Transitional Millisecond Pulsars: A Population of γ-ray-Emitting Low-mass X-ray Binaries

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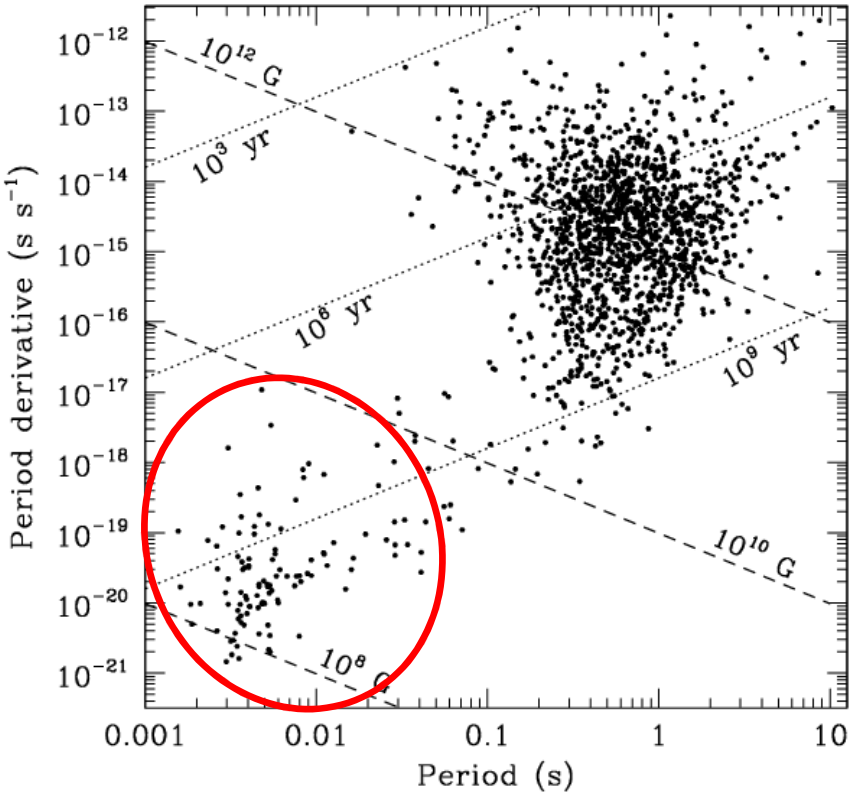
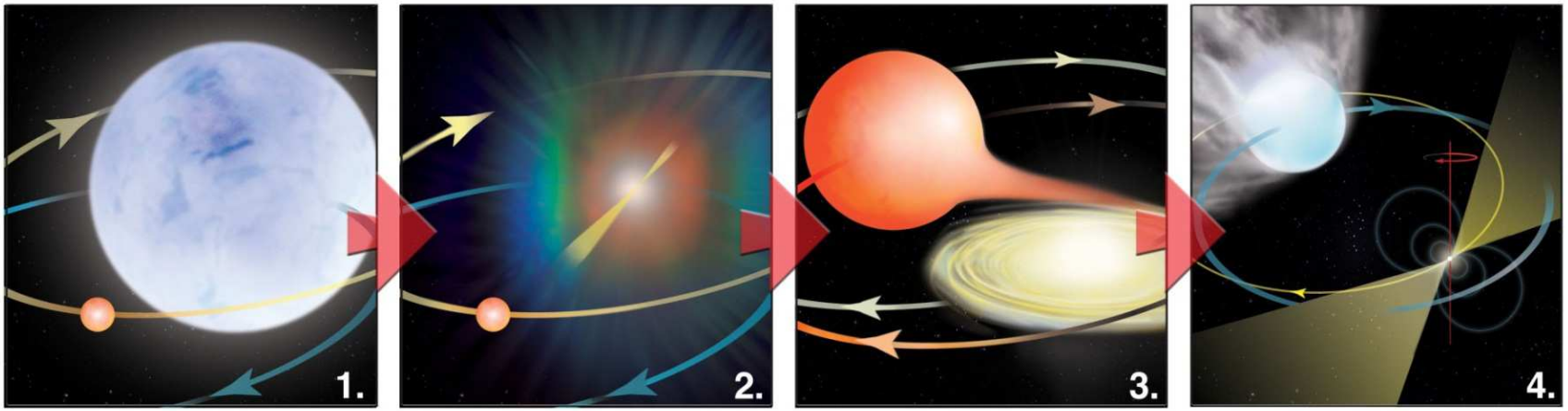
Rotation-powered ("recycled") millisecond pulsars

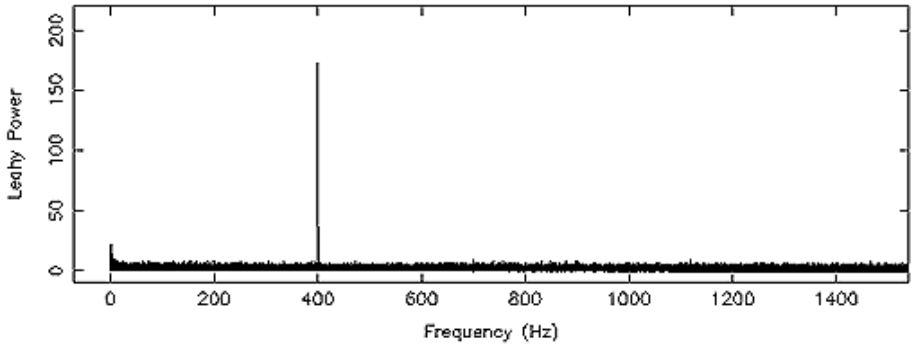
- Discovered at radio frequencies
  - PSR B1937+21 with Arecibo (Backer et al. 1982)
- Most radio MSPs are in binaries
- Spun-up ("recycled") by accretion in LMXBs (Alpar et al. 1982)



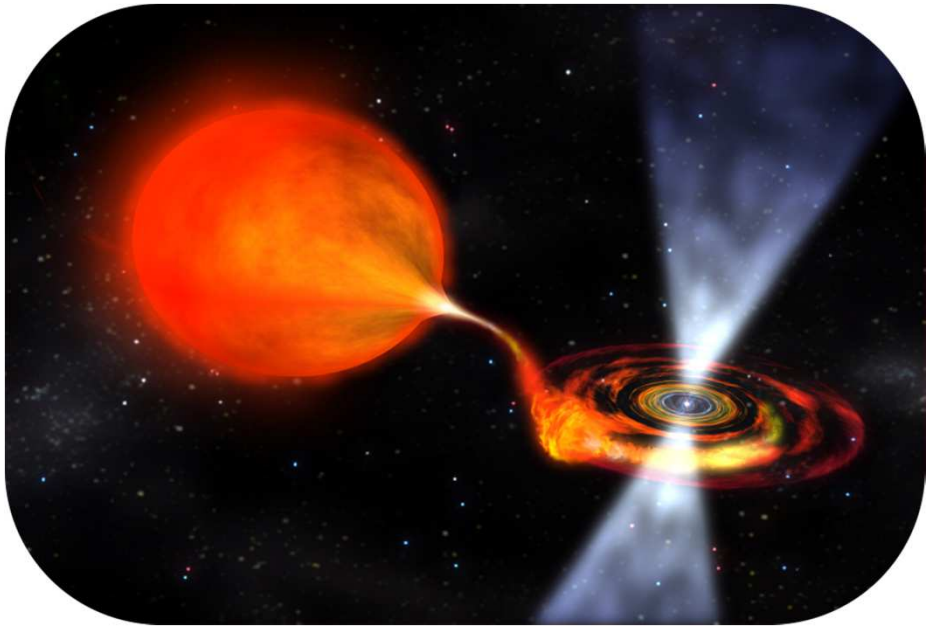


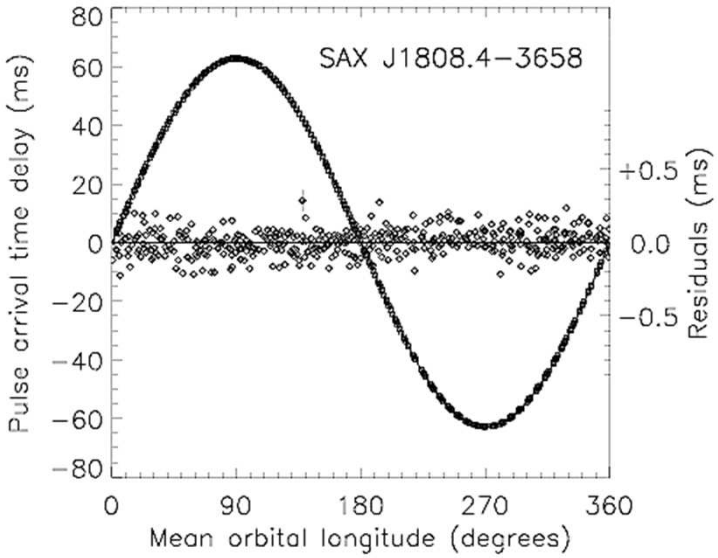
Accretion Powered MSPs: SAX J1808.4–3658

- First accretion-powered MSP ($\nu = 408$ Hz)



Wijnands & van der Klis 1998, Nature, 394, 344

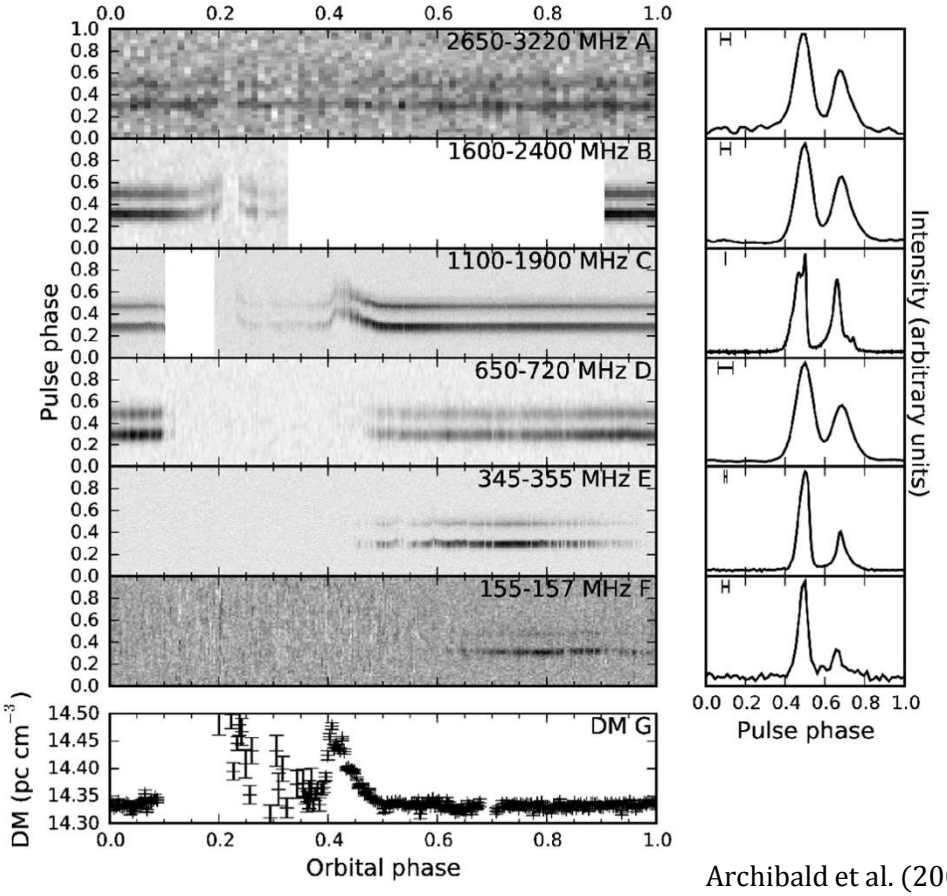




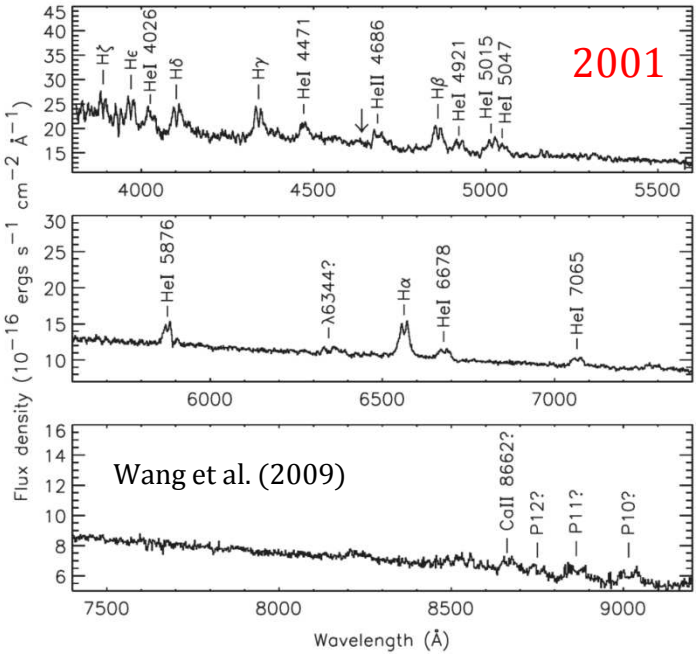
Chakrabarty & Morgan 1998, Nature, 394, 346

