MSP Binary in *Fermi* Era

-X/gamma-ray properties of BW/RBs-

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On behalf of

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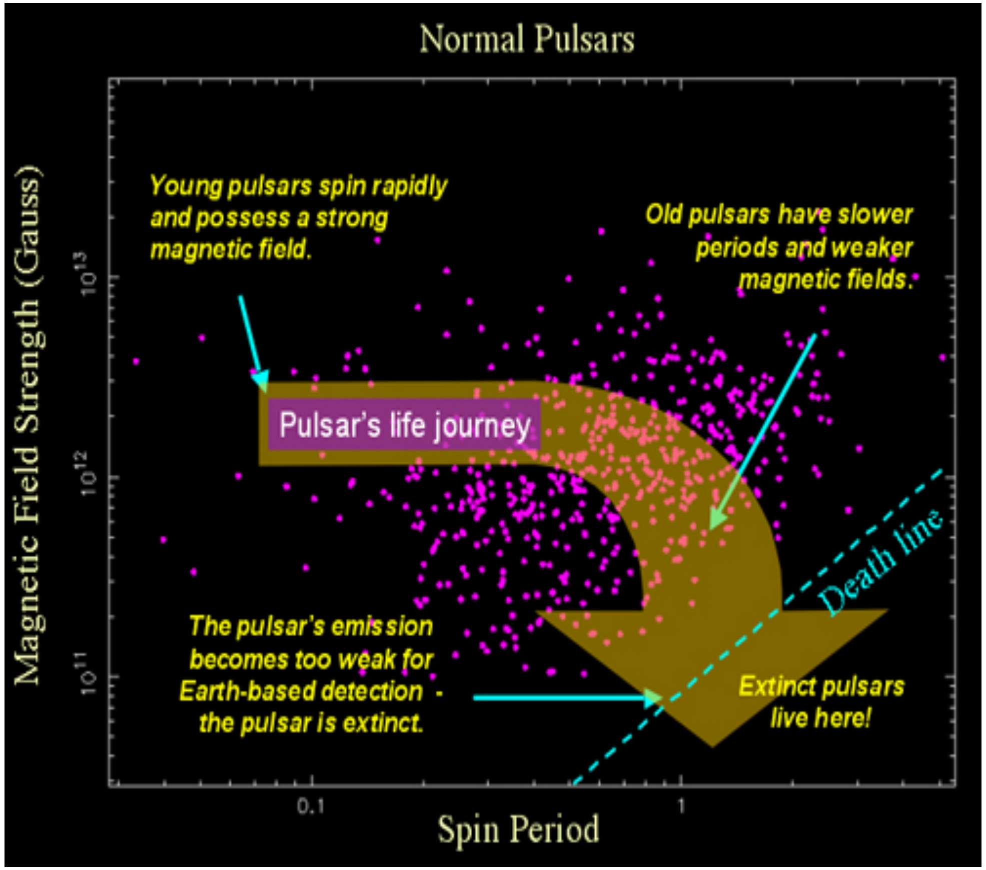
Outlines

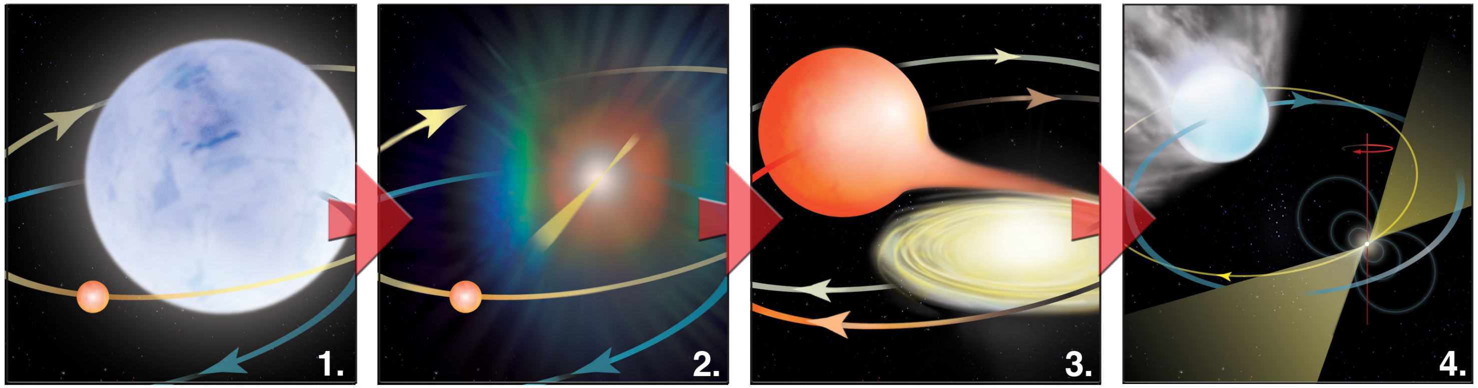
1. **Black widow** and **Redback** millisecond pulsars
- New MSP binaries in *Fermi*-Era
- BWs/RBs candidate at *Fermi* unidentified sources

2. X-ray/gamma-ray emissions of BWs/RBs
- Magnetosphere
- Cold relativistic pulsar wind
- Inter-binary shock

Formation of MSPs



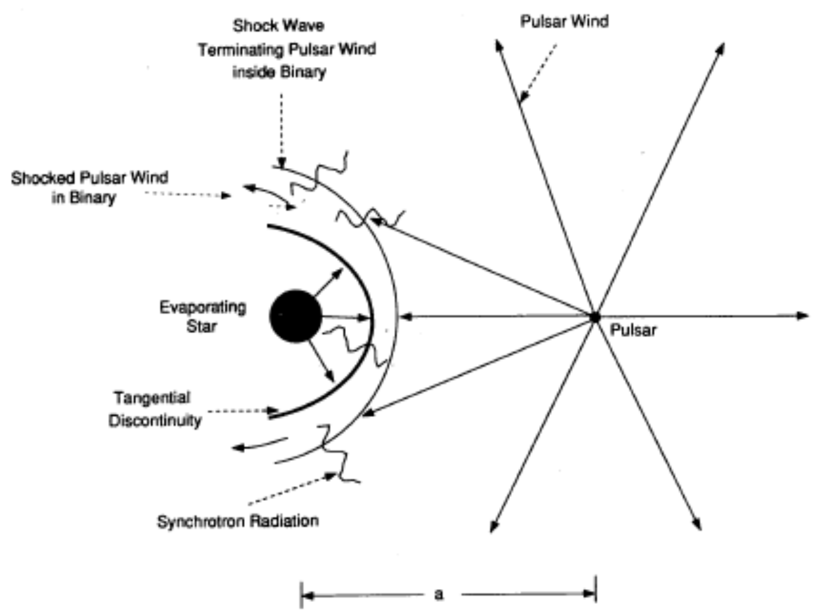
(Http://astronomy.swin.edu.au/cosmos/P/Pulsar+Evolution)



