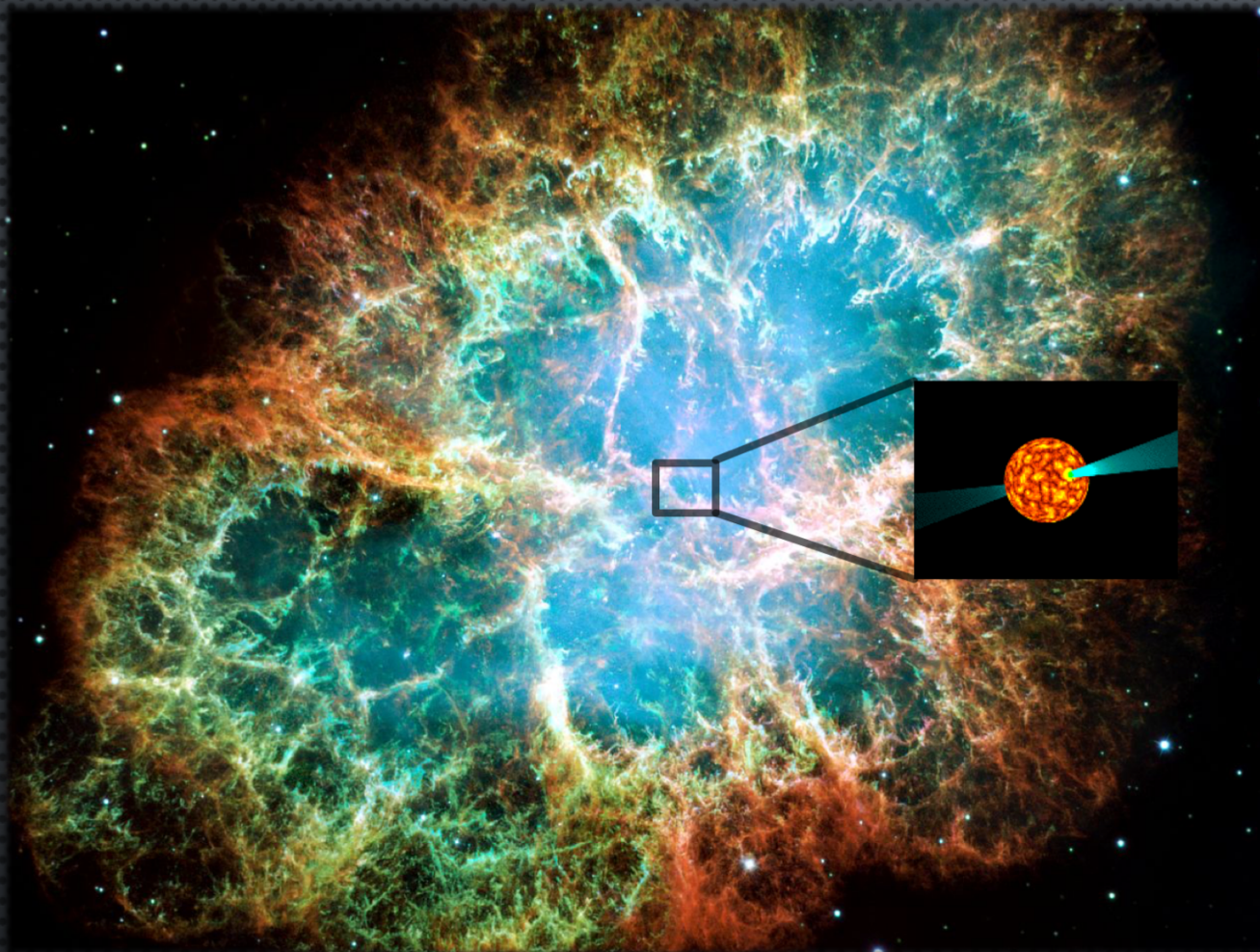


パルサーにおける突発現象

新沼浩太郎（山口大学）

木曽広視野サーベイと京都3.8m即時分光によるタイムドメイン天文学の推進

2017年2月20日-22日@京都大学理学部



INTRODUCTION

Pulsar (1) 60°

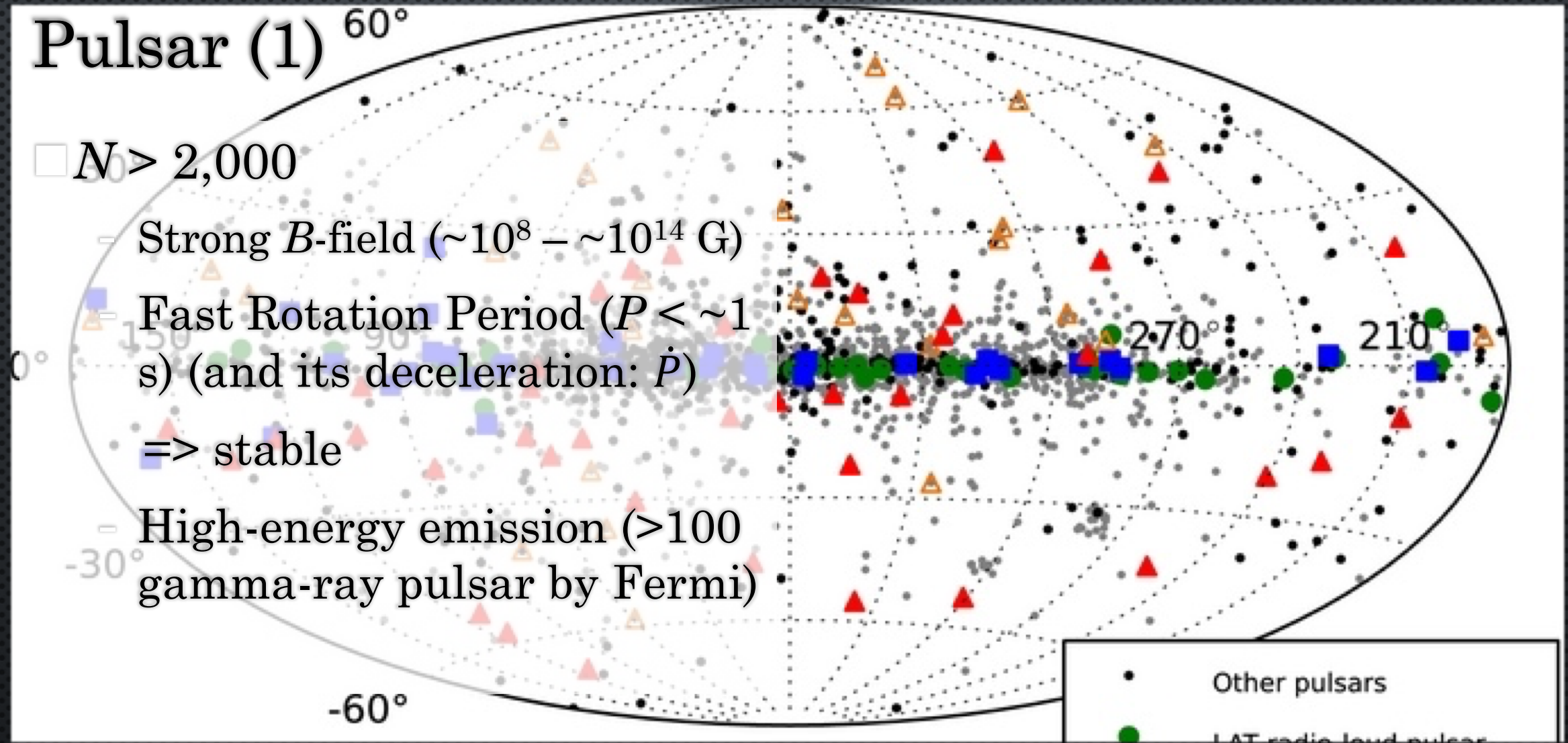
□ $N > 2,000$

- Strong B -field ($\sim 10^8 - \sim 10^{14}$ G)

- Fast Rotation Period ($P < \sim 1$ s) (and its deceleration: $\dot{P}$)

=> stable

- High-energy emission (> 100 gamma-ray pulsar by Fermi)



• Other pulsars

● LAT radio-loud pulsars

Pulsar (2) – *Tool for interstellar plasma physics*

□ Pulse Time of Arrival (ToA)

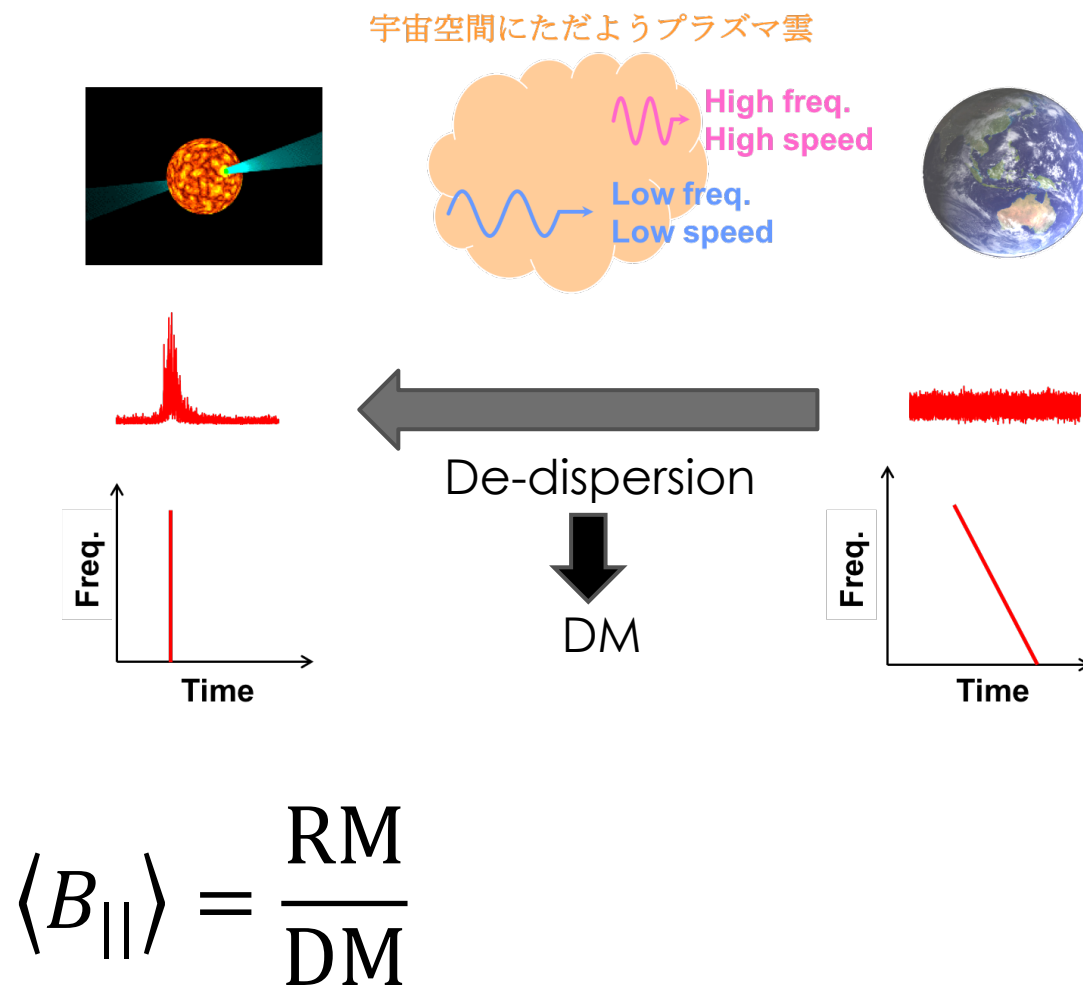
$$\Delta t = t_1 - t_2 = \frac{e^2}{2\pi m_e c} \times \left(\frac{1}{\nu_1^2} - \frac{1}{\nu_2^2} \right) \times \text{DM}$$