PSR J1023+0038: The "Missing Link"

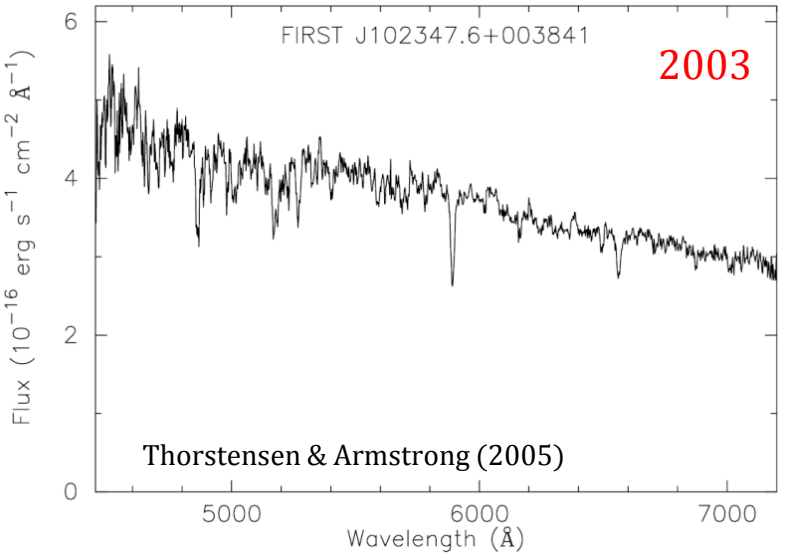
- System had accretion disk in 2001 but not after 2003
- Eclipsing ("redback") binary radio MSP ($P = 1.69$ ms, $P_b = 4.8$ d) discovered in 2009



Archibald et al. (2009)



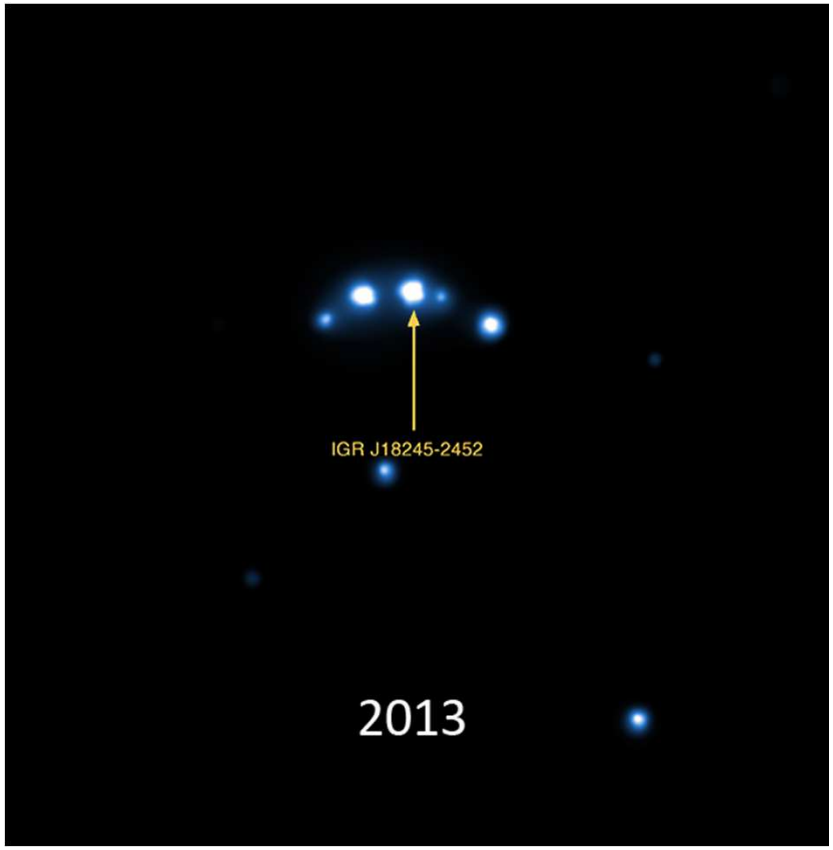
Wang et al. (2009)

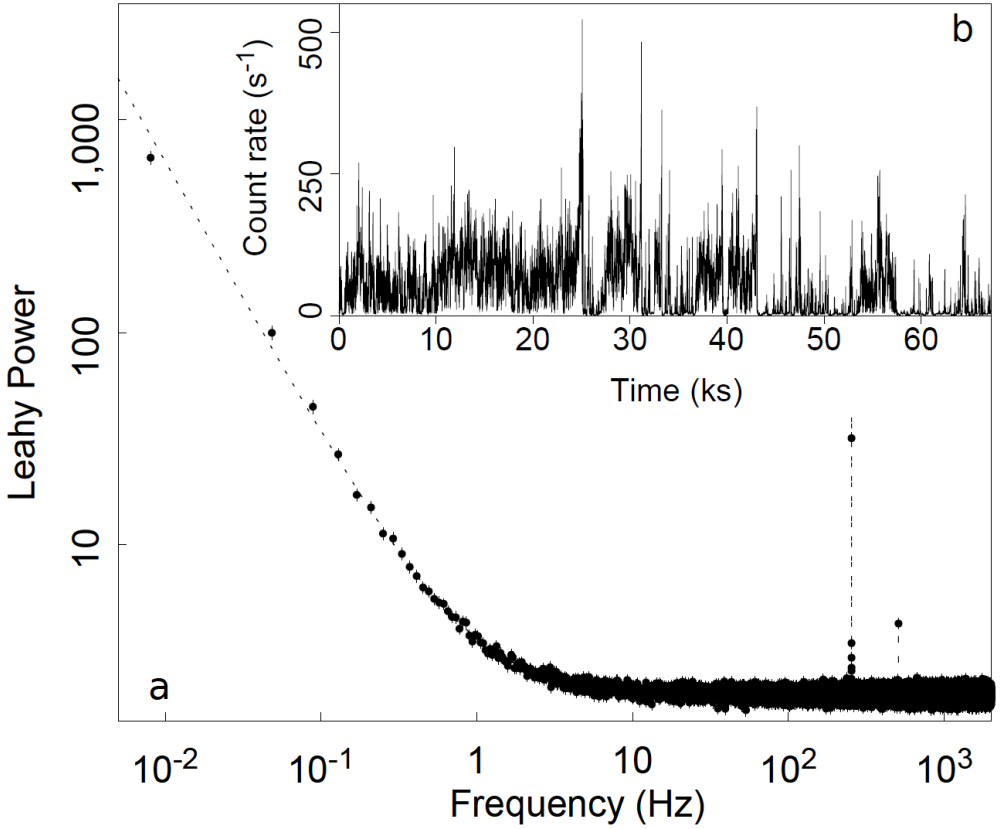


Thorstensen & Armstrong (2005)

PSR J1824–2452I / IGR J18245–2452 (M28)

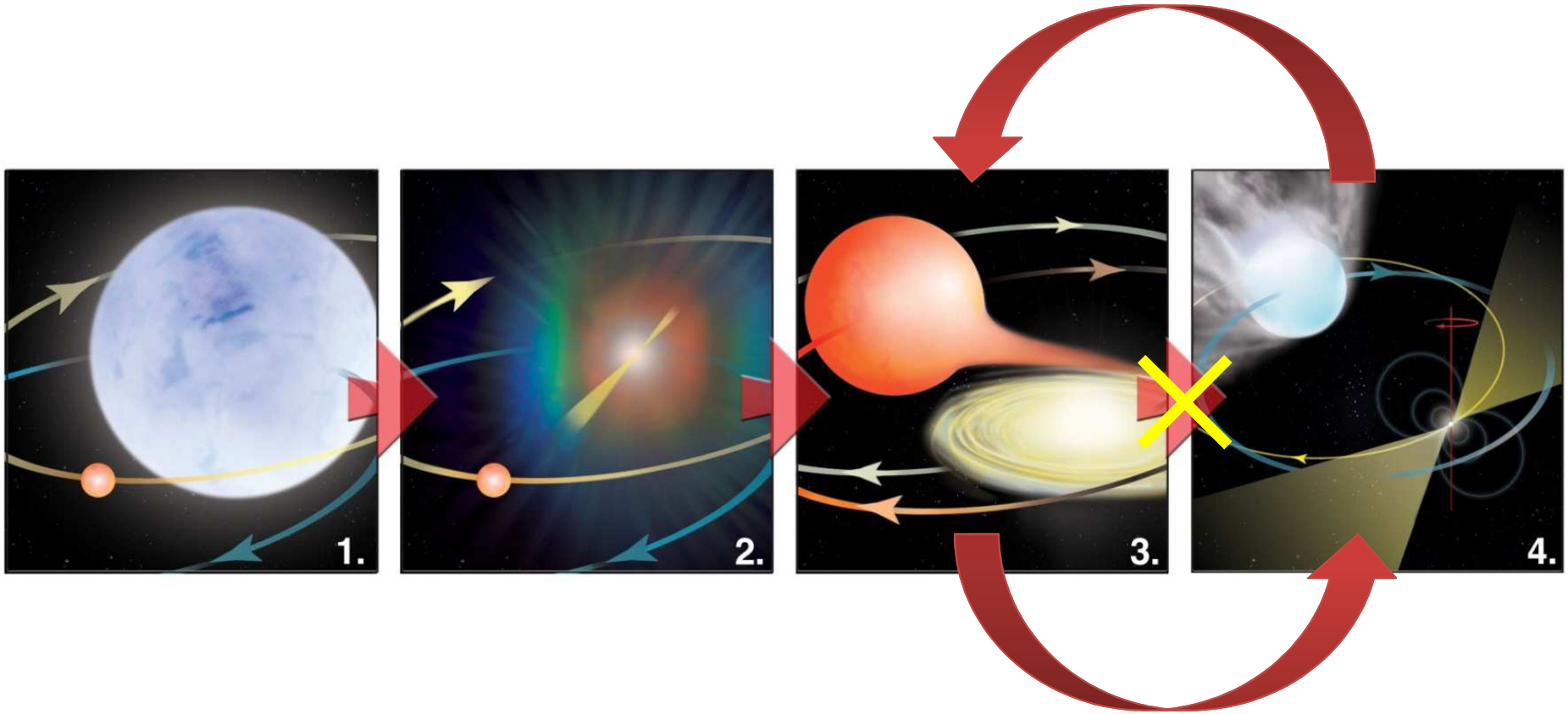
Rotation-powered (radio) MSP ⇔ Luminous accretion-powered (X-ray) MSP





Papitto et al. (2013)

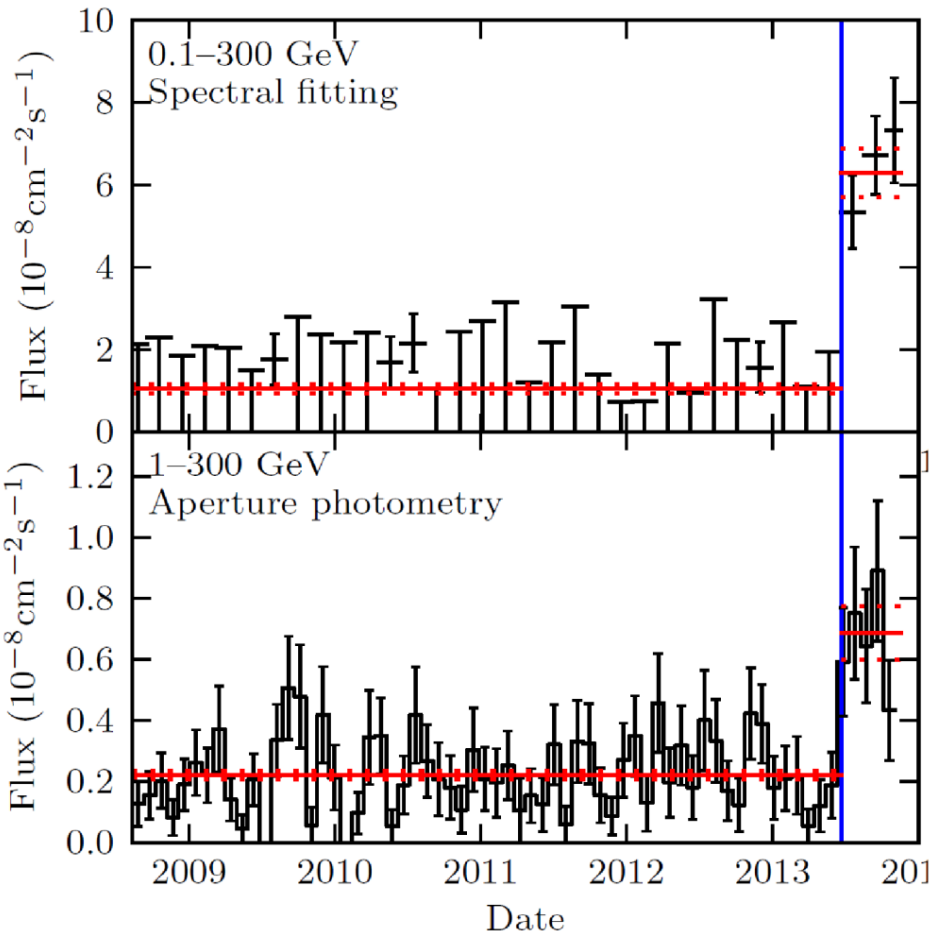
Direct link between low-mass X-ray binaries and “recycled” millisecond pulsars


1.
2.
3.
4.

