

# **X-ray studies of MSPs in Galactic Field and Globular Clusters**

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On behalf of

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# Outline

1. Introduction

2. **X-ray studies for two MSP binaries in Galactic field.**

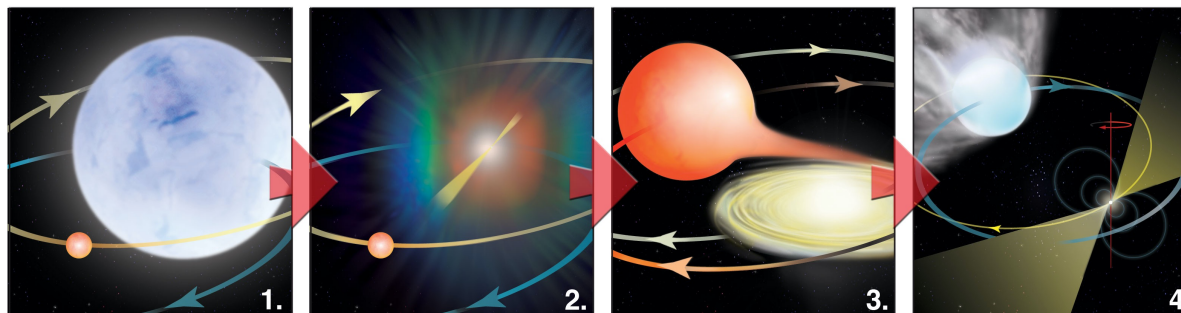
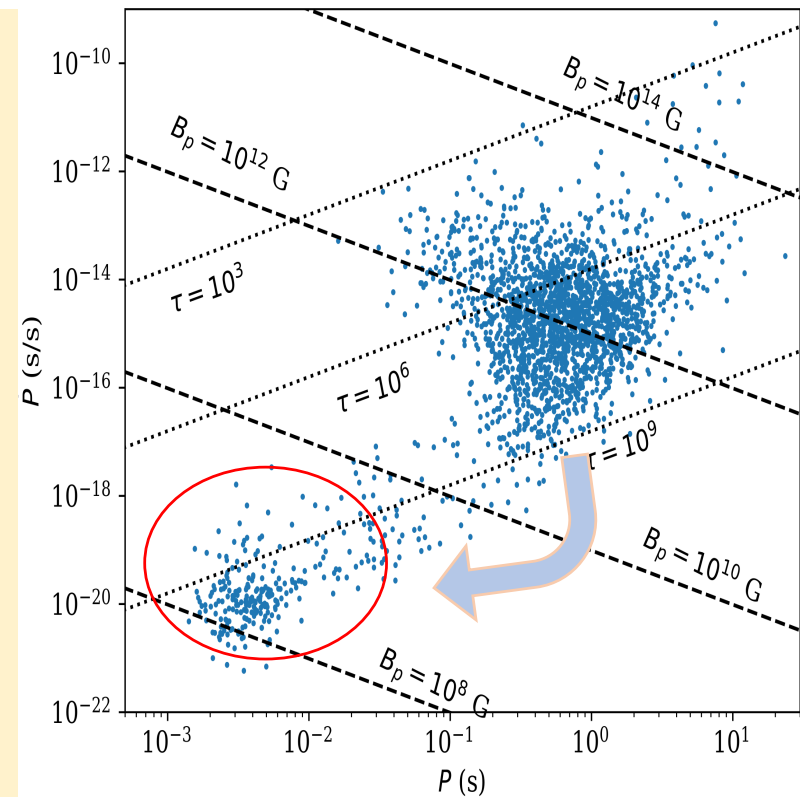
3. **Comparison between Galactic field and Globular cluster MSP properties.**

4. Summary

# 1 Introduction: Millisecond pulsar

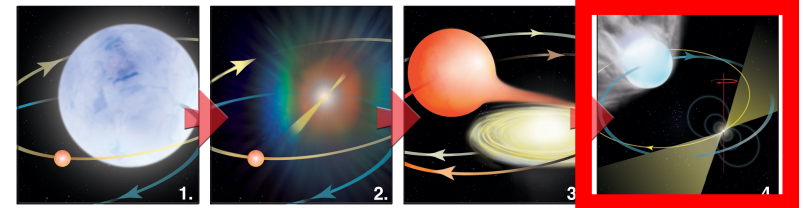
(Igoshev et al. 2021)

- Millisecond pulsars (MSPs):
  - Fast spinning:  $P_0 < 30\text{ms}$
- Population
  - Galactic Field (GF) MSPs  $\sim 420$ .
  - Globular Cluster (GC) MSPs  $\sim 280$ .
- **Recycle process** (Alpar et al. 1982).
  - MSP formation in binary system.



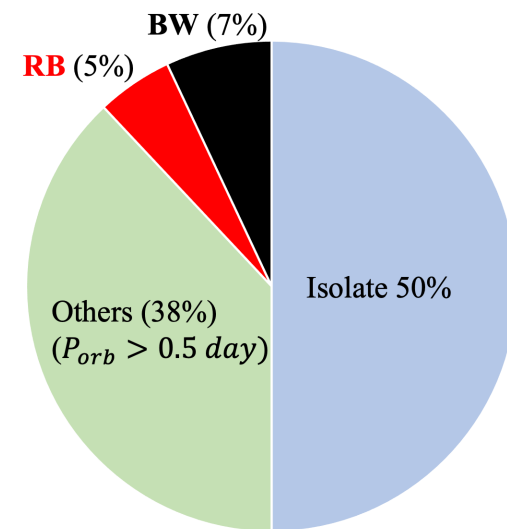
(<https://www.nrao.edu/pr/2006/mspulsar/mspulsar.graphics.shtml>)

# 1 Introduction: Millisecond pulsar



- **Spider pulsars:**
  - (i) **Black widow:** MSP + low mass white dwarf
  - (ii) **Redback:** MSP + M or K type star
  - Orbital period is less than 0.5 days.
  - Evaporating its companion star.
  - Candidate of progenitor to isolated MSPs.

