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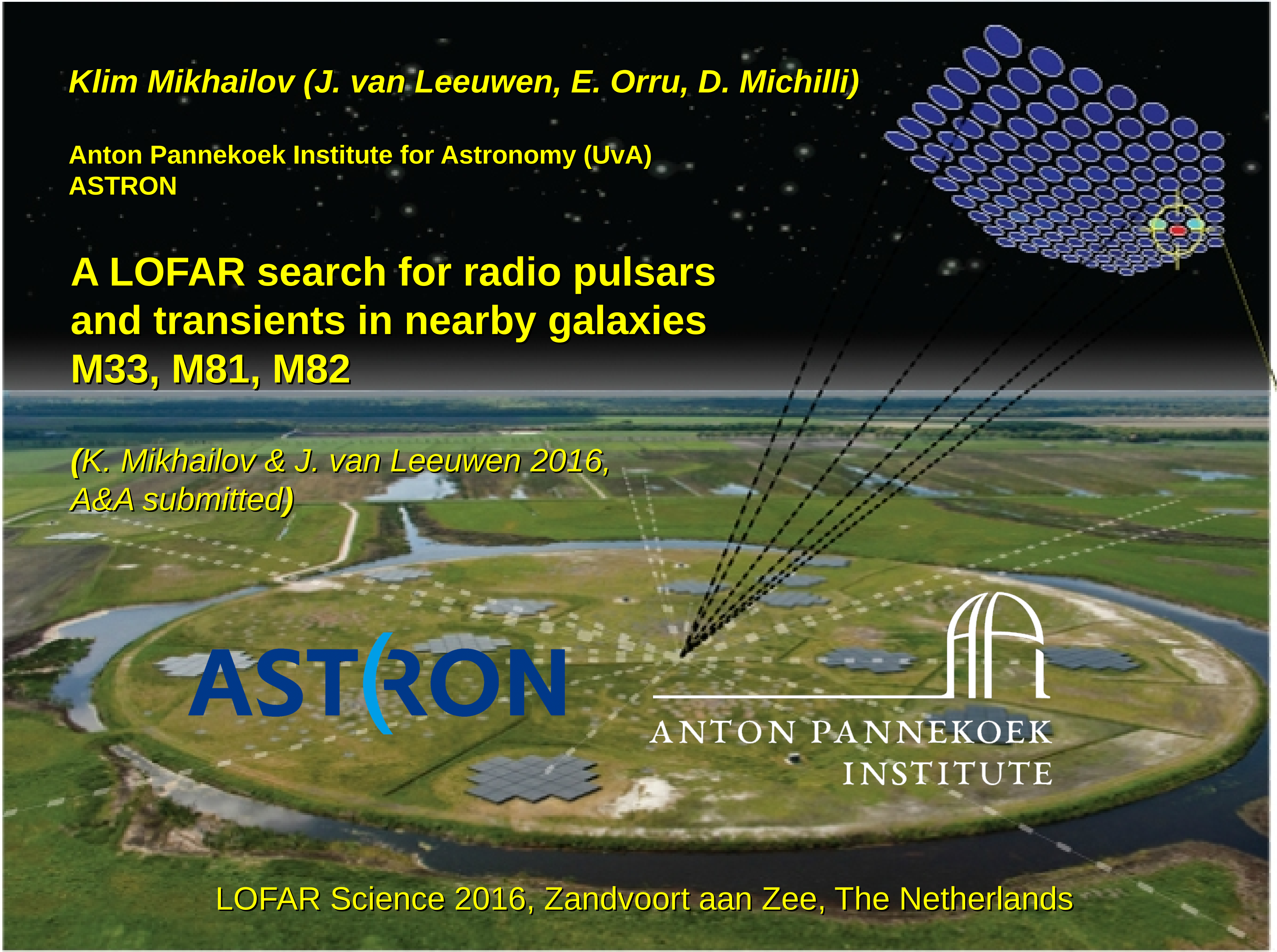
ASTRON

A LOFAR search for radio pulsars and transients in nearby galaxies M33, M81, M82

(K. Mikhailov & J. van Leeuwen 2016, A&A submitted)



ASTRON

ANTON PANNEKOEK INSTITUTE

LOFAR Science 2016, Zandvoort aan Zee, The Netherlands

Scientific goals

Neutron stars

- possess strong magnetic fields (B within 12 orders as stronger as on Earth), but small sizes (R around 10 km, i.e. 5 LOFAR cores)
- express ideal laboratories to study fundamental gravitational and particle physics

