Tomo-e Gozen による 可視パルサーサーベイ

Kiso Schmidt Symposium
Jul. 9, A.D.2018

ICHIKI Makoto (Institute of Astronomy, D1)

- パルサーについて

・わかっていること
・可視光での研究

- Tomo-e Gozenによるパルサー観測

・Crab pulsarの試験観測
・Tomo-e による可視パルサーサーベイ

- その他現状

・周期が未知の天体に対する発見方法の検討
・X線と電波との同時観測
・マグネターサーベイの検討

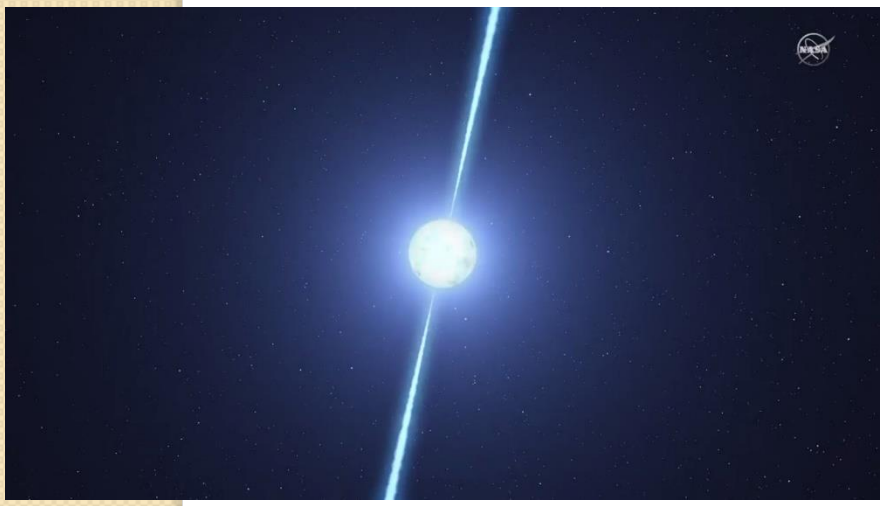
パルサーについて

パルサーについて

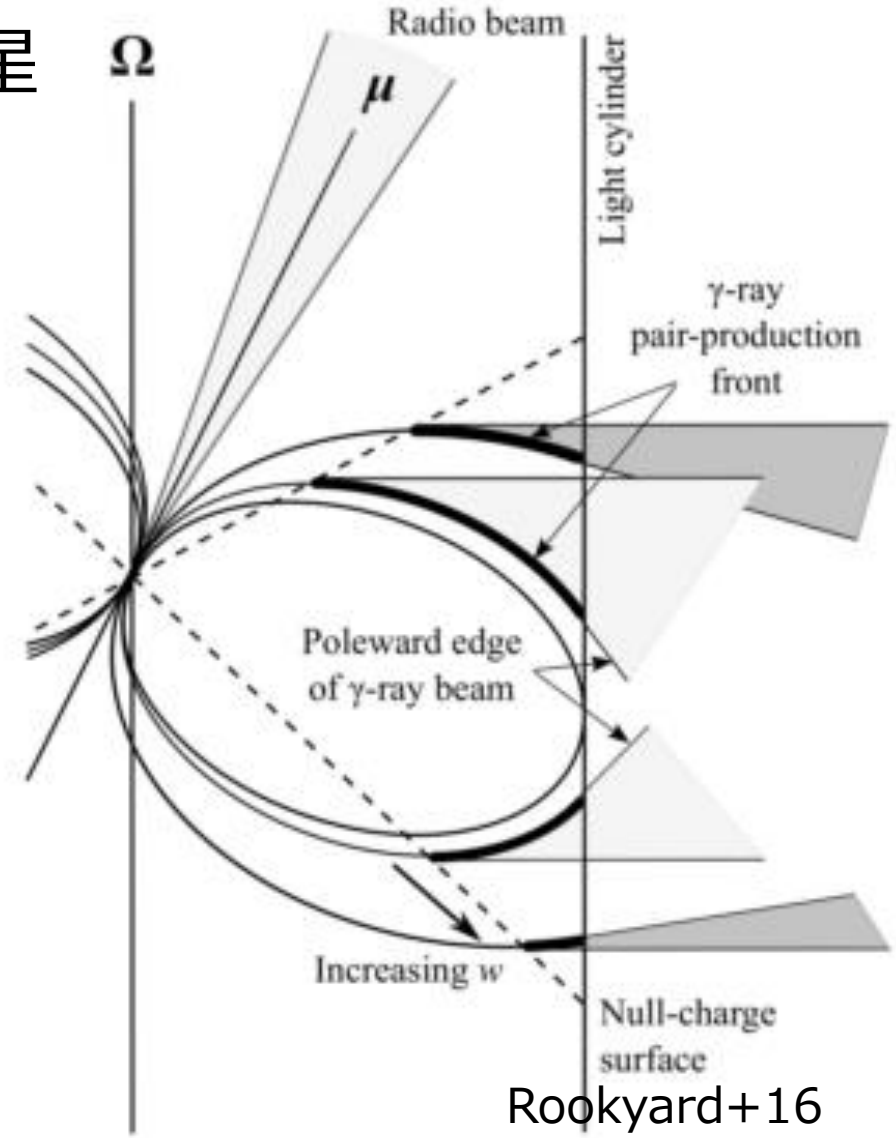
・パルス信号を発する天体（ビーミングと磁気極のずれによる）

・速い周期（速い自転 Period≲sec)

・強磁場 (~10^{12}G)の中性子星



Neutron star…
Radius ~ 10km
Mass ≳ 1.4 solar mass
Only visible Nuclear matter



Rookyard+16

Rotation-powered pulsar

Spin-down Luminosity

I…moment of inertia; P…period

$$\frac{dE}{dt} = -4\pi^2 I \frac{\dot{P}}{P^3}$$

Magnetic Dipole emission

r…surface of neutron star

$$\frac{dE}{dt} = \frac{2}{3c^3} r^6 B^2 \left(\frac{2\pi}{P}\right)^4 \sin^2\alpha$$

