Timing Irregularities in Pulsars using uGMRT and ORT

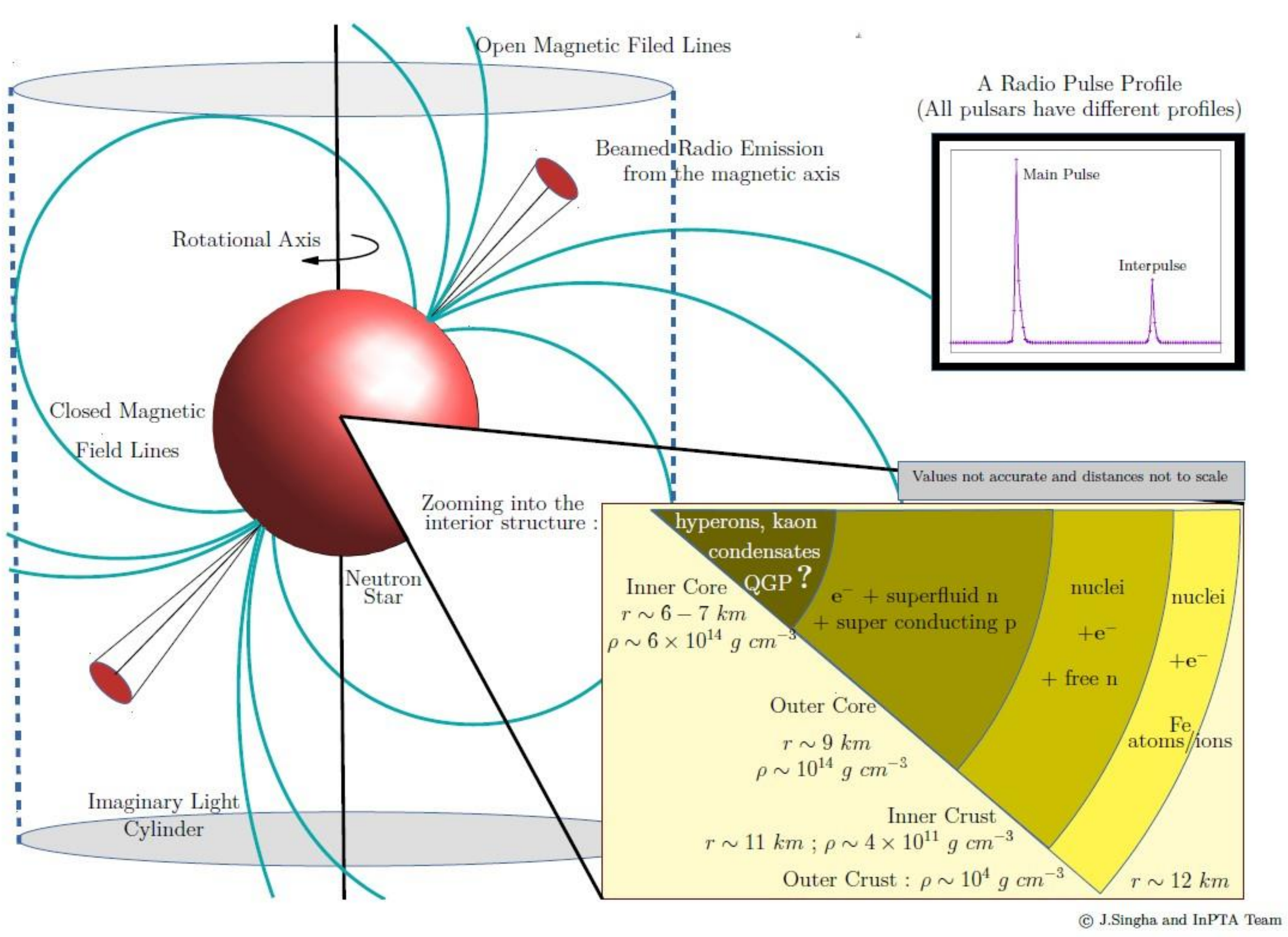
Jaikhomba Singha[1], Bhal Chandra Joshi[2], P. Arumugam[1] and Debades Bandyopadhyay[3]

1. *Department of Physics, IIT Roorkee, India*
2. *NCRA-TIFR, Pune, India*
3. *Saha Institute of Nuclear Physics, Kolkata, India*

Introduction

Pulsars are highly magnetized rotating neutron stars that emit periodic pulses of radiation. The slow-down law of pulsars is generally perturbed by two-timing irregularities: glitches and timing noise. Glitches are the sudden increase in the rotational frequency of pulsars. Glitches are rare. To this date, only 651 glitches in 207 pulsars have been observed. Timing noise is a slow, long term, discernible, stochastic deviation in the periods of pulsars. Several attempts have been made to identify timing noise as a random variation in rotation phase, or slowdown rate, or acceleration. But these specifications requires many years of timing observations because the noise spectrum extends to periodicities of several years. However, it now emerges that at least in some pulsars, or/and perhaps in all, the occurrence is not random. The theoretical understanding of timing noise is still not very clear yet, and it is still a mystery in pulsar astronomy. Glitches are usually observed in young pulsars where timing noise is also very prominent. Both glitches and timing noise are great tools to probe the interior of the neutron star. This poster presents the status of our monitoring program to study irregularities in pulsars using the upgraded Giant Meterwave Radio Telescope (uGMRT) and Ooty Radio Telescope (ORT).