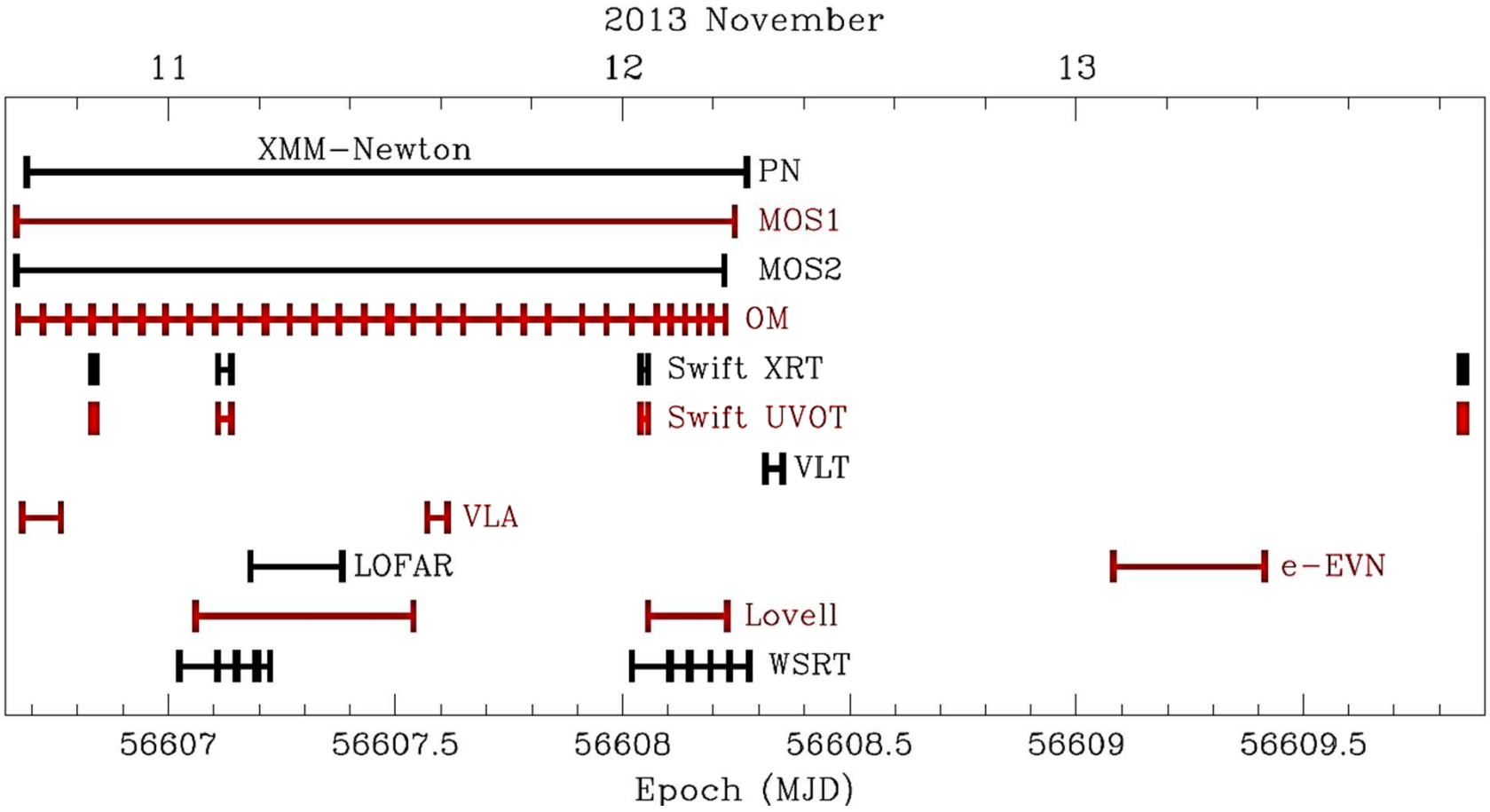
PSR J1023+0038: The Accretion Disk Returns

- Radio pulsar emission ceased on June 23rd, 2013
- Optical brightness increased by ~1 mag
- Double-peaked optical emission lines reappeared
- Average X-ray flux increased by ~order of magnitude
- ***Fermi*** **LAT flux increased ≈5-fold!**

Stappers et al. (2014)



PSR J1023+0038: The Accretion Disk Returns

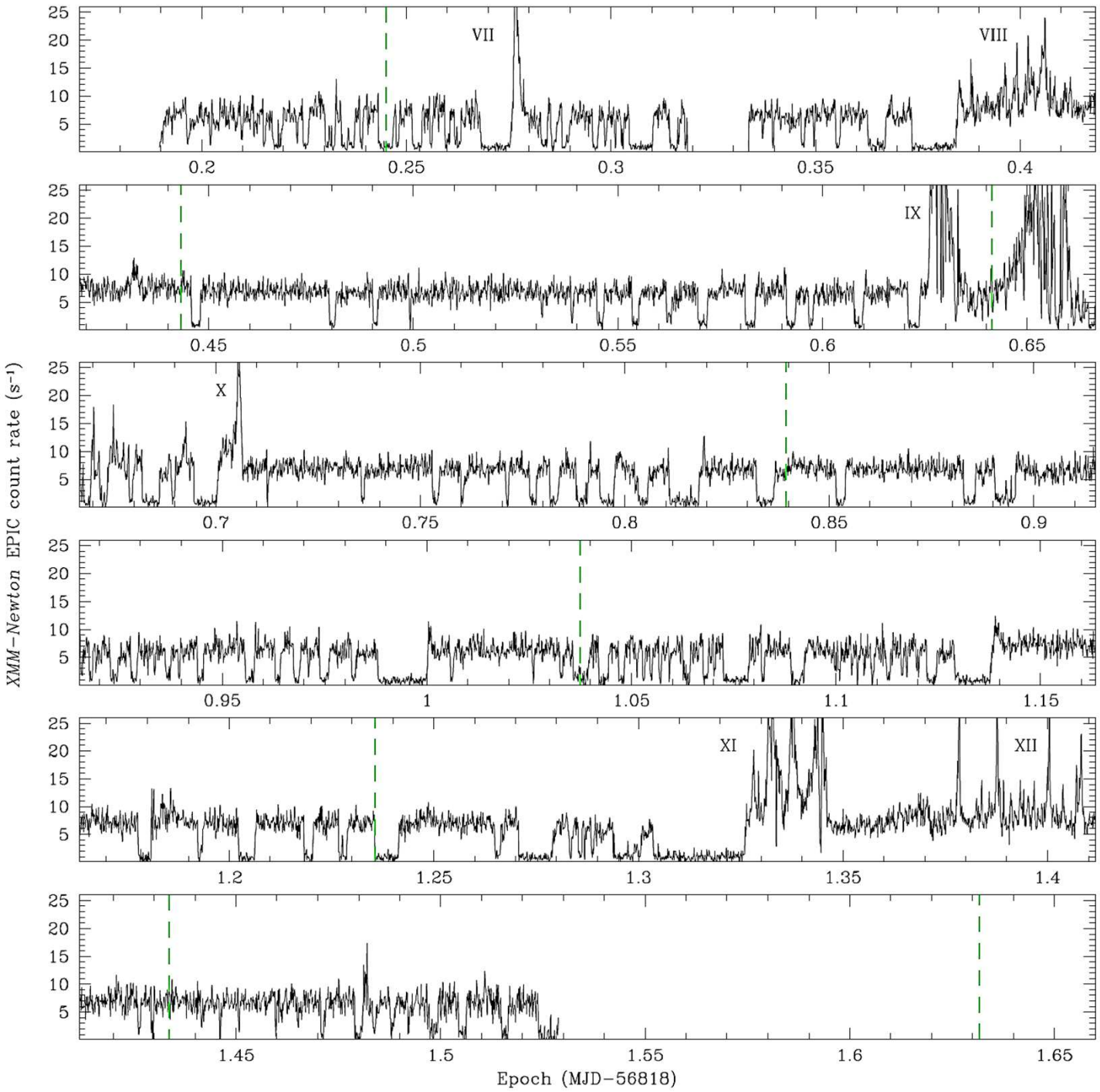


Bogdanov et al. 2015, ApJ, 806, 148

PSR J1023+0038

XMM-Newton EPIC
Jun 10th, 2014
117 ks

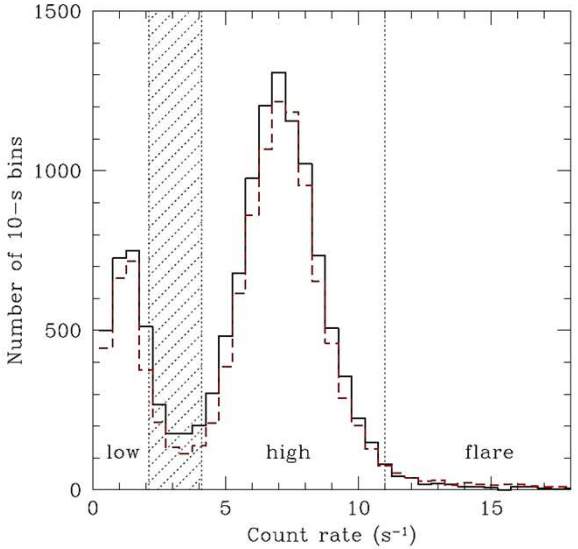
$L_X \approx 10^{33-34}$ erg s^{-1}
(0.3–10 keV)

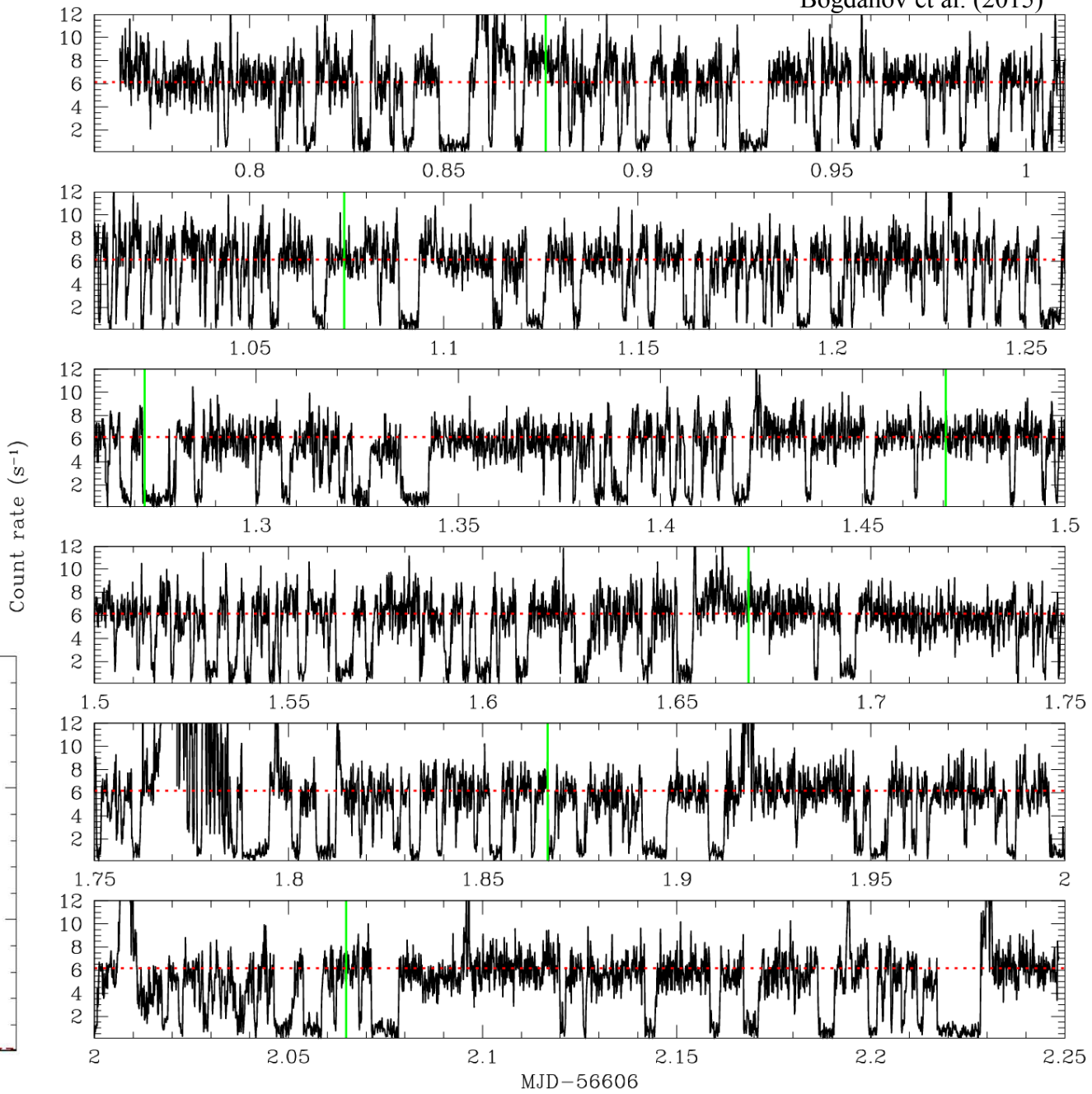


Bogdanov et al. (2015)