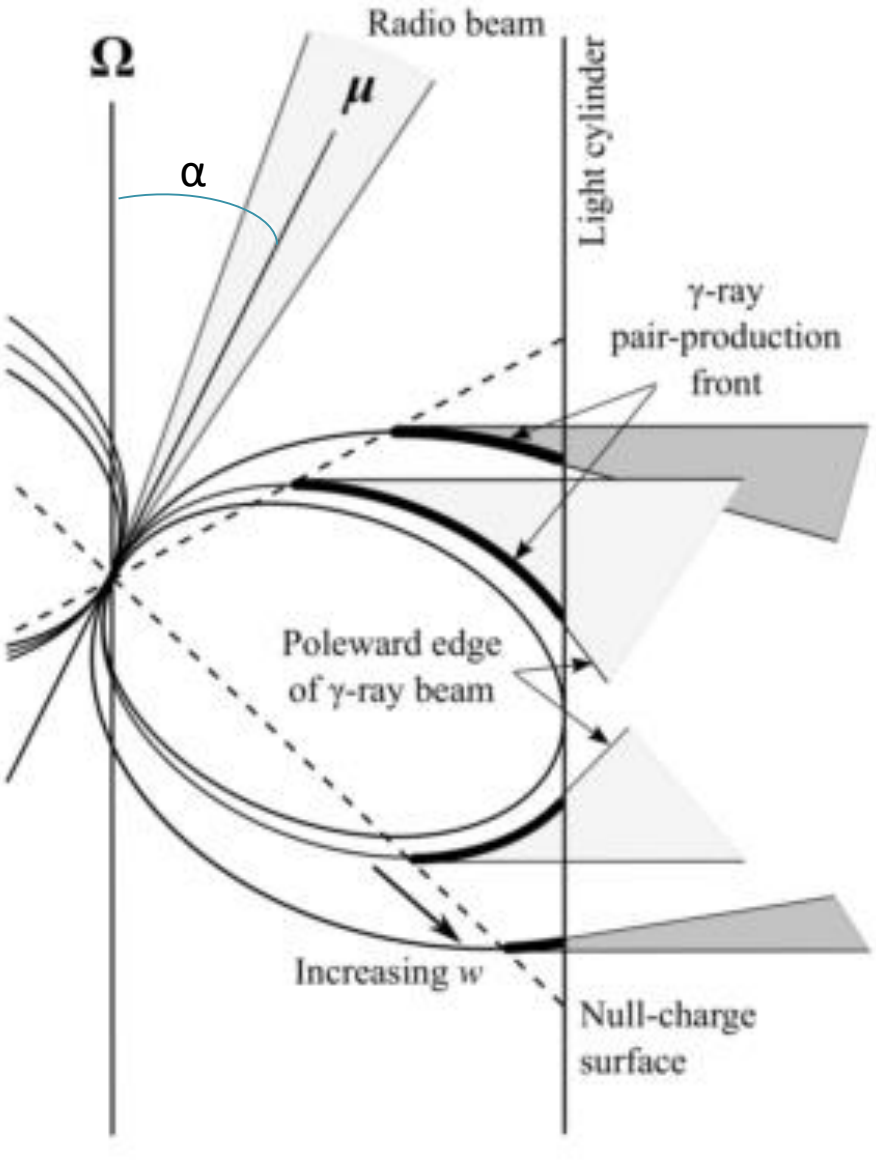
$\rightarrow$

the “Surface Magnetic Field”

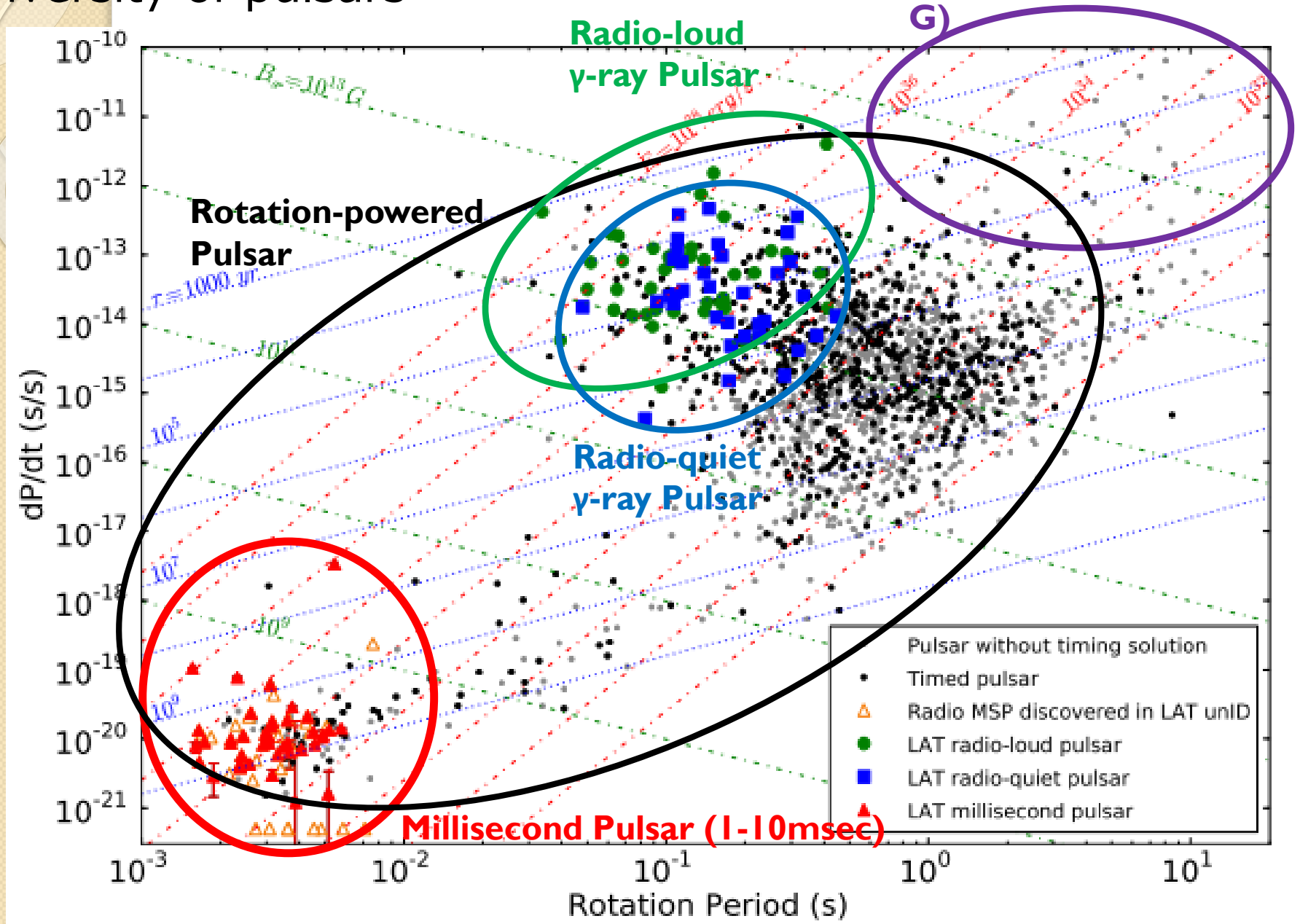
$$B \simeq 10^{12} G \left(\frac{\dot{P}}{10^{-15}}\right)^{\frac{1}{2}} \left(\frac{P}{1s}\right)^{\frac{1}{2}}$$

