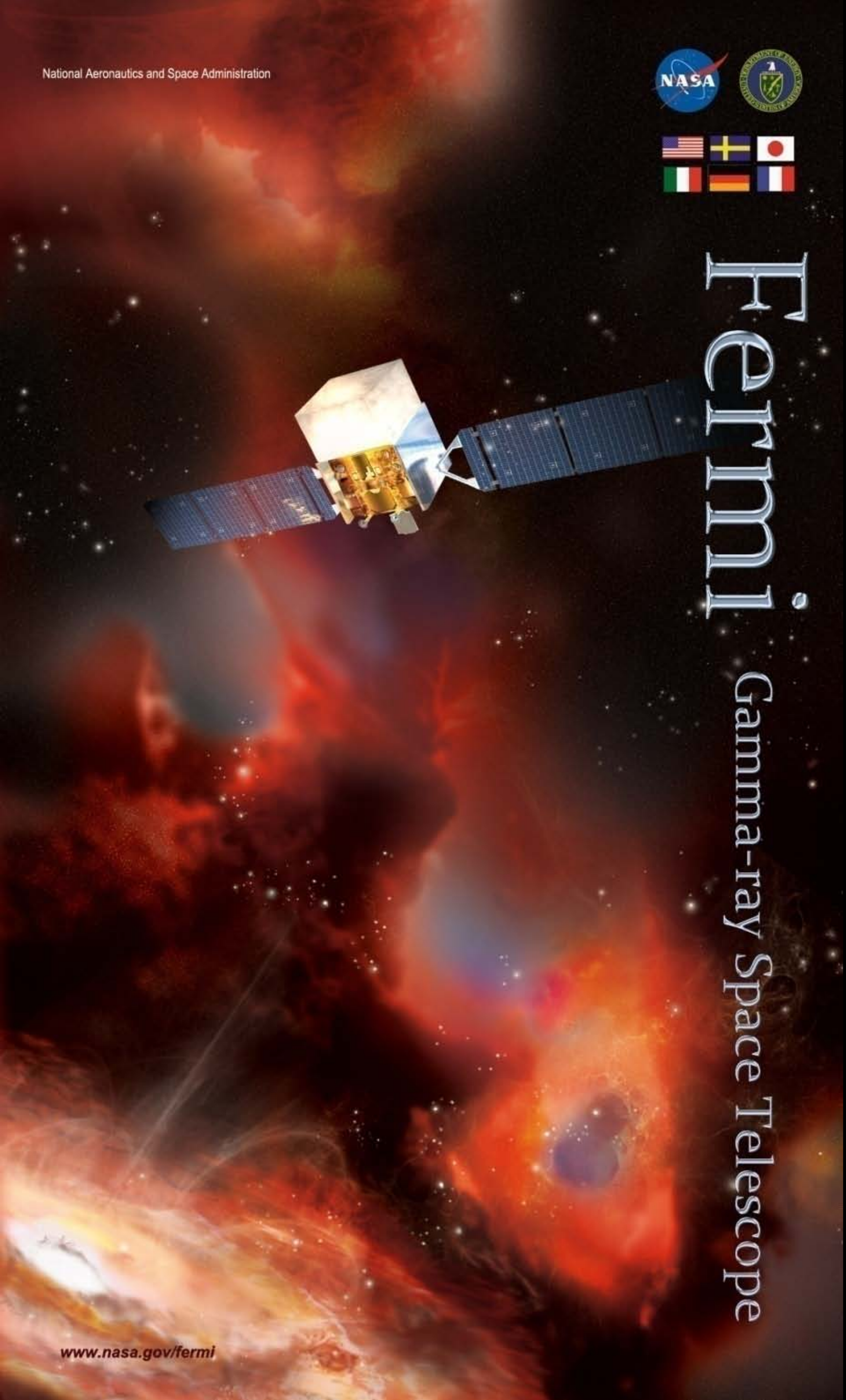

Gamma-ray emission from millisecond pulsar binaries

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on behalf of the Fermi-LAT collaboration

Institute of Space Sciences, Barcelona, Spain

Outline

- 1. Introduction

- 2. Gamma-ray emission from millisecond pulsar binaries

  (1) radio millisecond pulsar

  (2) transitional millisecond pulsar

  (3) accreting millisecond pulsar

- 3. Summary

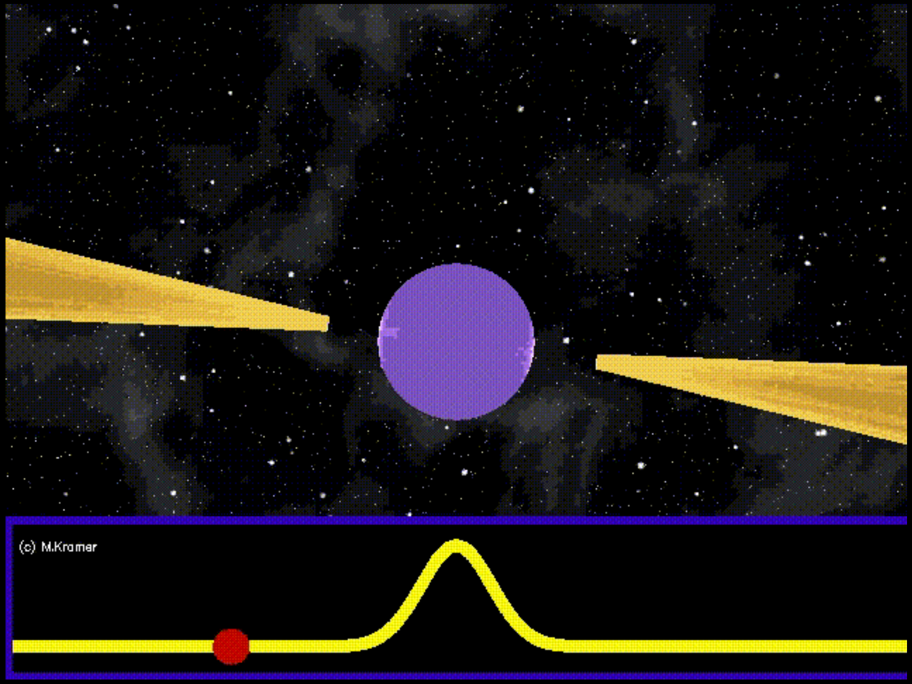
Outline

- 1. Introduction

some concepts for slides describing transitional millisecond pulsars are taken from presentations by Alessandro Papitto and Diego Torres

Introduction

A millisecond pulsar (MSP) is a pulsar with a rotational period in the range of milliseconds.



Milliseconds

PSR J1748-2446 is the fasted-spinning pulsar known, with a spin frequency of ~1.4 ms (716 Hz). At its equator it is spinning at approximately 24% of the speed of light,

Introduction

A millisecond pulsar (MSP) is a pulsar with a rotational period in the range of milliseconds.

Mid '70s – accretion driven spin up to ms periods proposed [Bisnovatyi-Kogan & Komberg 1974]
1982 – First ms radio pulsar [Backer + 1982]
The recycling scenario [Alpar+ 1982, Rhadhakrishnan+ 1982]
1988 – First ms radio pulsar ablating the companion [Fruchter 1988]
1998 – First accreting millisecond pulsar [Wijnands & van der Klis 1998]
2009 – First ms radio pulsar with a past faint accretion disk [Archibald+ 2009]
2013 – First ms pulsar switching between accretion and radio pulsar state [Papitto+ 2013]
2013/14 – Transitions from ms pulsar to faint accretion disk state observed in the two directions [Bassa+ 2014, Patruno+ 2014, Roy+ 2014, Stappers+2014]
2014 – Accretion powered X-ray pulsations observed in the sub-luminous disk state [Archibald+ 2015, Papitto+ 2015]

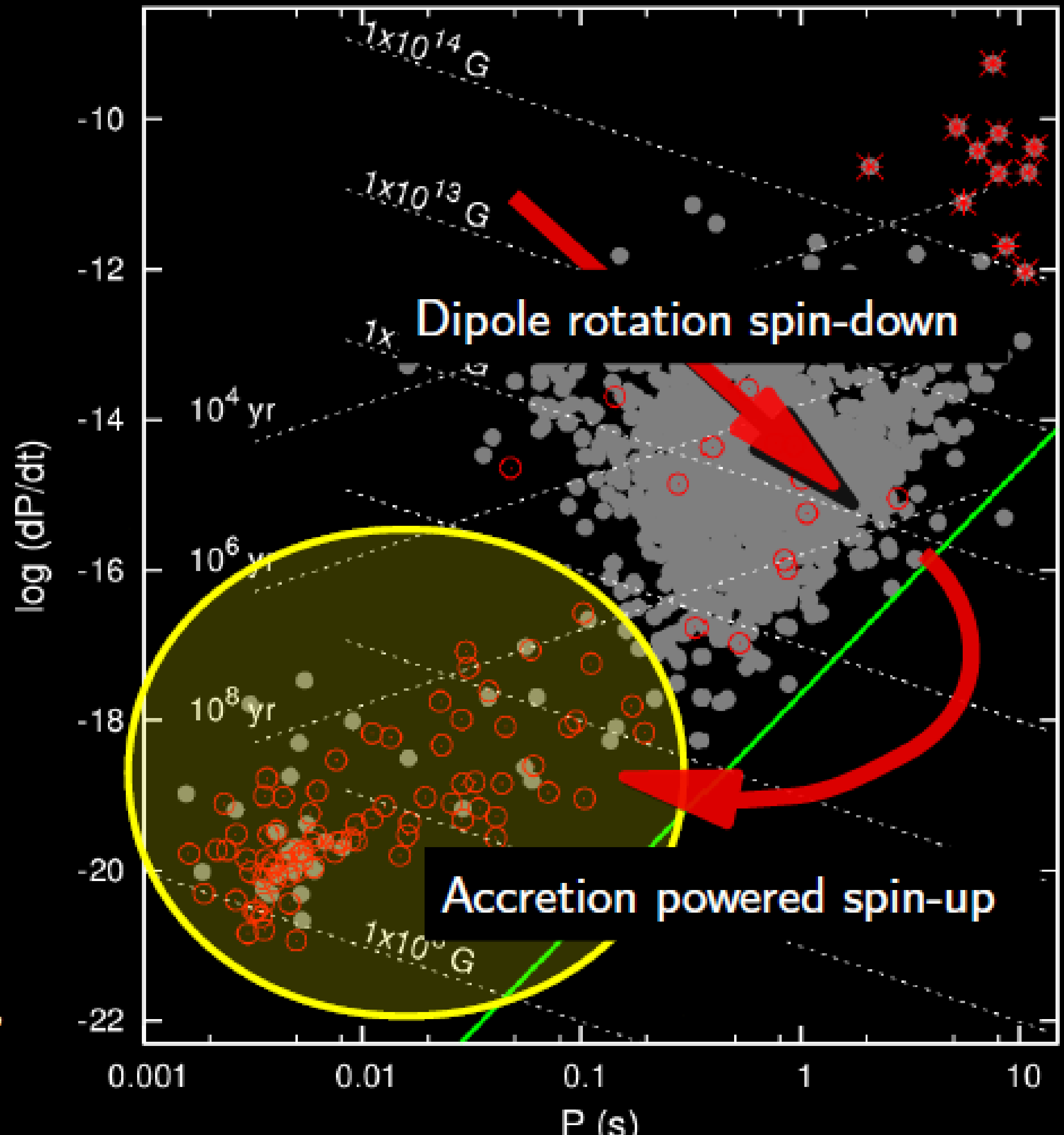
The fundamental plane of pulsars

Millisecond pulsars

[Backer+ 1982 Nature]

- weakly magnetized
- often found in globular clusters
  → old systems
- often in binaries

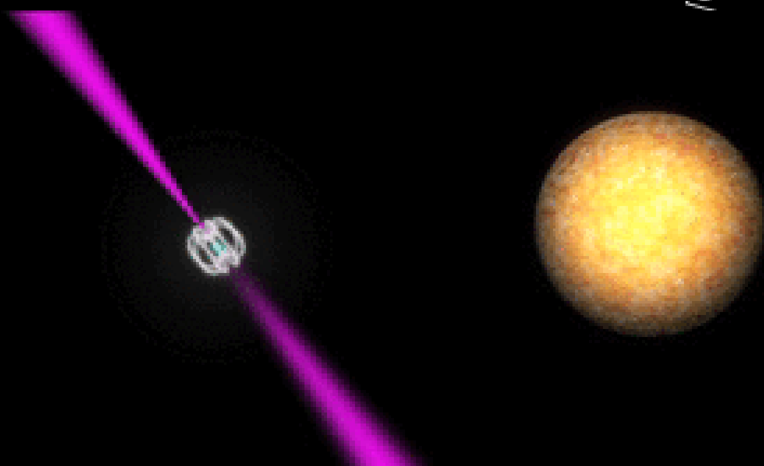
[Bisnovatyi-Kogan & Komberg 1974, Alpar+, Radhakrishnan+ 1982]

