Studying Single Pulse Emission from Pulsars using POLFAR

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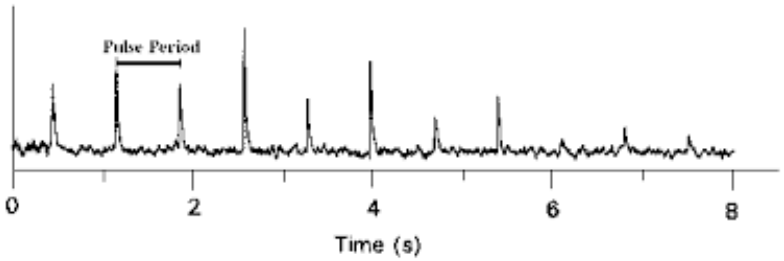
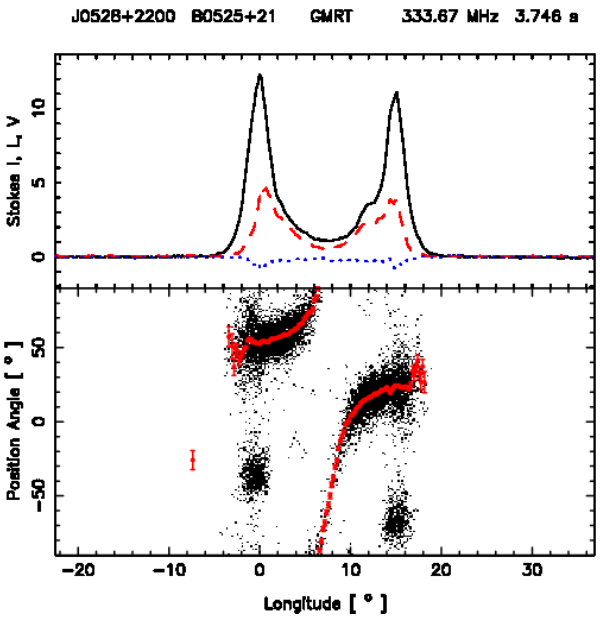
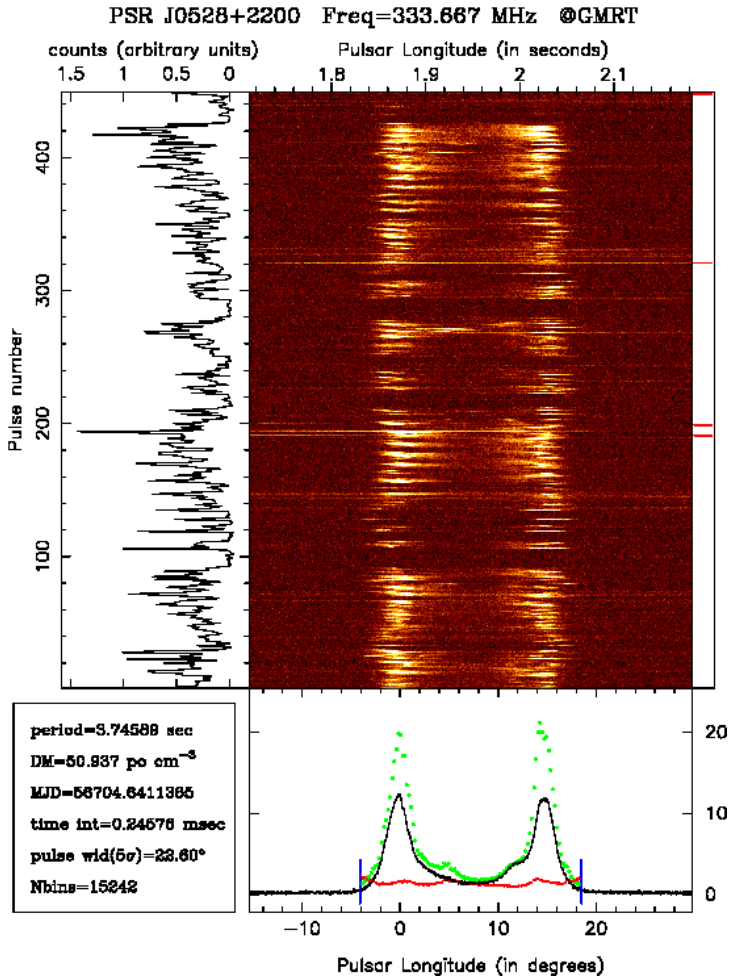
Pulsed Radio Emission from Pulsars







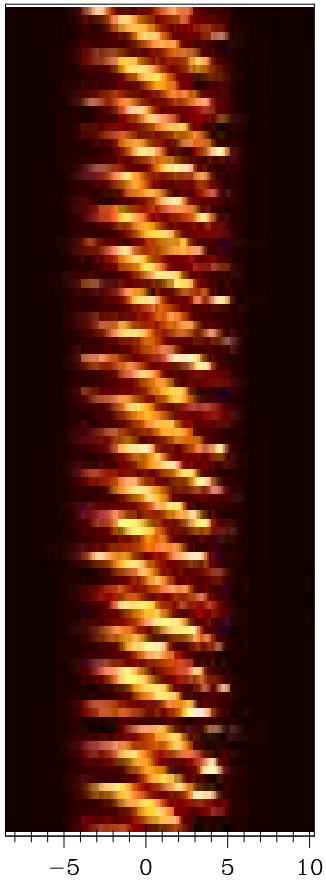
[Image Credit : Manchester & Taylor (1977, top left); Mitra et al. (2016) - MSPES survey (bottom left and right).]

