Emission variations in some millisecond pulsars

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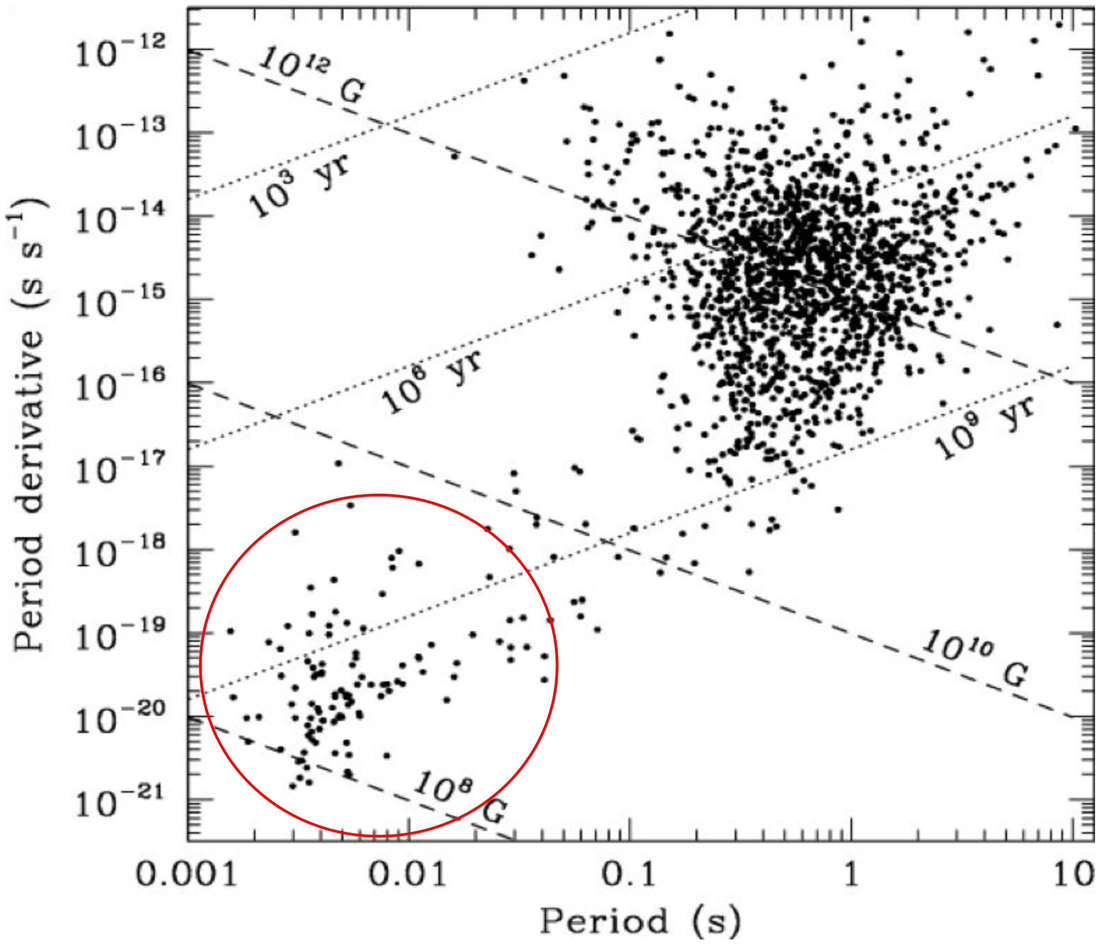
Outlines

- Background
- Some millisecond pulsars
- Summary

Background

Millisecond pulsar

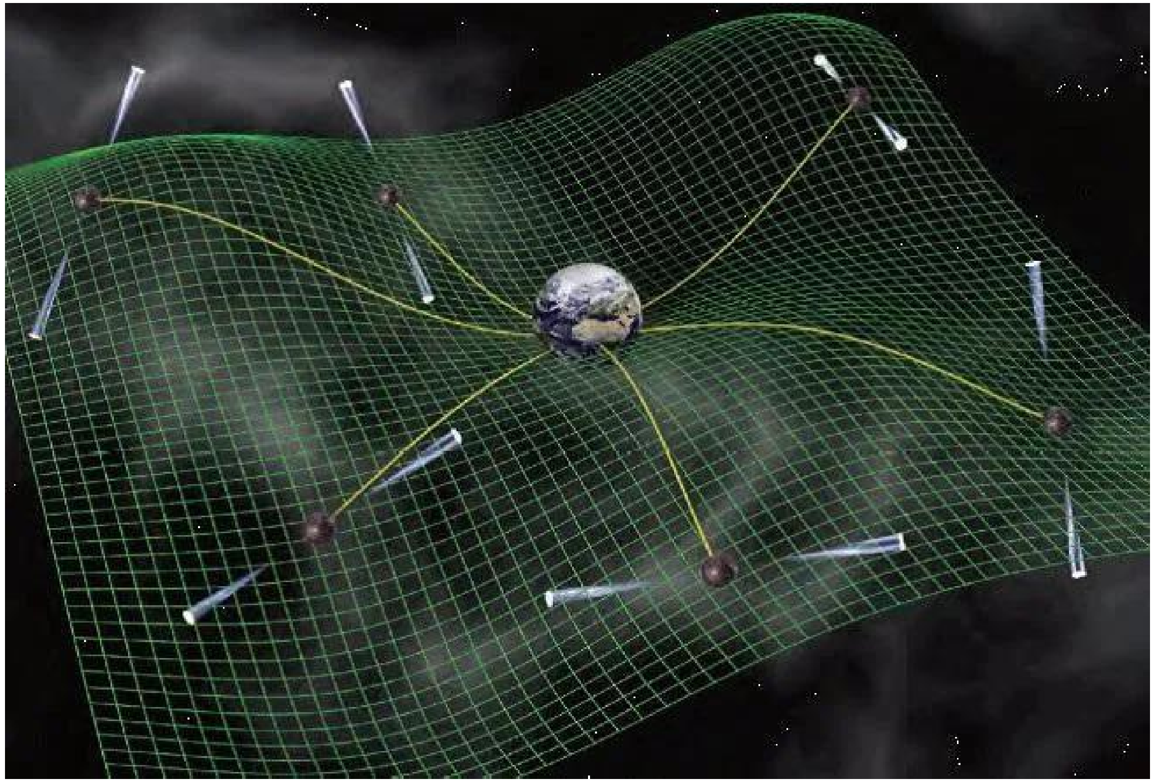
- Discovered at radio waveband (PSR B1937+21) by Arecibo with the spin period of several milliseconds (Backer et al. 1982)
- Most radio MSPs are in binaries, 30% are isolated
- Spun-up ("recycled") by accretion in LMXBs (Alpar et al. 1982)



Background

Pulsar timing array

- Detect nanohertz gravitational waves by monitoring pulse times of arrival (ToAs) of an ensemble of the most stable MSP.
- The success of this experiment strongly depends on the achievable timing precision.



Background

Noises on short timescales

- ToA uncertainties on short

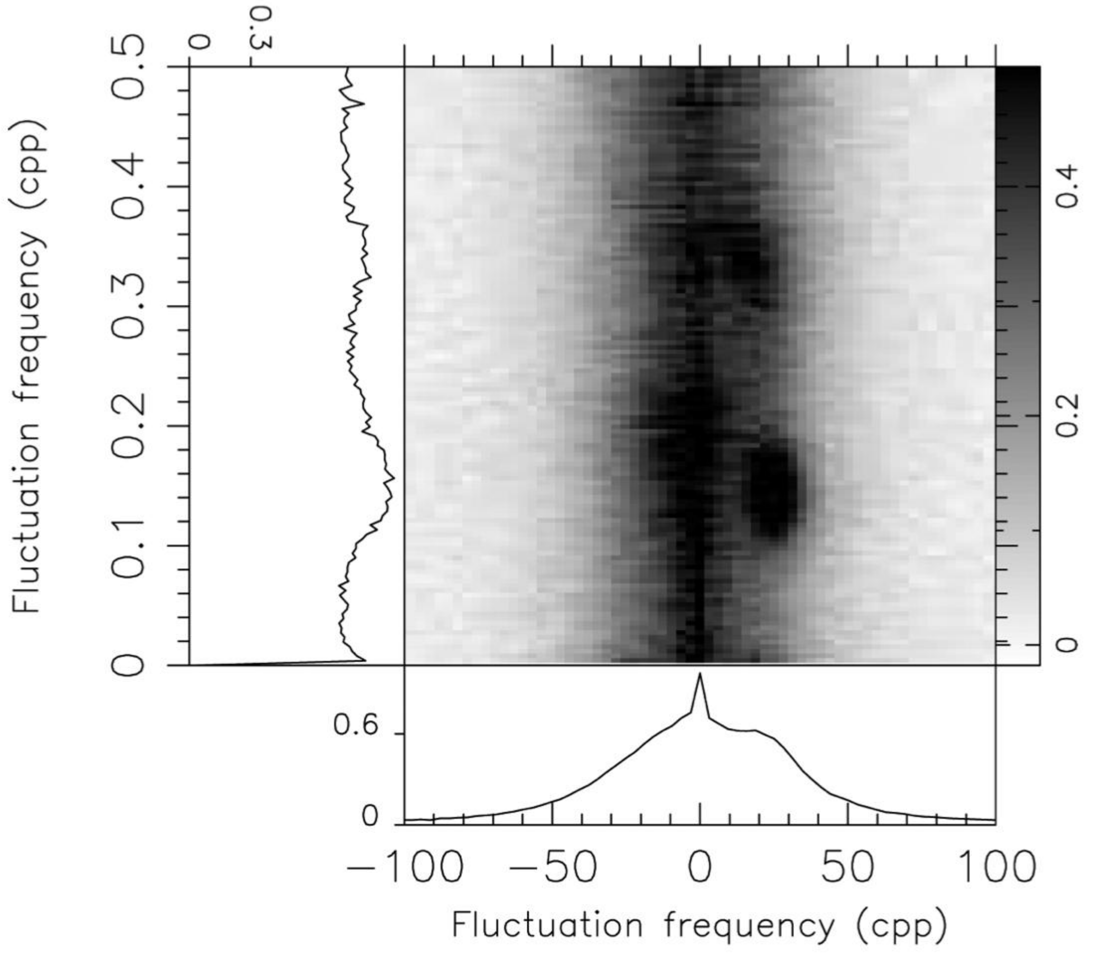
$$\sigma_{\rm total}^2 = \sigma_{\rm rm}^2 + \sigma_{\rm J}^2 + \sigma_{\rm scint}^2 + \sigma_0^2$$

- the uncertainties induced by radiometer noise, jitter noise, instability of short-term diffractive scintillation and all other possible contributions
- Jitter noise: intrinsic single pulse shape and phase variation.
- For highly sensitive radio telescopes, such as FAST, jitter noise expected to be dominant especially for bright pulsars.
- Jitter noise studies can provide a fundamental limit on the achievable timing precision on short timescales.

Emission variations in short timescale

Sub-pulse drifting

- Millisecond pulsars are very weak.
- Diffused sub-pulse drifting/periodical amplitude modulation have been detected in some millisecond pulsars (Edwards & Stappers 2003).
- Such as PSR J1713+0747 with P3 of 6.9 ± 0.1 P and 2.9 ± 0.1P (about tens of milliseconds).