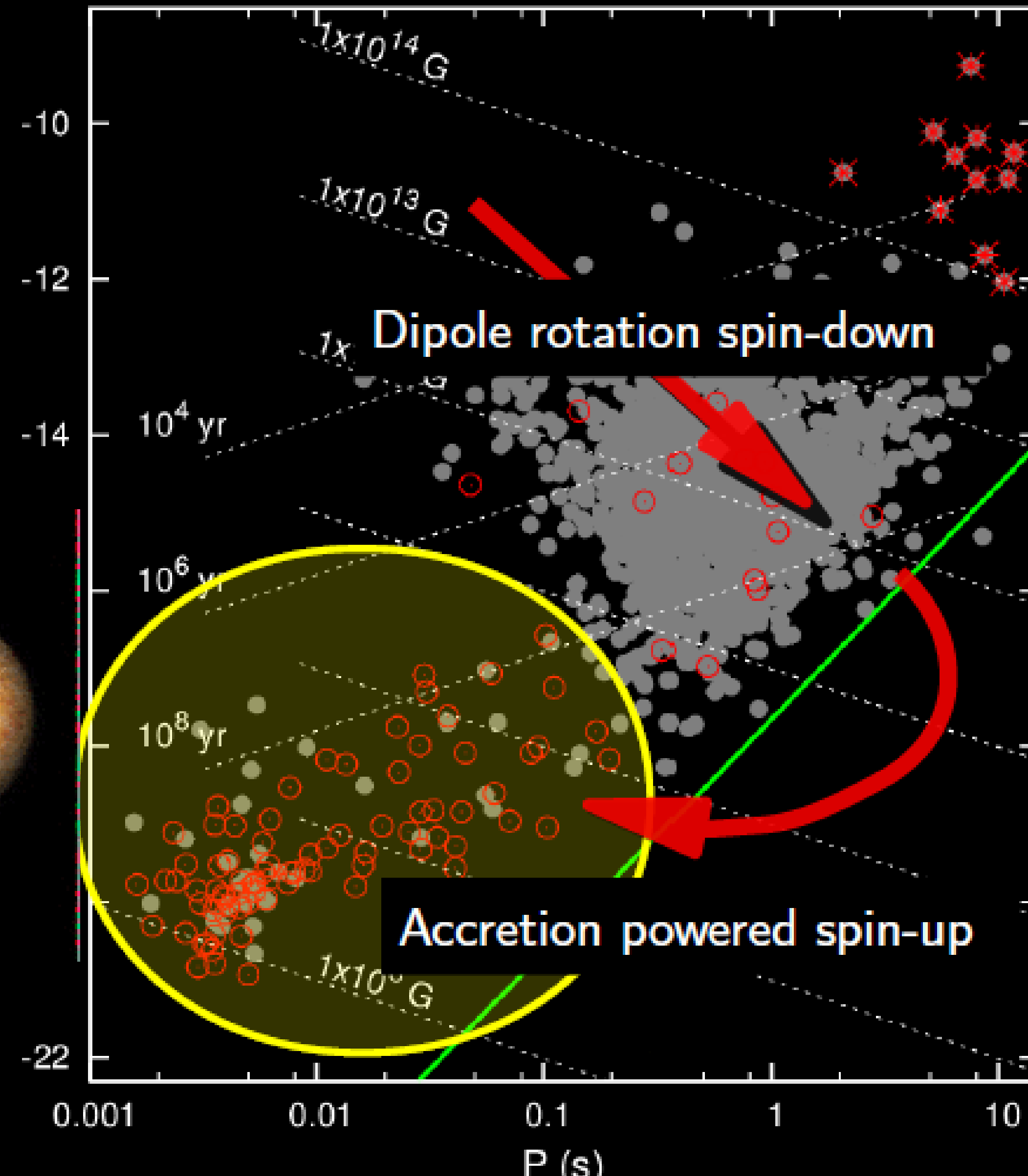


The fundamental plane of pulsars

Millisecond pulsars

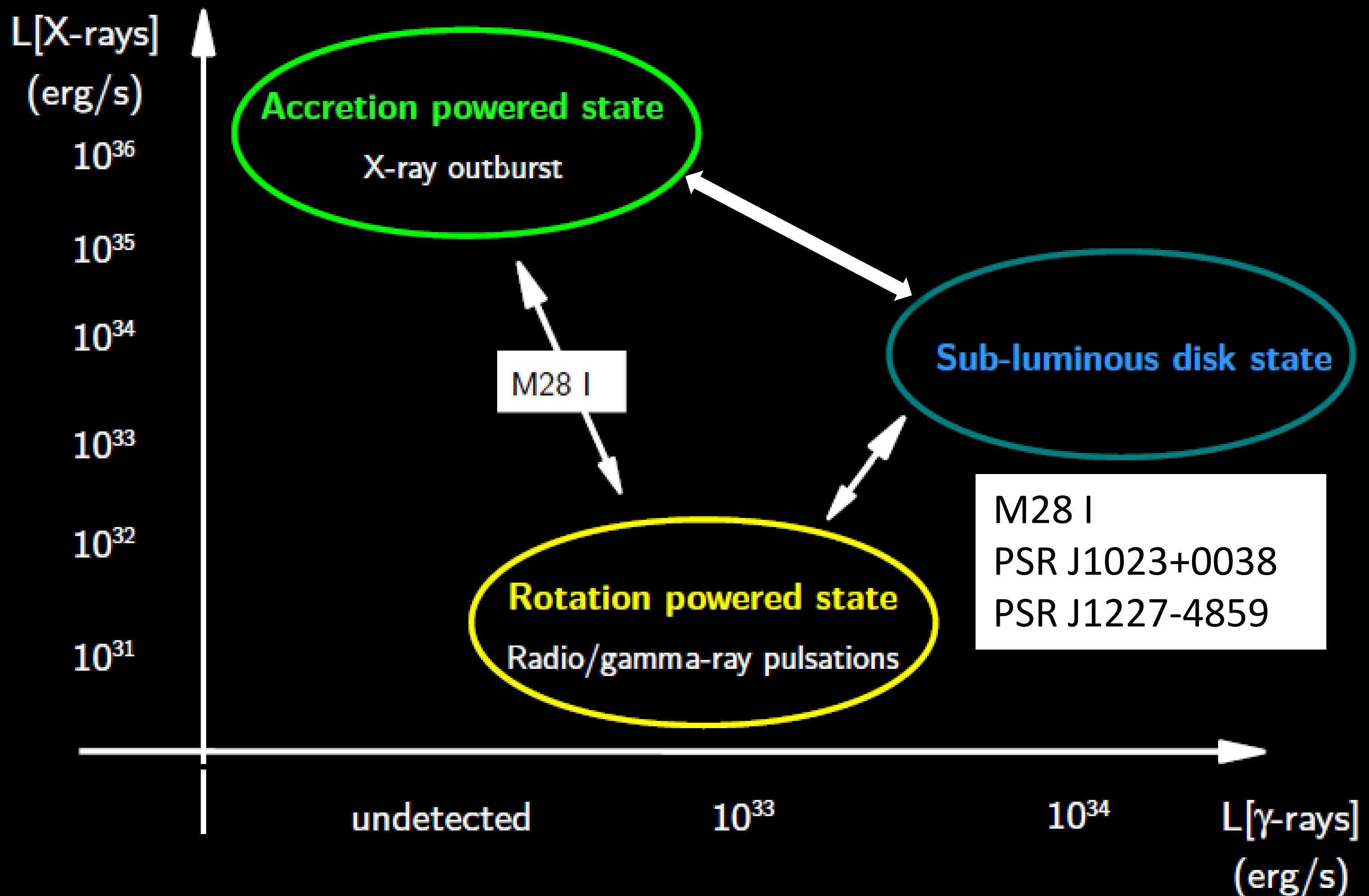
[Backer+ 1982 Nature]





[Bisnovatyi-Kogan & Komberg 1974, Alpar+, Radhakrishnan+ 1982]

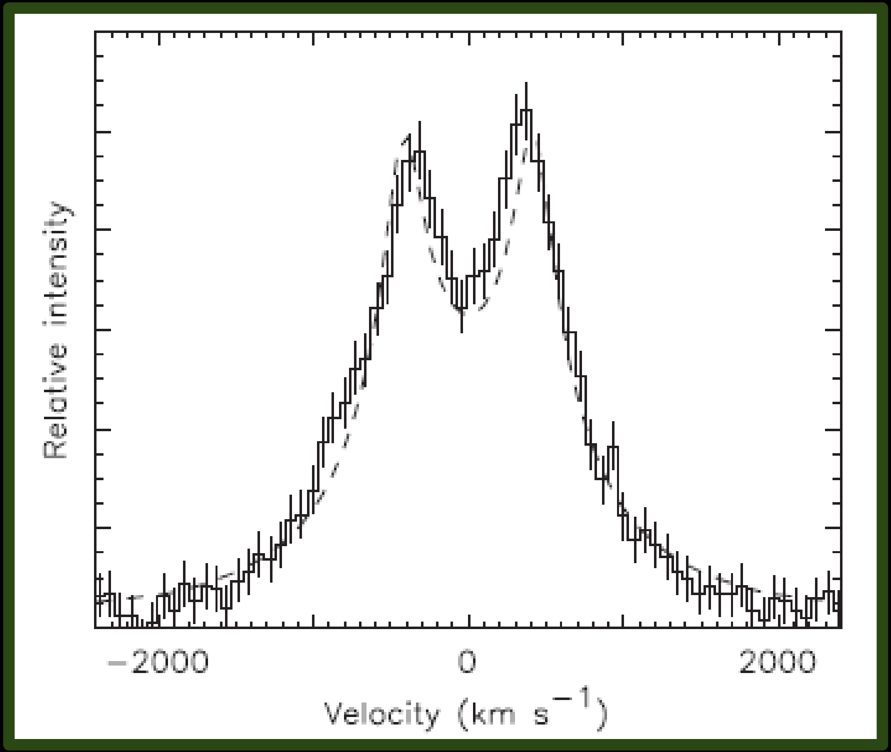
Millisecond pulsar has three state:

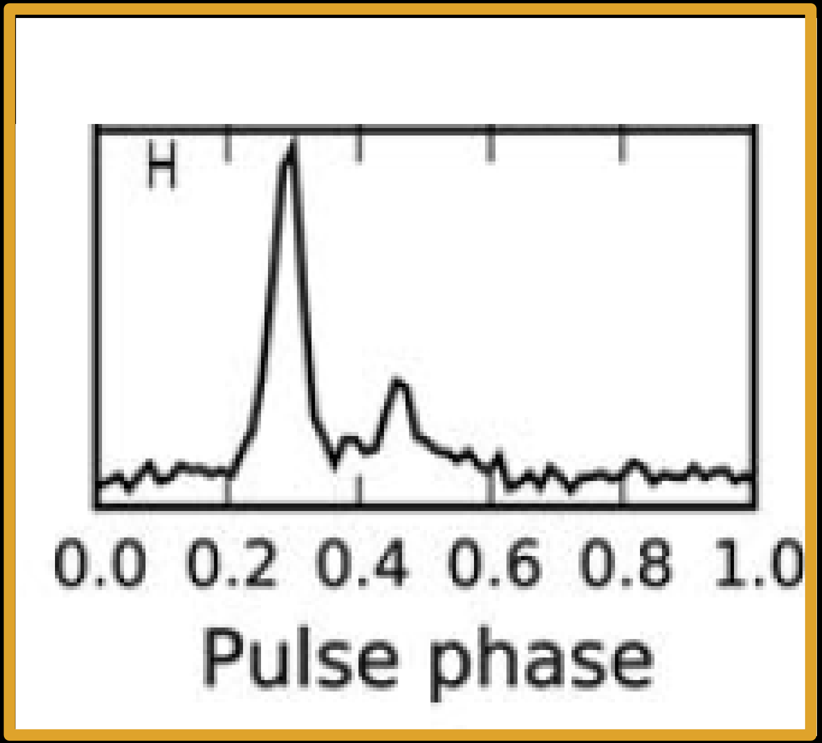


Transitional millisecond pulsar is millisecond pulsars showed transitions between different states.

Currently only 3 transitional millisecond pulsars are detected:
PSR J1023+0038, IGR J18245-2452 (M28 I), PSR J1227-4859

PSR J1023+0038 have shown indirect evidence of transitions





Accretion disk in 2000-2001
(but faint in X-rays, no pulses)

A ~1.7 ms **Radio PSR** in 2009

Implying that a state transition must have occurred,
even if unobserved (Archibald et al. 2009)

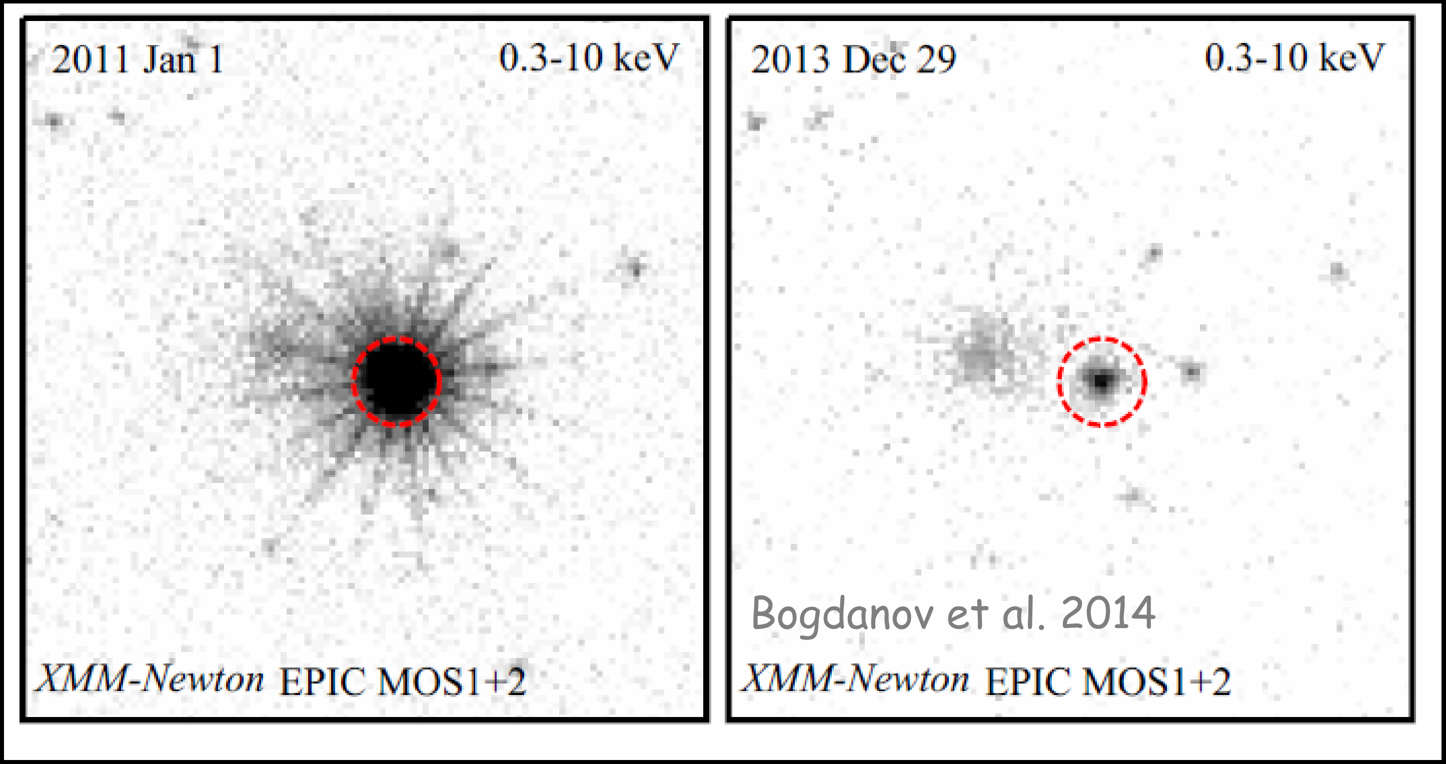
Another transitional pulsar: PSR J1227-4859 (twin of J1023)

Sub-luminous (~10^{34} erg/s) in X-rays
- X-ray variability
- Low mass companion and disk
- Gamma-ray bright

[De Martino+2010,2013; Saitou+2010; Hill+2011]

