



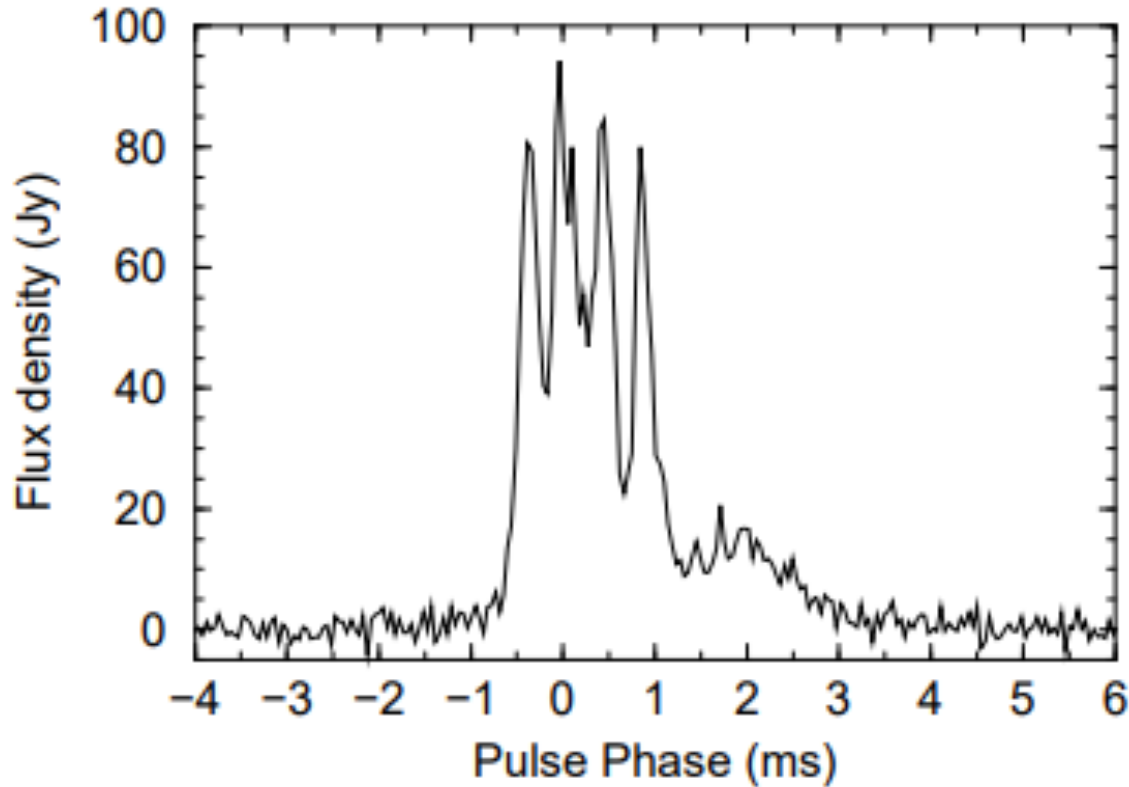
# Quasi-periodic sub-pulse structure as a unifying feature for radio-emitting neutron stars

<https://doi.org/10.1038/s41550-023-02125-3>

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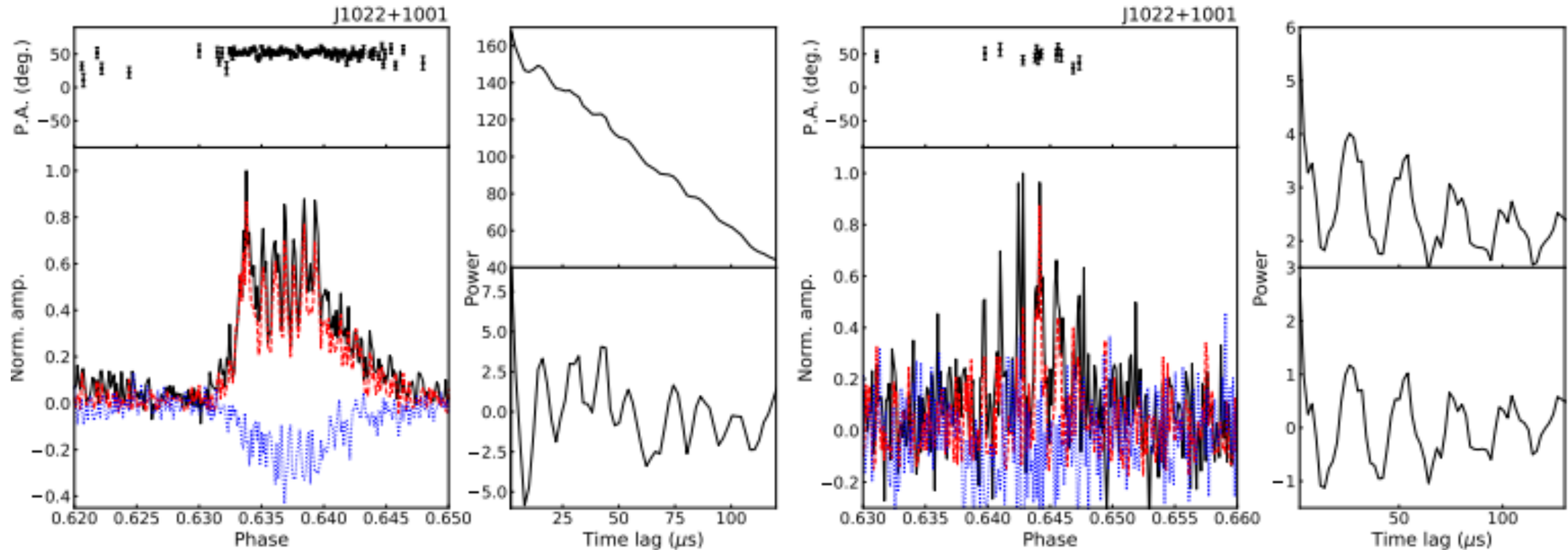
# Micro-pulses observed in pulsar signals