Radio pulsars

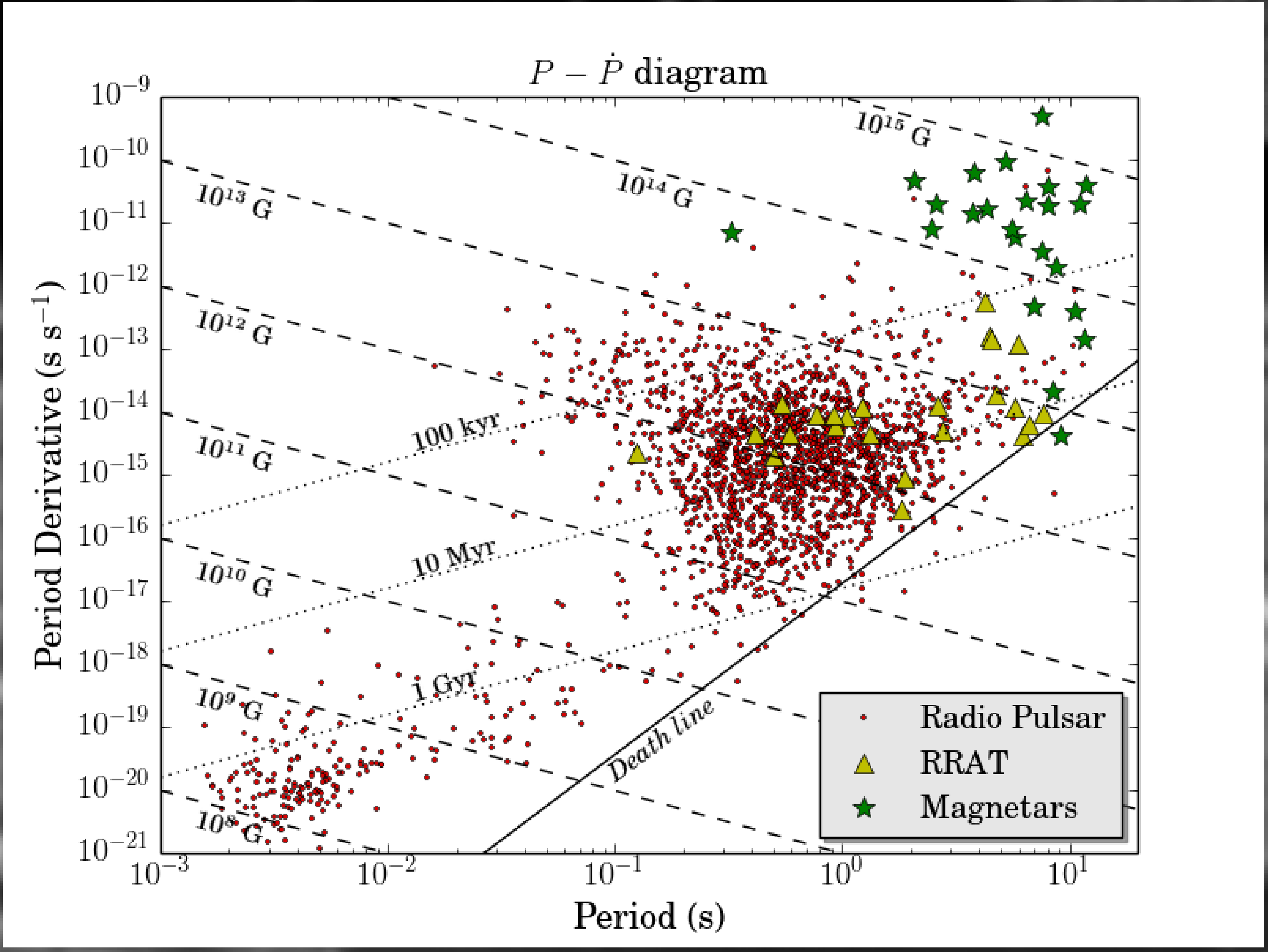
- rapidly rotating neutron stars
- periodicity search – integrated pulse profile with higher SNR

RRATs

- occasional emission
- single-pulse search – more sensitive

nowadays more than 2500 known

Scientific goals



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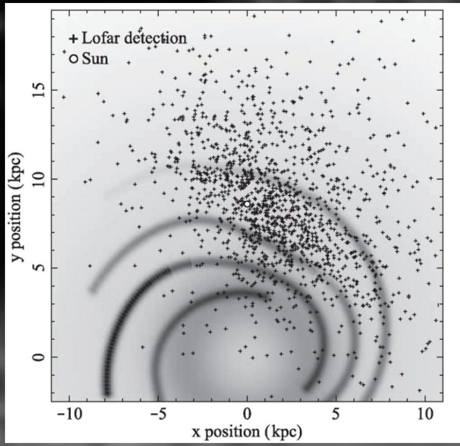
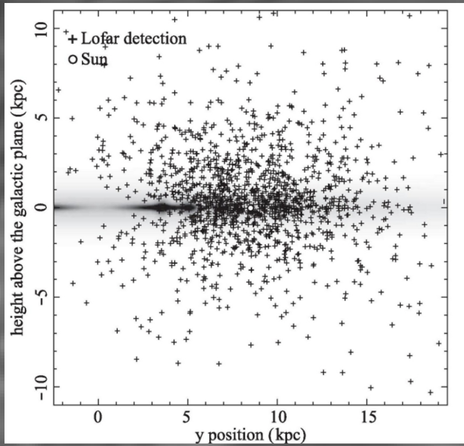
Galactic & extragalactic pulsars

- guide of the source birth rate, pulsar population, the spatial and flux density distributions
- probes of ISM in host galaxies as well as intergalactic medium
- link between the galaxy evolution and the pulsar population synthesis there → different galactic progenitors create different neutron star populations?
- "giant" pulses from relatively young pulsars in distant (host) galaxies?