XMM-Newton EPIC
Nov 10th, 2013
134 ks

Bogdanov et al. (2015)

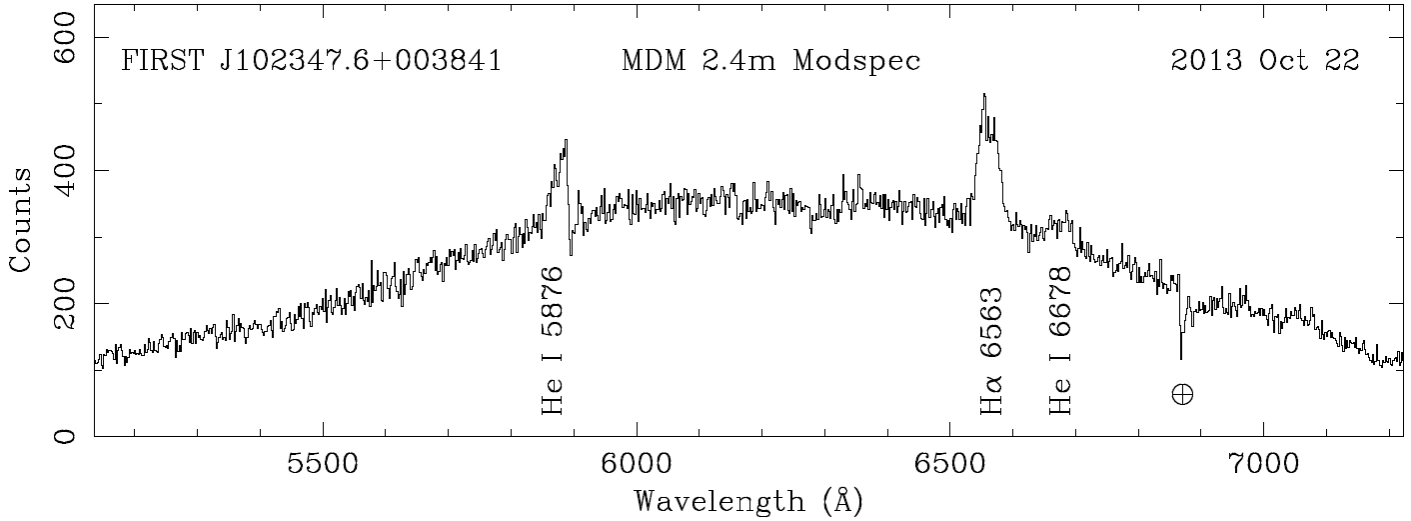




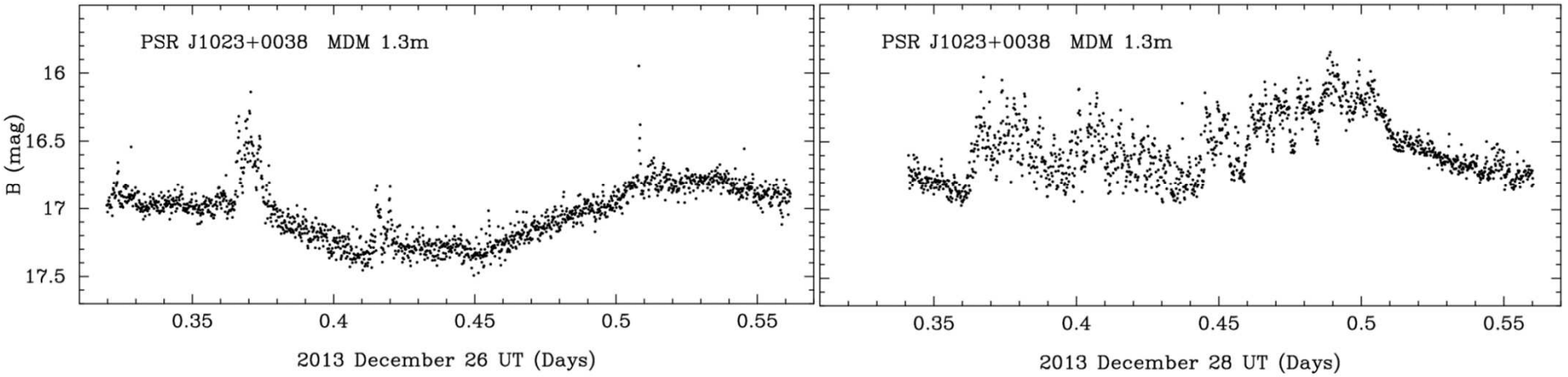
PSR J1023+0038: The Accretion Disk Returns

- "CV-like" optical properties

Halpern et al. (2013)

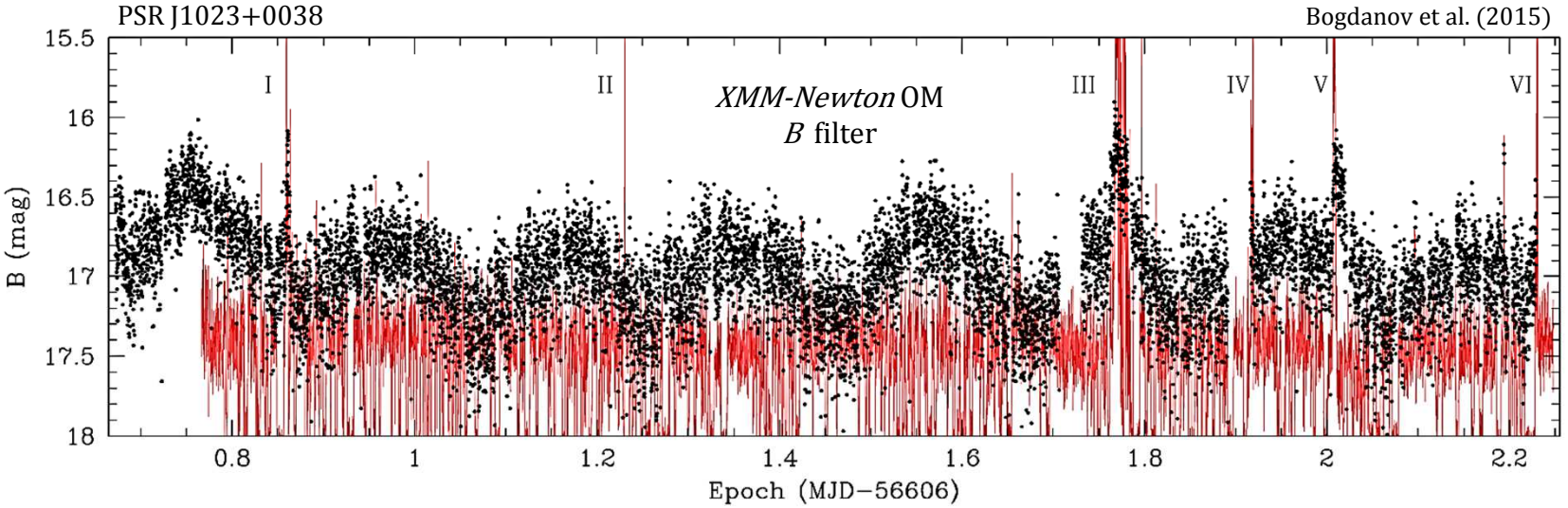


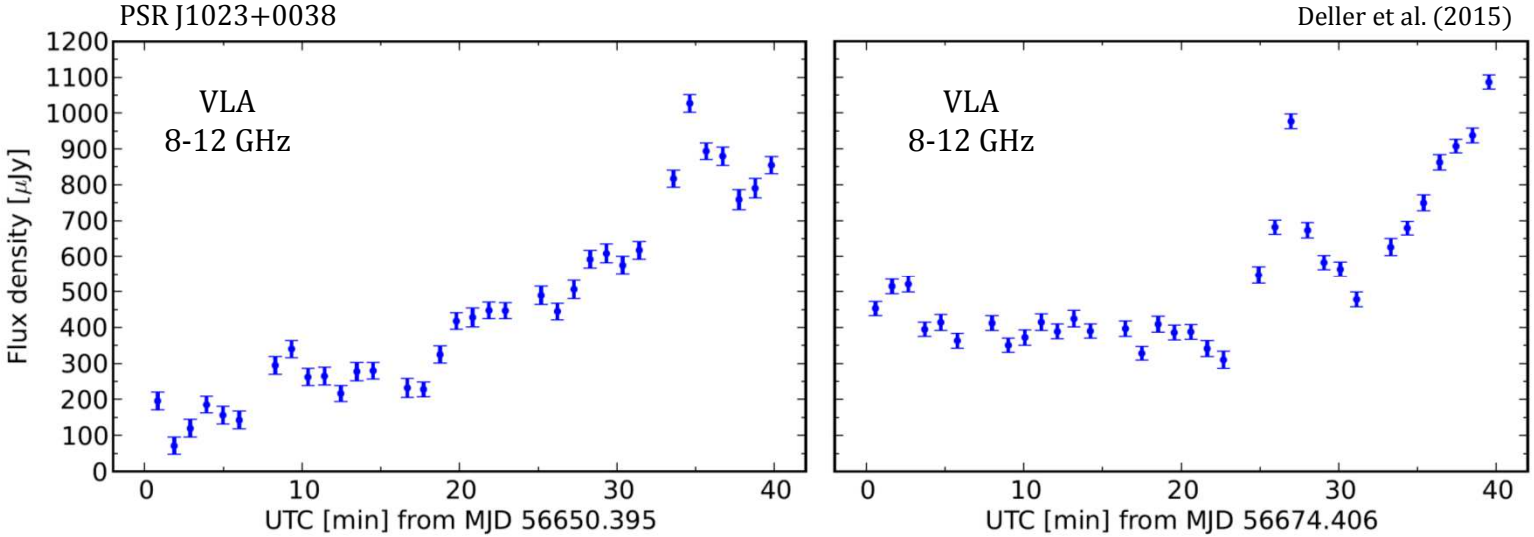
Bogdanov et al. (2015)