Intra-binary shock

- In 1988, the first eclipsing MSP PSR B1975+20 (Fruchter et al.)
- In 1990s, high-energy emission from intra-binary shock of MSP binary was discussed by several groups (Harding & Gaisseer 1990; Arons & Tavani 1993)
- In 2003, the first evidence of intra-binary shock emission

  --- X-ray emission from PSR B1957+20 (Stappers et al. 2003)

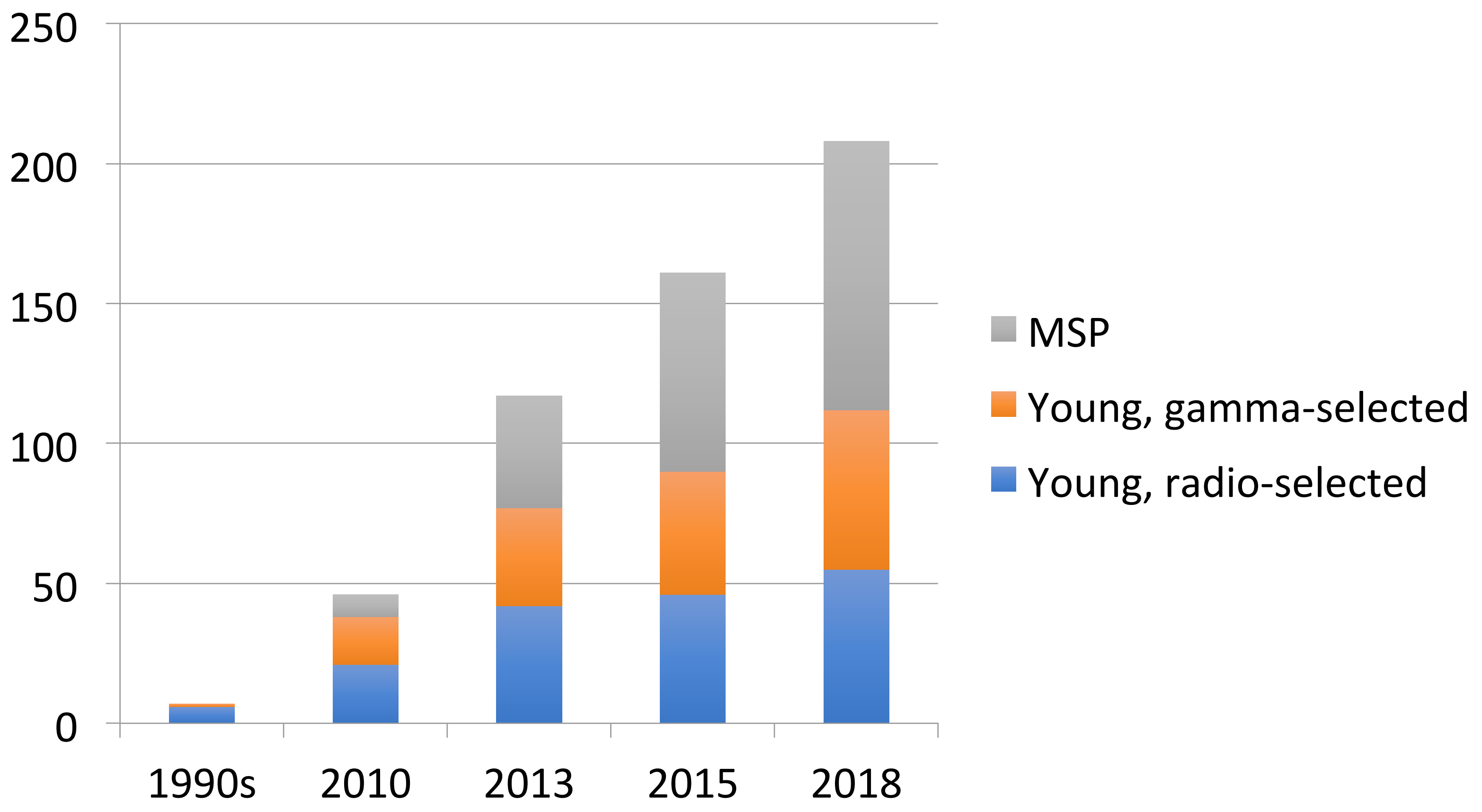


(Arons & Tavani 1993)

MSPs in *Fermi*-Era

- About a half of gamma-ray pulsars is MSPs.
  - Deep radio pulsar search at Fermi unidentified source.
  - Many compact MSP binary systems (P_{orb}<1day)