$$\text{DM} = \int_0^d n_e dl$$

□ Faraday Rotation

$$\Delta \Psi_{\text{Faraday}} = \frac{e^3}{\pi m_e^2 c^2 \nu^2} \int_0^d n_e B_{||} dl$$

$$\text{RM} = \frac{e^3}{2\pi m_e^2 c^4} \int_0^d n_e B_{||} dl$$



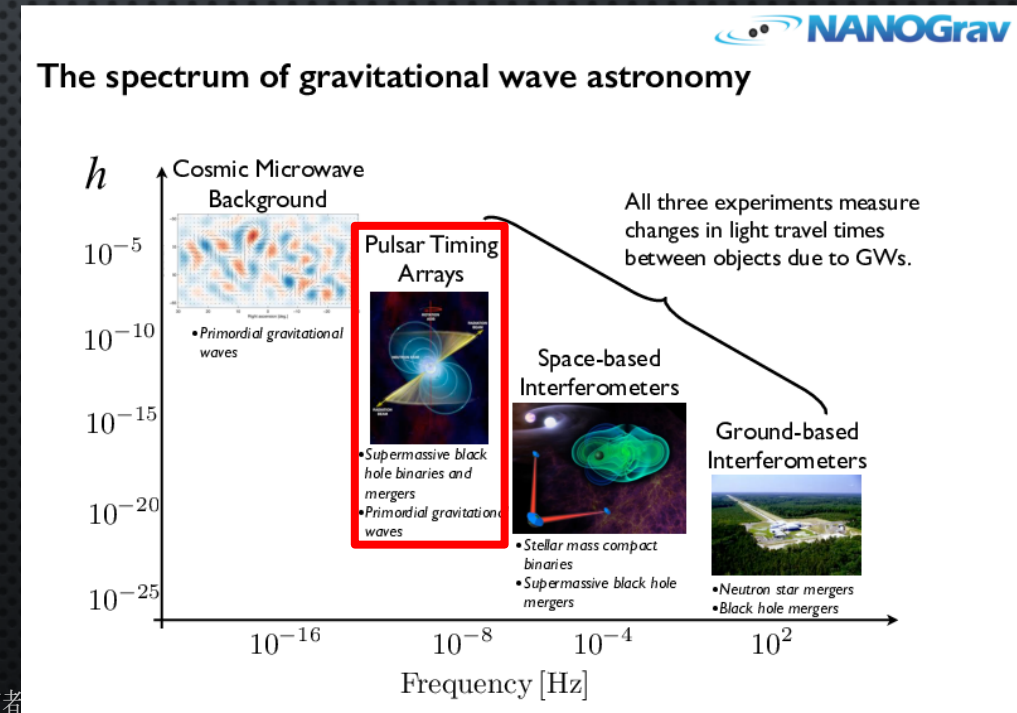
Pulsar (3) – *Tool for GW search*

■ Binary Pulsars (e.g., B1913+16)

- Indirect detection (or evidence) of GW
=> 1993 Nobel prize

■ Pulsar Timing Array

- Low Frequency GW from SMBH binary



Radio Observation (time-series)

■ Pulse Profile (*Intensity, Width*)

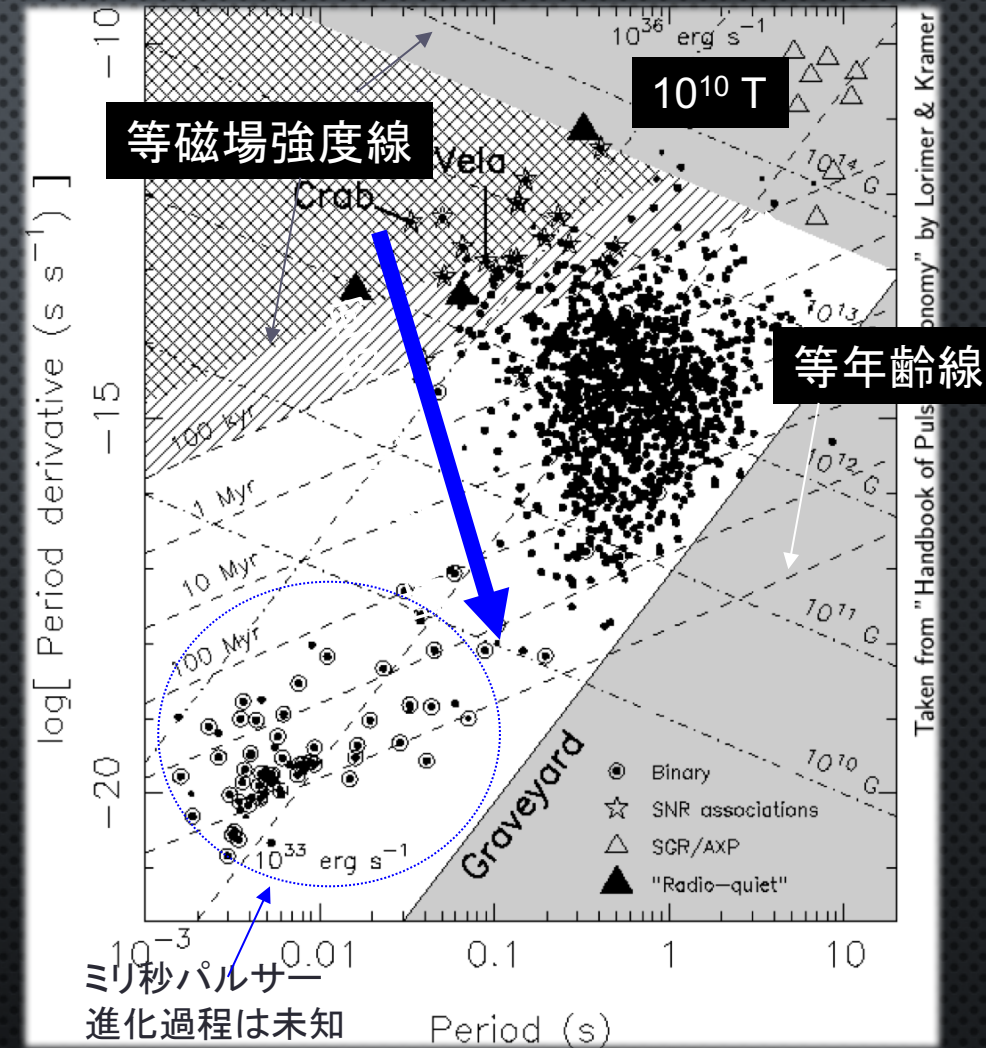
- Steep radio spectra (e.g., Maron+00)
 - Crab pulsar: $\alpha \sim 3$ ($S_\nu \propto \nu^{-\alpha}$)
- Width broadening: $\tau_s \propto \nu^{-4}$

■ Pulse Period ($P, dP/dt$)

- Characteristic age: $\tau_c = \frac{P}{2\dot{P}}$
- Magnetic field: $B \propto \sqrt{P \cdot \dot{P}}$

■ Pulse Arrival Time ($\Delta t \propto DM$)

■ Faraday Rotation



Radio Observation (interferometry)

