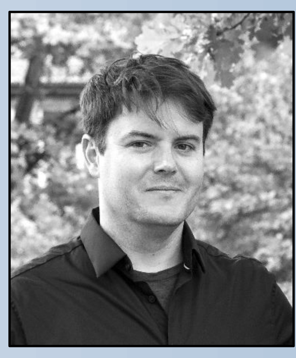
Pulsar Radio Phenomenology and Fundamental Physics



Fabian Jankowski

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

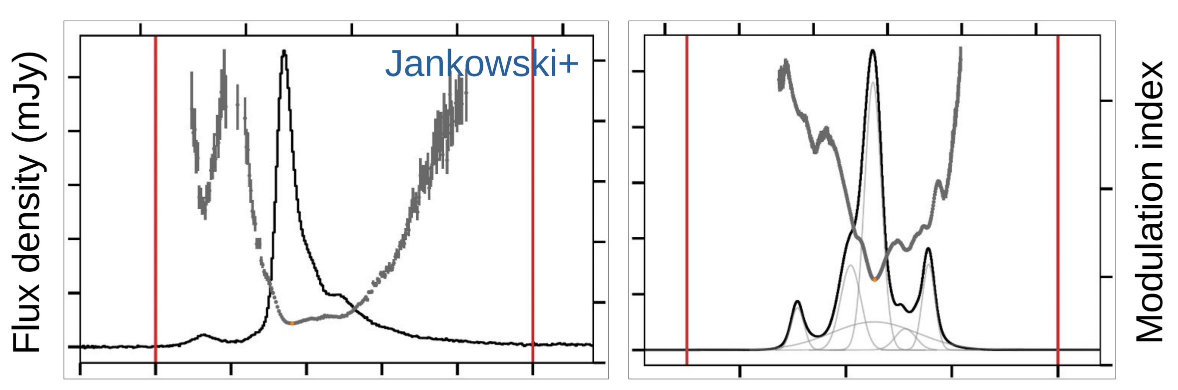
Abstract. In this poster, I introduce how pulsar radio phenomenology touches upon many areas of modern fundamental physics. I then summarise some of the key observables that characterise the pulsar radio emission and present examples from recent work we are involved in on integrated pulse profiles, pulsar polarimetry and geometry modelling, pulsar radio spectra, and pulsar single-pulse emission. I finish by describing how the SKAO will advance those research areas, offer my suggestions for SKA-Low Science Verification, and stress that pulsar radio phenomenology is crucial for understanding other radio transients, such as fast radio bursts (FRBs) and long-period transients (LPTs).

Motivation & Big Picture Science

- Pulsar radio phenomenology touches upon many areas for fundamental physics, some of which I list below.
- Matter at ultra-high densities, neutron star structure and Equation of State (solid state physics)
- Pulsar radio emission (plasma physics)
  - Solve the pulsar emission mechanism problem
- Pulsar radiation traces the Milky Way ISM free electron distribution and its turbulence (plasma physics, our Galaxy)
- Precision timing for GW discovery & GR tests