PSR J1023+0038: The Accretion Disk Returns

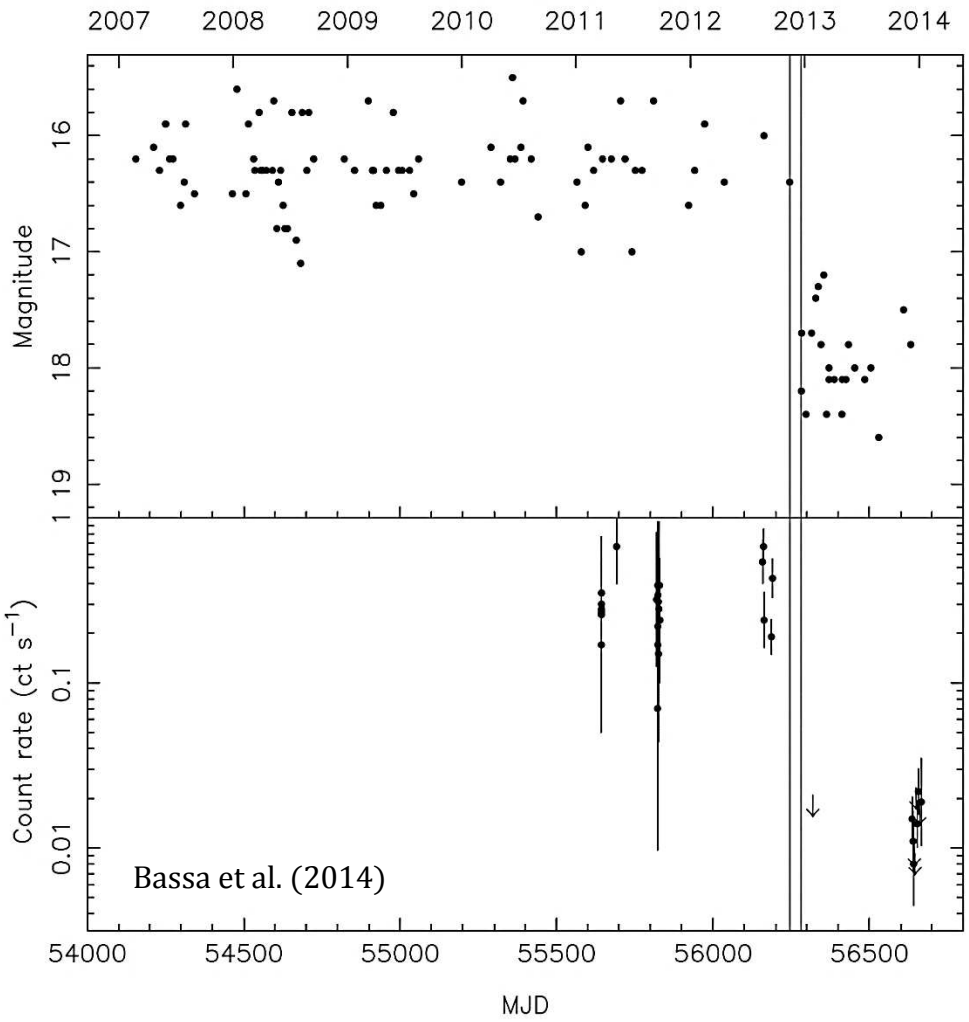
- X-ray, optical and radio variability



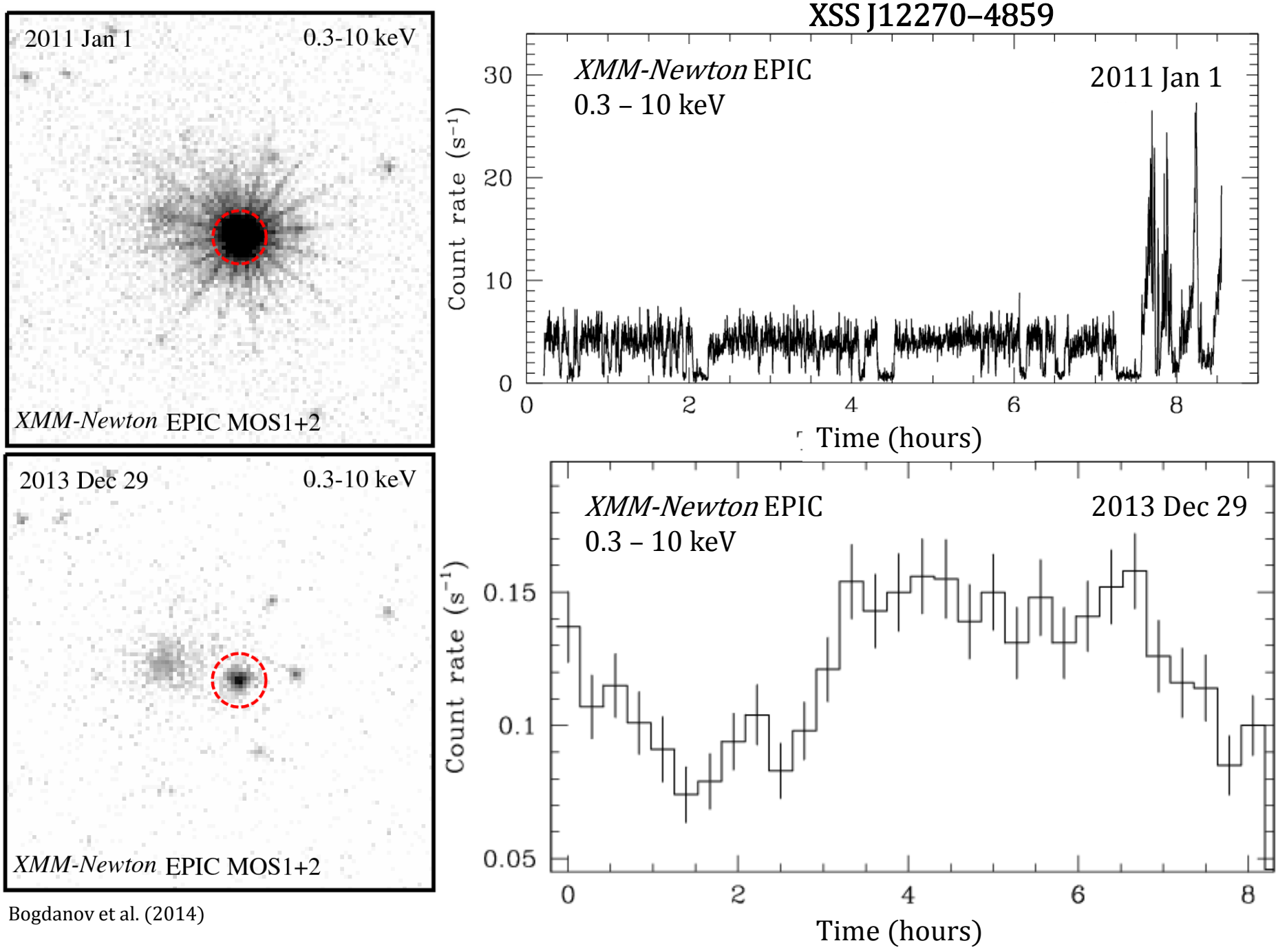


XSS J12270–4859: Another Transitional MSP System

- Low-mass X-ray binary with *Fermi* LAT counterpart: 2FGL J1227.7–4553 (Hill et al. 2011; de Martino et al. 2010,2013)
- In Nov/Dec 2012, optical flux declined by ~1.5 mag (Bassa et al. 2014)
- X-ray flux decreased by ~×10
- Optical emission lines disappeared (de Martino et al. 2015)
- Radio and γ-ray pulsations detected in non-accreting state at P=1.69 ms (Roy et al. 2014; Johnson et al. 2015)

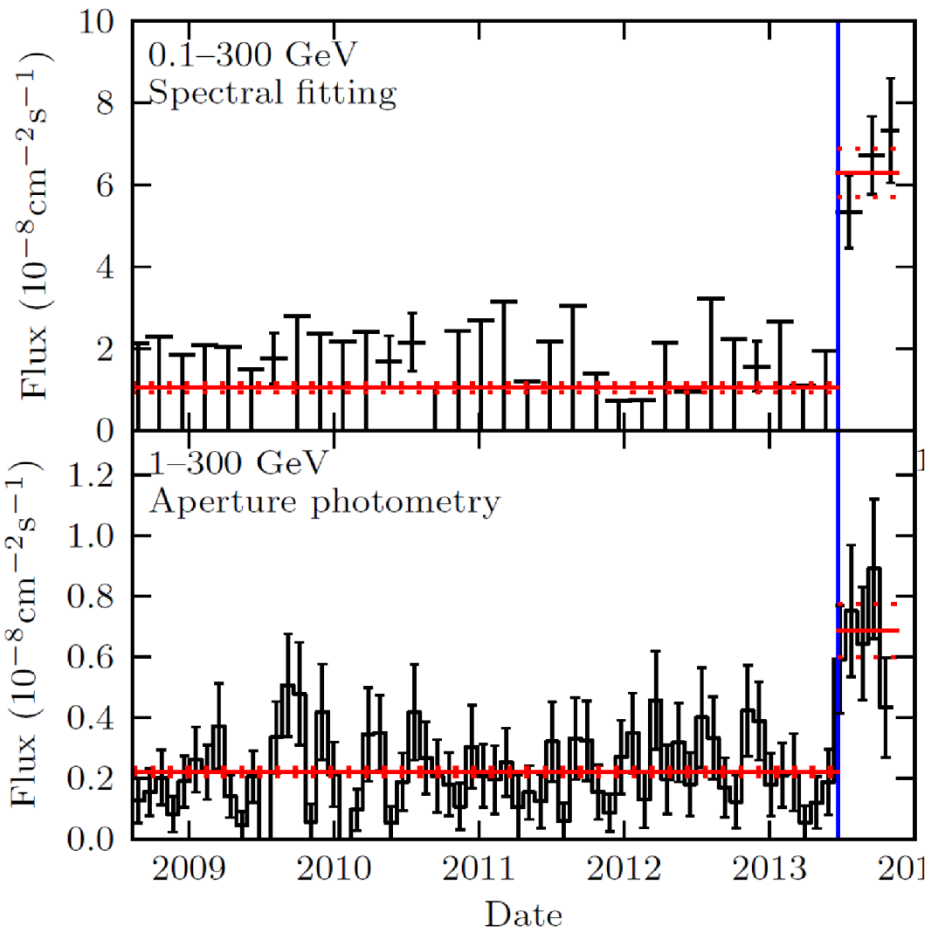


Transition from LMXB to "redback" radio MSP



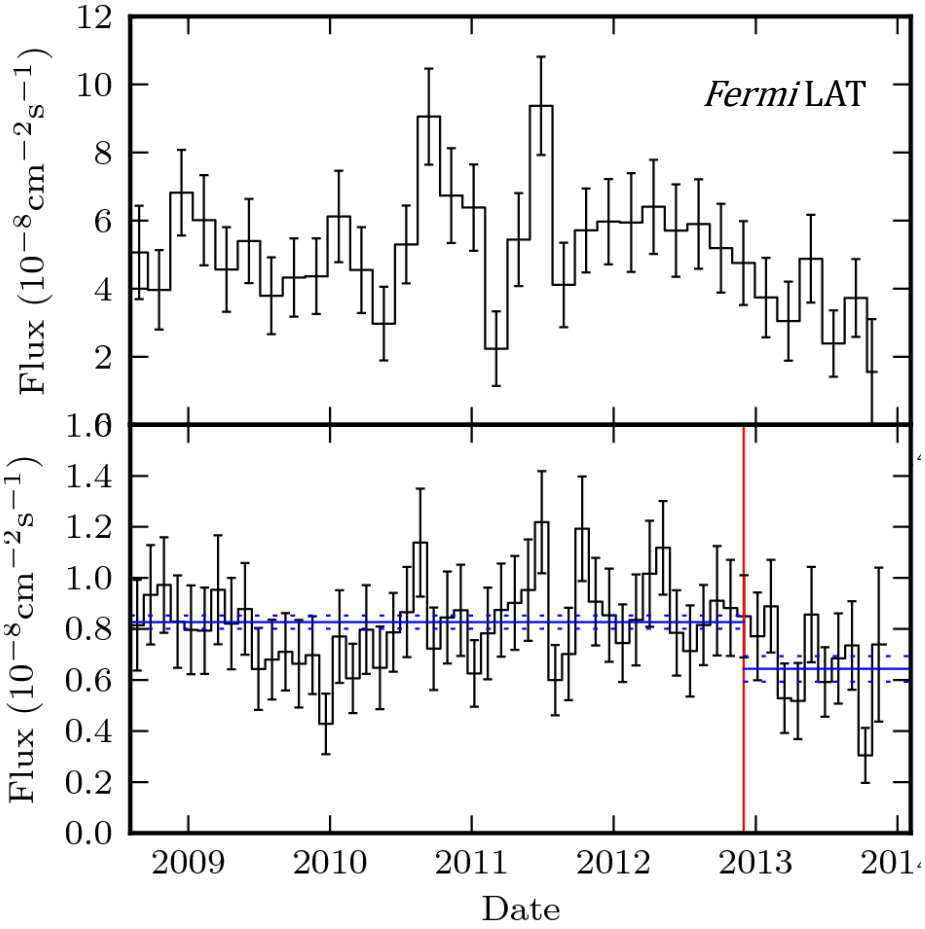
Bogdanov et al. (2014)