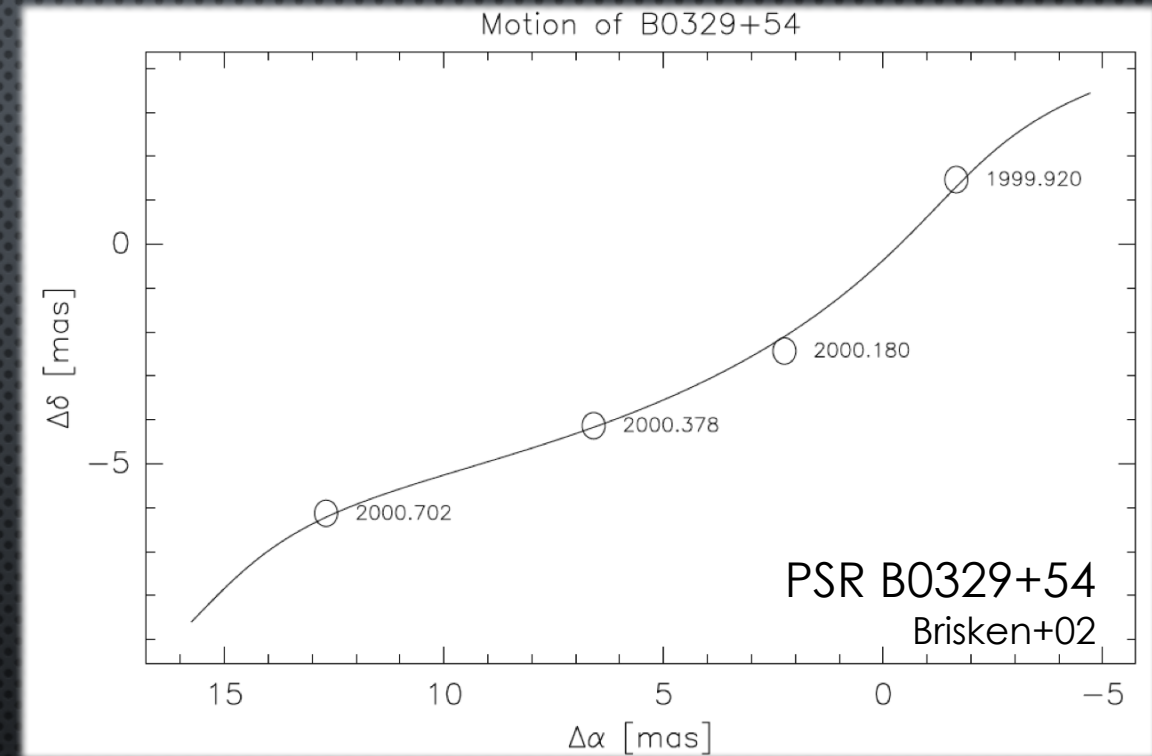
■ Astrometric Observation

- Proper motion (μ_α, μ_β)
 - Large kick velocity ($> \sim 100$ km/s)
- Annual Parallax Measurement
 - Direct measurement of the distance

~ VLBI astrometry: 54 pulsars

<http://www.astro.cornell.edu/~shami/psrvlb/parallax.html>

➡ direct estimation of n_e



Distance (DM): 1.35 – 1.43 kpc

Distance (π): 0.91 – 1.16 kpc

$$\Rightarrow n_e = 0.022 - 0.028 \text{ cm}^{-3}$$

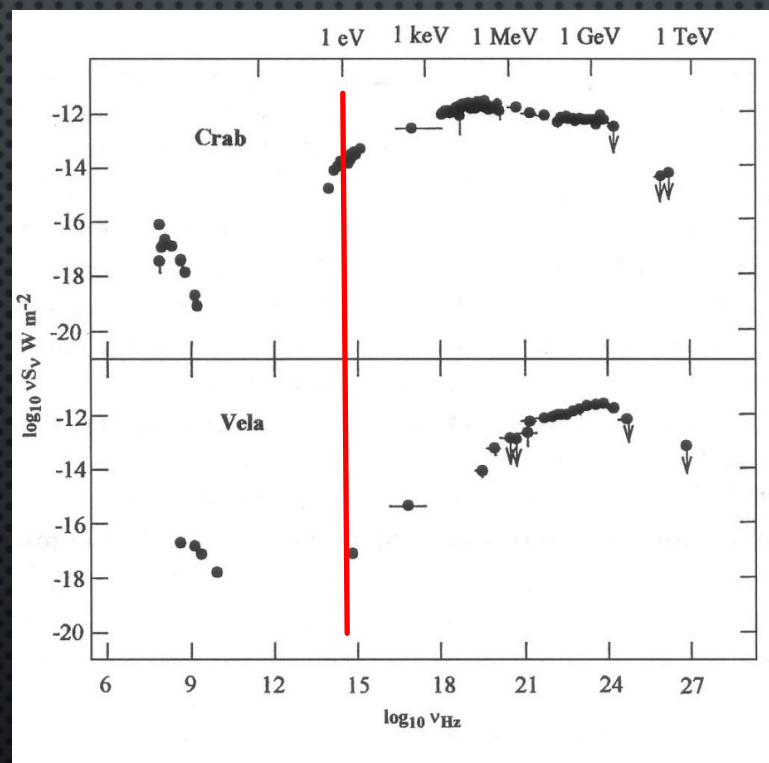
Multi- λ Observation



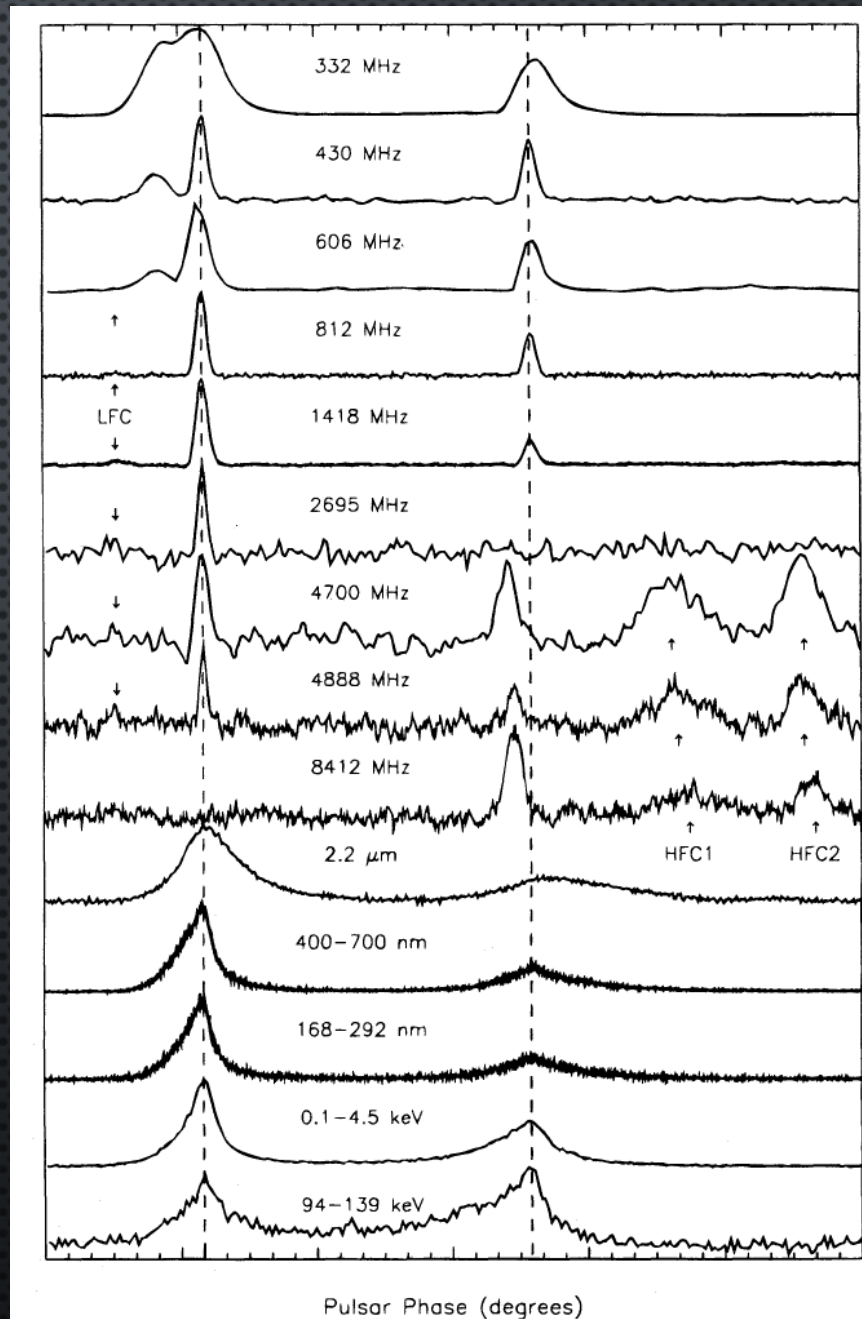
Credits for Opt./X-ray
Image: [NASA/CXC/ASU/J. Hester et al.](#)



Credit: Cambridge University Lucky Imaging Group



Relatively faint at optical



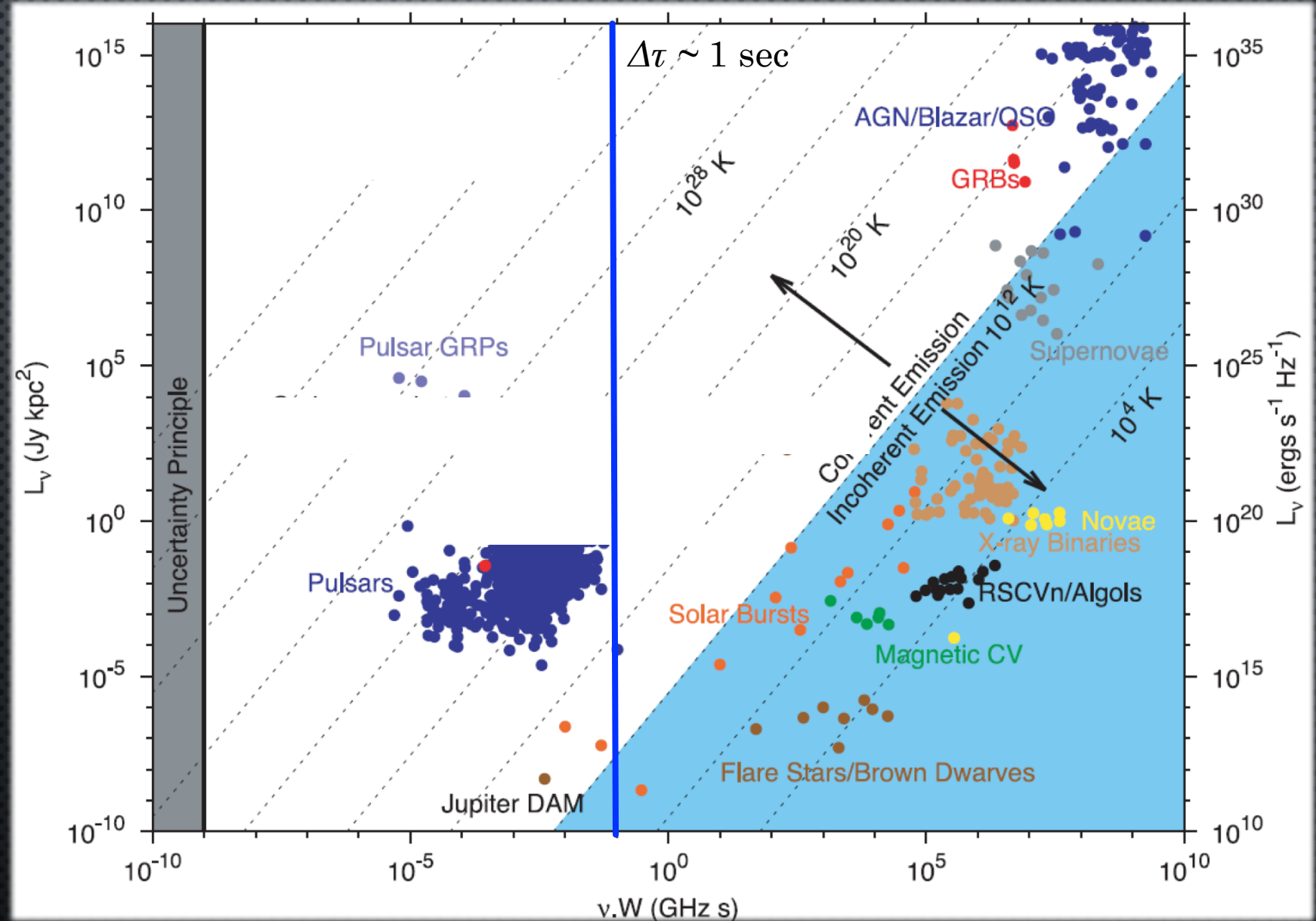
Moffett & Hankins (1996)