PSR B0833-45, M. Kramer et al. 2002

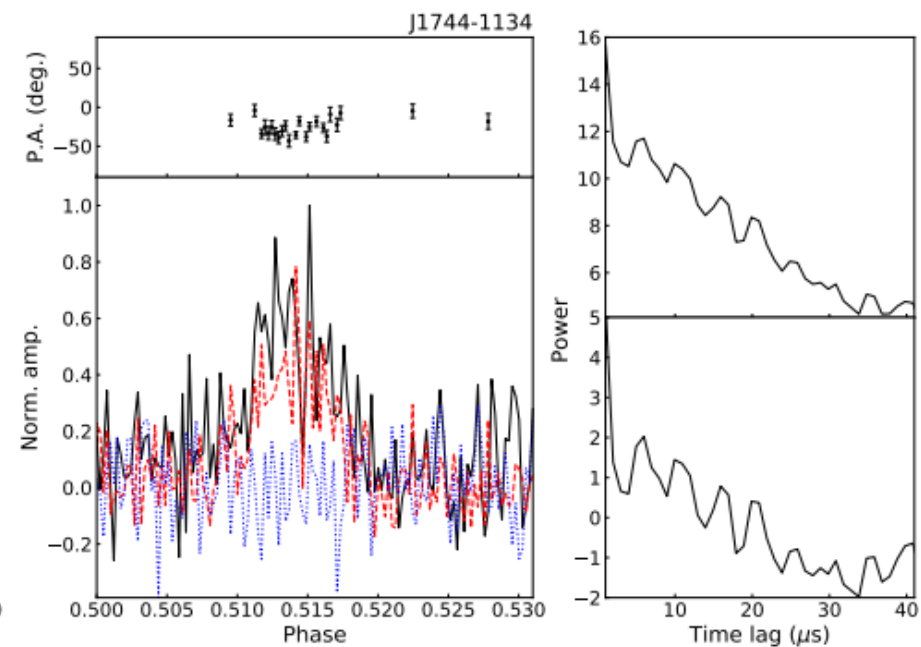
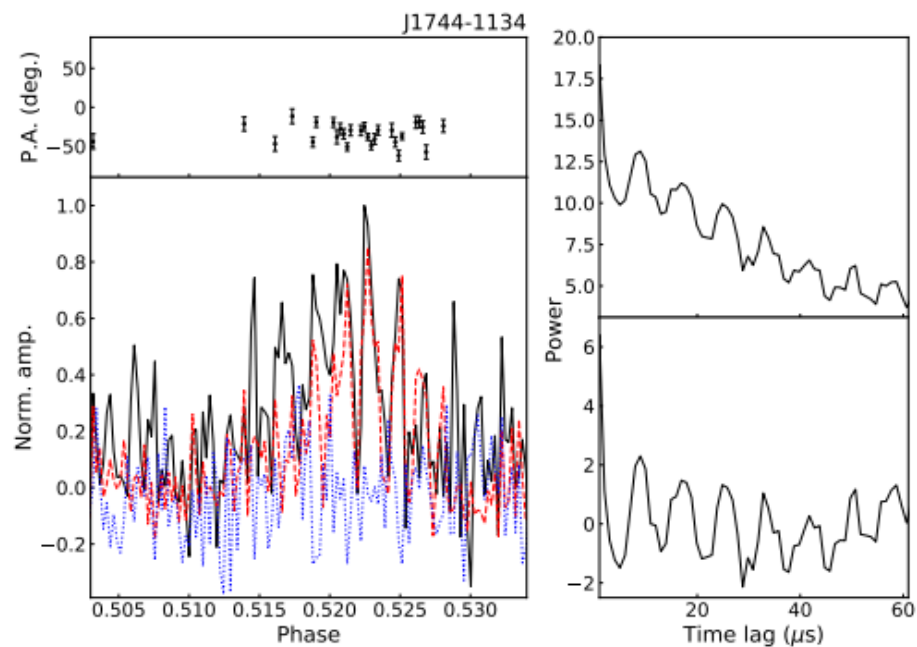
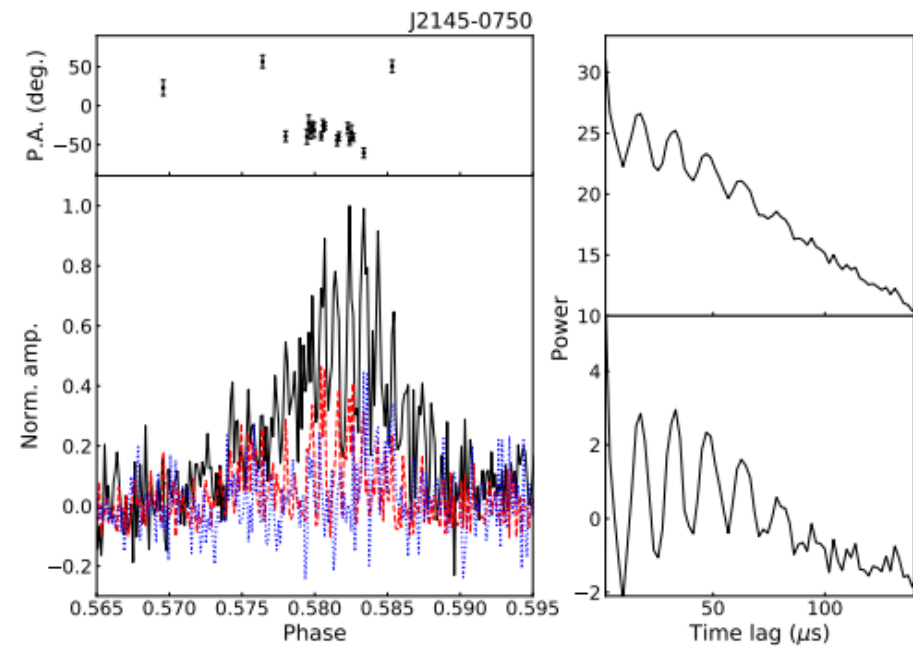
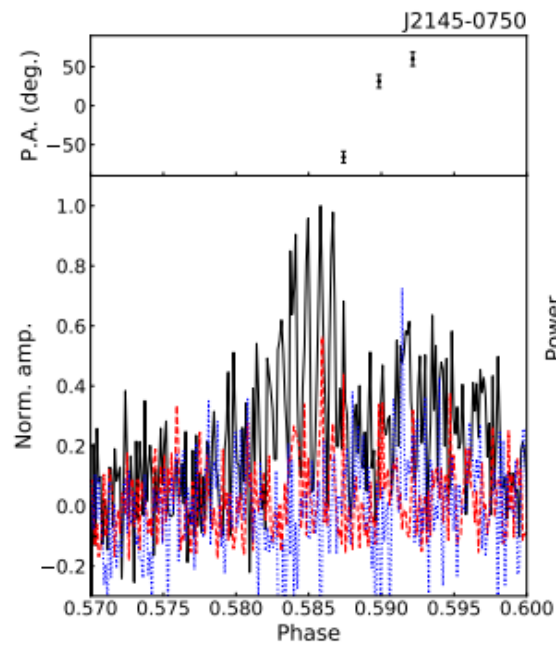
- Micro-pulses have been detected in many (80% for PSR B0833-45) pulses (independent of frequency);
- Some micro-pulses groups are quasi-periodic;
- Every quasi-periodic micro-pulses group has the same period (in the same object);
- Period depends on the rotation period.
- $P_\mu \approx 10^{-3}P, \tau_\mu \approx 0.5P_\mu$