PSR J1023+0038

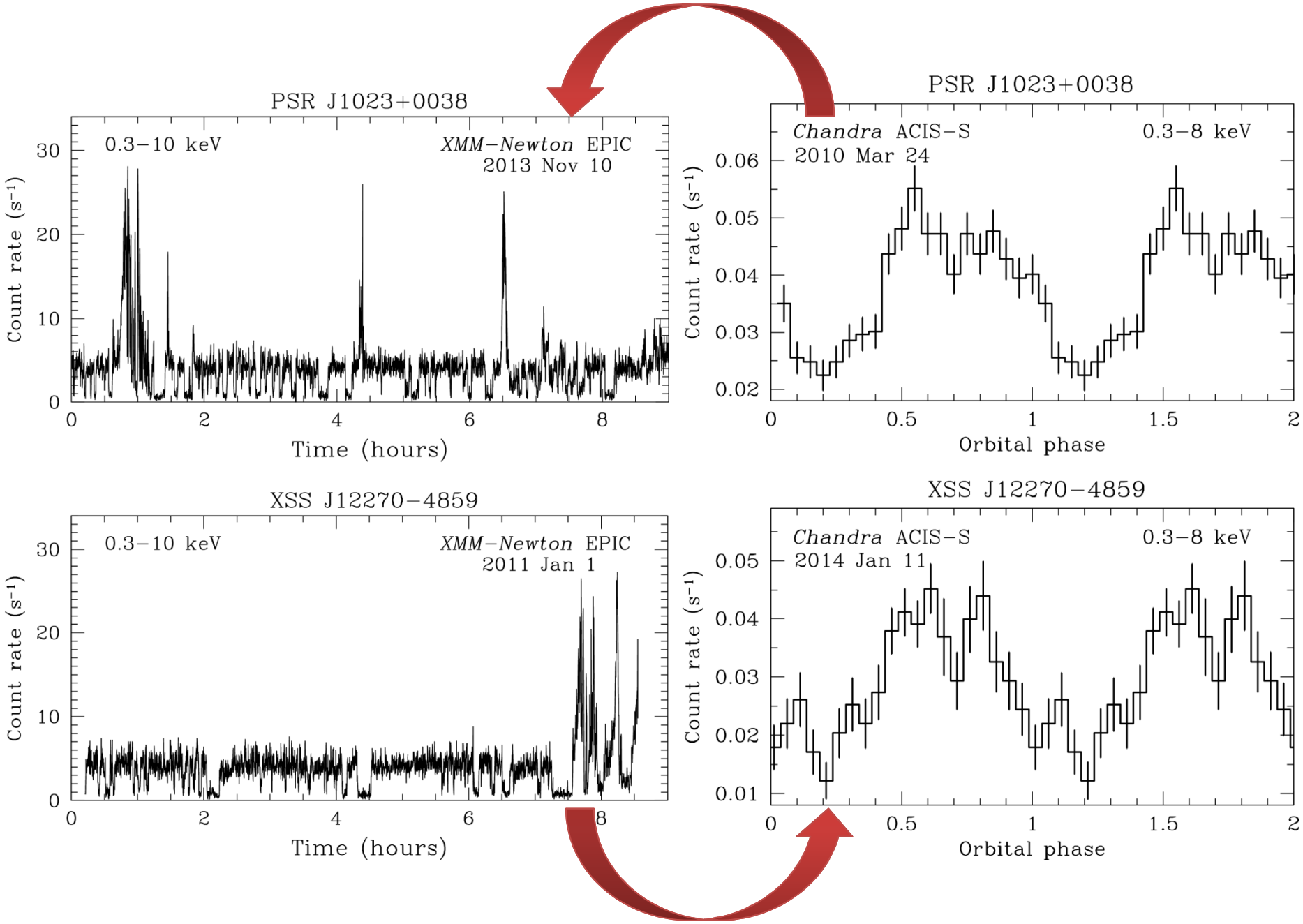


Stappers et al. (2013)

XSS J12270–4859



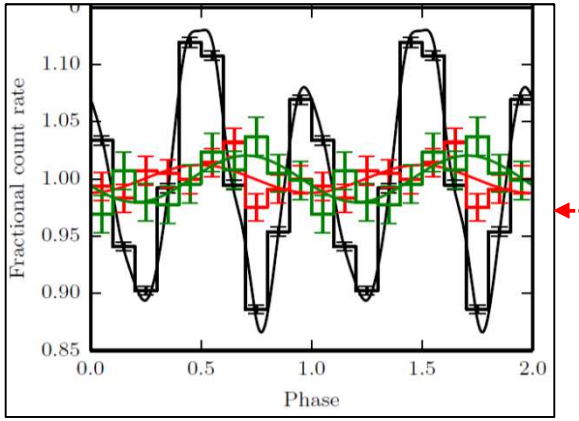
Courtesy of A. Archibald


PSR J1023+0038
0.3−10 keV
XMM−Newton EPIC
2013 Nov 10
Count rate (s⁻¹)
Time (hours)
PSR J1023+0038
Chandra ACIS−S
2010 Mar 24
0.3−8 keV
Count rate (s⁻¹)
Orbital phase
XSS J12270−4859
0.3−10 keV
XMM−Newton EPIC
2011 Jan 1
Count rate (s⁻¹)
Time (hours)
XSS J12270−4859
Chandra ACIS−S
2014 Jan 11
0.3−8 keV
Count rate (s⁻¹)
Orbital phase

Accretion-powered Coherent X-ray Pulsations!

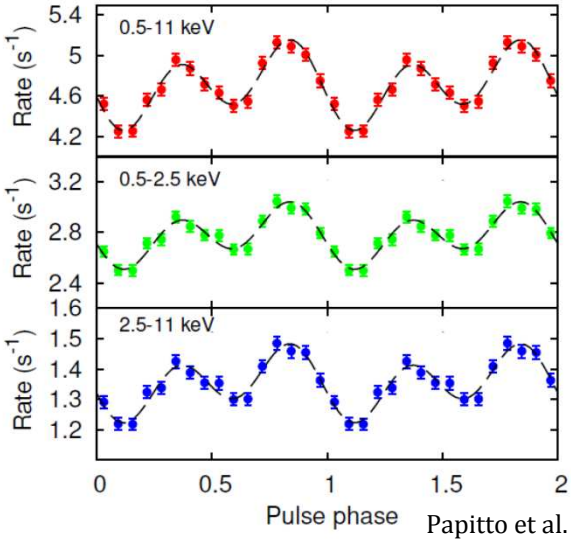
- X-ray pulsations only in "high" mode ⇒ channeled accretion onto neutron star polar caps at $L_X \approx 10^{33}$ erg s^{-1} ($\sim 10^{-5} L_{edd}$)

PSR J1023+0038

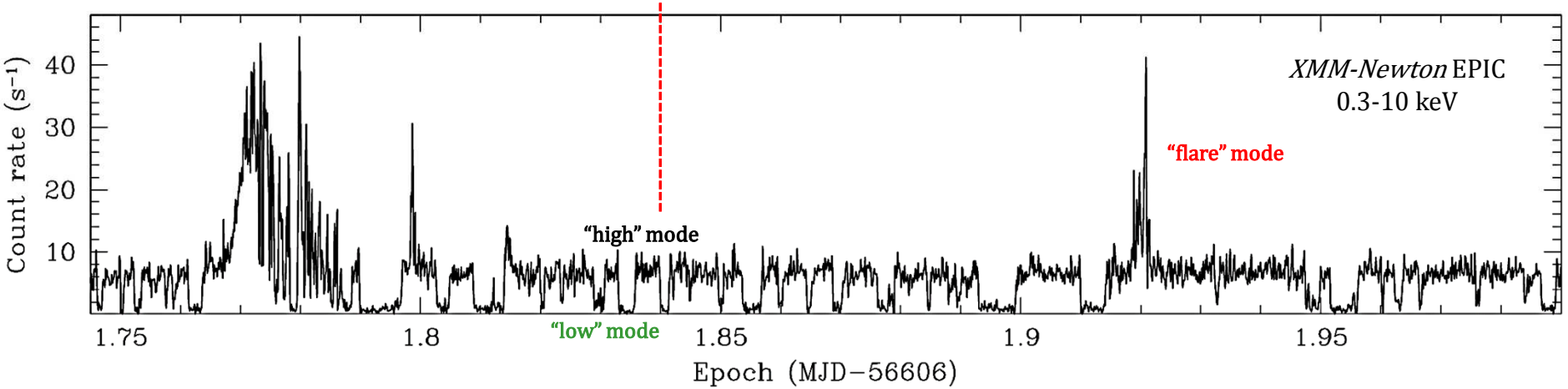


Archibald et al. (2015)

XSS J12270-4859



Papitto et al. (2015)



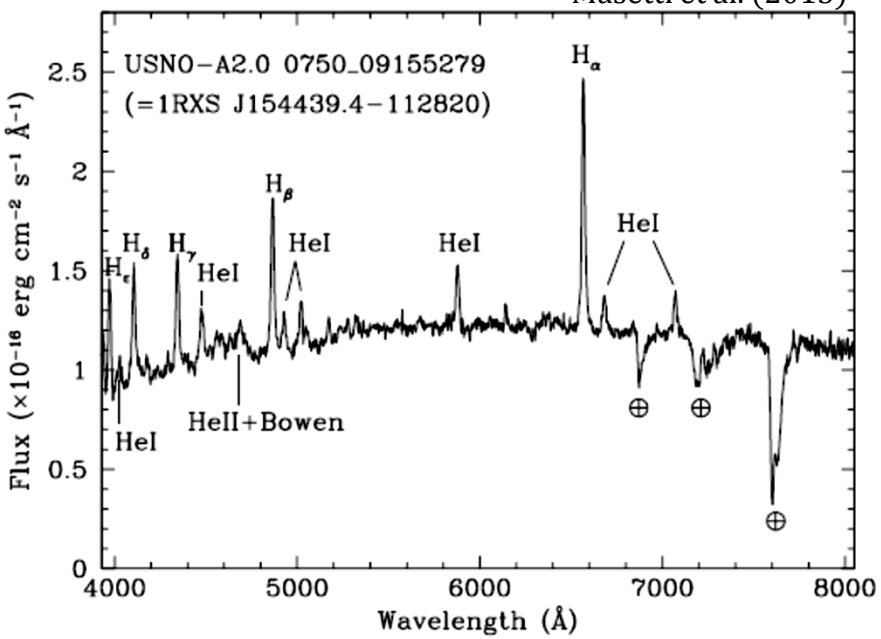
1RXS J154439.4–112820 / 3FGL J1544.6–1125: A New Transitional MSP Candidate

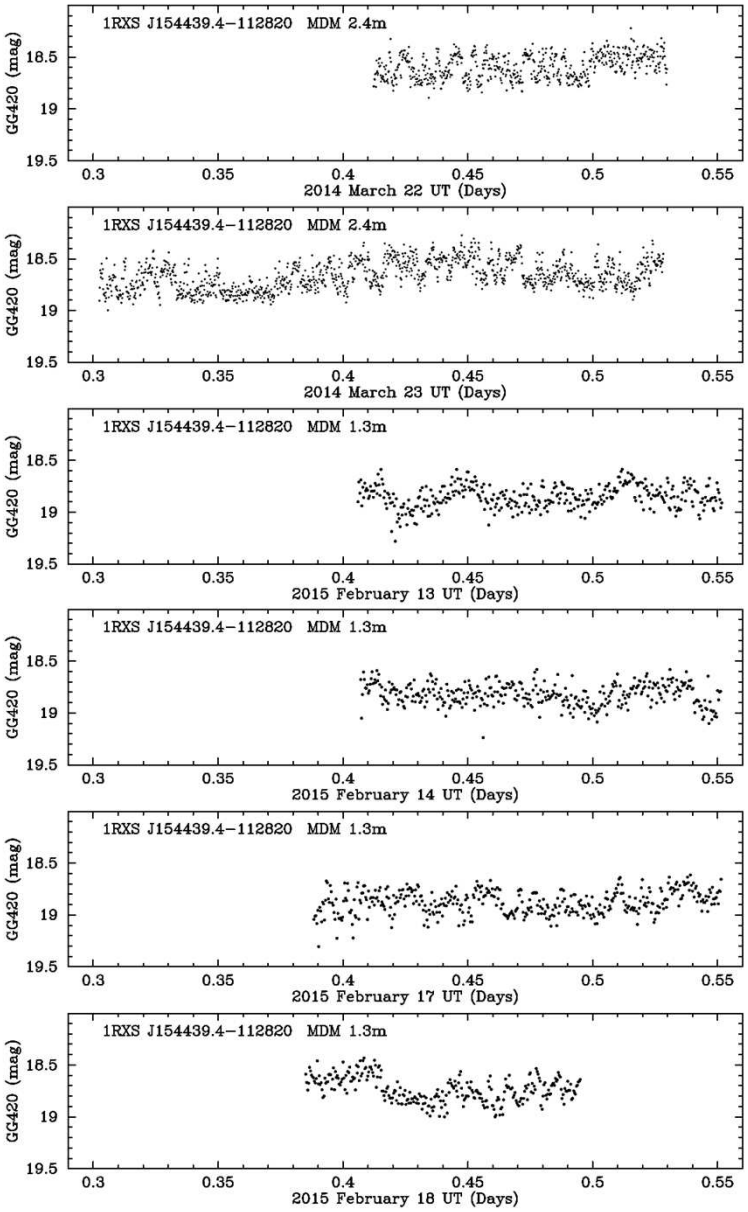
☑ Positional coincidence with unassociated *Fermi* LAT source

☑ CV-like optical spectrum

☑ Rapid optical/UV variability with modes

Masetti et al. (2013)