TRANSIENTS ASSOCIATED WITH PULSARS

Diversity of Pulsar Transients

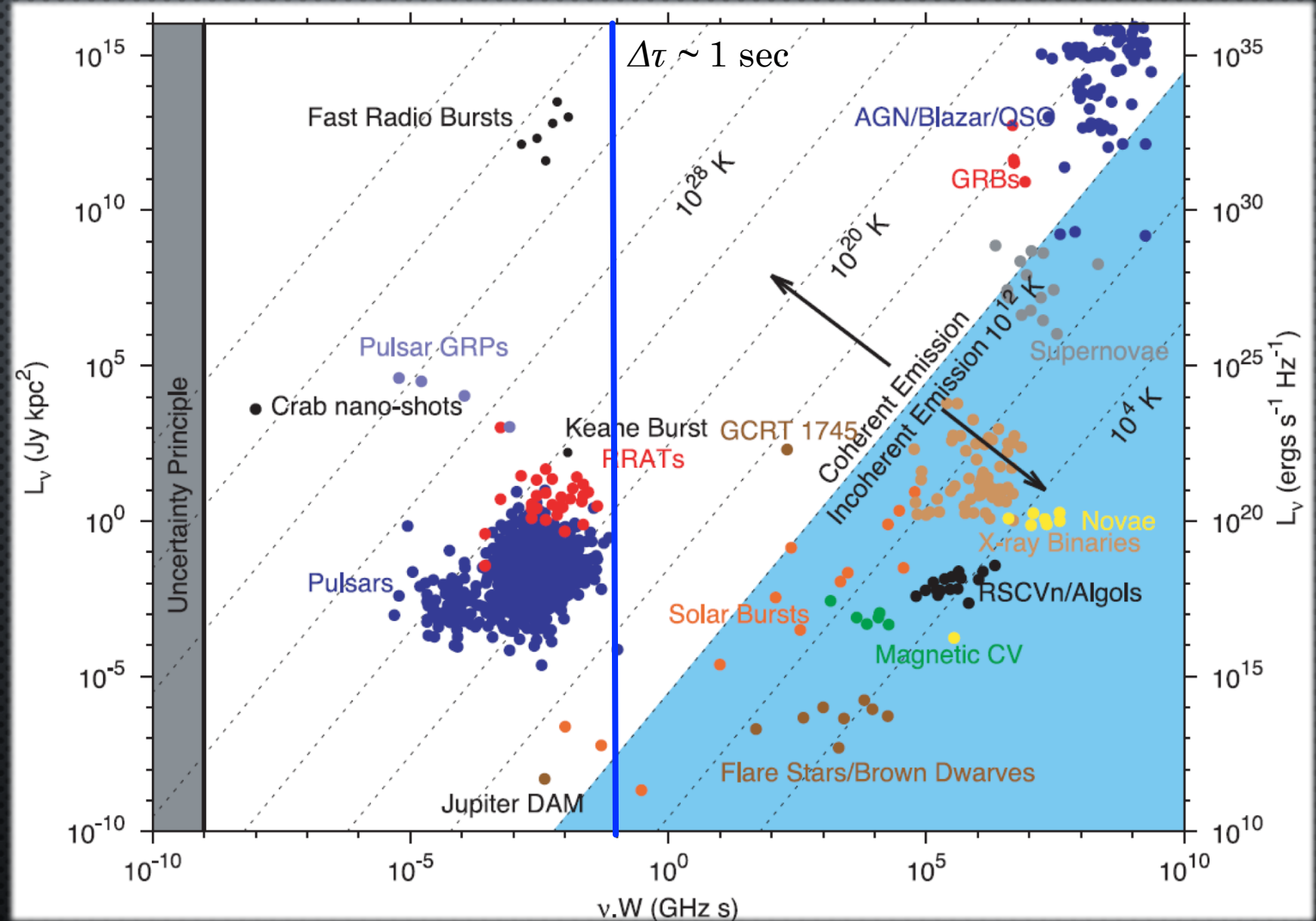
Radio Phase-Space (Pietka+15)

~ 2000



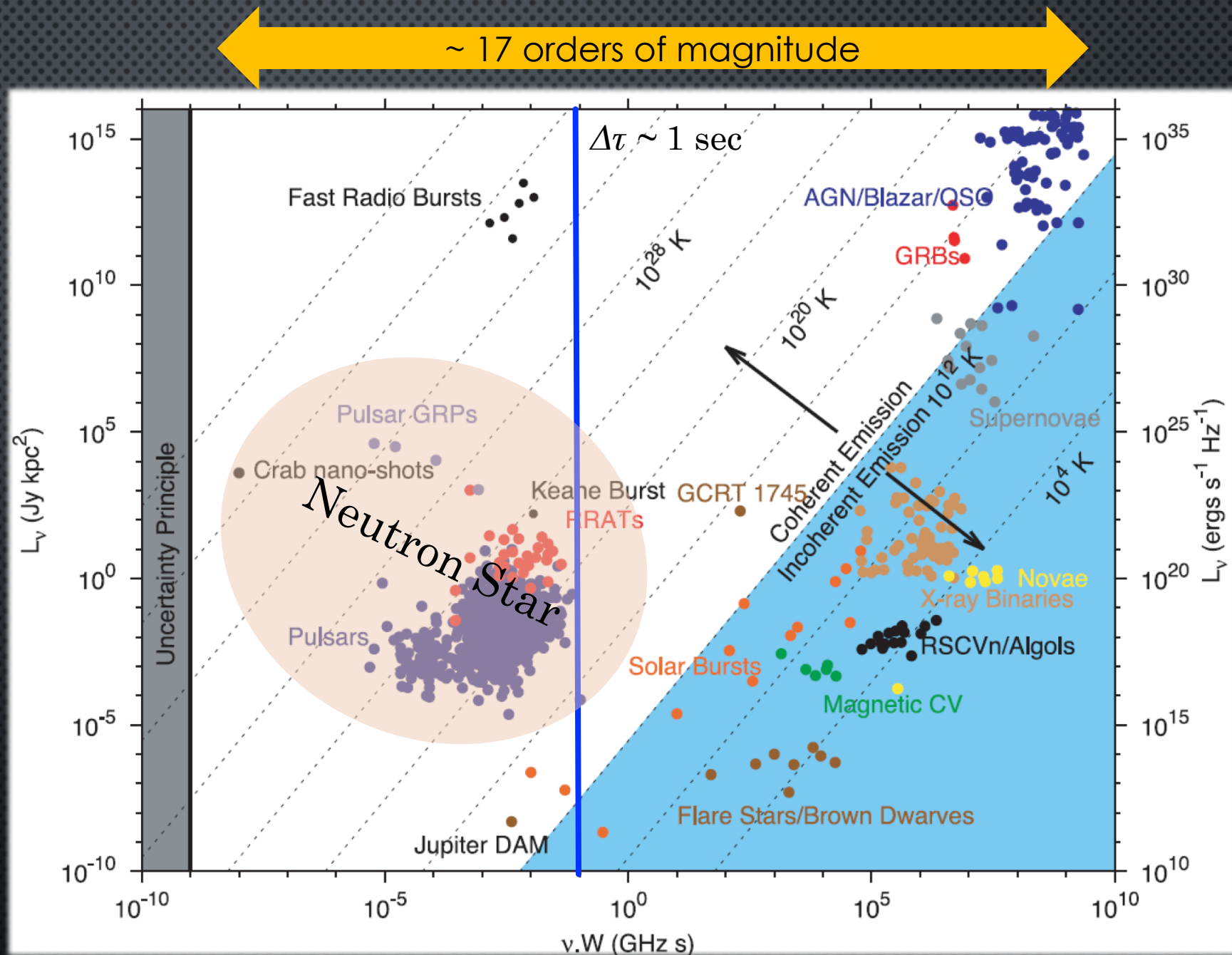
Radio Phase-Space (Pietka+15)

2000's -



Radio Phase-Space (Pietka+15)