Prominent Single pulse Phenomena in Pulsars

- **Subpulse Drifting** - Systematic shift of the emission components (subpulses) within the pulsed window.
- **Nulling**
- **Mode changing**
- **Periodic Modulation**

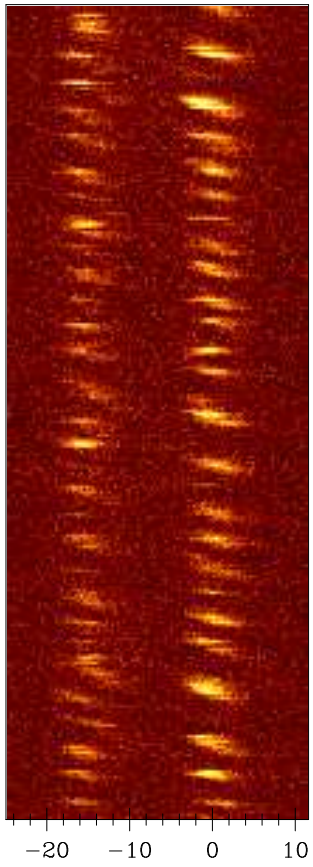
Subpulse drifting

PSR B0818-13



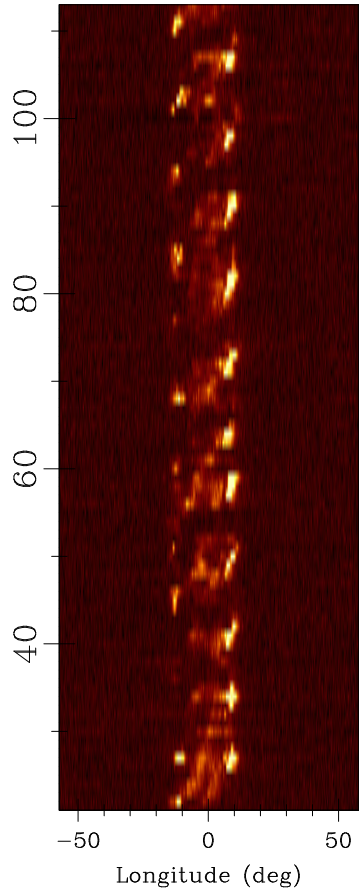
(Basu et al. 2016)

PSR J1555-3134



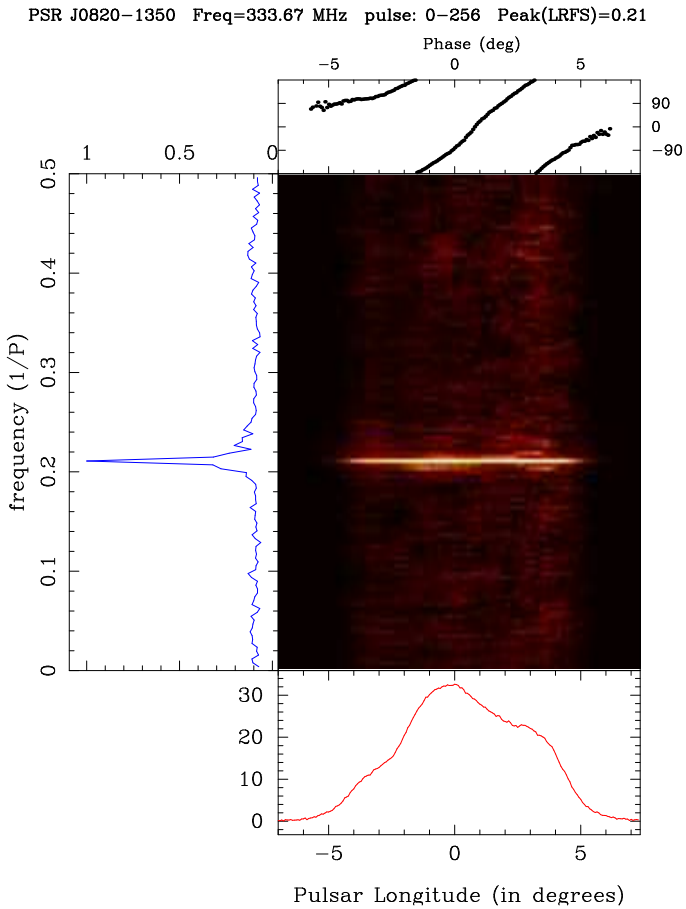
(Basu & Mitra 2018)

PSR B2319+60

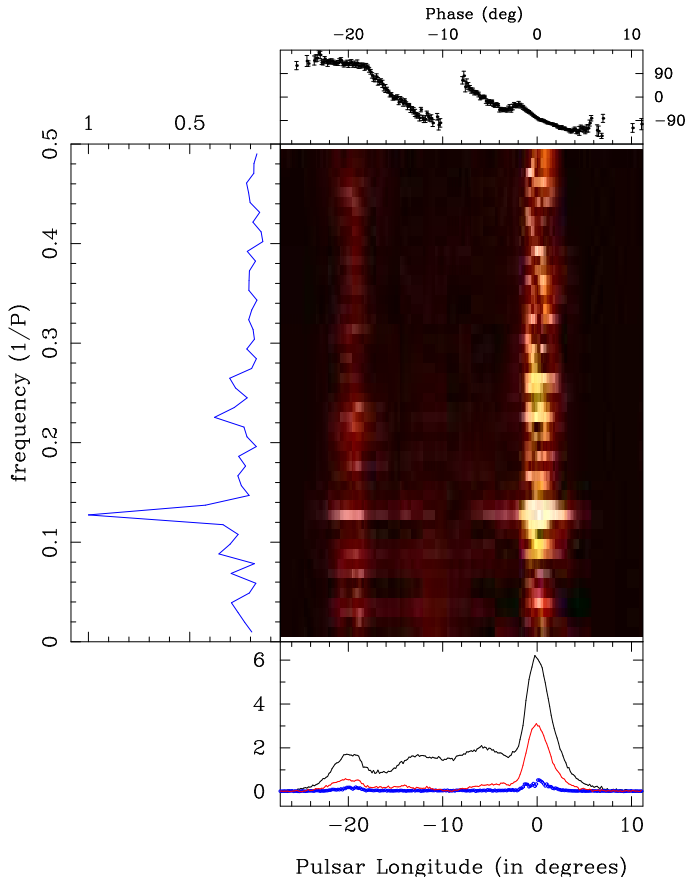


(Rahaman et al. 2021)

Longitude Resolved Fluctuation Spectra (LRFS)



PSR B0818−13 (Basu et al. 2016).