the “Characteristic Age”

$$\tau \simeq 16 Myr \left(\frac{10^{-15}}{\dot{P}}\right)\left(\frac{P}{1s}\right)$$

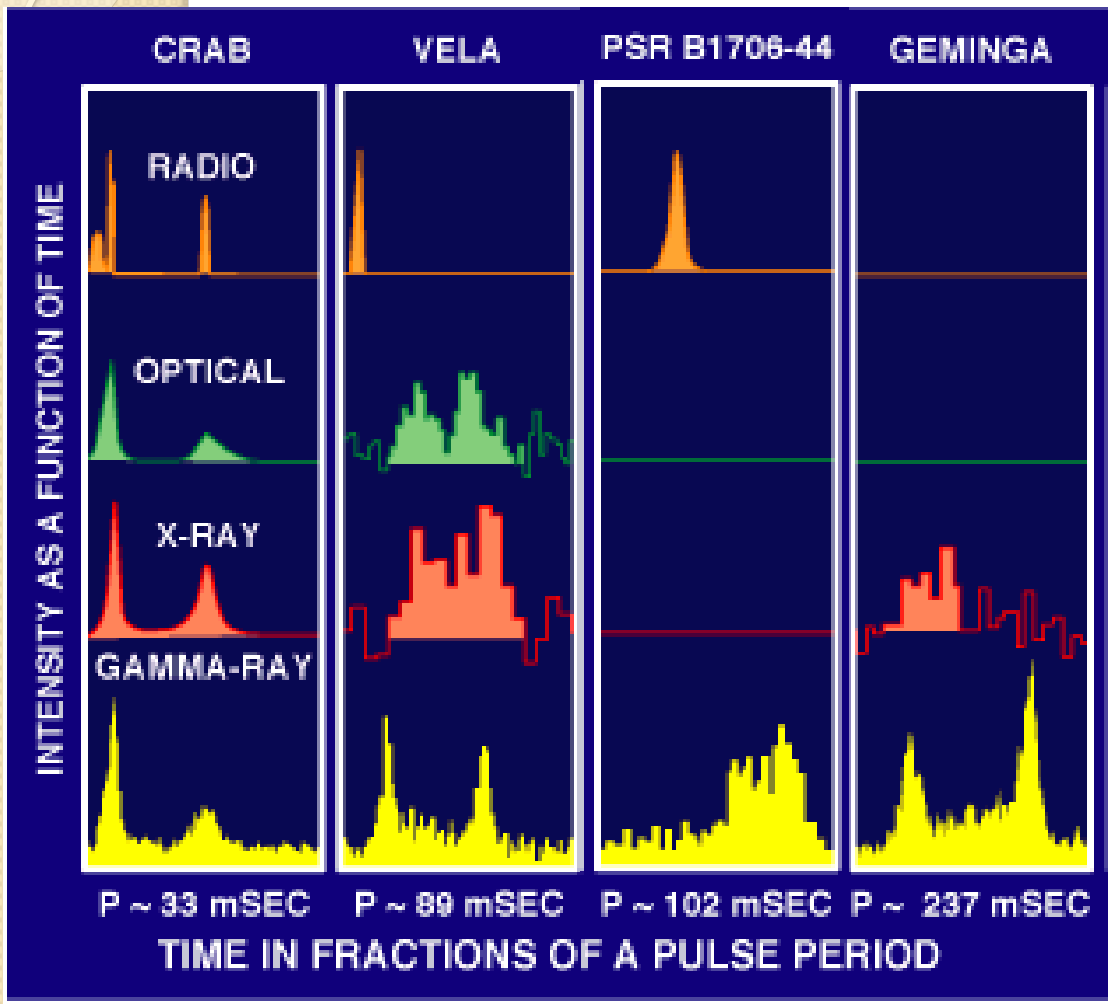


Diversity of pulsars



Abdo+13

光度曲線の多様性



in Radio,
~2000 pulsars
are detected.

In X-ray
~400 pulsars

In γ-ray
~200 pulsars

Thompson 04

In optical bands,
only 5 phase-resolved pulsars are detected.