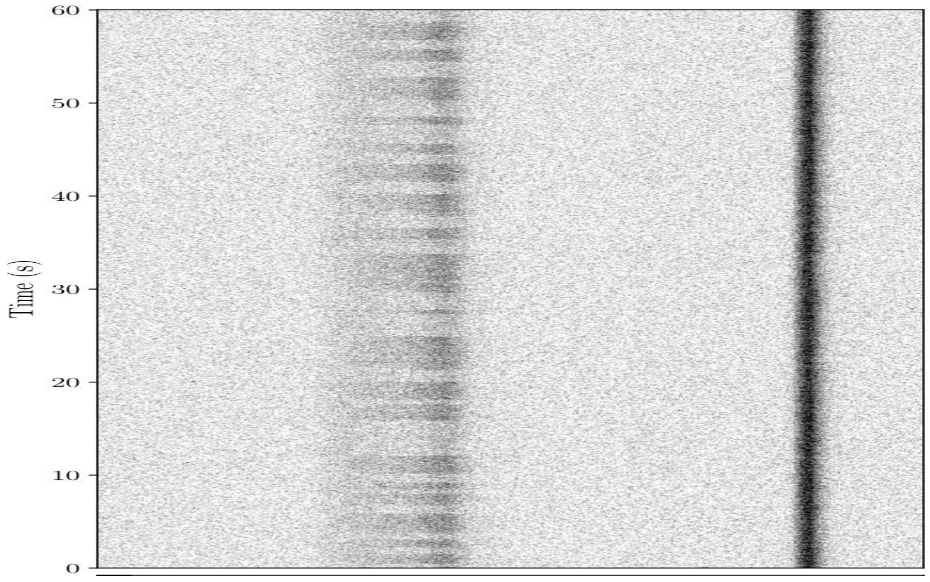


Liu et al. (2016)

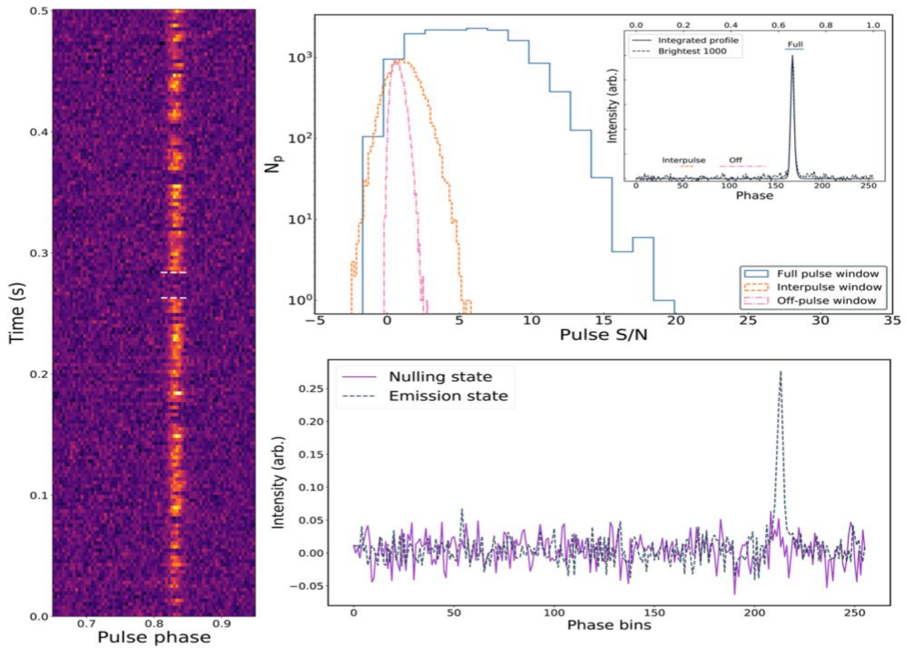
Emission variations in short timescale

Nulling and mode changing

- Mode changing was only seen in one millisecond pulsar, PSR B1957+20, with duration of several seconds, Arecibo (Mahajan et al. 2018).



- Nulling has been detected in PSR J1909-3744 by Meerkat with duration of several hundred milliseconds (Parthasarathy et al. 2021)



FAST observations

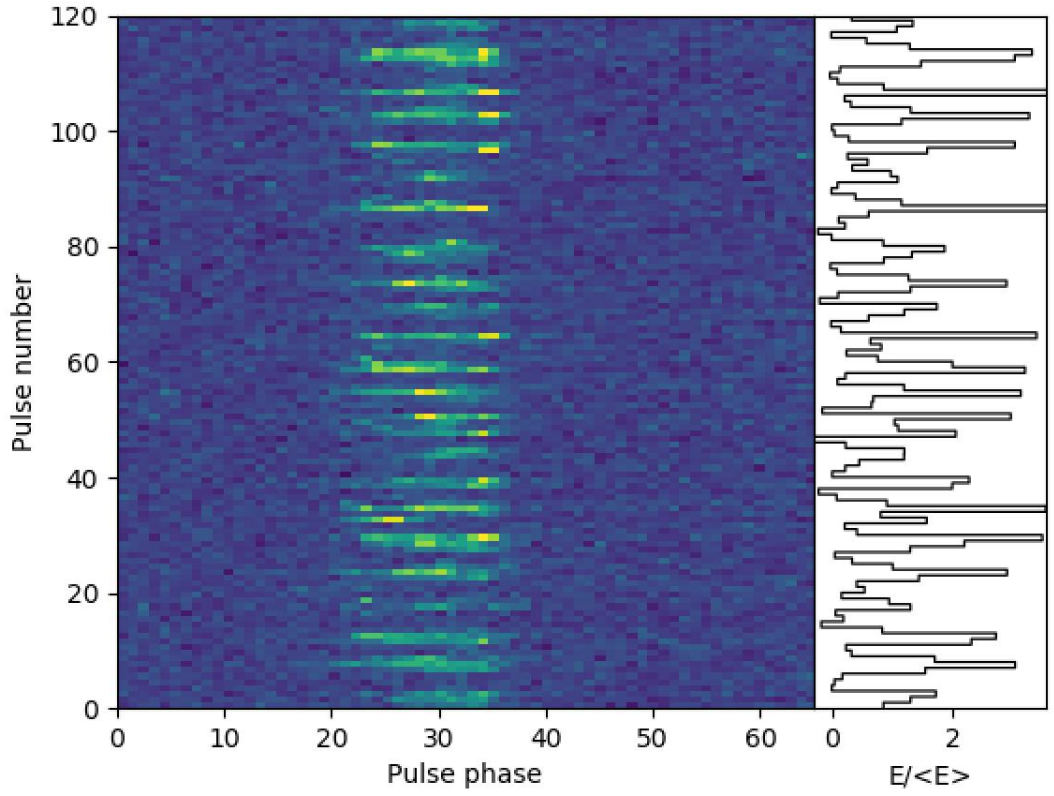
- The central beam of the 19-beam receiver with the bandwidth 1.05−1.45 GHz.
- The number of the frequency channels is 4096 with the channel band-width 0.122 MHz and the sampling time is 49.152μs. The data were recorded in a search mode PSRFITS file.

Pulsar	Project id	Observation date	Duration time (s)	Observation mode
J0621+1002	3062	20200114	1620	Search
J0636+5129	PT2020_21	20200917	1140	Baseband
J0030+0451	ZD2020_6	20210221	1800	Search

Three millisecond pulsars

PSR J0030+0451

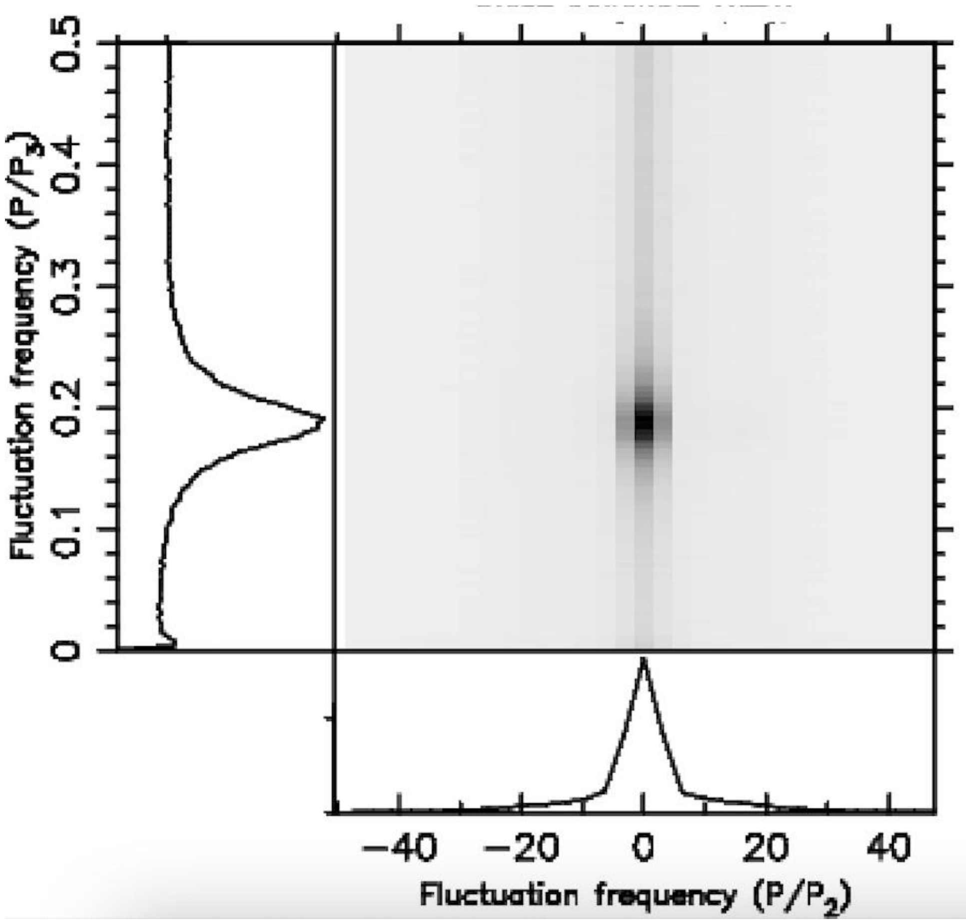
- A pulse stack of 120 single pulses.
- This pulsar shows a periodical pulse intensity modulation.



