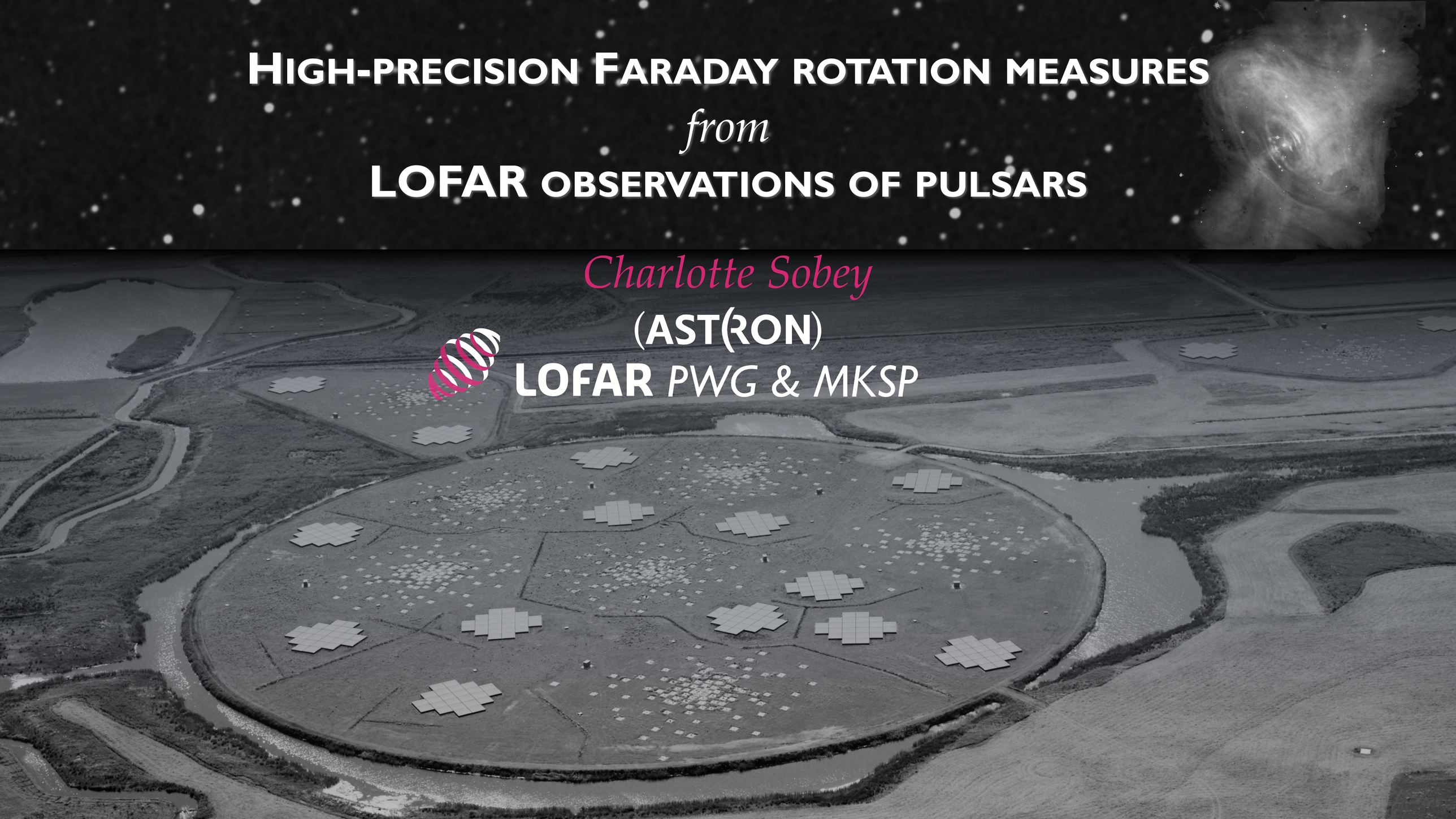
High-precision Faraday rotation measures *from* LOFAR observations of pulsars

Charlotte Sobey

(AST(RON)

LOFAR *PWG & MKSP*

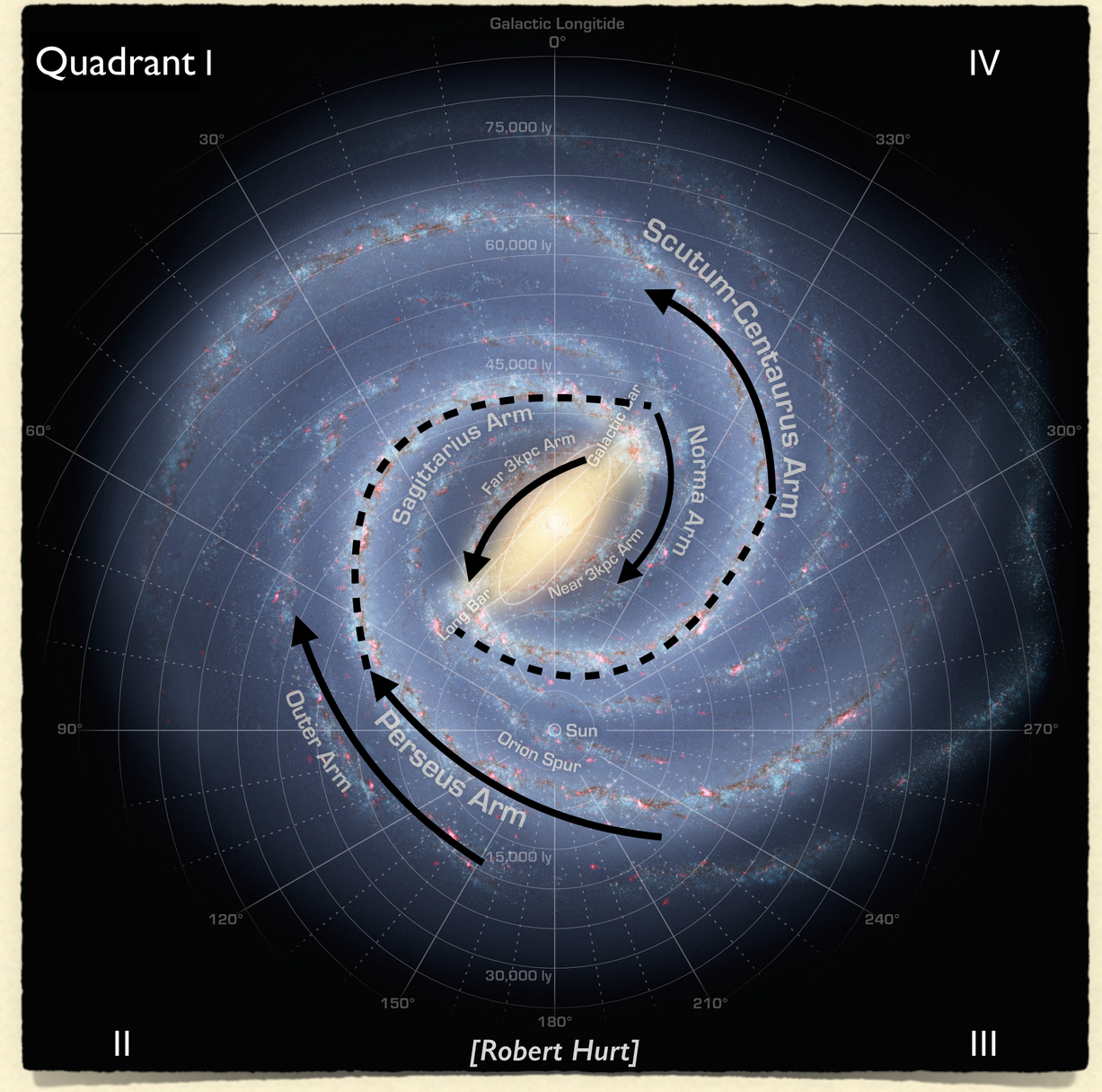


OVERVIEW

- Motivation
  - 3-D structure of the Galactic magnetic field
- Data
  - LOFAR Census of 195 northern pulsars, etc.
- Methods
  - Polarisation data for RM-synthesis
- Results
  - >130 precise Faraday rotation measures
- Summary & future outlook

MOTIVATION I

- Study 3-D Galactic magnetic field:
  - Permeates diffuse ISM
  - Plays role in numerous processes
  - Current picture:
    - Overall clockwise + reversal in S-C
    - BUT: no reversals in other galaxies!