Optical observation for pulsars

- 可視光でパルスが見える天体は　5個のみ

- 全て電波と高エネルギーで発見されたパルサーに対する
follow-up 観測　で見つかったもの

- Crab パルサーの観測からわかっていること↓

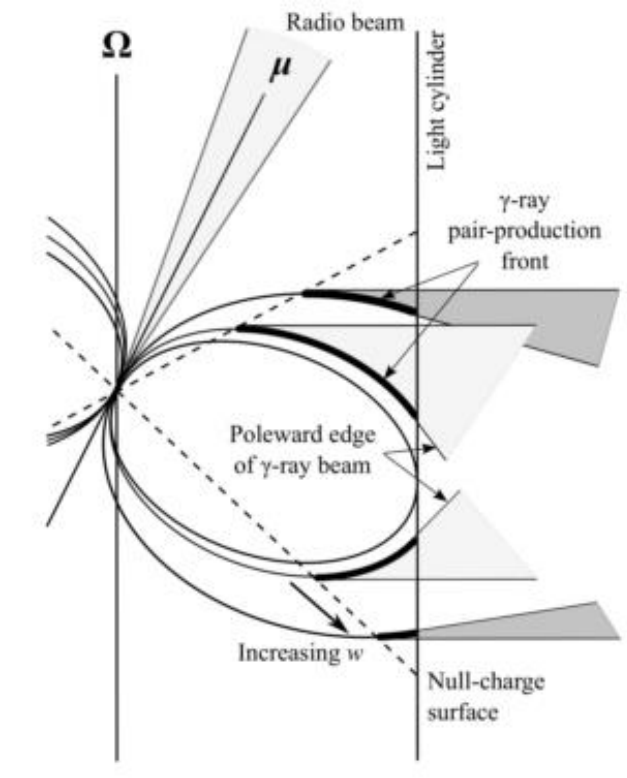
  - Luminosity variation of the pulses is
less than 1% in a year.

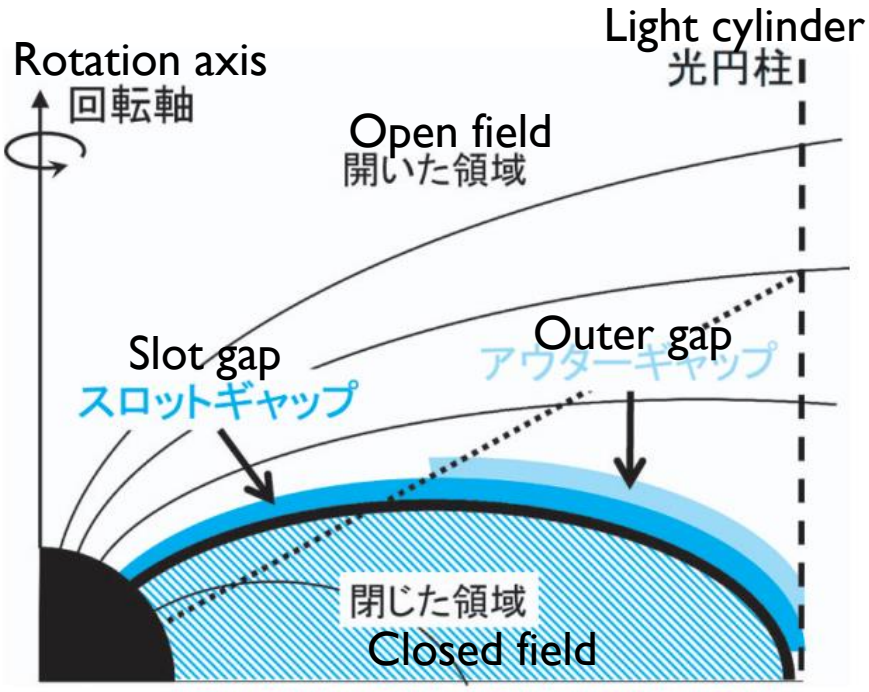
  - Correlation with Giant Radio Pulse (GRP) are present.

  - Polarization has a peak in the precurser phase.

Radiation zone

	Young pulsars	**Old pulsars**
Radio	Polar cap (coherent) Slot gap?	Polar cap (coherent)
Optical	Slot gap? Surface (thermal)	Slot gap? Surface (thermal)
X-ray		
γ-ray	Outer gap	Outer gap?





Kisaka+2012

Tomo-e Gozen
によるパルサー観測

Tomo-e Gozen Camera

Extremely wide field CMOS camera

Telescope	Kiso Schmidt (aperture105cm, seeing~4")
Filed of view	22 deg^2 in ϕ 9 deg
Sensor	CMOS (1k x 2k) x 84
Frame rate	2 frame / sec (0.5sec/frame)
Read out time	<0.5sec
Wavelength	optical

・部分読み出し (248 x 24 pix) → 5.5 msec / frame

and ~0.05deg^2 (84 sensors)

・little dead time

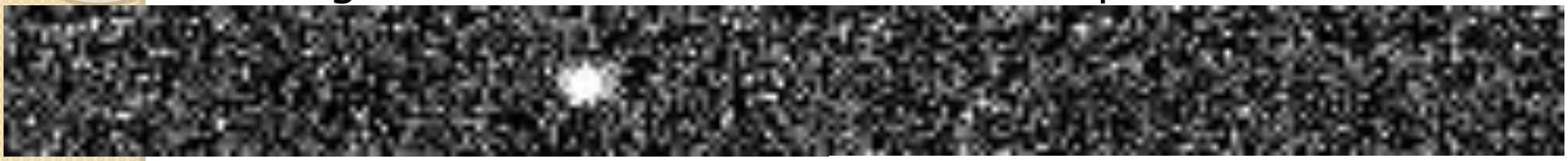
→ 初めての可視パルサーサーベイがTomo-eでできるかも。

Test observation for Crab pulsar

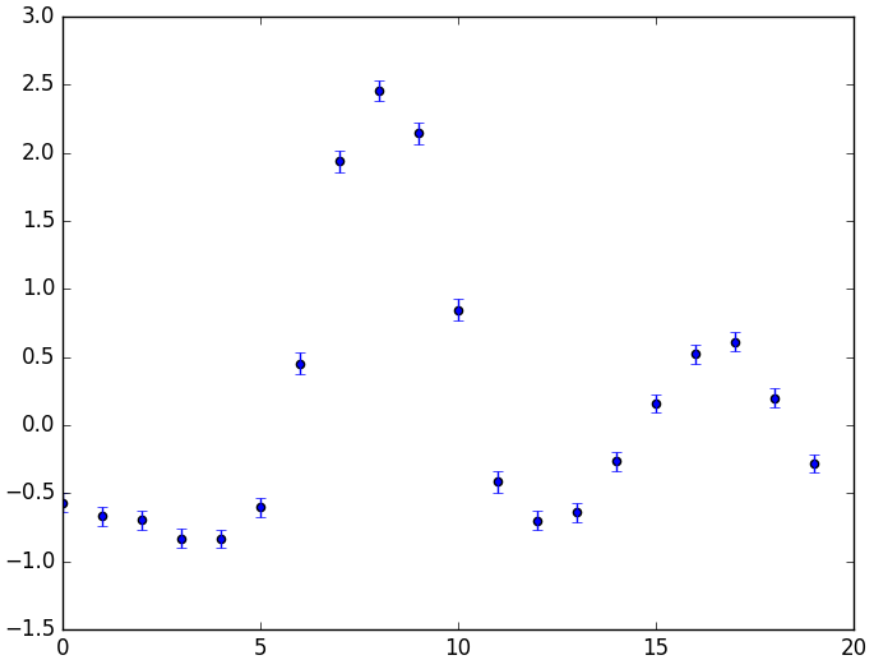
↓Mean image for 50000 frames (322 sec)