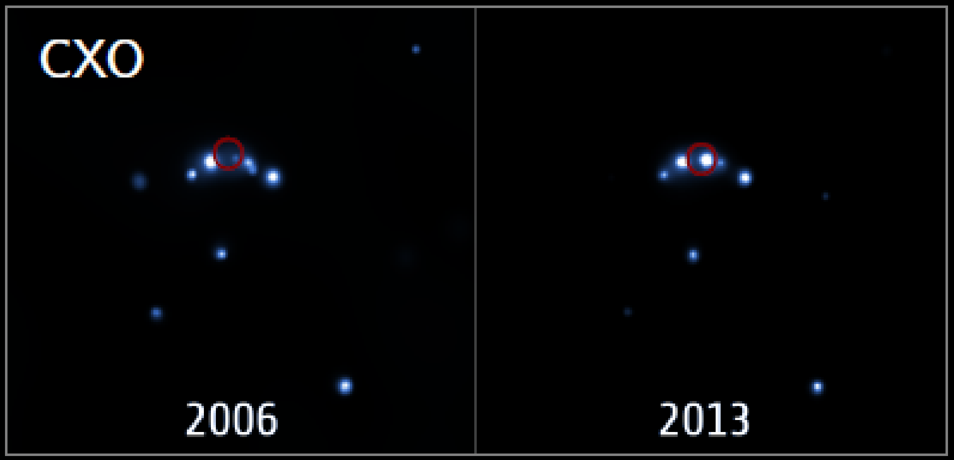
Detected as a **Radio PSR**
faint in X-rays (~10^{32} erg/s)
No disk

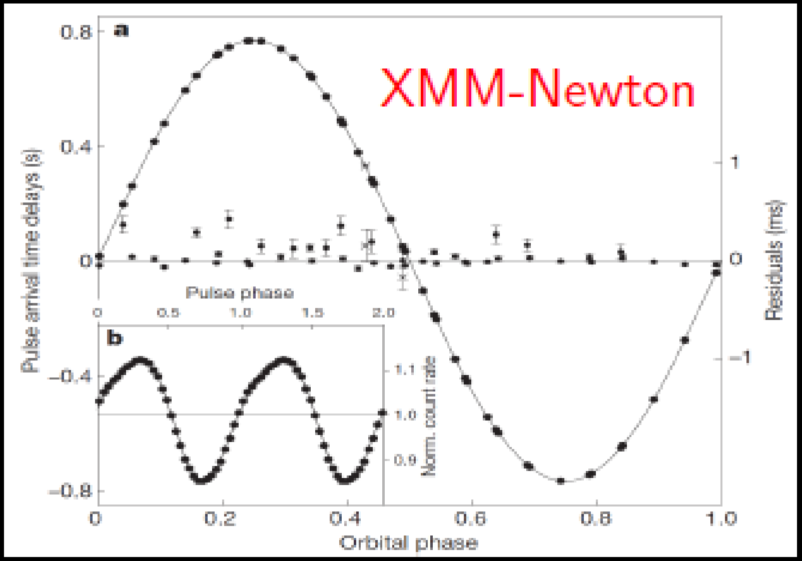
[Bassa+2014, Bogdanov+2014, Roy+ 2014]

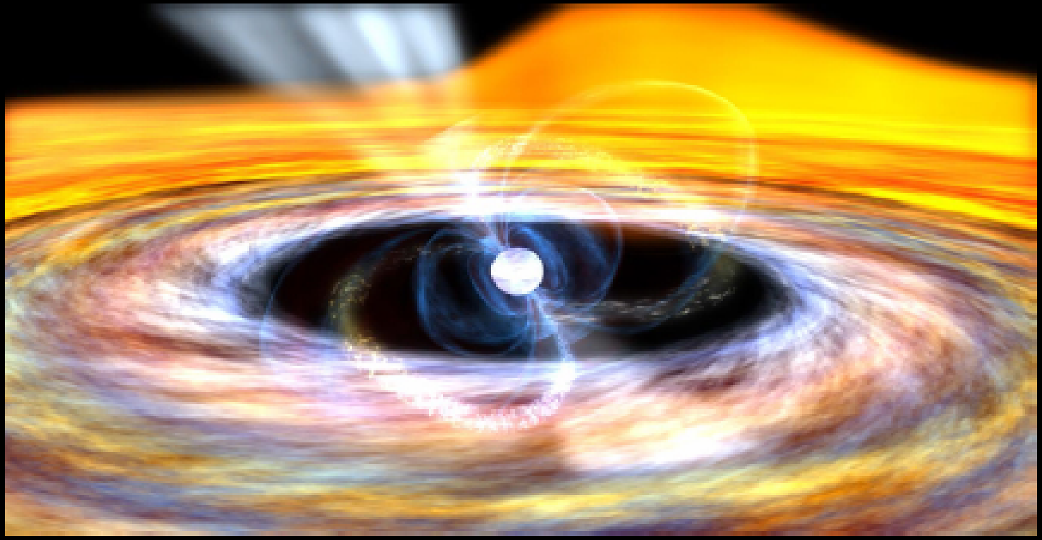


A new transient in M28, IGR J18245-2452

X-ray luminosity ~ few x 10^{36} erg/s → accretion power







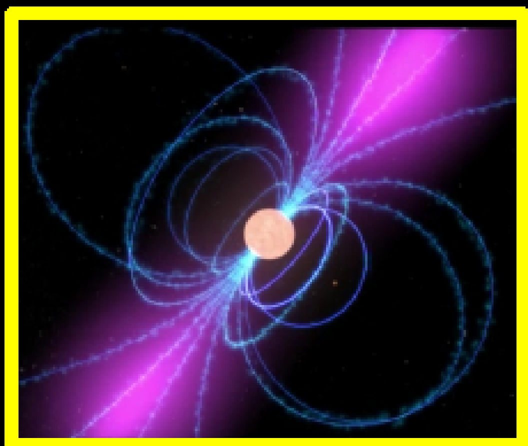
Pspin = 3.9 ms

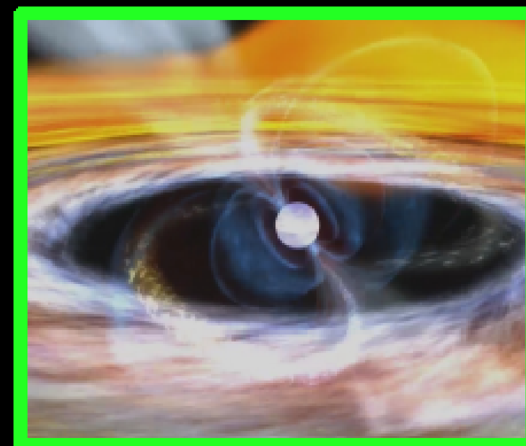
Porb = 11.0 hr

Mcomp ~ 0.2 Msun

Discovery of a transitional pulsar

Radio PSR (rotation power) → **X-ray pulsar** (accretion power)



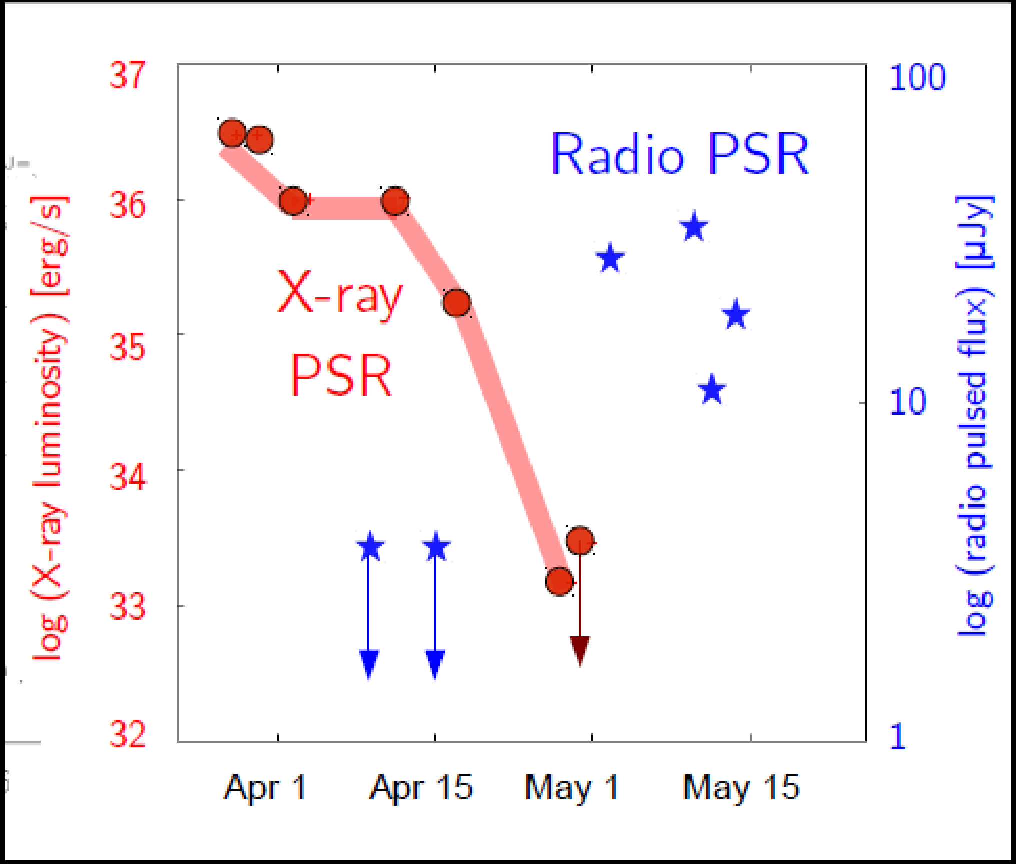


Parameter	IGR J18245–2452	PSR J1824–2452I
Right Ascension (J2000)	$18^h\ 24^m\ 32.53(4)^s$	
Declination (J2000)	$-24^\circ\ 52'\ 08.6(6)''$	
Reference epoch (MJD)	56386.0	
Spin period (ms)	3.931852642(2)	3.93185(1)
Spin period derivative	$< 1.3 \times 10^{-17}$	
RMS of pulse time delays (ms)	0.1	
Orbital period (hr)	11.025781(2)	11.0258(2)
Projected semi-major axis (lt-s)	0.76591(1)	0.7658(1)
Epoch of zero mean anomaly (MJD)	56395.216893(1)	

Papitto et al. 2013, Nature, 501, 517

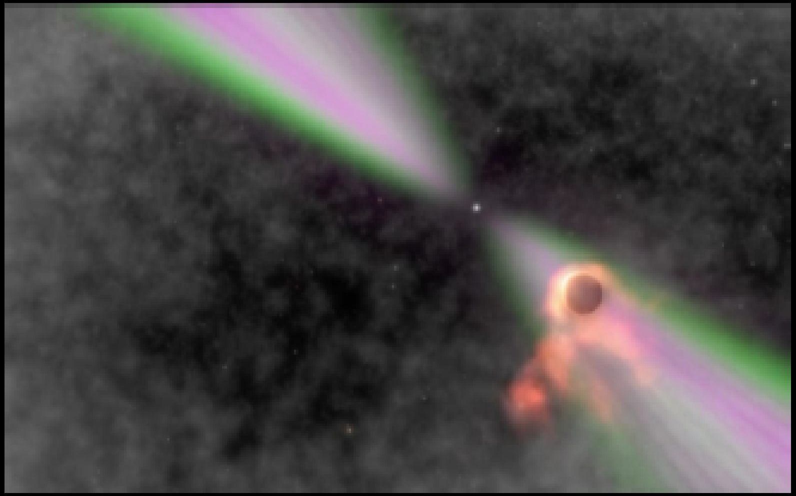
Reactive of the radio pulsar

- Weak radio pulsar signal (~10-50 microJy) detected less than two weeks since the end of the X-ray outburst (GBT, PKS, WSRT)

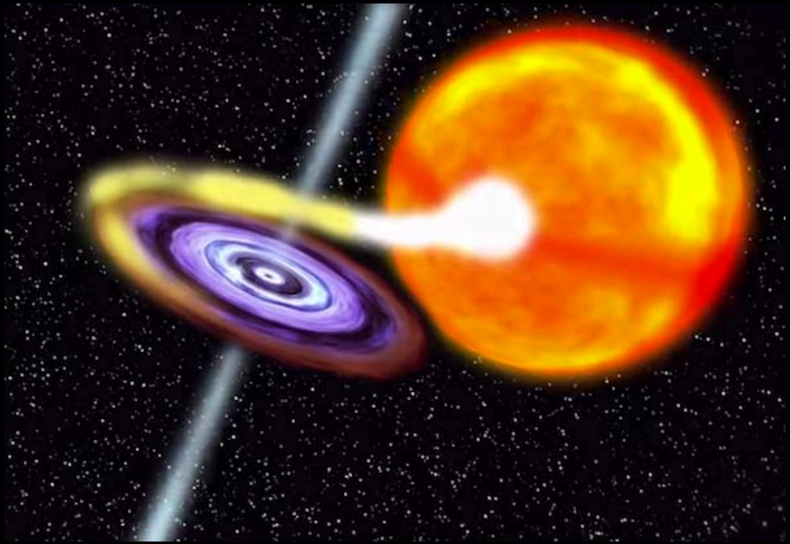


Swings driven by mass in-flow rate variability

Low Mass in-flow rate:
Magnetic field dominates
→ rotation powered **Radio PSR**



High Mass in-flow rate:
Gravity dominates
→ accretion powered **X-ray PSR**



[Stella+ 1994; Campana+ 1998; Burderi+ 2001]

Credits: NASA's Goddard Space Flight Center

- State transitions usually takes years to weeks

	Radio pulsar state	Sub-luminous disk state	Accreting ms pulsar state
X-rays	$<10^{32}$ erg/s Not always pulsed and variable at orbital period	10^{33}-10^{34} erg/s Pulsed and variable	$>10^{36}$ erg/s pulsed (sometimes variable)
Radio	Pulsed	Bright, not pulsed	(sometimes) bright, not pulsed
Gamma-rays	Pulsed	Bright, not pulsed	Not detected
optical	Variable at orbital period	bright	brighter

Outline

- 2. Gamma-ray emission from millisecond pulsar binaries

  (1) radio millisecond pulsar

  (2) transitional millisecond pulsar

  (3) accreting millisecond pulsar

Why millisecond pulsar binary?

- Considering their smaller scale than most populated gamma-ray sources (supernova remnant, globular cluster et al.), millisecond pulsar binary are extremely efficient particle accelerators.

- Binary systems give access to different physical conditions on relatively short periodic time scale. It allows access to different conditions for efficient particle acceleration along orbit and chance to study repetitions and divergence from repetition.