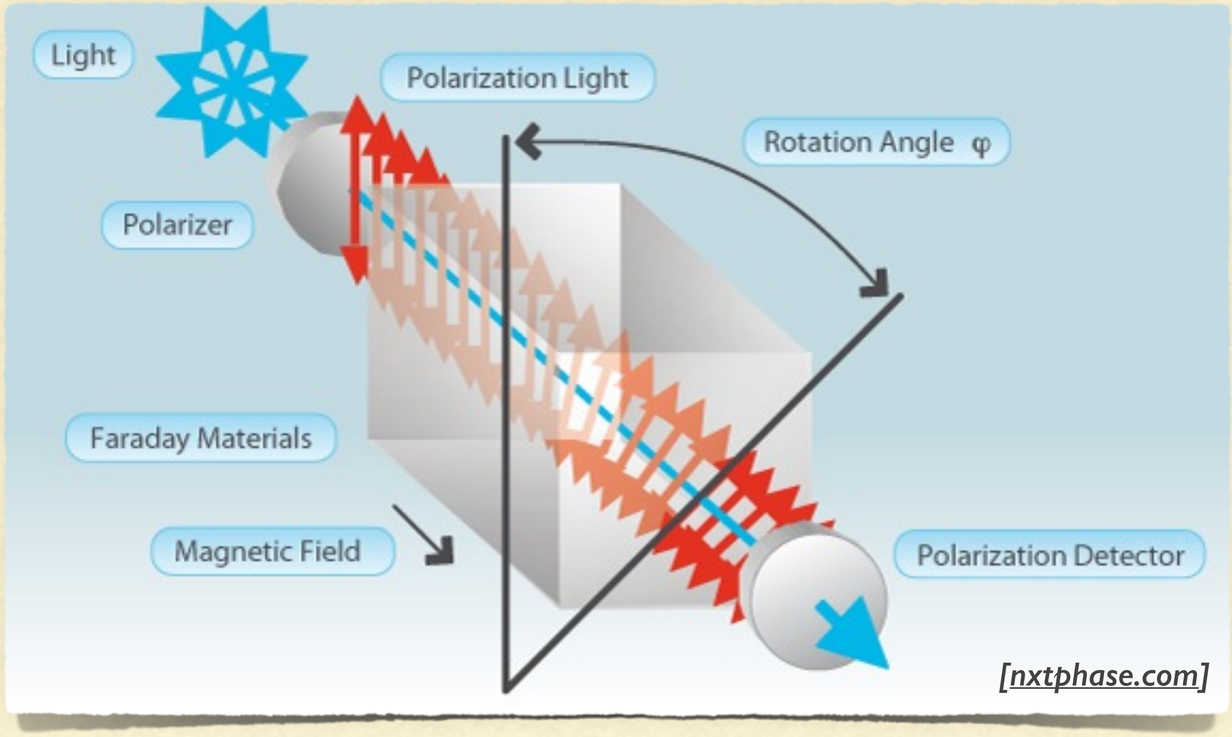


MOTIVATION II

- Why use pulsars? — Efficient!
  - Dispersion & Faraday rotation measures:

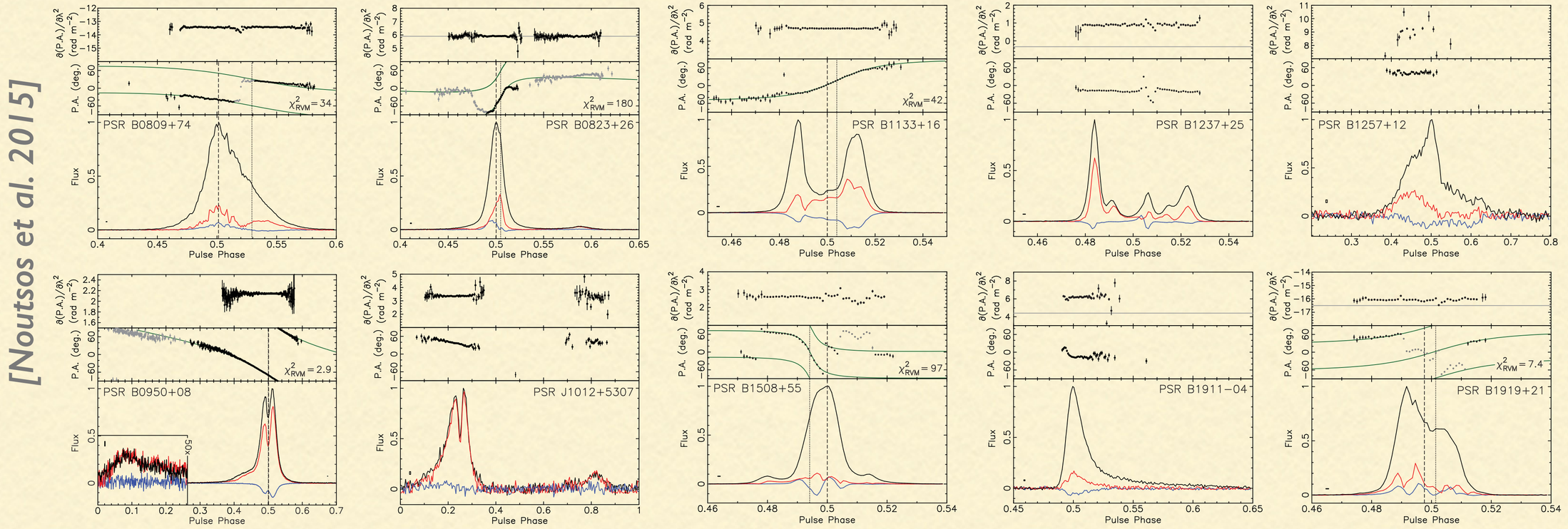
$$\langle B_{\parallel} \rangle = 1.232\ \mu G \frac{\mathrm{RM}=0.81 \int_{\mathrm{d}}^{0} n_{\mathrm{e}} \mathbf{B} \cdot \mathrm{d}\mathbf{r}\ \mathrm{rad\,m^{-2}}}{\mathrm{DM}=\int_{0}^{\mathrm{d}} n_{\mathrm{e}} \mathrm{dl}\ \mathrm{pc\,cm^{-3}}}$$

  - Emission (often!) highly (linearly) polarised
  - Negligible internal Faraday rotation
  - Distributed throughout the Galaxy
  - Independent distance measures for ~70



LOFAR HBA PULSAR DATA

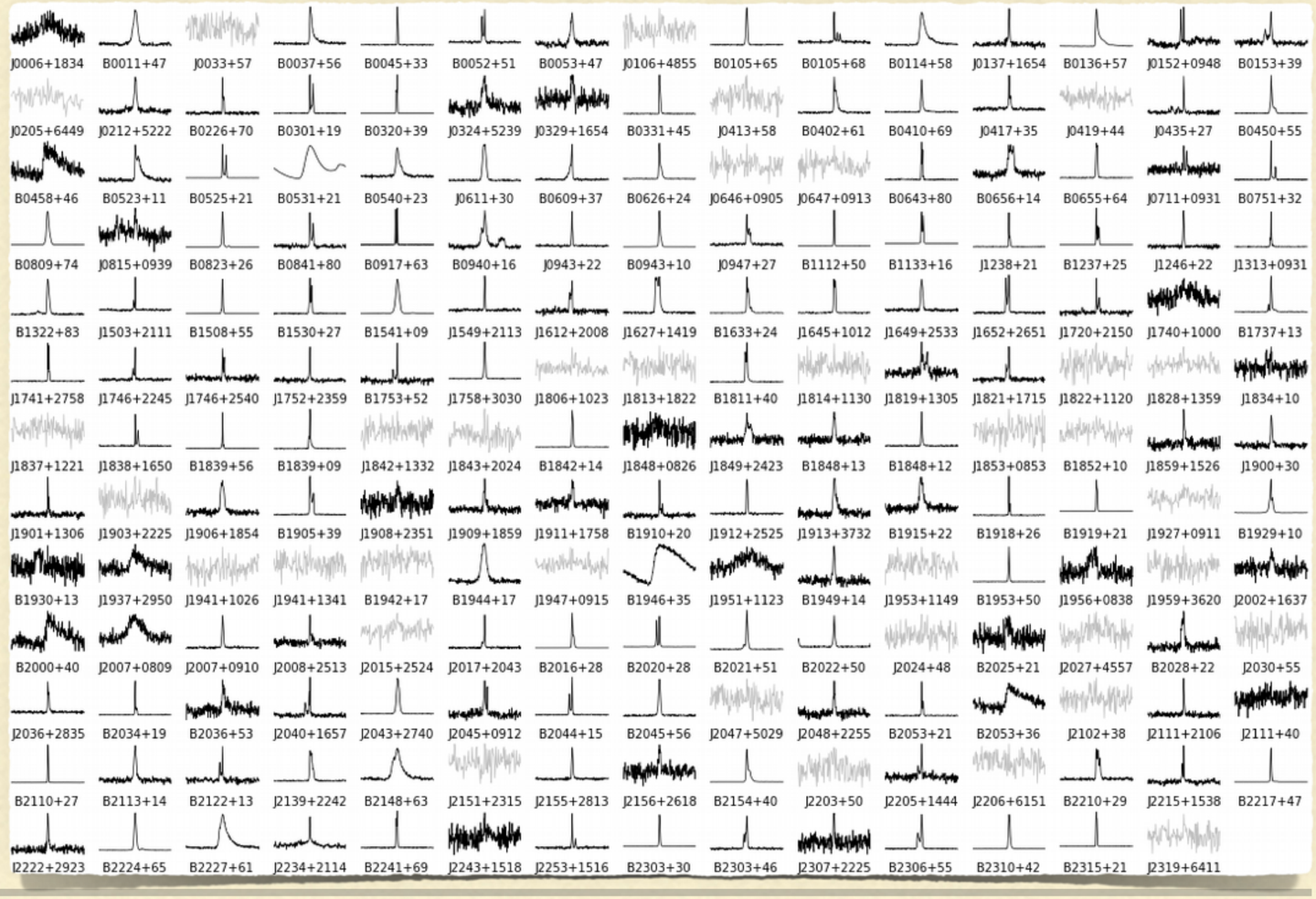
- LOFAR's large fractional bandwidth and collecting area combine to produce the highest-quality polarisation profiles of pulsars below 200 MHz to date.