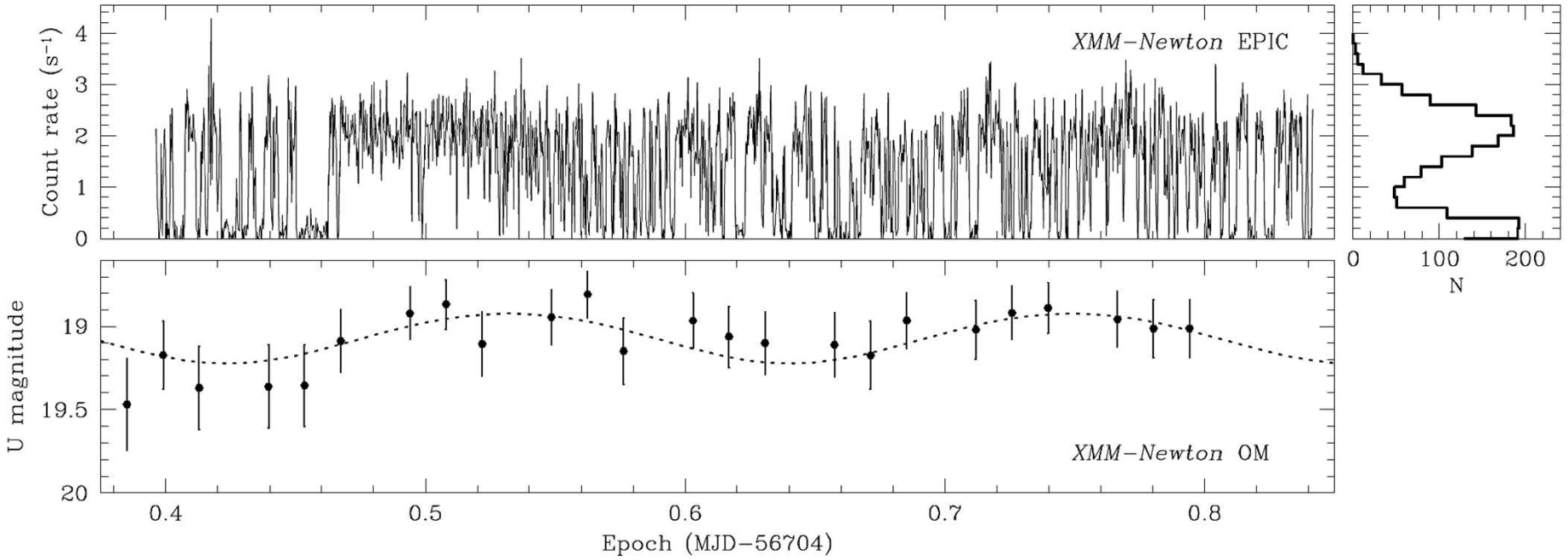




1RXS J154439.4–112820 / 3FGL J1544.6–1125: A New Transitional MSP Candidate

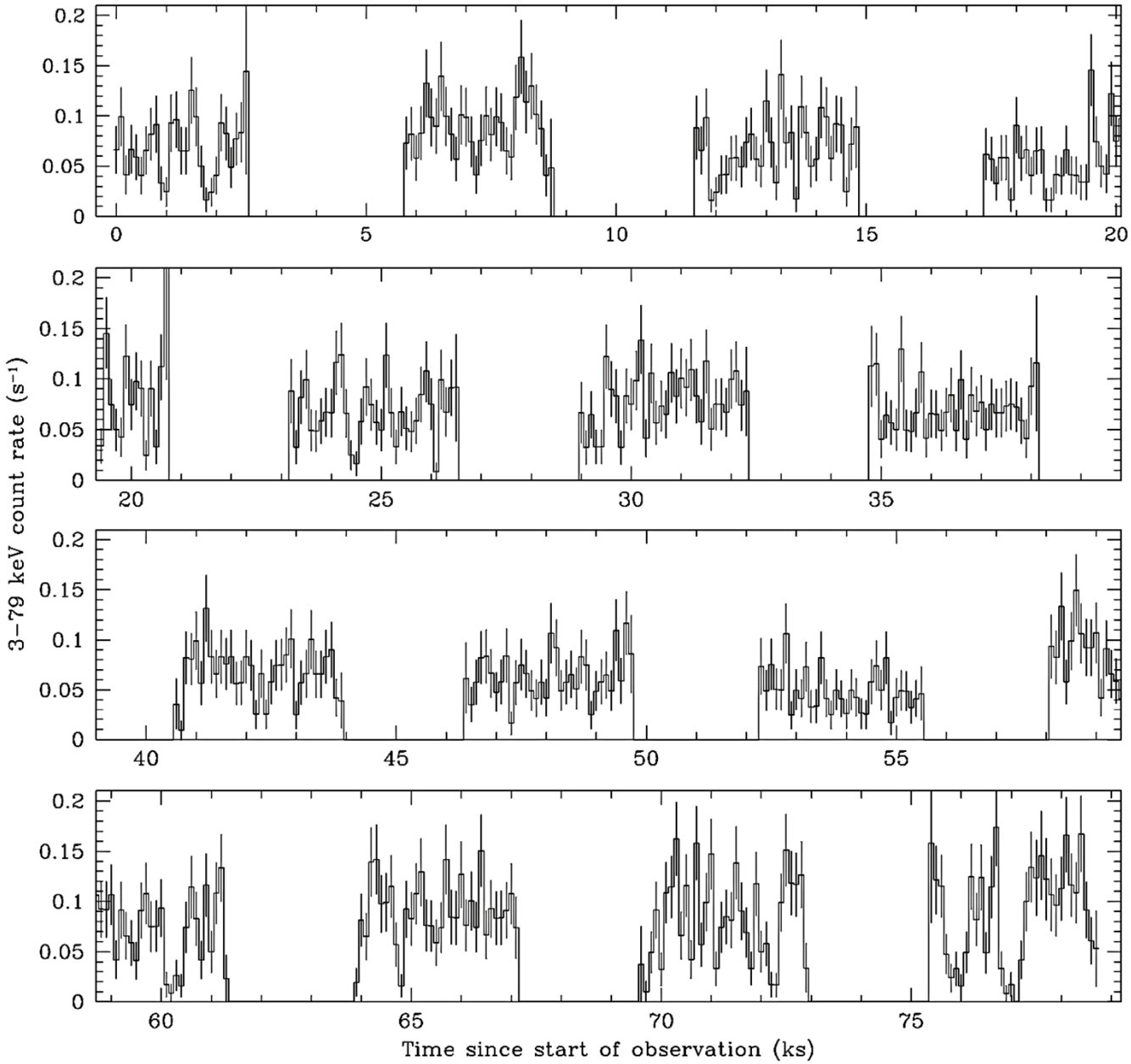
☑ Moderately bright X-ray emission with rapid mode switching and flux bimodality

Bogdanov & Halpern (2015)



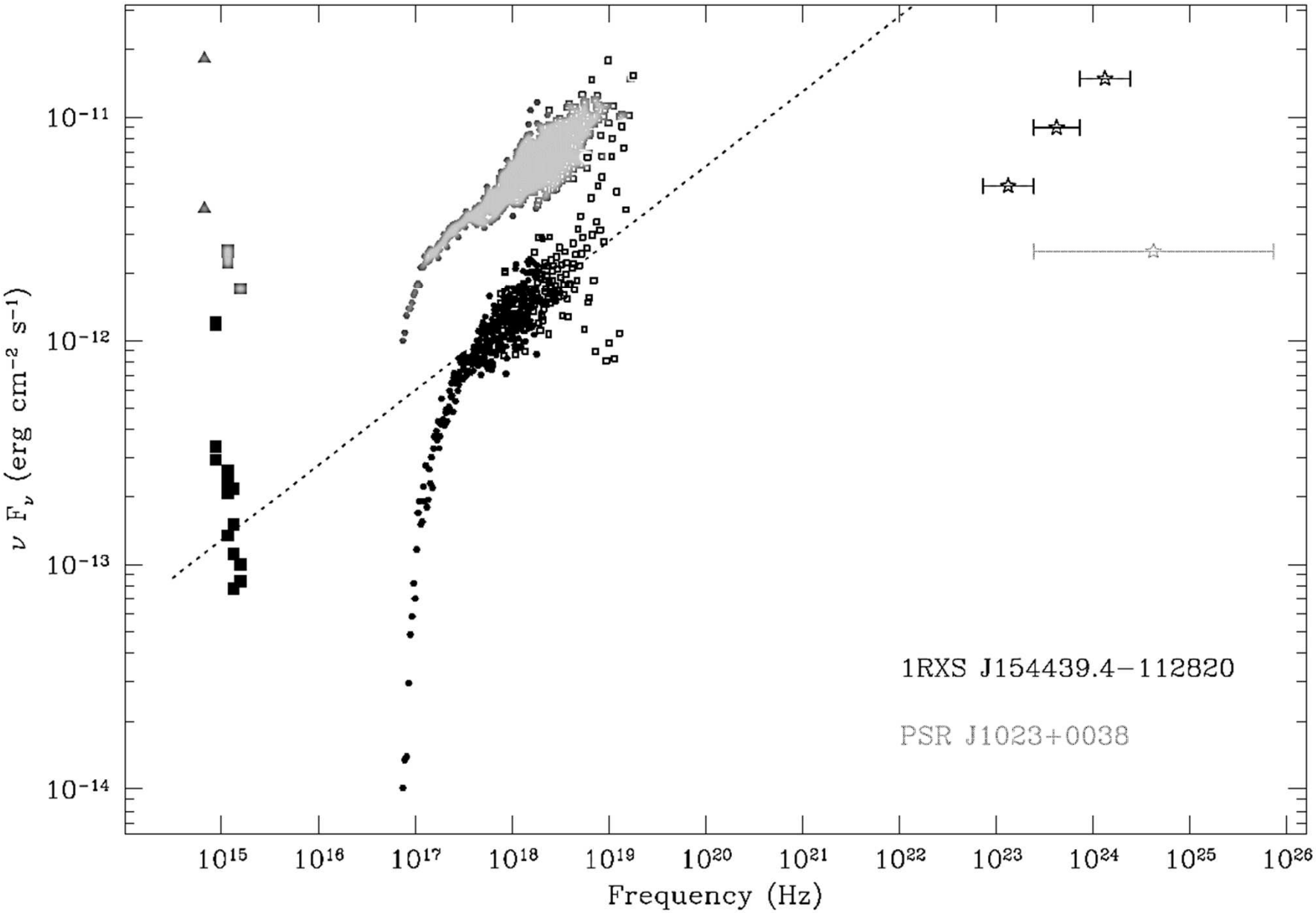
1RXS J154439.4–112820

NuSTAR
FPMA+FPMB
3-79 keV

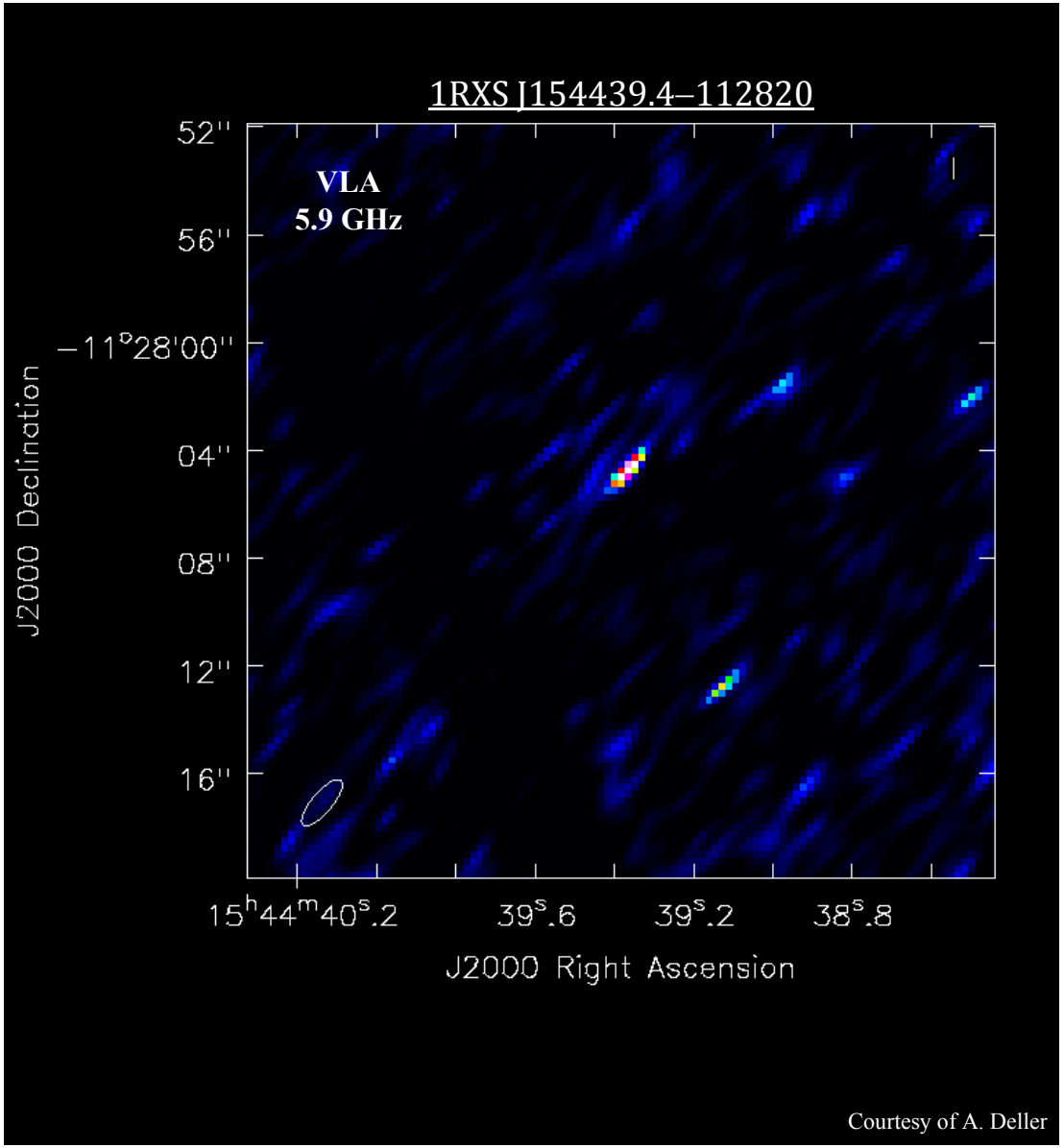


Bogdanov 2015, ApJ, submitted (arXiv:1508.05844)