Population of known MSPs



## Motivation 1

- Number of known spider pulsars ( $\sim 10\%$ ) is much less than isolated MSPs ( $\sim 50\%$ ).
  - Many spider pulsars are missing.
  - Searching for new spider pulsars at unidentified *Fermi*-LAT or X-ray sources.

# 1 Introduction: Millisecond pulsar

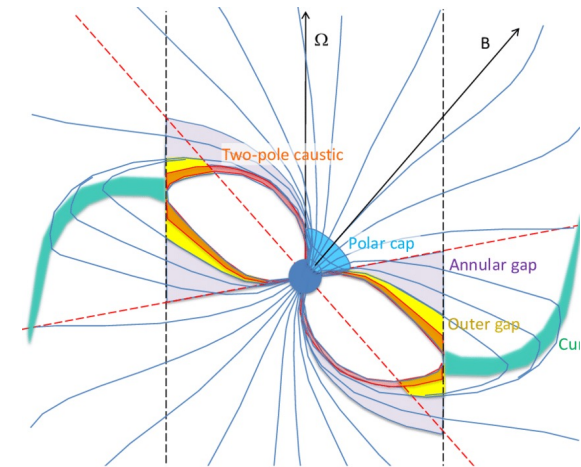
- **Emission from MSPs.**

[i] Radio emission from polar cap.

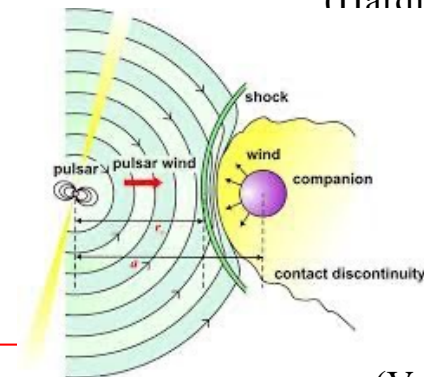
[ii] Thermal X-ray emission of the heated polar cap.

[iii] Non-thermal high-energy emission:

- Magnetosphere
- Intra-binary shock for spider systems



(Harding 2021)



(Venter 2015)

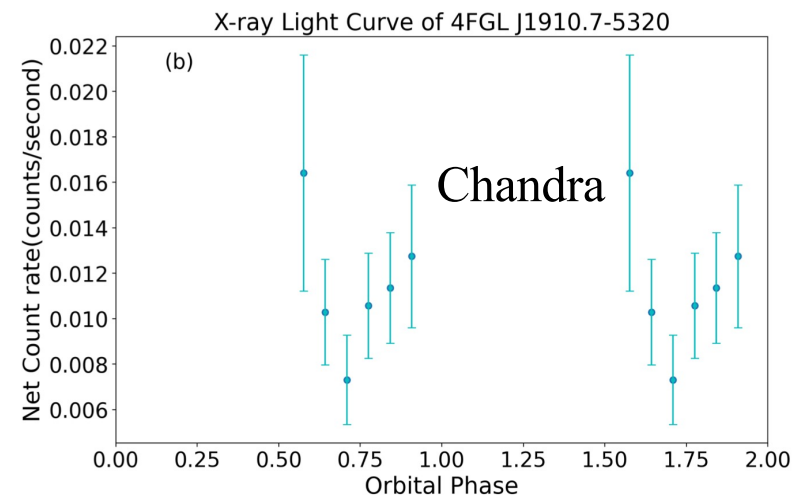
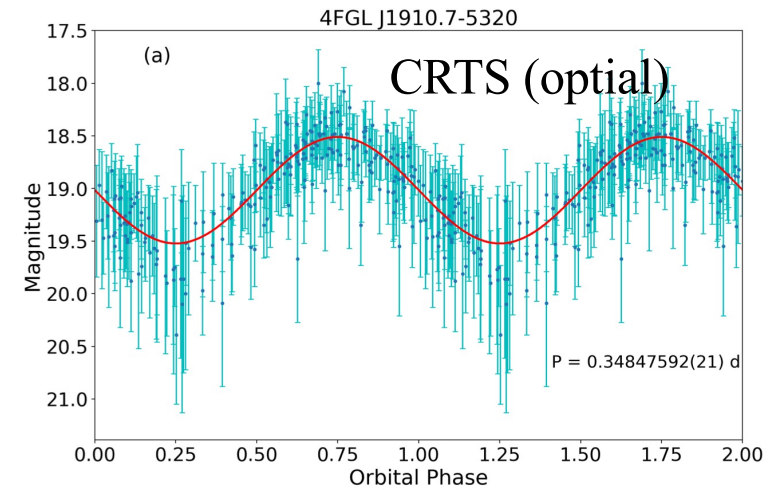
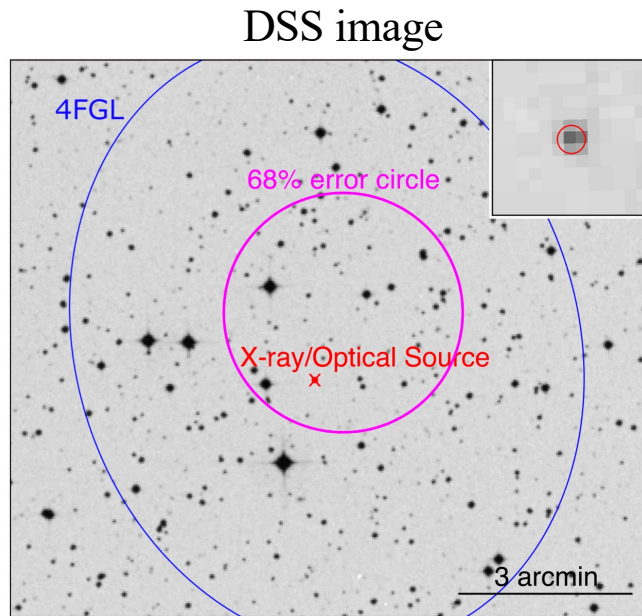
## Motivation 2

