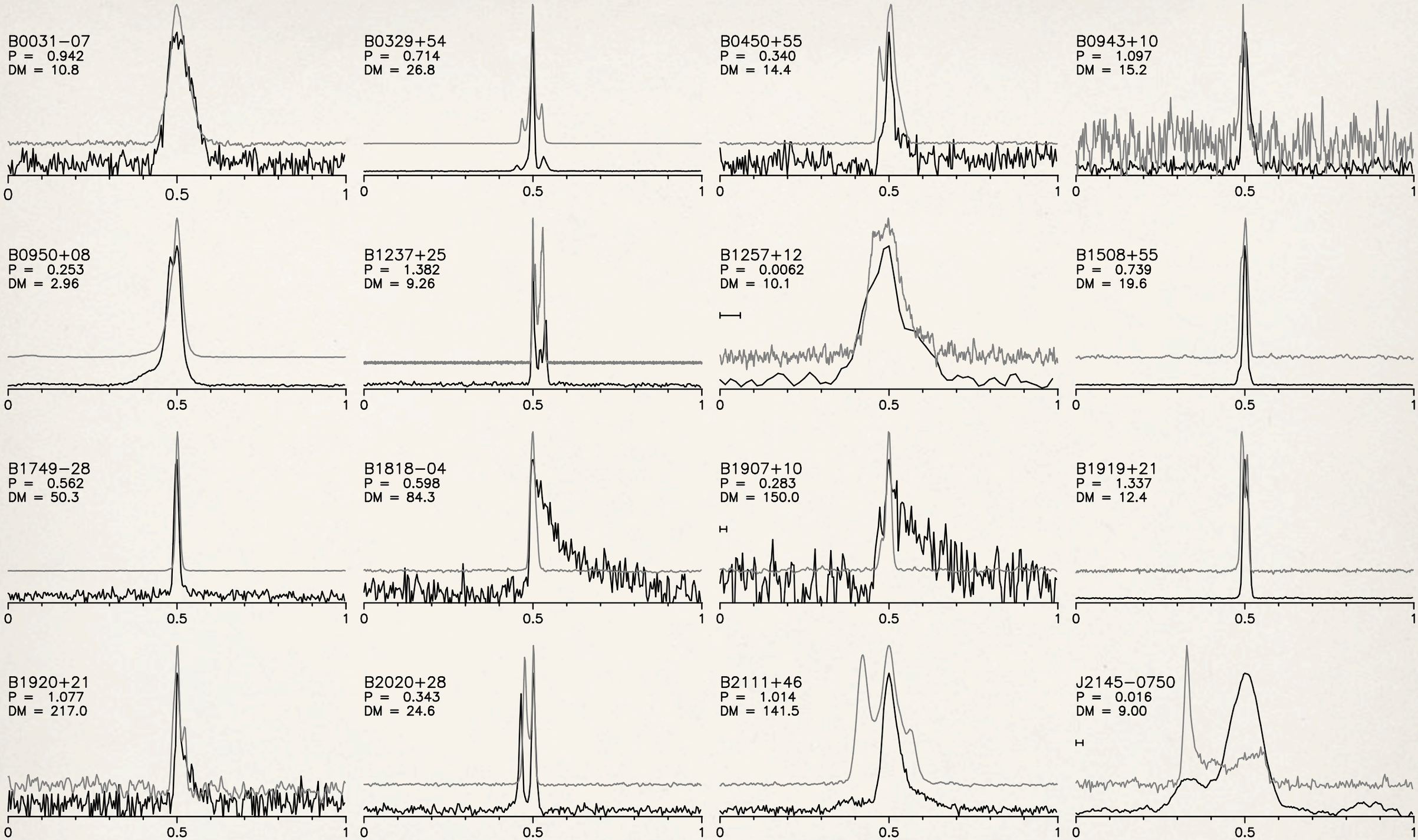
LOFAR Pulsar Surveys

- LOTAAS -- All Northern Sky Survey will find up to 1000 new pulsars
- Use > 100 Tied Array beams simultaneously.
- Will be so sensitive it will find entire local population (< 2kpc) allowing studies of luminosity function in detail
- Exotic objects like pulsar-pulsar and pulsar-BH binaries possible
- Sensitive enough to find first pulsars in external galaxies beyond MCs





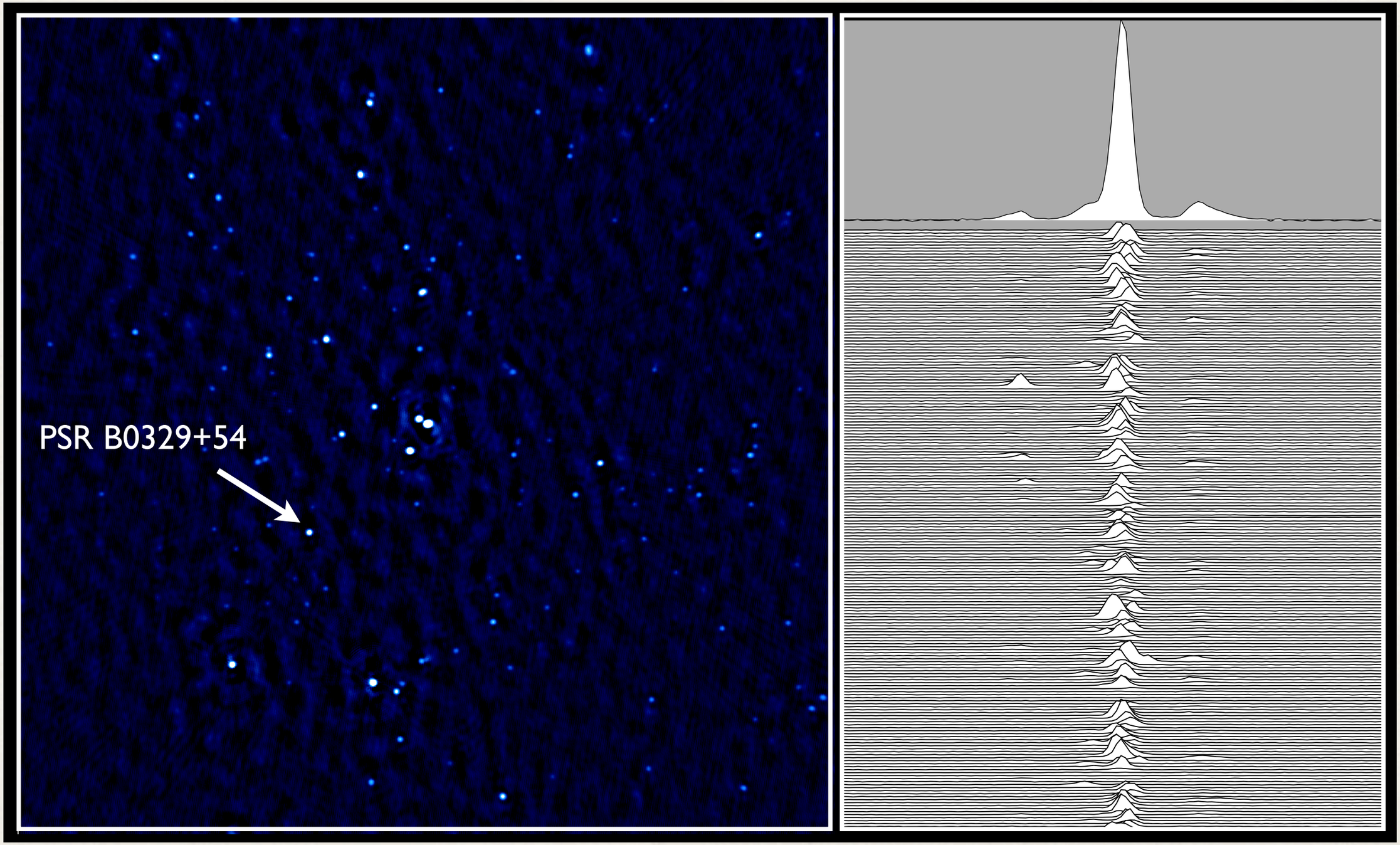
van Leeuwen & Stappers (2010) 2009arXiv0910.5118V:



48 MHz BW / 150 MHz / ms time resolution

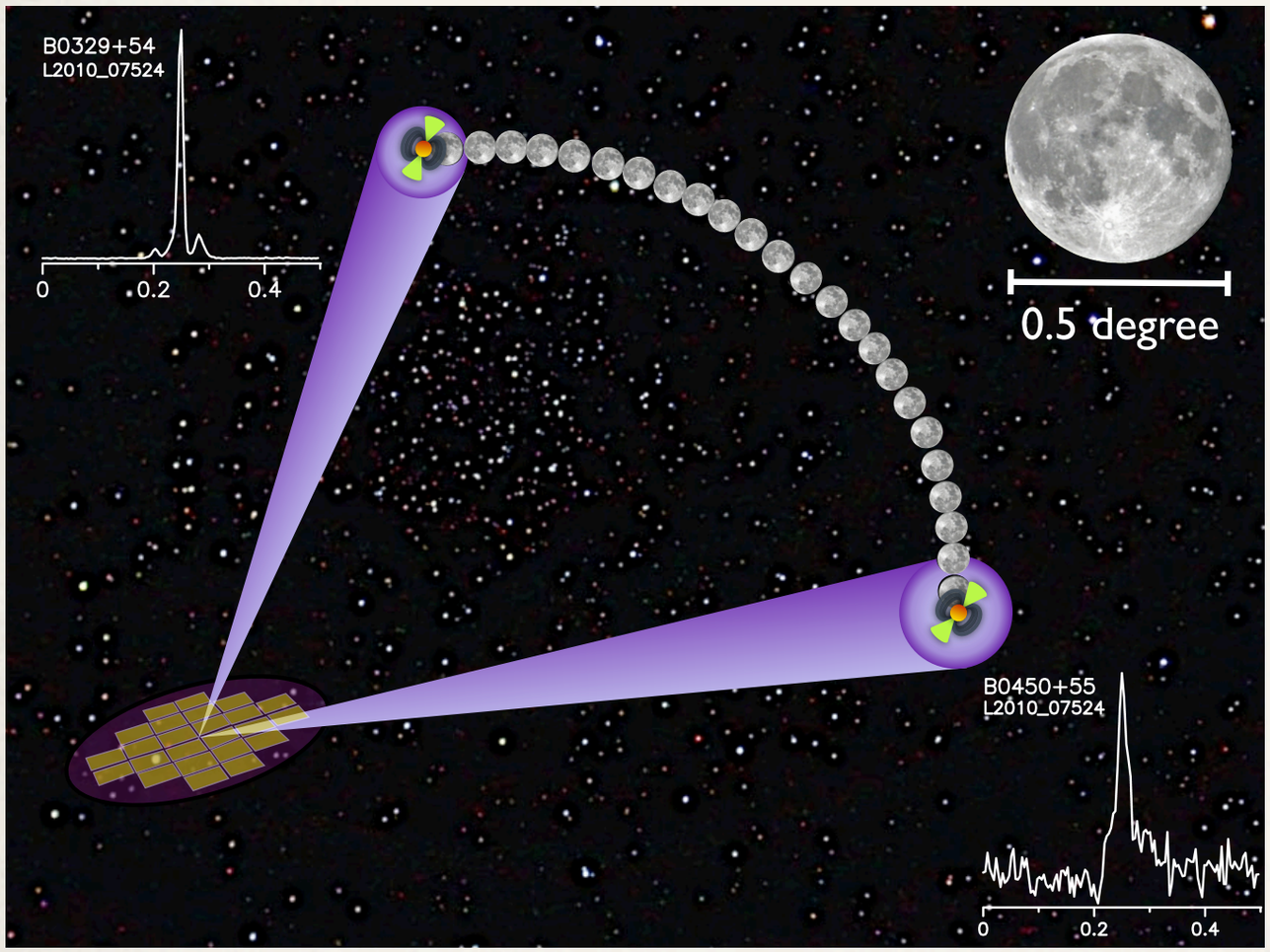
Example profiles obtained with the HBAs cf. with EPN 21cm profiles