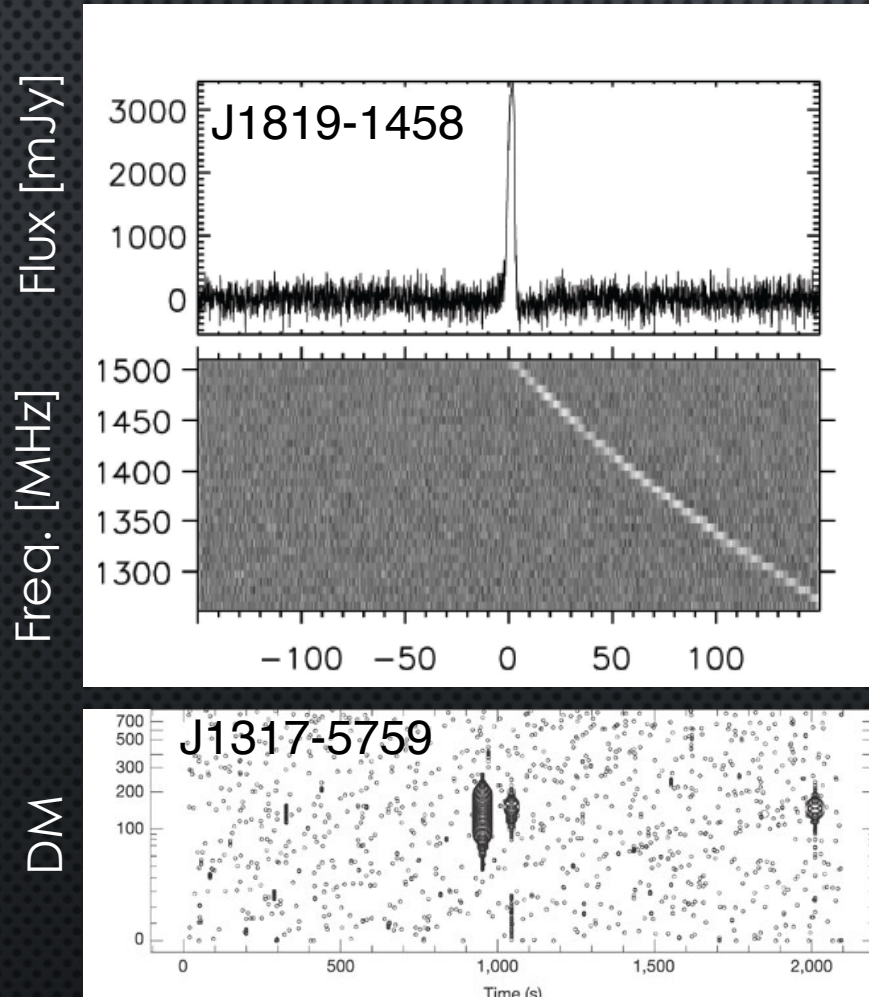
2000's -



Transients associated with Pulsar

- Sporadic Pulse from Rotating neutron star (Rotating Radio Transients: RRATs)
- Pulsar Giant Radio Pulses (GRPs)
- Extreme short duration radio burst (“*nano-shot*”)
- (Fast Radio Bursts (FRBs) -> 新納さん講演)

Rotating Radio Transients: RRATs

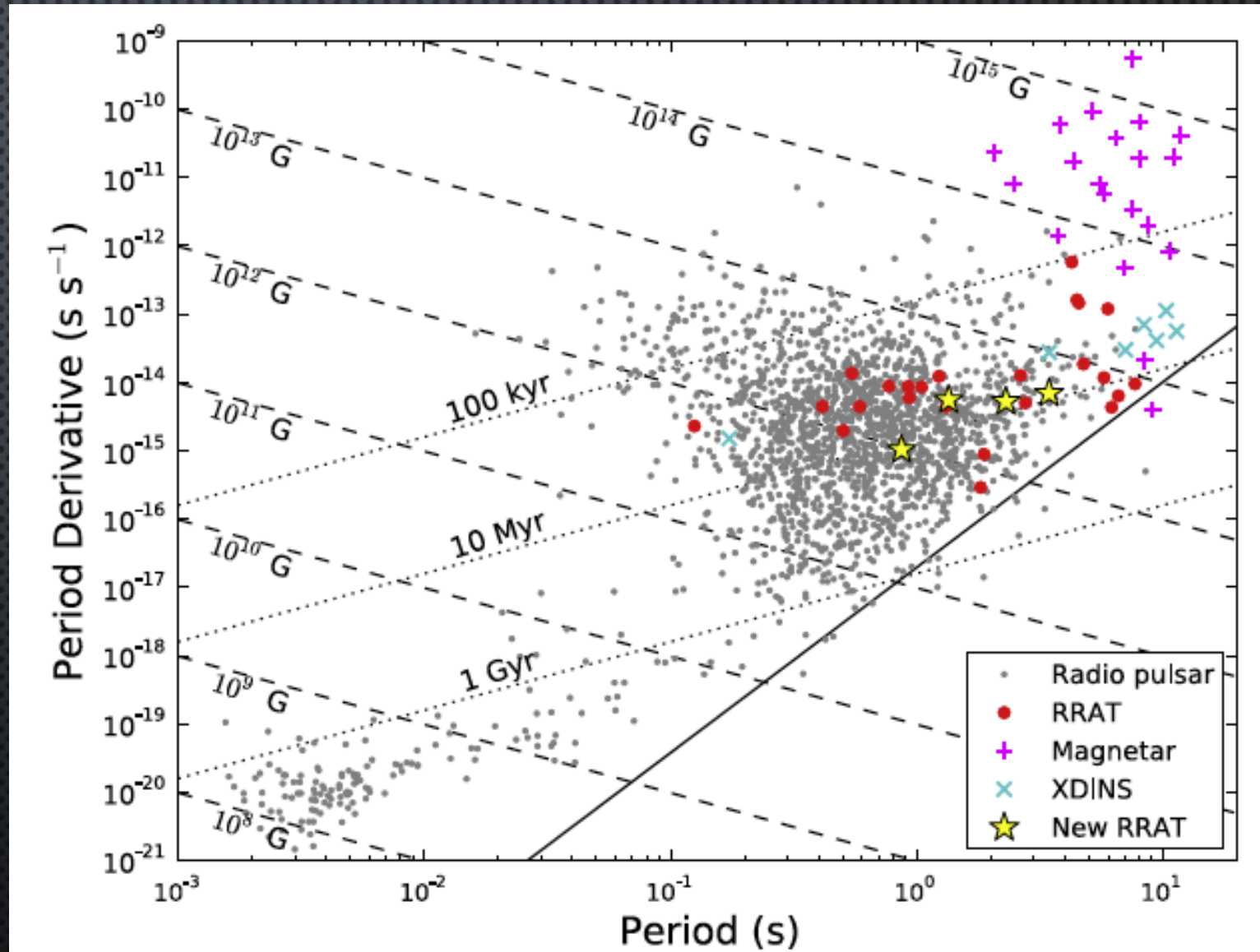


- New population of neutron stars
 - Period: 0.4 – 7 sec (in McLaughlin+06)
 - Time interval of bursts: 4 min – 3 hr
- Found by burst search technique (based on single pulse search method, Cordes & McLaughlin 2003)
- X-ray (faint and no variable) counterpart (Reynolds+06)
- Possible IR candidate for J1819 (Rea+09)

McLaughlin et al., *Nature* (2006)

RRATs: $P - \dot{P}$

- P : $0.1 \text{ s} \sim < 10 \text{ s}$
- B : $10^{12} - 10^{14} \text{ G}$

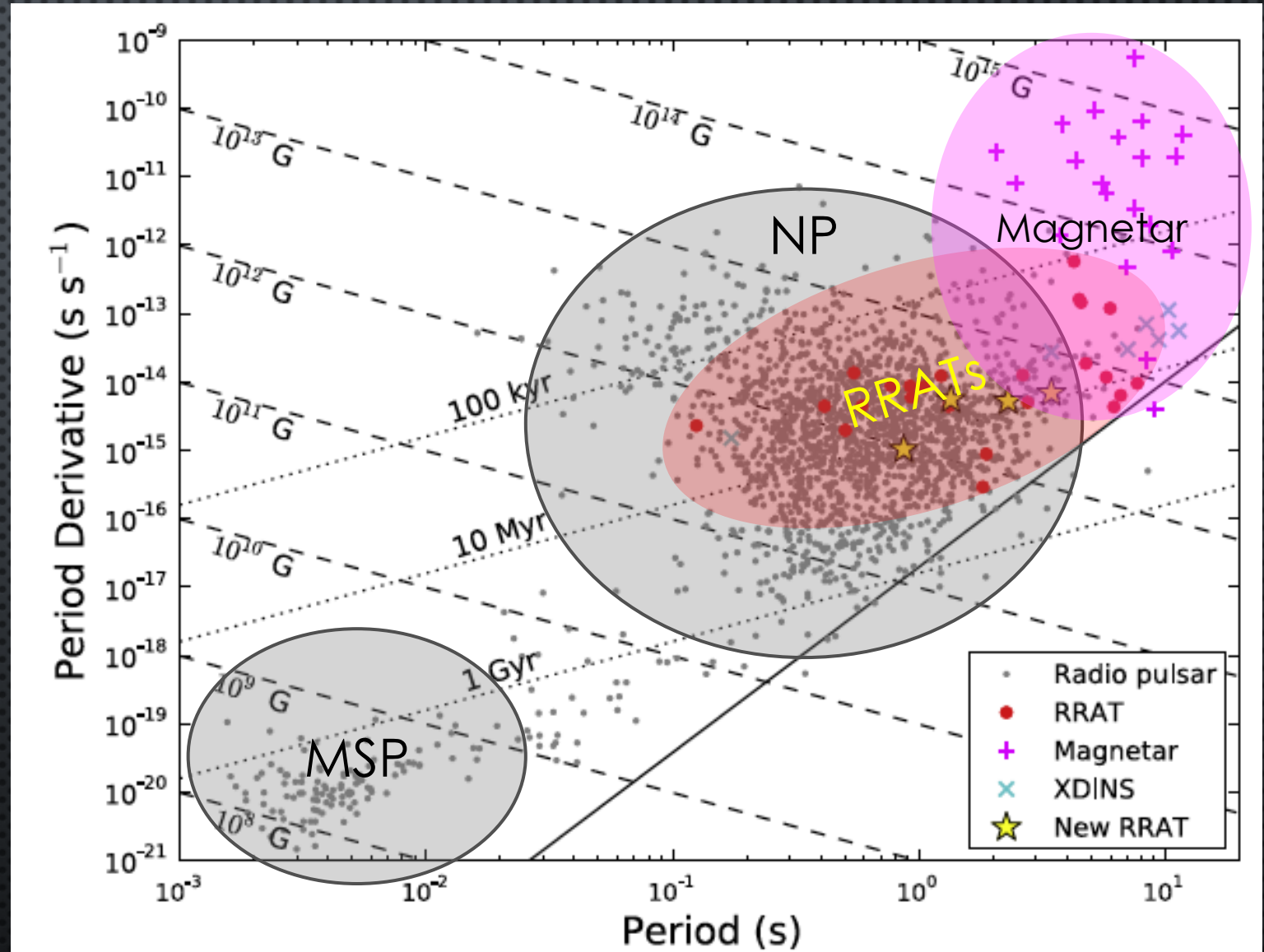


Karako-Argaman et al. (2015)