PSR J0030+0451

Periodical modulatiuons

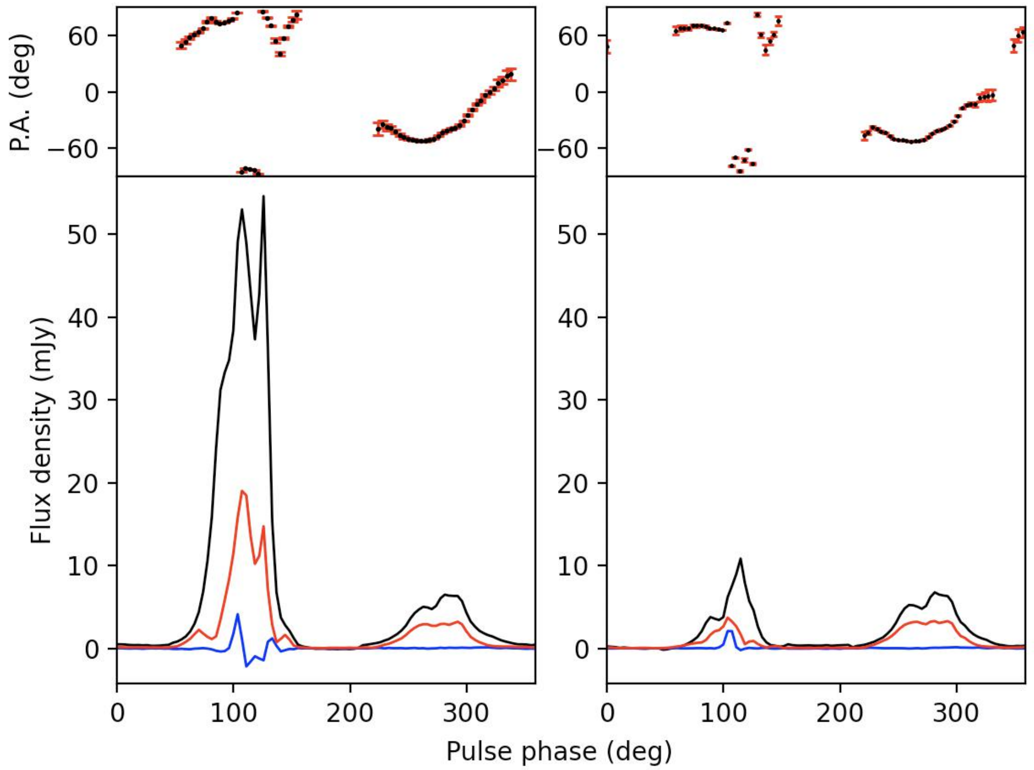
- 2DFS analysis with side panels showing horizontally (left) and vertically (bottom) integrated power.
- P3=5.21+- 0.02 P0 ~ 25 ms, which has the shortest mode-cycle time.
- The first periodical mode changing MSP.



PSR J0030+0451

Mode changing

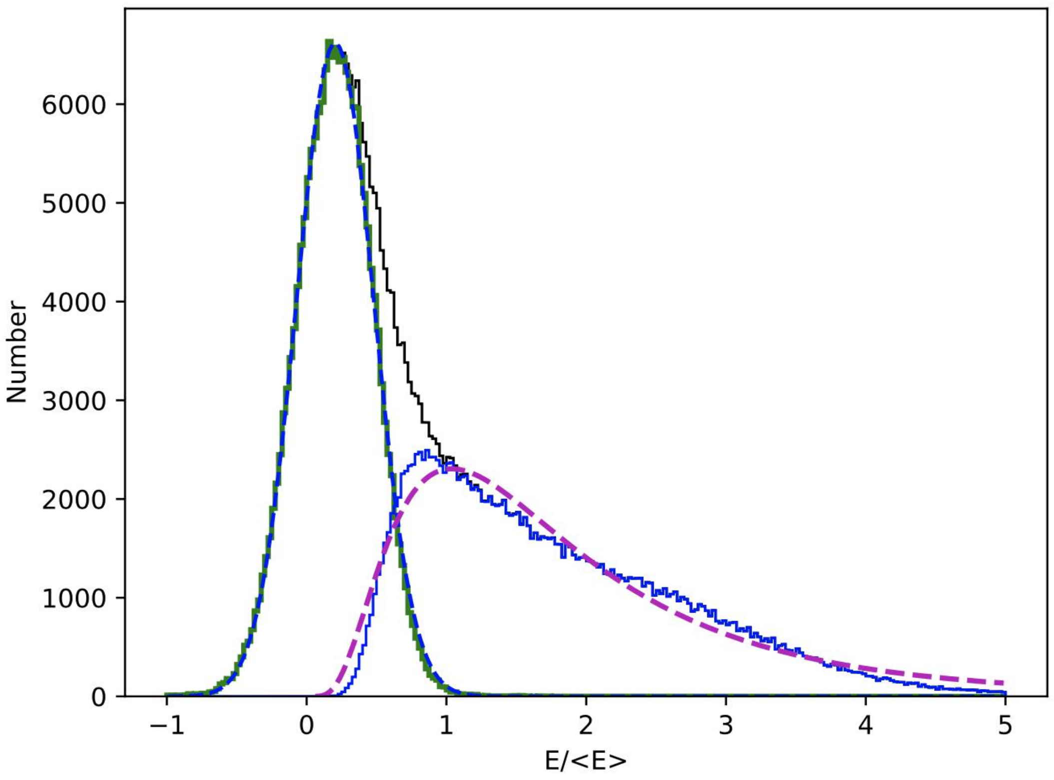
- The average profiles are different and that of the bright mode are brighter than that of the weak mode.
- The inter-pulse profile shapes for the two mode are almost the same, as well as the fractions of the linear and circler polarizations.



PSR J0030+0451

Energy distributions

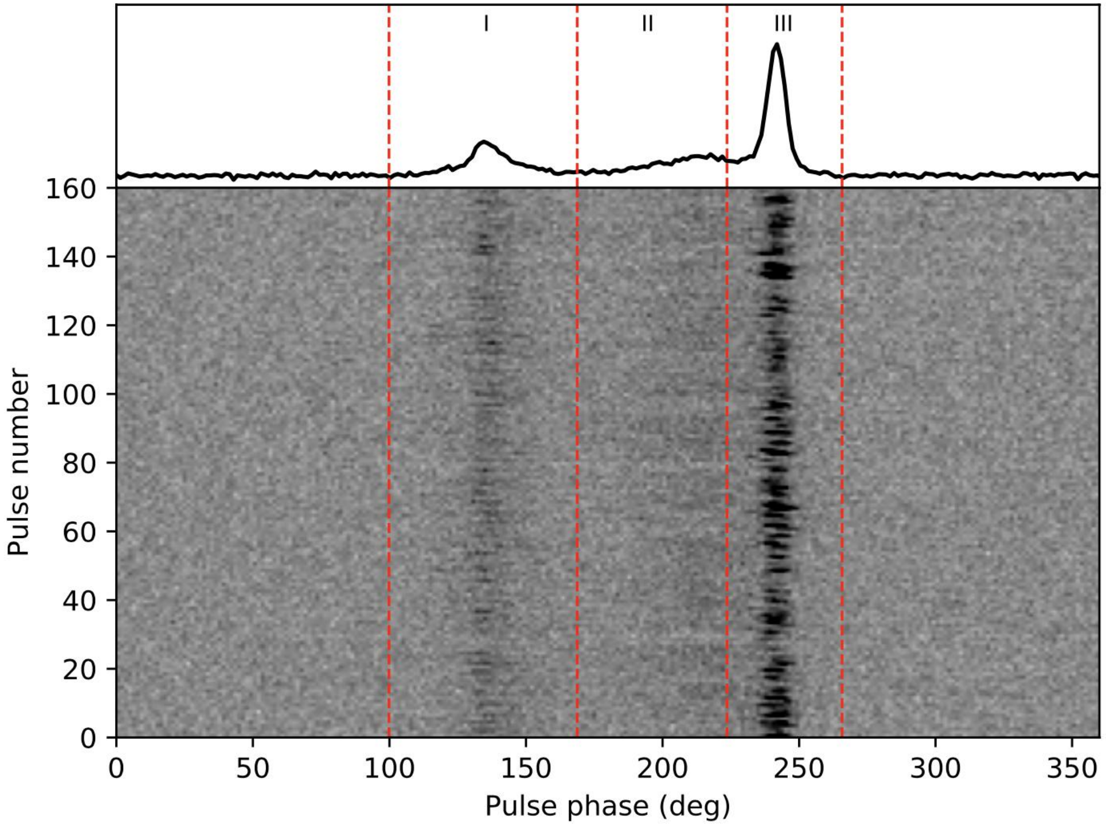
- The black, green and blue lines are for the energies of normalized on-pulse window, weak and bright modes, respectively.
- The energy of the weak and bright modes follow Gaussian and log-normal distributions.



PSR J0621+1002

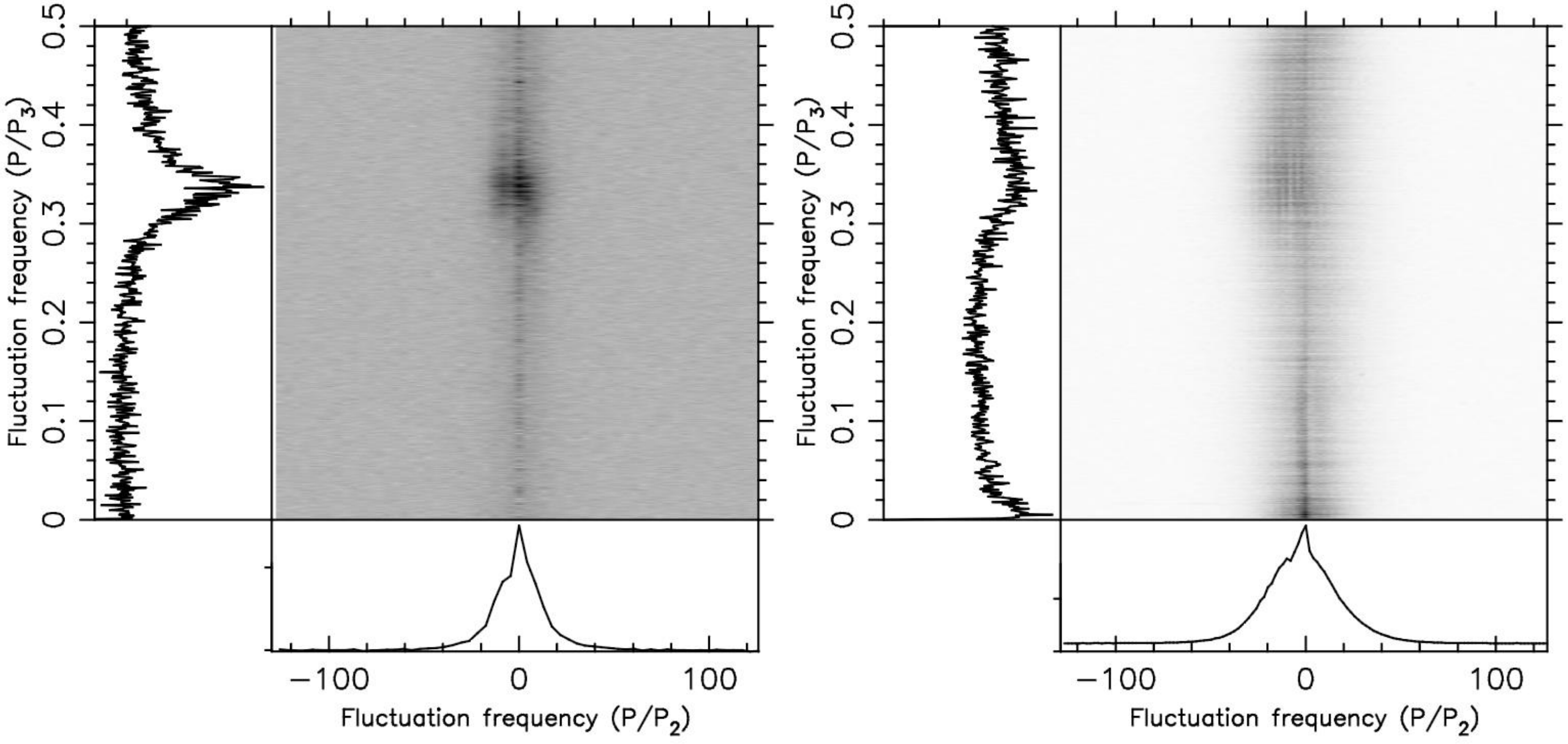
Single pulses

- The average pulse profile is shown in upper panel and the pulse profile is divided into three components (labeled as I, II and III) by the four vertical red lines.
- This pulsar shows a pulse intensity modulation in both the first and the third pulse components.