Simultaneous Imaging & Time Domain

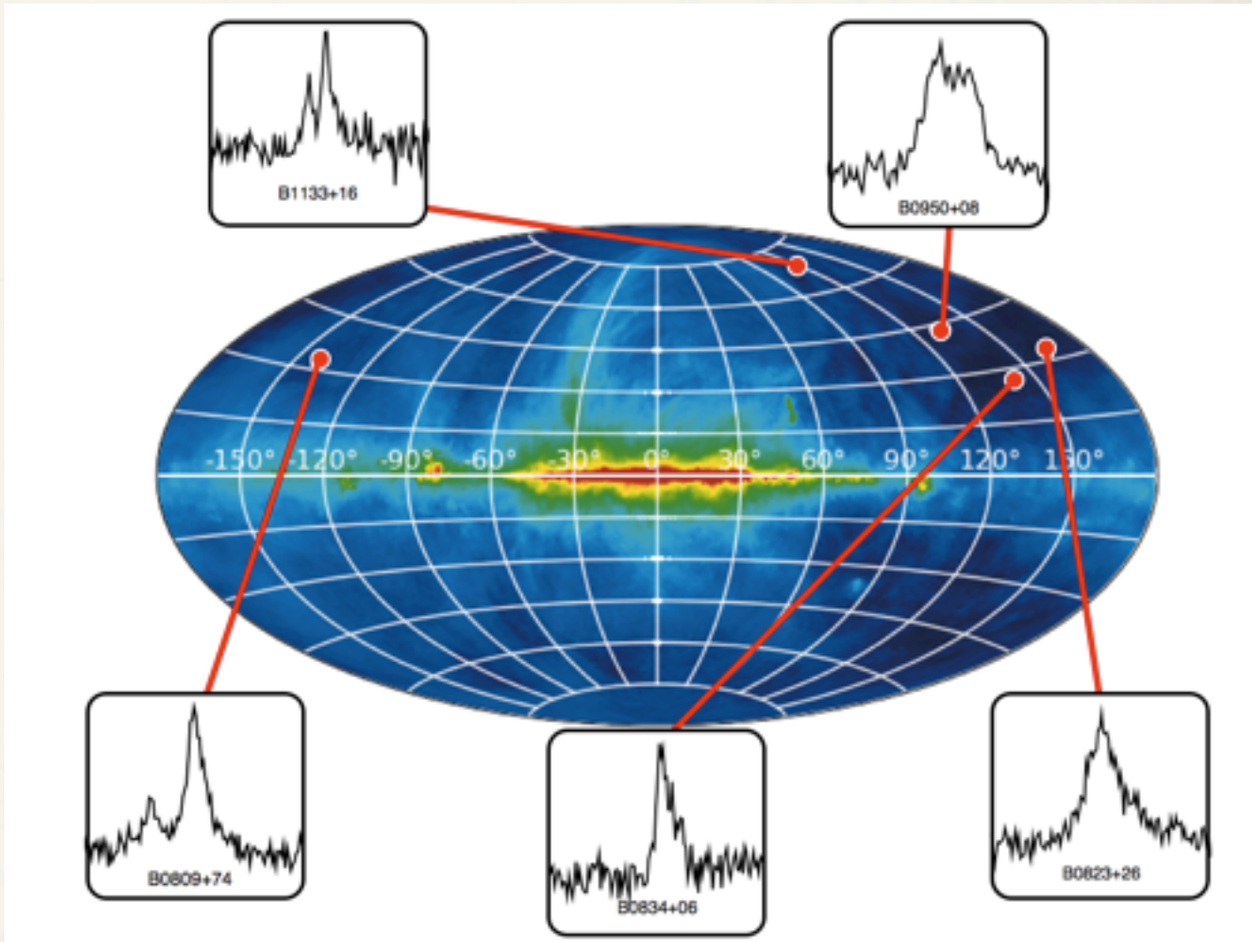


Multi-beaming

HBA



LBA



Hessels, Hassall, Stappers & PWG

Crab Giant Pulses

Giant Pulse

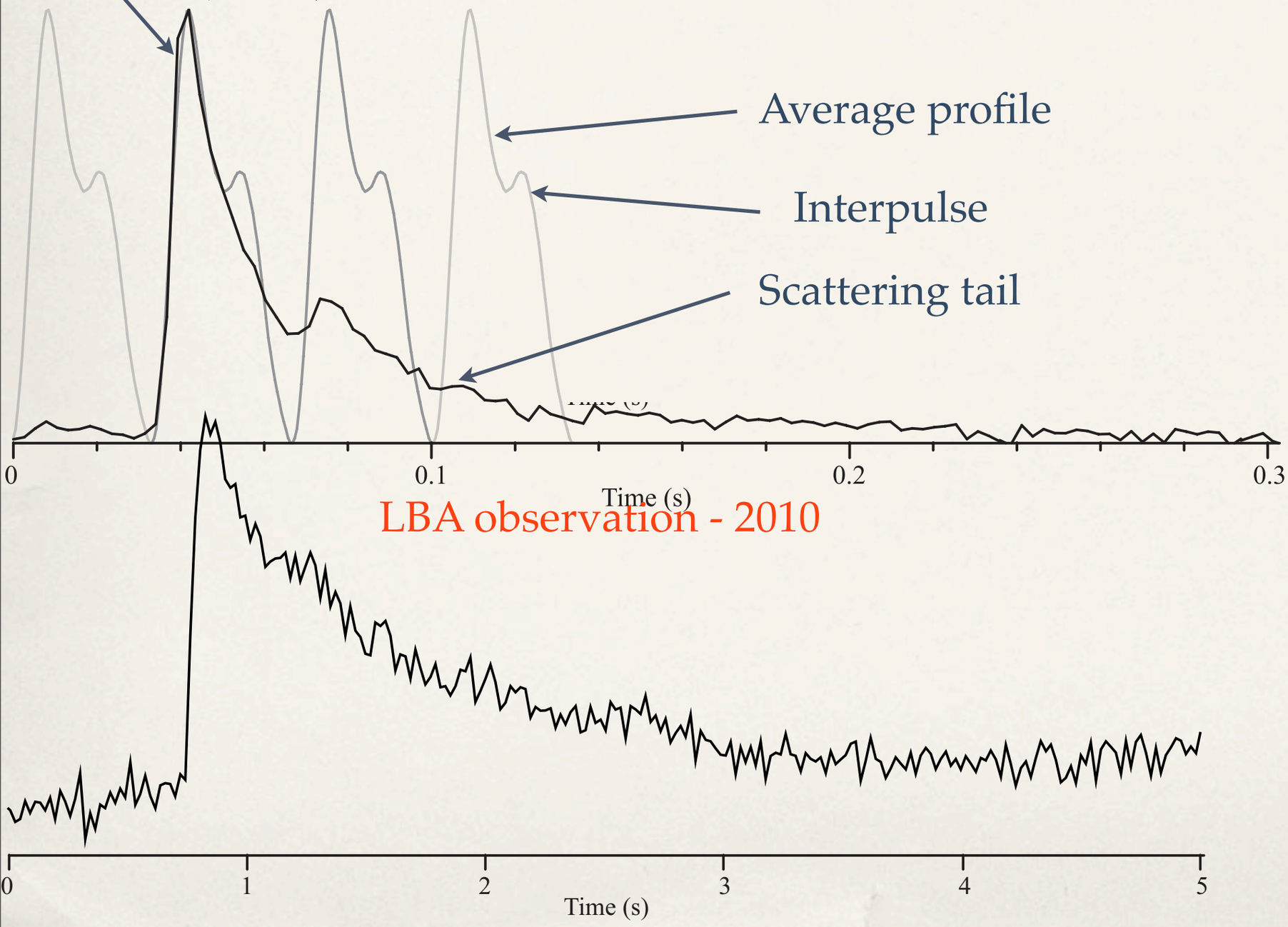
33 ms

HBA observation - 2010

Average profile

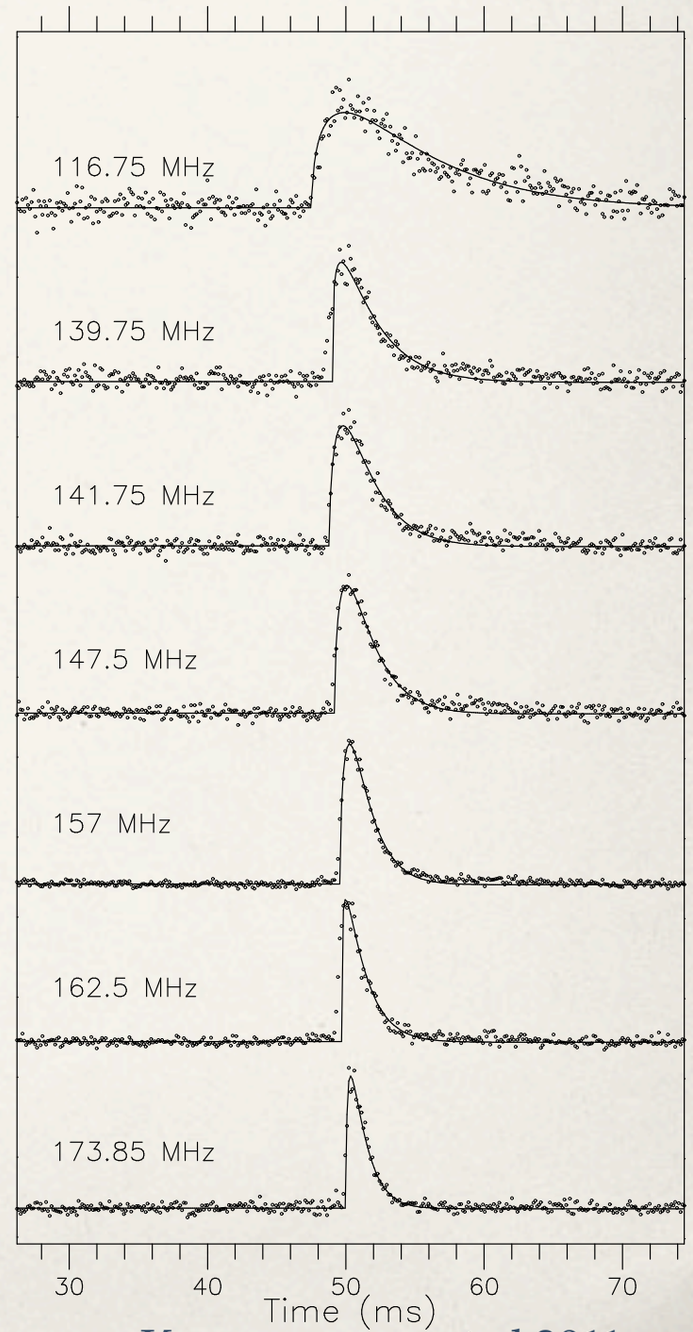
Interpulse

Scattering tail



LBA observation - 2010

WSRT - 2006