[Noutsos et al. 2015]

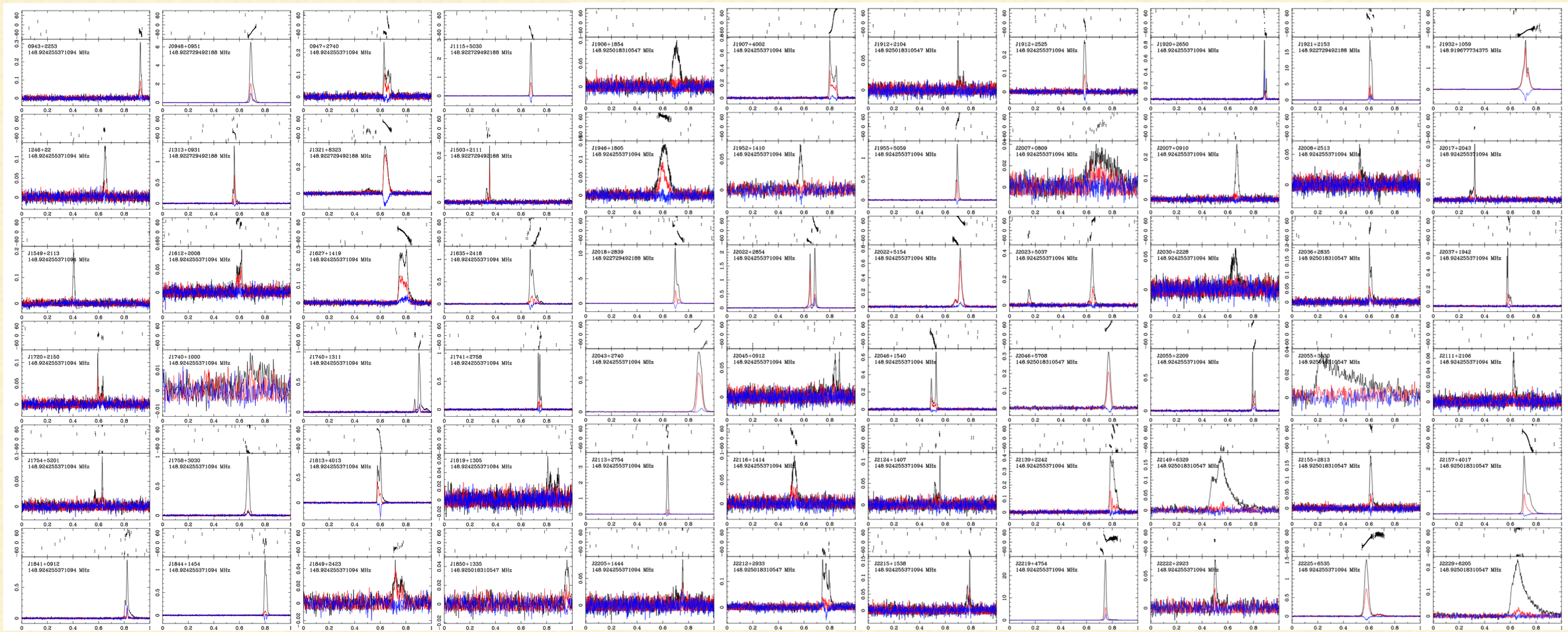
DATA: LOFAR HBA PULSAR CENSUS

- 195 pulsars (Cycle 1: Vlad Kondratiev)
- |b|>3 deg, dec>+8 deg
- Tied-array, all available CS[HBA], IQUV
- >= 20-minute integrations
- 149 MHz, 78 MHz bandwidth
- Studying radio emission and ISM:
- fluxes, spectra, profile evolution, DM, RM



[Anya Bilous]

LOFAR HBA PULSAR CENSUS POLARISATION



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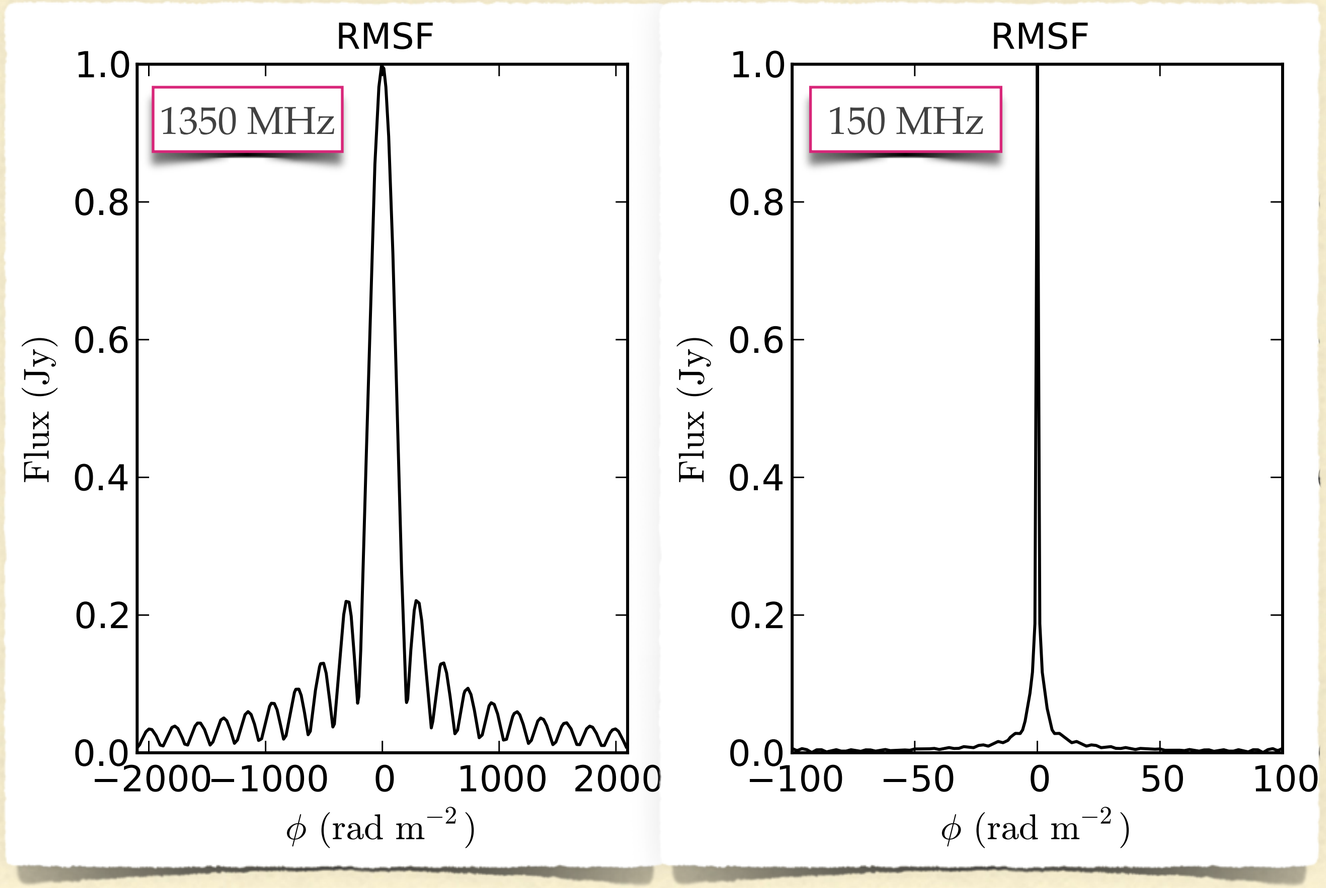
L
V