# For millisecond pulsars

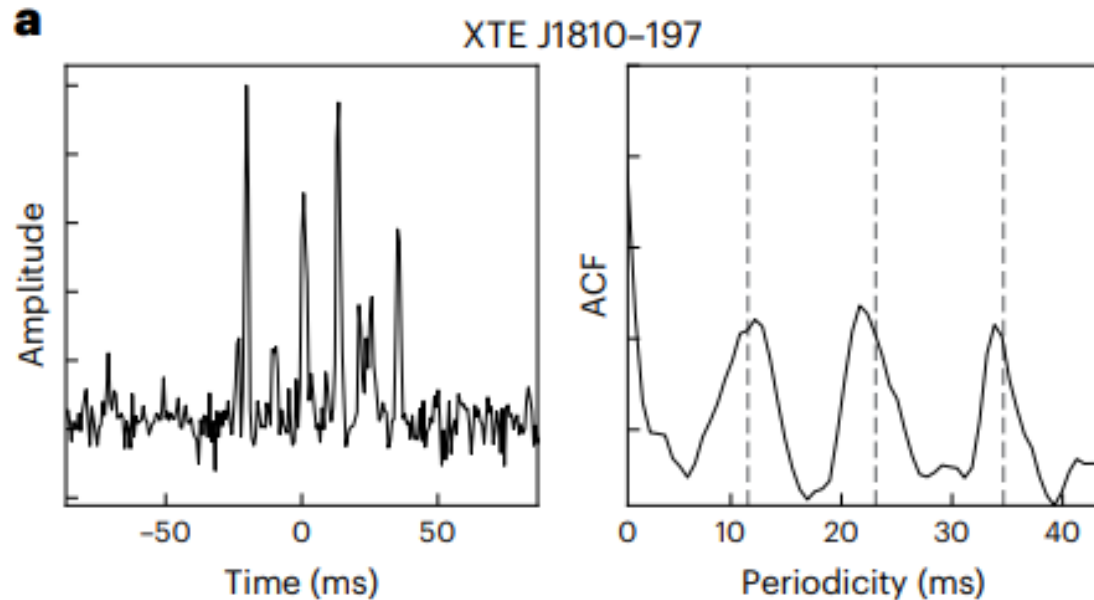


Black solid: total intensity  
Red dashed: linear polarization  
Blue dashed: circular polarization