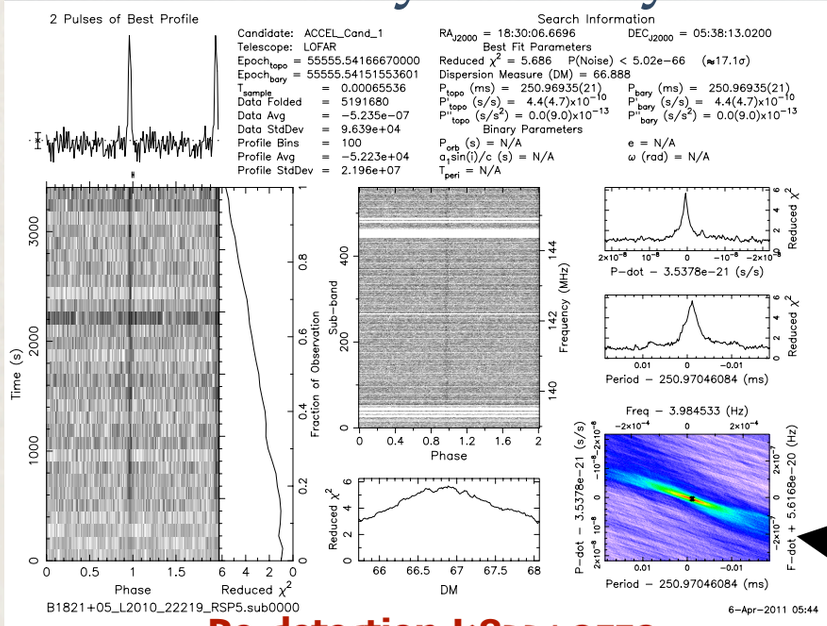


Karuppusamy et al 2011

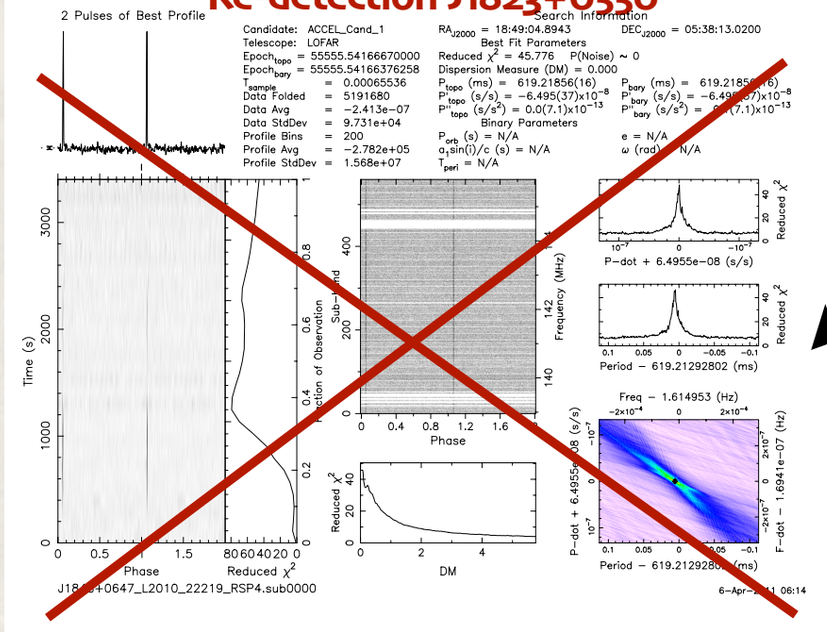
LOFAR Pilot Pulsar Survey (LPPS)

Coenen & PWG

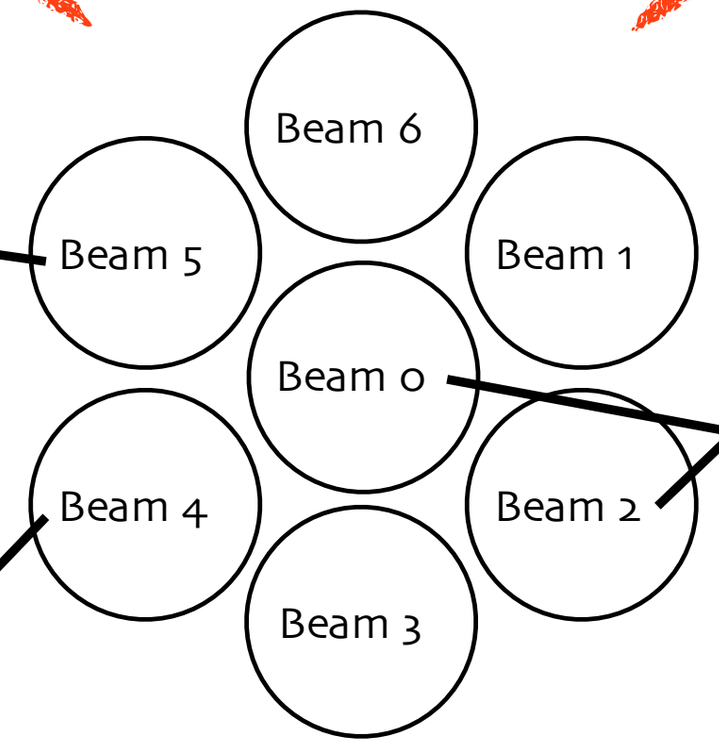
All sky survey with 7 HBA Station Beams summed incoherently



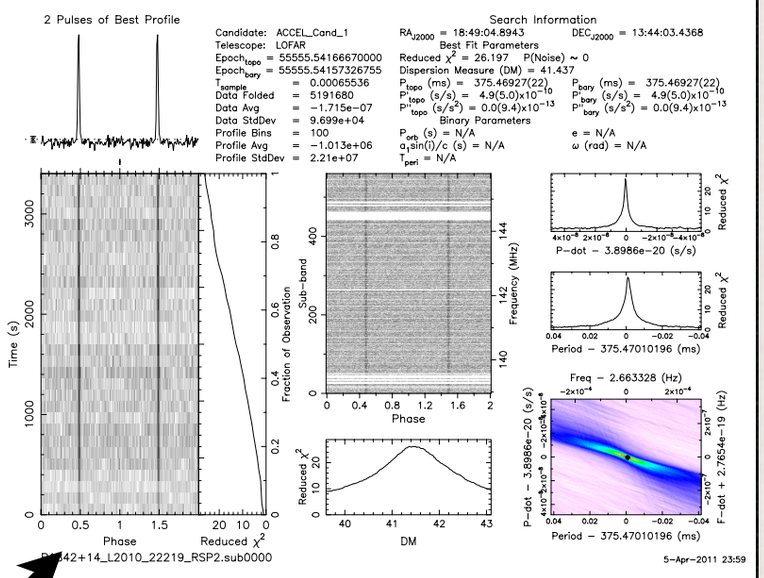
Re-detection J1823+0550



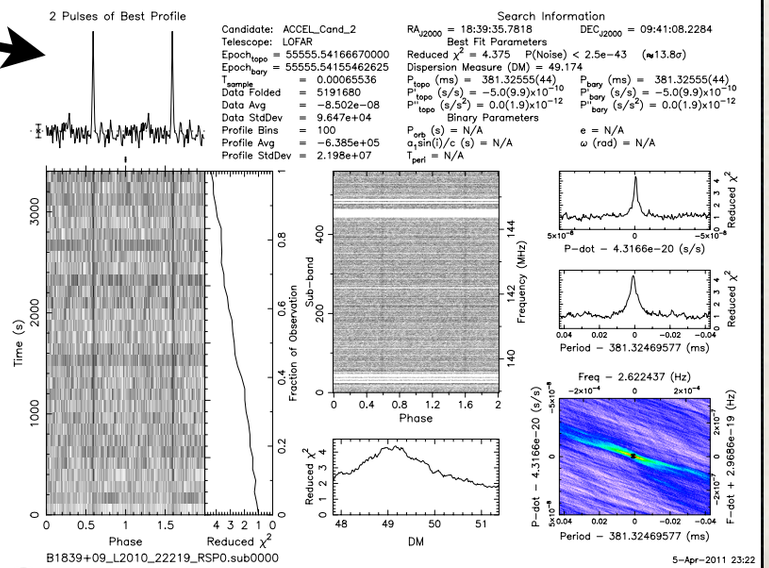
RFI (DM = 0 cm-3 pc)