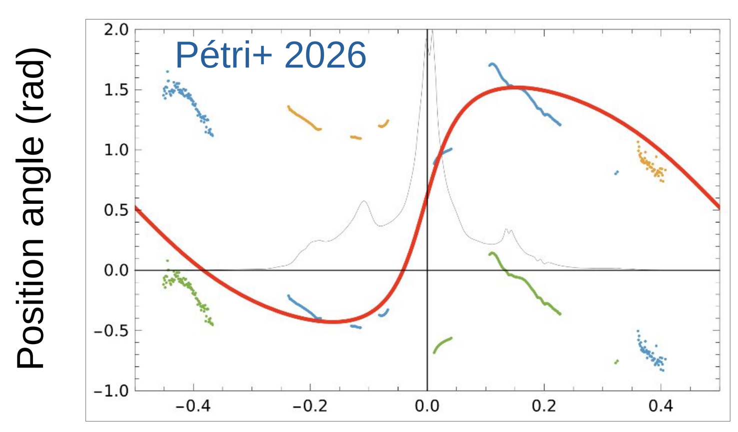
Integrated Pulse Profiles

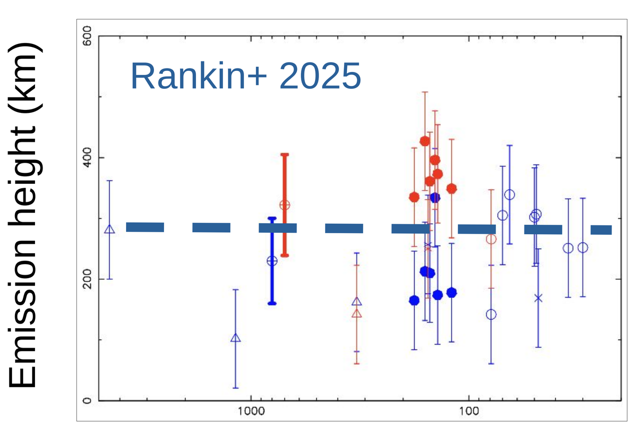
- Integrated pulse profiles are formed by phase coherent folding the dedispersed time series data at the pulsar's topocentric period.
- The resulting pulse profiles or light curves (amplitude versus rotational phase) are stable in time and characteristic fingerprints of a pulsar, once O(10k) rotations are averaged.
- The pulse profiles are the most readily-accessible observables of the pulsar radio emission.
- They trace the shape of the radio-emitting plasma in the pulsar beams and its frequency evolution.
- Their frequency dependence (e.g. width) relates to the emission altitudes of the radiation in the pulsar magnetosphere (radius-to-frequency mapping).



Polarimetry & Geometry

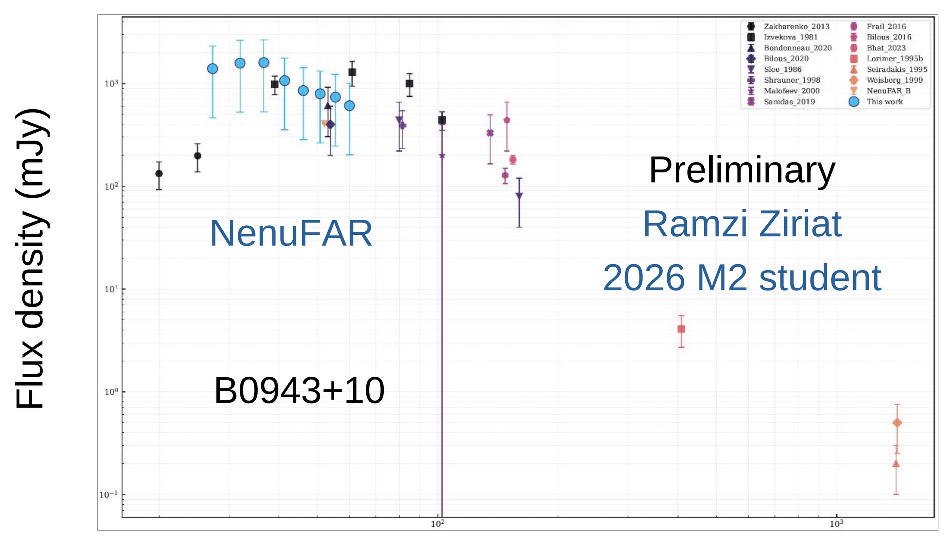
- The pulsar emission is intrinsically linked to the geometry of the pulsar and its magnetosphere, which is described by its magnetic inclination angle and the LOS impact parameter or viewing angle.
- Polarisation data allows us to constrain those angles by fitting the rotating vector model (RVM) to the linear polarisation position angle swing (ideal dipole assumption), which is often more complex.
- Recent work has challenged the RFM paradigm.