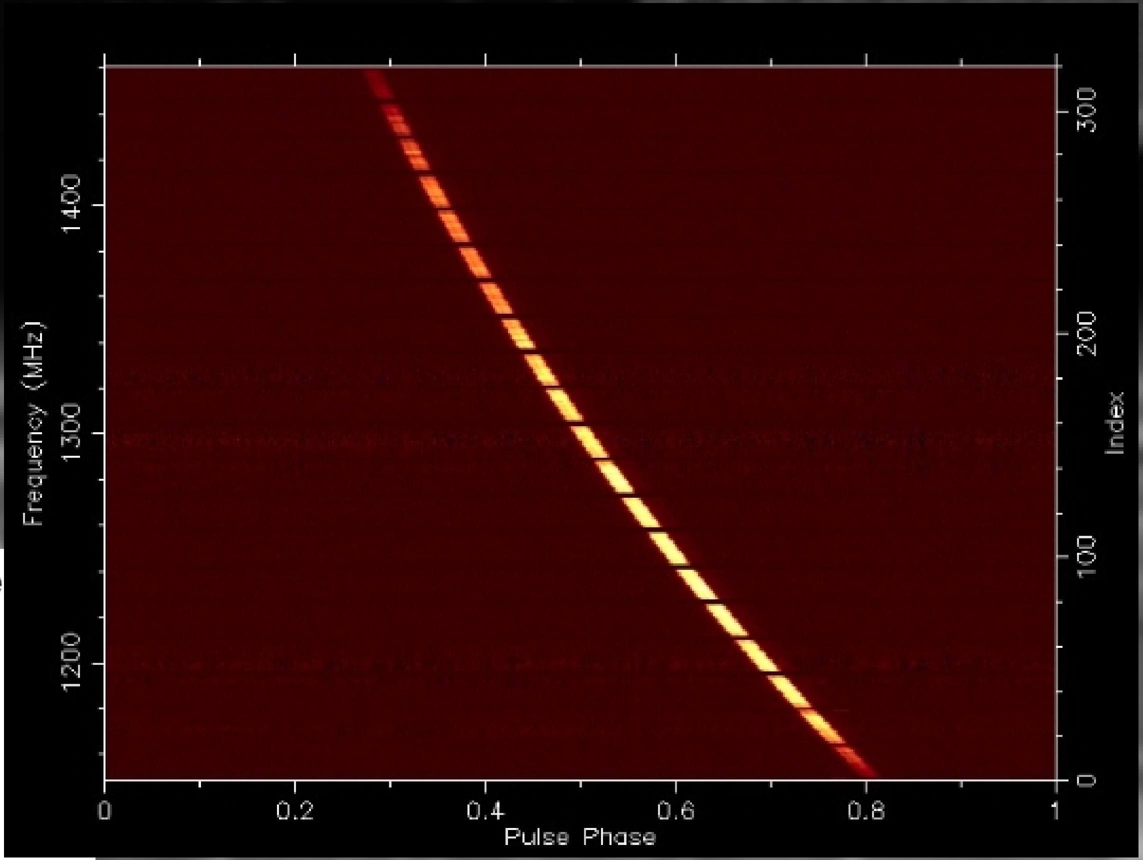


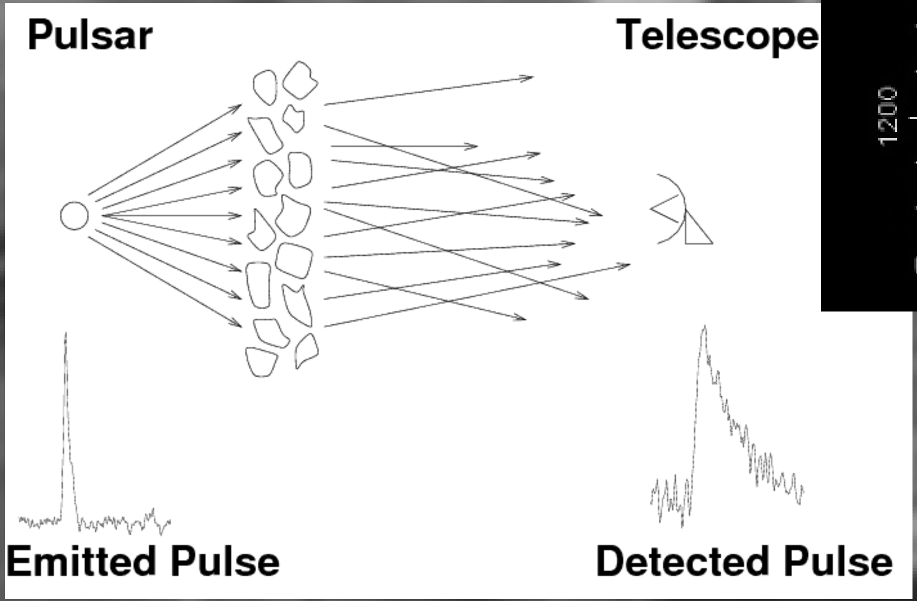


Simulation of the hundreds of pulsars that LOFAR is expected to find in an all-sky survey (van Leeuwen et al., 2010)

Deleterious effects

- Distance *d*: $S \propto d^{-2}$
- Dispersion: $S \propto \nu^{-2}$
- Scattering: $S \propto \nu^{-4}$