Pulsar Glitches and the interior structure of neutron star



Neutron Stars have very complicated interior with varying composition as a function of density. Glitches are the direct probes to the interior of neutron stars. The most accepted model presently relies on superfluid vortices and their dynamics. Superfliuidity exist inside the neutron star as the interior temperature is around 10^7 K. The interior superfluidity leads to a differential rotation. Hence, a large amount of angular momentum gets stored. Whenever this angular momentum is released, the crust spins up to produce a glitch. Timing noise is assumed to arise because of the coupling of pinned and co-rotating crustal superfluid with varying pinning strength to the observed crust, magnetospheric torque fluctuations, superfluid turbulence, etc.

Indian Radio telescopes

We monitor a sample of 20+ glitching pulsars using the ORT and the uGMRT, both of which have produced significant results over the years.

The ORT:

- 530-metre (1,740ft) long and 30-metre (98ft) tall cylindrical parabolic antenna.
- Latitude ~ 11 degrees.
- Operational frequency: 326.5 MHz with a 15 MHz usable bandwidth.
- SInce it operates at a very low frequency we monitor most of the low DM pulsars of our sample using ORT.

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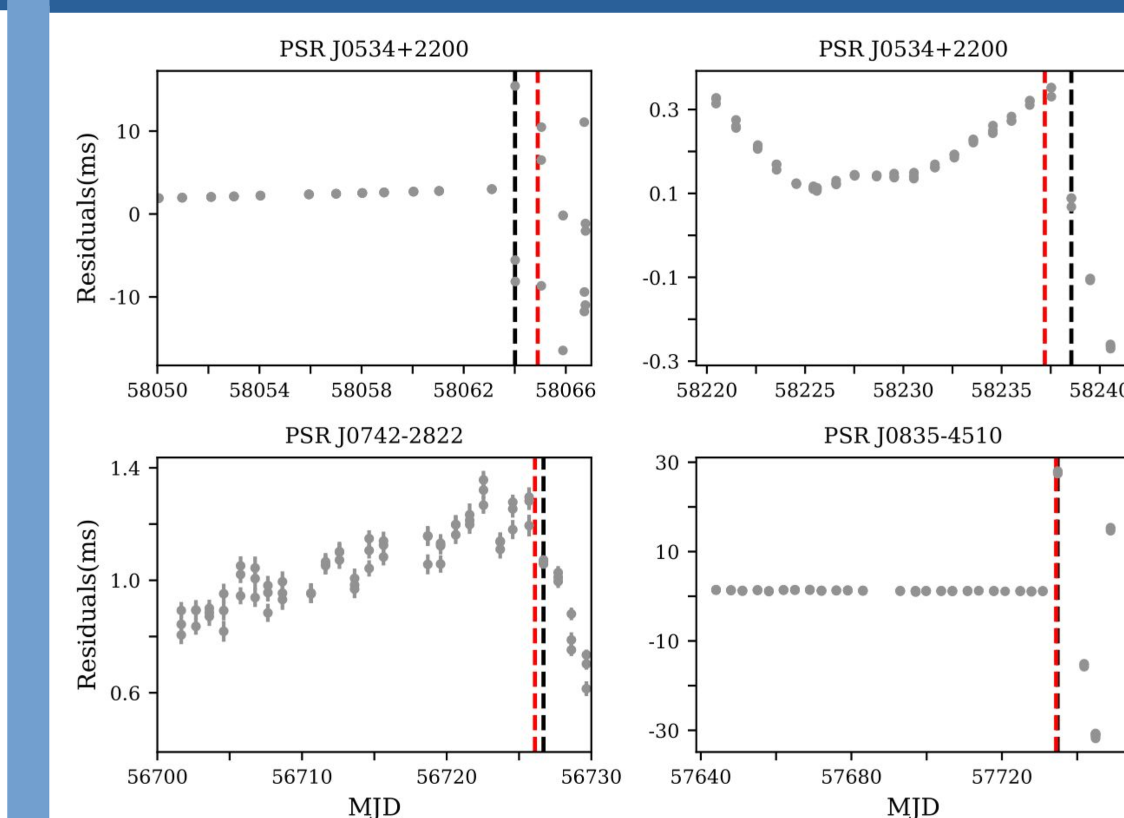
The uGMRT:

- Interferometric array with baselines of up to 25 kilometers. It consist of 30 antennas. 14 in central square kilometer region and the rest are distributed in Y-shaped array.
- Each antennas is a parabolic reflector with a diameter of 45 meters.
- Has 4 observation bands:
  - Band 2: 120 – 240 MHz
  - Band 3: 250 – 500 MHz
  - Band 4: 550 – 850 MHz
  - Band 5: 1050 – 1450 MHz
- We have divided our sample in two groups based to be observed in Band 4 and Band 5.