    \- **Black widow** and **Redback**



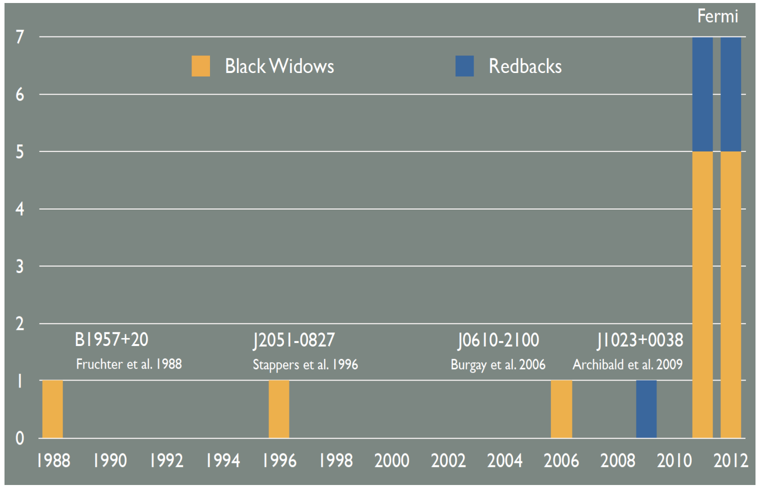
BW and RB MSPs

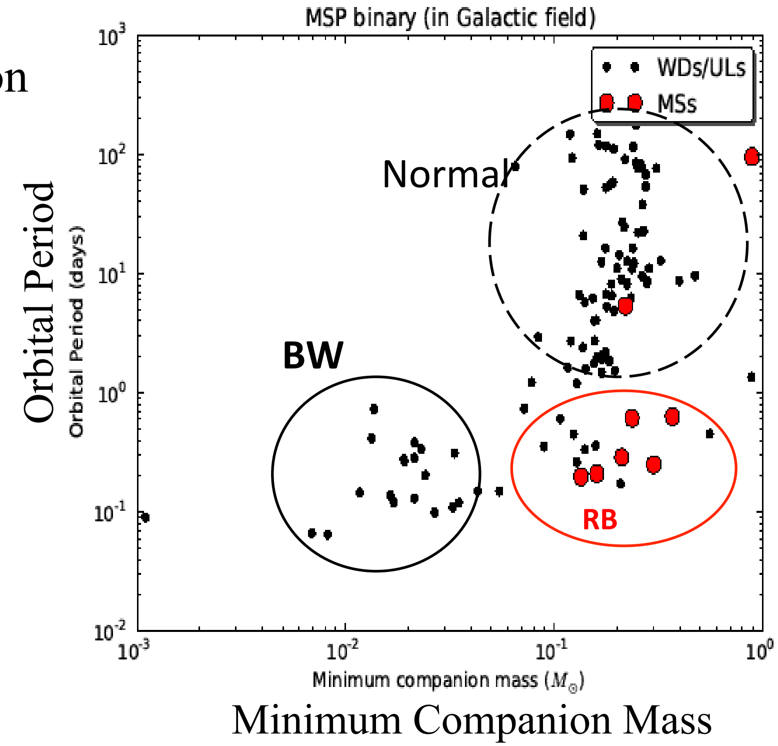
- P_{orb}<1day.

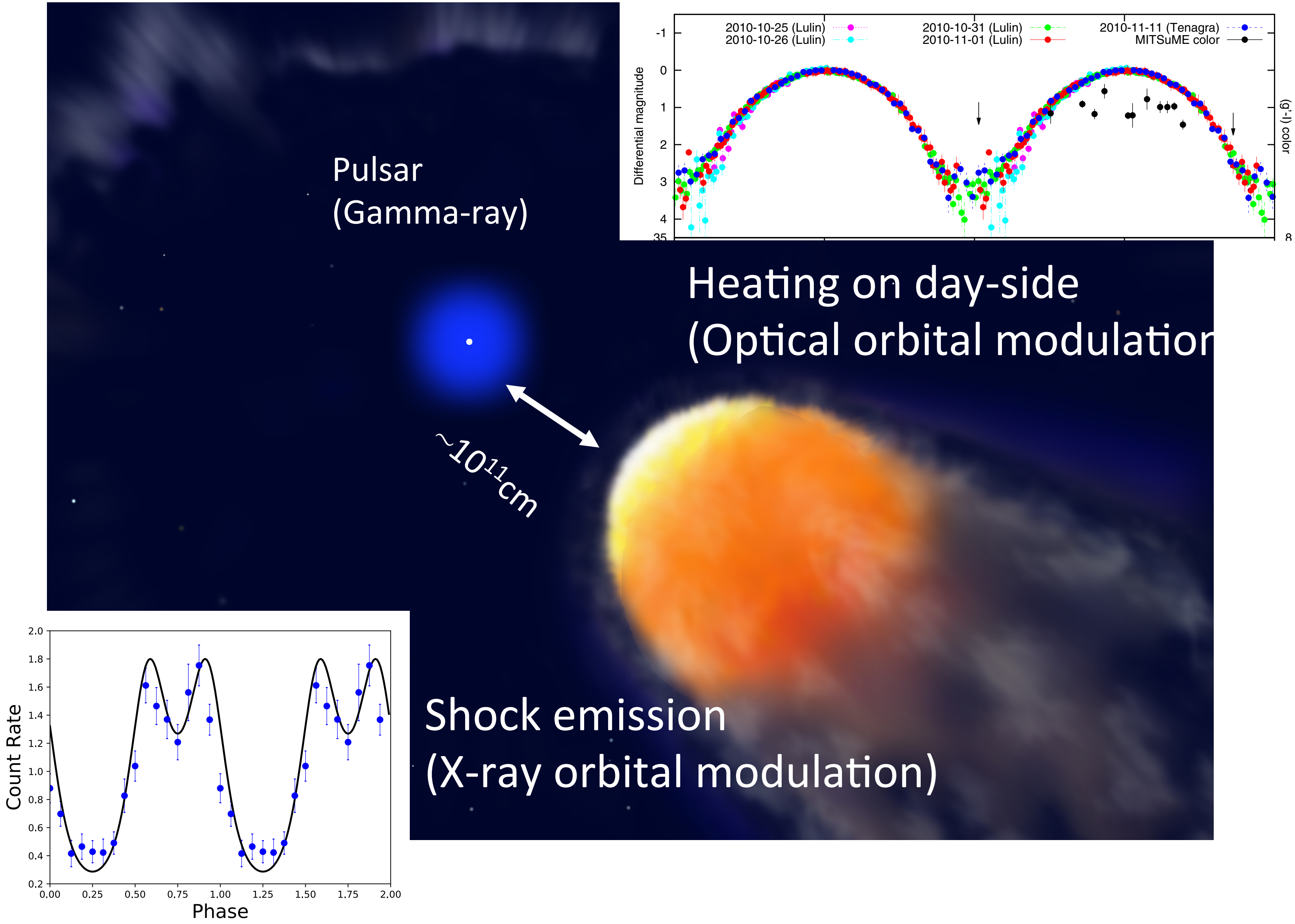
- **Radio eclipses** due to the evaporating material from the companion.

- **Black Widow** (~12)
  - very low mass (semi) degenerate companion (<$0.05M_{\odot}$)

- **Redback** (~8)
  - >$0.1M_{\odot}$ non-degenerate (G/M type) or degenerate companion