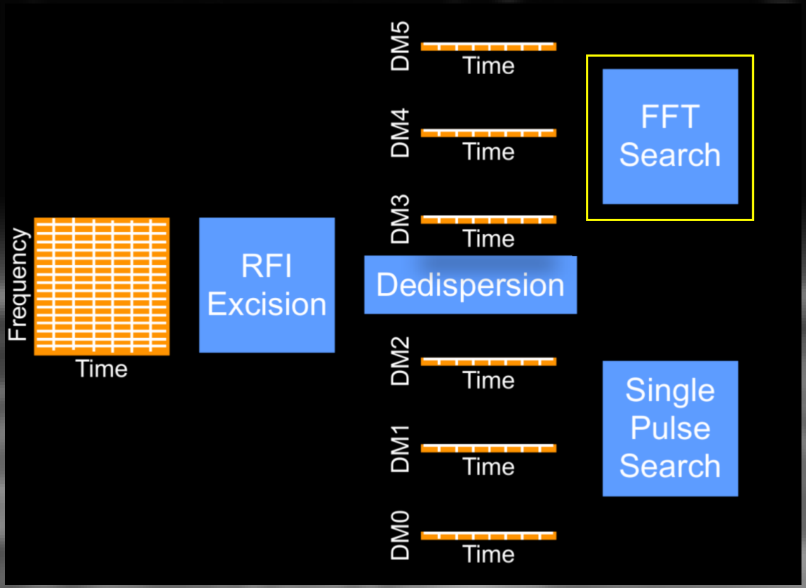


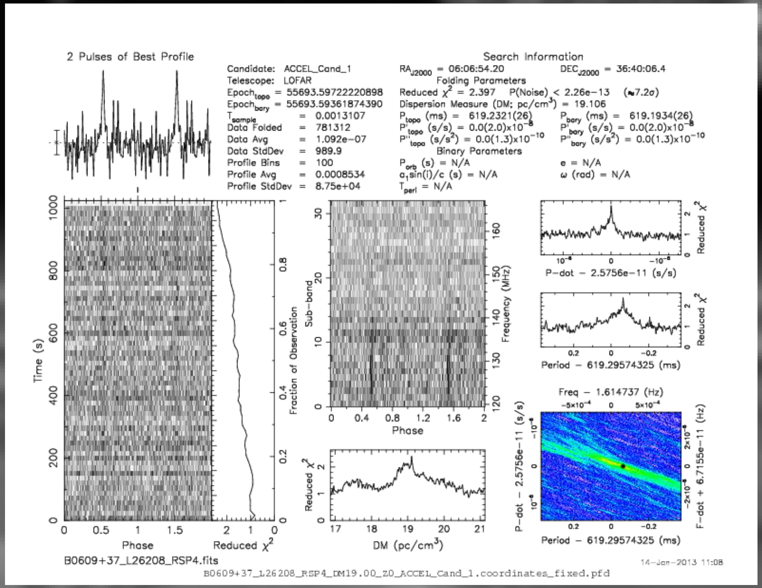


Past surveys in Local Group

- Nearby galaxies: NGC253, NGC300, Fornax, NGC6300, NGC7793, IC 10, Willman 1, UMI dw, Dra dw, Scl dw, Sex dw, CVn I, Leo I-II, UMa II, And II, III, VI, XI-XIV; Leo A, IC 1613, LGS 3, Peg dw, M31, M33
- Telescopes: Arecibo, Parkes, GBT, WSRT
- Explored frequency range: 328-1440 MHz
- Detections only in the Small and Large Magellanic Clouds (Crawford et al. 2001; Ridley et al. 2013)

Periodicity Search

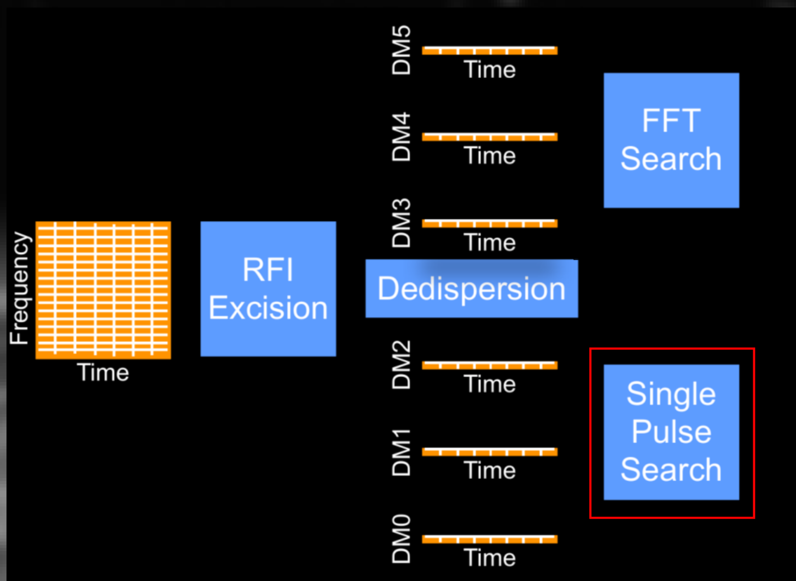


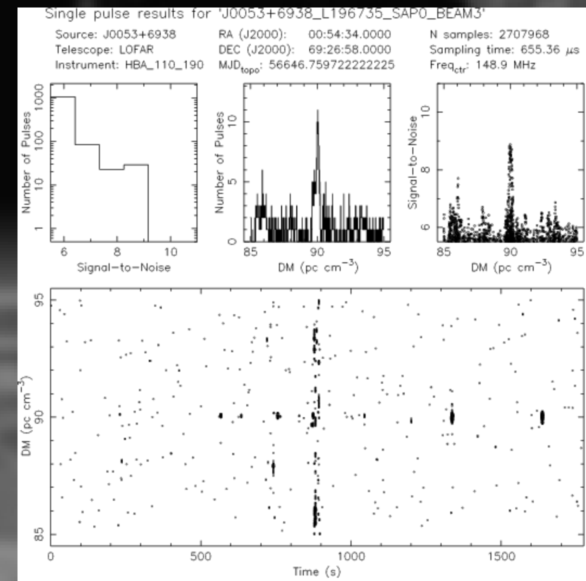


Credits: J. Hessels

Not applicable to sporadic sources → integration with much of noise!