- State transitions usually takes years to weeks

	Radio pulsar state	Sub-luminous disk state	Accreting ms pulsar state
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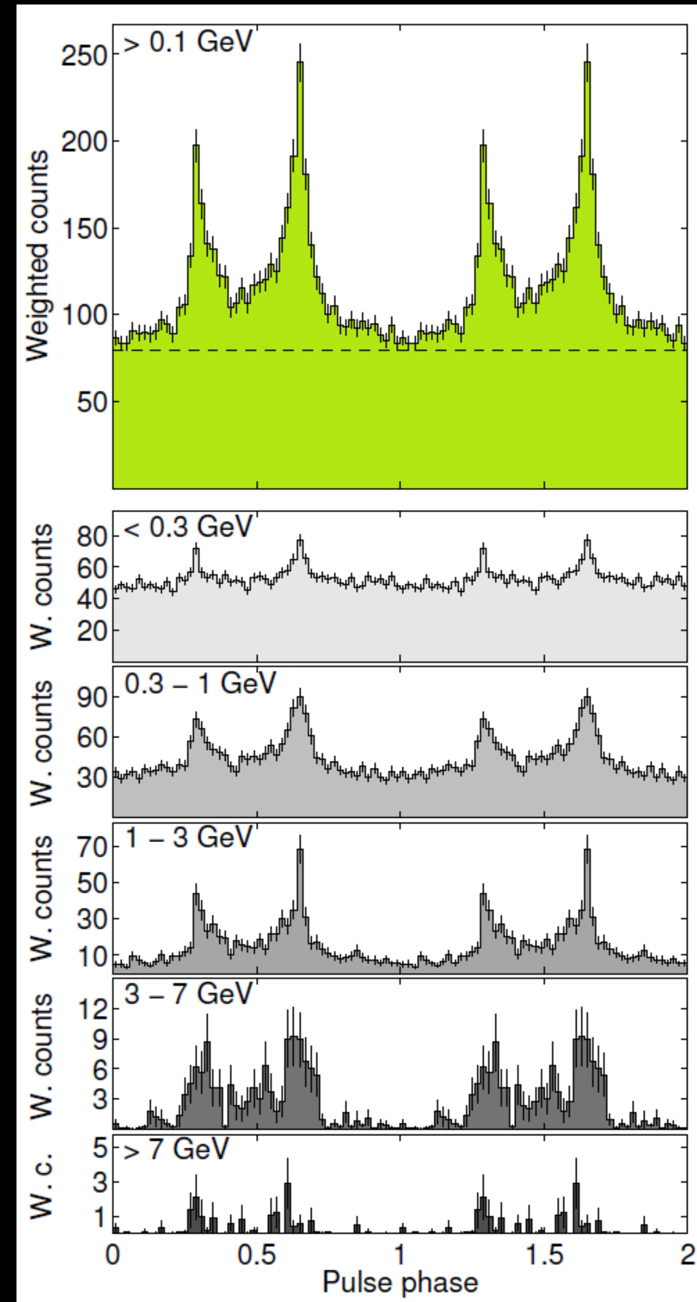
Gamma-rays	Pulsed	Bright, not pulsed	Not detected
optical	Variable at orbital period	bright	brighter

- Gamma-ray emission in radio millisecond pulsar.

(1) Gamma-ray pulsation

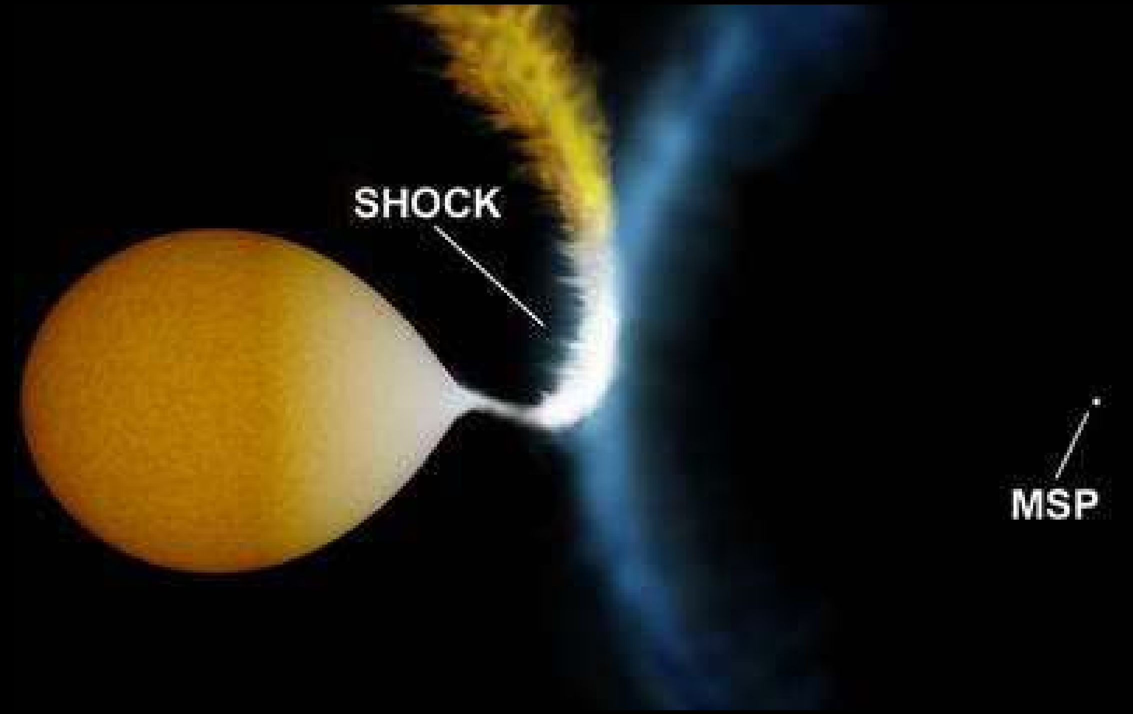
Many of the millisecond pulsars are gamma-ray pulsars
(Abdo et al. 2013, Femi second Pulsar catalog)



Gamma-ray pulsation of millisecond pulsar binary J1311-3430 (Pletsch et al. 2012)

- Gamma-ray emission in radio millisecond pulsar

(2) Pulsar wind-stellar wind collision induced gamma-ray emission



Because of limited statistics, only hints of shock-induced gamma rays are observed by Fermi/LAT for 6 millisecond pulsars in binary at the ~ 3 sigma level

- Gamma-ray emission in radio millisecond pulsar

(2) Pulsar wind-stellar wind collision induced gamma-ray emission

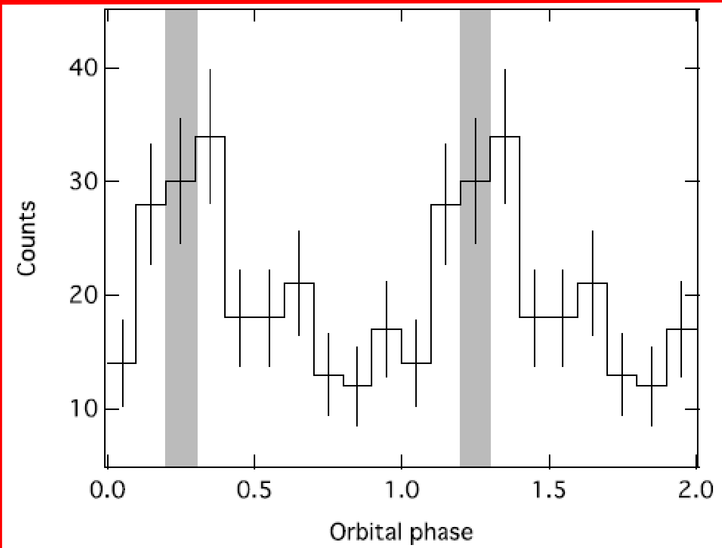
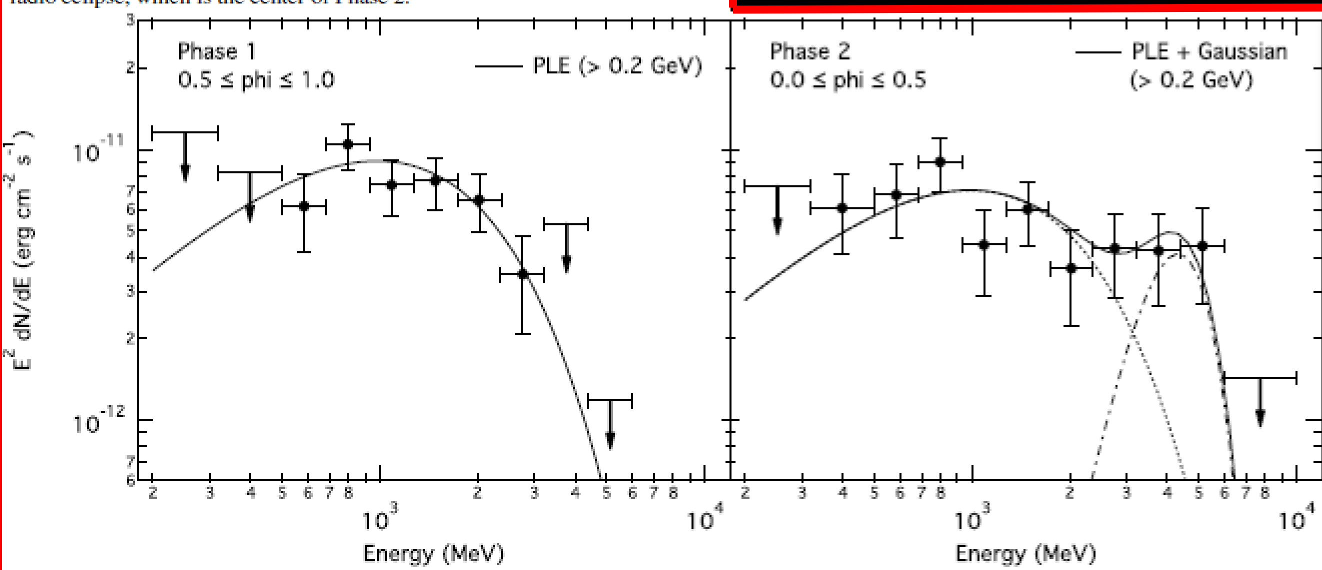
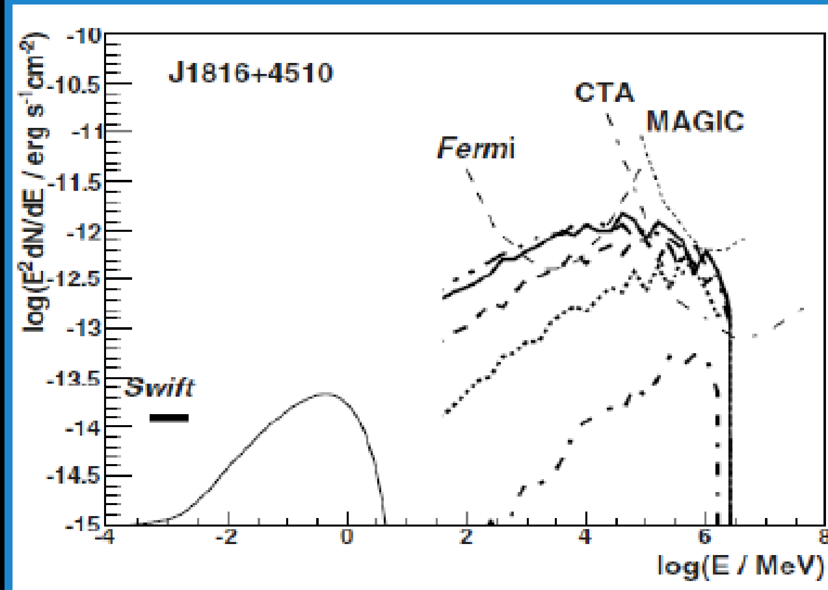


Figure 4. γ-ray light curve of PSR B1957+20 folded at the orbital period using the *Fermi* plug-in for TEMPO2, with the optimized size of aperture of 0°.965. Two orbits are shown for clarity. The shaded regions correspond to the phase of the radio eclipse, which is the center of Phase 2.





Model predicted gamma-ray emission from shock in PSR J1816+4510 (Bednarek 2014)

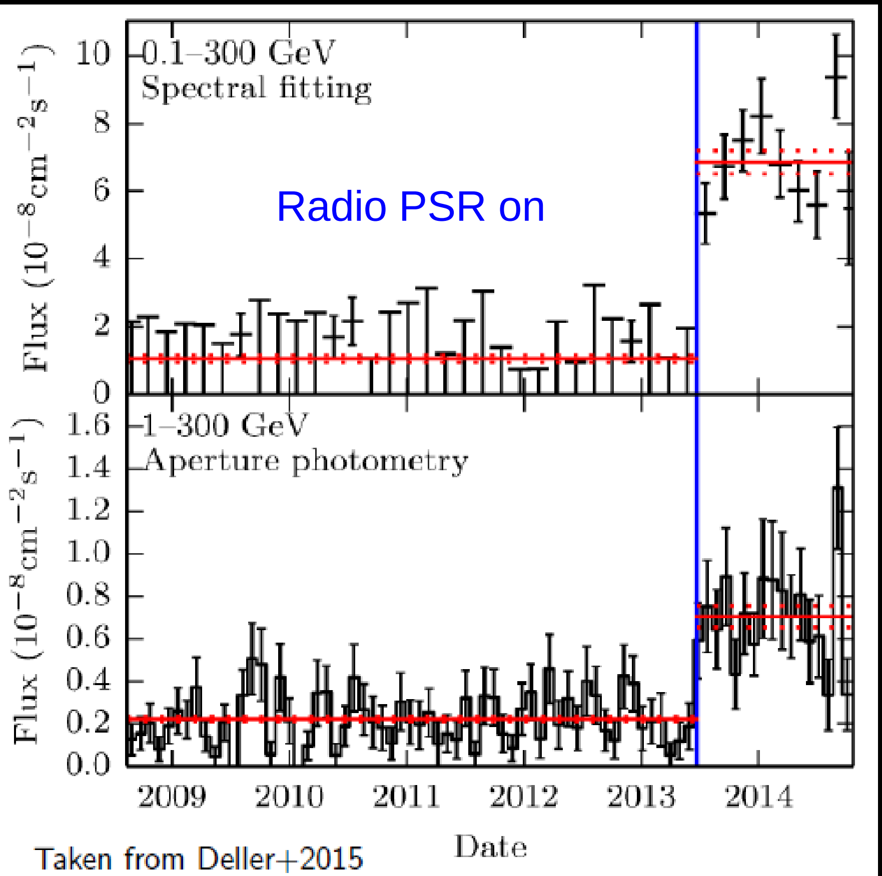
e.g. the hint of gamma-ray emission from shock in PSR B1957+20 (Wu et al. 2012)