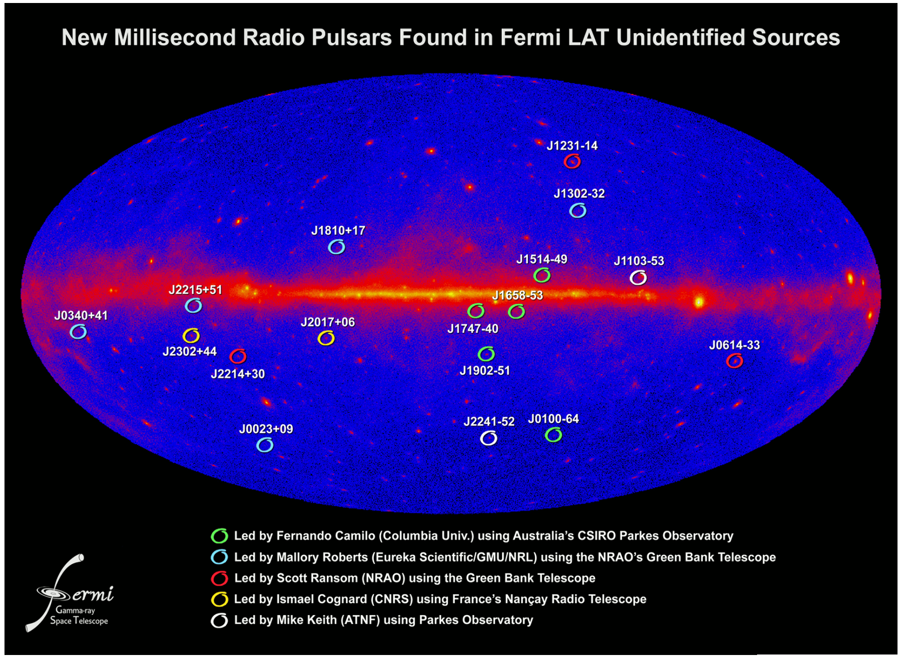


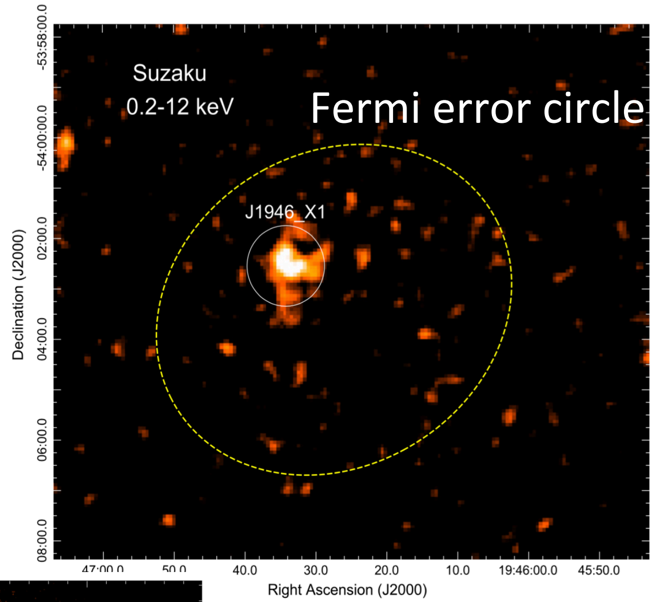


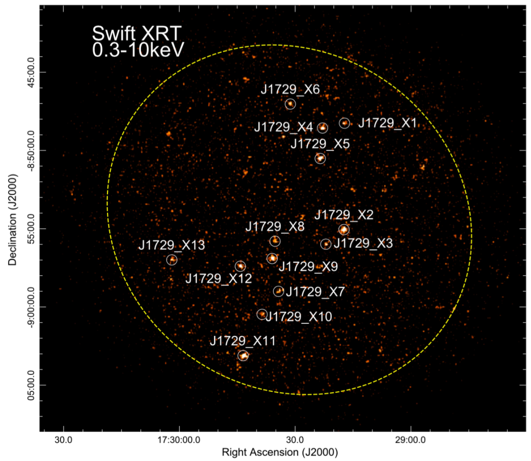


Pulsar
(Gamma-ray)
~10^11 cm
Heating on day-side
(Optical orbital modulation
Shock emission
(X-ray orbital modulation)
2010-10-25 (Lulin)
2010-10-26 (Lulin)
2010-10-31 (Lulin)
2010-11-01 (Lulin)
2010-11-11 (Tenagra)
MITSuME color
Differential magnitude
(g'-I) color
Count Rate
Phase

Candidate at *Fermi*-UNID sources





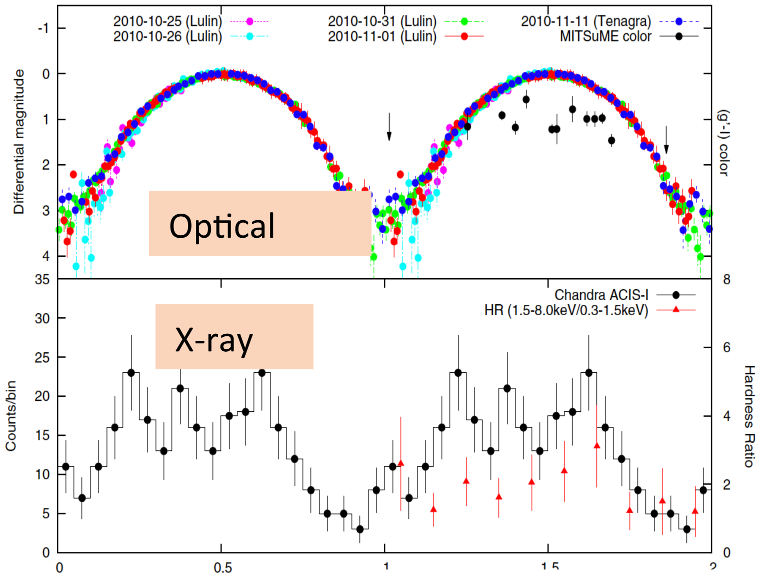


Candidates

- 2FGL J2339.6-0532 (Kong et al. 2011)=PSR J2339-0533
- 2FGL J1311.7-3429 (Romani 2012) = PSR J1311-3430
- 1FGL J0523.5-2529 (Strader+ 2014)
- 2FGL J2039.6-5620 (Romani 2015; Salvetti+ 2015)
- 3FGL J1544-1125 (Bogdanov & Halpern 2015)
- 3FGL J1048.6+2338(Deneva+ 2016)= PSR J1048+2339
- 3FGL J0212.1+5320 (Li+ 2016; Linares+ 2017)
- 3FGL J0838.8-2829 (Halpern+ 2017)
- 3FGL J0954.8−3948 (Li et al. 2018)

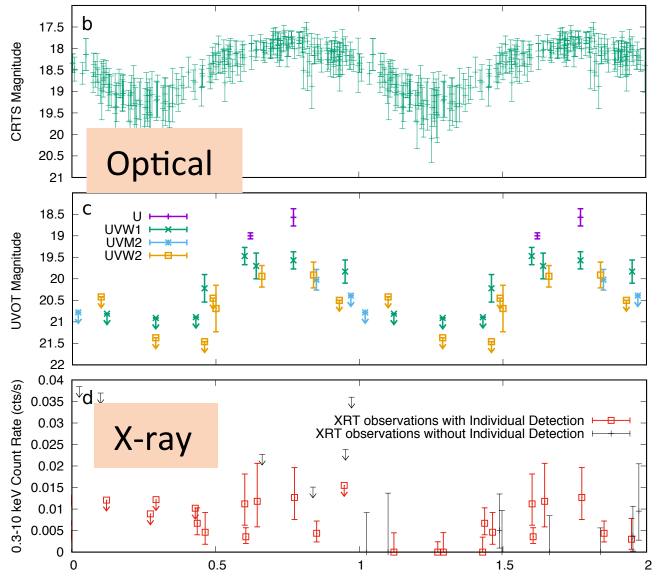
- See also Hui+ 2015 and Salvetti+ 2017 for other candidates