LPPS pointings contains 7 beams

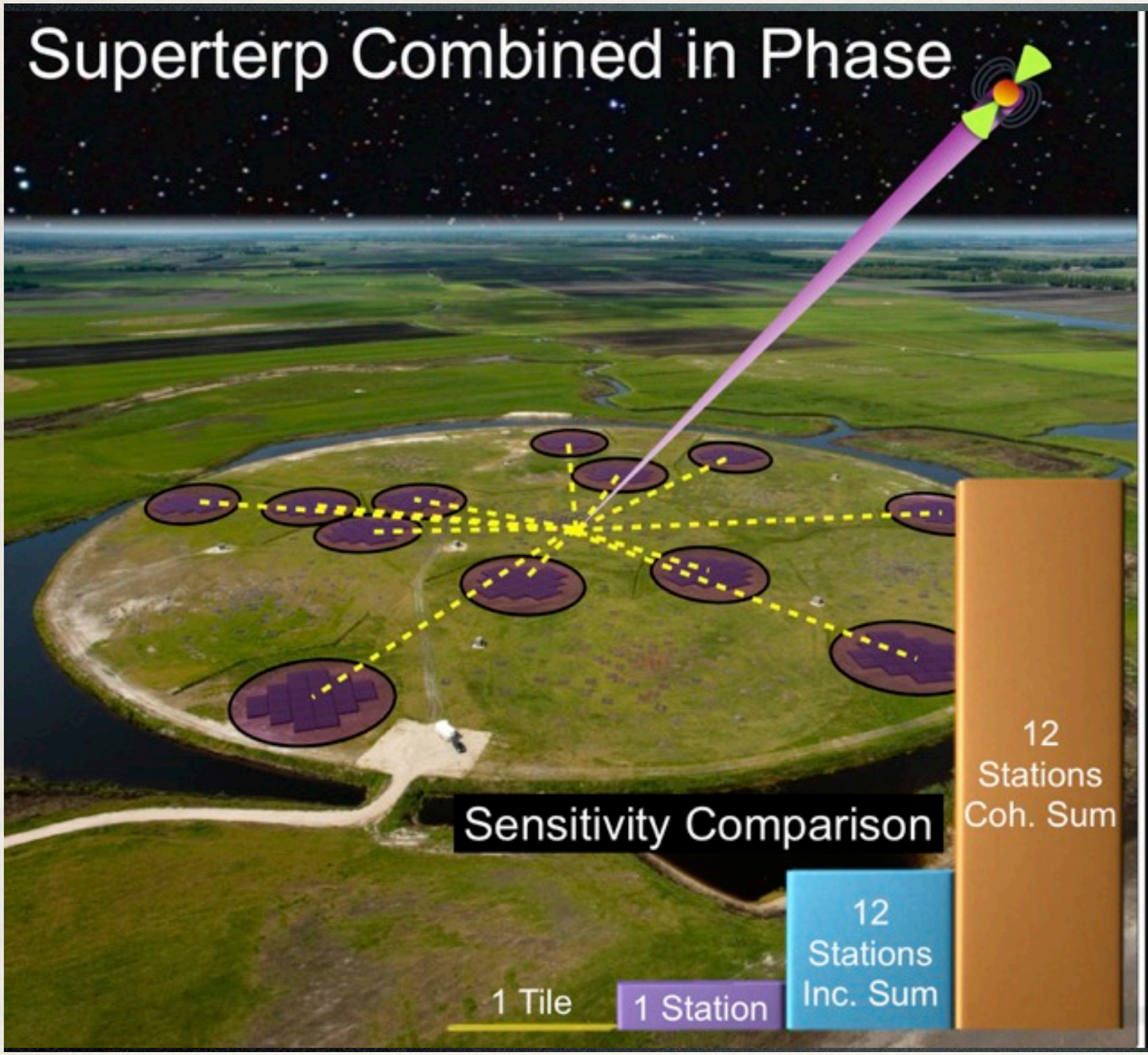


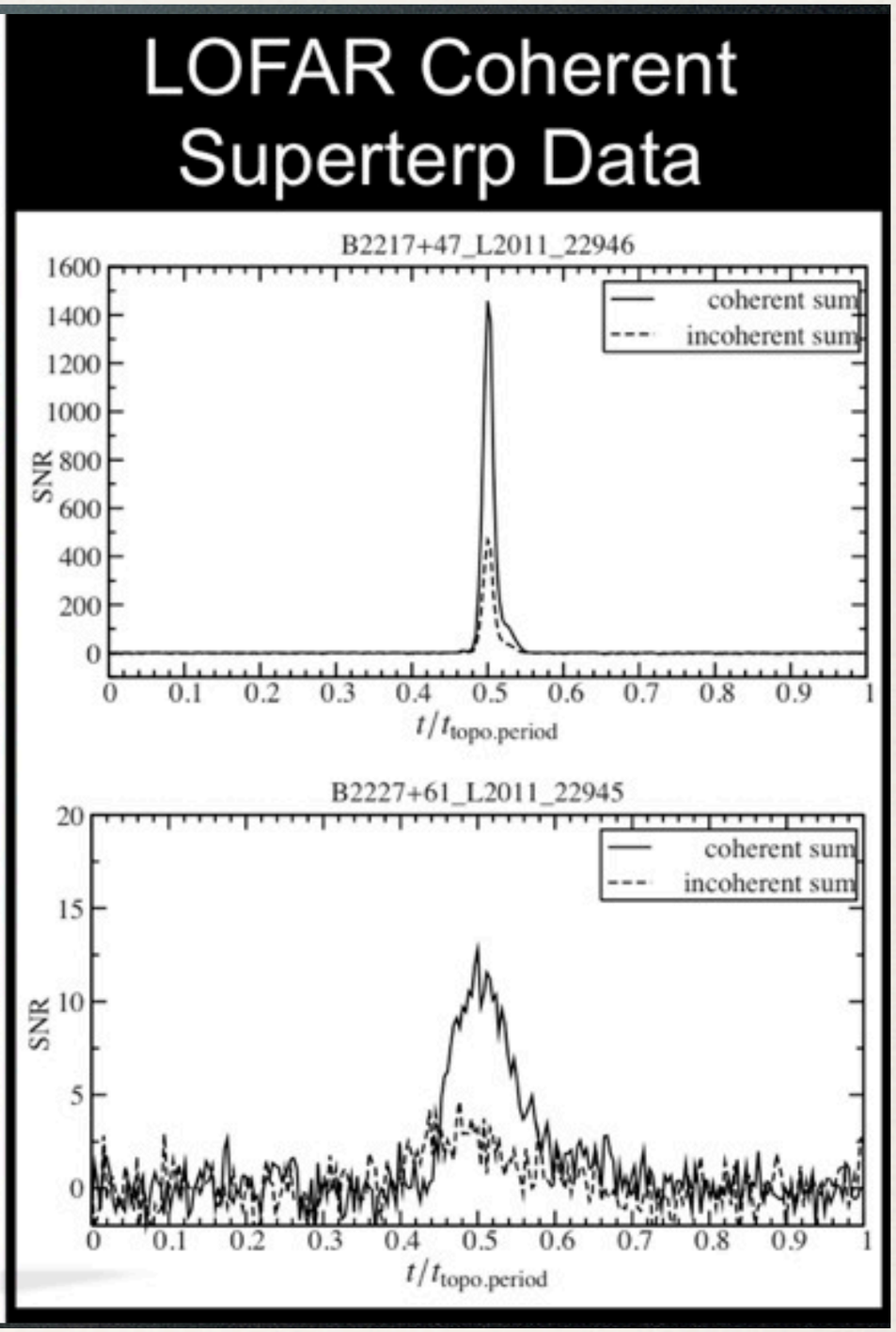
Re-detection J1844+1454



Re-detection J1841+0912

~400 7-beam pointings > -35 deg DEC





Achieved for both the HBAs and LBAs now.

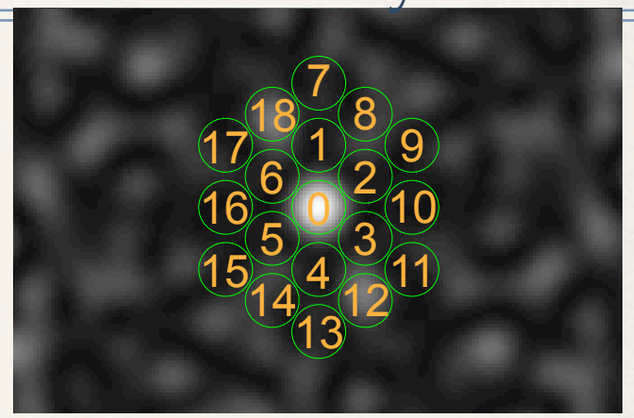
Good stability seen in both.

Hessels, Griessmeier & PWG

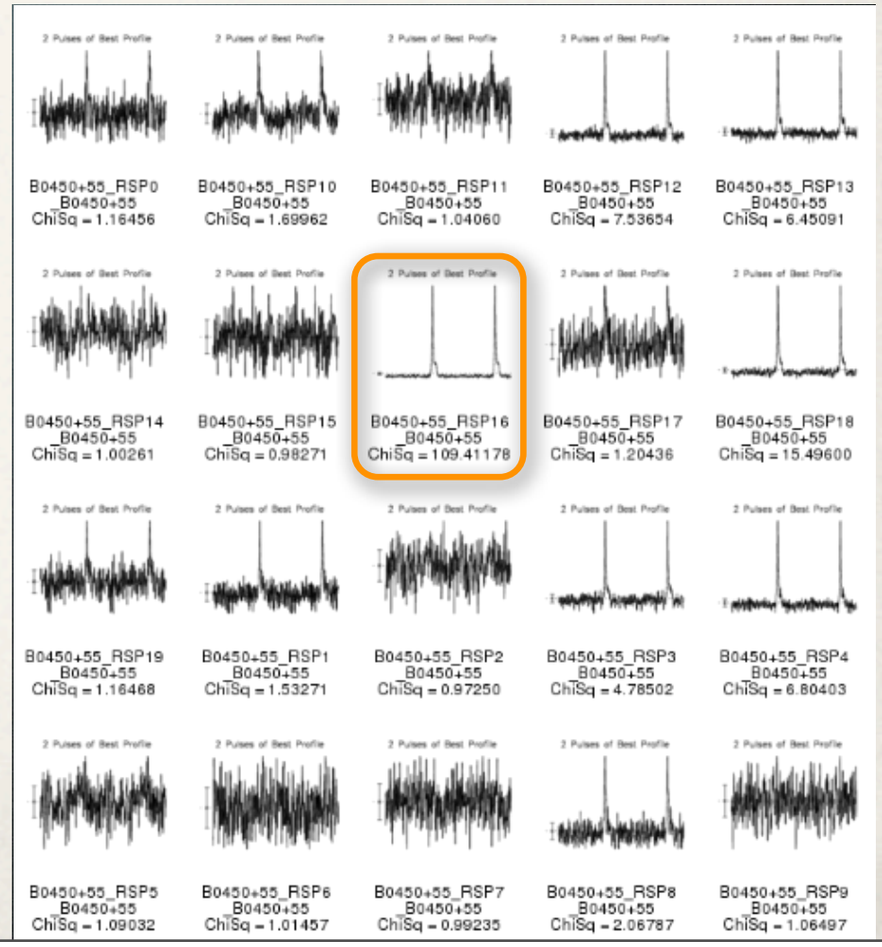
LOFAR Tied-Array Prep.Survey

- Tied-array (coherent) beams (Superterp)
- Central Frequency of about 150 MHz
- 19 beams with full 48MHz and 1.3ms samp.
- 17 minutes per pointing (246GB)
- ~3.7 sq. deg. FoV per pointing
- ~200 pointings taken from May 11-15th
- Used CEP2 and the new Scheduler
- Increase in sensitivity ~9xLPPS
- Less affected by RFI?
- Data processing just started on CEP2 and Hydra.

Beam Layout



Redetection of B0450+55



Hessels, Alexov, Stappers & PWG

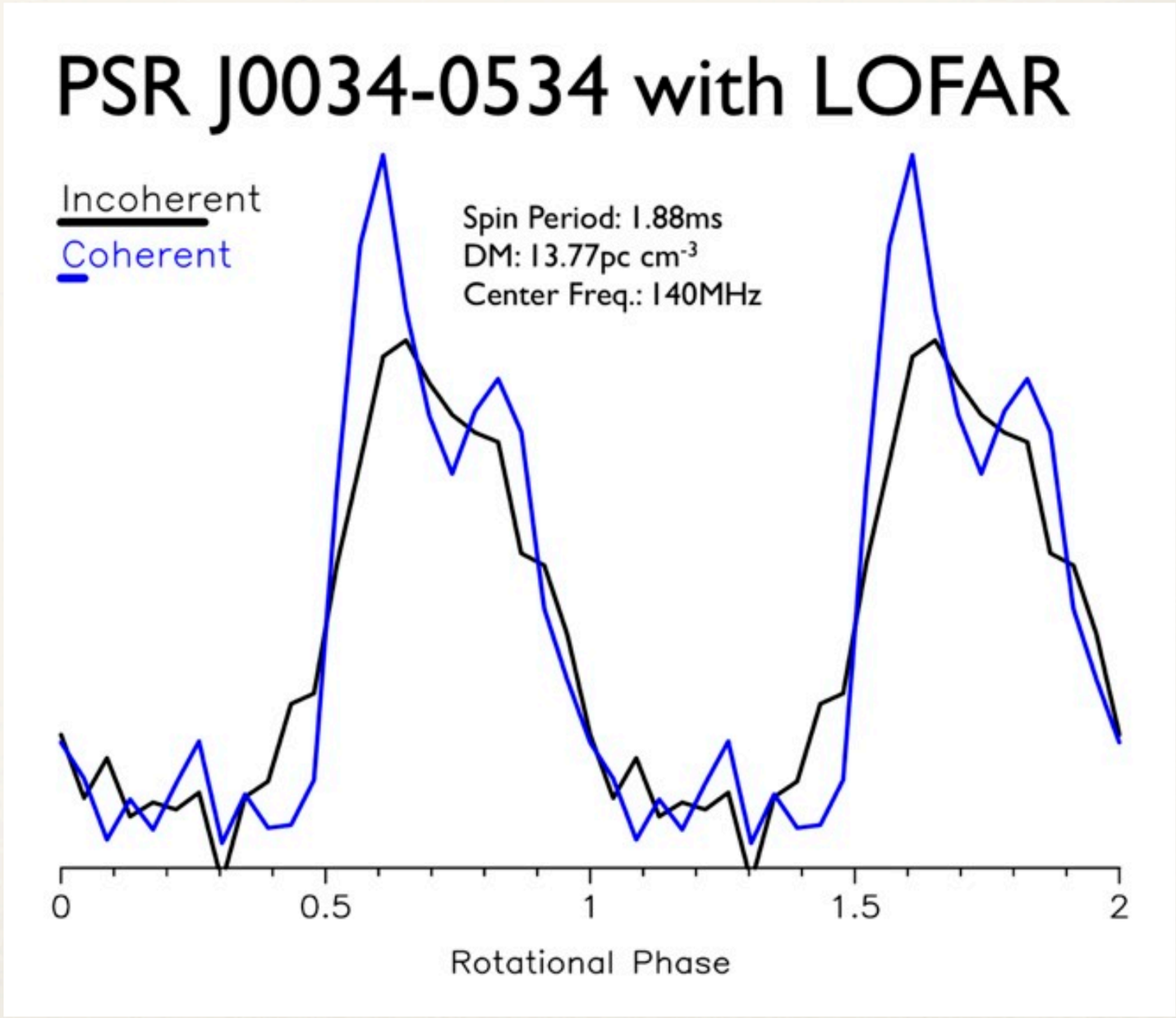
Online Coherent Dedispersion

- In real time on BG/P.