RRATs: $P - \dot{P}$

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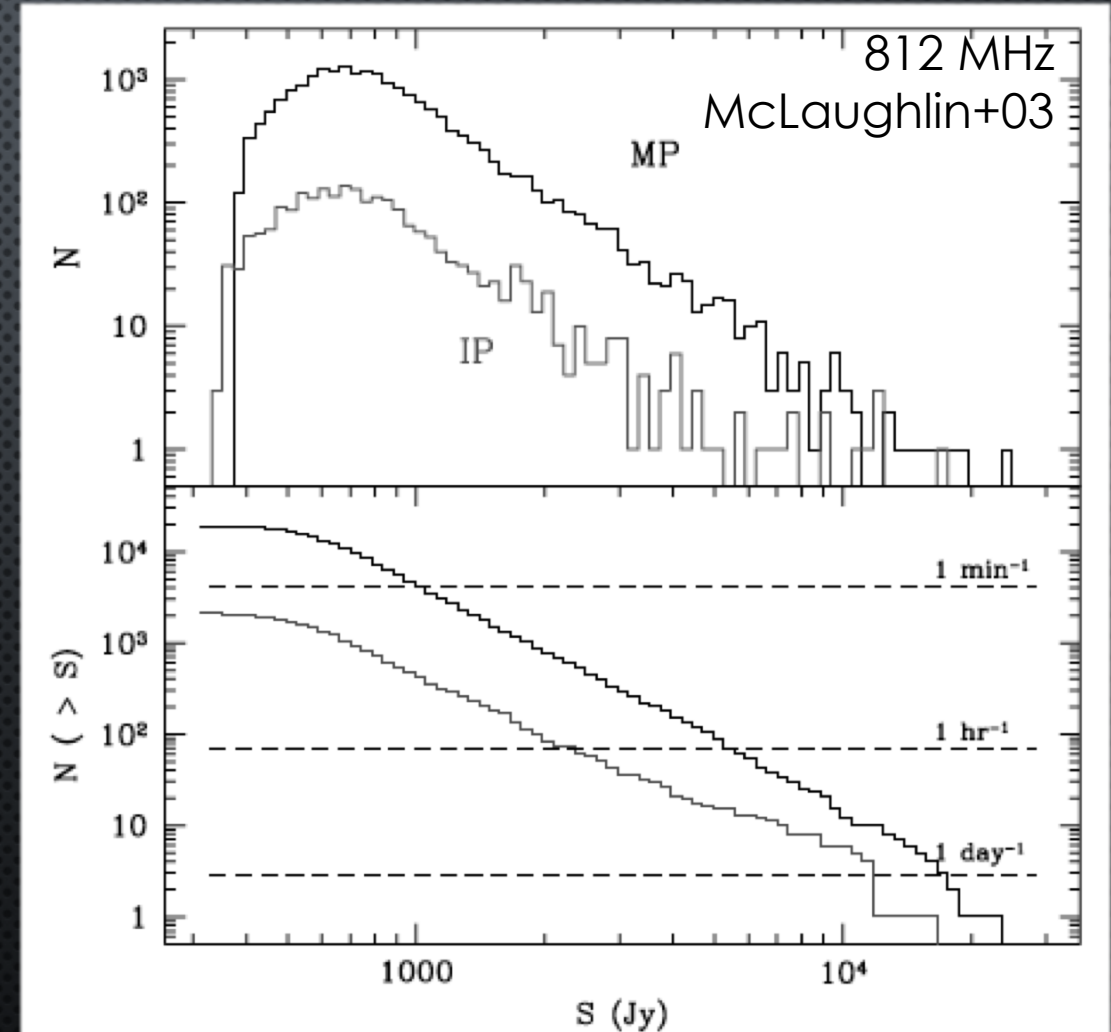
Both P (and $\dot{P}$) & B
are located between
NP and Magnetar ?



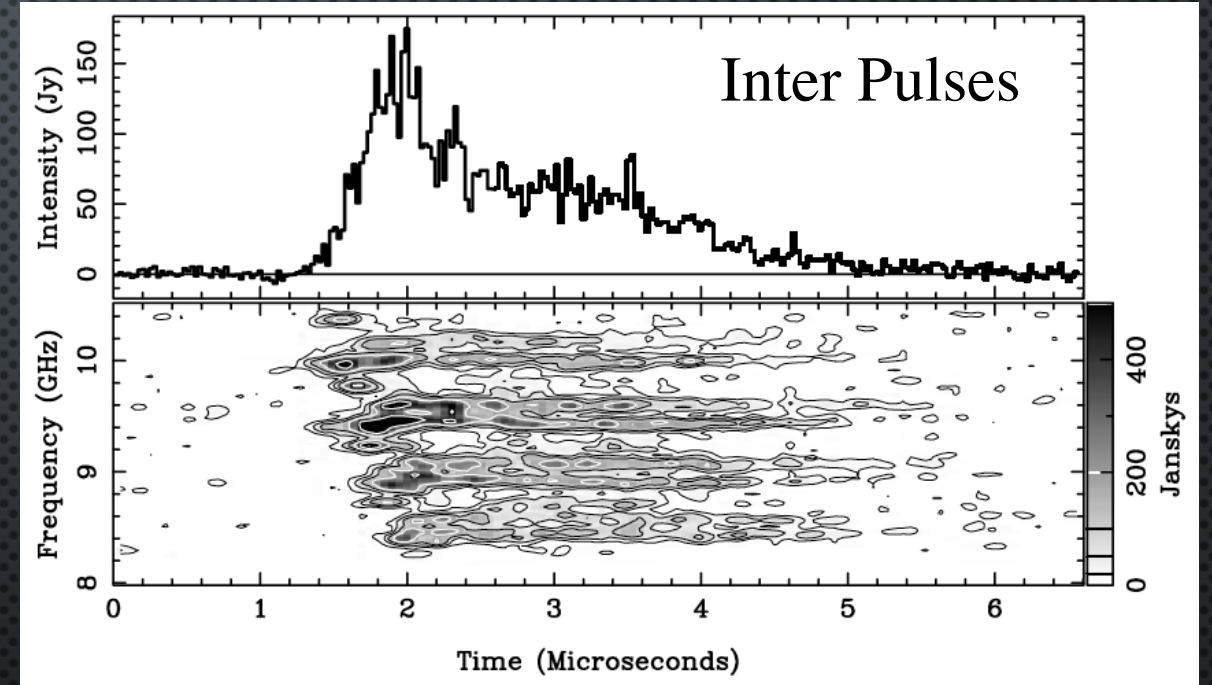
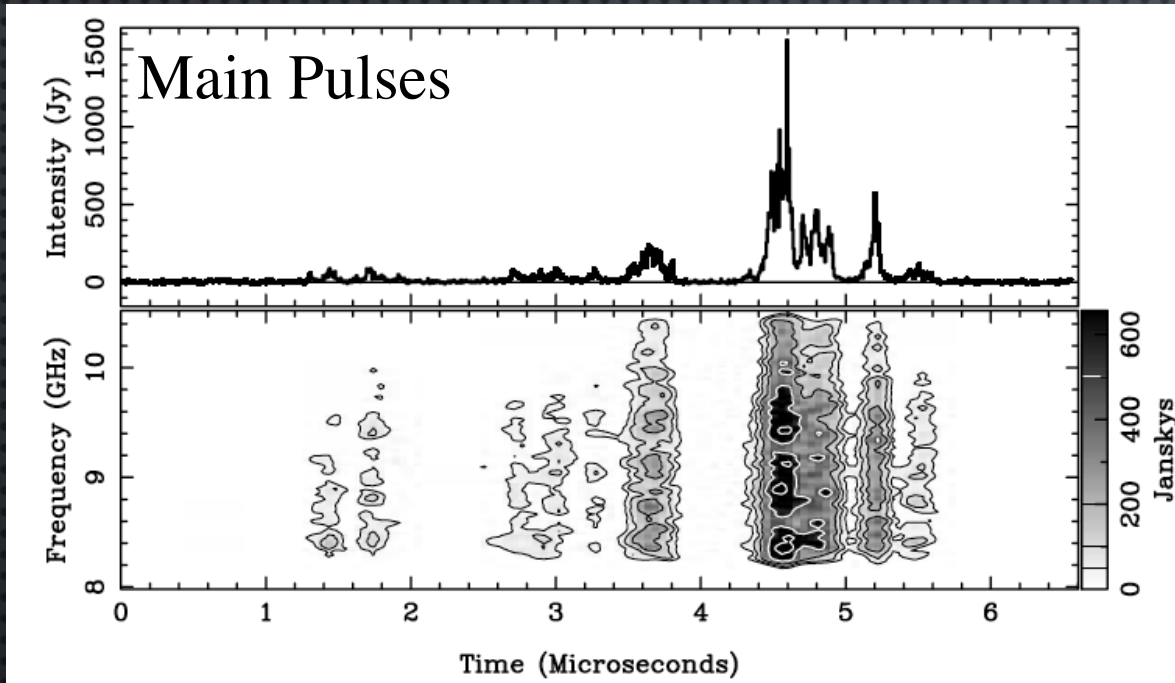
Karako-Argaman et al. (2015)

Pulsar Giant Radio Pulse (GRP)

- $> 10^3$ times stronger than normal pulse
- GRP intervals are a few min – a few hours depending on frequency
- ~ 10 pulsars have GRP