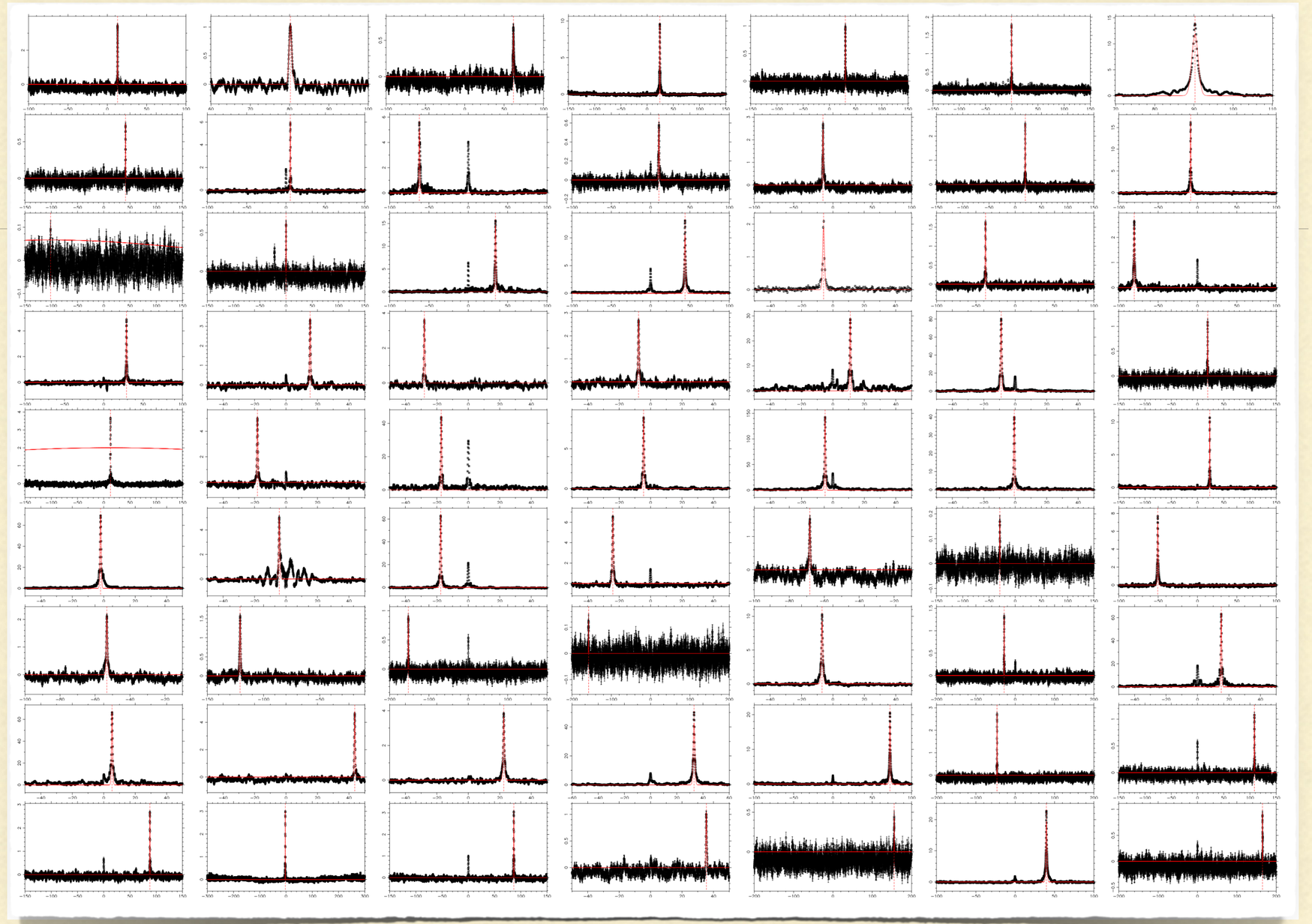
[Sobey, PWG]

METHOD: RM-SYNTHESIS

- Coherently add polarisation vectors at trial RMs
- (Burn 1966 & Brentjens & de Bruyn 2005)
- Error ~ $1/\Delta\lambda^2$
  - (10x lower freq = 100x more precise)
- Noiseless RMSF for HBA pulsar data: $FWHM_{150MHz}$ ~ 0.8 rad m^{-2}
- ($FWHM_{1.4GHz}$ ~ 300 rad m^{-2} & $FWHM_{350MHz}$ ~ 10 rad m^{-2})



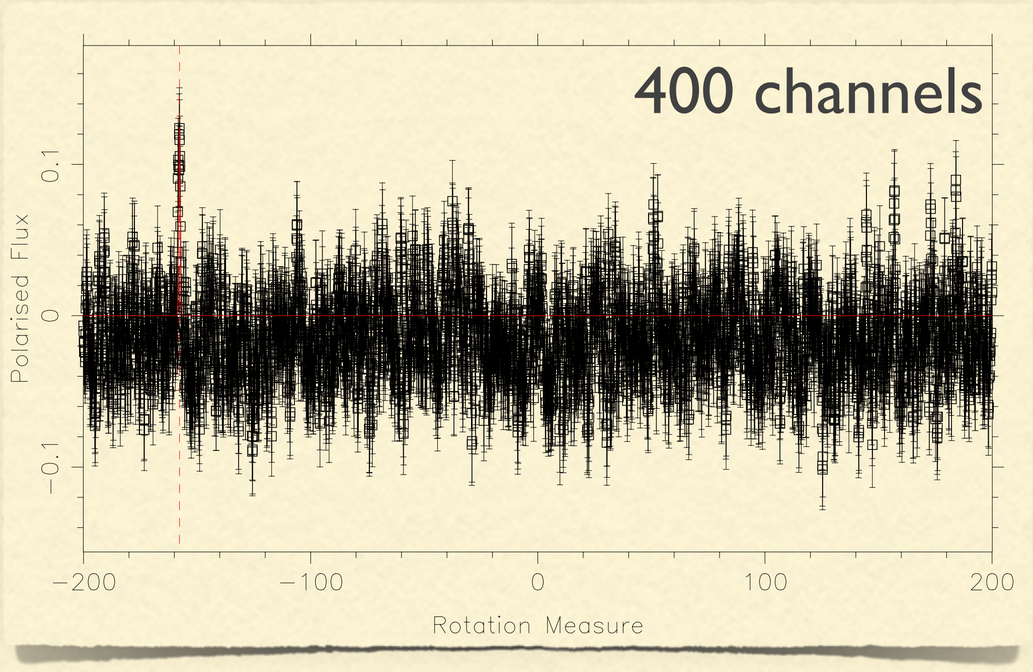
FARADAY SPECTRA

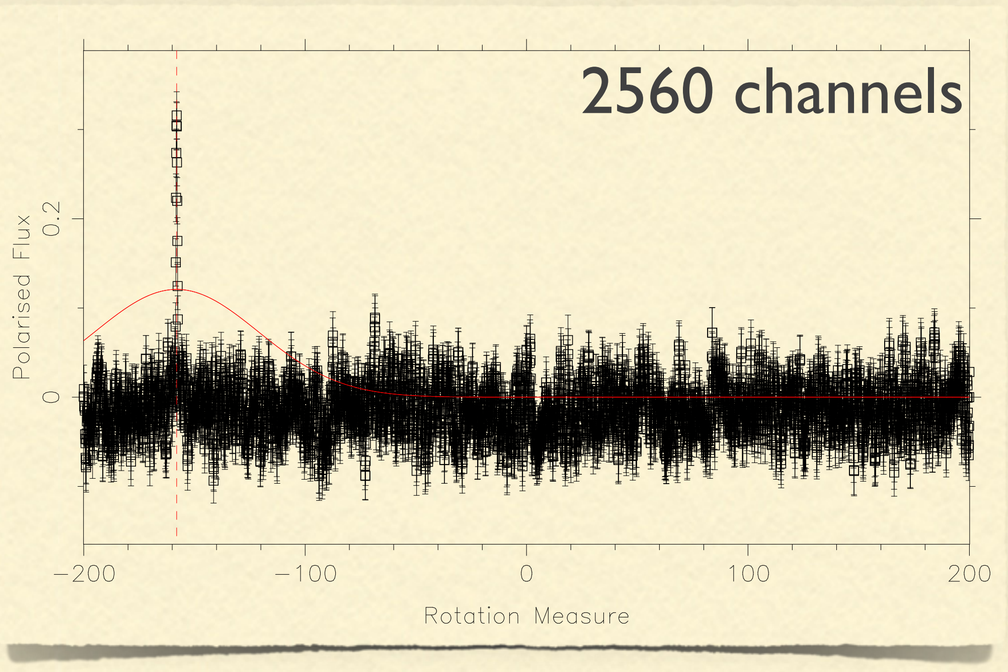


[Sobey et al. in prep.]