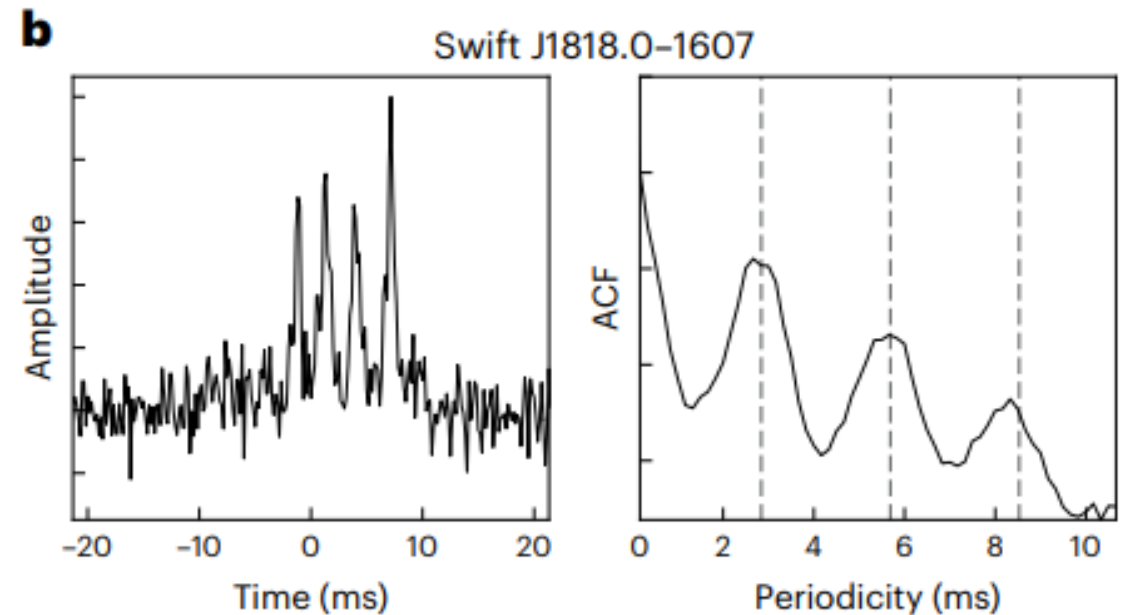
K. Liu et al. 2022



# For radio-loud magnetars

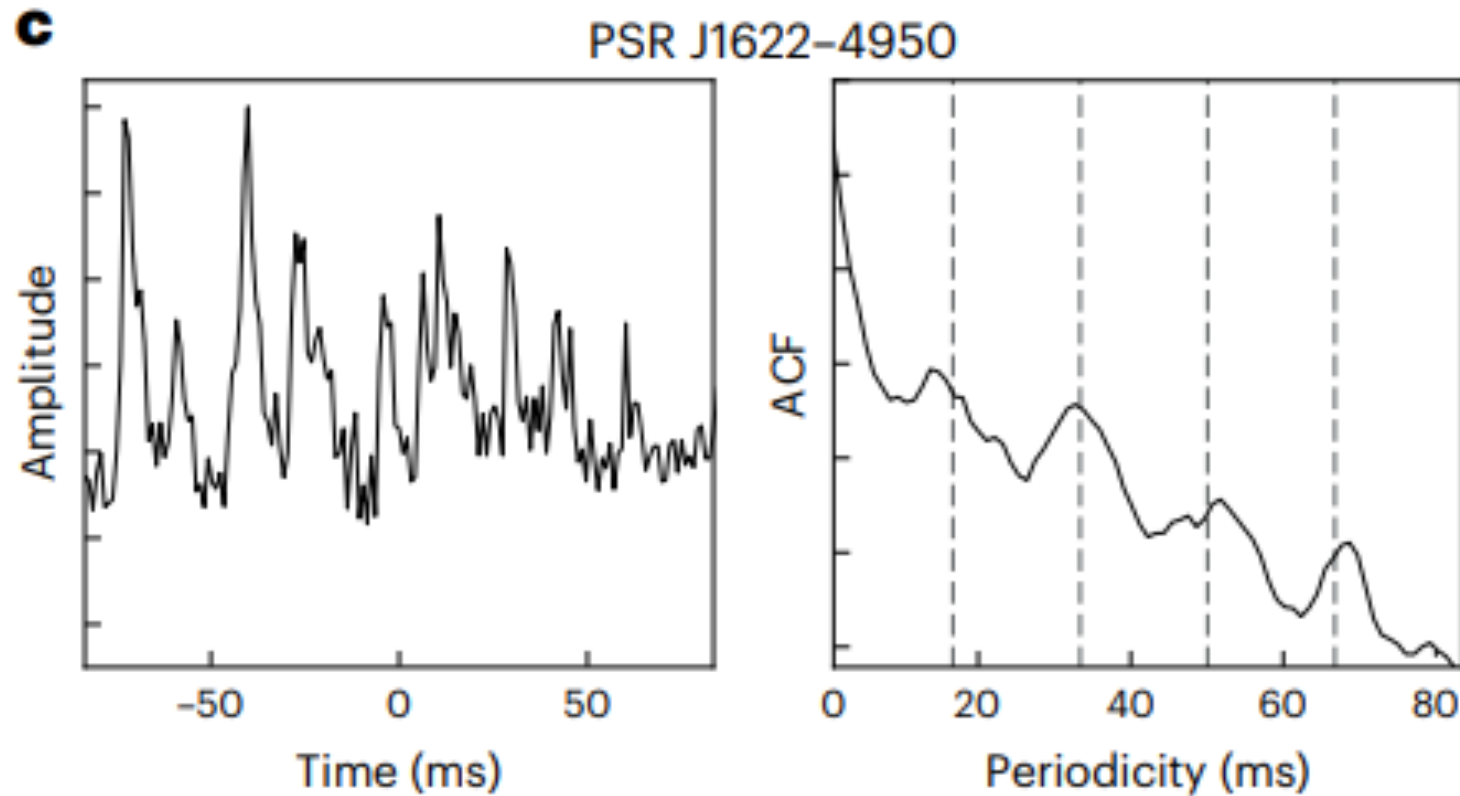


Rotation period: 5.54s  
Magnetic field:  $3 \times 10^{14}$  G