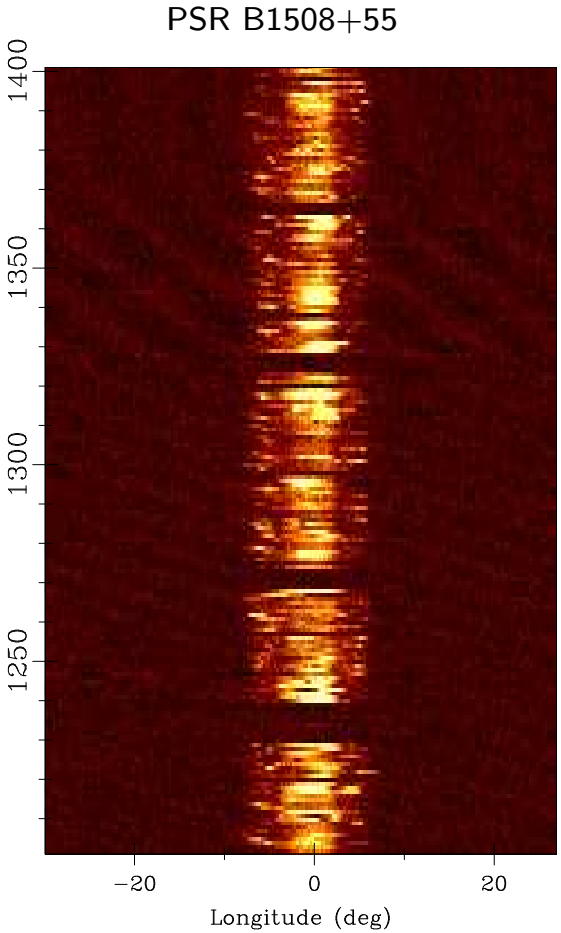
PSR B2319+60 (Rahaman et al. 2021).

LRFS - Drifting periodicity ($P_3 = 1/f_p$) and Phase variations across profile.

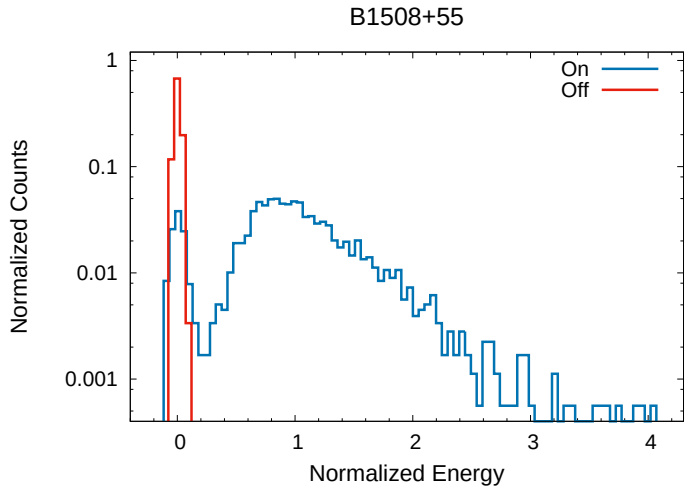
Prominent Single pulse Phenomena in Pulsars

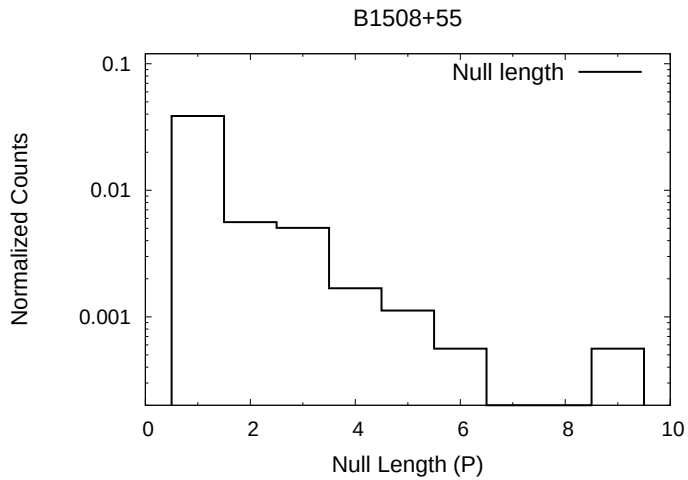
- Subpulse Drifting
- **Nulling** - The single pulse emission is below detection threshold. Repeats at regular but mostly random intervals.
- Mode changing
- Periodic Modulation

Nulling



Basu, Mitra & Melikidze (2020).