- MSPs in Globular Cluster have experienced **dynamical interactions**, which may affect to magnetosphere structure.
- Does the dynamics interaction affect to magnetospheric structure?  
→ **Statistical comparison between GF and GC MSPs.**



## 2: X-ray studies for two MSP binaries in GF

### 2-1 New Redback candidate at 4FGL J1910.7–5320 (Au et al. 2023)



- Optical light curve modulates with  $\sim 8.36$  hrs.  
- G or K type main-sequence star.
- $F_X \sim 0.1F_\gamma$  and a hint of X-ray modulation.  
 $\rightarrow$  Emission from the inter-binary shock.
- Typical Redback system.

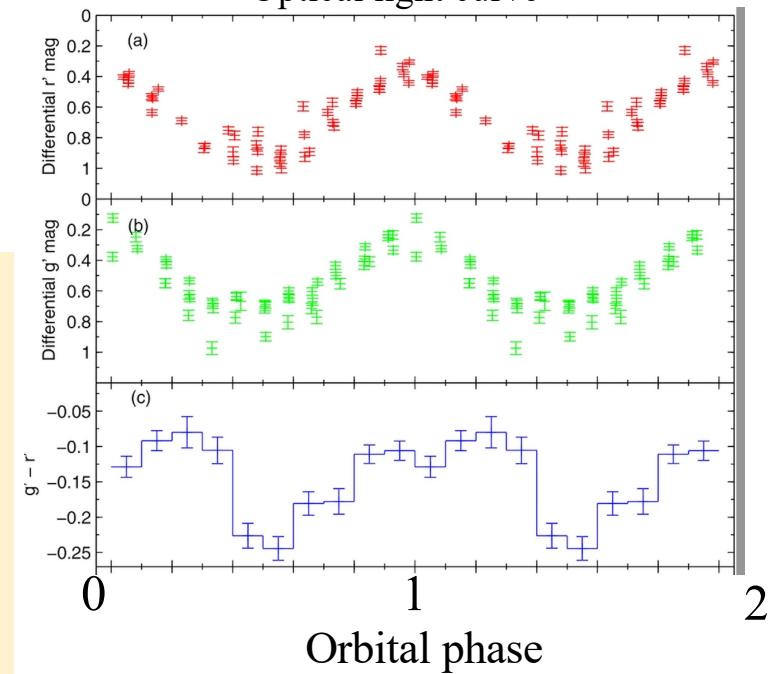
## 2: X-ray studies for MSP binaries

### 2-2 X-ray observations for compact binary PSR J1653-0158 (Long et al. 2022)

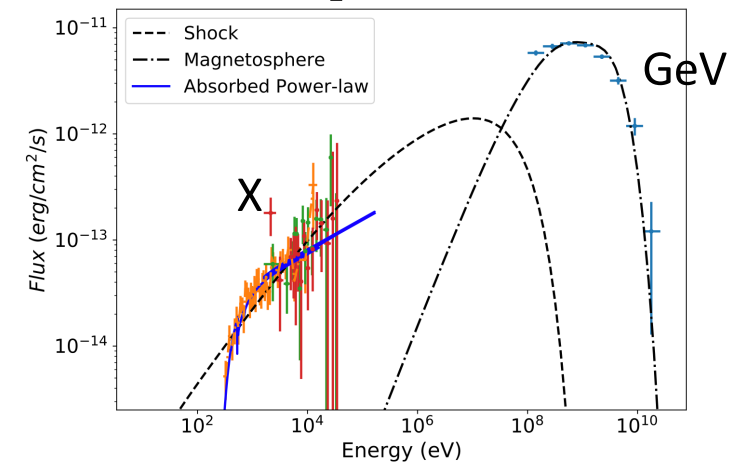
- MSP binary at 2FGL J1653.6-0159 (Kong et al. 2014)
  - Compact binary  $P_{orb} = 75$  minutes.
  - Very low companion mass  $M_c \sim 0.014M_{\odot}$
  - $P_s \sim 2ms$  in gamma-ray data (Nieder et al. 2020)
  - Radio quiet MSP.
- **Results of new XMM-Newton and NuStar observations:**
  - Non-thermal spectrum.
  - *No orbital modulation.*
  - Shock or magnetospheric emission?

