On the patchiness of spectra of individual pulses of pulsars at low radio frequencies

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Abstract

- Motivation: we used observations of PSR B0809+74 with the LOFAR Low-Band Antennas to search for the anomalously intensive pulses (AIPs) discovered by Ulyanov et al. 2006 with UTR-2 below 30 MHz.
- Found the “super-sequence”: the 50-pulse train showing bright narrowband patches, coherently drifting up in frequency and growing in spectral width. This is not a unique phenomenon, many similar shorter sequences have also been detected, from other pulsars as well.
- Origin: not a pulsar-intrinsic phenomenon, most likely caused by ionosphere or by instrumental issues.
- Implication: the observed phenomenon hinders investigation of single-pulse spectra and energy distributions at the very low frequencies. Depending on the origin, may also affect the appearance of individual pulses from ultra-large DM sources at higher frequencies (e.g. FRBs).

Observations — LOFAR

LOFAR Superterp

PSR B0809+74:
- P ~ 1.29 sec
- DM ~ 5.75 cm^{-3} pc

57-min session on 2011-10-26

LBA 6 Superterp:
- 15-62 MHz
- 7680 channels
- sampling time 491.52 μs

What did we find? An interesting sequence of single-pulse spectra:

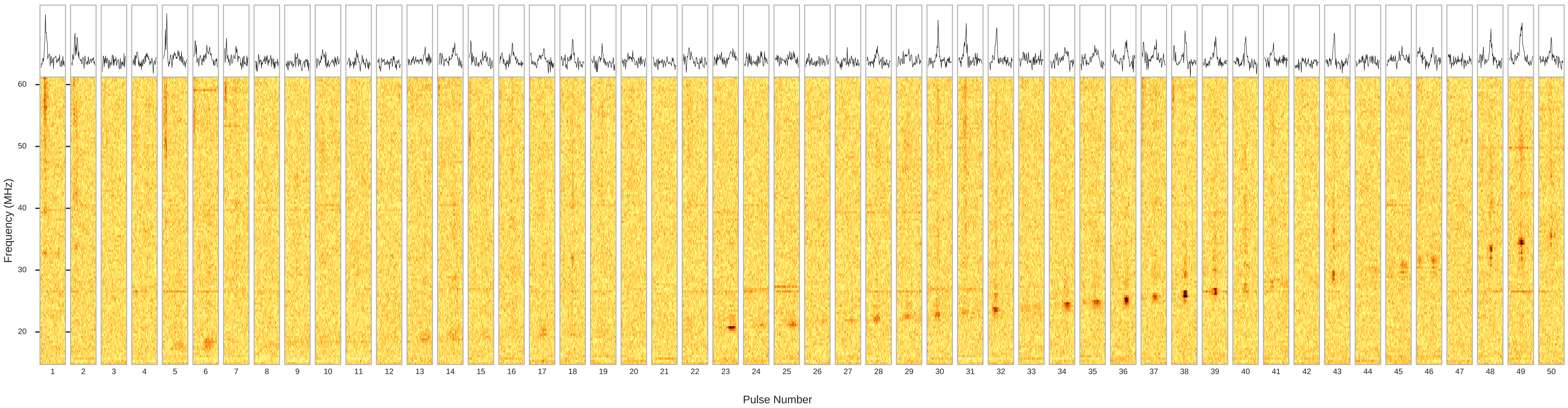


Figure 1. Spectra of 50 pulses dubbed as a super-sequence. Only on-pulse region is shown, with band-integrated profiles on the top row. Such peculiar frequency drift has not been reported in the literature before.

Is this frequency drift pulsar-intrinsic — e.g. produced by a plasma blob gradually moving towards NS surface and emitting according to radius to-frequency-mapping framework? Or is it caused by ISM/ionosphere scintillation or some instrumental issues?

Filterbank data, original (left) and de-dispersed (right), before 2D baseline removal