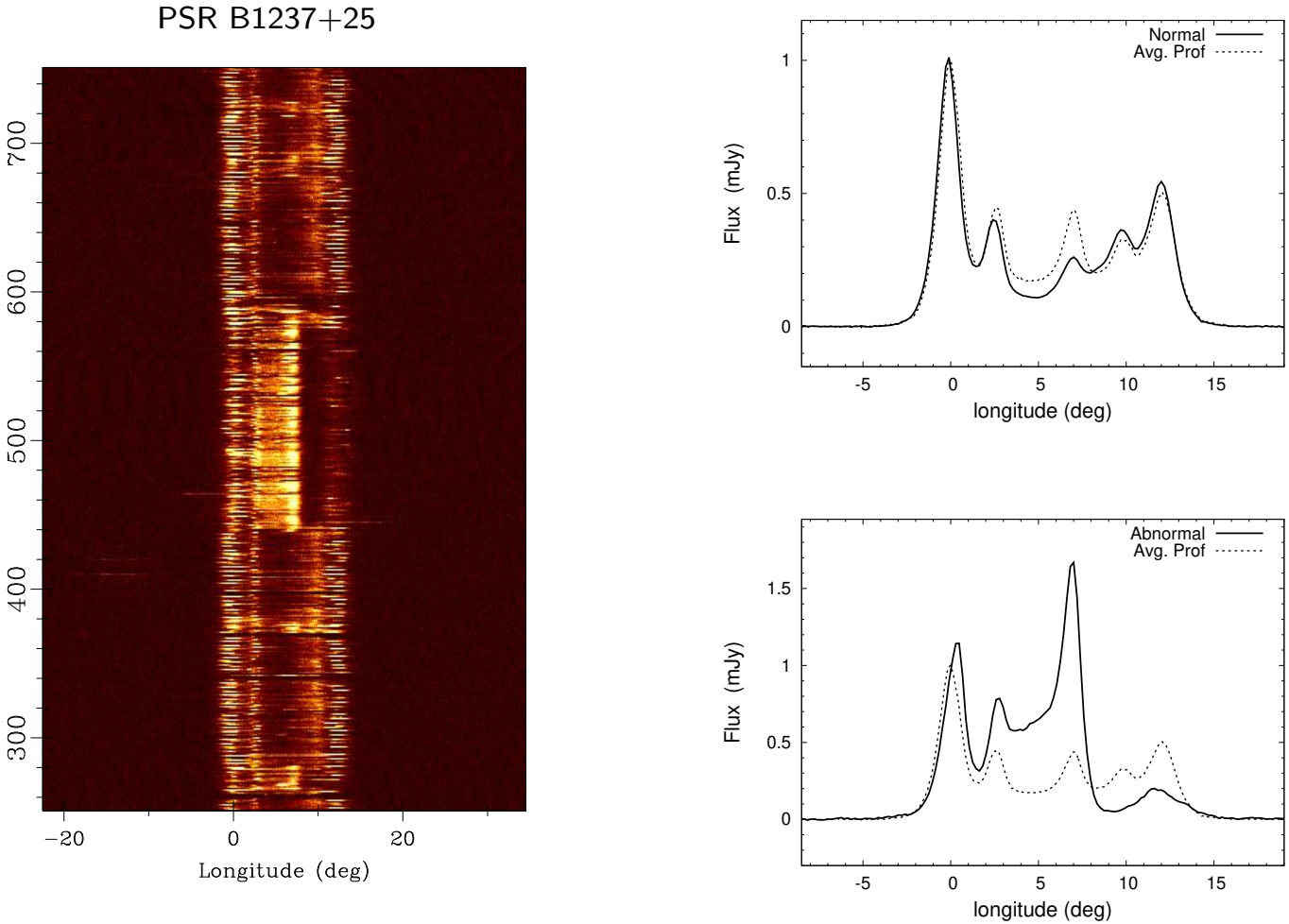


Nulling Fraction; Distribution of Null lengths and Burst lengths; Degree of intensity reduction; etc.

Prominent Single pulse Phenomena in Pulsars

- **Subpulse Drifting**
- **Nulling**
- **Mode changing** - Change in the emission properties like Profile shape, drifting periodicity, etc. Rapid transition between modes with large variation of mode lengths from few 100 pulses to hours at a time.
- **Periodic Modulation**

Emission Mode Changing



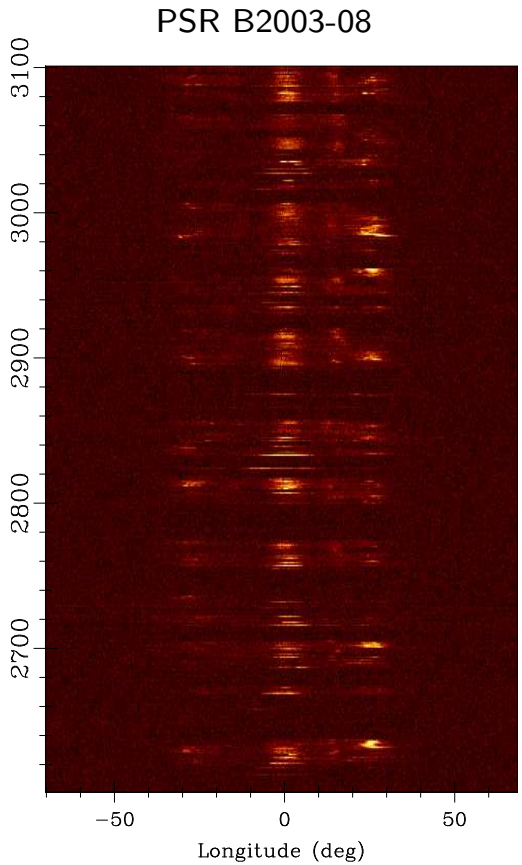
Basu, Mitra & Melikidze (2021).