Kong et al. (2014)

Optical light curve

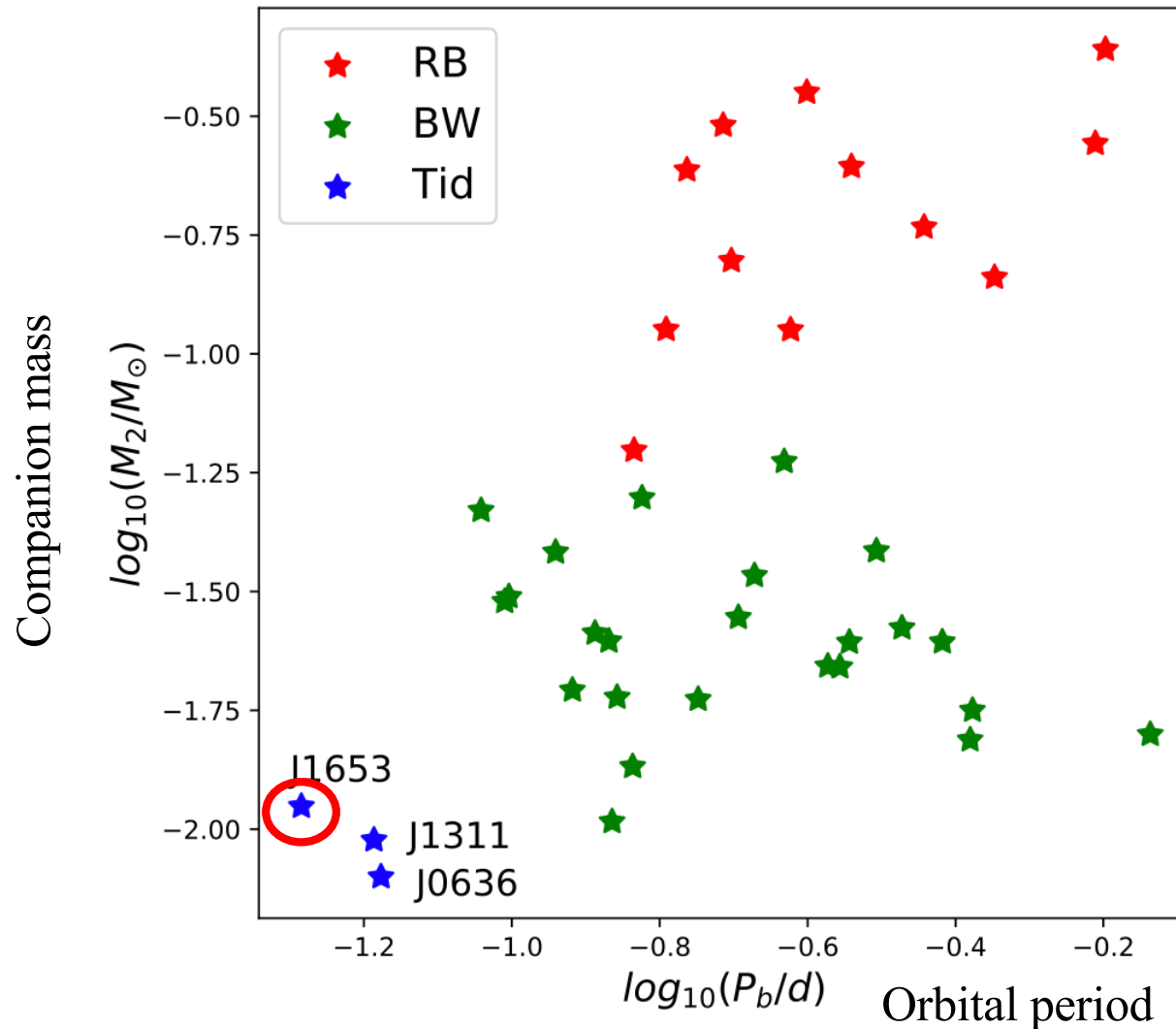


Spectrum



### Third type of spider pulsars?

- Three compact MSP binaries (called *Tiddaren* spider)
  - Different evolution path ?
- Future and current all sky surveys in X-rays are important.