Oct. 2017 by Tomo-e Q0

↓ “Mean image of Peak 10000 frames” – “Off-peak 40000 frames”



P=33.738 msec (UT)



cf. 電波での周期 P=33.741 msec (TDB)

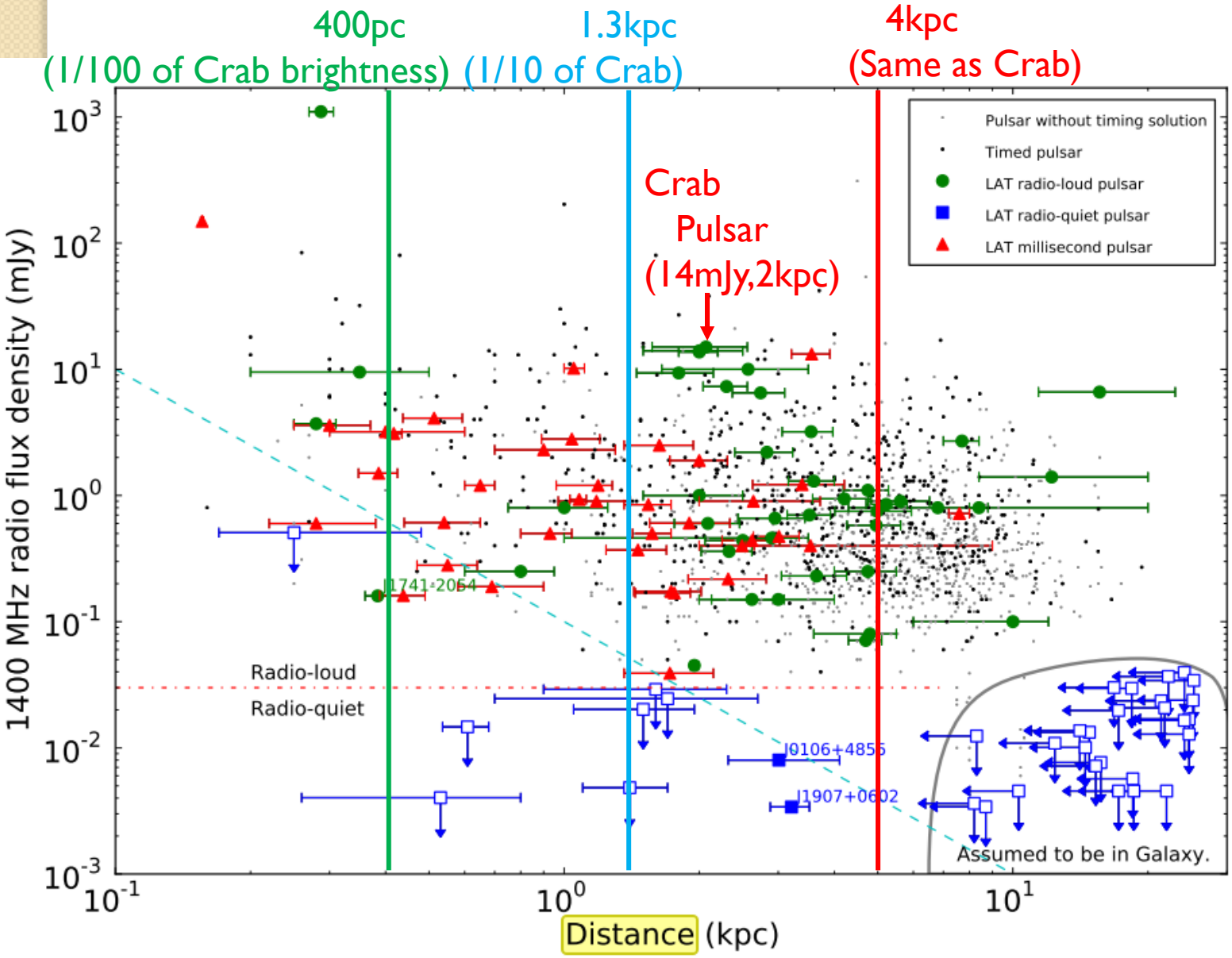
frames	Pulses	SD	S/N
100	∼20	0.73	8
300	∼70	0.46	13
1000	∼200	0.27	22
3000	∼700	0.19	30
10000	∼2000	0.13	50

S/Nと撮像回数の関係

Sufficient S/N for pulsar survey

Tomo-e Gozenによる
可視パルサーサーベイ

Survey depth (for 6 sec /FoV)