Already improved to allow 5us time resoln.

- Up to 50 coherent dispersion "trial DMs" possible!

- "Baseband" recording also possible for poln. and other studies

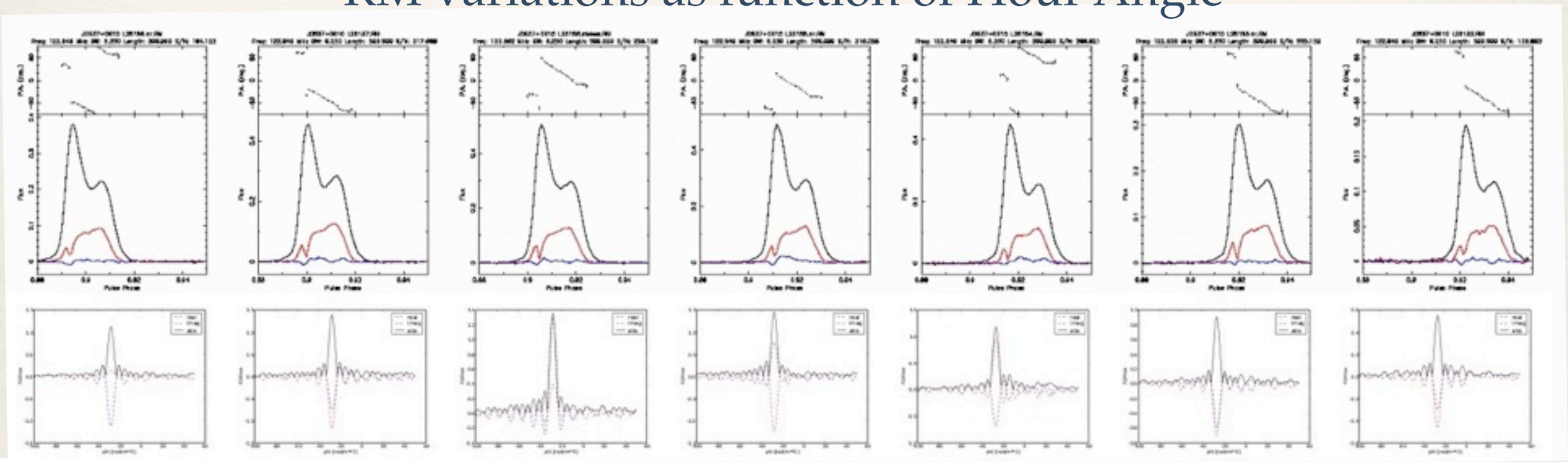


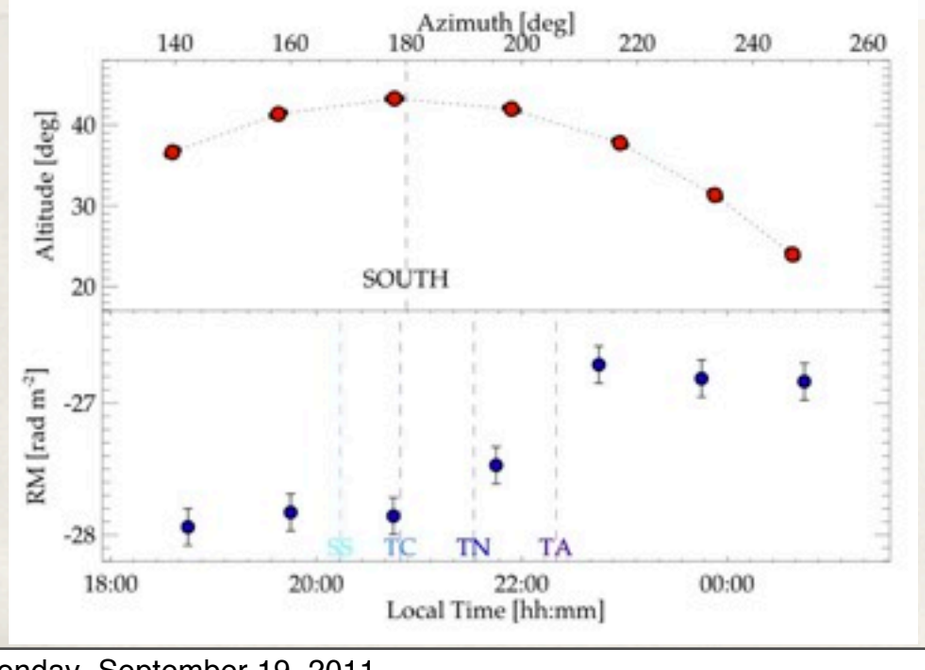
Hessels, Mol, Romein & PWG

Polarisation: PSR B0834+06

Sobey, Noutsos & PWG

RM variations as function of Hour Angle





- Polarisation profiles of PSR B0834+06
- Show v. similar profiles, only RM changes
- Calibration errors less than 5-10%
- Can still be improved with new station calibration and single clock.

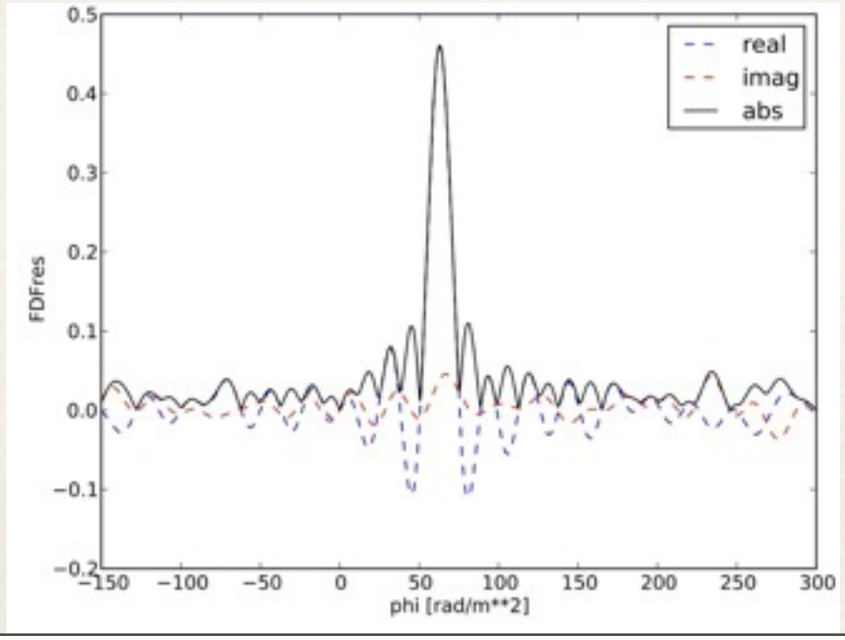
SS = sunset, T[C,N,A] = Twilight [Civil, Nautical, Astronomical]

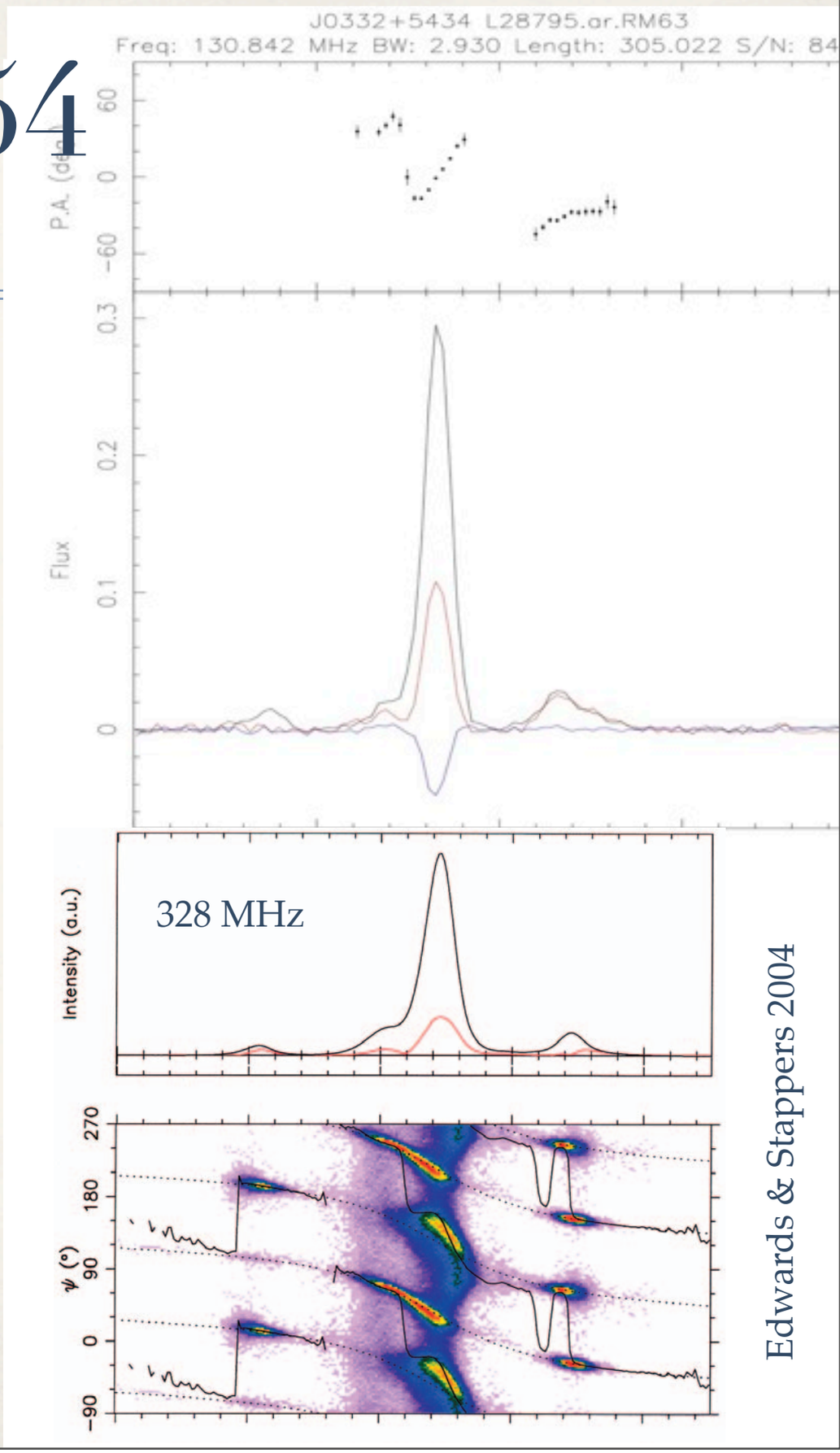
Polarisation: B0329+54

Sobey, Noutsos & PWG

- With calibration for single stations ok.
- Can look at well known pulsars to compare
- With B0329+54 get the correct RM
- Evidence for quite some evoln. with freq.