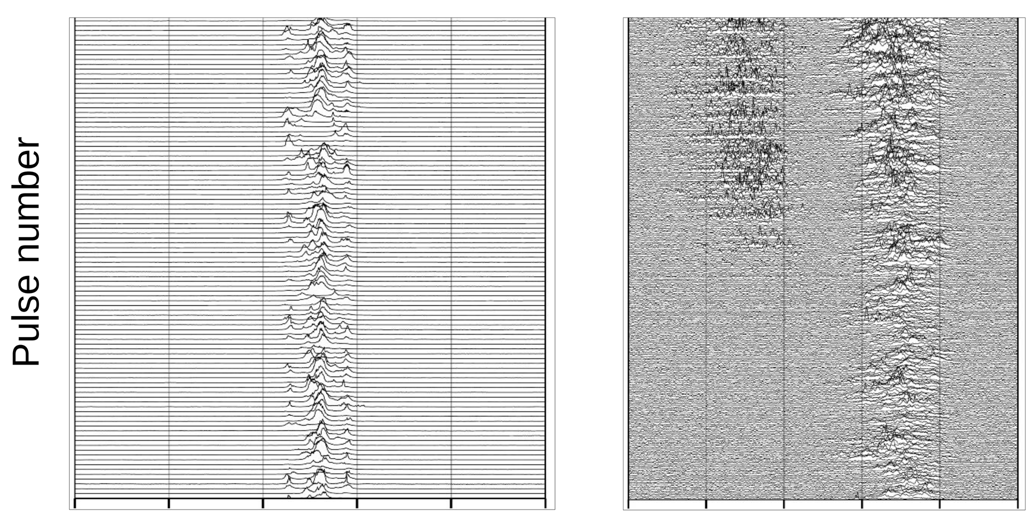
Radio Spectra

- The pulsar radio spectra, i.e. the pulsar pulse-averaged (continuum-equivalent) flux densities versus observed radio frequency, encode the frequency dependence of the radio emission mechanism as well as propagation effects (e.g. absorption) along the line of sight.
- The propagation effects are most prominent at low frequencies (~$\nu^{-4.4}$ to ν^{-2}).
- Using reliable distance measurements (parallax) and information about the emission and beam geometry, the radio spectra allow us to derive the pulsar luminosities, which probe the efficiency of the radio emission process.



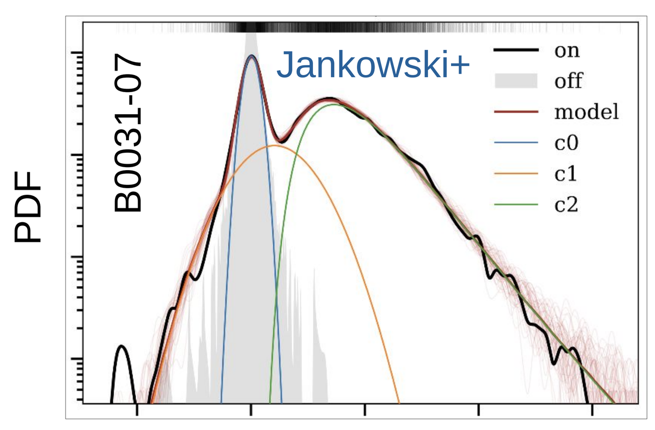
Single Pulse Emission

- While the integrated pulse profiles are considered stable in time, individual pulses (single pulses) from a pulsar vary greatly in amplitude, phase, width, and shape.
- Single pulses trace the pulsar's plasma physical emission process at a more fundamental level and reflect the dynamics of the pulsar magnetosphere.



SP Phenomena & Statistics

- Pulsar magnetospheres exhibit several complex phenomena at the single-pulse level, including quasi-stable plasma configurations (mode switching), systematic marching across pulse phase (sub-pulse drifting), and cessation of pulses for various durations (nulling).