2FGL J2339.6-0532 (P_{orb}=4.6hours)



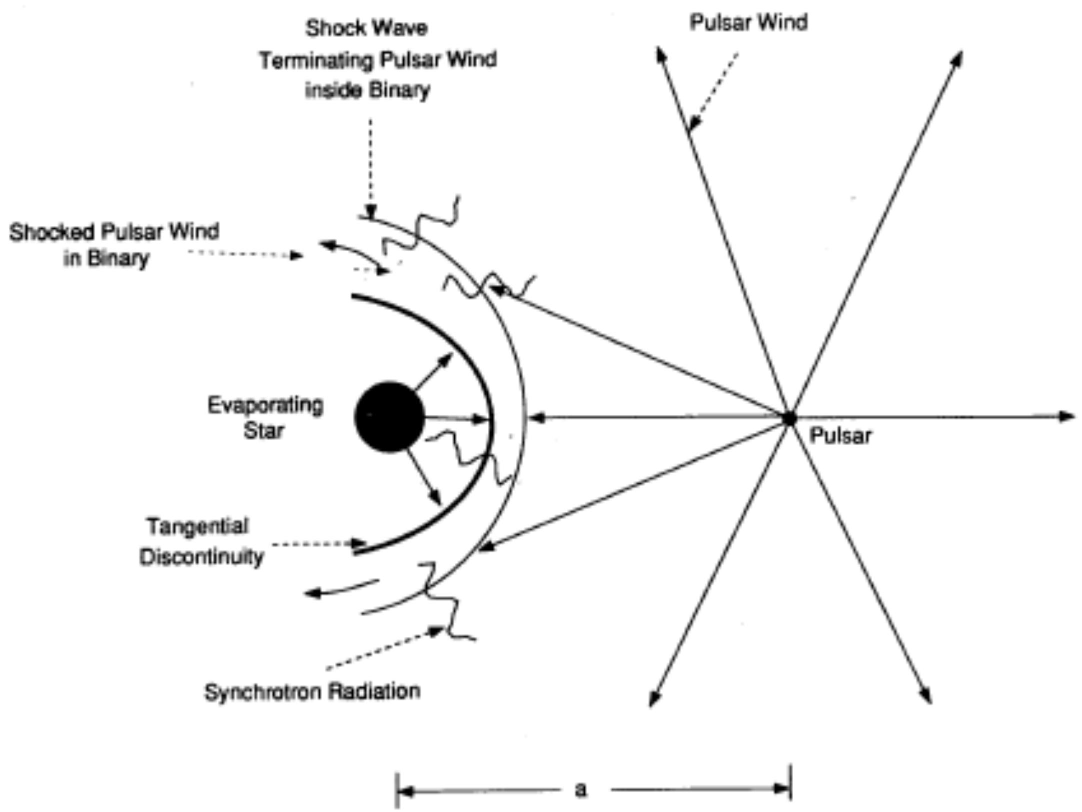
Orbital phase (Kong et al. 2012)

3FGL J0954.8−3948 (P_{orb}=9.3hours)



Orbital phase (Li et al. 2018)

- New BW and RB enable us to do a detail study of the high-energy emission from the MSP binary



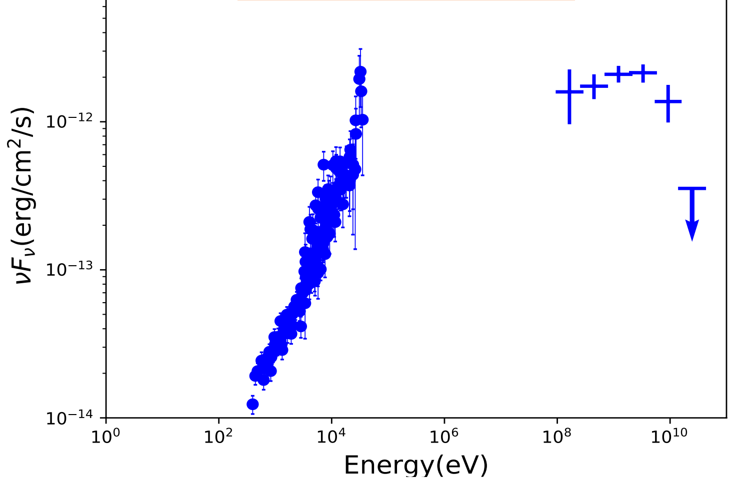
2. X-ray/gamma-ray emissions of BWs/ RBs

Broadband spectrum

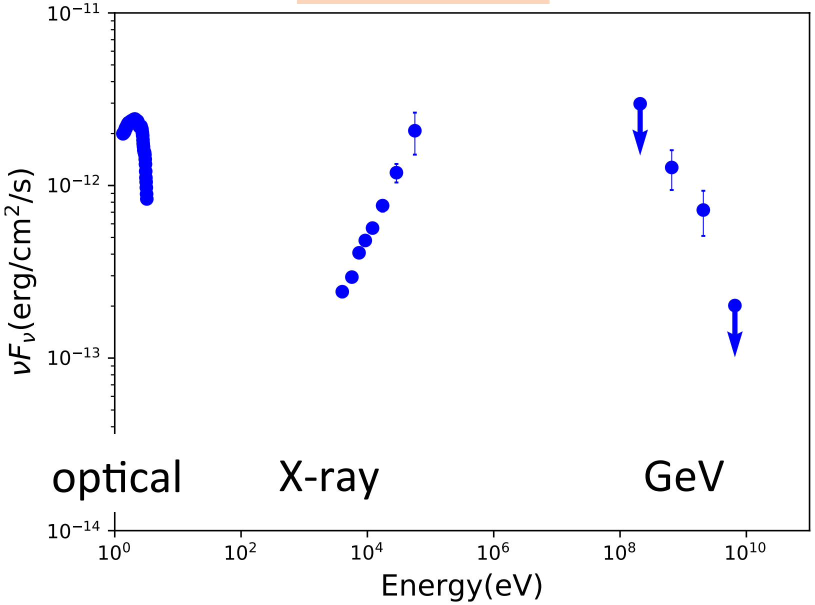
-- Optical (companion)