PSR J0621+1002

Periodical modulatiuons

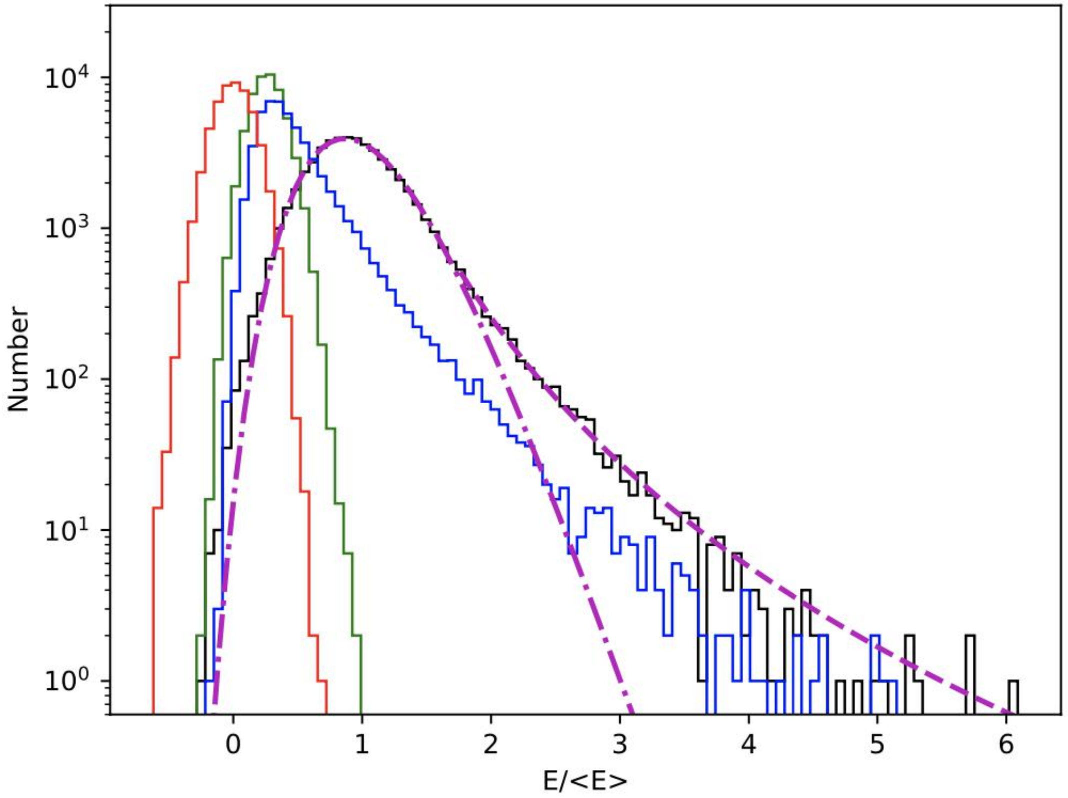


- The 2DFS analysis for the first (upper left) and third (upper right) pulse components.
- P3_1=3.0 spin periods, P3_3=3.0 and 200 spin periods, P2=0.

PSR J0621+1002

Energy distributions

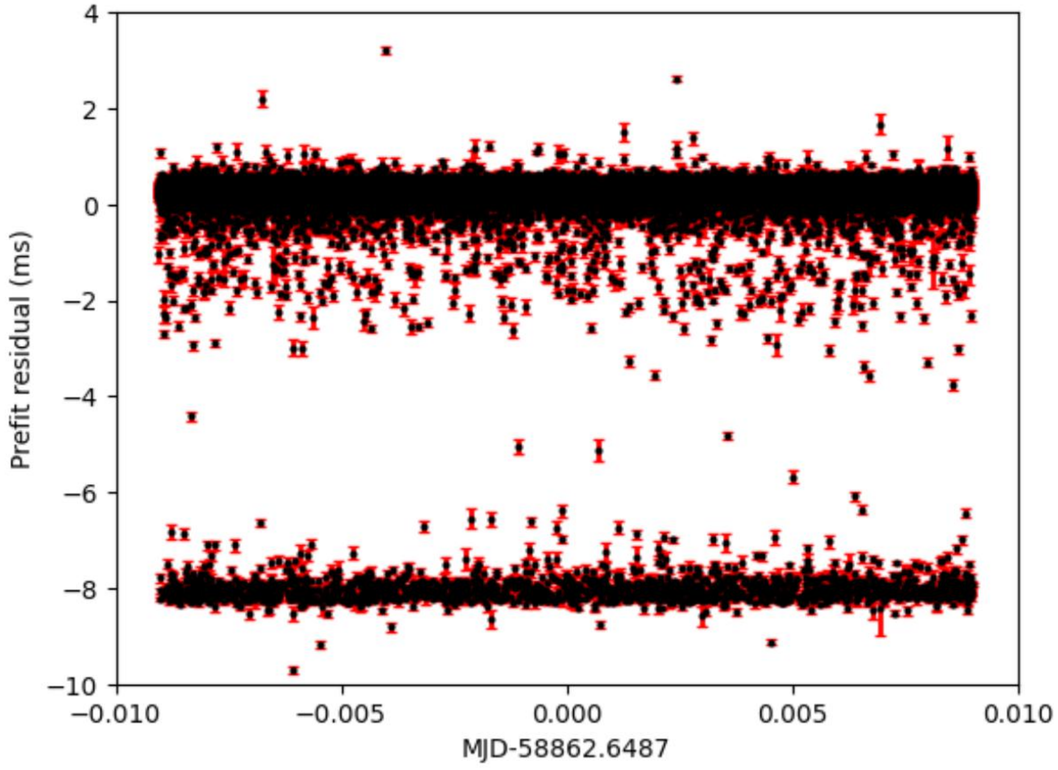
- The red, black lines are for the energies of off-pulse window, on-pulse window, respectively.
- The energy of the on-pulse is a log-normal distribution with a high-energy power-law tail (the magenta dashed and dash-dotted lines).



PSR J0621+1002

Single pulse timing

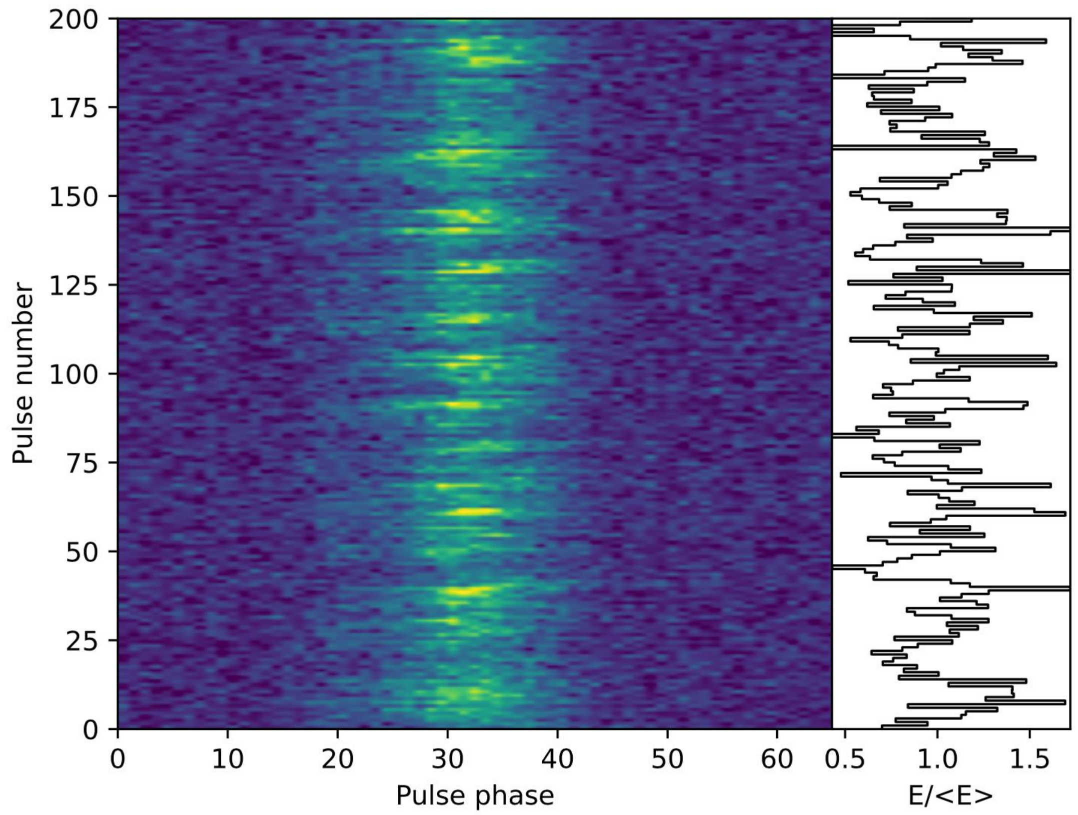
- The timing residuals are divided into two classes (different modes of jitter noise), named as class A and class B.
- The number of pulses in class A and class B are 52429 and 1637, respectively.
- This is not the mode changing in pulsars.