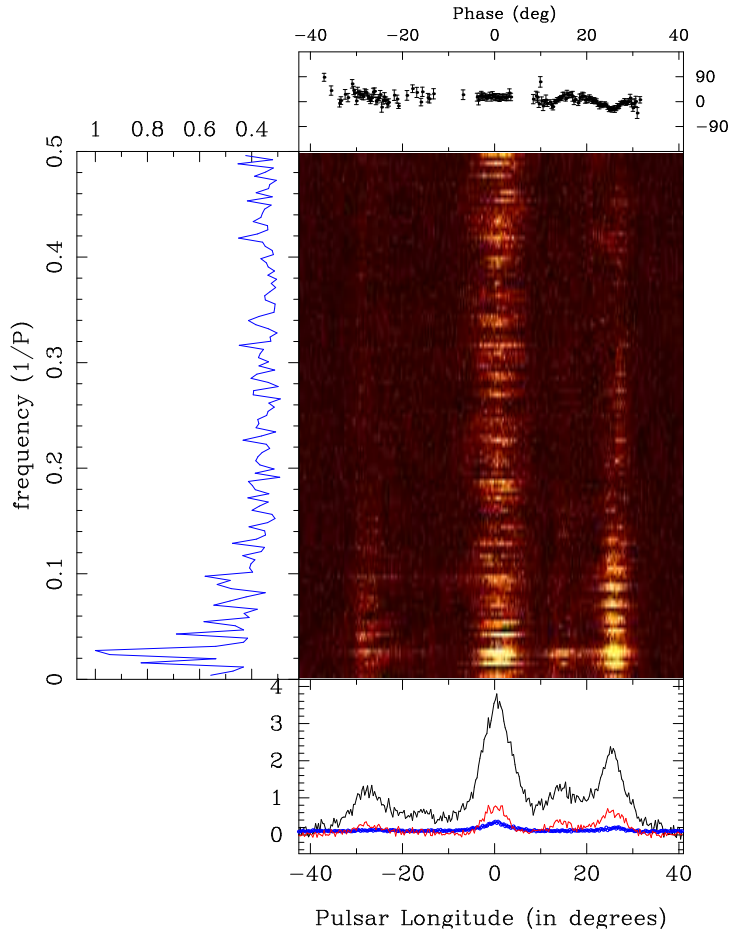
- Rapid transition between two distinct emission states.
- Change in Profile shape; Subpulse Drifting behaviour; etc.

Prominent Single pulse Phenomena in Pulsars

- Subpulse Drifting
- Nulling
- Mode changing
- **Periodic Modulation** - Emission within the entire window periodically changes in intensity.

Periodic Modulation





Basu, Paul & Mitra (2019).

- Two types : Periodic nulling; Periodic amplitude modulation.
- Longer periodicities and constant phase variations.

Observations with GMRT

- **Meterwavelength Single-pulse Polarimetric Emission Survey (MSPES)**

  (Mitra et al. 2016, 2023; Basu et al. 2016, 2017, 2021)

  - 123 pulsars, with $P > 0.1$ s, observed with GMRT.
  - $\sim$ 200 hours of observing time.
  - Observations at both 325 MHz and 610 MHz frequency bands.
  - Around 2100 polarized single pulses observed from each pulsar at both frequencies.

- **Assorted Studies**

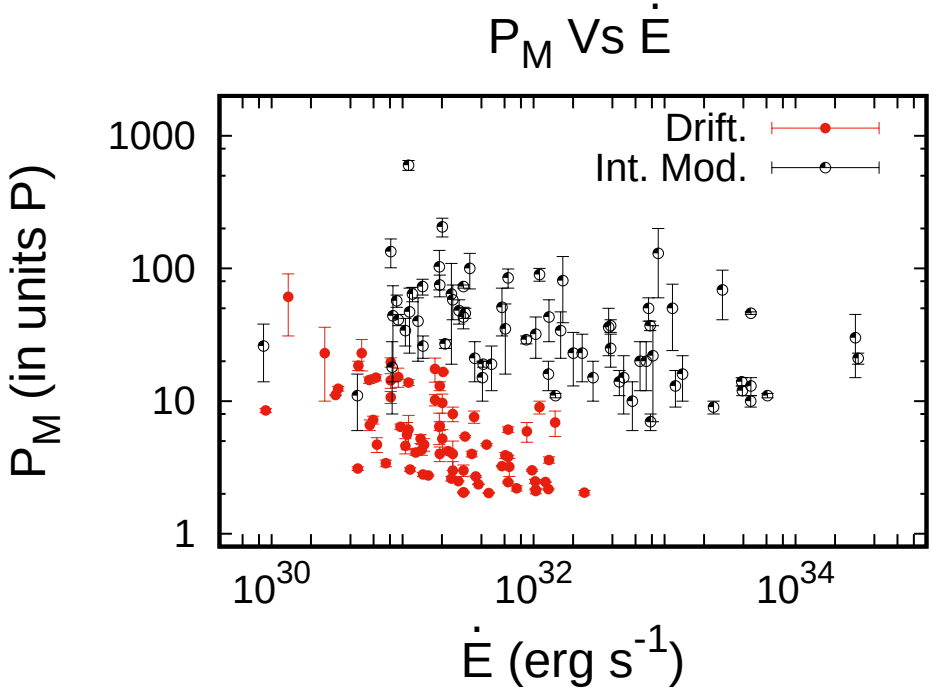
  (Basu & Mitra 2018a, 2018b, 2019; Basu et al. 2019a, 2019b, 2020; Mitra et al. 2020; Rahaman et al. 2021)

  - A separate list of >100 pulsars from multiple observing proposals as well as archival data (Mitra & Rankin, 2011; and other previously unpublished observations).
  - More than 500 hours of observing time in total.
  - Observations primarily at 325 MHz frequency band.
  - Longer observations ($>$ 5000 single pulses) on specific pulsars as well as shorter observations ($\sim$ 2000 pulses) on larger samples.