-- energy peak around 1MeV

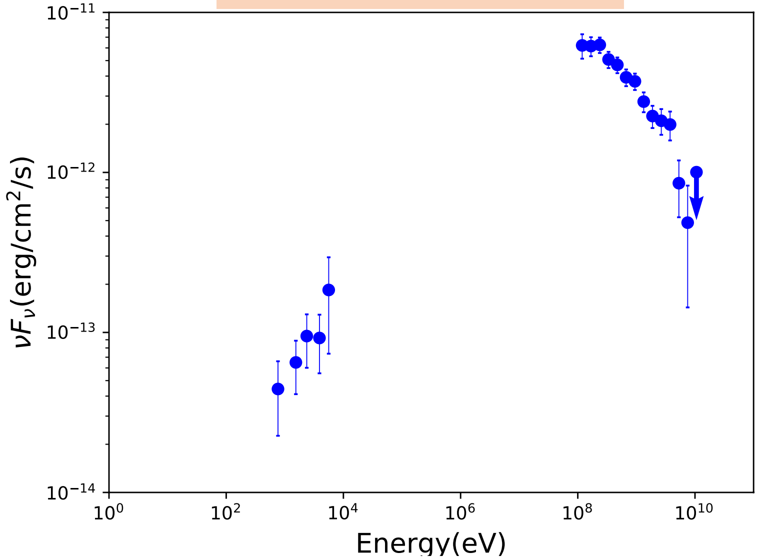
RB : J2129-4029



J1023+0023



3FGL J0954.8−3948



2. X-ray/gamma-ray emissions of BWs/RBs

2-1 X-ray emission (see Takata et al. 2012) :

1. Magnetosphere -- synchrotron process
2. Heated polar cap (~10^6K)
3. Intra-binary shock -- synchrotron process

L_x vs. L_{sd} (Lee et al. 2018)

- **BWs** : Heated polar cap emission dominates for lower spin down pulsar.

  (see Gentile et al. 2013 for spectral analysis)

→no pulsed emission has been confirmed yet.

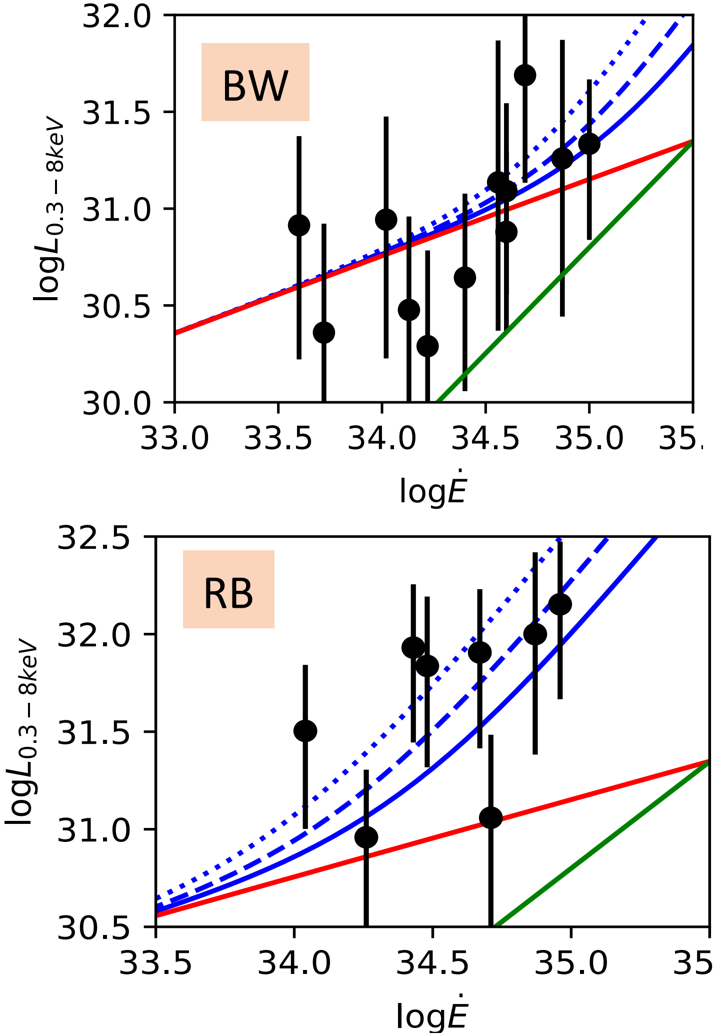
- **RBs**: Shock emission dominates.

→ X-ray spectrum is well fitted by a power law function.

L_x vs. L_{sd} (Color : model)

Blue : Total Red : Heated PC

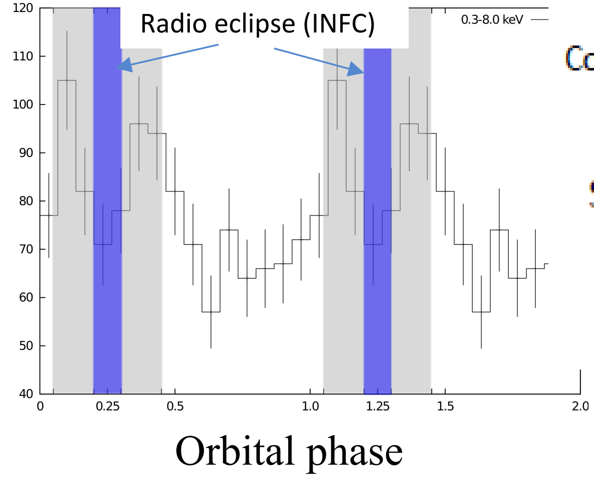
Green : Magnetosphere

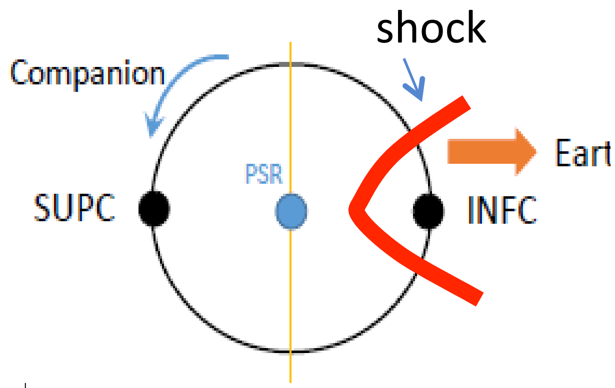


X-ray orbital modulation: Doppler boosting

BWs : Only PSR B1957+20 is bright enough to measure the orbital variation.
→ Shock wraps the companion.