Survey Parameters

Conditions

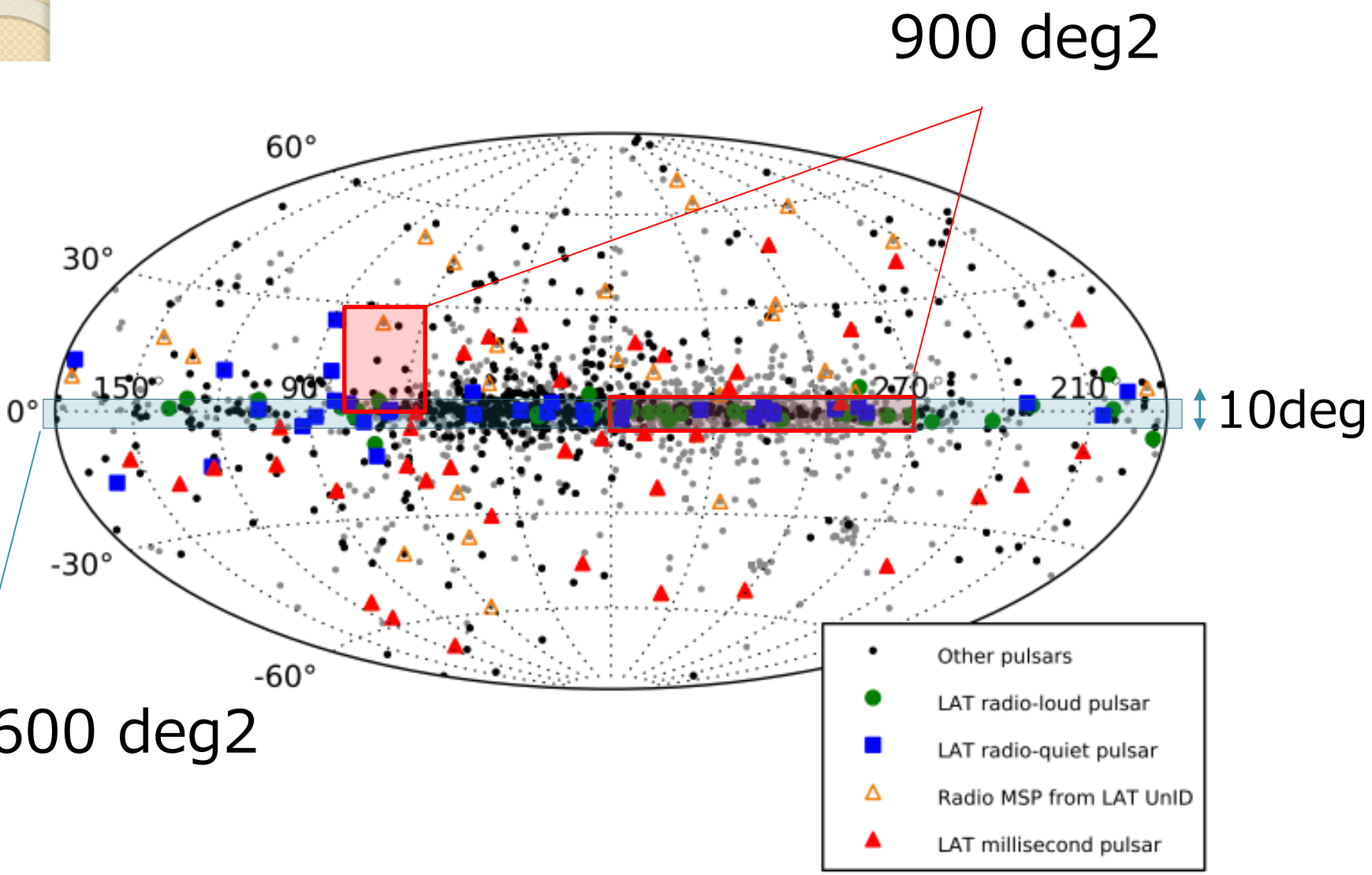
- FoV of Tomo-e Gozen: 0.04 deg^2
- Time for Telescope moving: 6 sec

Parameters

- Total Exposure time
- Total Observation time

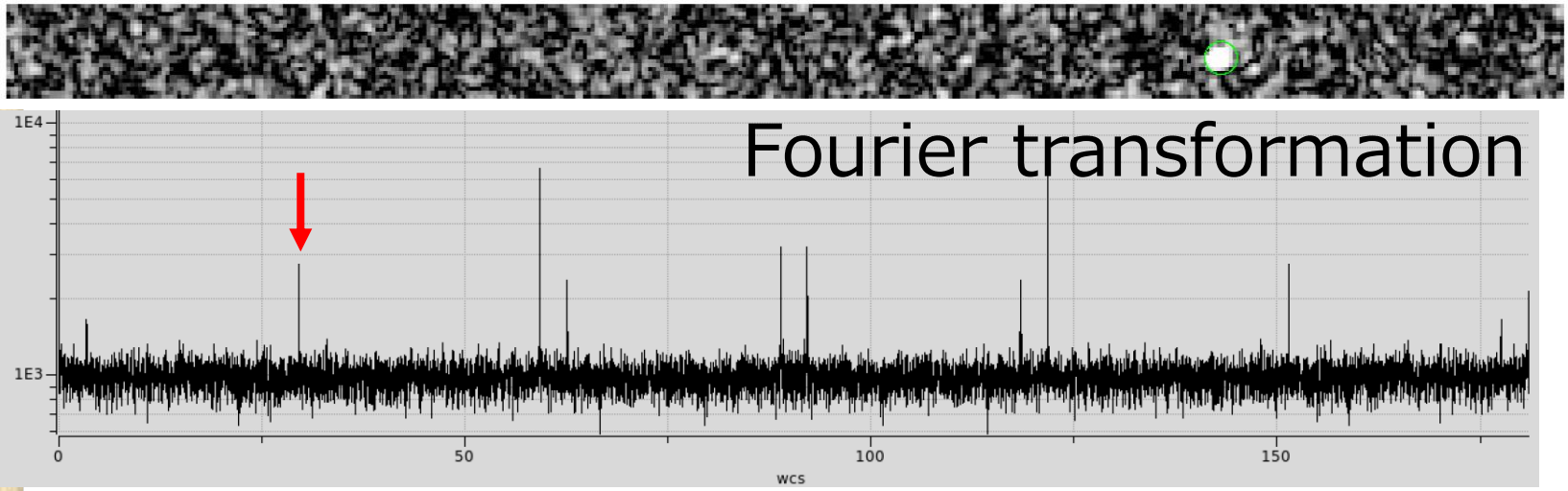
e.g. Observation of 6 sec / FoV for 10 nights
gives 950 deg^2
(x 4 season = 3800 deg^2)

Survey Area


900 deg2
60°
30°
0°
-30°
-60°
150°
90°
270°
210°
10deg
3600 deg2
Other pulsars
LAT radio-loud pulsar
LAT radio-quiet pulsar
Radio MSP from LAT UnID
LAT millisecond pulsar

Further studies

- Detection for pulsars that have unknown periods



周期のおおよその精度

10000フレームの場合

周期 33.746(2) [msec]