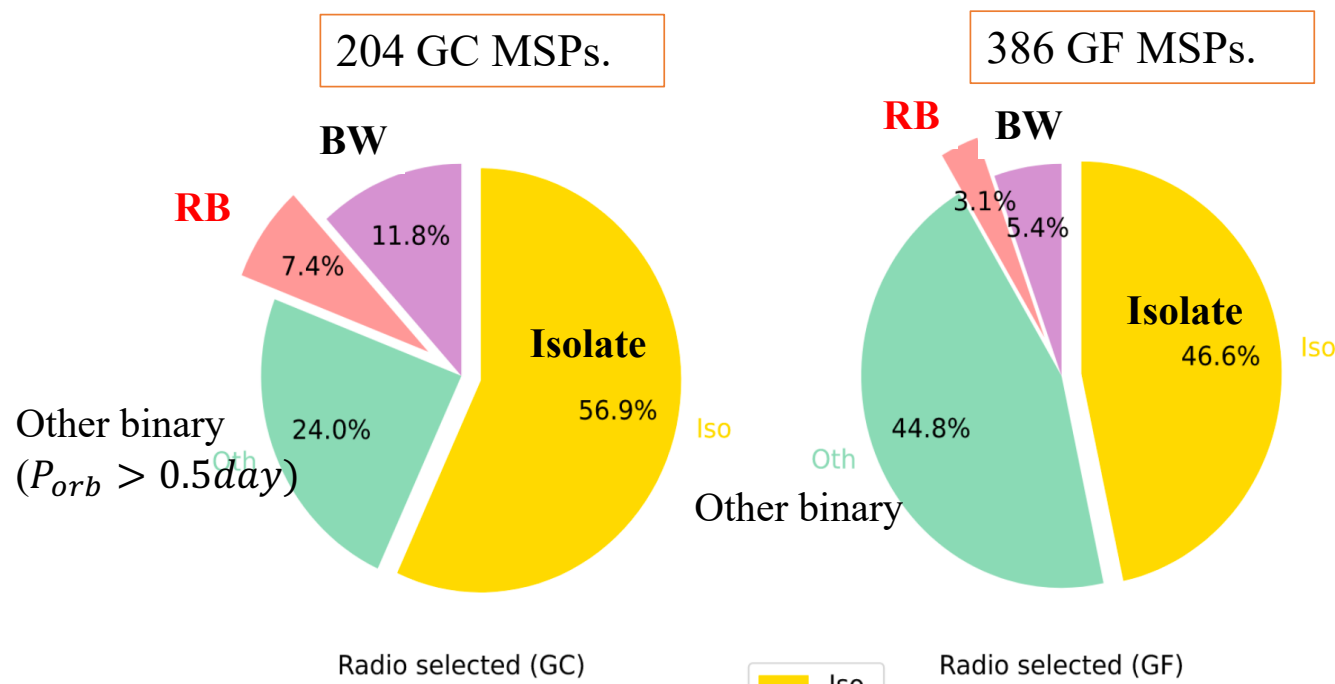




# 3: Comparison between Galactic field (GF) and Globular cluster (GC) MSPs

## 3-1. Catalogs and population

- (i) Galactic Field (GF) MSP catalog [<http://astro.phys.wvu.edu/GalacticMSPs/GalacticMSPs.txt>]
  - (ii) Globular Cluster (GC) MSP catalog [<http://www.naic.edu/~pfreire/GCpsr.html>]
  - (iii) Chandra X-ray data.
- GC includes more fraction of isolated MSPs and RB/BW systems.

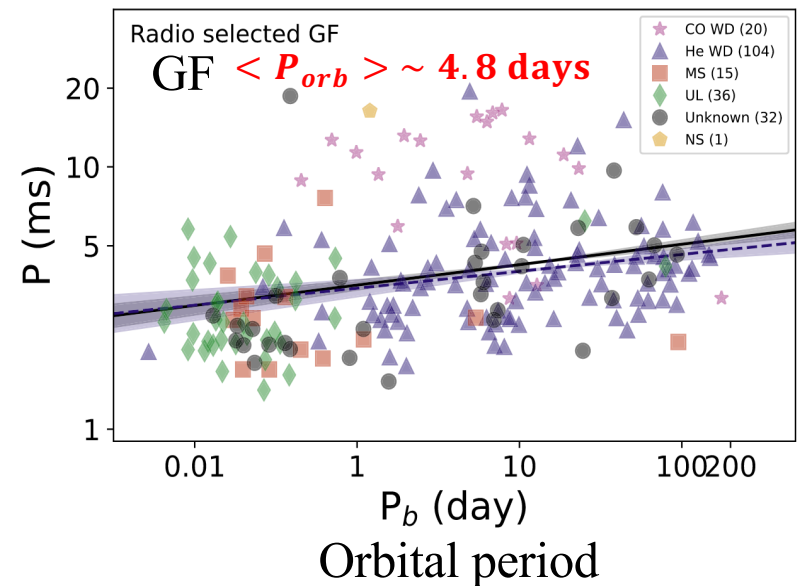
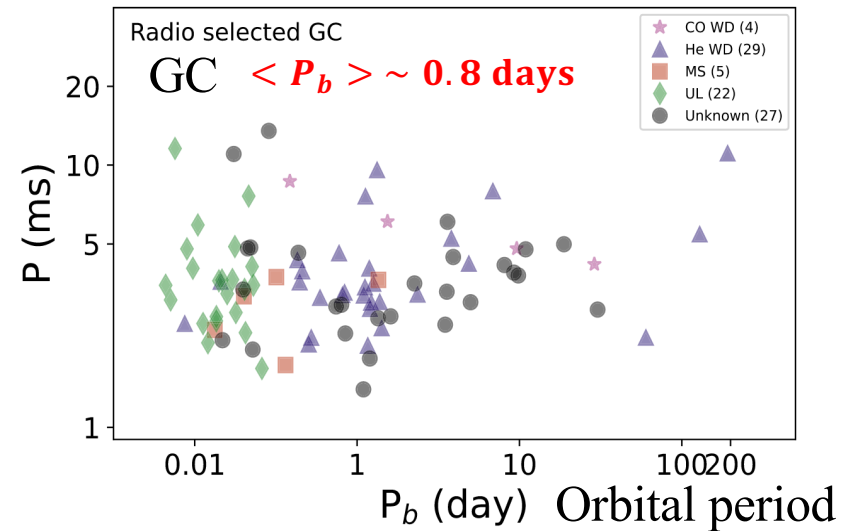


### 3: Comparison between Galactic field (GF) and Globular cluster (GC) MSPs (Lee et al. 2023)

#### 3-2. Orbital periods of GC

- Lack of the MSP/WD systems with  $P_{orb} > \sim 10$  days.
- Dynamical interaction in GC.
  - (i) Making the binary system harder.
  - (ii) Disruption of the long orbit binary system.