PSR J0636+5129

Pulses stack

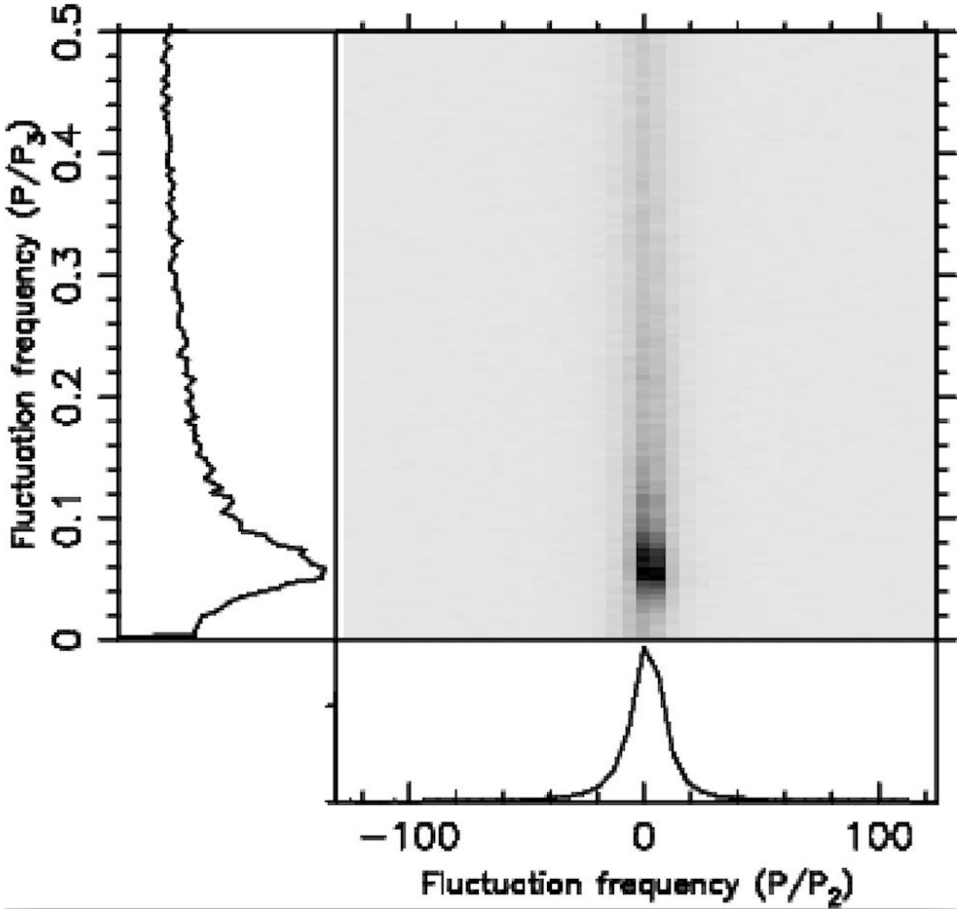
- A pulse stack with the sub-integration of 5 single pulses.
- This pulsar shows a periodical pulse intensity modulation.



PSR J0636+5129

Periodical modulations

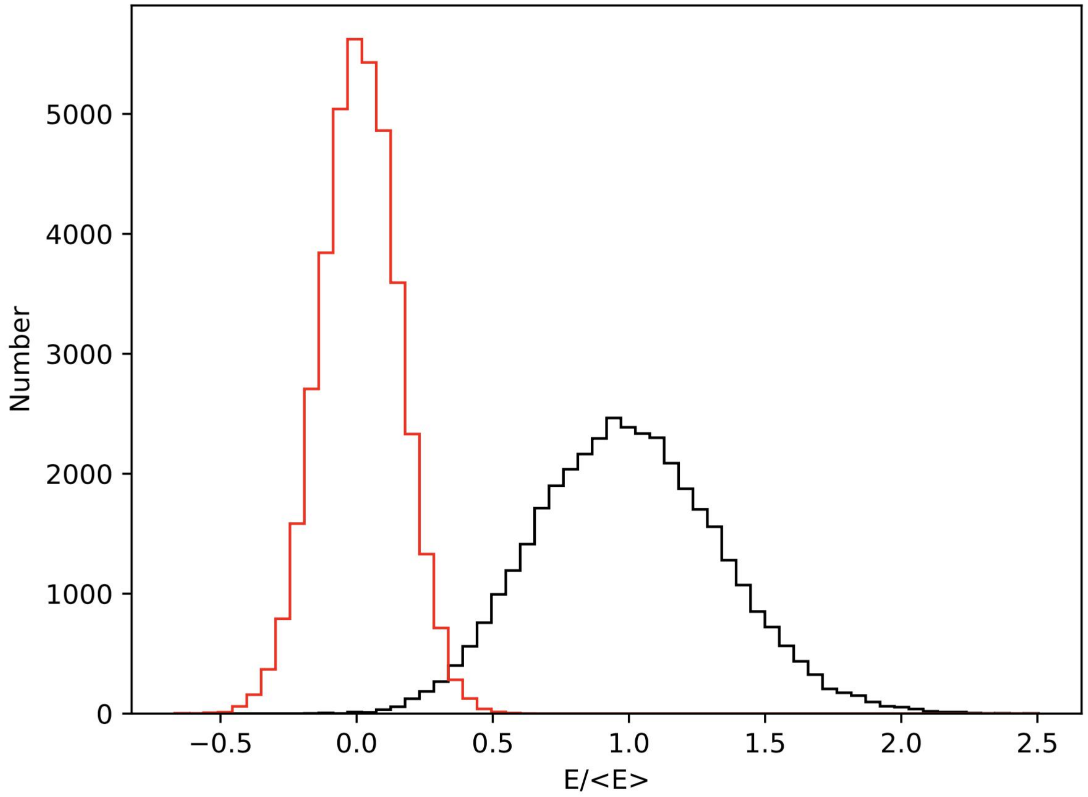
- 2DFS analysis with side panels showing horizontally (left) and vertically (bottom) integrated power.
- P3=17.3 +- 0.1P0 ~ 248ms



PSR J0636+5129

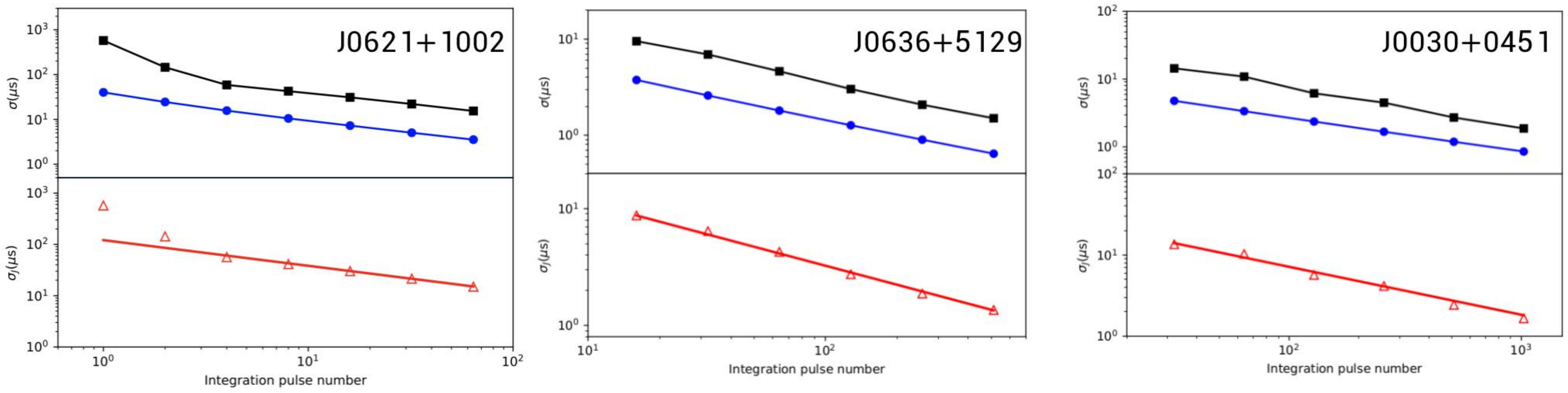
Energy distributions

- The red and black lines are for the energies of off-pulse window, on-pulse window and on-pulse window, respectively.
- The energy of the on-pulse follows a simple Gaussian distribution, rather than two peaks.



Jitter noise

➢ The quadrature difference between the rms timing residuals and ToA uncertainties.



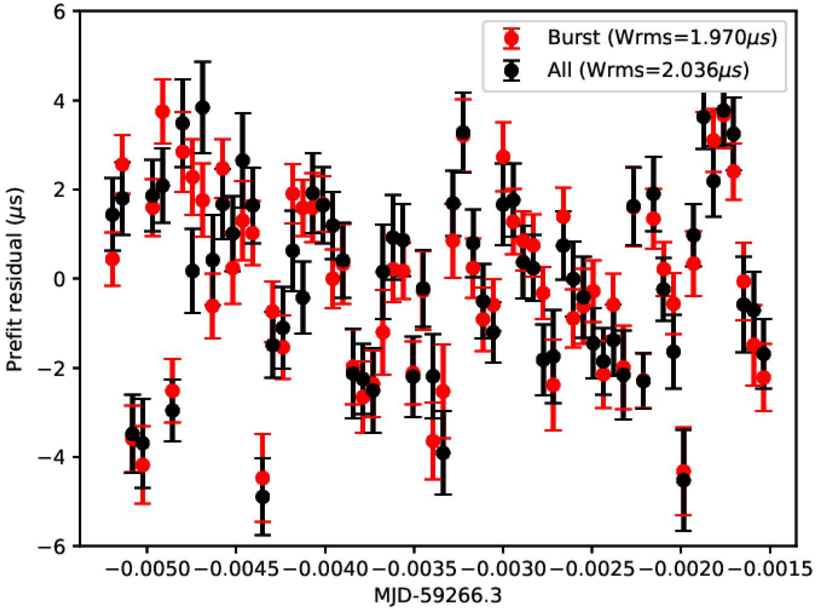
σ_J (1 hr) = 510ns.

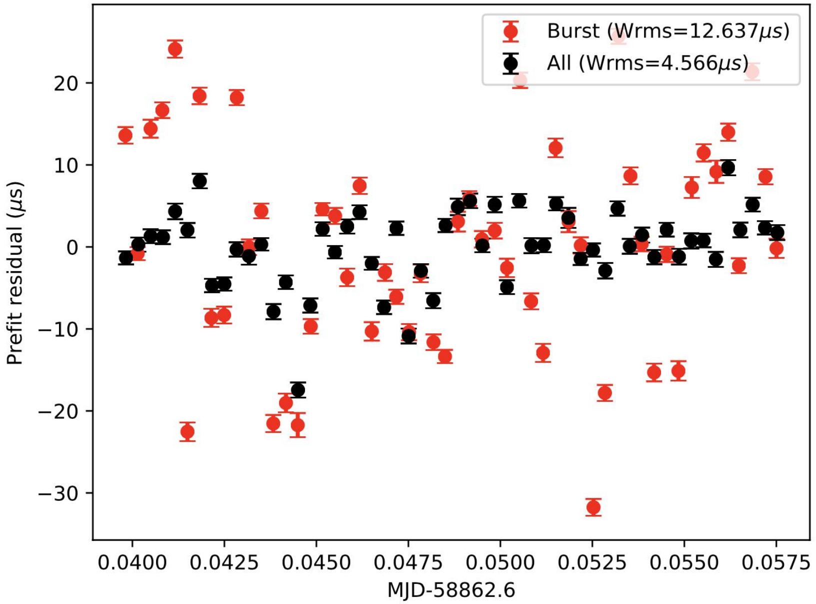
σ_J (1 hr) = 34ns.

