# Probing Pulsar Magnetospheres Using Coordinated Single-Pulse Observations


Fabian Jankowski for the SUSPECT collaboration

**Paris Observatory, LPC2E, CNRS, France (fabian.jankowski@cnrs-orleans.fr, https://fabian.jankowskis.org)**



**Abstract.** The '**S**cience **U**sing **S**ingle-**P**ulse **E**xploration with **C**ombined **T**elescopes' (SUSPECT) project is an effort to understand the radio emission of pulsars, particularly at the single-pulse level. Our team designed and established a new pulsar observing programme at the Nançay Radio Observatory telescopes (NenuFAR, LOFAR, NRT) in France and the upgraded GMRT in India. We focus on coordinated multi-telescopes and multi-frequency single-pulse pulsar observations. Since early 2023, we have spent, in aggregate, hundreds of telescope hours observing our first sample of 22 pulsars. Science highlights include the development of a new model for the mode switching phenomenon, its application to PSR B1822–09, and the discovery of a new bright flaring emission mode in the pulsar. The project overview paper was published in February 2025, and two Master's student projects were completed in 2023–2024.


## The SUSPECT Project

- **S**cience **U**sing **S**ingle-**P**ulse **E**xploration with **C**ombined **T**elescopes (SUSPECT)
- New pulsar observing programme running since early 2023, i.e. for about 2 years now
- Coordinated pulsar observations using the radio telescopes at the Nançay Radio Observatory in France (NenuFAR, LOFAR, NRT) and the upgraded GMRT in India
- Aims
  - Understanding the wide-band single-pulse properties of radio pulsars
  - Study single-pulse properties (pulse-energy distributions, modulation)
  - Others: pulse profiles, radius-to-frequency mapping
- Focus on mode switching and sub-pulse drifting pulsars
  - Master's student research projects (M2) in 2023 and 2024 supervised by Jankowski & Grießmeier


Fig. 1: The NenuFAR telescope (10–85 MHz) in front of the LOFAR FR606 HBA antennas (110–240 MHz) with the NRT (1.1–3.5 GHz) in the background.


Fig. 2: Some of the GMRT core antennas.

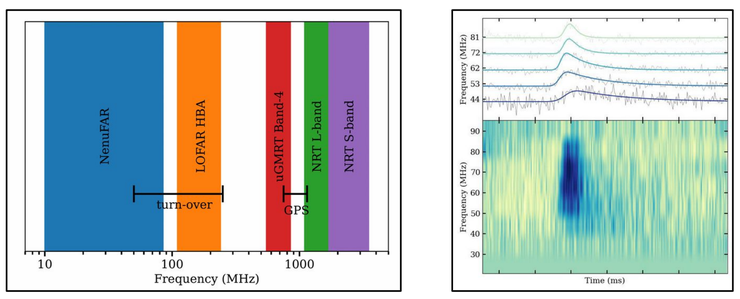



Fig. 3: Frequency coverage of our data from the Nançay telescopes & GMRT (left). Scattering fit of PSR B0355+54's NenuFAR data with our *scatfit* software (FJ 2022; right).

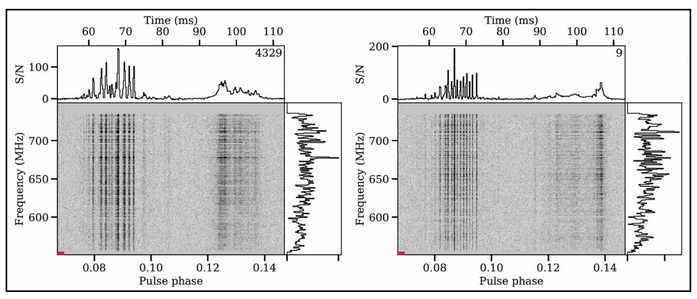



Fig. 4: Quasi-periodic shot-like micropulse emission detected in PSR B1822–09's precursor pulse component (FJ+ 2025).

## Understanding the Pulsar Radio Emission – Our Approach

- Wide-band data
- Several telescopes
- (Quasi)-simultaneous observations
- Two complementary approaches

1) Highest S/N single pulses, intermediate frequencies (~600 MHz), low scattering

→ probe the **intrinsic** emission

GMRT & NRT

2) Long-term observing campaigns (> 5 years), low frequencies (10s – 100s MHz), timing models, rare modes, time evolution, DM & scattering

→ **intrinsic** and **extrinsic**

NenuFAR & LOFAR

## Project Status

- 22 pulsars observed so far (NenuFAR & FR606 & GMRT)
  - Time granted for another 6 observations
- Initial data reduction completed for all
- ~12 worked on in more detail (M2 projects, paper)
- 2 Master's student projects (M2) completed

## Publications

- Project overview paper published (SUSPECT paper I; Jankowski et al. 2025)

**Science Using Single-Pulse Exploration with Combined Telescopes**

**I. The mode switching, flaring, and single-pulse morphology of PSR B1822–09**

F. Jankowski[1,*], J.-M. Grießmeier[1,2], M. Surnis[3], G. Theureau[1,2,4], and J. Pétri[5]

- Currently working on SUSPECT paper II
  - Multi-frequency pulse profiles, modulation, and pulse-energy distributions
  - Expected to be submitted soon
- Some data shared for collaborator projects

## Results

- Single-pulse stacks, updated DMs, scattering parameters, pulse profiles, modulation properties, pulse energy distributions, and all that for 3–5 radio frequency bands