Single-Pulse Search





Credits: J. Hessels

RFI contamination!

Why LOFAR?

- HBA, 120 – 240 MHz → frequency range approximately coincides with the peak of pulsar flux density distribution (Stappers et al. 2011)
- Much increased bandwidth (≈ 70 MHz), the high core gain (≈ 8.8 K/Jy), relatively low antenna temperature (≈ 160 K)
- Multi-beaming allows for efficient, deep integrations
- Dispersion and scattering degrade the inherently sharp pulsar peaks

LOFAR Observations of nearby galaxies M33, M81, and M82

(Stellar) Triangulum Galaxy (M33, d ≈ 0.73 − 0.94 Mpc)
(Stellar) Bode's Galaxy (M81, d ≈ 3.50 −3.74 Mpc)
(Starburst) Cigar Galaxy (M82, d ≈ 3.5 − 3.8 Mpc)

M33

M81

M82

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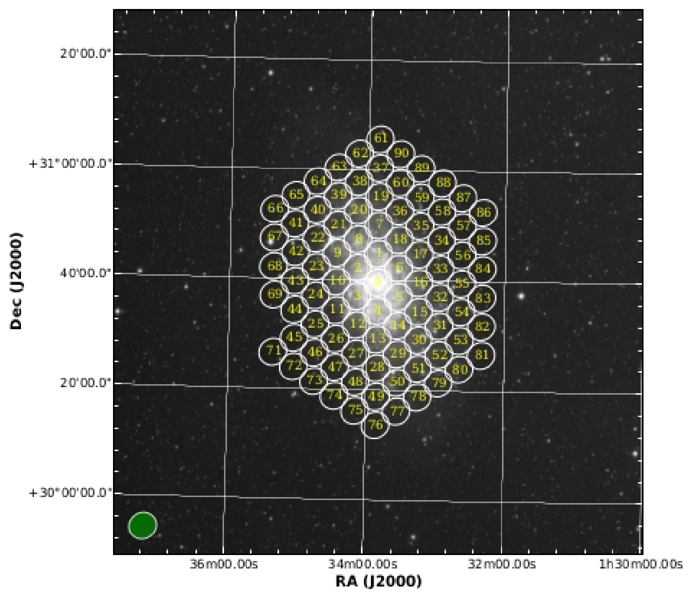
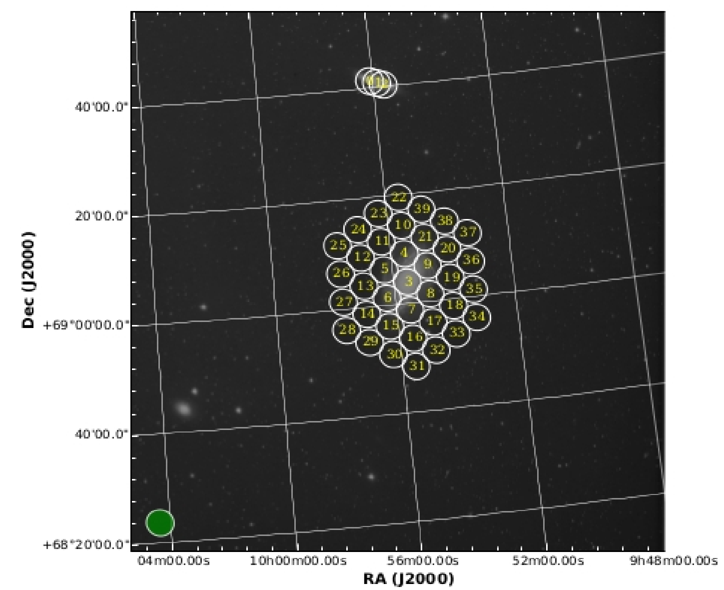
LOFAR pointings



(a) M33 galaxy



(b) M81 and M82 galaxies

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Two 4-h radio observations (Acknowledgements: E. Orru)