Observations with GMRT : Results

- **Subpulse drifting :**
  - Detailed classification of the drifting behaviour in ∼80 pulsars.
  - Phase variations characterised for the first time in majority of them.
  - 20% increase in drifting population.
  - Dependence on spin-down energy loss ($\dot{E}$).
- **Periodic Modulation :**
  - First identified as a separate phenomenon in pulsar radio emission.
  - Found ∼70 pulsars with periodic modulations.
  - Classification into two groups : Periodic Nulling and Periodic Amplitude Modulation.
  - ∼15 pulsars with both subpulse drifting and periodic modulation seen as separate peaks in the Fluctuation spectra.
- **Nulling and Mode Changing :**
  - Studied nulling behaviour in around 60 pulsars. Several new detections.
  - Characterized the emission modes in around 10 pulsars, which represent around 30% of the population.

Subpulse drifting and Periodic Modulation



Basu, Mitra & Melikidze (2020).

- Subpulse drifting seen in low energetic pulsars with $\dot{E} < 5 \times 10^{32}$ erg s^{-1}
- Bunching of drifting periodicity, P_3, around $2P$ and $P_3 \propto \dot{E}^{-0.5}$
- Periodic modulation seen across the entire $\dot{E}$ range, mostly longer periodicities $> 10P$.

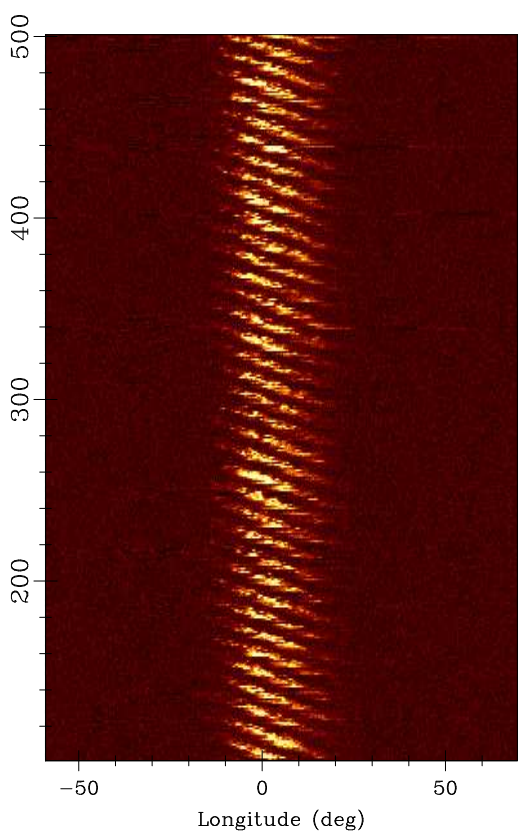
Observations with Individual POLFAR stations

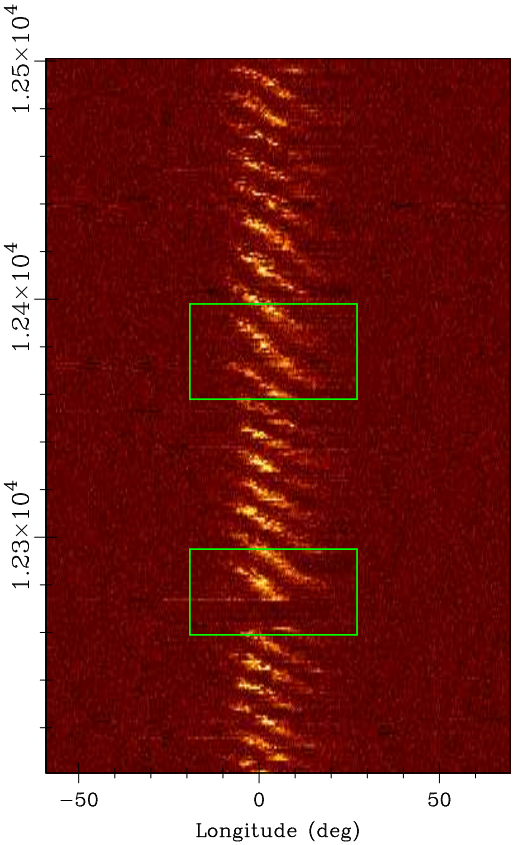
- The steep spectral nature of Pulsars makes it possible to detect single pulse emission from several pulsars at lower frequencies using Individual POLFAR stations.

- Possibility of longer observations repeated at regular intervals. Ideally suited for emission mode changing behaviour with timescales of hours.

- Characterise the low frequency single pulse behaviour in pulsars to complement higher frequency results.