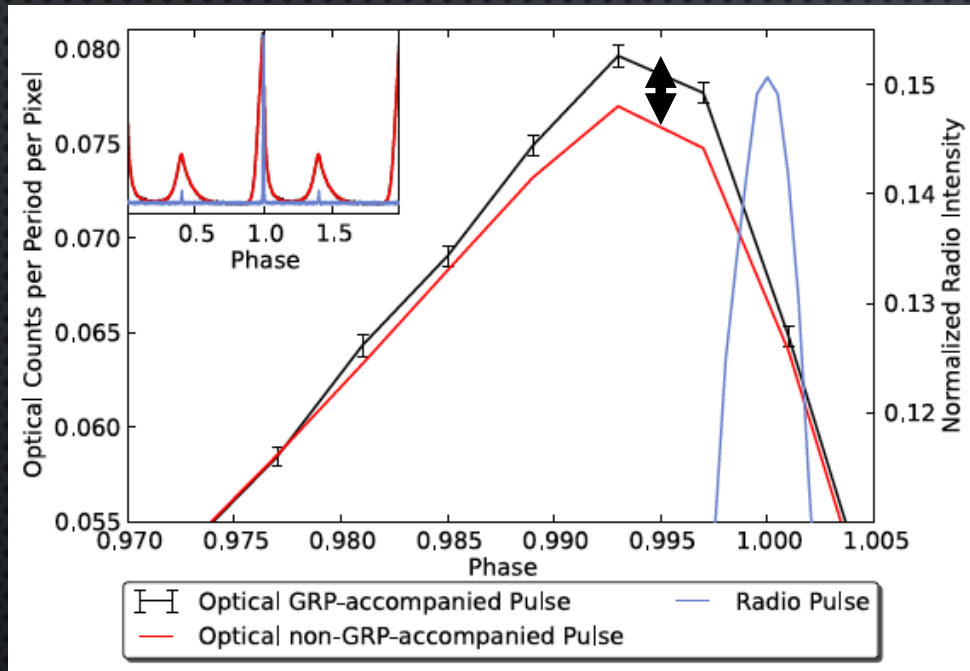
Pulsar GRPs – micro structure



- Consist of several “microbursts”
- Each pulse is well resolved
- More dispersed than main pulse

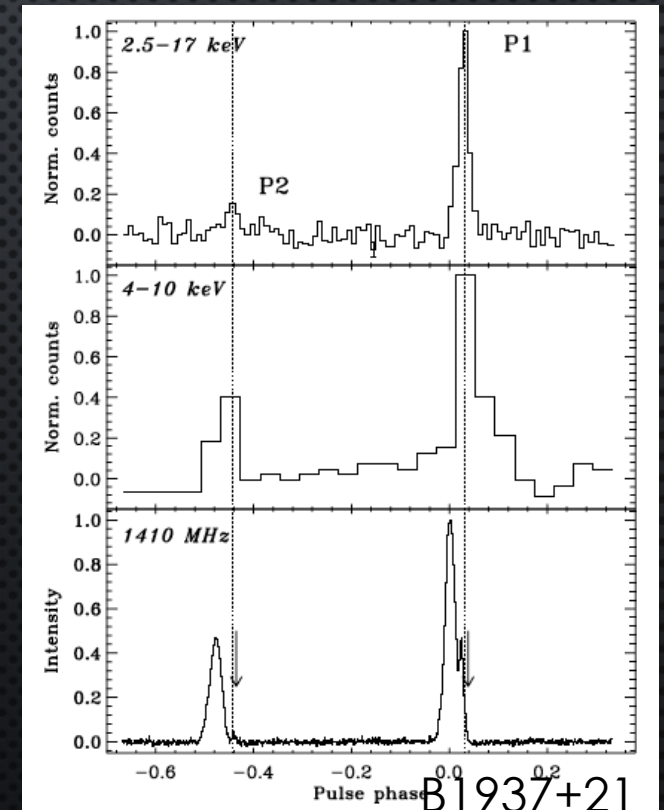
Pulsar GRPs – correlation between other λ

Optical Enhancement ($\sim 3\%$ increase)

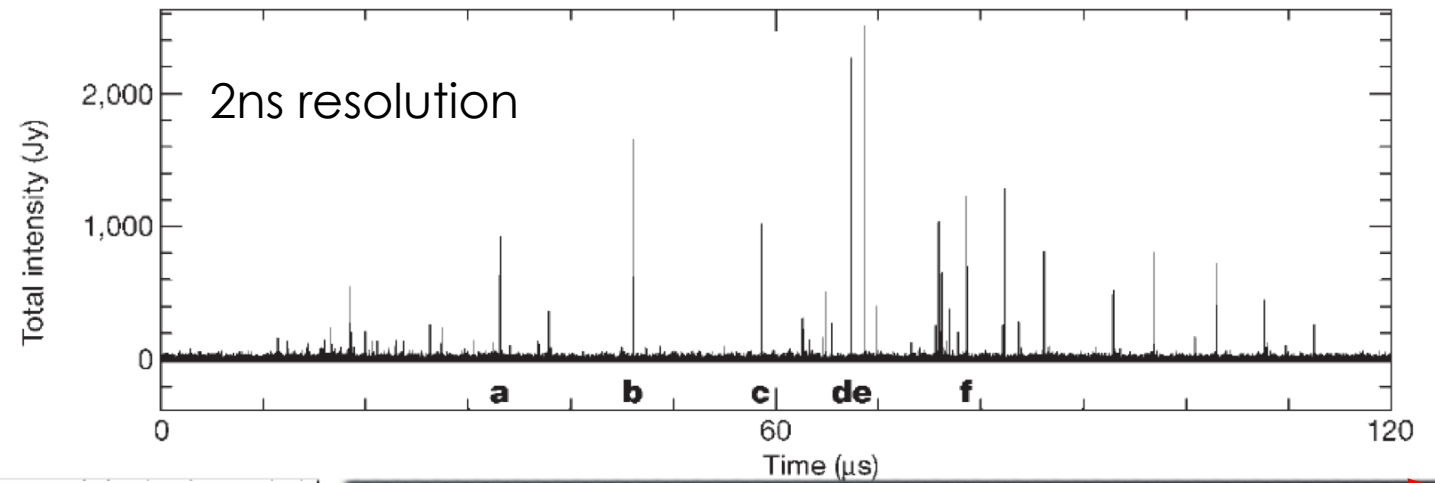
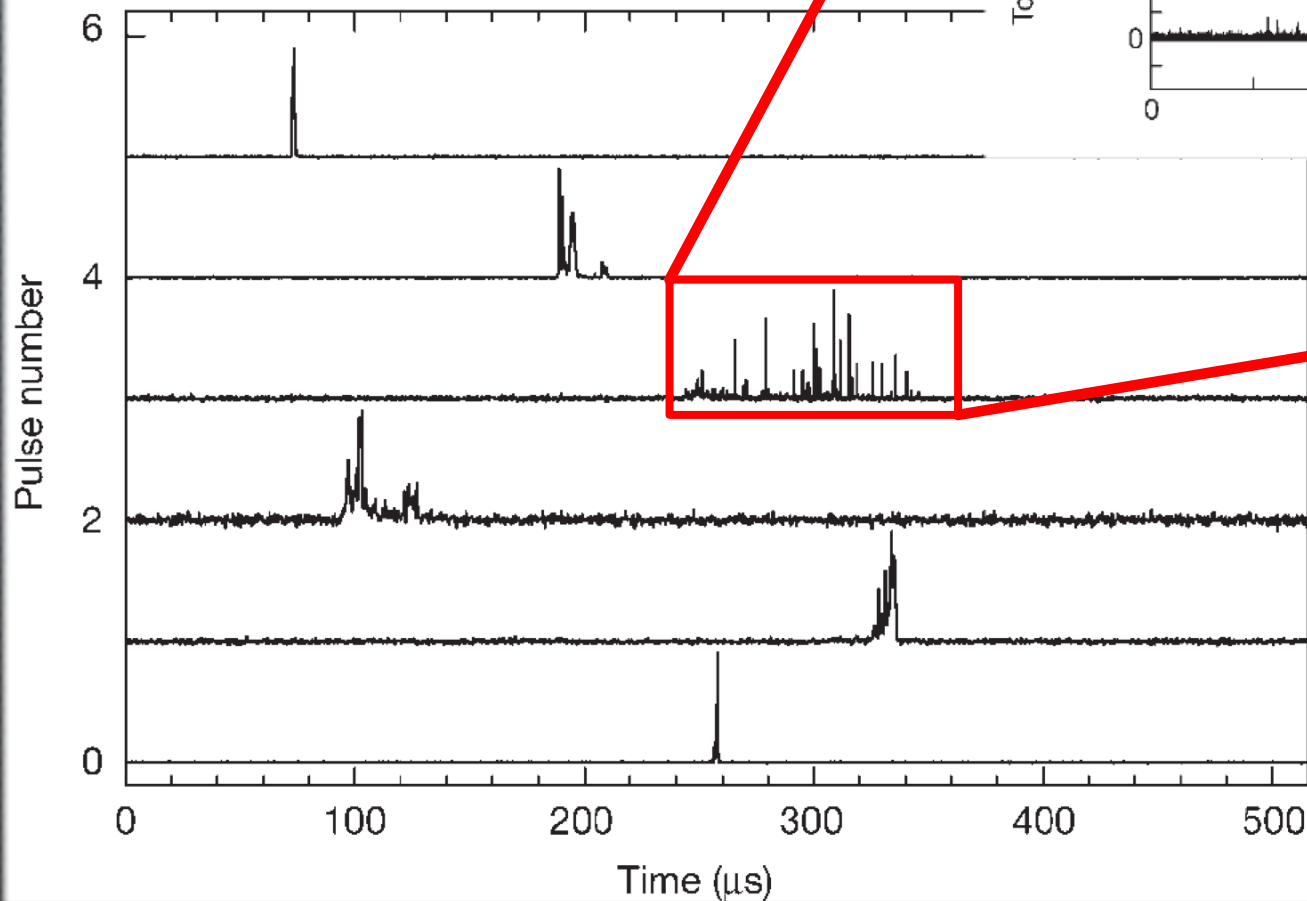


Strader et al. (2013) but the data originated from Shearer et al., *Sci*, (2003)

- Crab: no strong correlation between radio and high energy (soft X-ray to VHE gamma-ray; Lundgren+95, Bilnous+11, 12, Aliu+12)
- MSP B1937+21: phase of both radio and X are almost synchronized? (Cusumano+03)
- Same emitting region?