- Gamma-ray emission in transitional millisecond pulsar

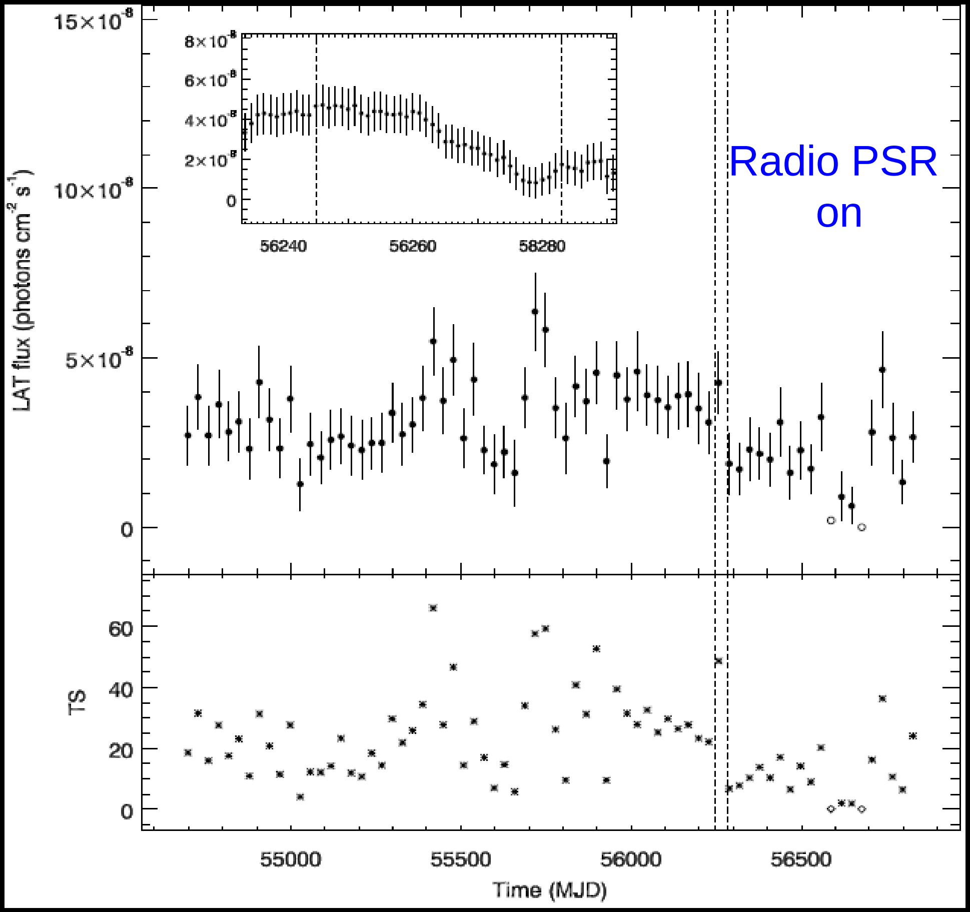
	Radio pulsar state	Sub-luminous disk state	Accreting ms pulsar state
X-rays	$<10^{32}$ erg/s Not always pulsed and variable at orbital period	10^{33}-10^{34} erg/s Pulsed and variable	$>10^{36}$ erg/s pulsed (sometimes variable)
Radio	Pulsed	Bright, not pulsed	(sometimes) bright, not pulsed
Gamma-rays	Pulsed	Bright, not pulsed	Not detected
optical	Variable at orbital period	bright	brighter

- During state transitions, the gamma-ray flux of millisecond pulsars may change by a factor of ~2-5

PSR J1023+3308



PSR J1227-4859



Gamma-ray emission observed with Fermi/LAT could be a very good tracer of the state transitions of millisecond pulsars.

The gamma-ray emission

Ecut ~ few GeV

→ radio pulsar models, GeV electrons of magnetospheric origin

→ propeller model, electrons accelerated at the turbulent disk-magnetospheric boundary

Propeller hypothesis:

→ synchrotron (up to MeV)

→ self-synchrotron Compton (up to GeV)

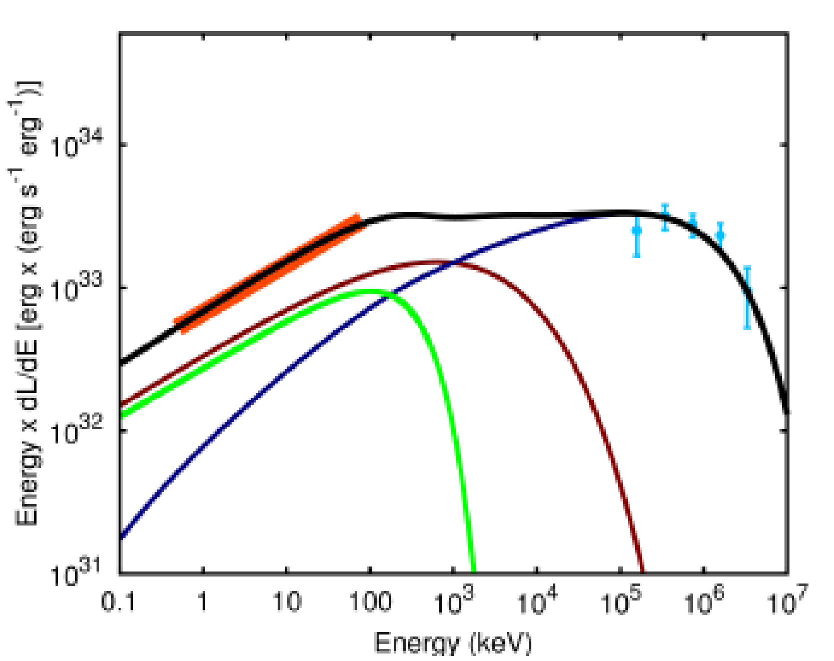
A solution found for:

Rin = 1.8 Rco

$(dM/dt)_{disk} = 2.4\times10^{-11}$ M_{sun}/yr ~30 $(dM/dt)_{NS}$

Papitto & Torres 2015, ApJ,

Papitto, Torres, Li, 2014, MNRAS,

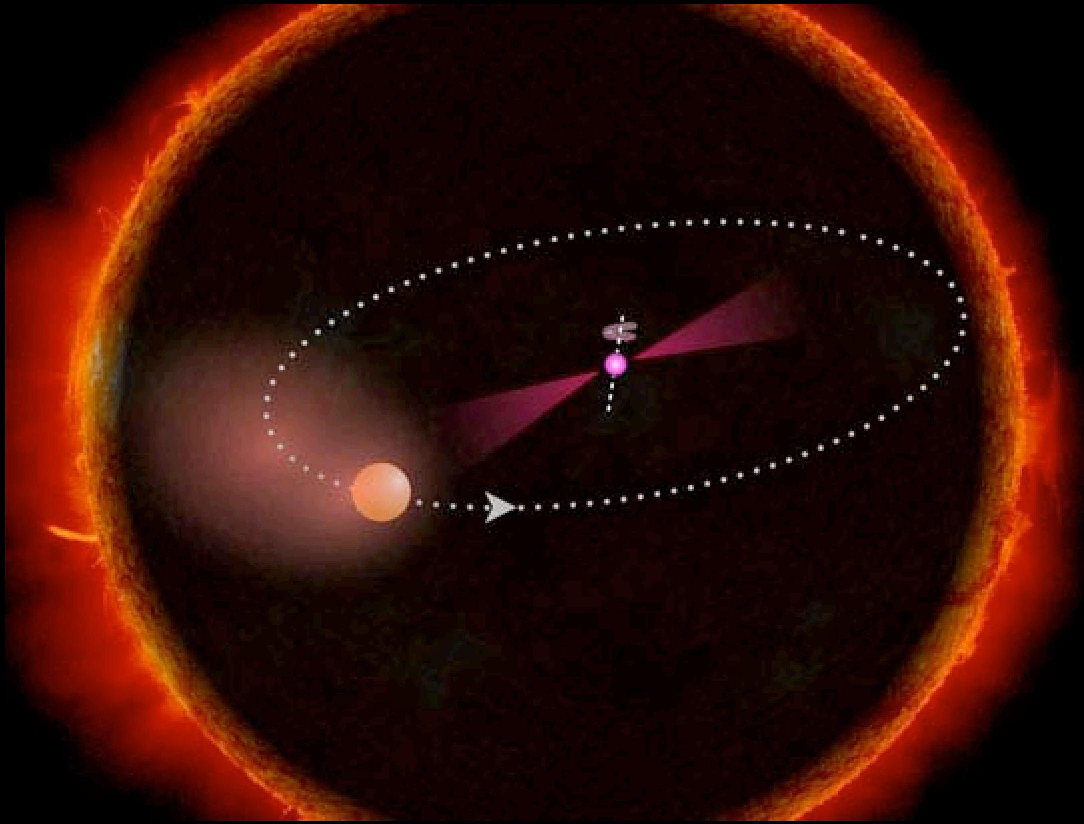


Candidate of transitional millisecond pulsars

- Redback and black widow are spiders that eat their companions.

Candidate of transitional millisecond pulsars

- Redback and black widow pulsars (RBs & BWs) are close millisecond pulsar binaries (orbital period < 1 day), consisting of millisecond pulsars and low-mass stars (RBs, $M_{companion}$ ~ 0.2-0.4 M_{sun}; BWs, $M_{companion}$ << 0.1 M_{sun}).



- They are the candidates of transitional millisecond pulsars.

- All three confirmed transitional millisecond pulsars are all RBs.

Candidate of transitional millisecond pulsars

- Redback and black widow pulsars (RBs & BWs) are close millisecond pulsar binaries (orbital period < 1 day), consisting of millisecond pulsars and low-mass stars (RBs, $M_{companion}$ ~ 0.2-0.4 M_{sun}; BWs, $M_{companion}$ << 0.1 M_{sun}).

- They are the candidates of transitional millisecond pulsars.

- All three confirmed transitional millisecond pulsars are all RBs.

Candidate of transitional millisecond pulsars

- We have carried out Fermi/LAT data analysis of the 12 confirmed RBs and the 18 confirmed BWs to search for new transitional millisecond pulsars.

- Gamma-ray emission from RBs and BWs could originate from:
  (1) gamma-ray pulsation
  (2) shock between stellar wind and pulsar wind
  (3) state transition

- With 7 years of Fermi/LAT Pass 8 data, 11 out of 12 RBs, and 15 out of 18 BWs are significantly detected in the 0.1-300 GeV band.

RB name PSR	3FGL source	TS	Index	Flux (10^{-11} erg cm^{-2} s^{-1})	class (3FGL)	l deg	b deg	2PC/list
J0523.5−2529	J0523.3-2528	1378.79	$2.48 \pm 0.05 \pm 0.03$	$2.03 \pm 0.11 \pm 0.06$	...	80.84	-25.48	no/no
J1023+0038	...	1093.87	$2.37 \pm 0.03 \pm 0.08$	$1.96 \pm 0.01 \pm 0.13$	...	155.92	0.68	no/no[a]
J1023+0038†	...	75.62	$2.31 \pm 0.03 \pm 0.04$	$0.50 \pm 0.09 \pm 0.05$	...	155.92	0.68	no/no
J1023+0038‡	...	1652.71	$2.41 \pm 0.10 \pm 0.13$	$5.55 \pm 0.20 \pm 0.27$	...	155.92	0.68	no/no
J1227−4859	J1227.9-4854	2448.85	$2.40 \pm 0.02 \pm 0.06$	$3.72 \pm 0.11 \pm 0.07$	psr[b]	186.98	-48.90	no/yes
J1227−4859†	J1227.9-4854	2058.7	$2.36 \pm 0.06 \pm 0.09$	$4.57 \pm 0.15 \pm 0.08$	psr	186.98	-48.90	no/yes
J1227−4859‡	J1227.9-4854	369.7	$2.42 \pm 0.03 \pm 0.15$	$1.79 \pm 0.16 \pm 0.17$	psr	186.98	-48.90	no/yes
J1431−4715	...	13.03	...	< 0.45	...	217.75	-47.25	no/no
J1544.6−1125	J1544.6-1125	407.29	$2.48 \pm 0.05 \pm 0.11$	$1.43 \pm 0.09 \pm 0.04$	...	236.17	-11.43	no/no
J1628−3205	J1628.0-3203	372.11	$2.36 \pm 0.02 \pm 0.04$	$1.01 \pm 0.09 \pm 0.09$	psr	247.02	-32.06	no/no
J1653−0158	J1653.6-0158	2911.29	$2.24 \pm 0.02 \pm 0.07$	$3.28 \pm 0.12 \pm 0.05$	...	253.42	-1.98	no/no
J1723−282	...	34.53	$2.67 \pm 0.15 \pm 0.17$	$0.83 \pm 0.23 \pm 0.40$	...	260.75	-28.62	no/no
J1816+4510	J1816.5+4512	951.56	$2.12 \pm 0.04 \pm 0.02$	$0.94 \pm 0.06 \pm 0.04$	psr	274.13	45.20	no/yes
J2129−0429	J2129.6-0427	401.82	$2.22 \pm 0.05 \pm 0.06$	$1.10 \pm 0.08 \pm 0.03$	psr	322.41	-4.46	no/no
J2215+5135	J2215.6+5134	787.64	$2.08 \pm 0.04 \pm 0.09$	$1.33 \pm 0.09 \pm 0.06$	psr	333.91	51.58	yes/yes
J2339−0533	J2339.6-0533	3963.47	$1.94 \pm 0.01 \pm 0.04$	$5.05 \pm 0.19 \pm 0.53$	psr	354.90	-5.55	no/yes

PRELIMINARY

- Gamma-ray emission from RBs and BWs could originate from:
  (1) gamma-ray pulsation
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- With 7 years of Fermi/LAT Pass 8 data, 11 out of 12 RBs, and 15 out of 18 BWs are significantly detected in the 0.1-300 GeV band.