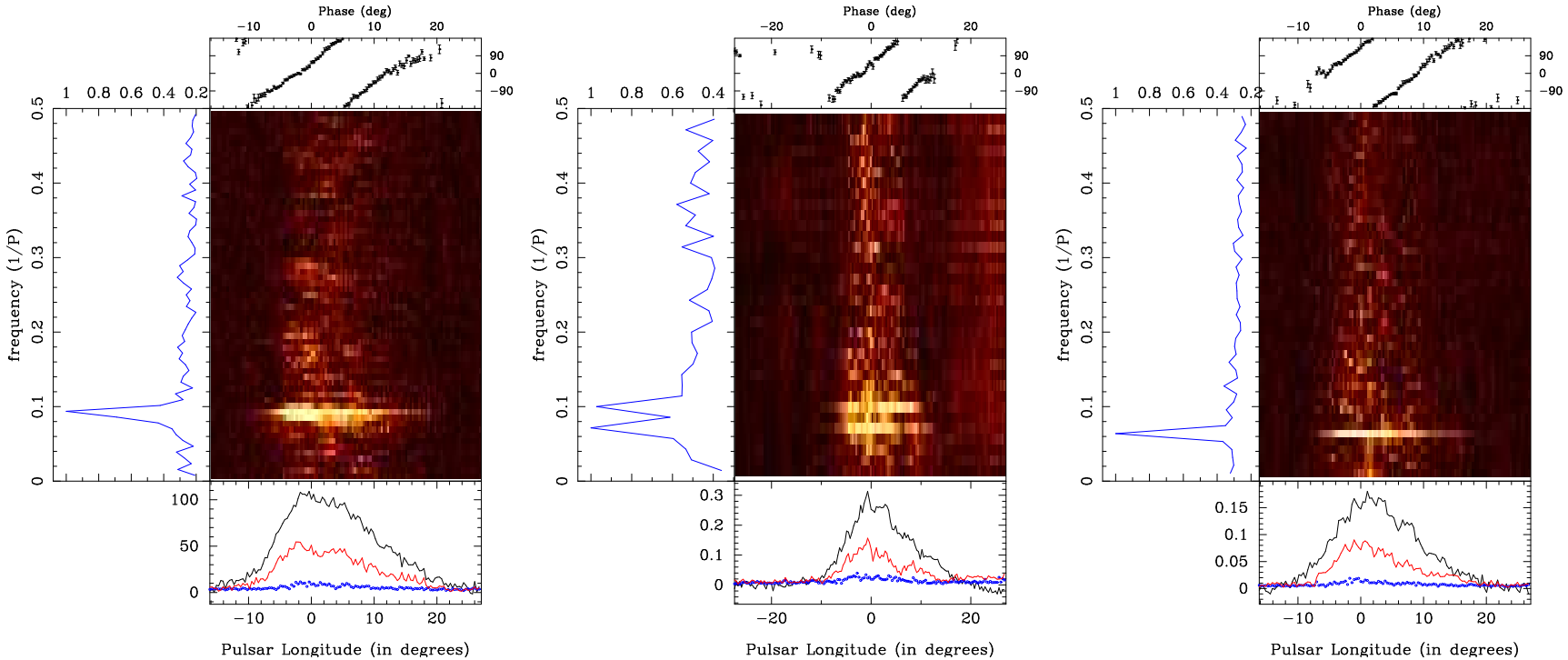
POLFAR observation of PSR B0809+74 : Mode Changing





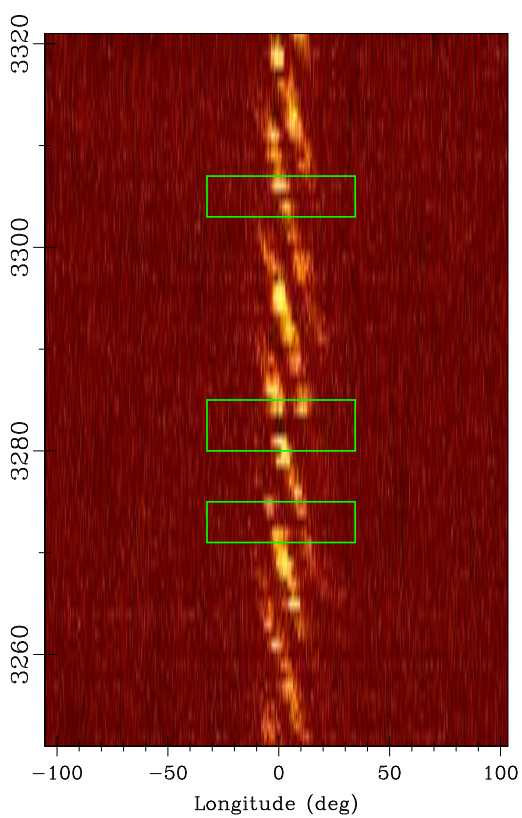
- Prominent Subpulse drifting seen for 95% of observing time.
- Switches to a short lived Slow-Drift mode for around 50 pulses.

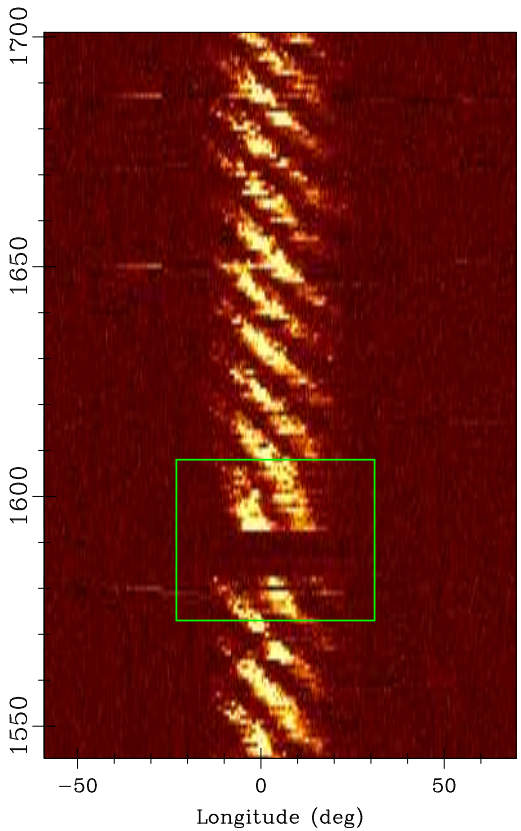
POLFAR observation of PSR B0809+74 : Subpulse Drifting



- Normal Mode : $P_3 = 11P$; Slow-Drift Mode : $P_3 = 16P$
- Linear Phase variations remaining unchanged in the two modes.