Rotation period: 1.36s  
Magnetic field:  $2.5 \times 10^{14}$  G

# For radio-loud magnetars

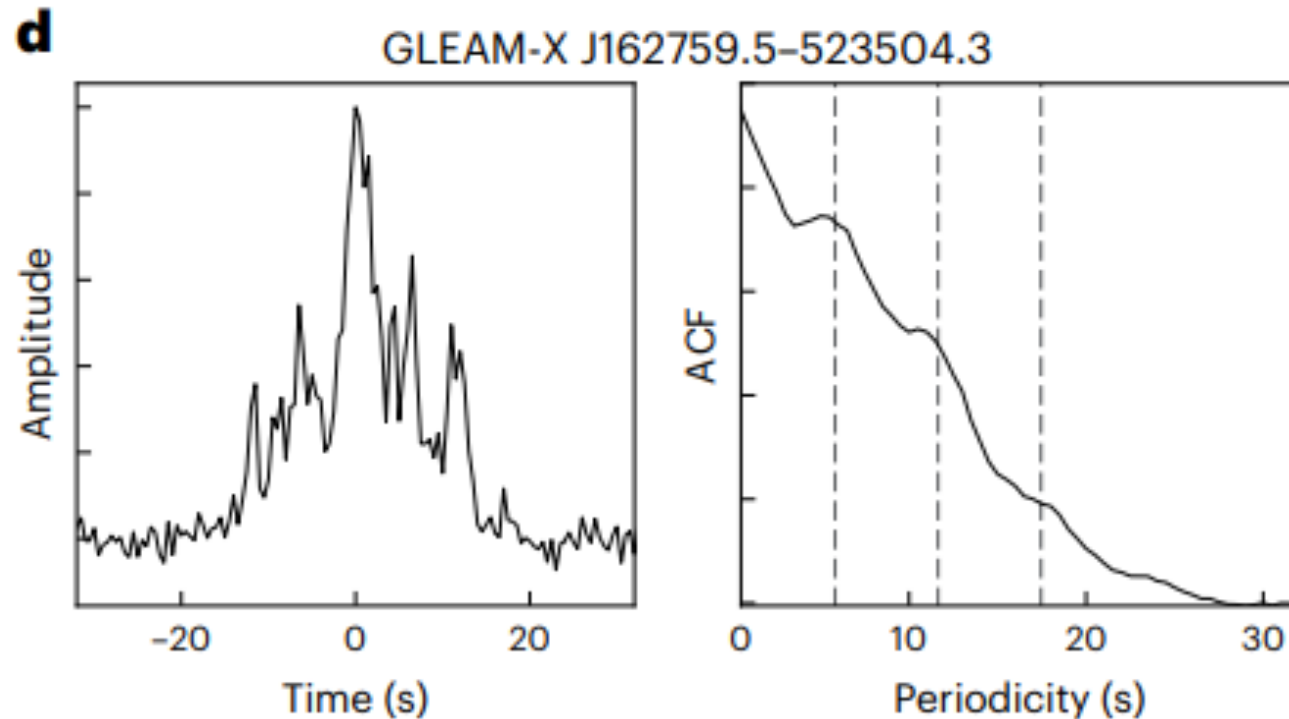


Rotation period: 4.3s