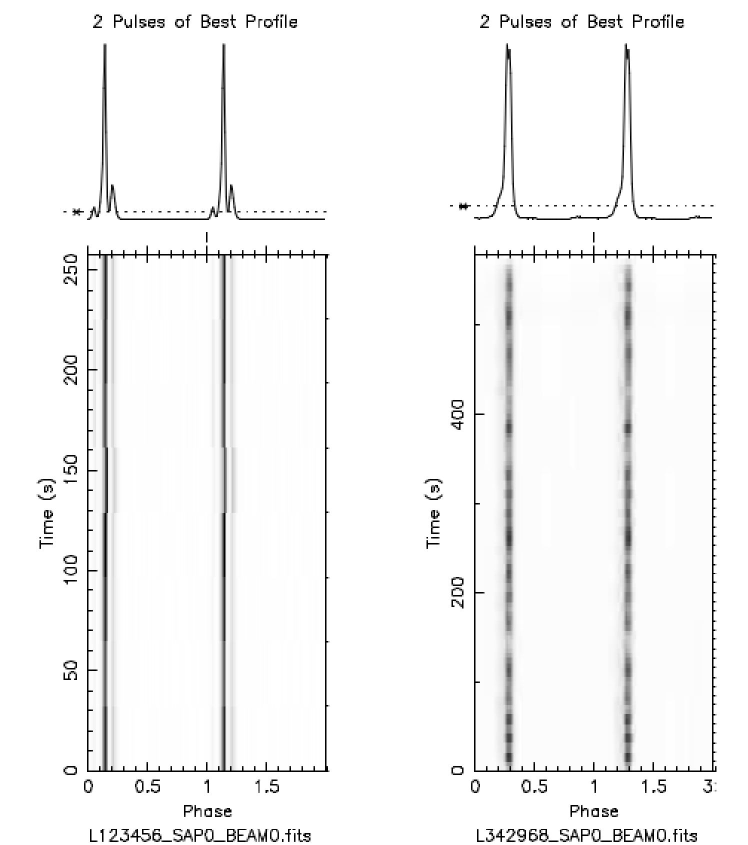
LOFAR Observational setup

Observational dates:	**March, 10 and May, 9, 2015**
Telescope:	**LOFAR**
Receiver:	**HBA**
Backend:	**COBALT**
Number of Tight-Array Beams:	
– First observation:	**90**
– Second observation:	**40**
Polarisations/beam:	**2**
Central frequency:	**146 MHz**
Frequency Bandwidth:	**68.5 MHz**
Frequency channels:	**11232**
Sample time:	**1310 μs**
Integration time:	**14400 s**

Test pulsars

Pulsar	t_{int} (s)	subbands	P (ms)	DM (pc cm^{-3})	S/N_{peak}
PSR J0332+5434	260	128	714.501	26.77	99.21
PSR J0953+0755	600	288	253.063	2.969	63.92

Both successfully found in periodicity and single-pulse searches

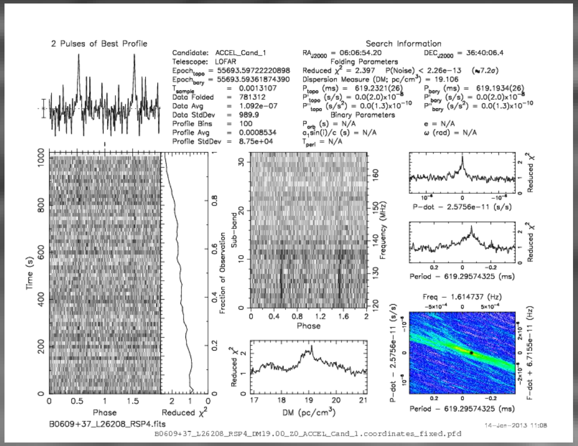


Test profile for the 714 ms PSR J0332+5434.

Test profile for the 253 ms PSR J0953+0755.

Data analysis

LTA → Cartesius → PRESTO



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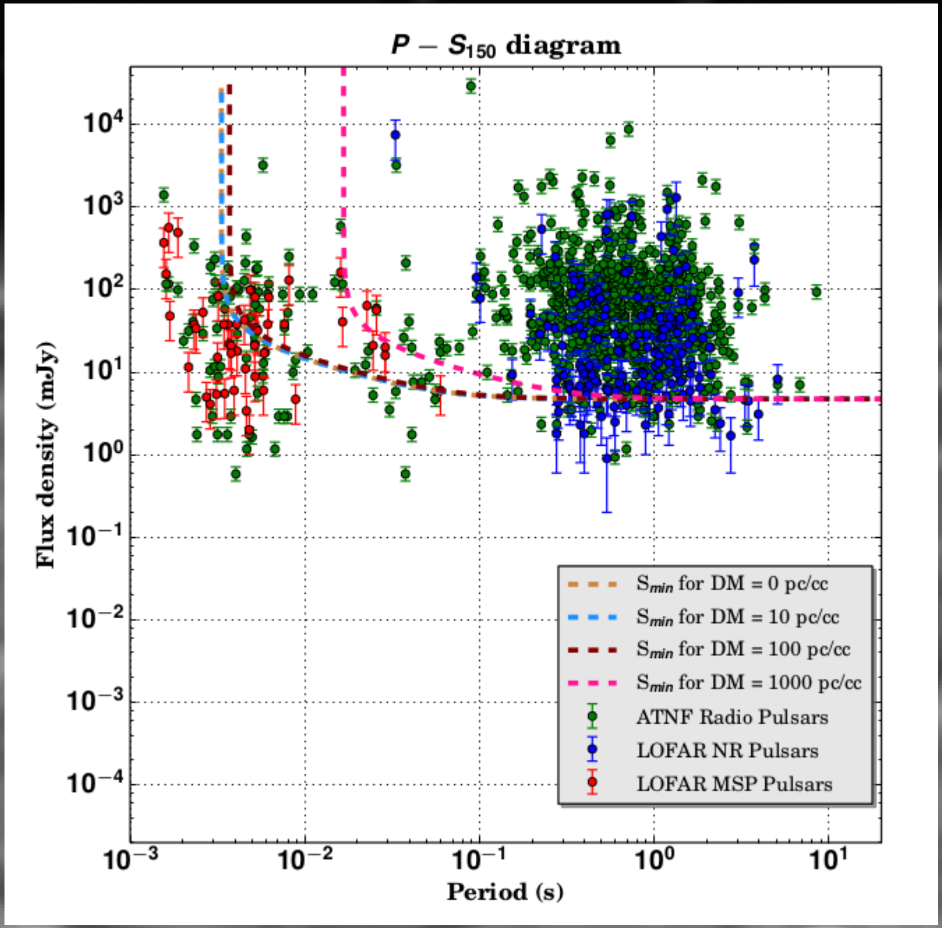
Sensitivity estimates for MW