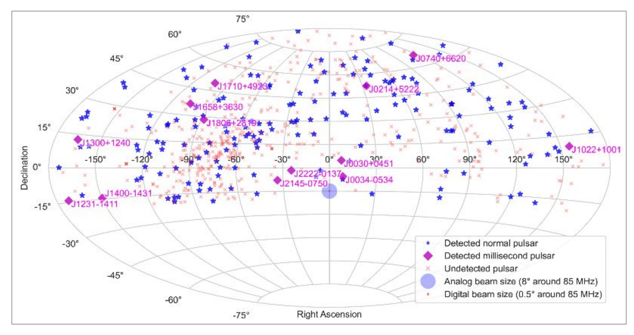
- Single-pulse energy statistics measure modes, nulling, and ISM modulation.
- They relate to the emission process and compare to theory (SGT, SOC).

SKAO Advancements

- Higher instantaneous sensitivity with a significant boost in low-frequency performance (~4x LOFAR HBA, ~20x LOFAR LBA, less after core station deferral).
- Wider frequency coverage and instantaneous bandwidths, quieter RFI environment.
- Pulsar science at low frequencies (LBA - HBA) will receive a huge boost.

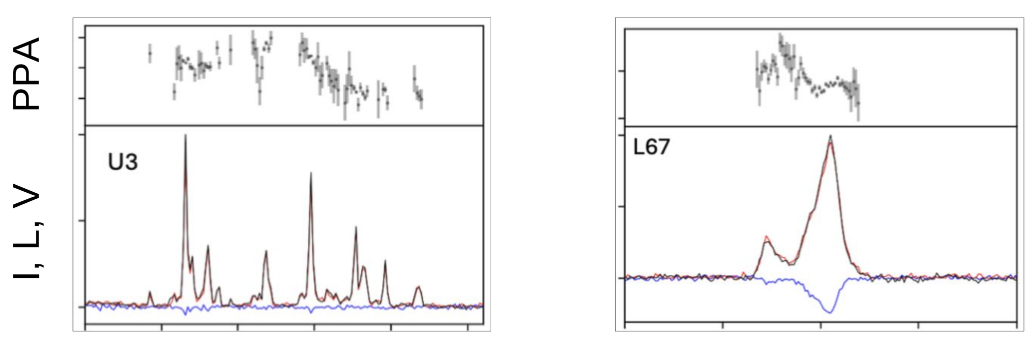
Suggestions for SKA-Low Science Verification

- Target the most northern pulsars (δ ≥ -20 deg) to overlap with NenuFAR and LOFAR coverage.
- Compare the integrated pulse profiles with the LOFAR Census and NenuFAR Census.
- Compare the polarimetry and beam calibration.
- Check how the Milky Way RMs match and that the ionospheric RM contributions are as expected.
- Test the pulsar timing system and verify its clock stability.
- Simultaneous observations with other telescopes.



Links with other Transients

- Although we do not know the progenitors of fast radio bursts (FRBs) yet, magnetospheric emission from extragalactic magnetars is one of the leading theories. NenuFAR FRB programme (Dacoene+), MeerKAT (Jankowski+), CHIME, CHORD (Ng+)
- Similarly, several long-period transients (LPTs) have recently been discovered in the radio. Most of them seem to be white dwarf binaries, while some could still be Galactic neutron stars. NenuFAR LPT monitoring programme & Effelsberg, uGMRT collaborators (Jankowski+)
- Thus, there are strong synergies with other radio transients on the emission physics & progenitor side, and on technique development.



Conclusions

- Pulsar radio phenomenology continues to provide major insights into many areas of fundamental physics.
- SKAO will significantly advance our ability to probe these deeper and across a wider parameter space. Boost at low frequencies.
- Pulsar emission is the key for understanding other radio transients (e.g. FRBs, LPTs).

References

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