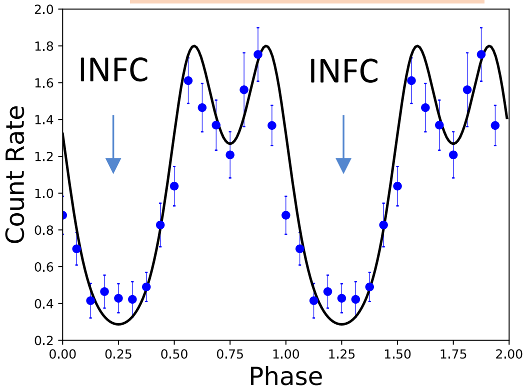
BW: PSR B1957+20





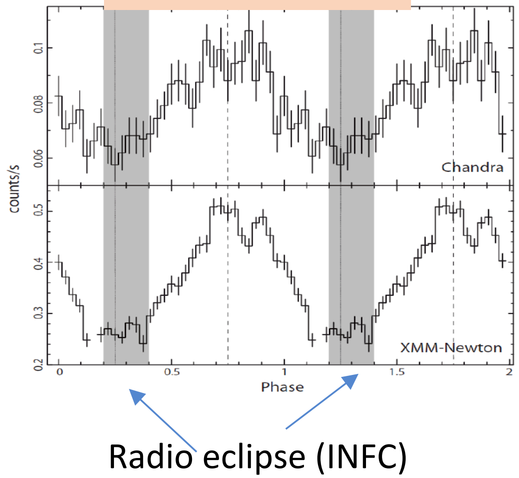
RBs: Peak at around SUPC
→ Some sources show double peak
→ Shock wraps the companion.

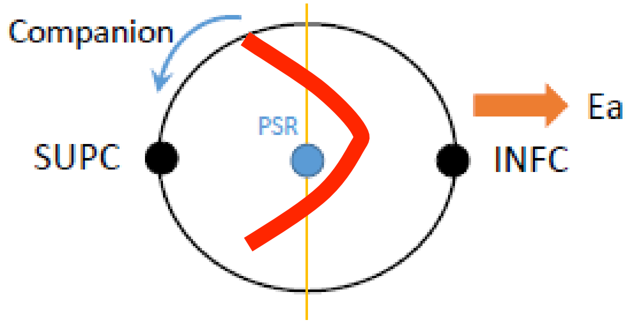
RB : J2129-4029



(Kong et al. 2017, 2018)

J1723-2837





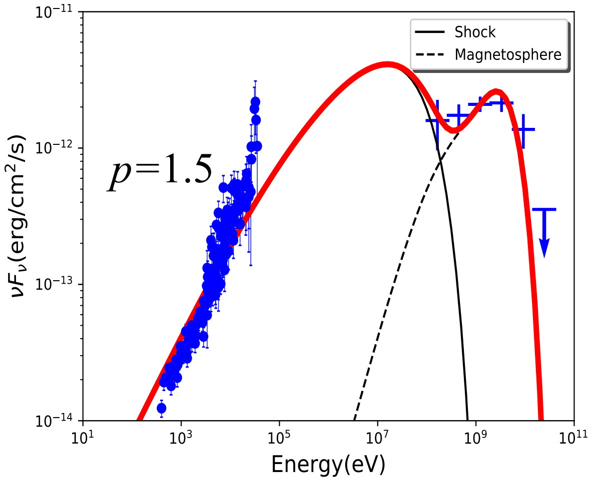
- Magnetized stellar outflow could overcome the PW pressure

Very hard X-ray spectrum

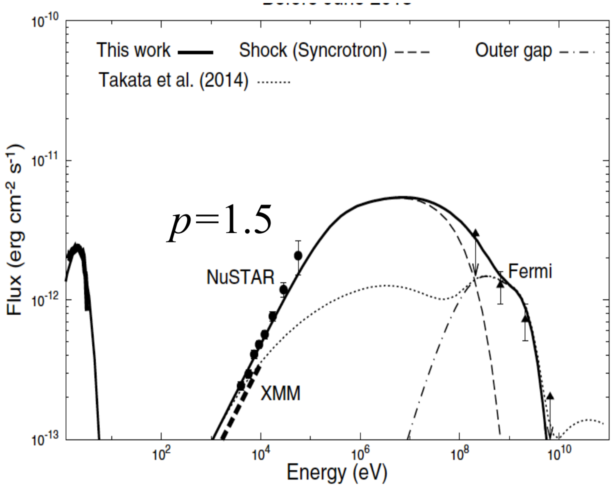
RB : Synchrotron emission from the inter-binary shock

- A single power law spectrum extends above 70keV.
- A very hard photon index Γ=1-1.3
    - Power law index of energy distribution of the shocked pulsar wind : $p\sim1.5$