Magnetic field:  $2.6 \times 10^{14}$  G



# For long-period pulsating radio sources (NS?)

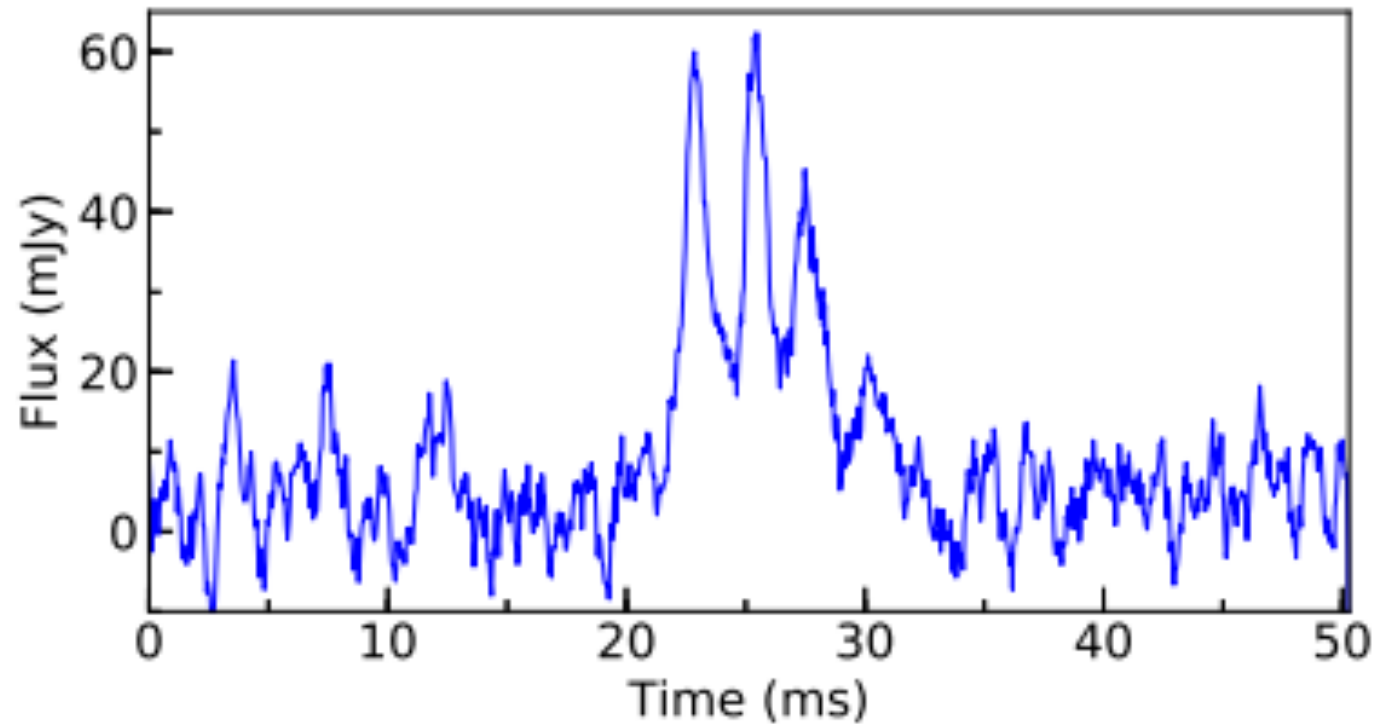


Rotation period: 1091s

Magnetic field: ?

(more than  $10^{16}$  G if NS)