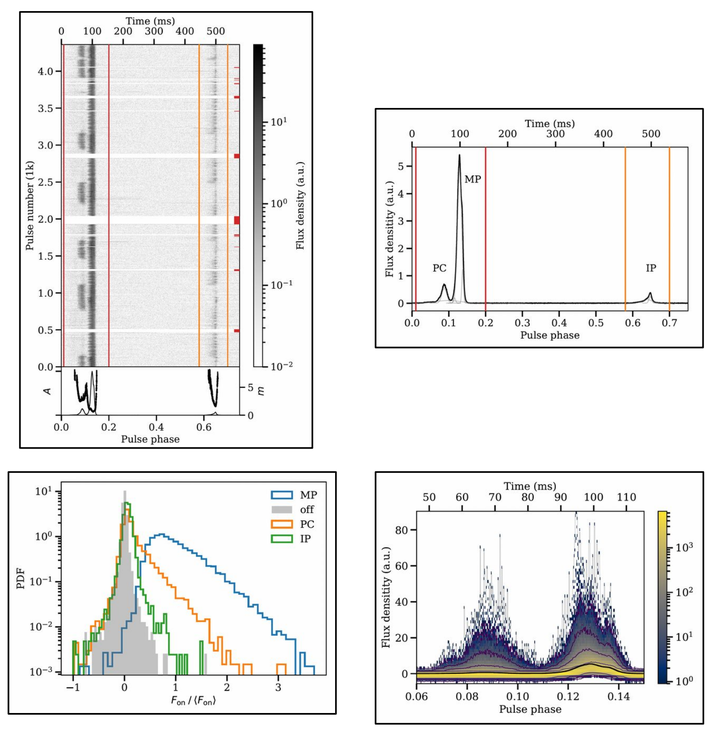
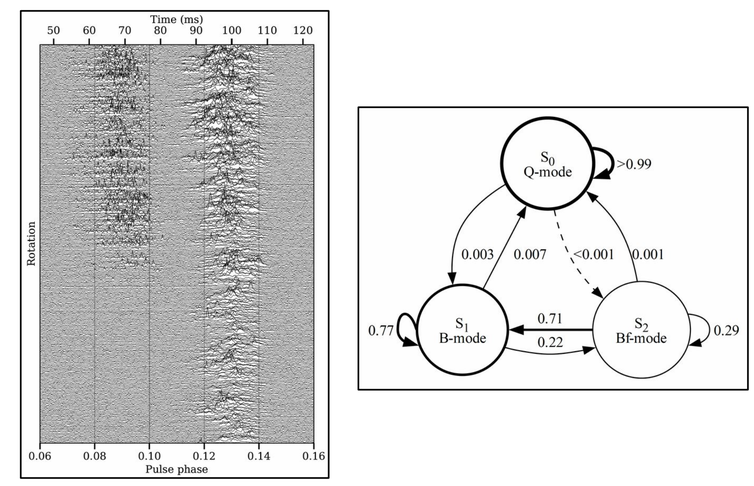
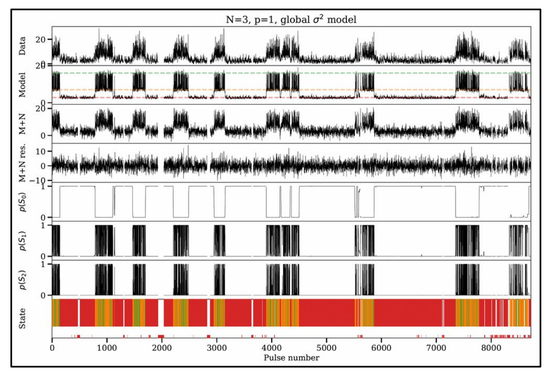



Fig. 5: Single-pulse stack, integrated pulse profile, pulse-energy distributions, and flux-phase distribution of PSR B1822–09 measured from our uGMRT data (FJ+ 2025).

## A Model for the Mode Switching Phenomenon

- Some pulsars do strange things
- This pulsar (B1822–09) quasi-randomly switches between several emission modes
  - Stable configurations of the plasma in the magnetosphere
- We want to understand the physics behind it
- Can we understand and model it?
  - Yes! Hidden Markov model with autoregressive emissions
  - Automatic mode classification
  - Mode detection and their number
  - New mode discovered!



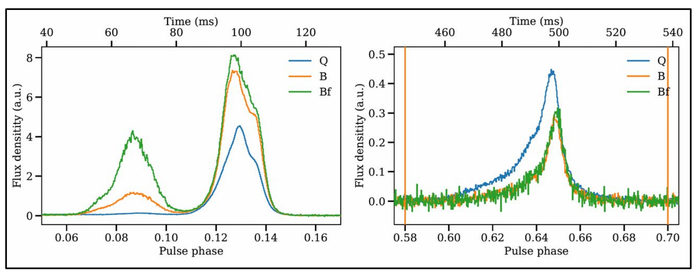




Fig. 6: Mode switching analysis of PSR B1822–09 based on our uGMRT data. Joy Division plot, the Markov state diagram, our best-fitting 3-state Markov switching model, and the resulting mode-separated pulse profiles (FJ+ 2025).

## Conclusions

- The combination of high-S/N data with long-term observations (> 5 years) is extremely powerful
- Having multi-frequency data allows many interesting tests
- Managing observations at several telescopes is non-trivial
- We have barely scratched the surface of what is possible with this data set. Lots of work still ahead. Probably work for several years.

## References


Jankowski et al. A&A **695**, A203 (2025)

Project website: https://suspectproject.com

*Scatfit* software, Jankowski ASCL, 2208.003 (2022)

GitHub: https://github.com/fjankowsk/scatfit