after 2D baseline removal

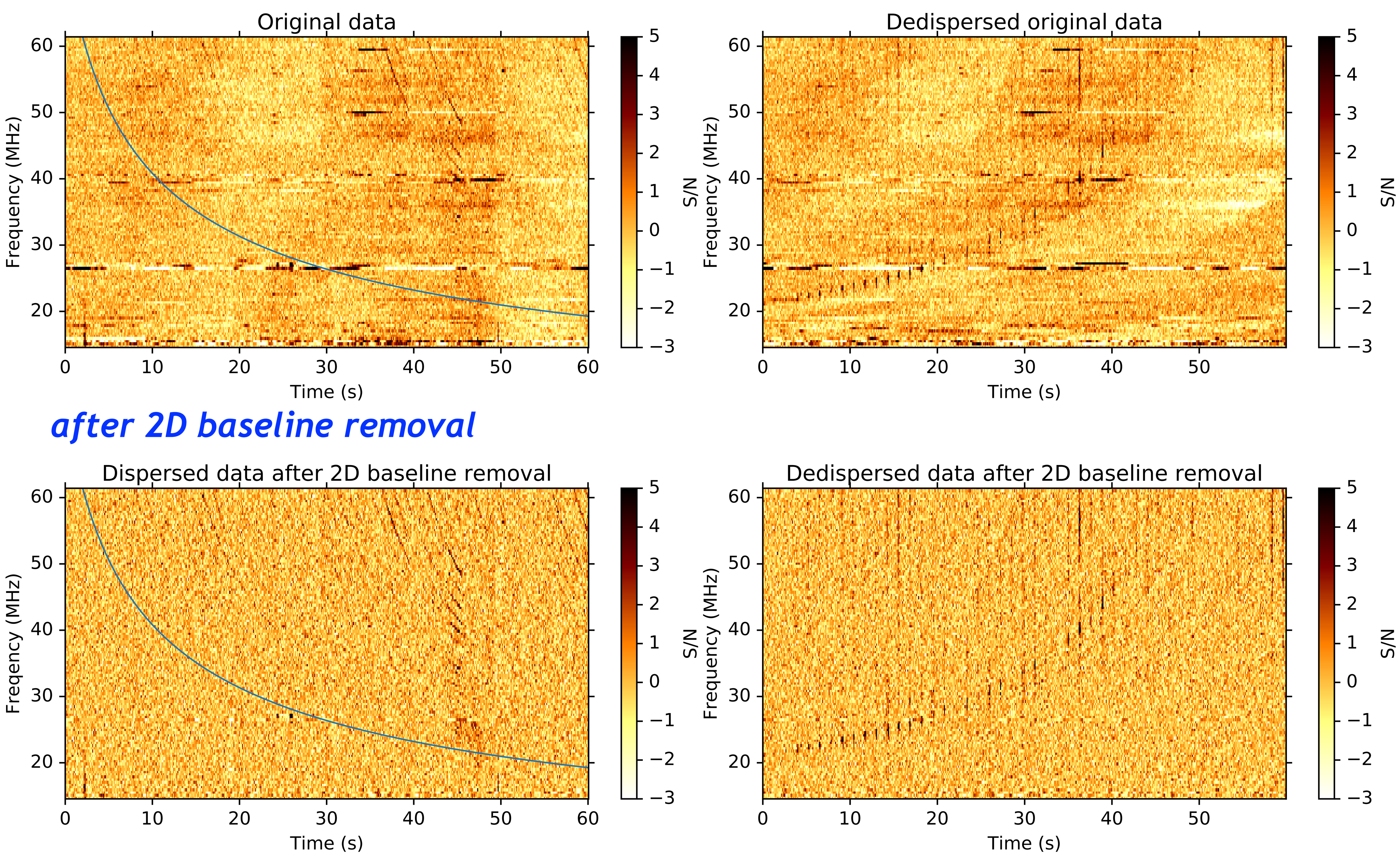


Figure 2. Filterbank data for 60-sec chunk before and after 2D baseline removal. Frequency and time resolution are 0.39 MHz and 0.1 sec, respectively.

The filterbank data show some broadband background intensity variations (Fig. 2, top left plot). After de-dispersion, the bright patches follow the inverse dispersion track → not likely to be pulsar-intrinsic phenomenon.

Are patches due to baseline variation or they are caused by the changes in momentarily S/N? In order to investigate this, we flattened the baseline by subtracting mean and dividing by rms calculated in 2D (time/frequency) blocks after excluding outliers and the on-pulse window.

After 2D baseline removal: background intensity variations were minimised, but no additional emission uncovered. Thus, bright patches are due to changes in S/N of the pulsar signal.