RB name PSR	3FGL source	TS	Index	Flux (10^{-11} erg cm^{-2} s^{-1})	class (3FGL)	l deg	b deg	2PC/list
BW name								
B1957+20	J1959.5+2047	562.11	$2.40 \pm 0.04 \pm 0.38$	$1.52 \pm 0.02 \pm 0.06$	psr	299.89	20.80	yes/yes
J0023+0923	J0023.4+0923	407.26	$2.27 \pm 0.01 \pm 0.08$	$0.79 \pm 0.07 \pm 0.13$	psr	5.86	9.39	yes/yes
J0610−2100	J0610.2-2059	365.71	$2.28 \pm 0.05 \pm 0.04$	$1.09 \pm 0.08 \pm 0.04$	psr	92.55	-20.99	yes/yes
J1124−3653	J1123.9-3653	1040.61	$2.12 \pm 0.04 \pm 0.07$	$1.28 \pm 0.08 \pm 0.03$	psr	170.99	-36.89	yes/yes
J1301+08	J1301.6+0832	504.60	$2.25 \pm 0.05 \pm 0.08$	$1.18 \pm 0.08 \pm 0.13$	psr	195.42	8.54	no/yes
J1311−3430	J1311.8-3430	9522.95	$2.21 \pm 0.01 \pm 0.04$	$6.20 \pm 0.13 \pm 0.04$	psr	197.96	-34.50	no/yes
J1446−4701	J1446.6-4701	163.14	$2.08 \pm 0.03 \pm 0.05$	$0.91 \pm 0.08 \pm 0.07$	psr	221.66	-47.03	yes/yes
J1544+4937	J1544.0+4938	156.22	$2.27 \pm 0.09 \pm 0.09$	$0.45 \pm 0.05 \pm 0.02$	psr	236.02	49.65	no/yes
J1653−2054	...	1.30	$1.47 \pm 0.73 \pm 0.16$	< 0.14	...	253.38	-20.92	no/yes
J1731−1847	...	5.5	$2.32 \pm 0.20 \pm 0.38$	< 0.55	...	262.82	-18.79	no/no
J1745+1017	...	0.00	$2.38 \pm 12.64 \pm 0.32$	< 0.17	...	266.25	10.28	no/no
J1810+1744	J1810.5+1743	1701.03	$2.35 \pm 0.03 \pm 0.43$	$2.34 \pm 0.09 \pm 0.18$	psr	272.64	17.72	yes/yes
J2047+1053	J2047.1+1054	140.11	$2.34 \pm 0.53 \pm 0.12$	$0.29 \pm 0.03 \pm 0.12$	psr	311.78	10.91	yes/yes
J2051−0827	J2051.3-0828	126.49	$2.21 \pm 0.10 \pm 1.09$	$0.33 \pm 0.05 \pm 0.15$	psr	312.83	-8.48	yes/yes
J2214+3000	J2214.6+3000	5379.73	$2.04 \pm 0.02 \pm 0.05$	$3.16 \pm 0.09 \pm 0.01$	psr	333.66	30.01	yes/yes
J2234+0944	J2234.8+0945	719.66	$2.20 \pm 0.05 \pm 0.10$	$1.14 \pm 0.09 \pm 0.10$	psr	338.71	9.75	no/yes
J2241−5236	J2241.6-5237	6423.94	$2.03 \pm 0.02 \pm 0.07$	$3.27 \pm 0.09 \pm 0.03$	psr	340.42	-52.62	yes/yes
J2256−1024	J2256.7-1022	438.90	$2.02 \pm 0.05 \pm 0.05$	$0.56 \pm 0.05 \pm 0.11$	psr	344.18	-10.38	no/no

PRELIMINARY

- Gamma-ray emission from RBs and BWs could originate from:

  (1) gamma-ray pulsation
  Many of the RBs and BWs are know gamma-ray pulsars and gamma-ray pulsation are expected to be steady (except for PSR J2021+4026, Allafort et al. 2013).

  (2) shock between stellar wind and pulsar wind
  Shock emission could be orbital modulated and haven't been detected to show long term variability

  (3) state transition
  During state transitions of the few transitional millisecond pulsars known, their gamma-ray flux was observed to vary by a factor of 2 to 5
  (e.g. PSR J1023+0038, PSR J1227-4859).

- Gamma-ray emission from RBs and BWs could originate from:

(3) state transition

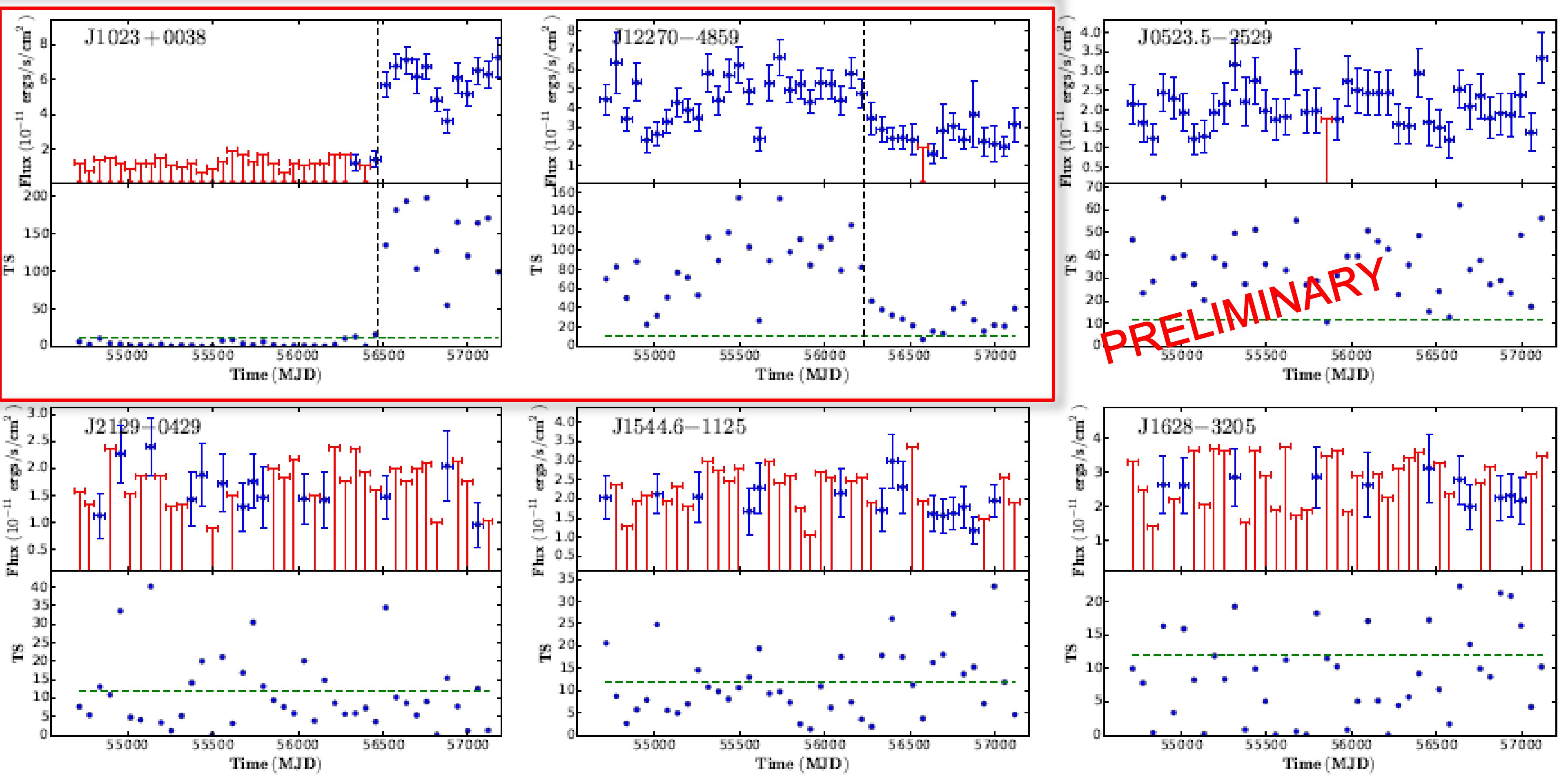
During state transitions of the few transitional millisecond pulsars known, their gamma-ray flux was observed to vary by a factor of 2 to 5 (e.g. PSR J1023+0038, PSR J1227-4859).

To search for possible state transitions in all RBs and BWs, we produced long-term light curves for all systems in Table 1. with a time bin of 60 days

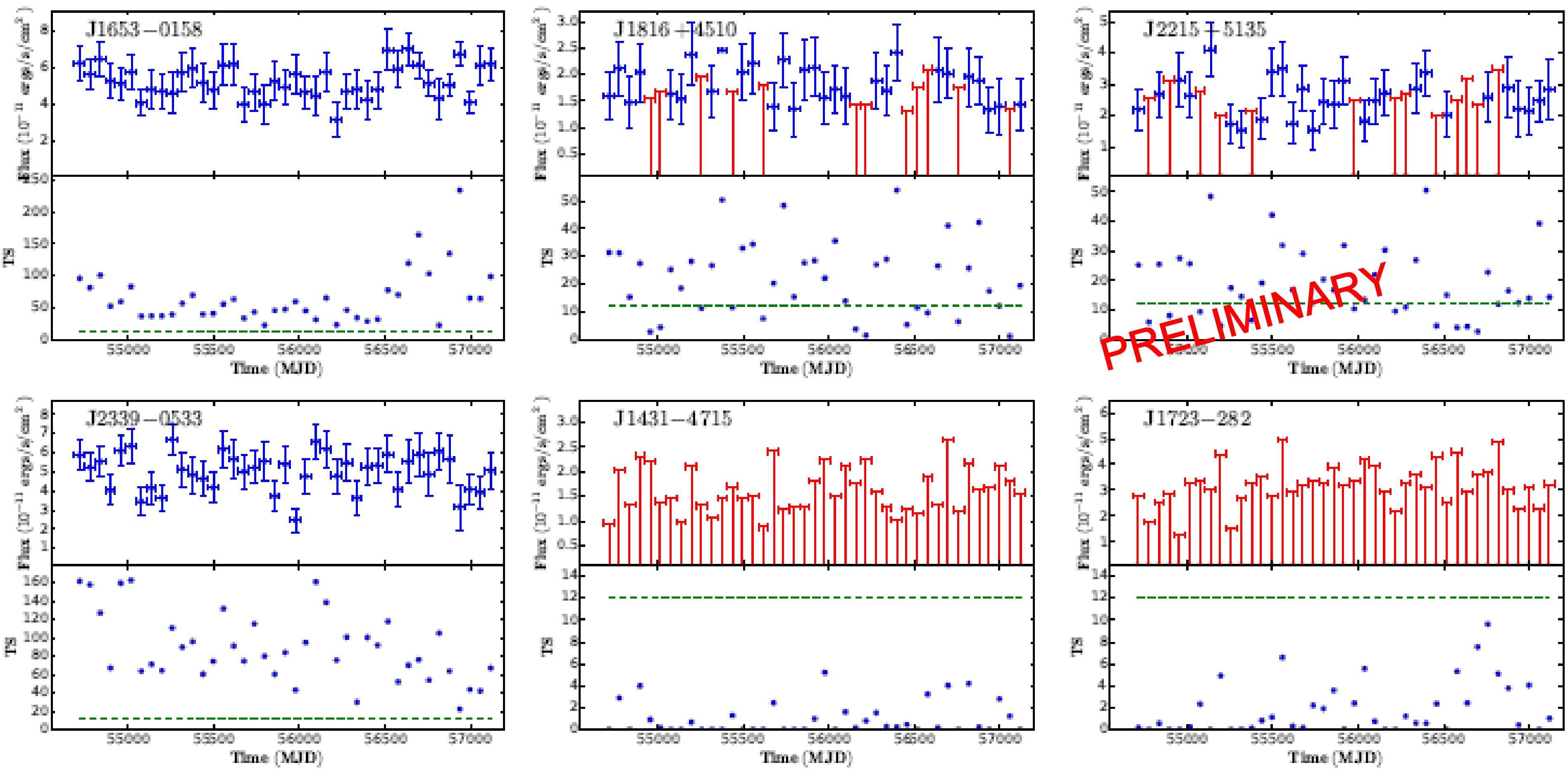
This timescale was earlier used to analyze the known transitional pulsars and candidates (e.g., Stappers et al. 2014, Bogdanov & Halpern 2015, also Bogdanov 2015).

It is also a sensible one for most of the average values of fluxes.

The known transitions of PSR J1023+0038 and PSR J1227-4859 are detected



- However, no transition was discovered except for the known cases of PSR J1023+0038 and PSR J1227-4859.



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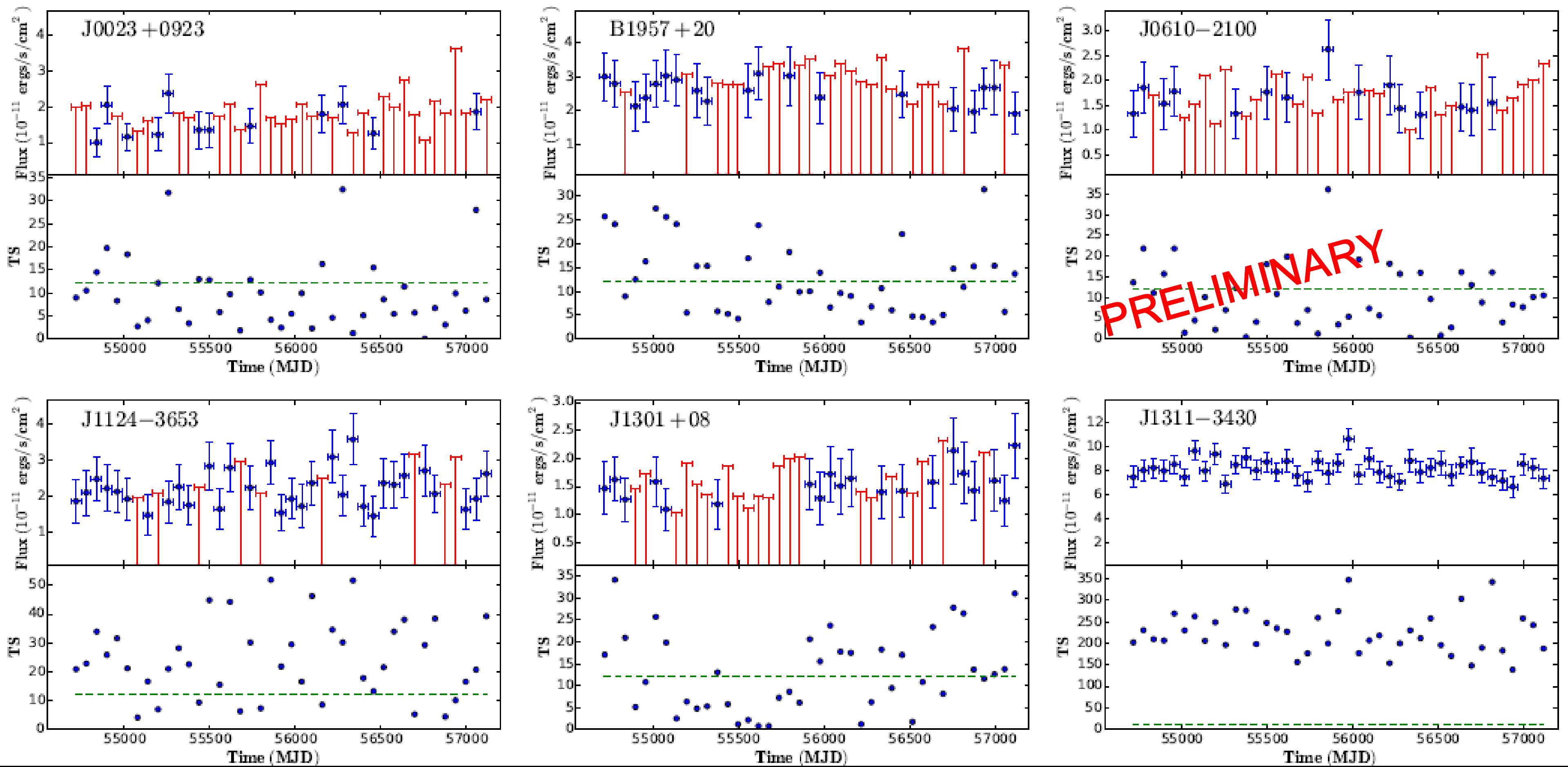