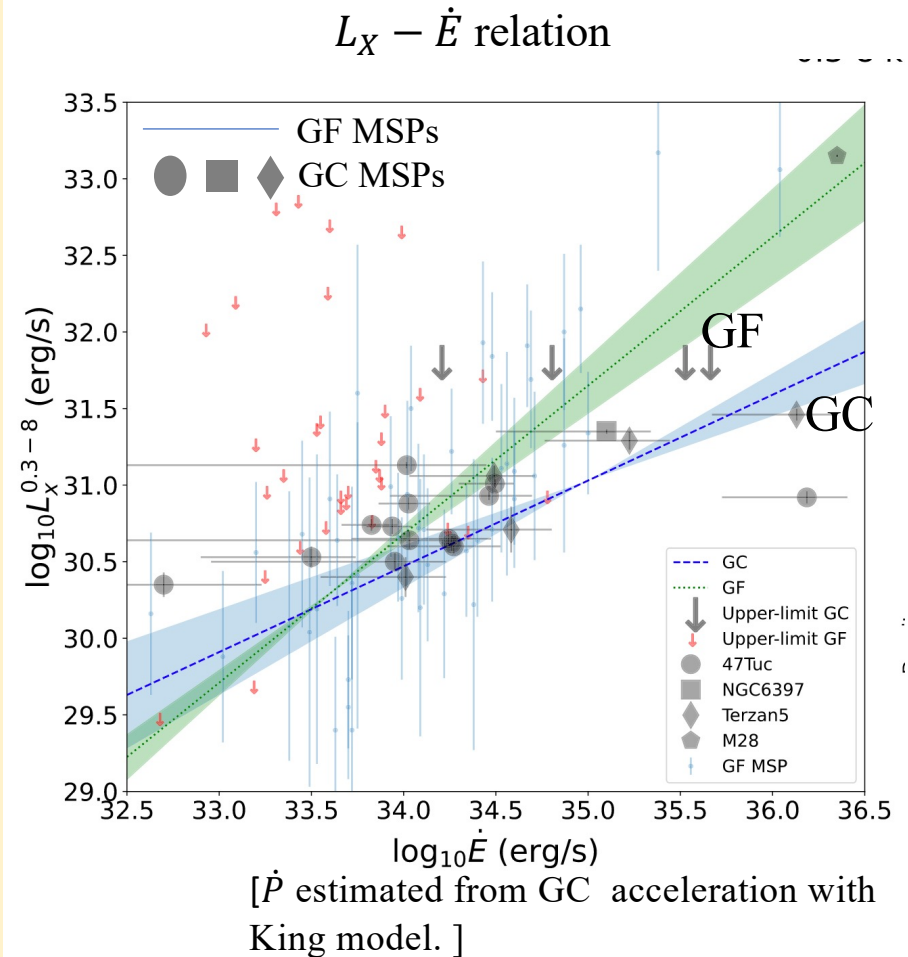
#### Spin period – Orbital period



### 3: Comparison between Galactic field (GF) and Globular cluster (GC) MSPs (Lee et al. 2023)

#### 3-3. Comparison on X-ray property

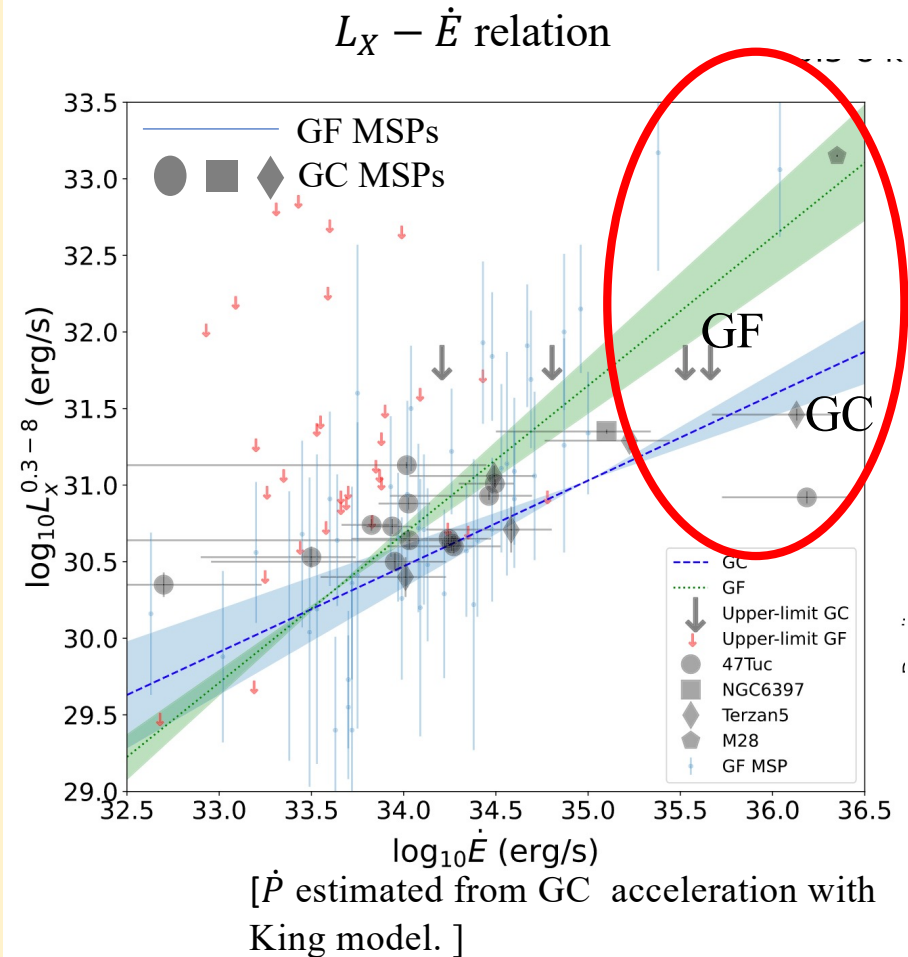
- $L_X - \dot{E}$  relation is different.
  - GC MSPs have more flat in  $L_X - \dot{E}$  relation.
- **5 energetic X-ray emitting MSPs with  $\dot{E}_{SD} \sim 10^{36}$  erg/s**
  - (i) Three *isolated* MSPs
    - PSRs B1937+21/J0218+4232 in GF
    - PSR B1821-24 (M 28A) in GC.
  - (ii) Two BW systems in GCs.
    - PSR J1748-2446O (Ter5 O)
    - PSR J0024-7204J (47Tuc J)