Interpretation of the super-sequence

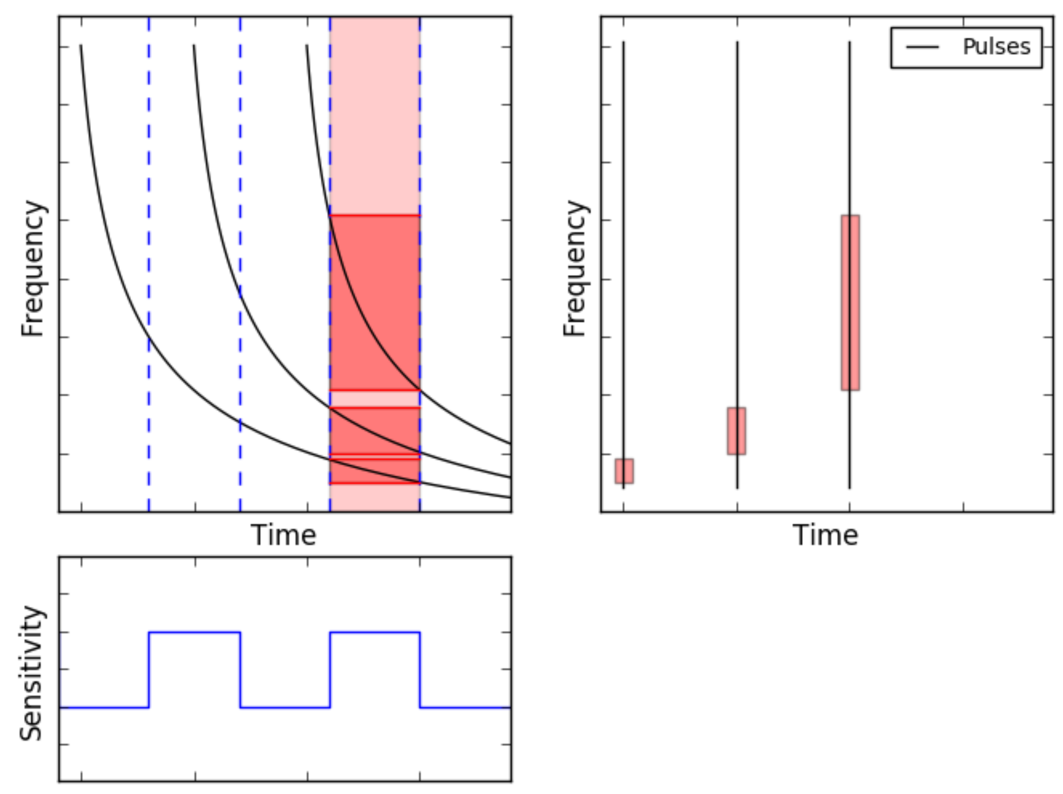


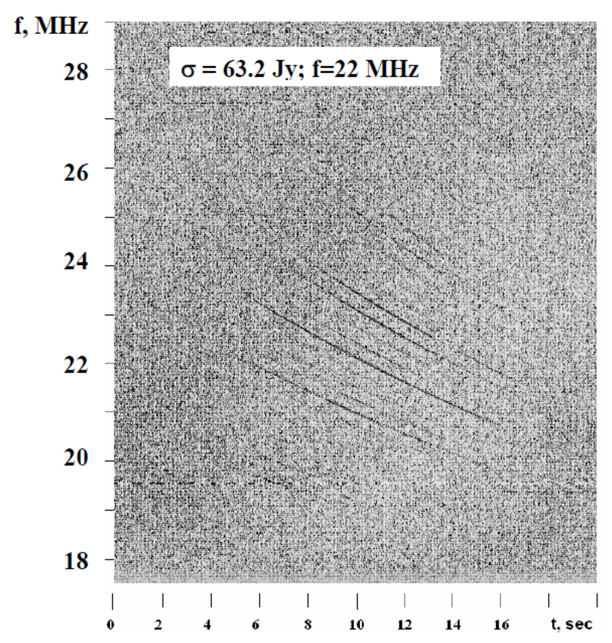
Figure 3. Schematic demonstration of super-sequence, the region of higher sensitivity (pink) affects the pulses passing through it. The affected spectral width is larger for higher frequencies. After de-dispersion, the high intensity stripes will show up as patches in individual pulses.

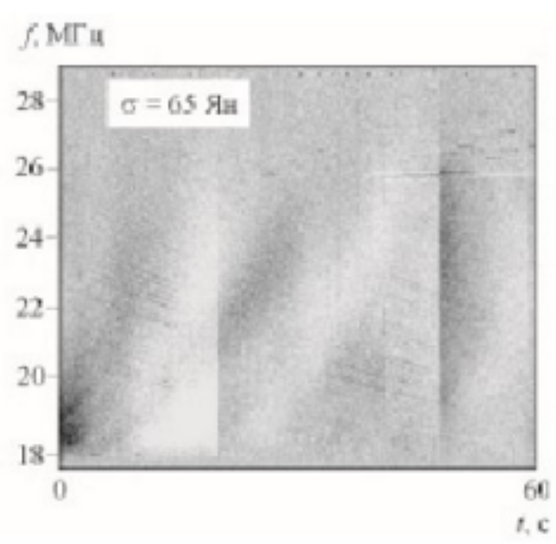
So what could be the origin of super-sequence?

Background variation timescale (measured by ACF): ~20 sec

ISM diffractive scintillation	×	averaged out as: $\triangle f$ ~ 0.4 MHz from dynamic spectra, $\triangle f_{DISS}$ = 7 kHz at 41 MHz and 2 kHz at 62 MHz, respectively (Smirnova & Shishov, 2008).
ISM refractive scintillation	×	Timescale too long: mins to hours to days (Lorimer & Kramer, 2006).
IPM scintillation, solar wind	×	Timescale too short: 1-2 sec PSR B0809+74 has high ecliptic latitude of 52° → thus less affected by solar wind.
Ionosphere scintillation	×	Timescale is comparable: 10-100 sec (Loi et al 2016), but there are no strong scintillation sources in the FoV.
Beam wandering by ionosphere	?	Beam jitter due to refraction in the ionosphere and IPM (10+ arcmin depending on heliospheric distance) → gain variations. Superterp’s FWHM is 43 and 86 arcmin at 60 and 30 MHz, respectively (van Haarlem et al 2013).
Instrumental issue	?	The subset of subbands from one-two stations can drop out during an observation which causes gain variations.

Background intensity variations seen by other authors





Ulyanov et al. (2006) claimed that IPM and ionosphere scintillation gave some contribution to the background intensity variations, but the main effect should be from pulsar plasma in the magnetosphere.

Figure 4. Dynamic spectra of B1133+16 (left) and B0943+10 (right) by Ulyanov et al. (2006).

References:
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