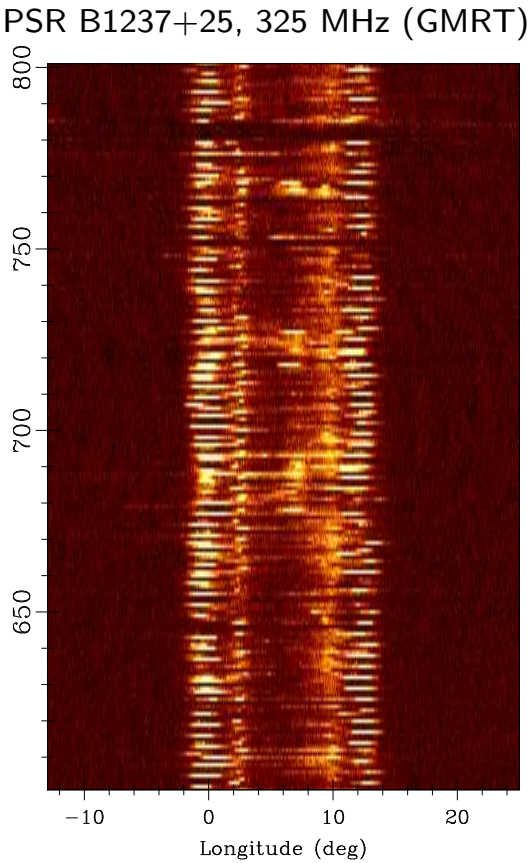
POLFAR observation of PSR B0809+74 : Nulling

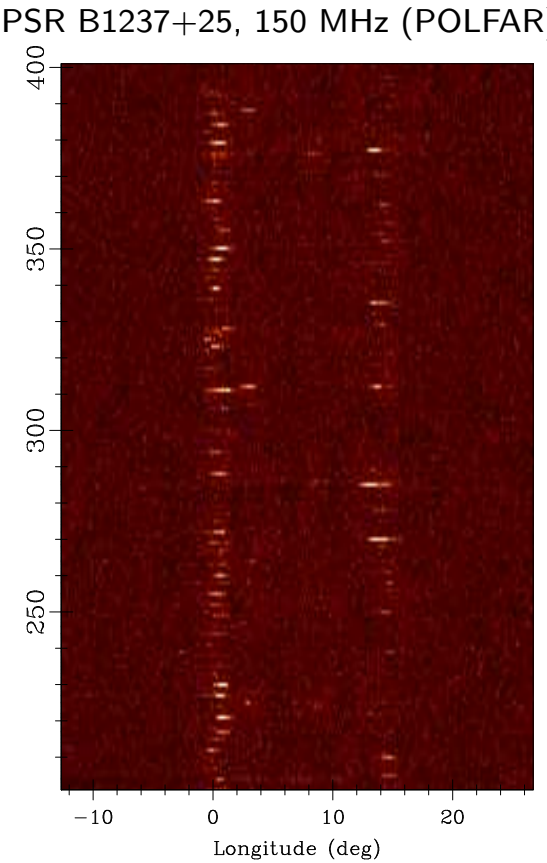




- Two different types of nulls, short duration 1-2P and longer duration lasting 5-10P.
- The short nulls repeat with periodicity of 44P.

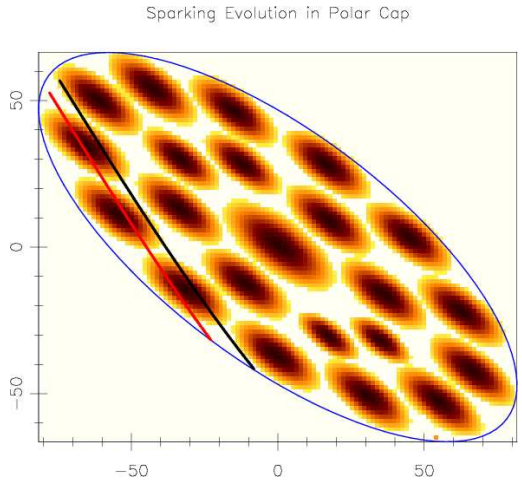
POLFAR observation of PSR B1237+25 : Flaring

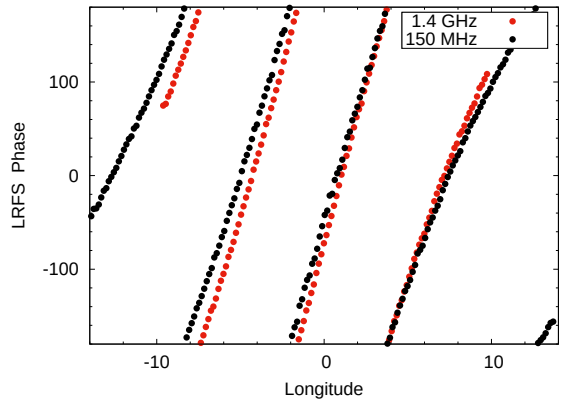




- Emission changes with frequency, showing flaring bursts at low frequency.
- The typical intensity of these flares are 20 times the average intensity.

Frequency evolution of Drifting





Basu, Melikidze & Mitra (2023)

- Radio emission in outflowing plasma generated due to sparking discharge in an Inner Acceleration Region (IAR) above polar cap.
- The sparks undergo **E**x**B** drift in the IAR resulting in subpulse drifting.
- The drifting phase behaviour is expected to change due to the frequency evolution of the line of sight traverse.
- Program to compare drifting phase behaviour at higher frequencies from GMRT and low frequency using individual POLFAR stations.

Summary

- The single pulse emission from pulsars shows a number of interesting phenomena like subpulse drifting, nulling, emission mode changing, periodic modulation, etc., that are closely associated with the physical processes within the pulsar magnetosphere.
- Understanding the nature of each of these phenomena requires dedicated observations of a sizeable sample of pulsars to characterize their behaviour in individual sources as well as finding general trends in the larger population.
- The high frequency single pulse behaviour in a significant sample of pulsars have been conducted in the past few years using the GMRT.
- We are currently in the process of extending these studies to the low frequency regime using the individual POLFAR stations, with several pulsars like PSR B0809+74 and PSR B1237+25 providing new insights which are distinct from the high frequency behaviour.

Thank you for your attention!