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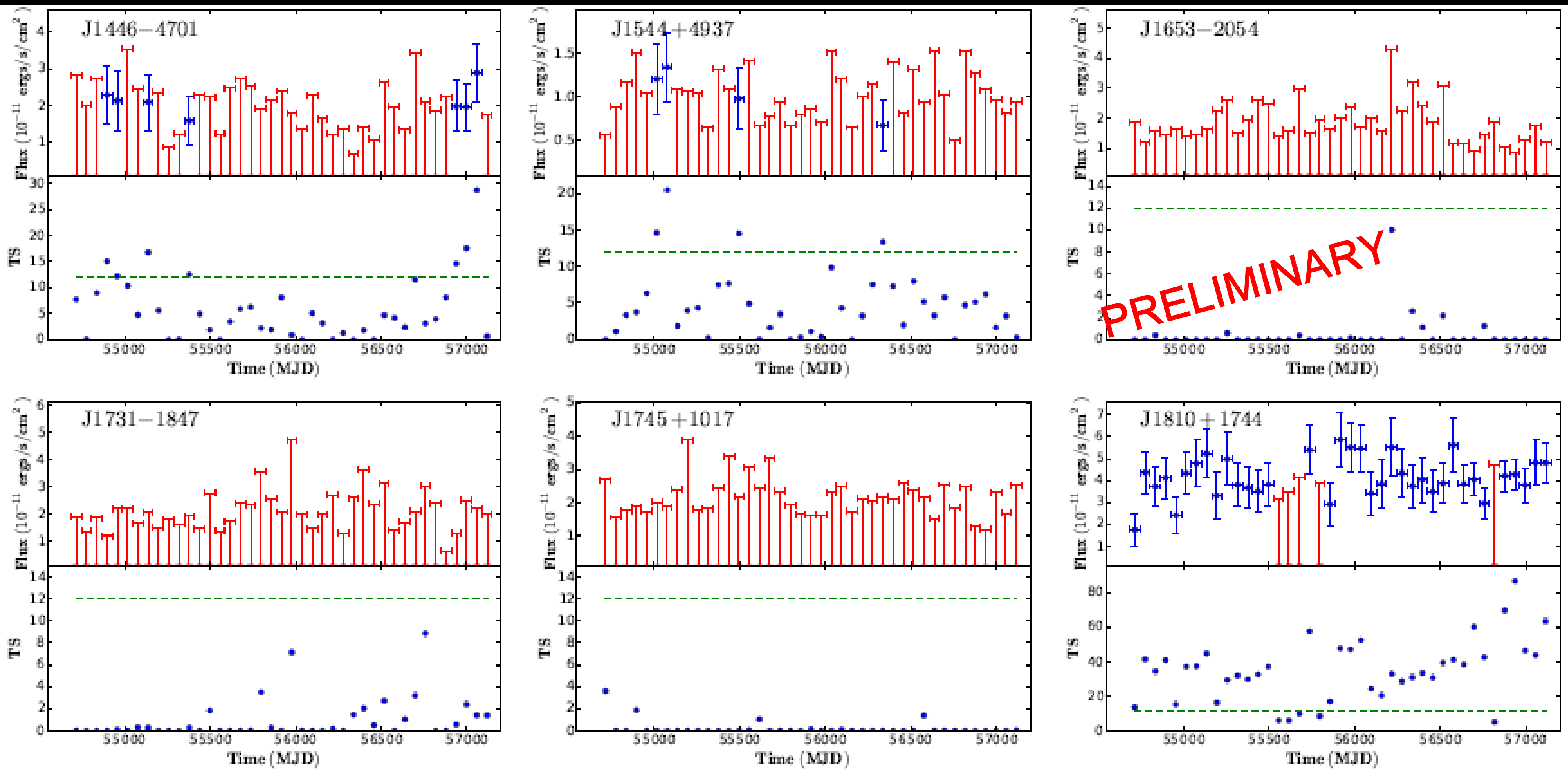

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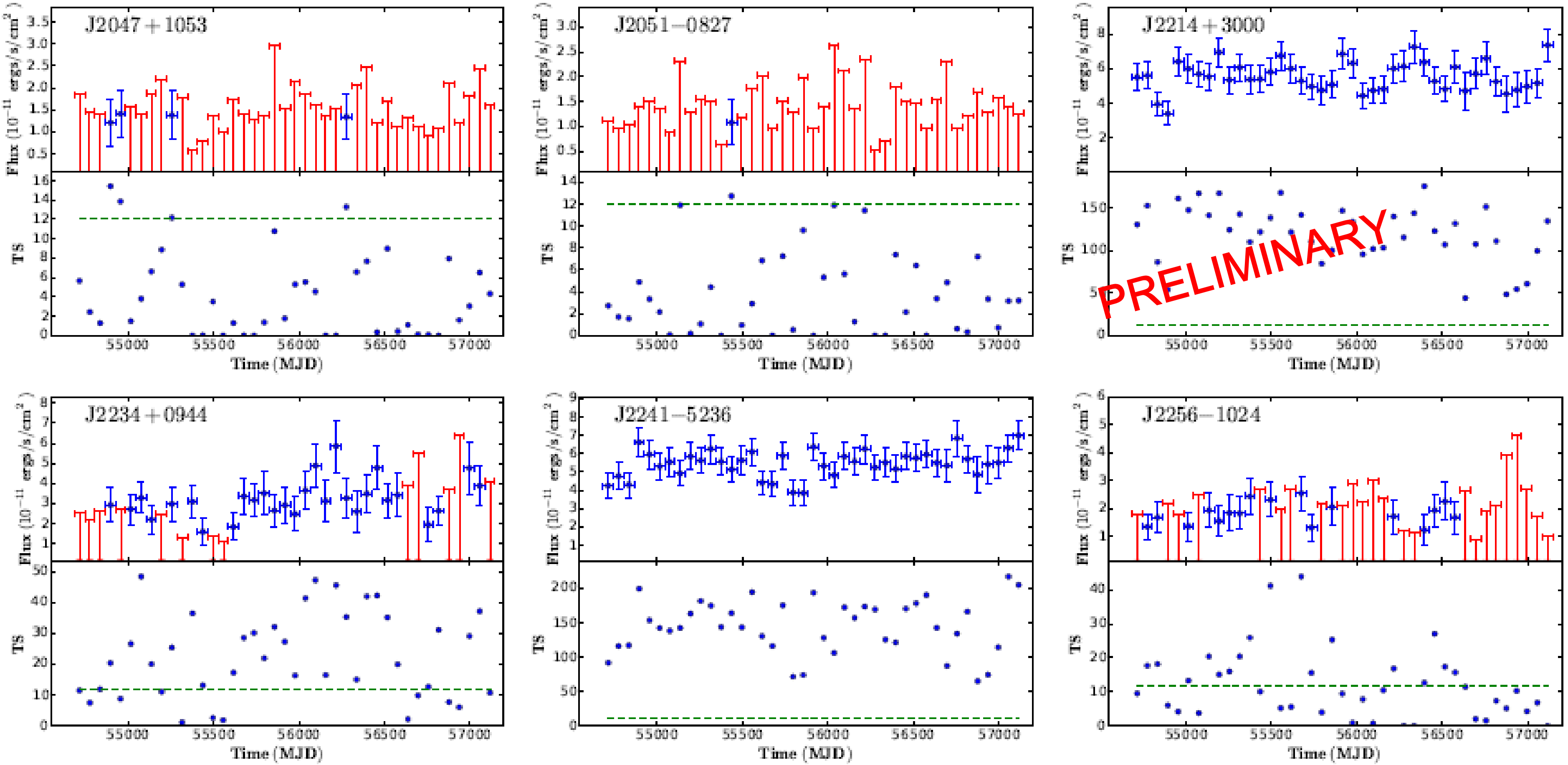
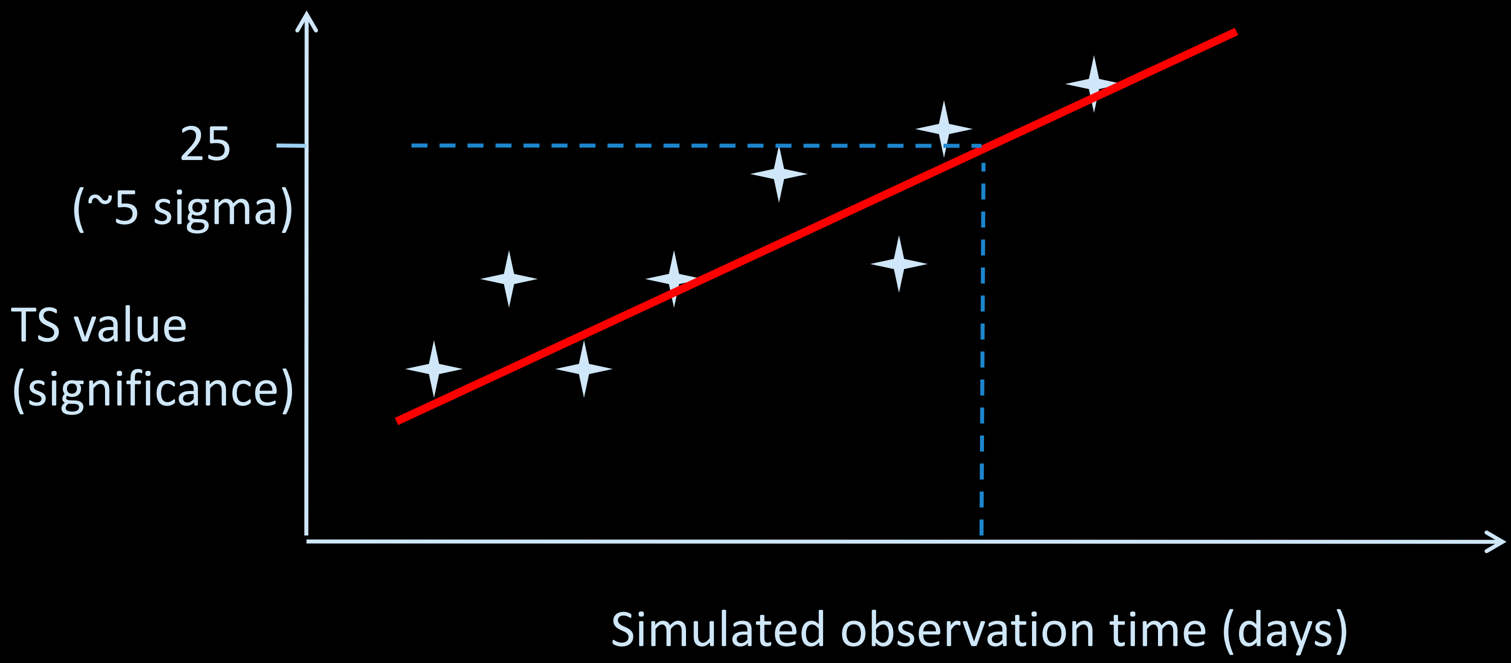
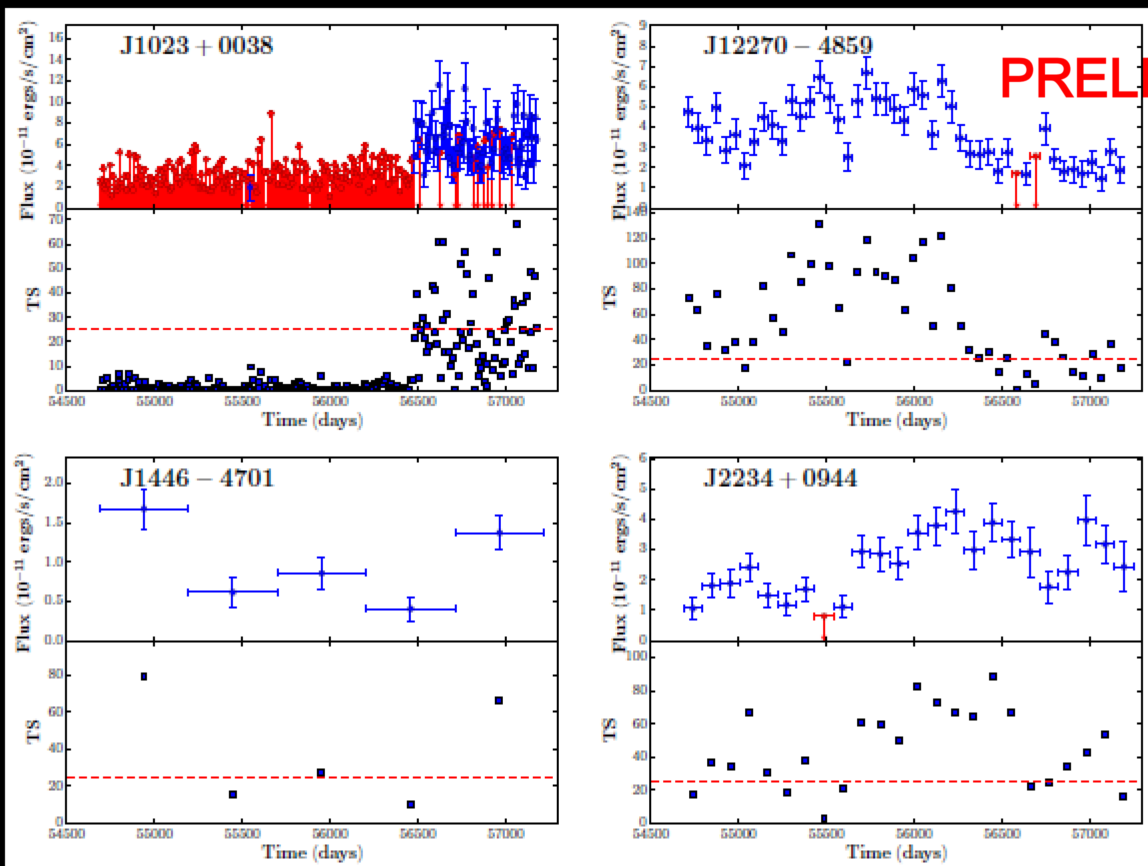


- Because of the different flux among sources, 60 days may not be the optimum time bin for individual source.
- For individual source, we take the overall average flux and carried out simulations to estimate the time bin in which the source will be detected with TS =25 (~5 sigma significance), assuming there is no flux variations.



- Light curves binned in these time scales are produced and flux variations are detected in several sources.
- J1446-4701 and J2234+0944 are the two best candidates for transitional millisecond pulsars.