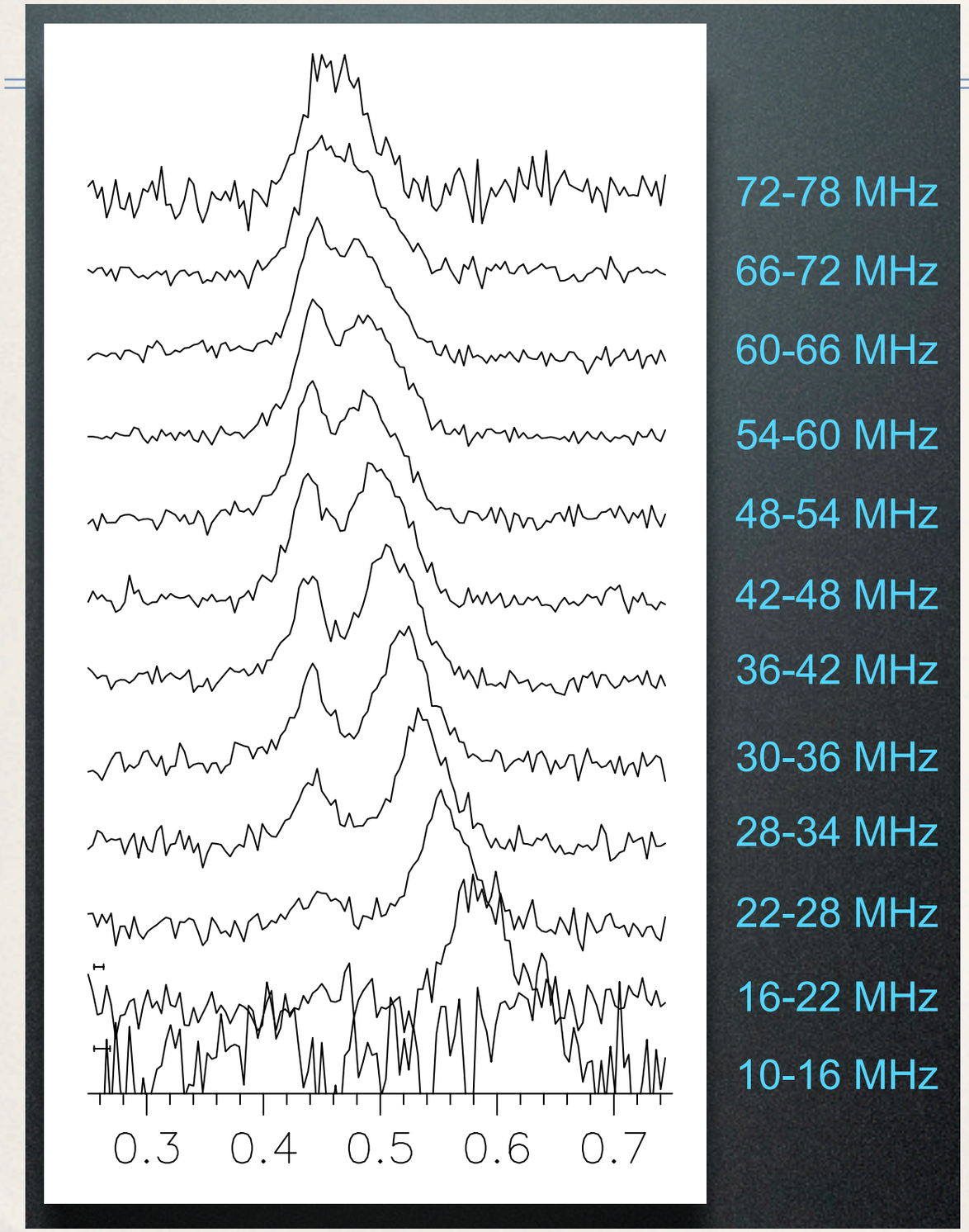
RM Synthesis





Edwards & Stappers 2004

How Low can you go?

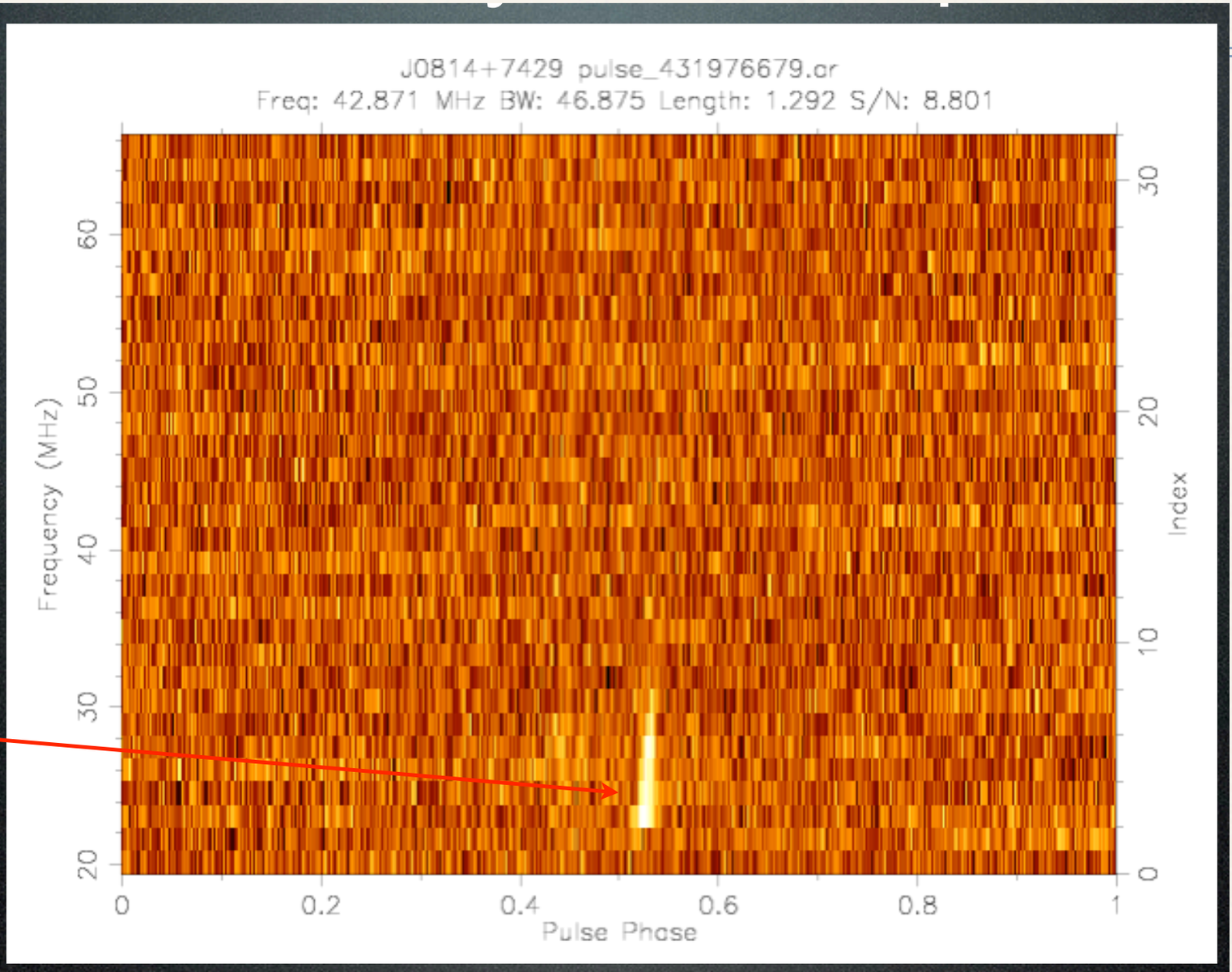


- PSR B0809+74
- First LOFAR detection of pulsar to 16 MHz and perhaps below!
- We can already do better as can now form coherent sum of LBA superterp stations.
- Will soon try other pulsars too.

Stappers, Hassall & PWG

Anomalous intensive pulses

Kondratiev, Bilous & PWG



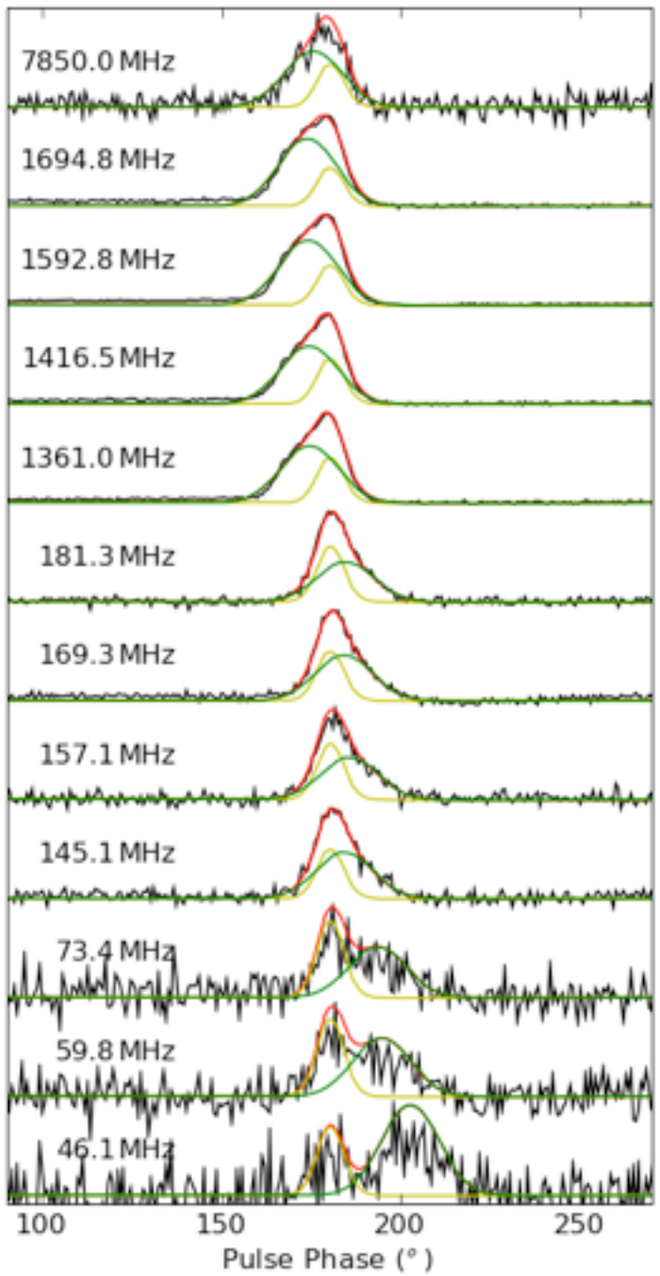
Single, narrow-band bright pulse

Using coherent sum of LBA superterp

- Investigate further with simultaneous LBA/HBA data.
- Relation with classical “giant pulses”?