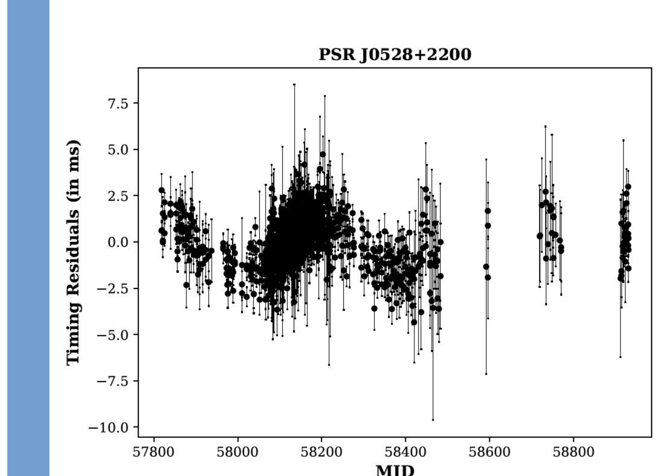
Status of monitoring program



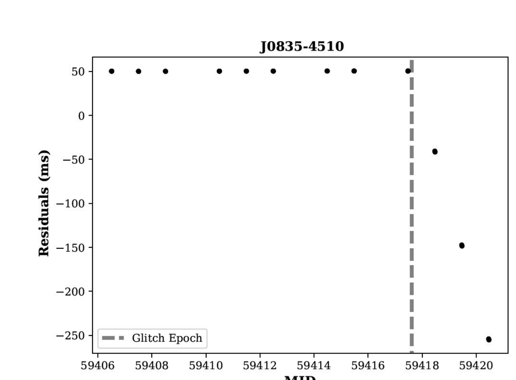
AGDP tested on real glitch data

Automated Glitch Detection Pipeline (AGDP) is a real time pipeline developed to detect glitches and send alarm to the observers. This pipeline has been implemented for a sample of pulsars at the Ooty Radio Telescope (ORT). The pipeline is optimised with proper timing noise parameters for particular pulsar.

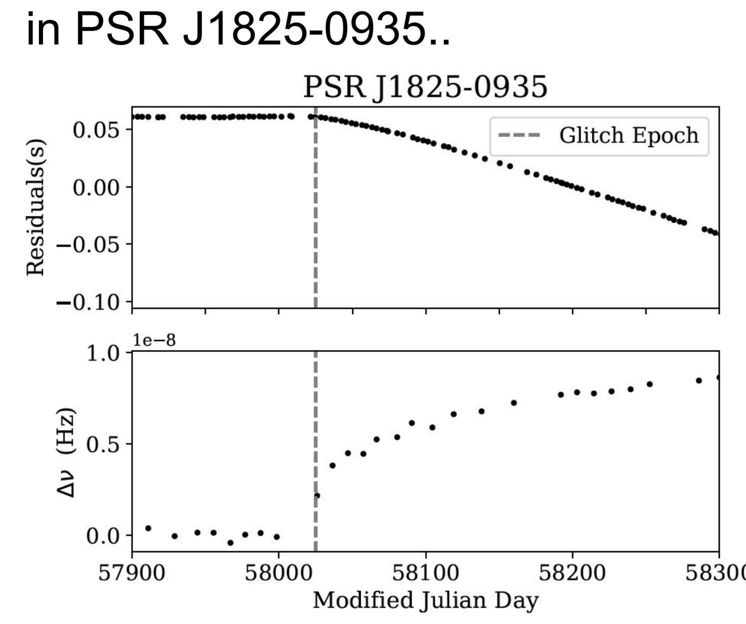
Detection of Glitches : The glitch monitoring programs using the uGMRT and ORT have already produced good results. The first results of this monitoring program were reported in Basu et al. (2019) presenting 11 glitches in 8 young pulsars. We have further detected around 12 more glitches. We have also detected a slow glitch, characterised by delayed rise time, in PSR J1825-0935..