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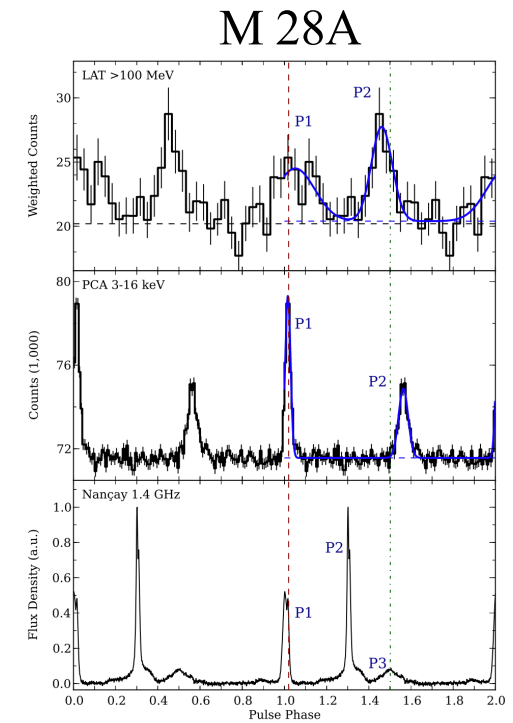
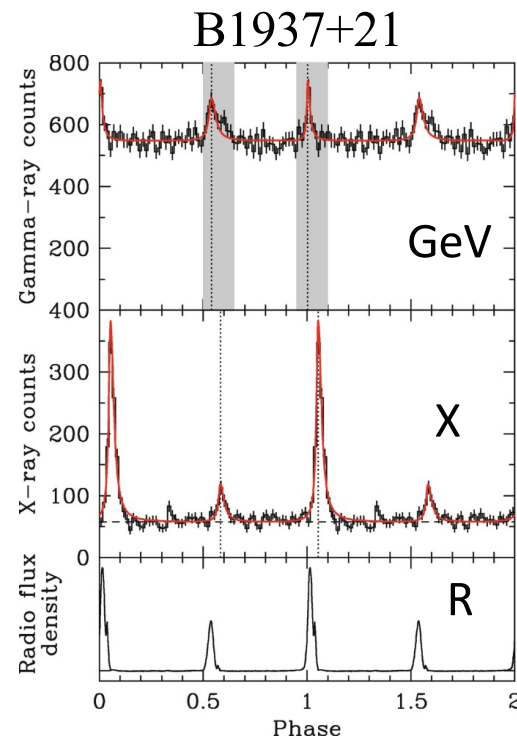
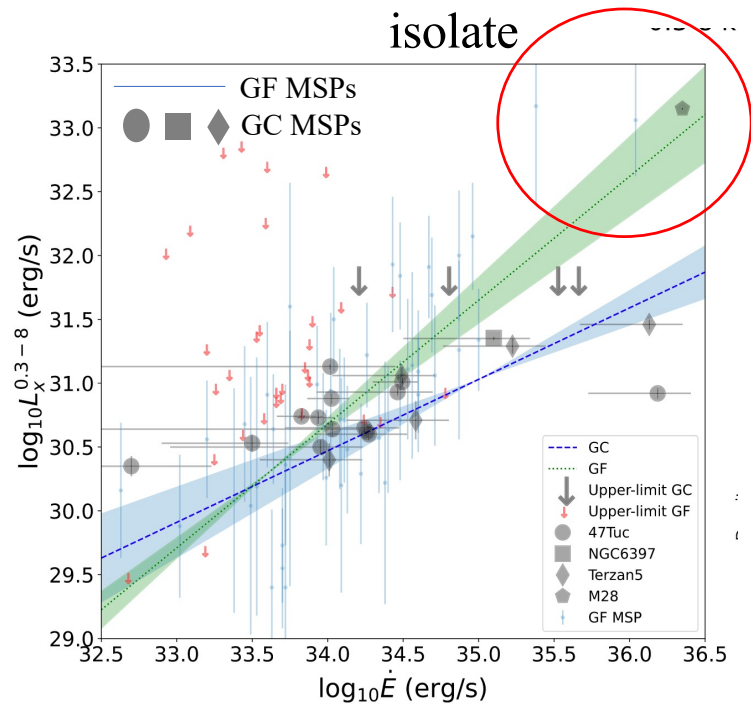


## [i] Isolated energetic MSPs.

- *Crab-like MSPs*

- Magnetospheric X-rays and gamma-ray emissions.
- Radio, X-ray and gamma-ray pulse phases are almost in phase.
- Emission regions near the light cylinder.

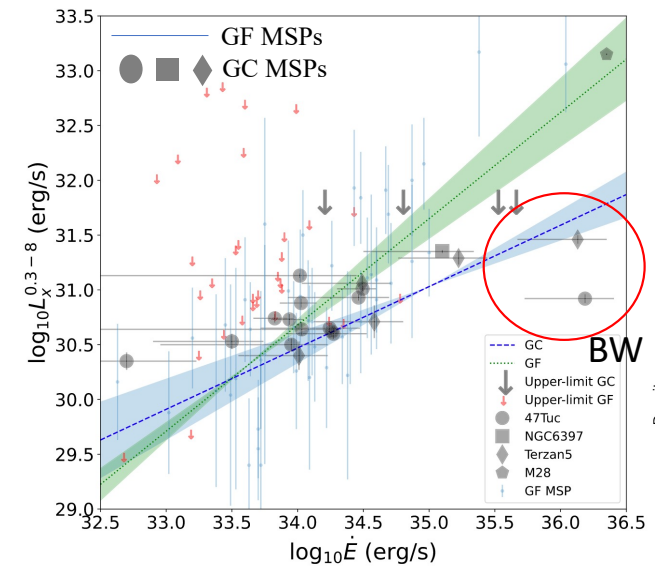
- Isolated energetic MSPs in GF and GC share similar emission properties.