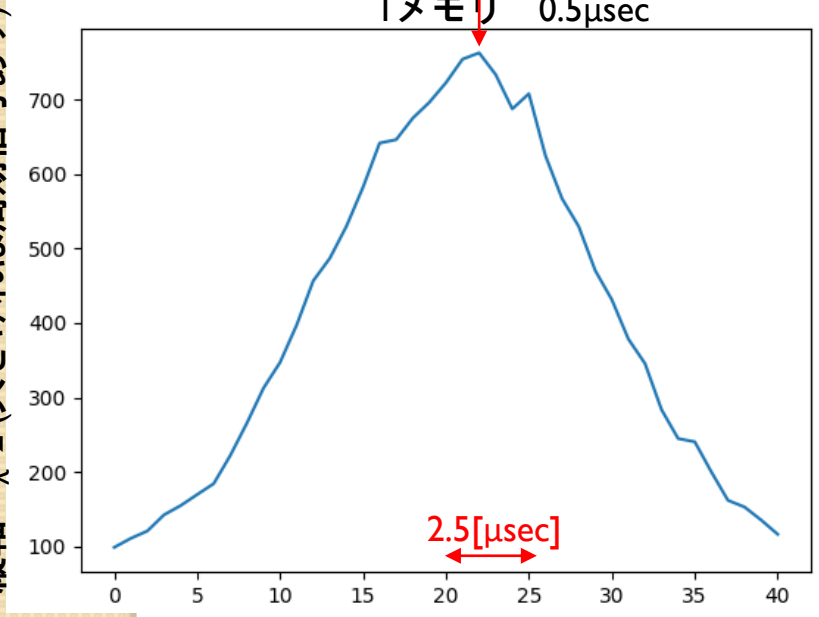
電波での周期

P = 33.7464765718070ms

横軸：P=33.745が20にあたる。

1メモリ 0.5μsec

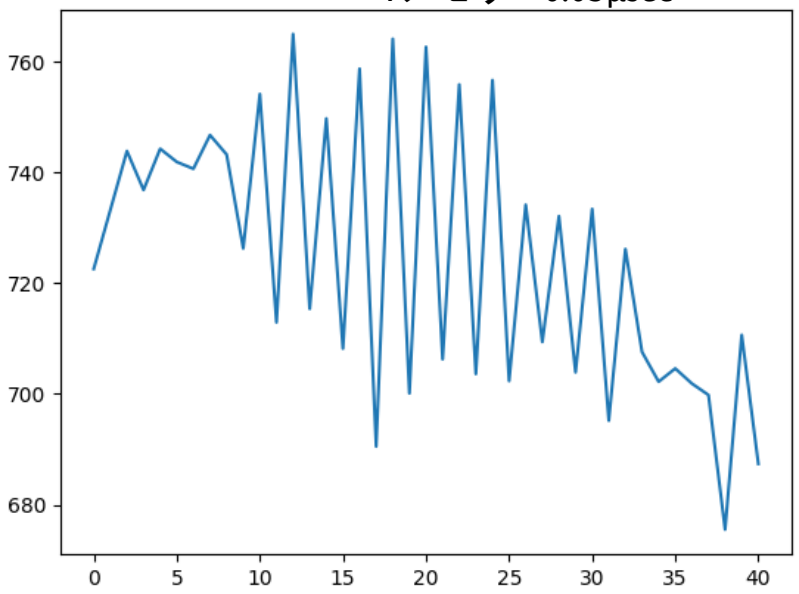
縦軸：χ^2 (大きければ周期信号あり)