Manchester et al. 2005
Kondratiev et al. 2015
Bilous et al. 2015

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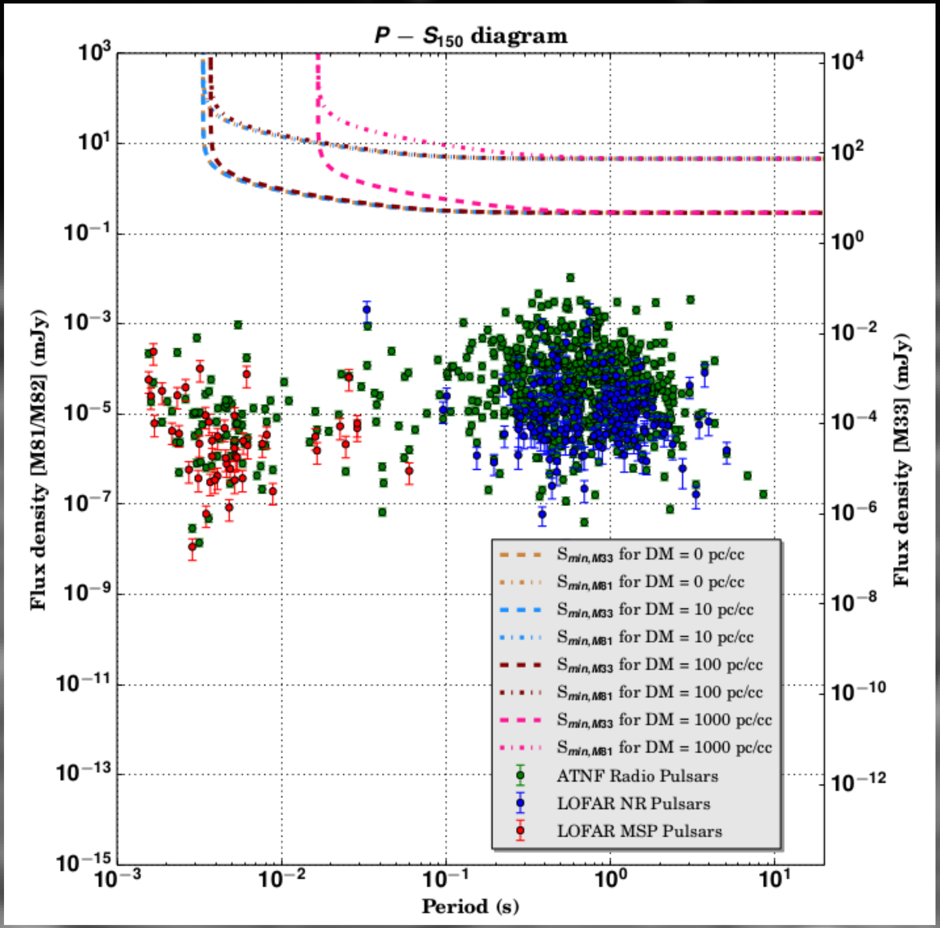
Sensitivity estimates for NGs