FARADAY SPECTRA: FREQUENCY RESOLUTION

- Higher frequency data analysed for higher DM/RM sources
  - e.g. B1848+13: DM ~ 60 pc cm^{-3}, RM ~ 158.0 rad m^{-2}





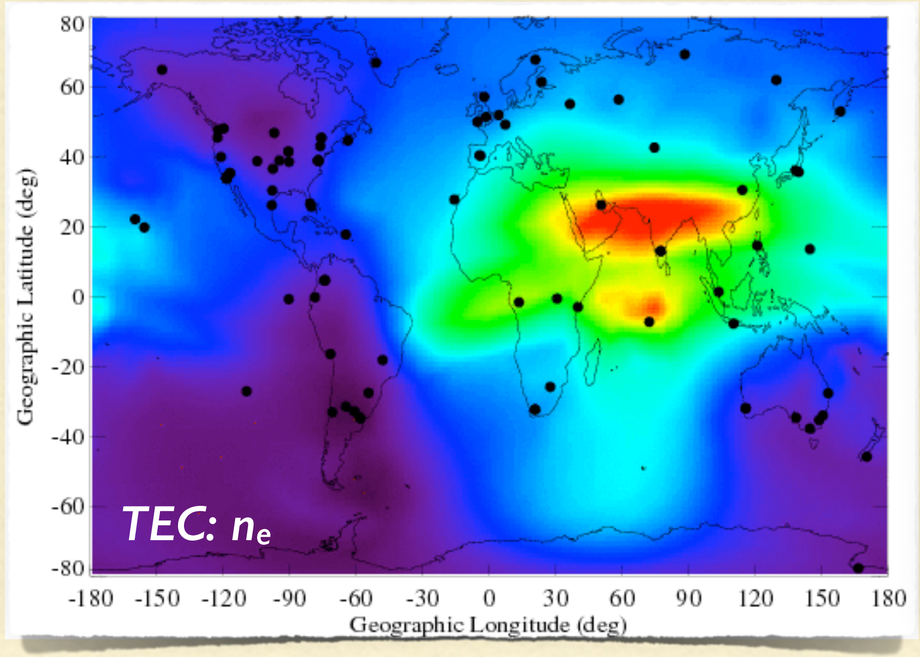
IONOSPHERIC FARADAY ROTATION

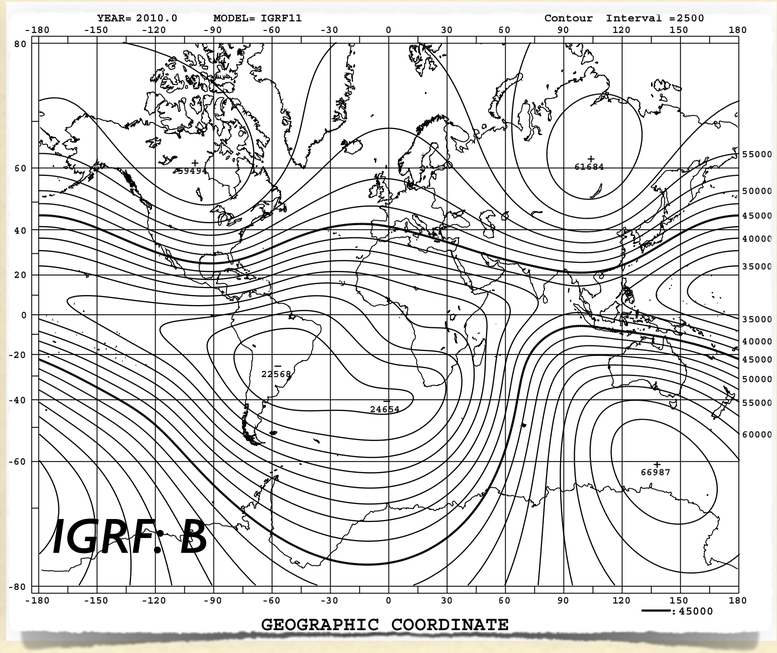
- Magneto-ionic medium, introduces time & position dependence:

$$\mathrm{RM_{obs}} = \mathrm{RM_{ISM}} + \mathrm{RM_{ion}}$$

- ionFR code (Sotomayor et al. '13):