Nano-Shot

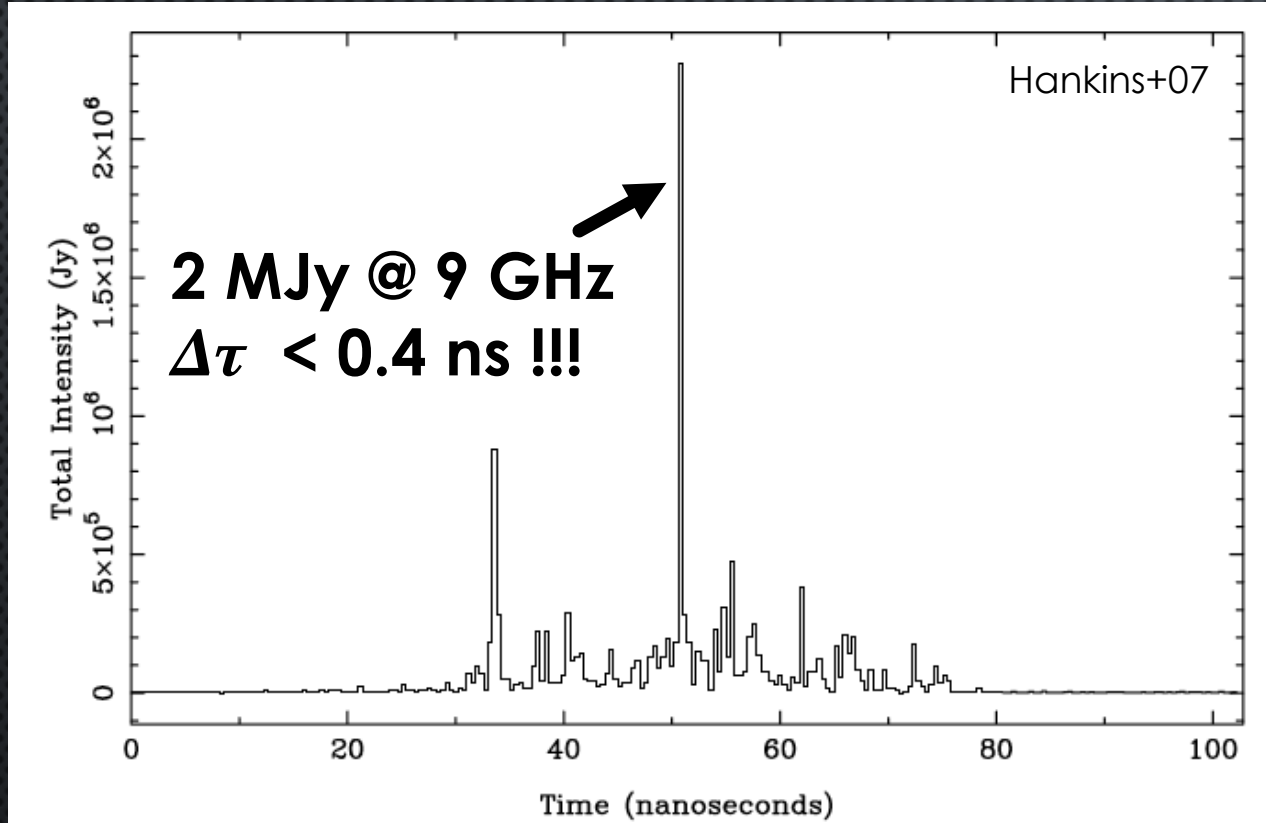


- Frequency ν : 5.5 GHz and 8.6 GHz (higher than typical obs.)
 - Avoiding pulse-width broadening
- Wide band: 0.5 and 1 GHz
 - Higher time resolution ($\sim$ ns)

$$\Delta\tau < 2 \text{ ns} !!!$$

Hankins+03, *Nature*

Extreme *Nano-Shot*



■ Observation:

- $\nu = 9.25 \pm 1.1$ GHz
- time resolution of ~ 0.4 ns

■ Emitting Region:

- $R \sim 12$ cm (!?)
- $T_B \sim 10^{41}$ K

→ Assuming relativistic motion
($\gamma \sim 10^2 - 10^3$)

- $R \sim 10^3 - 10^5$ cm
- $T_B \sim 10^{35} - 10^{37}$ K

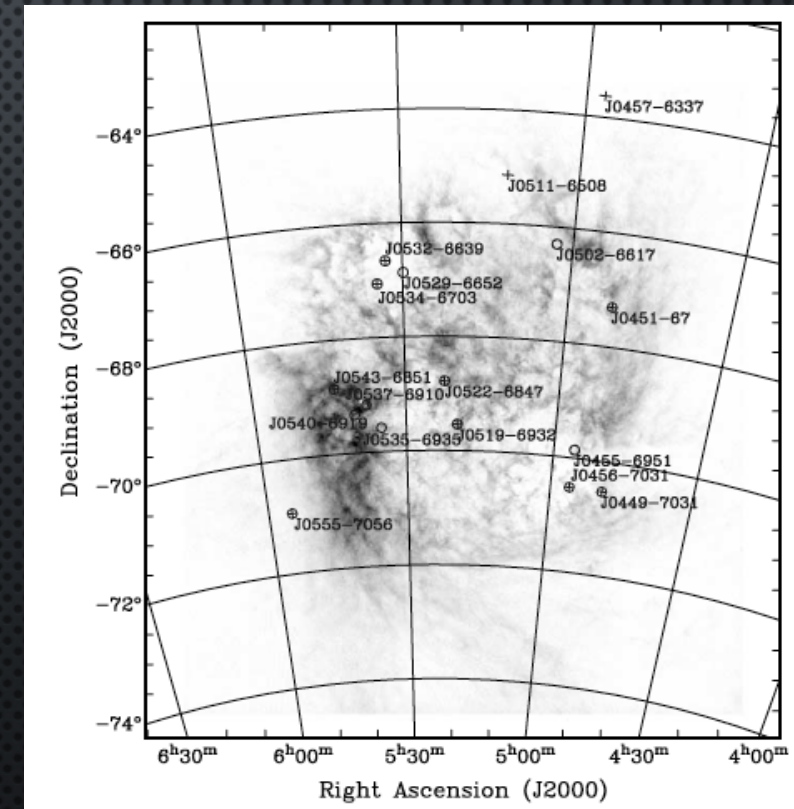
Summary + α

■ Transients associated with Pulsar (neutron star)

- Emission-mechanism / -region still under the debate
 - Multi-band obs. is essential
- Some correlation between opt. and radio of GRP in crab
 - In case of other pulsars?
- Except for crab, no intensive study at other λ
 - Crab : 16-17 mag, a few : 23-24 mag at optical

■ Potential probe to search for extragalactic pulsars

- 20 extragalactic pulsars located at LMC (16) and SMC (4)
- GRP from LMC pulsar (B0540-69, Johnston+03)
- Relation with (repeating) FRBs?



LMC pulsars (Manchester+06)

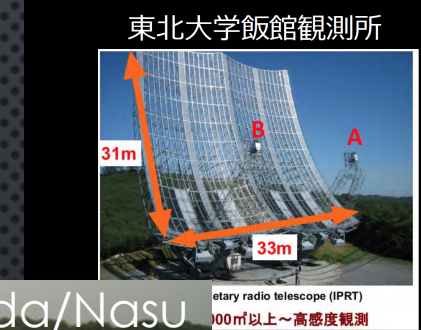
Nano-shot (or GRP) survey

■ Japanese Radio Telescopes

- Low frequency (< 2 GHz):
Tohoku Univ., Waseda Univ.,
NICT, JAXA
- Mid frequency (6-8 GHz): Ibaraki
Univ., Yamaguchi Univ.

→ suitable for nano-shot search

■ Based on pulsar catalog or local group (?)



Tomo-e spec

Sensitivity

Sensitive wavelength	350 to 700 nm
Photoelectric conversion efficiency	0.5 at a peak of 500 nm
Read noise (2 fps)	1.9, 4.3, 9.9 e ⁻ in High-, Mid-, Low-gains
Well depth (full)	6,400, 26,000, 60,000 e ⁻ in High-, Mid-, Low-gains
Well depth (linearity < 1%)	5,800, 24,000, 48,000 e ⁻ in High-, Mid-, Low-gains
Dark current	0.1 e ⁻ sec ⁻¹ pix ⁻¹ at 277K 1 e ⁻ sec ⁻¹ pix ⁻¹ at 293 K
Sky background (dark night)	52 e ⁻ sec ⁻¹ pix ⁻¹ (no filter) 5 e ⁻ sec ⁻¹ pix ⁻¹ (V-band)
5σ limiting mag (no-filter, High-gain)	17.2, 18.8, 20.0 mag at t _{exp} of 0.1, 1, 10 sec in the g-band
Photometric stability	a few milli-mag
Slit-less grism spectroscopy (optional)	350 to 700 nm, R ~ 10

Simulated low-intensity optical pulsar observation with single-photon detector (*Research Note*)

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ABSTRACT

Context. Optical radiation of pulsars offers valuable clues to the physics of neutron stars, which are our only probes of the most extreme states of matter in the present-day universe. Still, only about 1% of all cataloged pulsars have known optical counterparts.

Aims. The goal of this work is to develop an observational method optimized for discovering faint optical pulsars.

Methods. A single-photon detector transforms the signal received by the telescope into a pulse sequence. The events obtained are time tagged and transformed into a histogram of event time differences. The histogram envelope presents the autocorrelation of the recorded optical signal and thus displays any periodicity of the input signal.

Results. Simulations show that faint pulsars radiating in the optical regime can be detected in a straightforward way. As an example, a fictitious pulsar with a V -magnitude of 24.6 mag and a signature like the Crab pulsar can be discovered within one minute using an 8-m class telescope. At the detector's peak sensitivity the average optical flux density would then amount to $F_{\nu} = 0.63 \mu\text{Jy}$. With a 40-m class telescope, such as the forthcoming European ELT, the detection of optical pulsars with magnitudes $V < 30$ mag is within reach for a measurement time of one minute. A two-hour “blind search” with the ELT could reach $V \sim 31.3$ mag.

Conclusions. This method allows detecting faint periodic optical radiation with simple equipment and easy signal processing.

Key words. instrumentation: detectors – pulsars: general – pulsars: individual: Crab pulsar (PSR 0513+21) – methods: data analysis