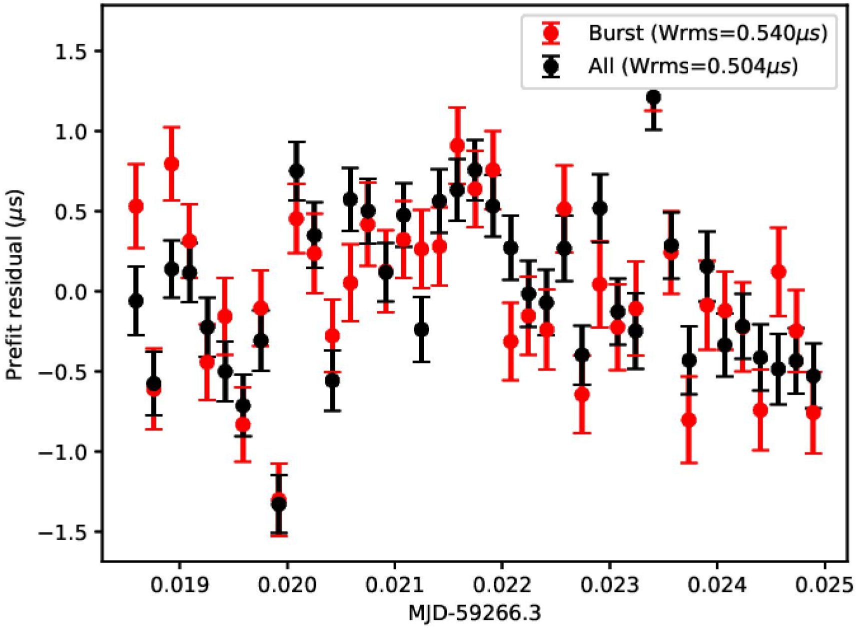
σ_J (1 hr) = 126ns.

Timing using a sub-set of pulses

Timing rms values





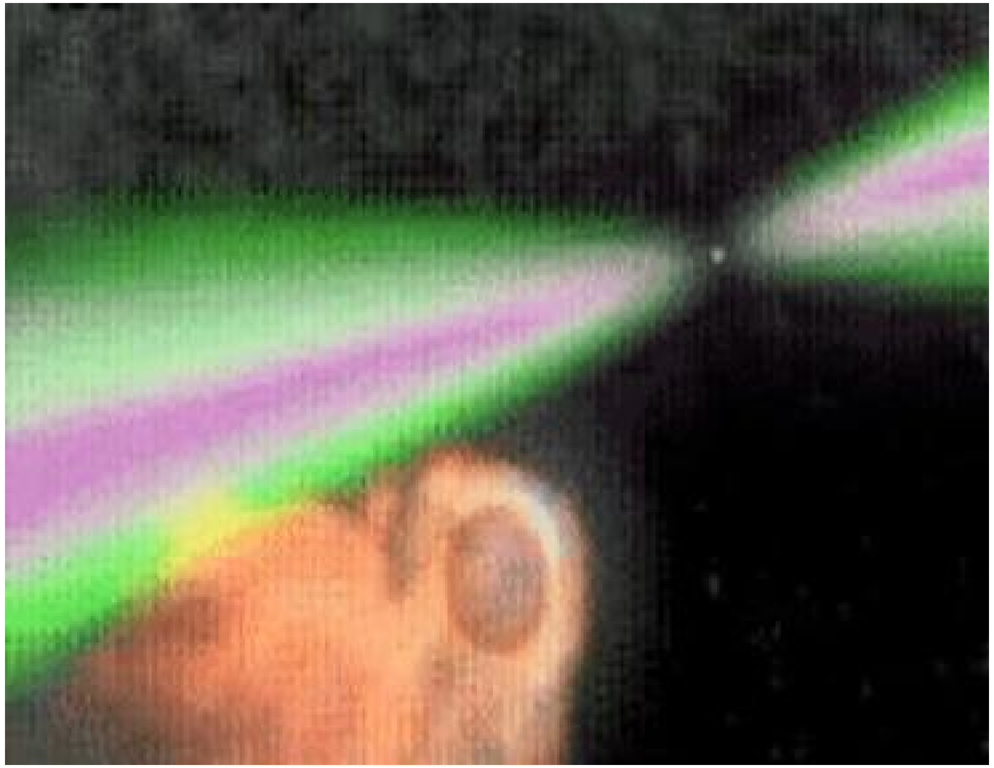


- The timing precision impooved about 1% for PSR J0030+0451
- No improvements in timing precision were found for PSR J0621+1002 and PSR J0636+5129.

Binary evolution

Spider pulsars

- Redbacks (RBs) and black widows (BWs) are subpopulations of MSPs in close binary systems.
- The companion masses of RBs: 0.2 ~ 0.4$M_\odot$, BWs: 0.02 ~ 0.05$M_\odot$
- The high energy emission of the pulsars irradiate the companions.
- Radio eclipse.

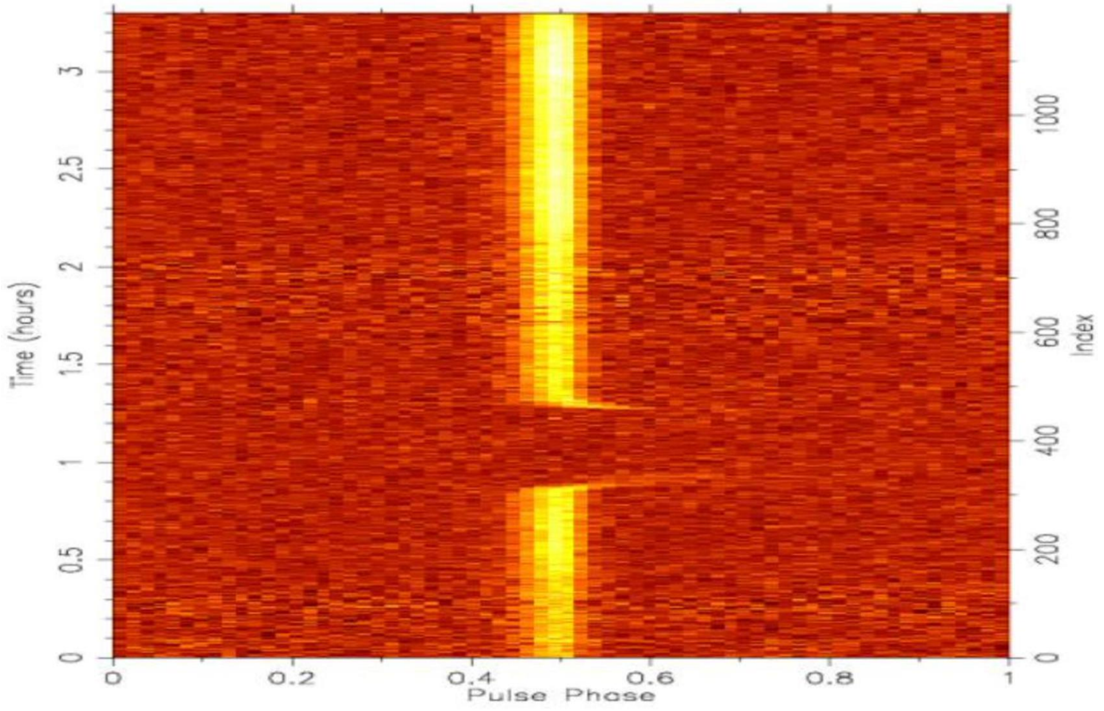


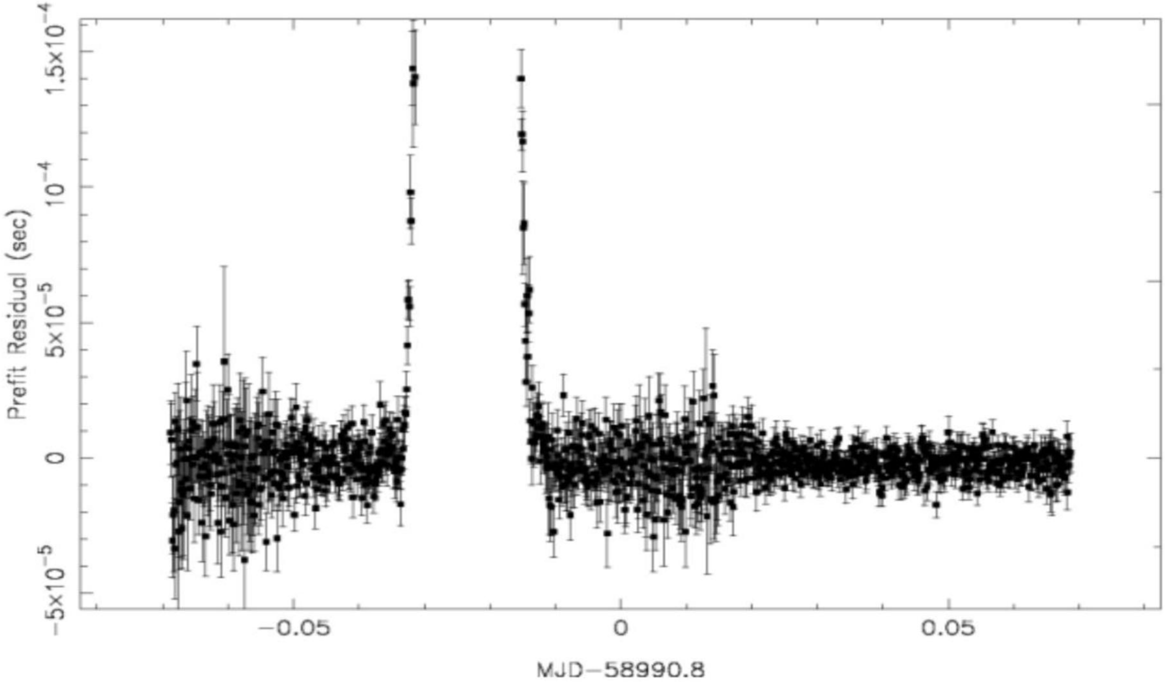
The predecessor of isolated MSP!!!

19C13

Black widow!!!

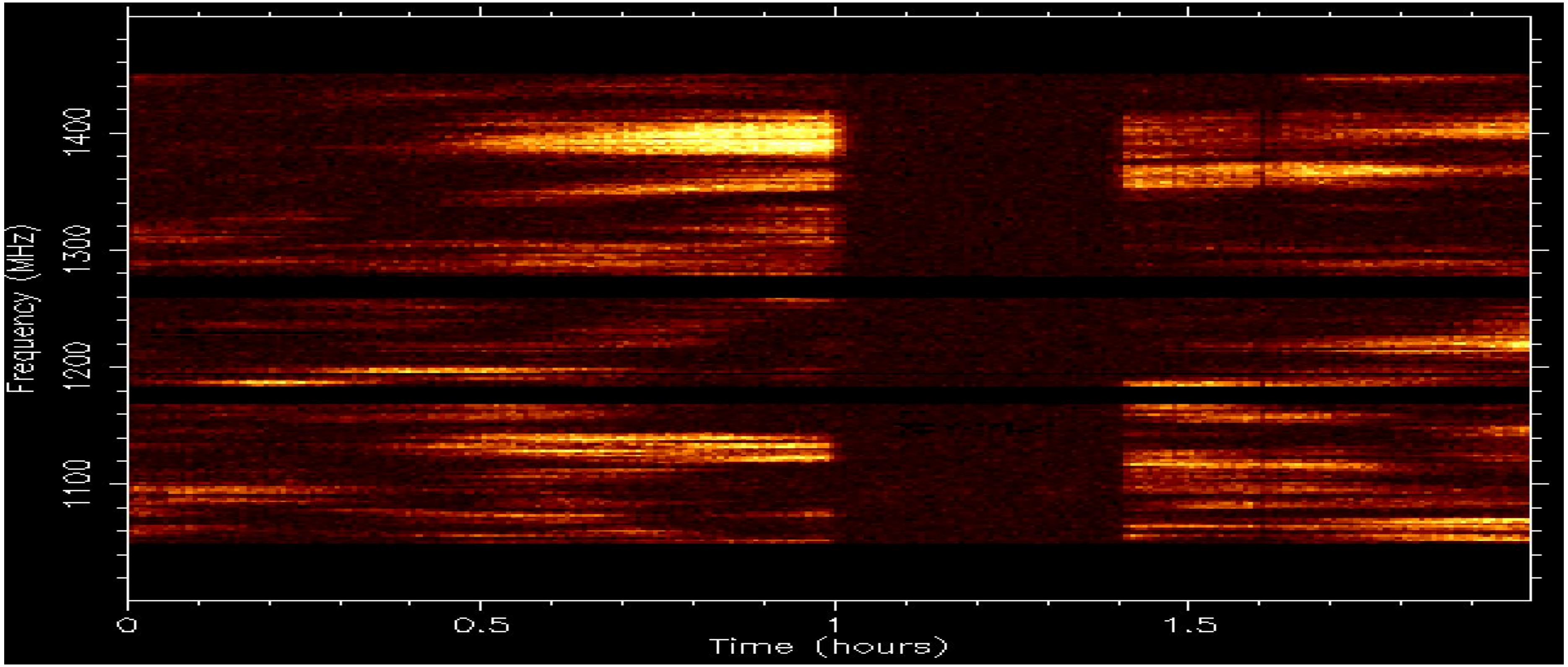
- The thirteenth pulsar that discovery in CRAFTS, comfirmed to be a black widow by ZD2020_6.
- Spin period 3.26 ms, Orbital period 3.16 hr.
- Companion mass 0.034 solar mass.
- Radio eclipse .