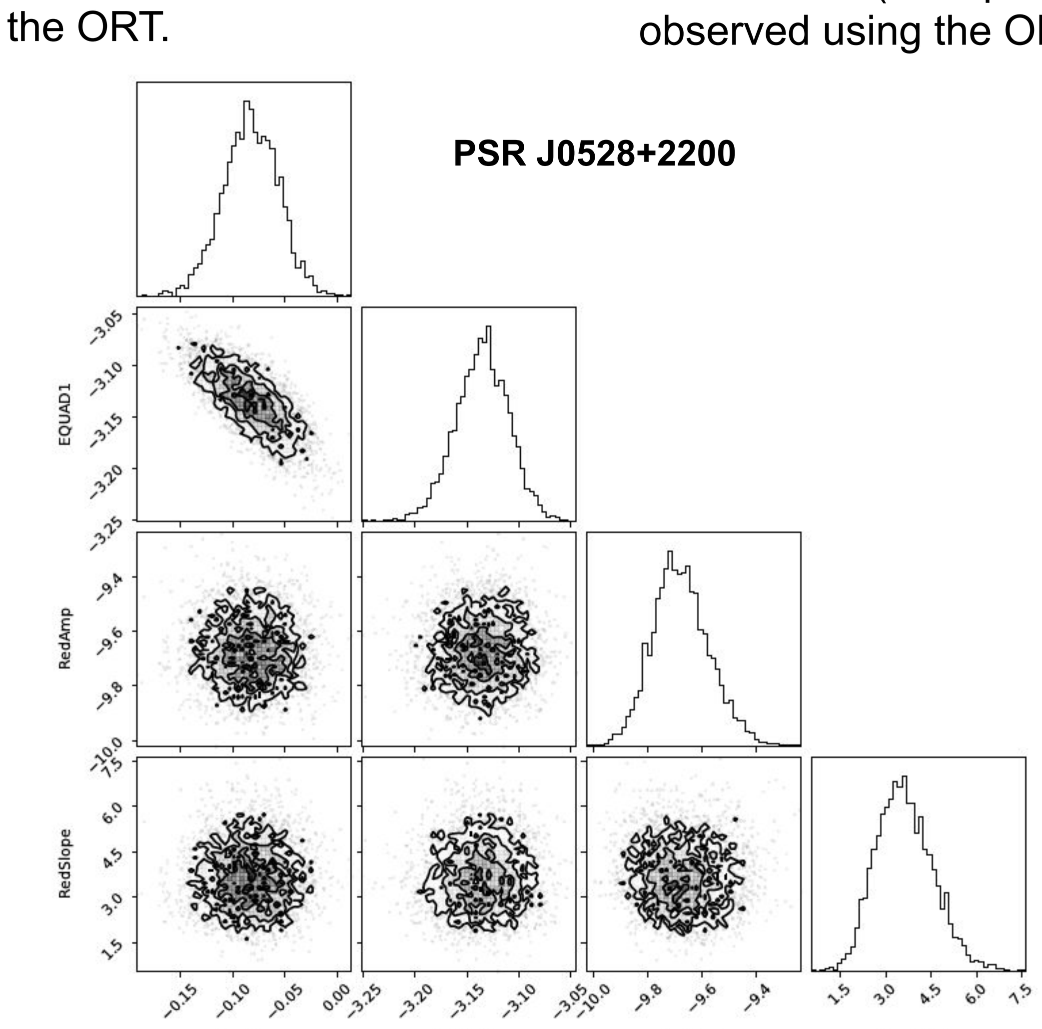
The timing residuals of pulsar J0528+2200 observed with the ORT.



A glitch seen in PSR J0835-4510 (Vela pulsar) observed using the ORT.



A slow glitch seen in PSR J1825-0935. The upper plot shows the timing residuals and the lower plot represents the frequency evolution during the glitch.



The posteriors obtained using TempoNest, a Bayesian analysis software which uses MultiNest to perform nested sampling and obtain the timing noise parameters. Here EFAC1 and EQUAD1 are the white noise parameters and RedAmp and RedSlope are the red noise amplitude.

Timing Noise Studies: We have also characterised timing noise in the sample of pulsars observed using the same data collected for glitch detection. Timing noise can be modelled as red noise processes, and its power spectrum density is given as

$$P(f) = \frac{A_{red}}{12\pi^2}(1/f)^{-\beta}$$

where A_{red} is the red noise amplitude and ß is the index.

Towards future telescopes like SKA: The uGMRT due to its seamless coverage of a broad frequency range, large bandwidth, multiple frequencies of operation and high sensitivity phased array capabilities have been given the status of SKA-pathfinder. Because of the successful run of out monitoring prgram at uGMRT and ORT, we can actively participate in such programs with the upcoming SKA.Optimal observing strategies developed for the uGMRT along with AGDP can be implemented in observations with SKA..

References

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