1μ秒の桁はぎりぎり

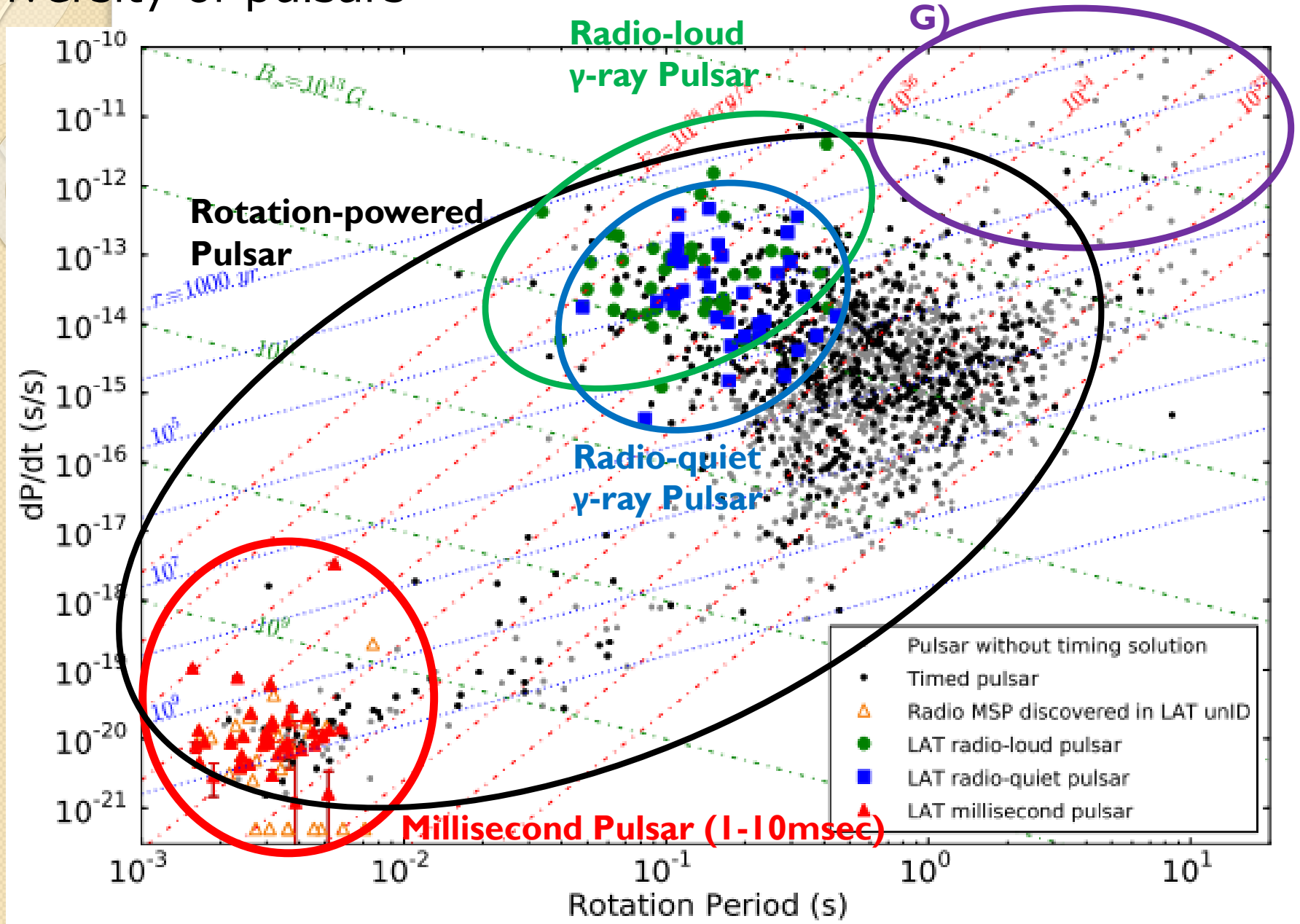
横軸：P=33.746が20にあたる。

1メモリ 0.05μsec



0.1μ秒の桁は特定できない

Diversity of pulsars



Abdo+13

Magnetar (a theoretical object) Turolla+2015, review

($B \gtrsim 10^{13}$ G) X-ray luminosity > spin down luminosity

Following observed objects are candidates for Magnetar.

- Anomalous X-ray Pulsar (AXP)

  discovered as pulsar in soft-X ray ($\sim 10^{34\text{-}36}$ erg/s)

- Soft Gamma Repeater (SGR)

  discovered as short burst (0.1 - 1 sec) in X/soft-γ ray

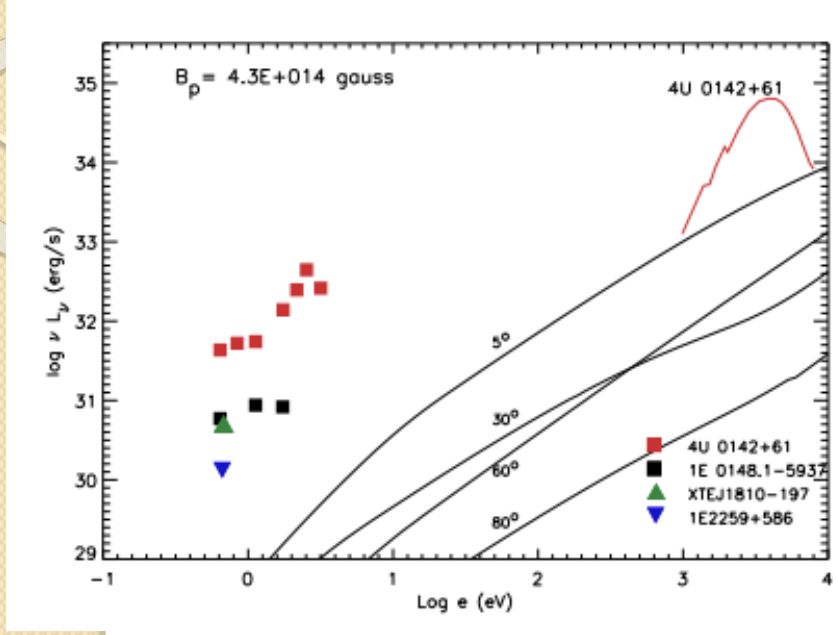
Common characteristcs

- lack of evidence of binary components
- pulsations in relatively long period, ~2-12sec
- large spin-down rate, $dP/dt \sim 10^{-13\text{--}11}$ s/s
- short(0.1-1s) & intermediate(1-40s) burst

Both are thought to be a single class, probably magnetar.

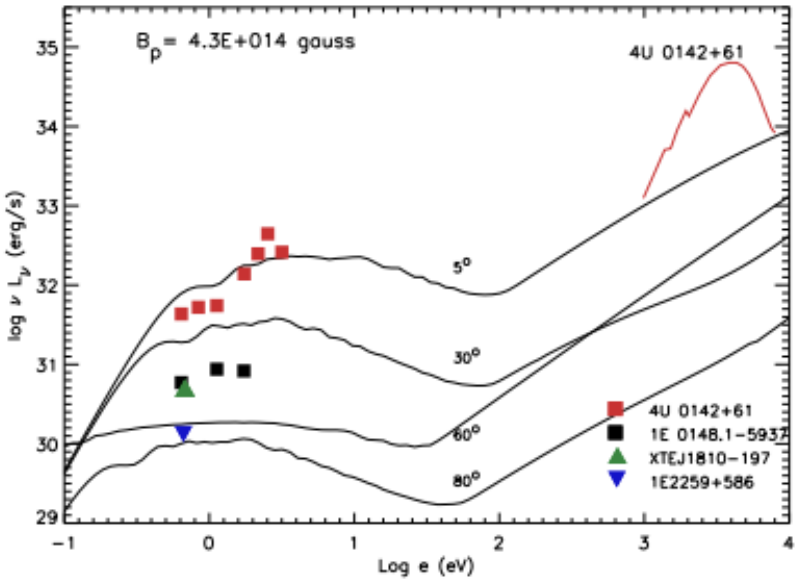
Magnetar in optical/IR

Cyclotron Radiation ↓



Zane+2010

+Coherent emission ↓



band energy

Radiation from N-particles

$$E^2 = \left| E_0(\lambda) \sum_{n=1}^{N} \exp\left(-i\frac{2\pi x}{\lambda}\right) \right|^2$$

$$= E_0(\lambda)^2 N \left(1 + (N-1)\left|\int \exp\left(-i\frac{2\pi x}{\lambda}\right) S(x)dx\right|^2\right)$$

E_0 : electric field for 1 particle

x : coordinate of a particle

S(x) : distribution of particles

When Distance between particles < wavelength

→ Coherent emission($\propto N^2$)