Pulse phase

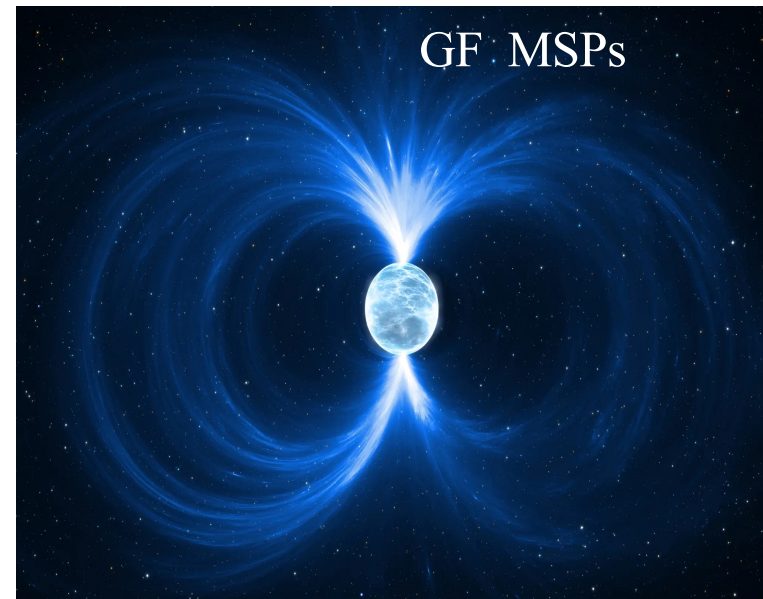
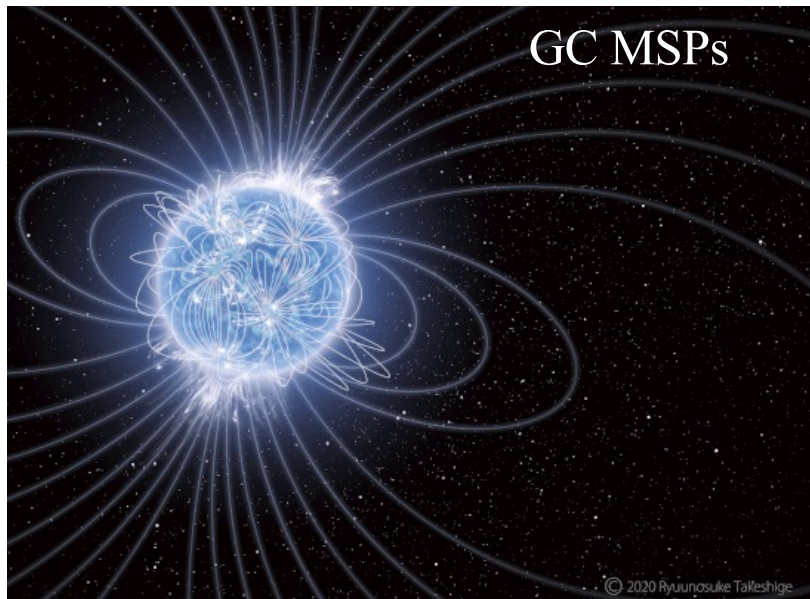
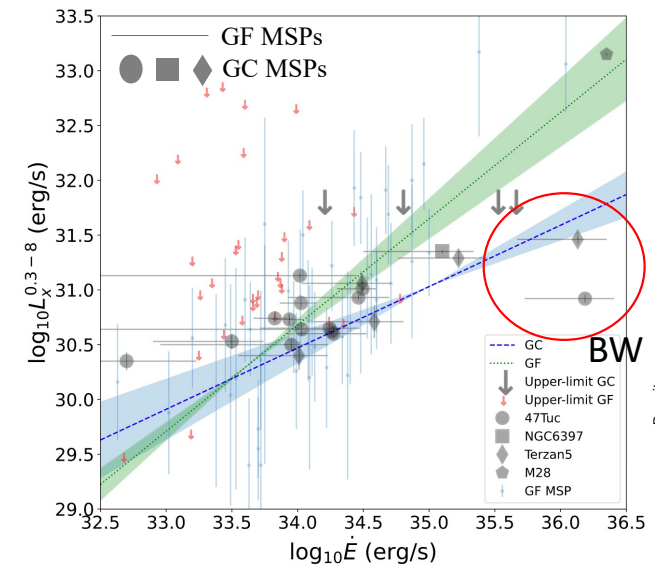
## [ii] Energetic BW MSPs in GCs

- BW systems with energetic MSPs.
  - PSR J1748-2446O,  $P_s \sim 1.6ms$
  - PSR J0024-7204J,  $P_s \sim 2.1ms$
- X-ray emission with orbital modulation.
  - Intra-binary shock emission.
- Suppression of the magnetospheric emission.
  - Complicated structure of the magnetosphere?



## [ii] Energetic BW MSPs in GCs

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- X-ray emission with orbital modulation.
  - Intra-binary shock emission.
- Suppression of the magnetospheric emission.
  - Complicated structure of the magnetosphere?
- **A comparison of the radio emission properties (e.g. pulse structure, luminosity) are on going.**



# Summary

- X-ray studies of GF and GC MSPs.
- Identify new Redback candidate with  $P_b \sim 8.36$  hrs
- Detection strong non-thermal emission from a Tidarren spider, PSR J1653-0158.
- **X-ray emission properties of energetic *isolated* MSPs in GF and GC are similar.**
- **Evidence of the suppression of the magnetospheric X-ray emission of two energetic BW systems in GC.**