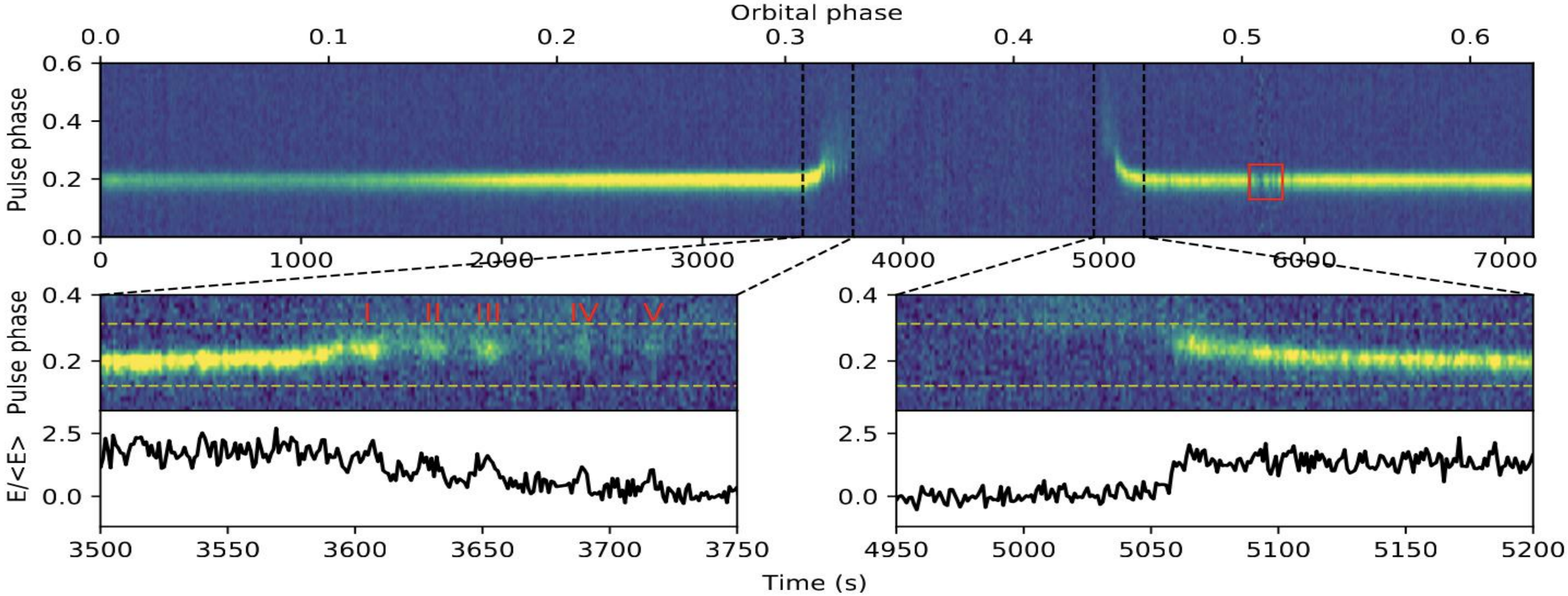


19C13-follow up: PT2020_0022

Scintillation maximum during the eclipse



19C13

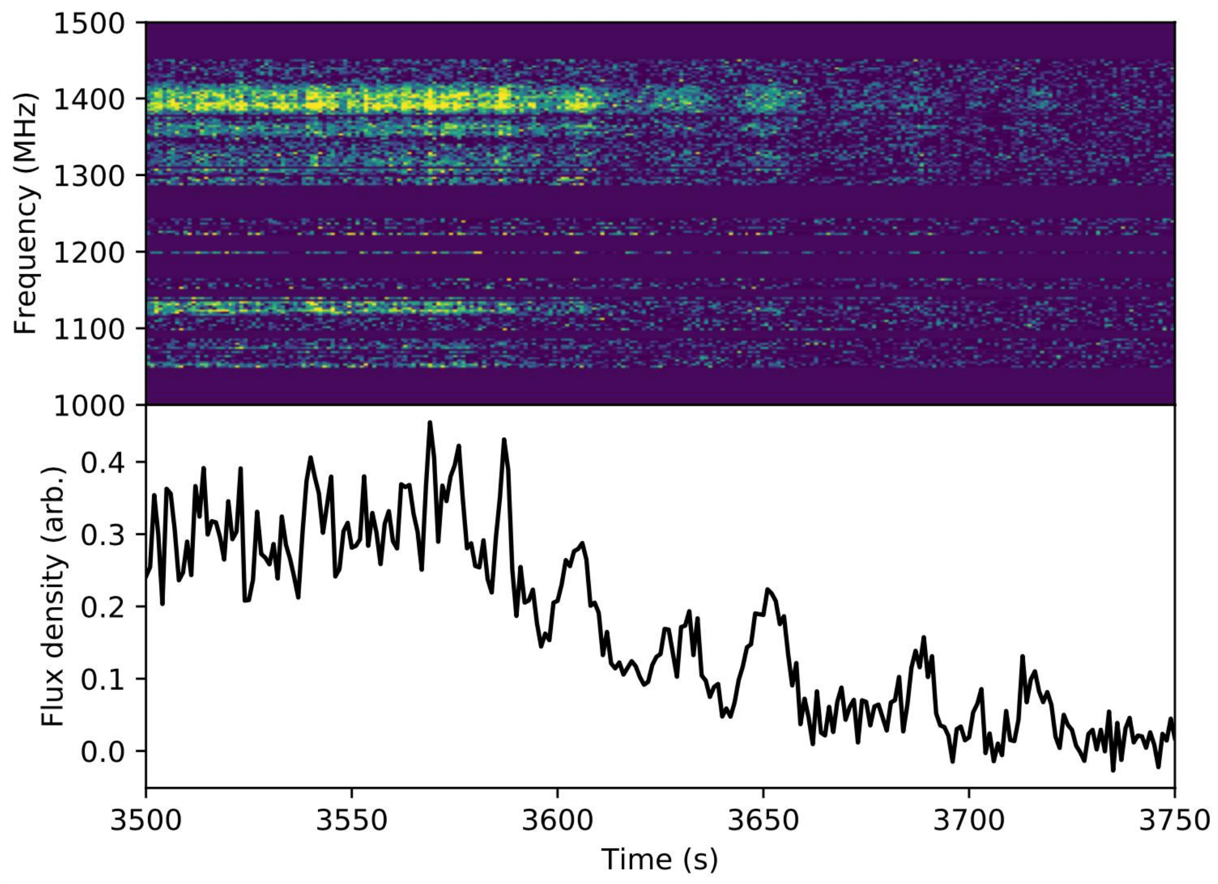


- The pulse emissionof this pulsar during the ingress show a modulation.
- No such modulations are detected duringthe egress of the eclipse of this pulsar.
- The emission modulations during the ingress are quasi-periodic with a period of 26 s.

19C13

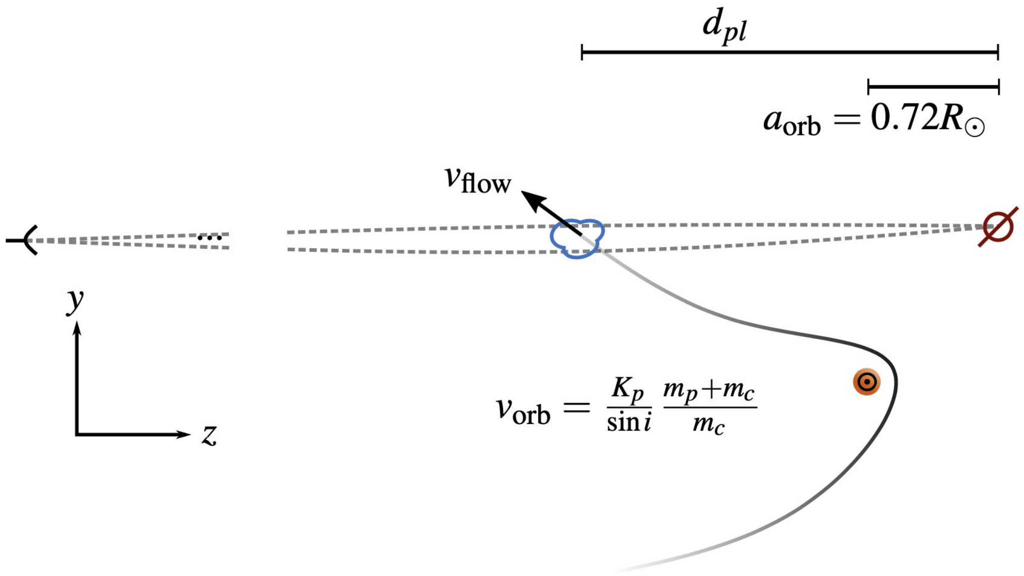
Dynamic spectrum during ingress

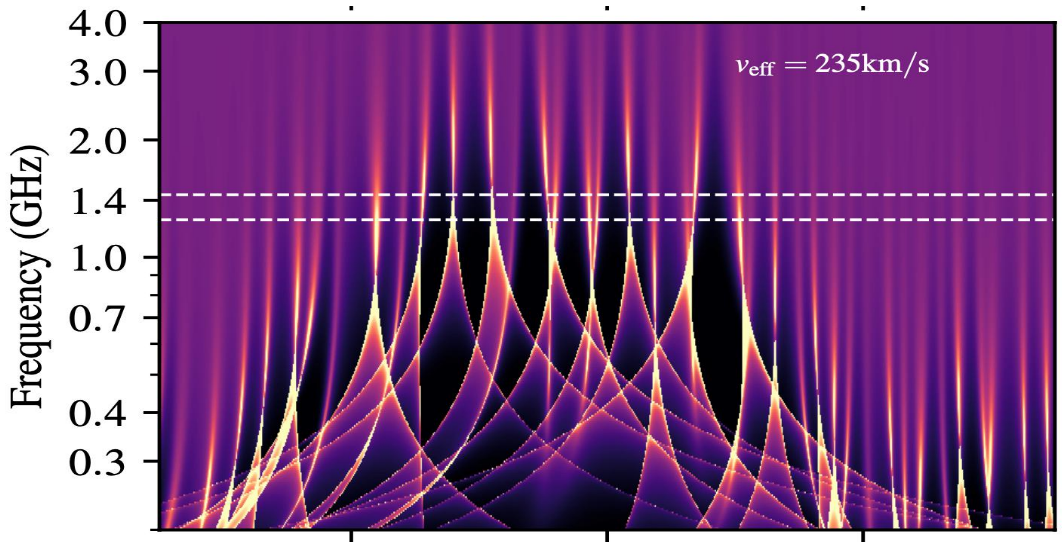
- The emission modulations are clearly seen at about 1125 MHz and 1400 MHz.