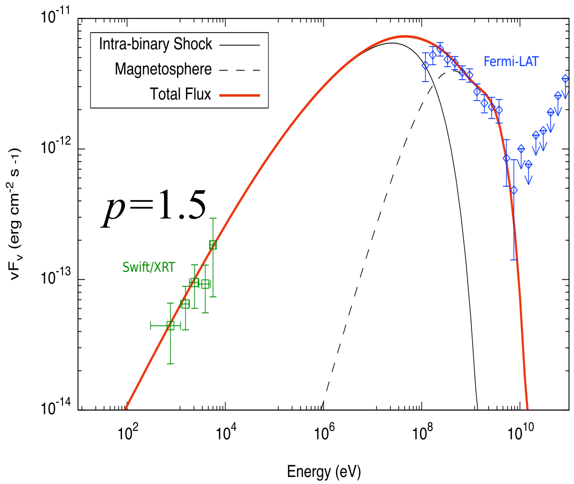
RB : J2129-4029



J1023+0023



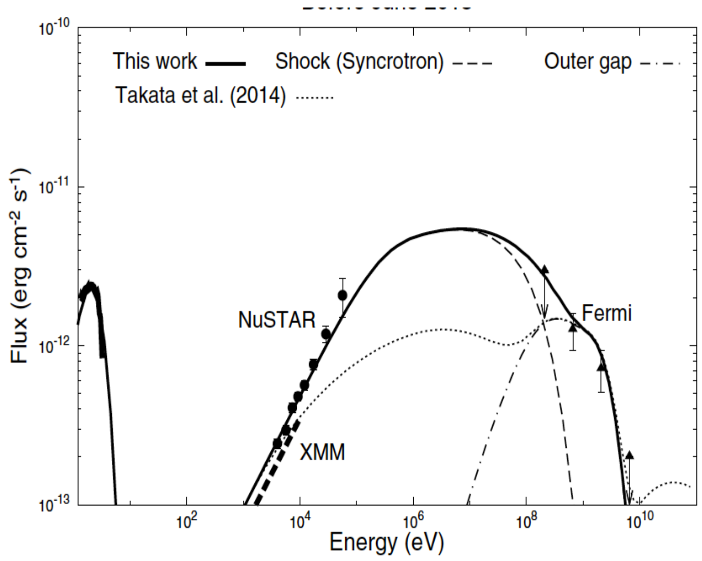
3FGL J0954.8−3948



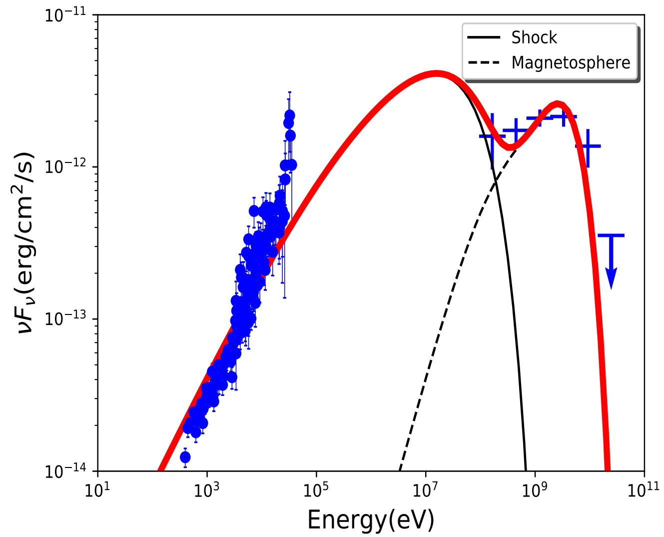
(see Takata et al. 2014, Li eta l. 2014, Kong et al. 2017, 2018, and Li et al. 2018)

2-2 Gamma-ray emission :

1. Magnetosphere (GeV)
   → Curvature radiation
2. Relativist cold pulsar wind (GeV)
   → Inverse-Compton scattering
3. Intra-binary shock
   → Inverse-Compton scattering (TeV)



- Spectra observed by *Fermi* are well described by the power law + exponential cut-off
  → Magnetospheric emission dominates



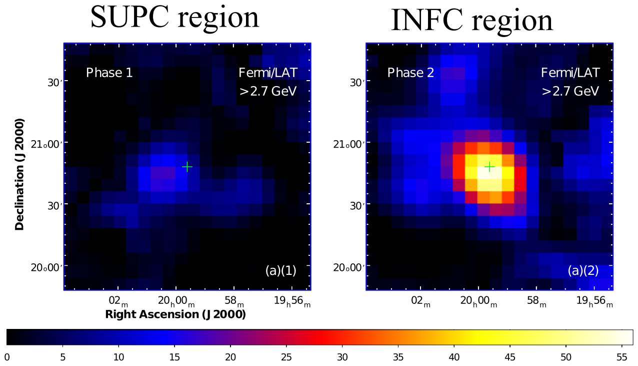
Orbital modulation of gamma-rays

- Three candidates:
  - PSR B1957+20 (Wu et al. 2012)
  - PSR J1311–3430 (Xing and Wang 2015)
  - 3FGL J2039.6-5618 (Ng et al. 2018)
- They are **brighter at around INFC**.

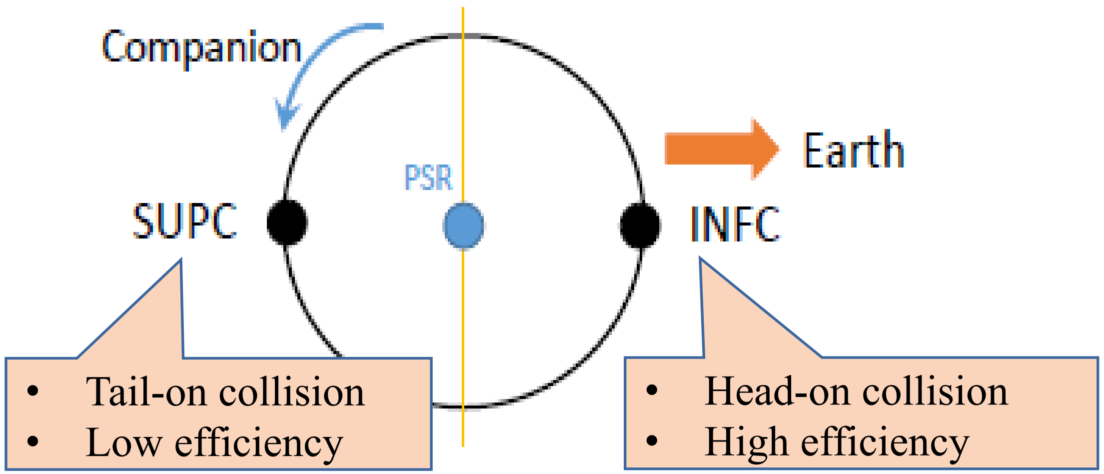
- The **cold-relativistic pulsar** wind produces the GeV gamma-rays by the inverse-Compton process.

→Anisotropic I.C. process → Orbital modulation

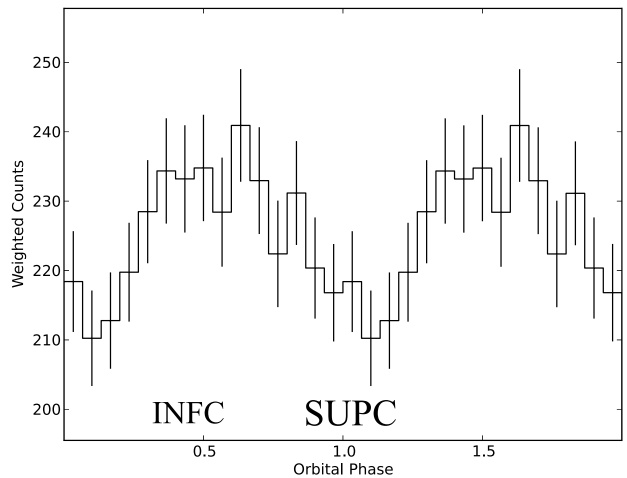
BW: PSR B1957+20



(Wu et al. 2012)



RB Candidate : 3FGL J2039.6-5618



(Ng et al. 2018)

Summary

- *Fermi* increases the population of BWw and RBs.
- X-ray properties of BWs and RBs show some differences.

  -- Heated polar cap emission is important for BWs.
- Shock acceleration produces a very hard energy distribution of the particles.

  -- we need MeV telescope to determine the maximum energy of the particles.
- X-ray orbital modulation shape indicates the shock wraps the pulsar for the **RB**

  -- Magnetized stellar wind?
- The magnetospheric emission dominates in GeV, but IC scattering of the cold-relativistic pulsar wind also contributes for some systems.

Future works

- How many RB/BW populations ?

→ *Fermi* unidentified source

→ A deep search by FAST

- Formation process

→RB are BW are evolutionally connected?

- Destiny

→Isolate MSP ?

→Ultra compact MSP binary?

→Merger?