- Calculates ionospheric RM using TEC & IGRF

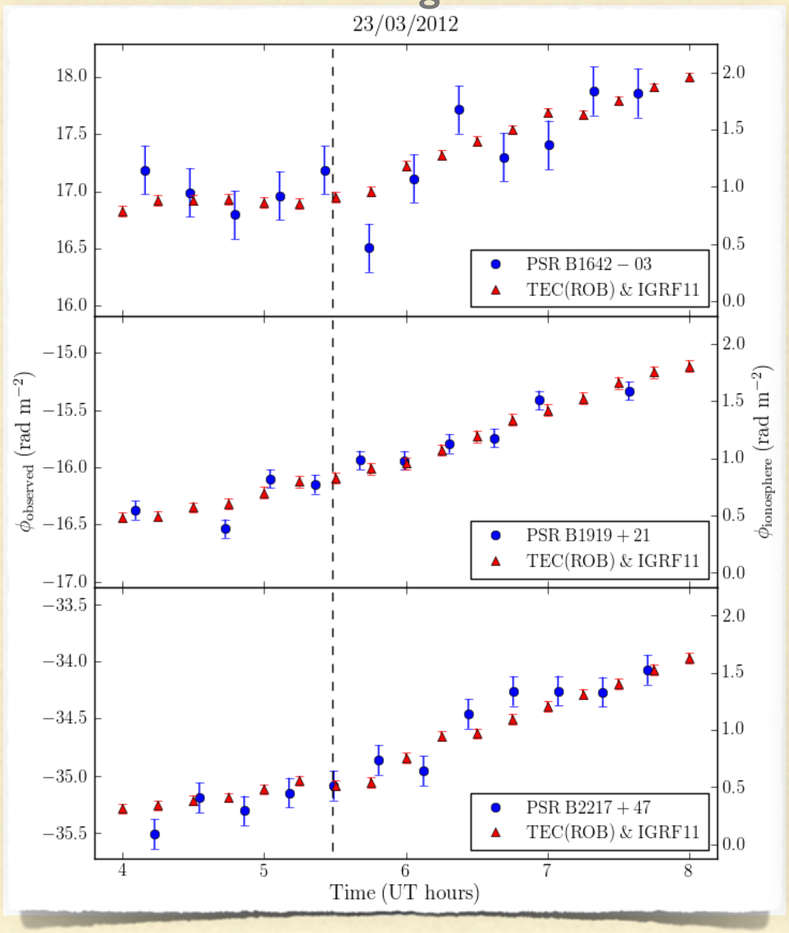




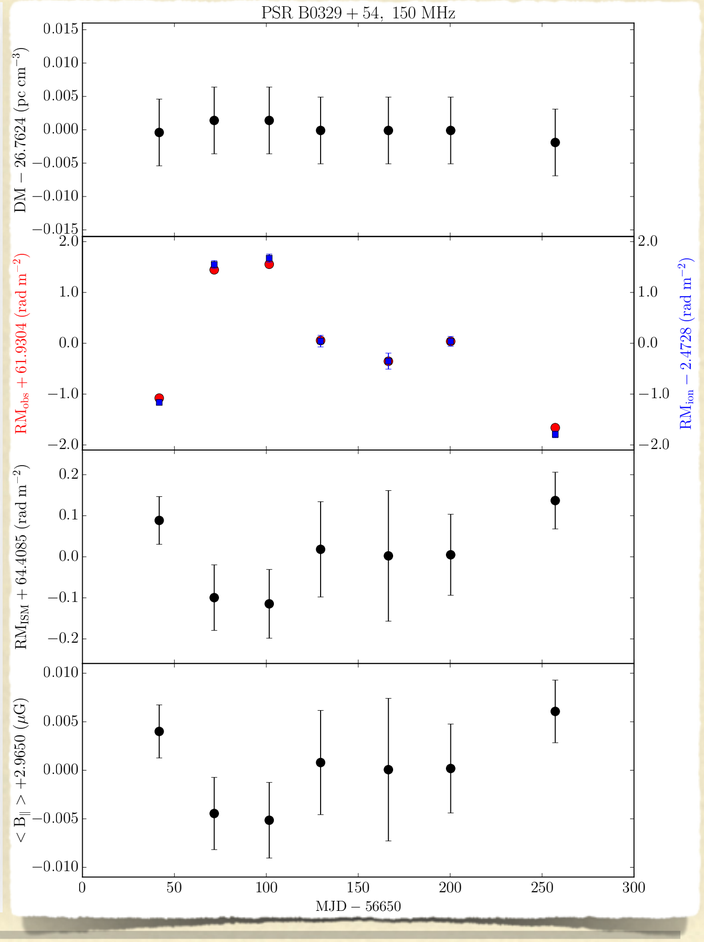
COMPARISON TO LOFAR OBSERVATIONS

- After correction for ionosphere:
- Accuracy ~ 0.1 rad m^{-2} / 0.005 uG

Commissioning: ~4 hours



Timing: ~9 months



RM RESULTS

- 150 pulsars detected with S/N(I)>7
- 136 precise RMs (so far!)…
- 71 with previous RM measurements
  - (57 ionosphere corrected)
- 65 without previous RM measurements

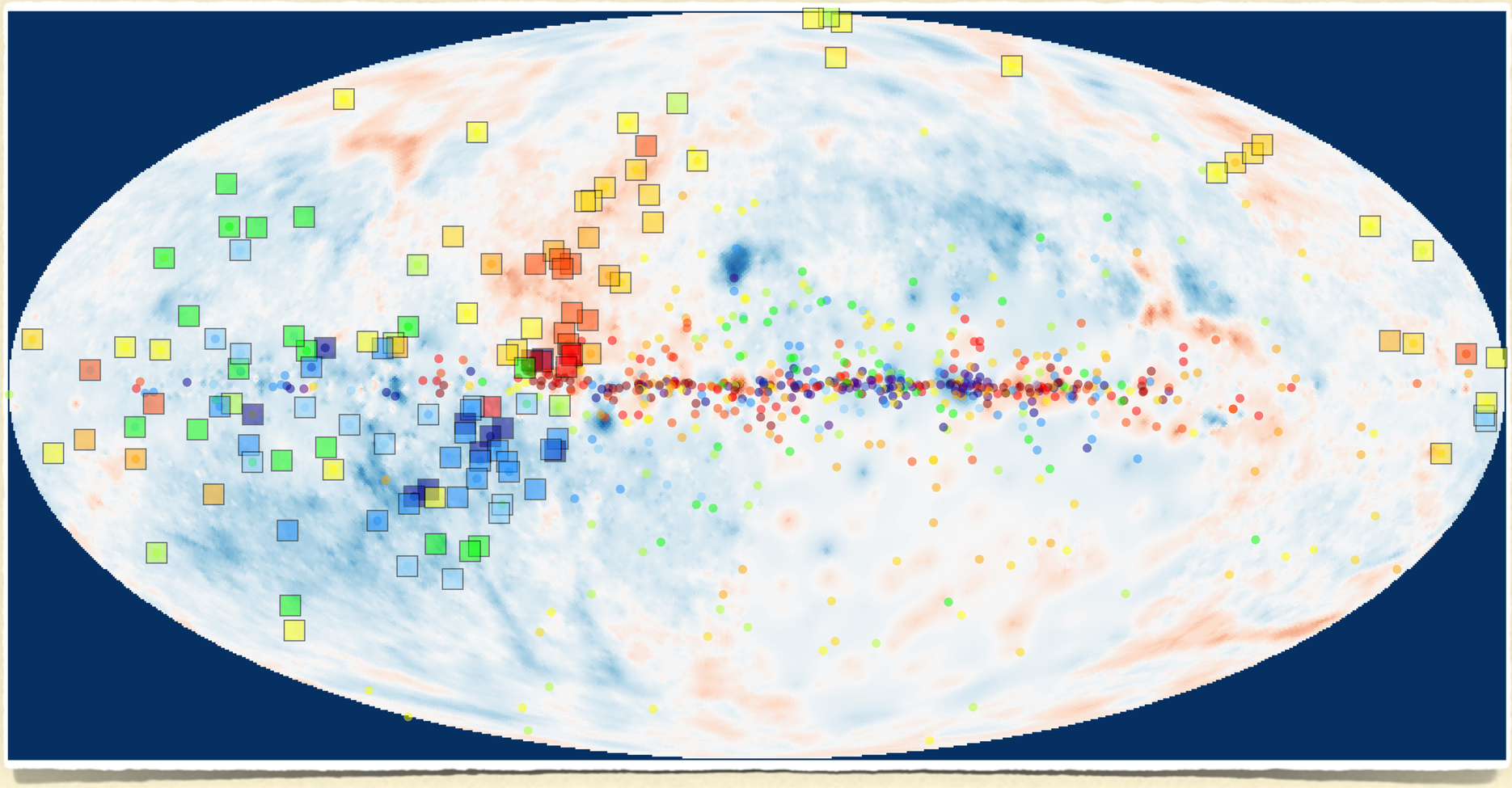
Table 1: LOFAR observations centred at 148.925 MHz, using 78.125 MHz bandwidth and 400 channels, included in this summary. Note: nd = no convincing detection yet! * = check (low S/N or high instrumental).

PSR (name)	**OBSID**	**Date** (dd.mm.yy)	**Time** (UT)	$\tau_{\rm int}$ (min)	$\mathbf{DM}_{\rm psrcat}$ ($\rm pc\,cm^{-3}$)	$\mathbf{RM}_{\rm psrcat}$ ($\rm rad\,m^{-2}$)	$\mathbf{DM}_{\rm LOFAR}$ ($\rm pc\,cm^{-3}$)	$\mathbf{RM}_{\rm LOFAR}$ ($\rm rad\,m^{-2}$)
J0006+1834	L204692	15.02.2014	13:47	20	12.0(6)	–	11.406696	nd
B0011+47	L221897	26.04.14	10:57	21	30.85(7)	–	30.404790	–13.06(5)
B0037+56	L215805	06.04.14	09:58	20	92.595(9)	9(13)	92.514581	–155.71(20)
B0045+33	L204694	15.02.14	14:29	21	39.94(4)	–	39.922037	–80.22(7)
B0052+51	L222340	29.04.14	07:24	36	44.125(15)	–	44.012725	–61.84(5)
B0053+47	L204693	15.02.14	14:08	20	18.09(4)	–23(22)	18.135353	–42.56(10)
B0105+65	L227584	07.05.14	09:30	22	30.46(5)	–29(3)	30.548183	–24.37(5)
B0105+68	L204695	15.02.14	14:51	20	61.092(16)	–46(19)	61.061654	–30.51(5)
B0114+58	L227167	03.05.14	11:08	20	49.423(4)	–	49.420675	–0.27(5)*
J0137+1654	L204696	15.02.14	15:18	20	26.6(4)	–	26.083760	–13.4(2)
B0136+57	L215807	06.04.14	10:40	20	73.779(6)	–90(4)	73.811406	–90.26(5)
J0152+0948	L227585	07.05.14	10:02	46	21.87(2)	–	22.881164	5.55(18)
B0153+39	L221899	26.04.14	11:40	31	60.0(6)	–	59.833422	65.8(1)
J0212+5222	L221900	26.04.14	12:12	20	38	–	38.235546	–11.14(5)
B0226+70	L204697	15.02.14	15:58	25	46.64(3)	–56(21)	46.679440	–41.6(1)
B0301+19	L204698	15.02.14	16:24	24	15.737(9)	–8.3(3)	15.656766	–5.47(3)
B0320+39	L204699	15.02.14	16:49	51	26.01(3)	58(3)	26.189752	62.24(4)
J0324+5239	L227168	03.05.14	11:39	20	119	–	115.463559	244.19(20)