RB name PSR	Binning (days)	σ
J0523.5−2529	66.88	2.09
J1023+0038[a]	9.27	...
J1023+0038†[a]	9.27	...
J1023+0038‡	9.27	1.02
J1227−4859	53.47	9.82
J1227−4859†	53.47	4.67
J1227−4859‡	53.47	0.63
J1431−4715	...	...
J1544.6−1125	214.83	0.31
J1628−3205	833.86	1.48
J1653−0158	36.56	1.08
J1723−282	367.96	1.02
J1816+4510	93.96	0.66
J2129−0429	311.72	0.5
J2215+5135	138.64	0.12
J2339−0533	24.53	2.41
BW name		
B1957+20	192.08	0.47
J0023+0923	155.98	0.11
J0610−2100	171.11	0.08
J1124−3653	104.36	0.41
J1301+08	126.40	2.4
J1311−3430	11.85	0.21
J1446−4701	506.37	4.2
J1544+4937	370.17	0.16
J1653−2054	...	...
J1731−1847	...	...
J1745+1017	...	...
J1810+1744	48.71	1.87
J2047+1053	445.63	0.68
J2051−0827	688.61	0.39
J2214+3000	17.88	0.23
J2234+0944	106.69	5.51
J2234+0944†	106.69	1.22
J2234+0944‡	106.69	1.19
J2241−5236	15.23	0.27
J2256−1024	182.62	1.00

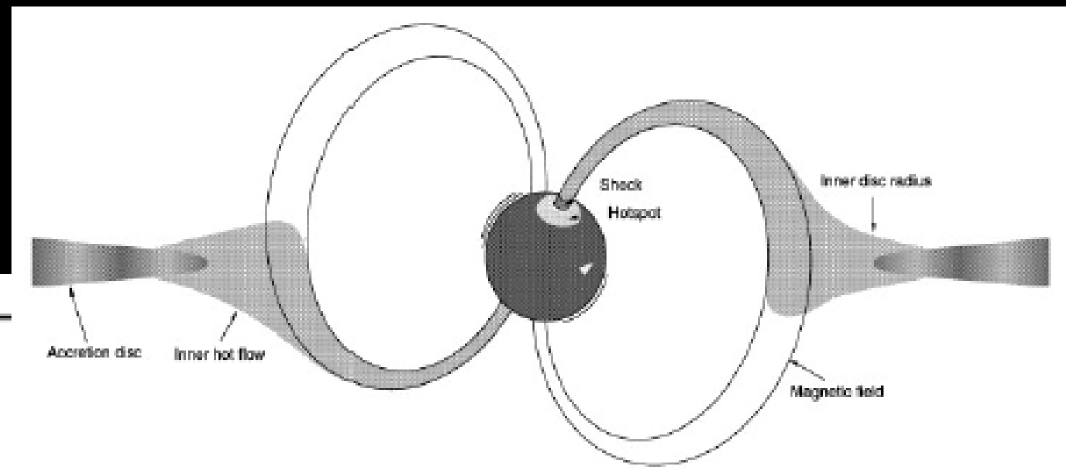
- Gamma-ray emission in accreting millisecond pulsar

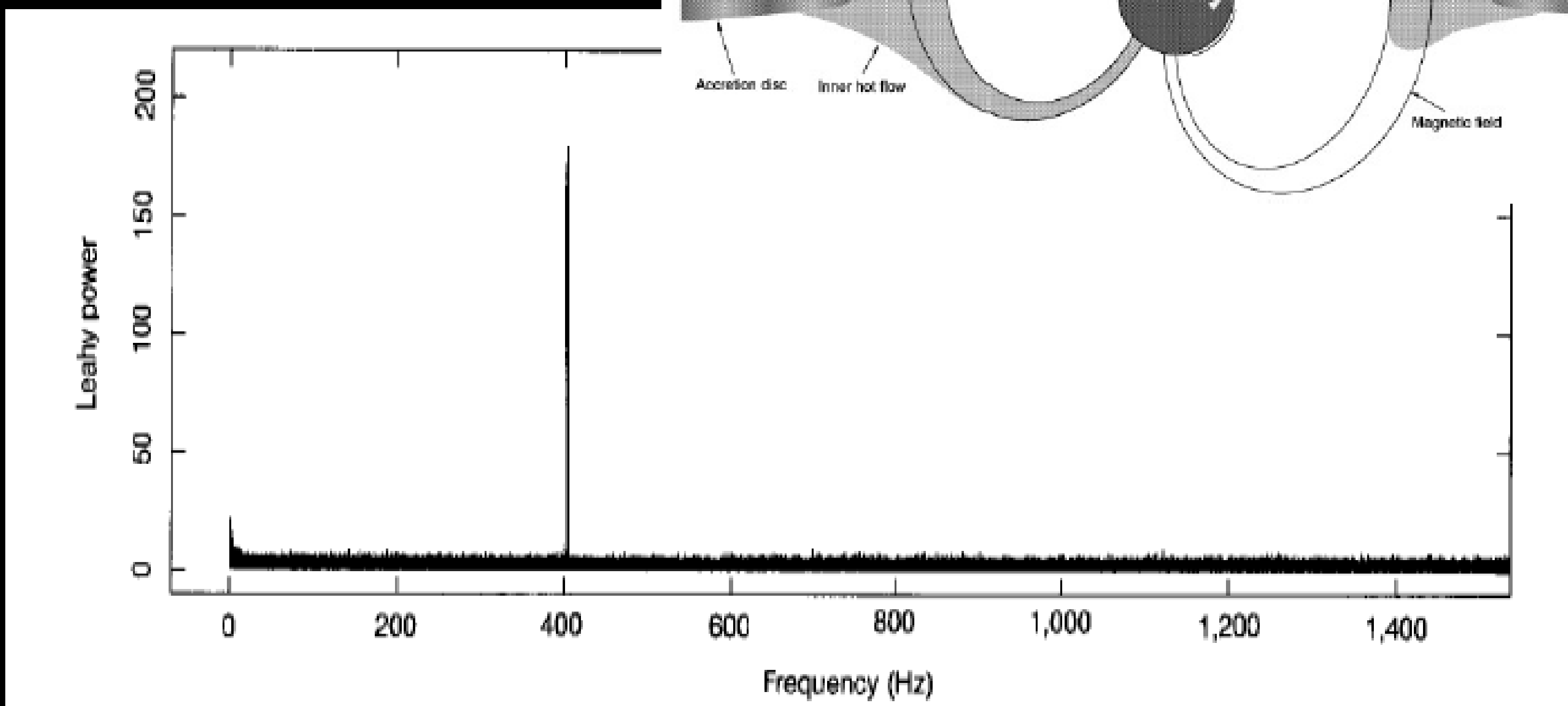
	Radio pulsar state	Sub-luminous disk state	Accreting ms pulsar state
X-rays	$<10^{32}$ erg/s Not always pulsed and variable at orbital period	10^{33}-10^{34} erg/s Pulsed and variable	$>10^{36}$ erg/s pulsed (sometimes variable)
Radio	Pulsed	Bright, not pulsed	(sometimes) bright, not pulsed
Gamma-rays	Pulsed	Bright, not pulsed	Not detected
optical	Variable at orbital period	bright	brighter

Accreting millisecond pulsars

An RXTE heritage [Wijnands & van der Klis 1998, Nature]

15 AMSPs out of ~150 NS-LMXBs



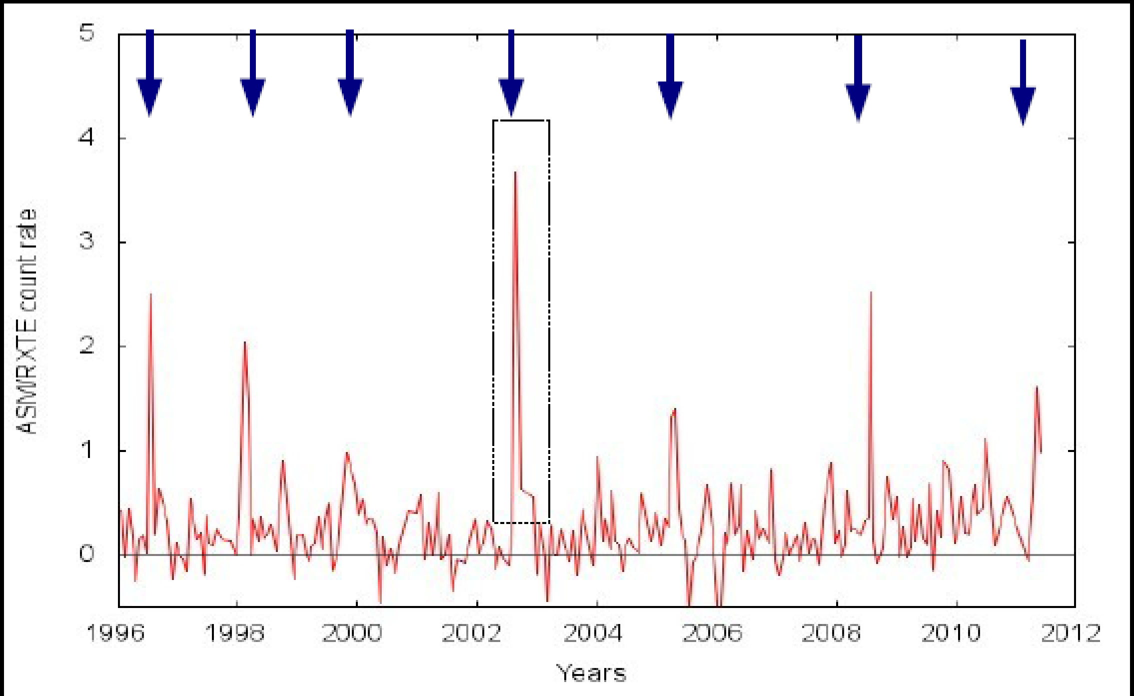


A census of accreting ms pulsars

	P(ms)	Porb(hr)	Md,min ($M_\odot$)	Donor type	Year disc.
SAX J1808.4-3658	2.5	2.0	0.04	BD	1998
XTE J1751-305	2.3	0.7	0.01	He WD	2002
XTE J0929-314	5.4	0.7	0.008	C/O WD	2002
XTE J1807-294	5.2	0.7	0.007	C/O WD	2003
XTE J1814-338	3.2	4.3	0.17	MS	2003
IGR J00291-2455	1.7	2.5	0.04	BD	2004
HETE J1900.1-2455	2.6	1.4	0.02	BD	2005
Swift J1756.9-2508	5.5	0.9	0.007	He WD	2007
Aql X-1	1.8	18.9	0.6	MS	2008
SAX J1748.9-2021	2.3	8.8	0.1	MS/SubG?	2008
NGC 6440 X-2	4.9	0.9	0.007	He WD	2009
IGR J17511-3057	4.1	3.5	0.13	MS	2009
Swift J1749.4-2807	1.9	8.8	0.59	MS	2010
IGR J17498-2921	2.5	3.8	0.17	MS	2011
IGR J18245-2452	3.9	11.0	0.17	MS	2013

- Is there any gamma-ray emissions from accreting ms pulsar?
- Is there any state transitions in these accreting ms pulsar?

A case study: SAX J1808.4-3658



SAX J1808.4-3658 – one outburst every ~2.5 years

Is a **radio pulsar or gamma-ray pulsar** turning on during quiescence (L~$10^{32\text{-}33}$ erg/s)?

Is there a swing between pulsar state and sub-disk state?

SAX J1808.4-3658: a coincident source, but no pulsations

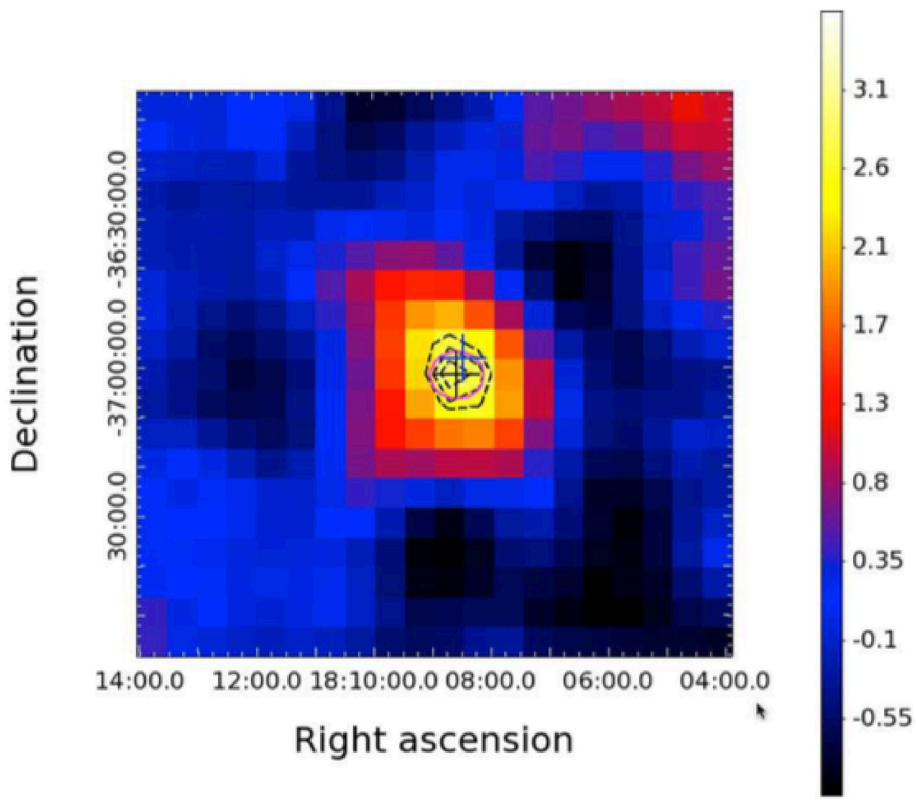


Figure 1. *Fermi*-LAT residual 2°×2° (using a pixel size of 0.1° × 0.1°) count map above 1 GeV of the SAX J1808.4–3658 region smoothed with a Gaussian of width $\sigma = 0.3°$ (units of the scale on the right are counts). The best-fit position of the gamma-ray source is marked with a black cross whereas the position of SAX J1808.4–3658 is marked in blue. The black-dashed lines show the TS significance contours above 1 GeV corresponding to CL of 68%, 95% and 99%. The magenta circle shows the 95% CL error in the best-fit position.

A candidate gamma-ray counterpart for SAX J1808.4-3658

A detection of gamma-ray pulsations from SAX J1808.4–3658 would imply rotational-powered activity in quiescence mode

Accurate search for gamma-ray pulsations did not yield to a detection
L_g =(3.5+/-0.3) x 10^{33} erg cm-2

→ ~30% of the spin down power of SAX J1808.4-3658 could go into gamma-rays

[de Oña, Papitto, Li, Rea, DFT, et al MNRAS 2016]

Outline

- 3. Summary

Information to take away

- 1. Millisecond pulsars binaries are gamma-ray emitters.
- 2. Millisecond pulsars binaries may transit between different states (radio pulsar state, sub-luminous state, accreting state).
- 3. The gamma-ray emitting processes are different in different states/different millisecond pulsars
- 4. Only three transitional millisecond pulsars binaries are known. We searched for new ones and proposed two candidates (PSR J1446-4701; PSR J2234+0944).

Thank you!