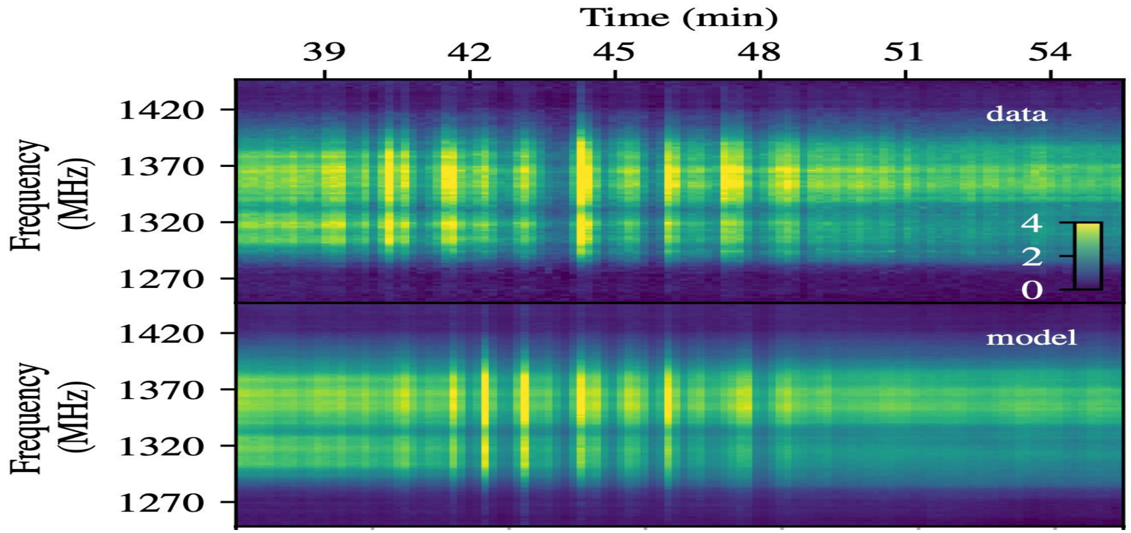


PSR J2051-0827

Plasma lensing!!!







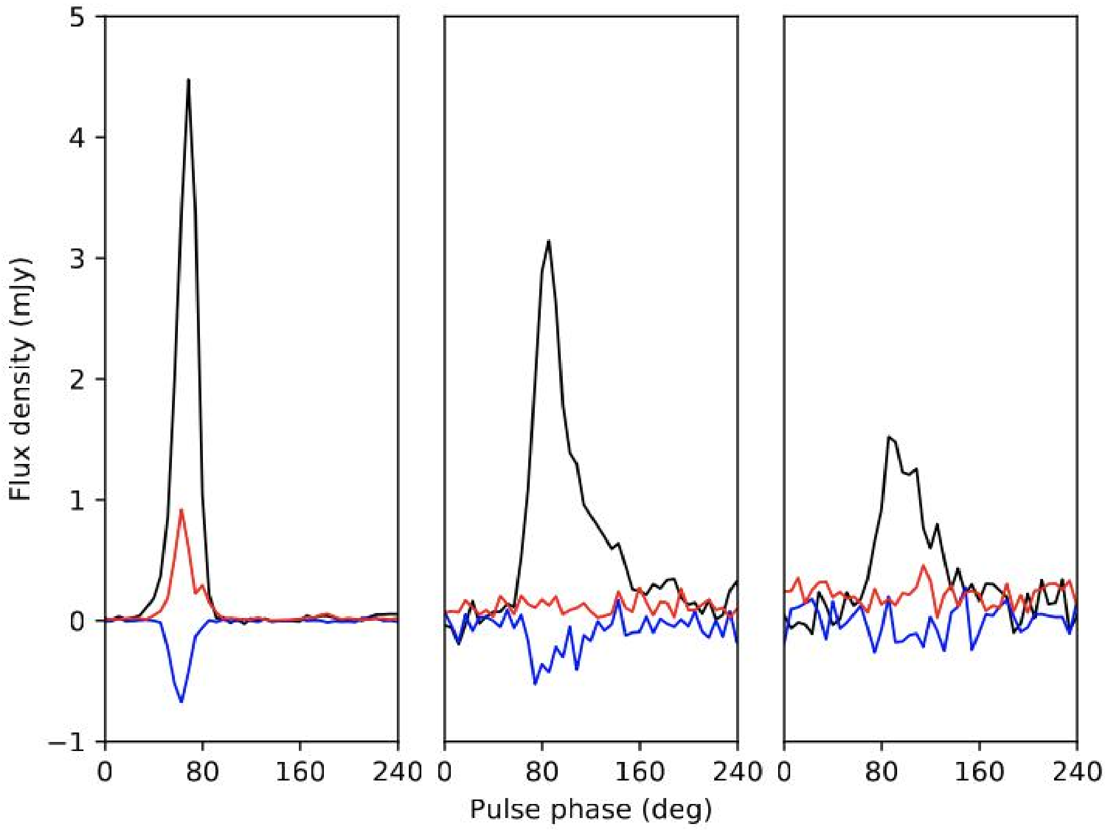
BW PSR J2051-0827 shows highly variable flux density throughout the eclipse, which demonstrates the causal link between DM and lensing.

F. X. Lin et al. (2021)

19C13

Profiles

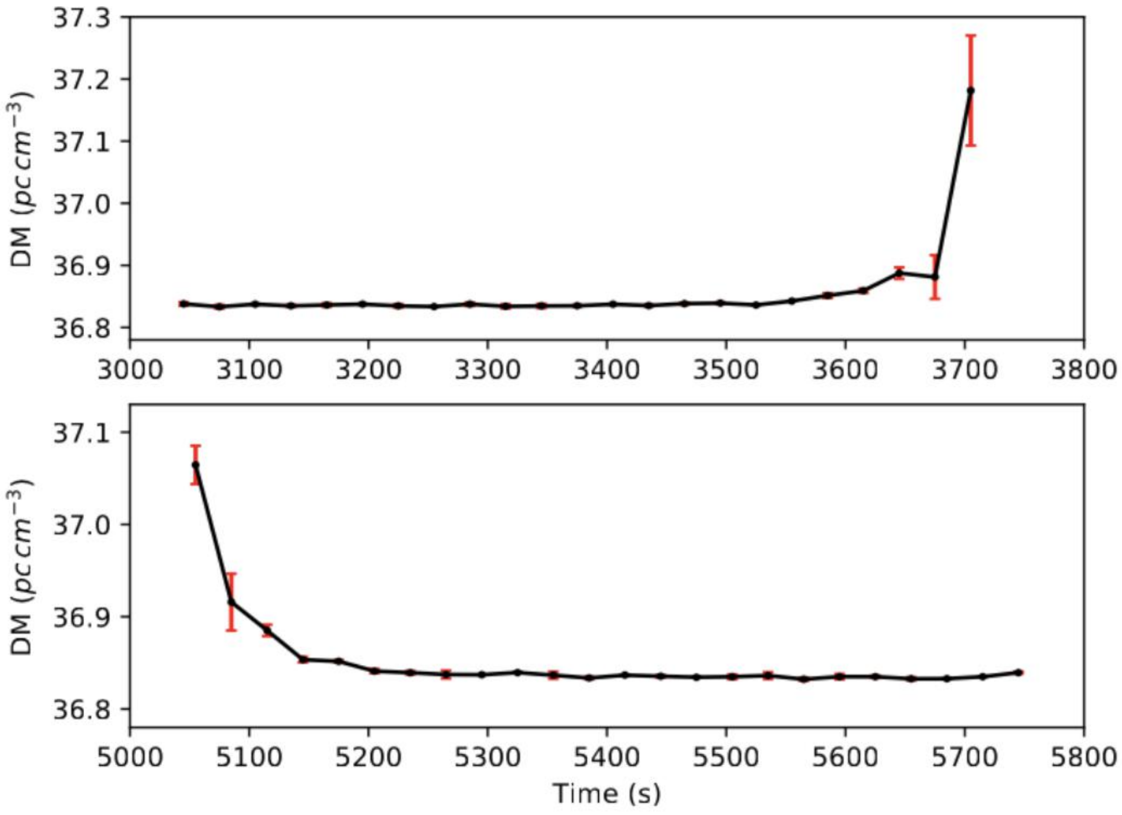
- The pulses become much wider.
- The liner polarisations of the emission disappear, while the circular polarisations still exist.
- The multipath propagation of the radio emission in the magnetized plasma medium can cause the short timescale RM fluctuations, which may cause the depolarization.



19C13

DM variatuions

- The max ΔDM = 0.35 cm^3 pc
- The estimated mass-loss rate of the companion is about 10^−13 M⊙ yr−1.



Summary1

- We used FAST to observe three millisecond pulsars that in IPTA list and found periodical modulations in them for the first time.
- The modulation periods are 87 ms and 5.78 s for PSR J0621+1002, 248 ms for PSR J0636+5129.
- PSR J0030+0451 is the first periodical mode changing millisecond pulsar with the mode-cycle timescale of only 25 ms which is the shortest in all mode changing pulsars.
- We examined the achievable timing precision using only the bright pulses. No significant improvement in timing precision was found for PSR J0621+1002 and PSR J0636+5129. The timing precision available for PSR J0030+0451 improved about 1%.

Summary2

- We used FAST to observed 19C13 which is a black widow pulsar discovered by the FAST-CRAFTS survey. Our observation with a scintillation maximum provides great details on the emission variations near the eclipse.
- There is a quasi-periodic pulse emission variations with the modulation period of 26s during the ingress, which may be corresponding to the plasma lensing. No such modulation was found during the egress.
- The pulse emission for this pulsar becomes depolarized near the eclipse, which suggested that there is significant magnetic field in the eclipse medium.
- By fitting the DM variations during the eclipse, we estimated the mass-loss rate from the companion to be about 10^−13 M⊙ yr−1.

THANKS!