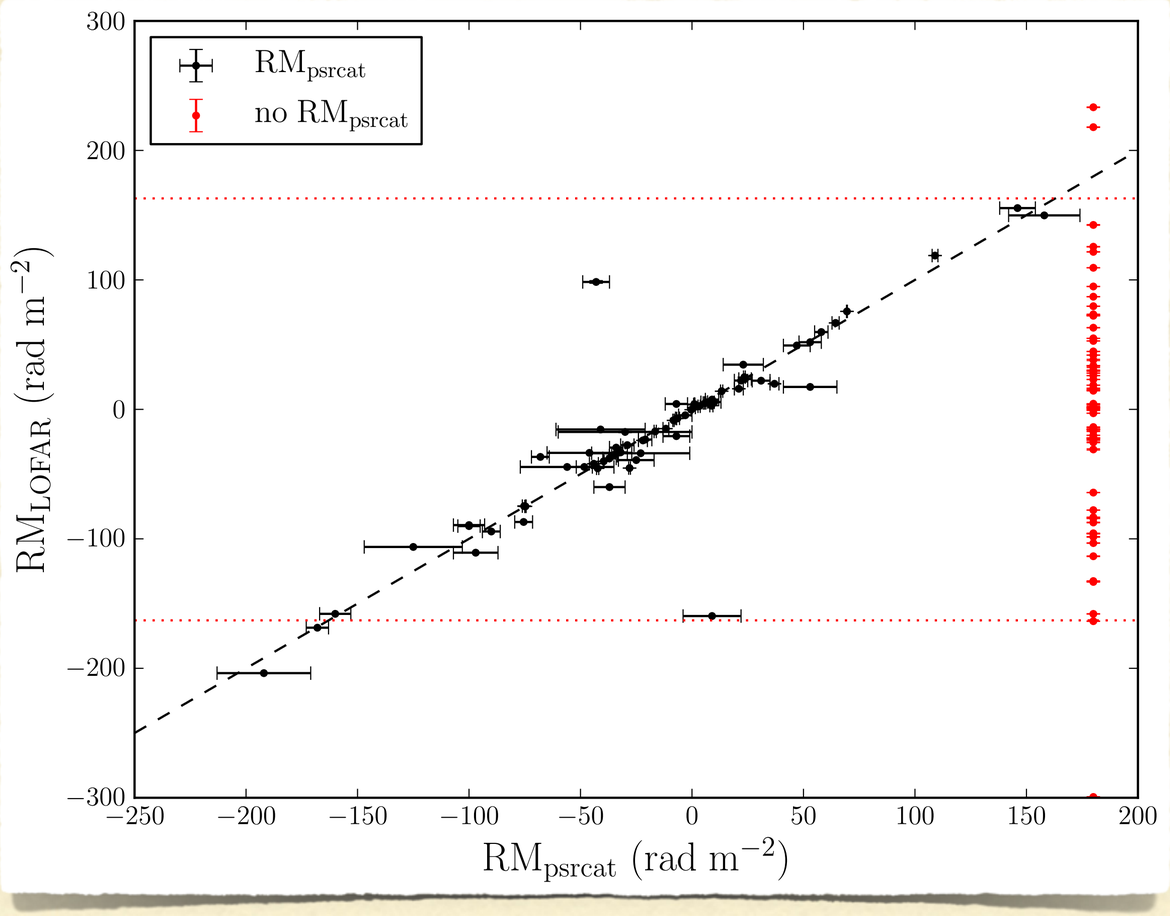
⋮

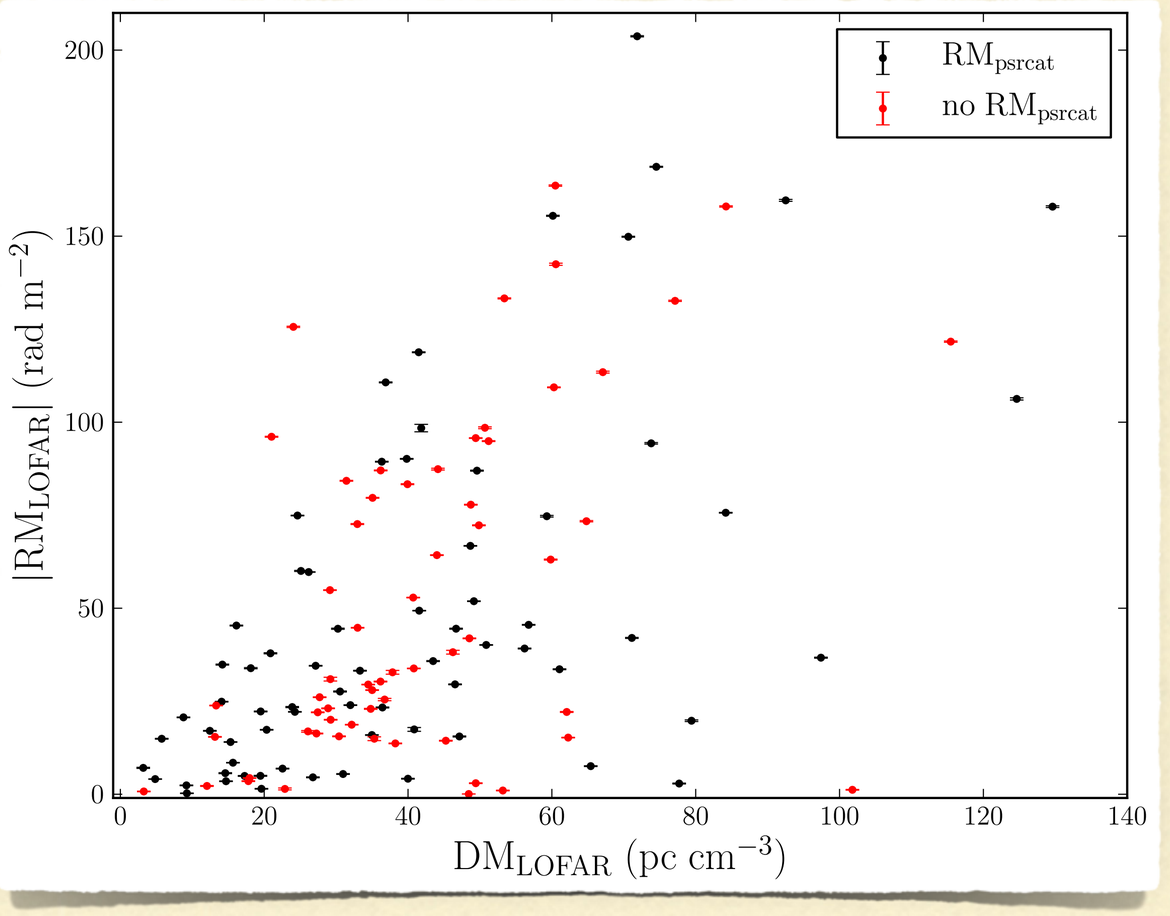
HIGH-PRECISION LOFAR RMs I

- LOFAR HBA RMs
  - (136 so far, squares)
- Current pulsar RM catalogue
  - (680, circles)
- Oppermann et al. 2014
  - (background)