First seen by Ulyanov et al at UTR2 - but had narrower band instrument

Simultaneous Multifrequency



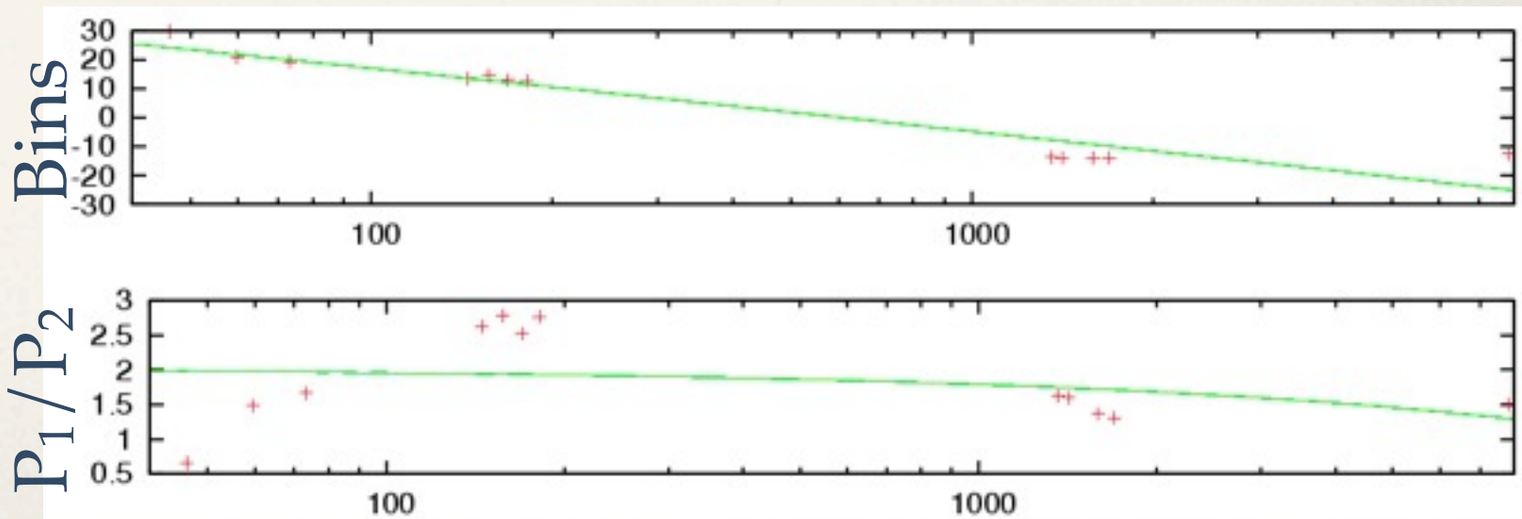
Effelsberg 100-m

Jodrell 74-m

Dutch LOFAR

Effelsberg LOFAR

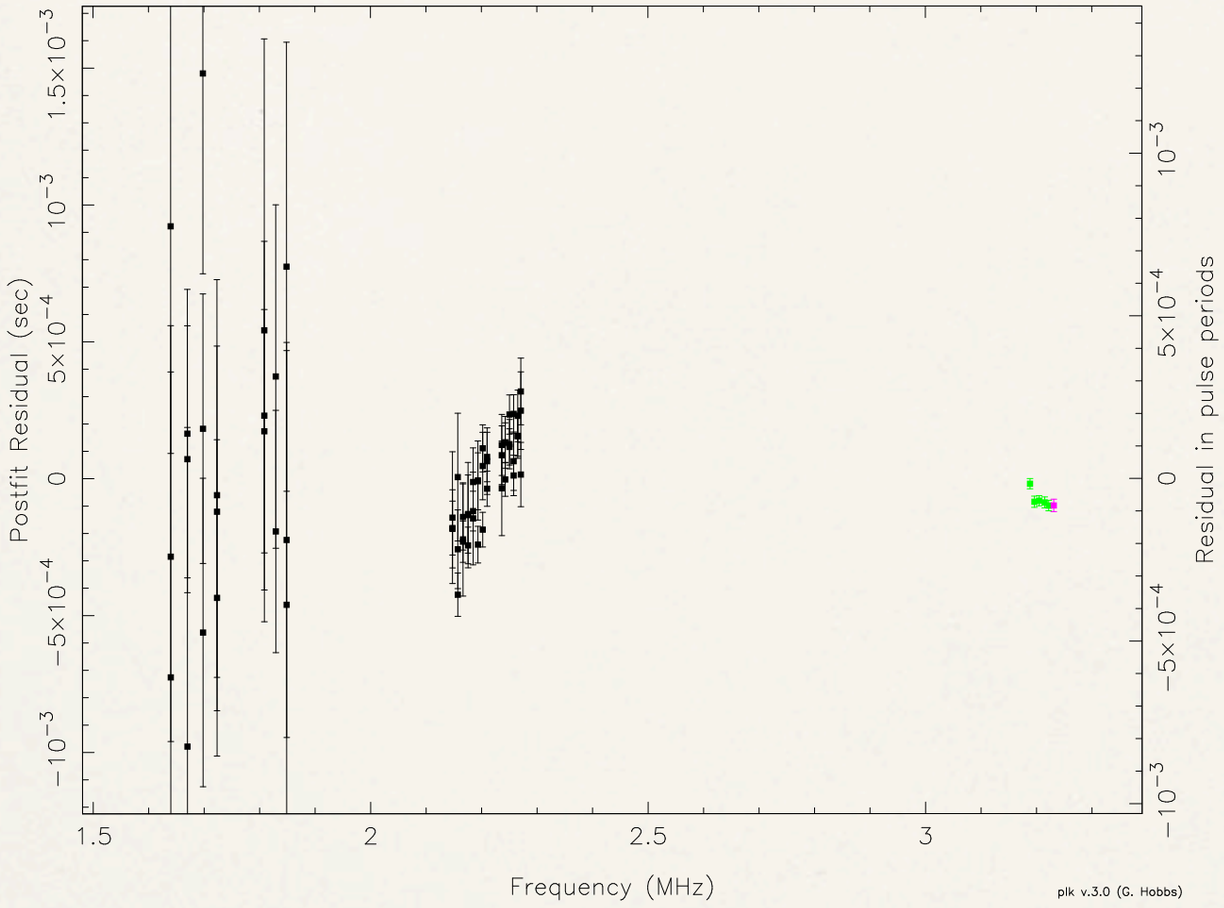
- Observations of PSR B0809+74 Dec 2010
- Some of the widest band simult. obs ever
- Attempt to disentangle DM / Profile changes
- Model the profile, otherwise can't get a single value of DM
- Able to track completely components vital for magnetospheric and high precision timing study.
- Get a value for DM accurate to $1/10^6$
- Both LBA and HBA sensitivity greatly improved since.



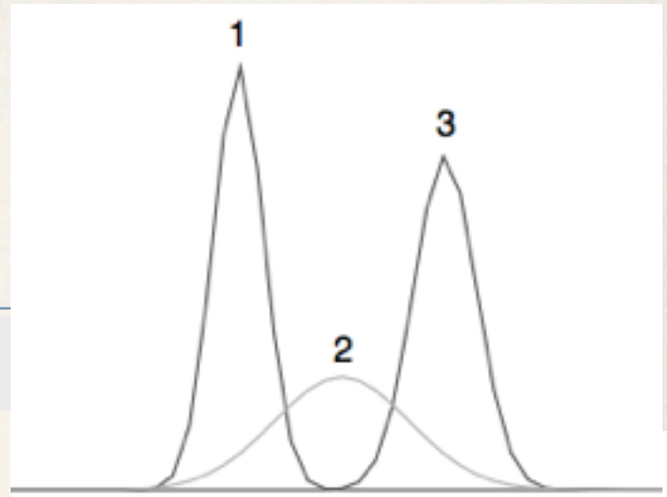
Dispersion vs Pulse Shape Changes

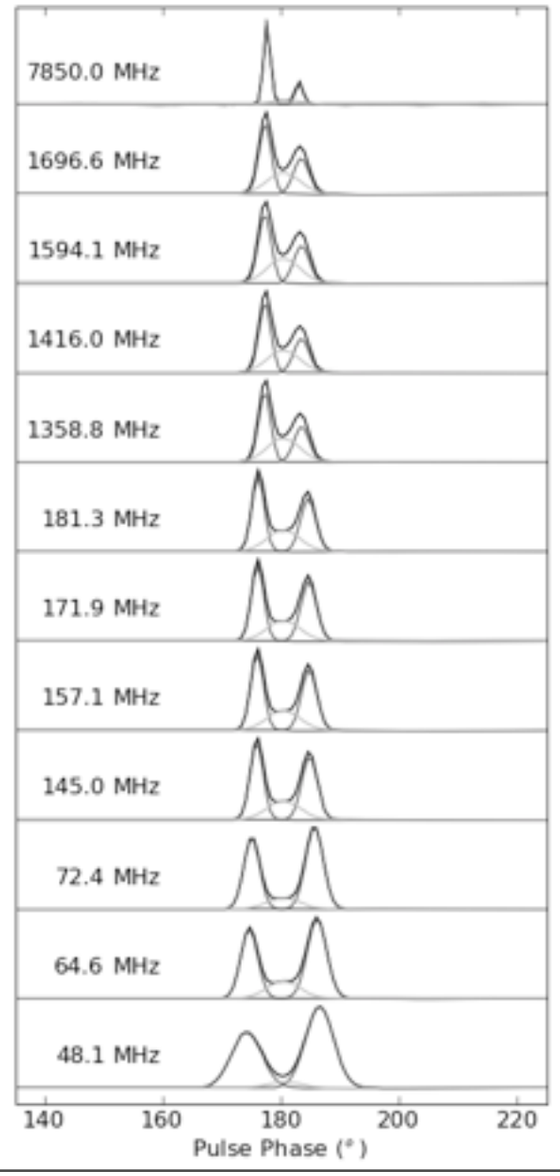
Hassall, Stappers & PWG

Simultaneous observations of PSR B1133+16 with LOFAR & Lovell & Eff.



- Timing residuals generated in “usual” way
- See strong deviations from a single DM fit
- Not due to higher order DM effects, not simple power law
- Require instead to build a frequency dependent model