# For rotating radio transients (RRAT)

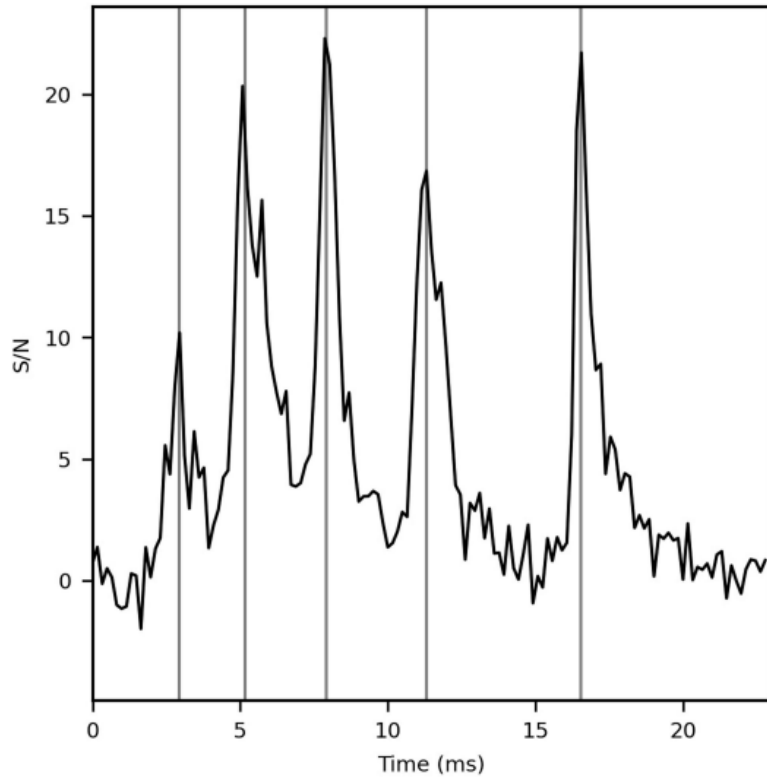


Rotation period:  $2479.21 \pm 0.03$  ms

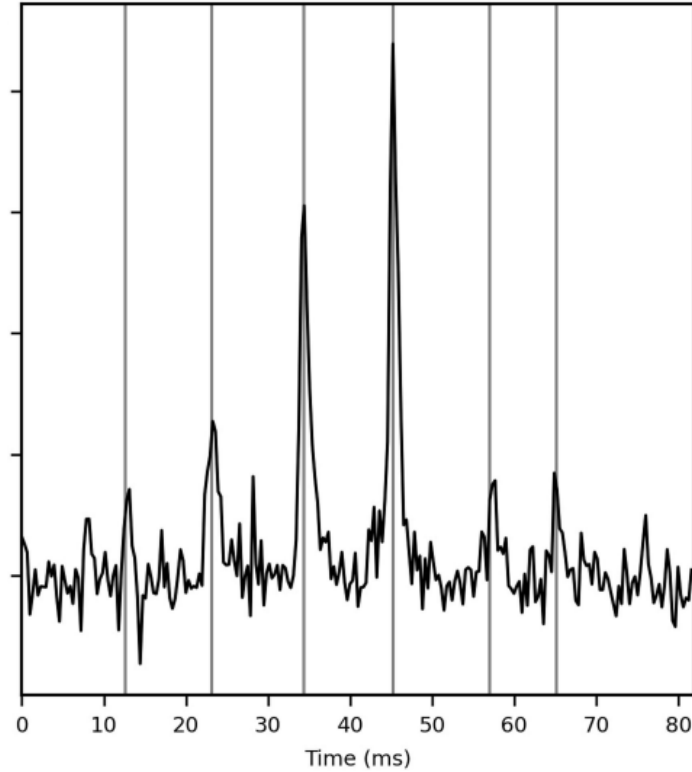
J. L. Chen et al. 2022



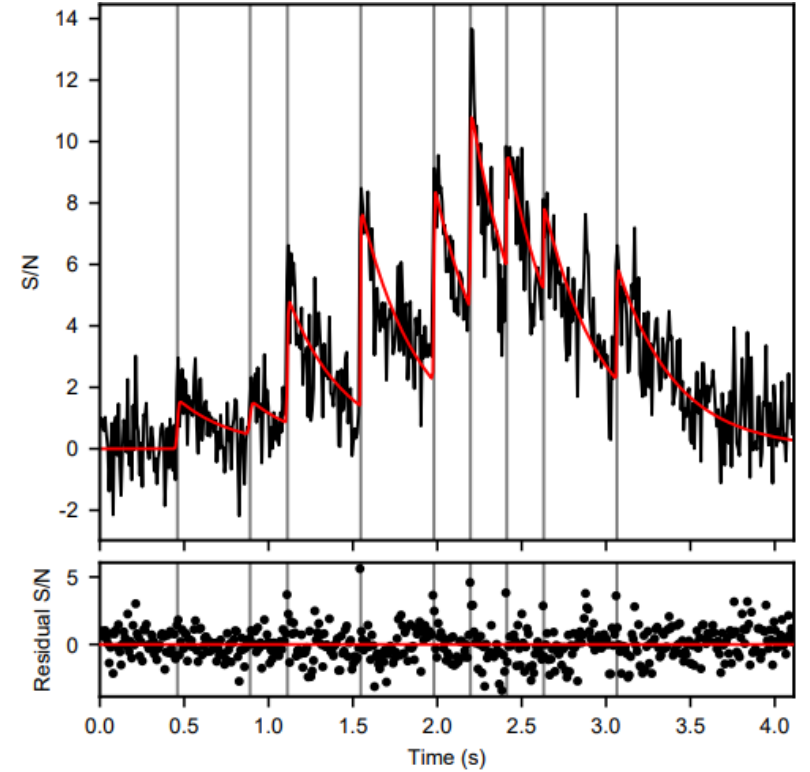
# For fast radio bursts



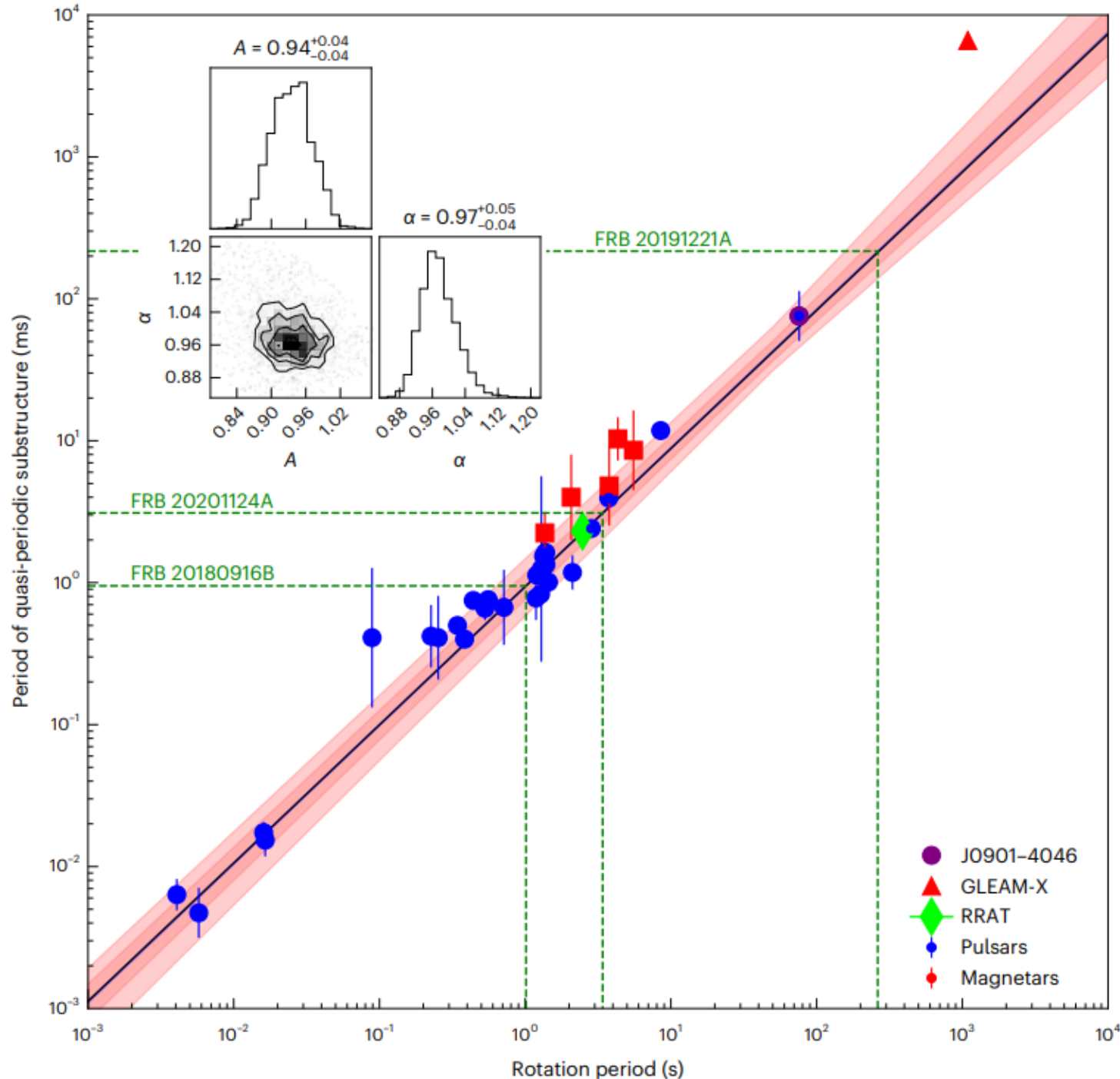
FRB 20210206A



FRB 20210213A



FRB 20191221A



$$P_{\mu} = (0.94 \pm 0.04) \times P^{(0.97 \pm 0.05)} ms$$

$$\tau_{\mu} = (0.59 \pm 0.03) \times P^{(0.99 \pm 0.02)} ms$$

- The relation extends over about **six** orders of magnitude;
- The quasi-periodic sub-pulses is not always present;
- Fluctuation of period of sub-pulses are observed;

# Discussion and summary

- The relation extending over about **six** orders of magnitude suggests that a unifying mechanism exists in all kinds of neutron stars.
- They think the quasi-periodic sub-pulse may comes from some temporary angularly periodic structure.
- Some people try to explain the structure with tearing instabilities of current sheet in magnetic reconnection process, but the work hasn't been connected to the rotation period of neutron stars. The cause of this phenomenon remains to be studied.