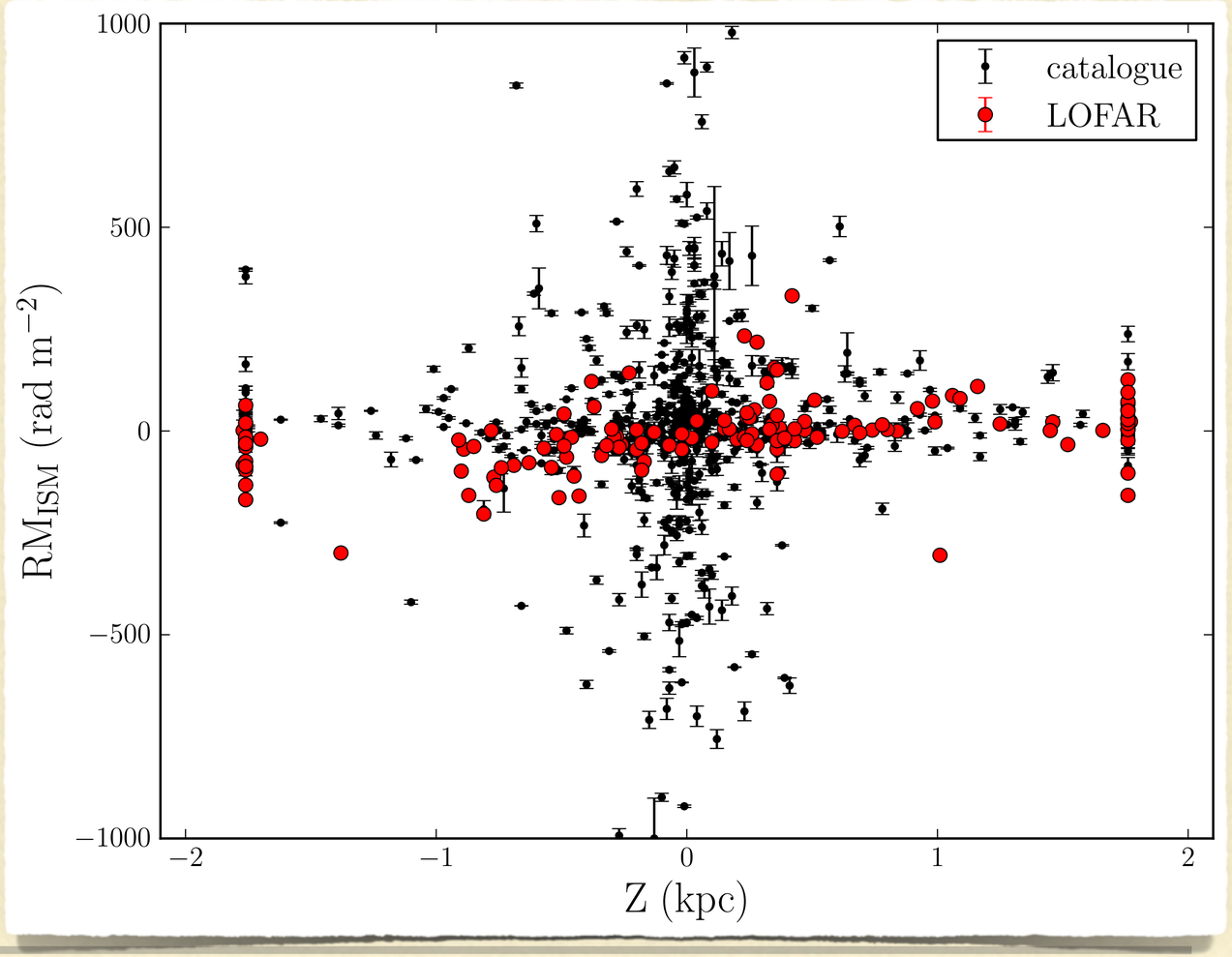
HIGH-PRECISION LOFAR RMs II





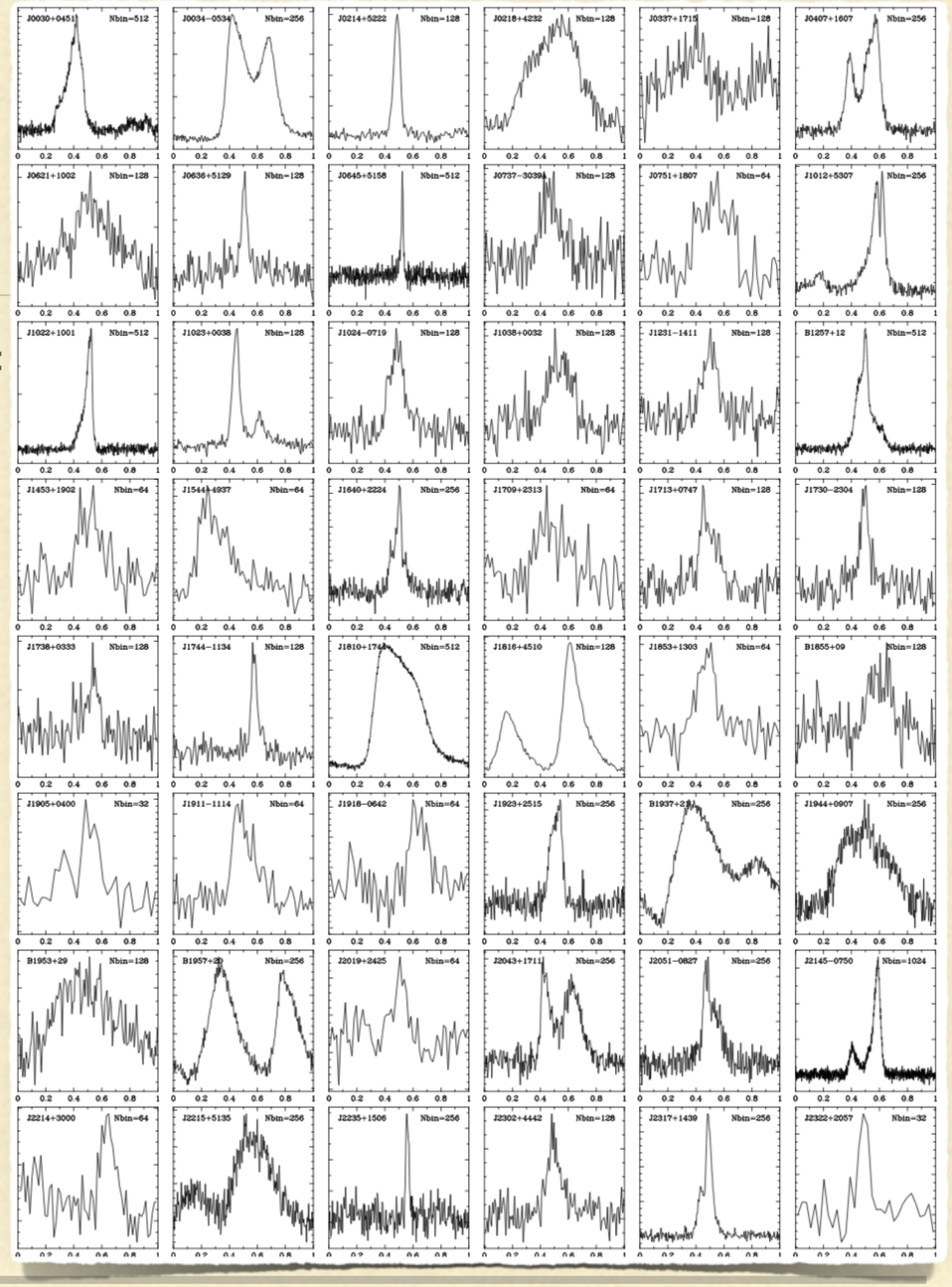
INDEPENDENT DISTANCES

- Now estimated DM distances are limitation
- Independent distances desirable
  - e.g. VLBI parallax
- ~20 of these have parallax measures
- LOFAR Cycle 4 proposal…



DISCUSSION

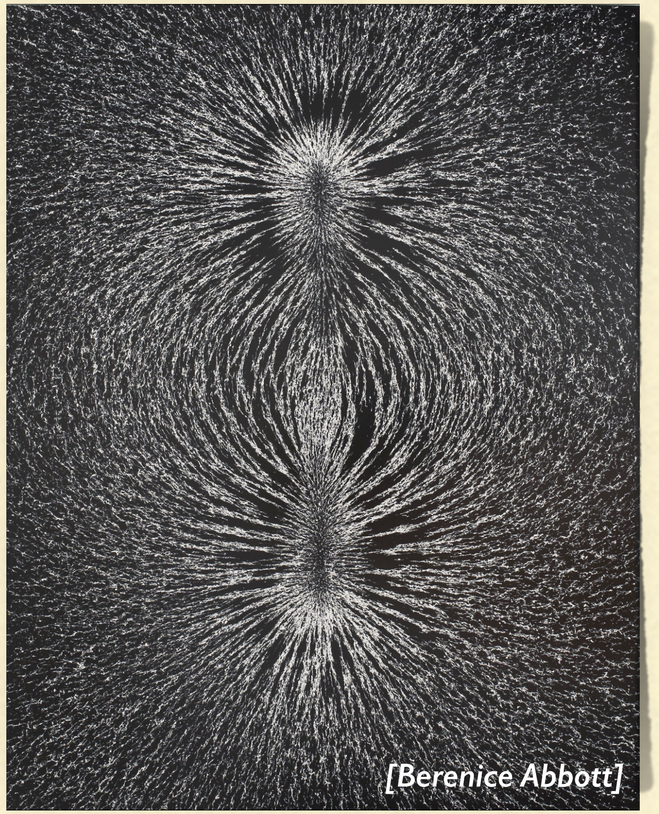
- Increased number of RMs provide more information about the GMF
- LOFAR data provide high precision (& accuracy) RMs for pulsars
- Ongoing work:
  - Error analysis
  - Continuing measuring RMs from timing data &
  - MSP data (48 detected with HBAs: Vlad Kondratiev)
- Further analysis



MSPs: [Vlad Kondratiev]

SUMMARY & FUTURE WORK

- Precise RMs from LOFAR HBA data: 136 (so far!), 65 of these new
- Provide much improved information about GMF in northern sky



- Independent distances also desirable for GMF reconstruction
- LOFAR proposal Cycle 4: observations of further 45 pulsars with parallax

- Technique can also be used for further investigations of B-fields
  - Ongoing work to detect heliospheric magnetic field
  - LOFAR proposal: targeted search of globular clusters (e.g. M5) for polarised emission from (at least?!) two pulsars

Thank you for listening!