Manchester et al. 2005

Kondratiev et al. 2015

Bilous et al. 2015

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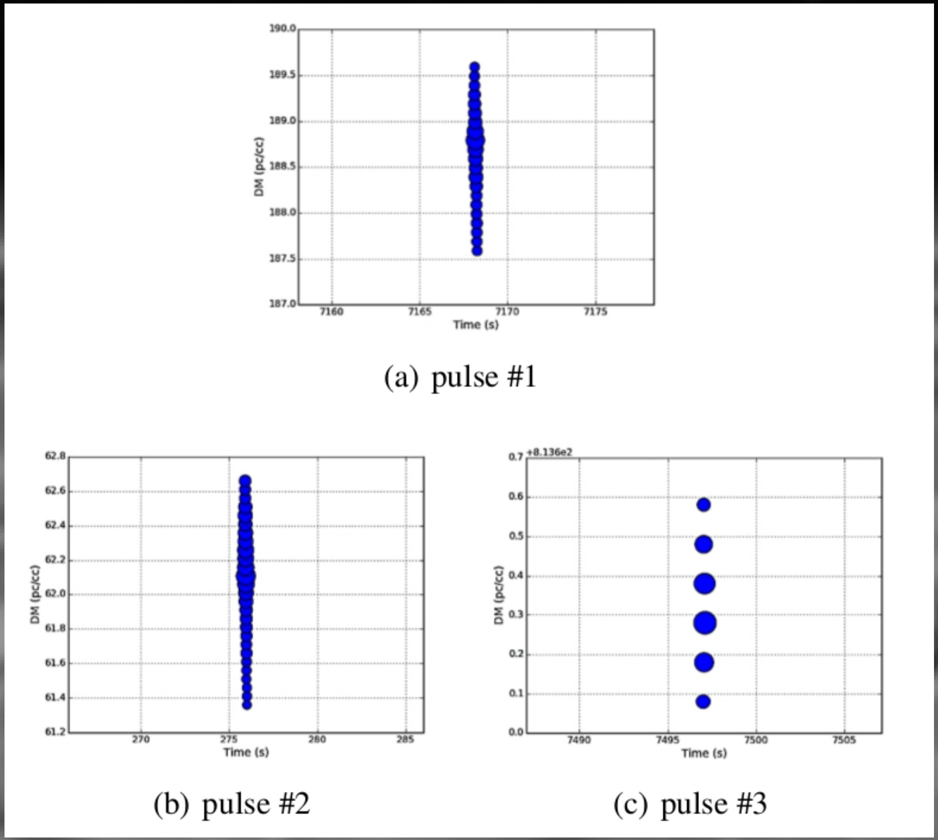
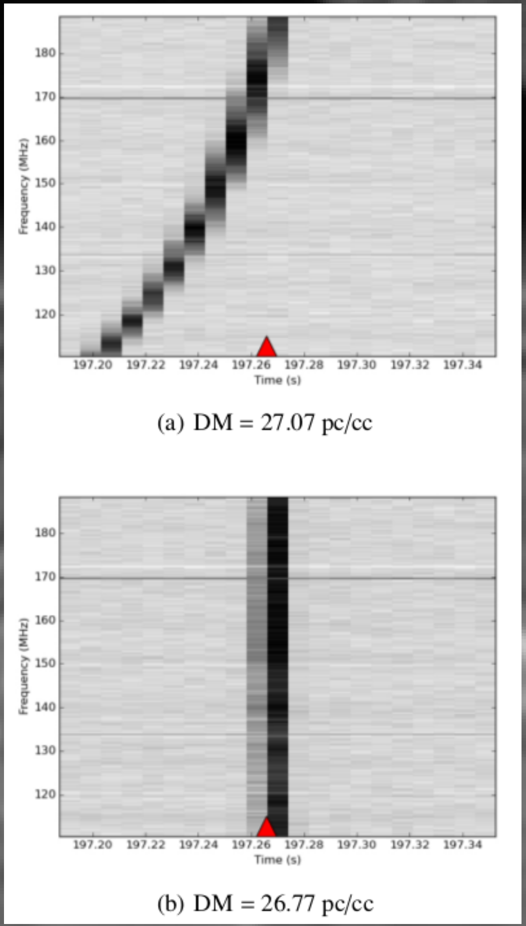
Data analysis – SPS



(a) pulse #1
(b) pulse #2
(c) pulse #3



(a) DM = 27.07 pc/cc
(b) DM = 26.77 pc/cc

Acknowledgements: D. Michilli

Summary

- Search for radio pulsars and other time-domain transients in nearby galaxies M33, M81, and M82 with the currently highest possible sensitivity at low frequencies
- Using 130 LOFAR beams in total, we have searched up to DMs of 1000 pc/cc starting with 2.6 ms sampling time, 4 hours integration time
- Compared to the Milky Way population, there are no extragalactic pulsars that are one order of magnitude brighter in M33, and two orders of magnitude brighter in M81 or M82

Data analysis – PS

minimum detectable flux density

$$S_{\mathrm{min,\ ps}} = \beta \frac{T_{\mathrm{sys}}}{G\sqrt{n_{\mathrm{p}}\,\Delta\nu\, t_{\mathrm{int}}}} \times S/N_{\mathrm{min}} \times \sqrt{\frac{W(P)}{P - W(P)}} \approx 2.06 \times 10 \times \sqrt{\frac{W(P)}{P - W(P)}}\ \mathrm{mJy}.$$

broadening pulse width

$$W(P) = \sqrt{w_{\mathrm{av}}^2(P) + w_{\mathrm{dm}}^2 + w_{\mathrm{sub}}^2 + w_{\mathrm{chan}}^2 + w_{\mathrm{samp}}^2 + (2\, w_{\mathrm{scatter}})^2}.$$

Data analysis – SPS

search criteria

$$S/N_{\rm min} \geq 8$$
$$\mathrm{DM} \geq \mathrm{DM}_z, \text{ where } \mathrm{DM}_z = 25 \text{ pc cm}^{-3}$$
$$W \leq 50 \text{ ms}$$

minimum detectable flux density

$$S_{\rm min,\ sps} = \frac{T_{\rm sys}}{G\sqrt{n_{\rm p}\,\Delta\nu\,W}} \times S/N_{\rm min} = \frac{T_{\rm sys}}{G\sqrt{n_{\rm p}\,\Delta\nu\,t_{\rm int}}} \times S/N_{\rm min} \times \sqrt{\frac{t_{\rm int}}{W}}$$

$$S_{\rm min,\ sps} \approx 2.06\,\mathrm{mJy} \times 8 \times 0.5 \cdot 10^3 \approx 8.2\,\mathrm{Jy}.$$