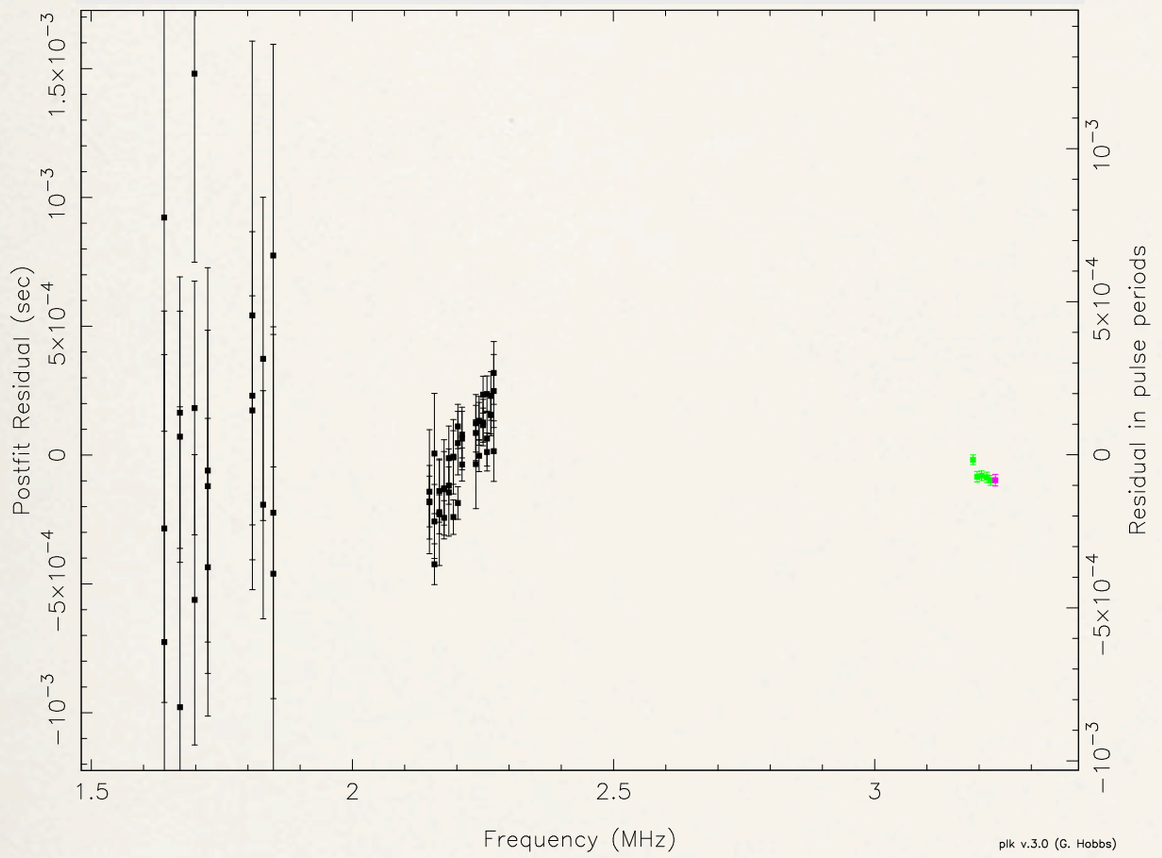




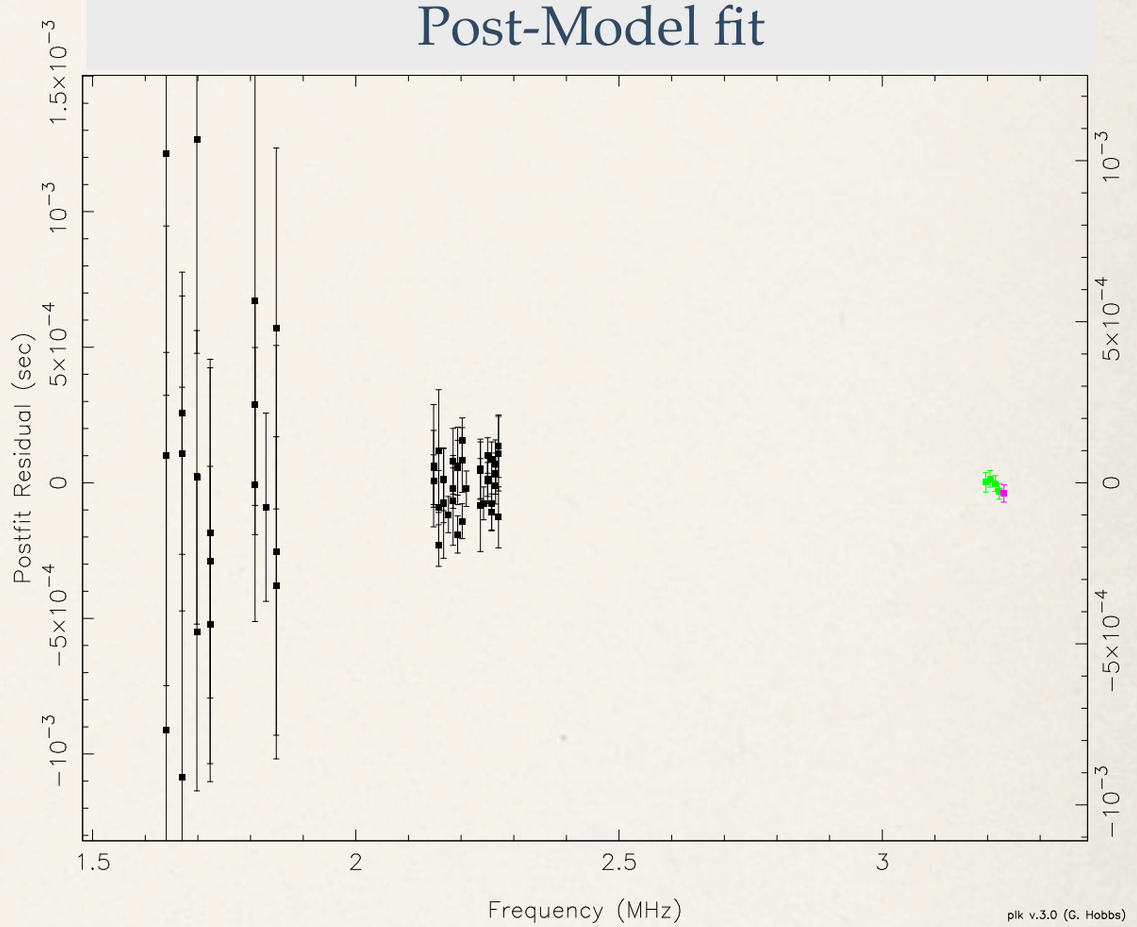
Dispersion vs Pulse Shape Changes

Hassall, Stappers & PWG

Pre-Model fit



Post-Model fit

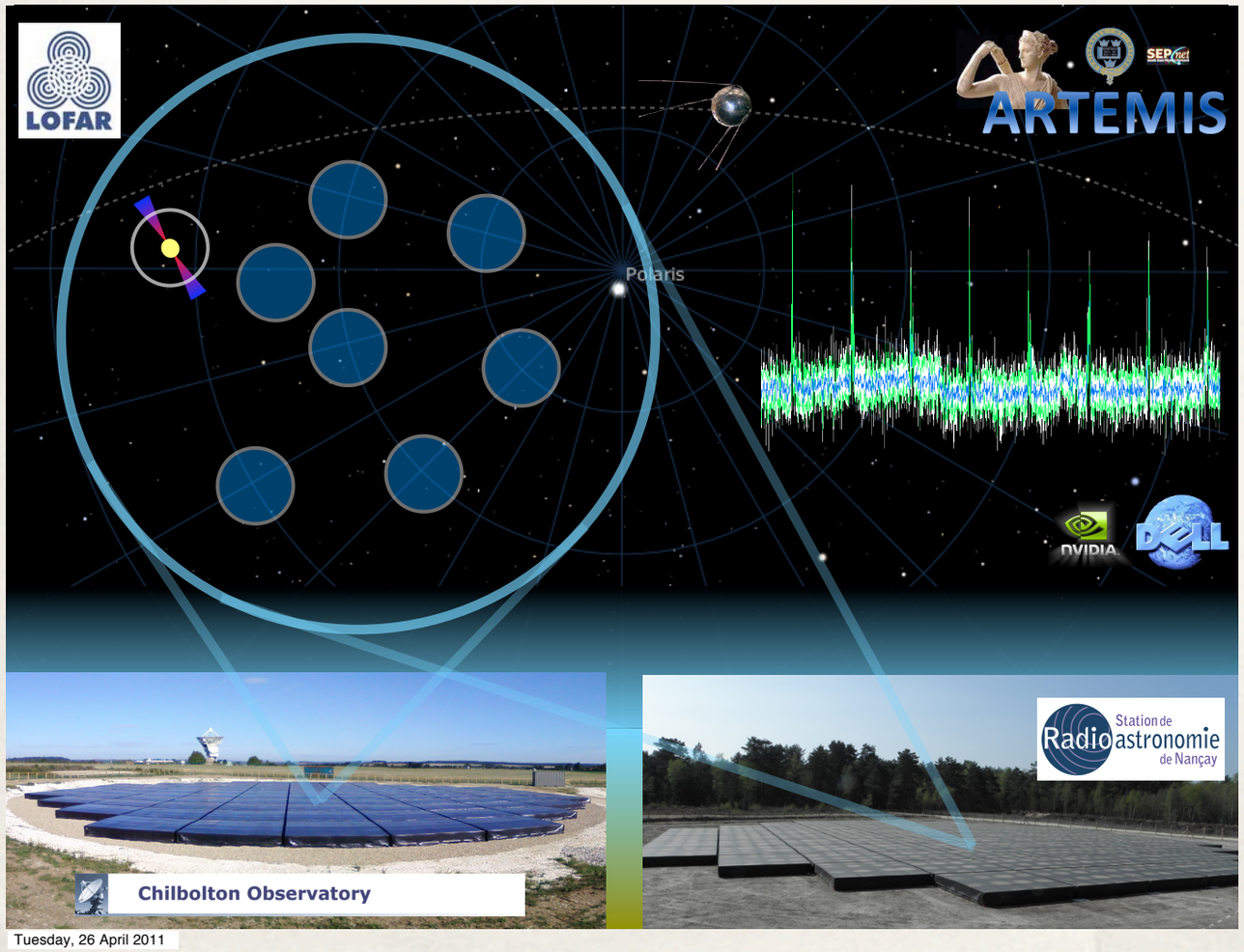


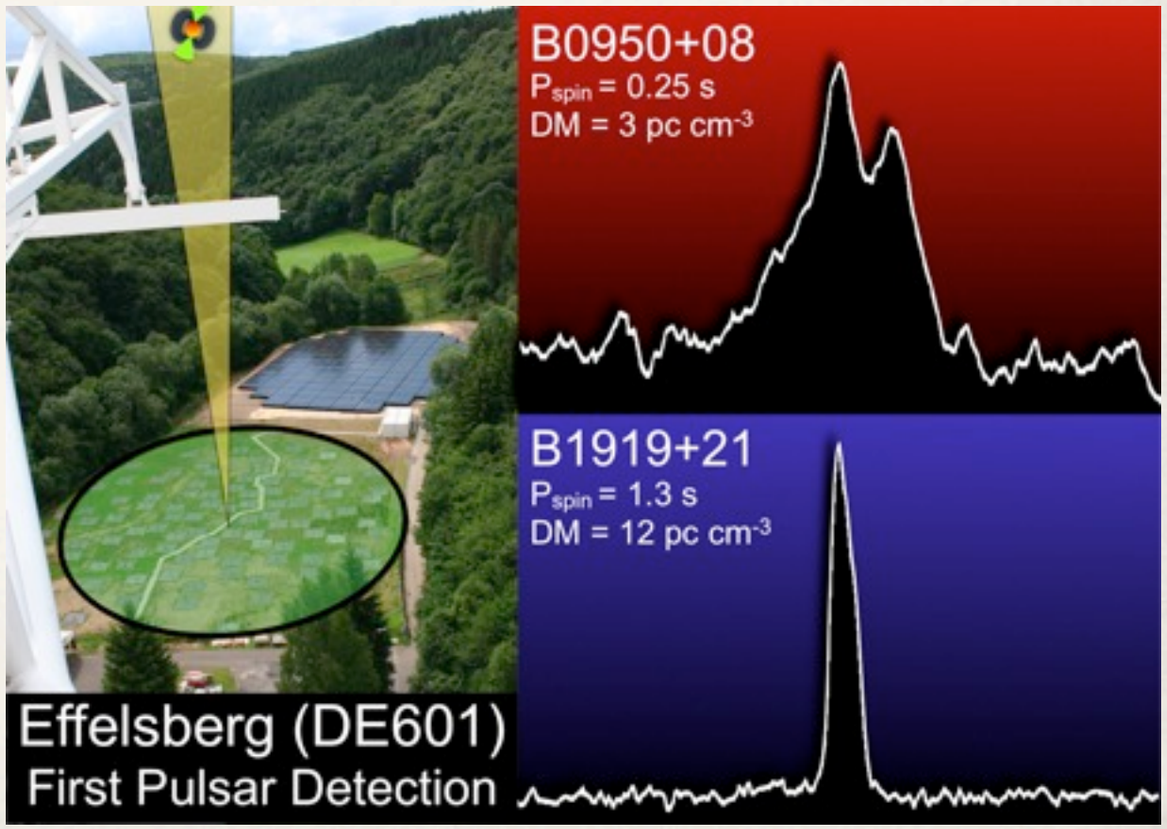
- The model isn't perfect but greatly improves residuals and is consistent with single DM.
- Can use this to constrain any deviations from a cold plasma dispersion law, including scattering, refraction, clumpiness, and numbers like emission measure and scattering meas.
- Can also use this to learn a lot about emission in magnetosphere: super dispersion, absorption, refraction, emission heights, evolution of components ...
- Extending down from our limit here of about 40 MHz to 20 MHz will strongly improve constraints

Single Station Use

Karastergiou + ARTEMIS & PWG

- Although sensitivity is 10% core it is still equivalent to 100 m dish!
- Efficient rapid surveys of entire sky (8 beams X 4.5 sq deg X 6 MHz BW!)
- Can also use multiple single stations, incoherently or fly's eye
- Useful for fast transients like RRATs, intermittent pulsars, AXPs, scintillating sources, extrem nullers, **double Pdot sources**, **new things**...
- Frequent timing observations, High Energy, GWs, Glitches, ...





LOFAR Timeline

- Official opening was in June 2010
- Currently 28 NL and 6 Eu (4DE, UK, FR) stations complete
- 2 More NL stations by year end + SE607
- Another 4-5 stations to come, mainly remote.
- Commissioning is ongoing for all modes until ~ 2012
- More EU stations to be rolled out / New stations/countries joining.
- Station roll out in NL mostly complete in 2011
- Some of the Key Science will begin early in 2012

Conclusions

- We are making excellent progress in commissioning the high time resolution, pulsar and transient modes of LOFAR
- We are already capable of taking data of high scientific quality and interest (see recent paper)
- There is still much more to come in terms of sensitivity with extended coherent addition and BW.
- Many important lessons learnt for the SKA
- 2011 is a very exciting year and 2012 will be even better.