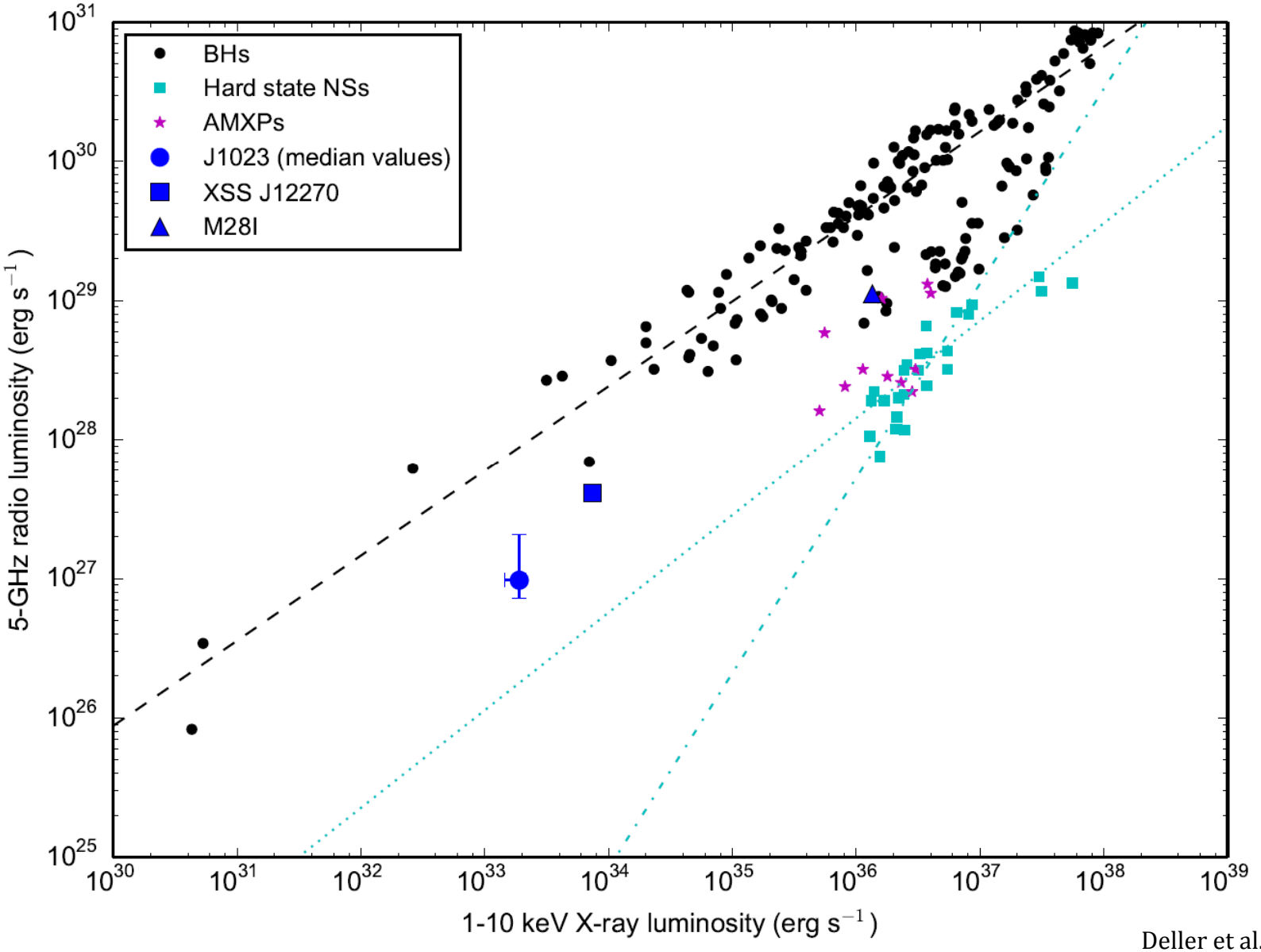
1RXS J154439.4–112820 vs PSR J1023+0038



☑ Flat-spectrum radio source

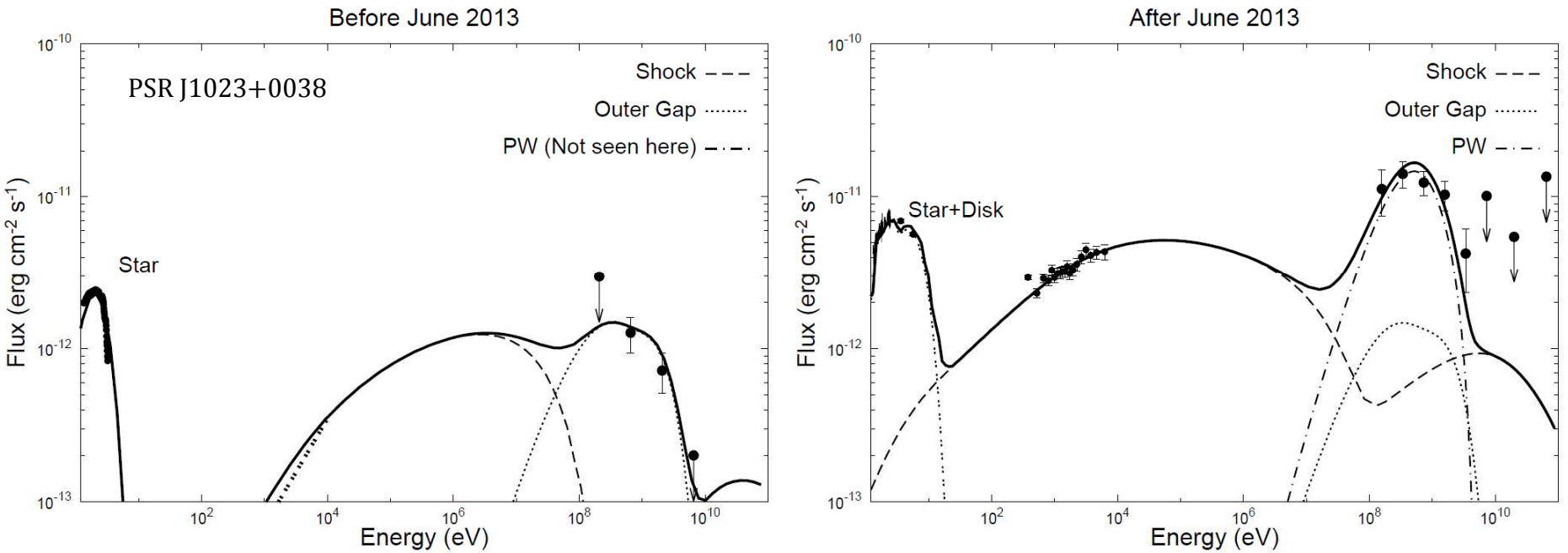


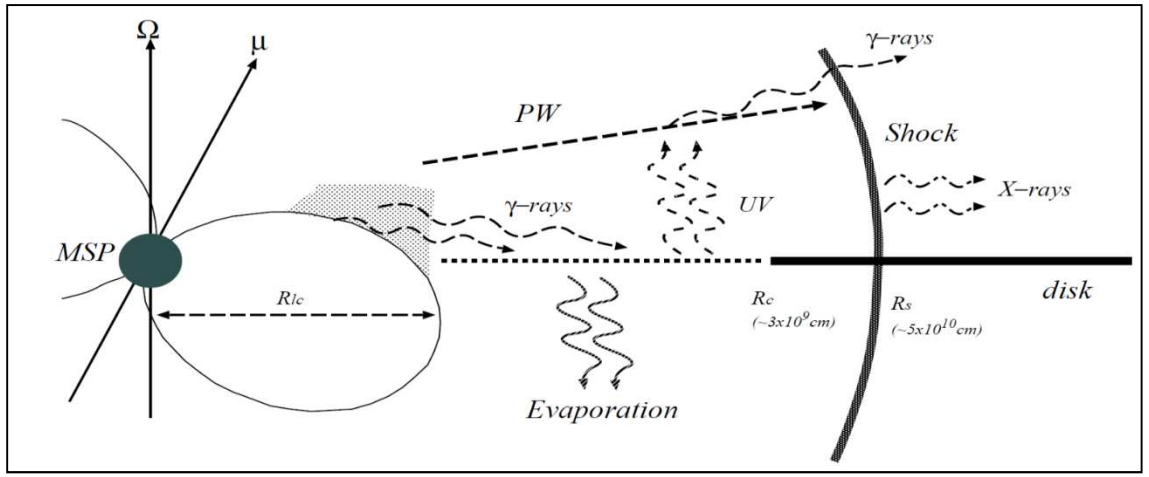
An X-ray/Radio Luminosity Correlation for accreting MSPs?



Deller et al. (2015)

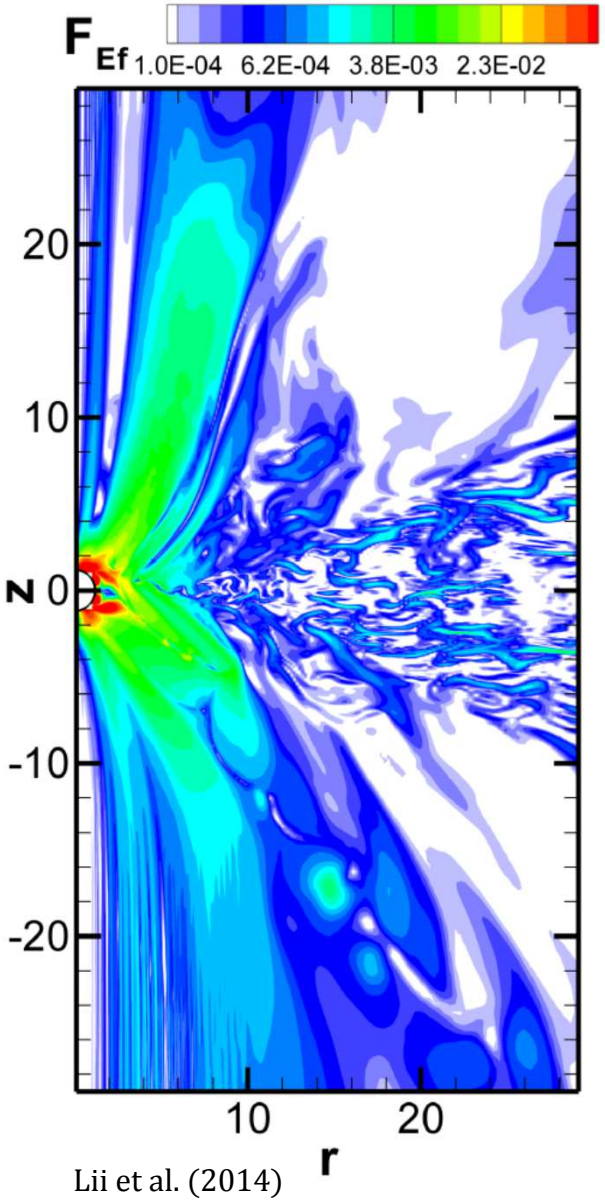
Origin of γ-rays: Intra-binary Shock?





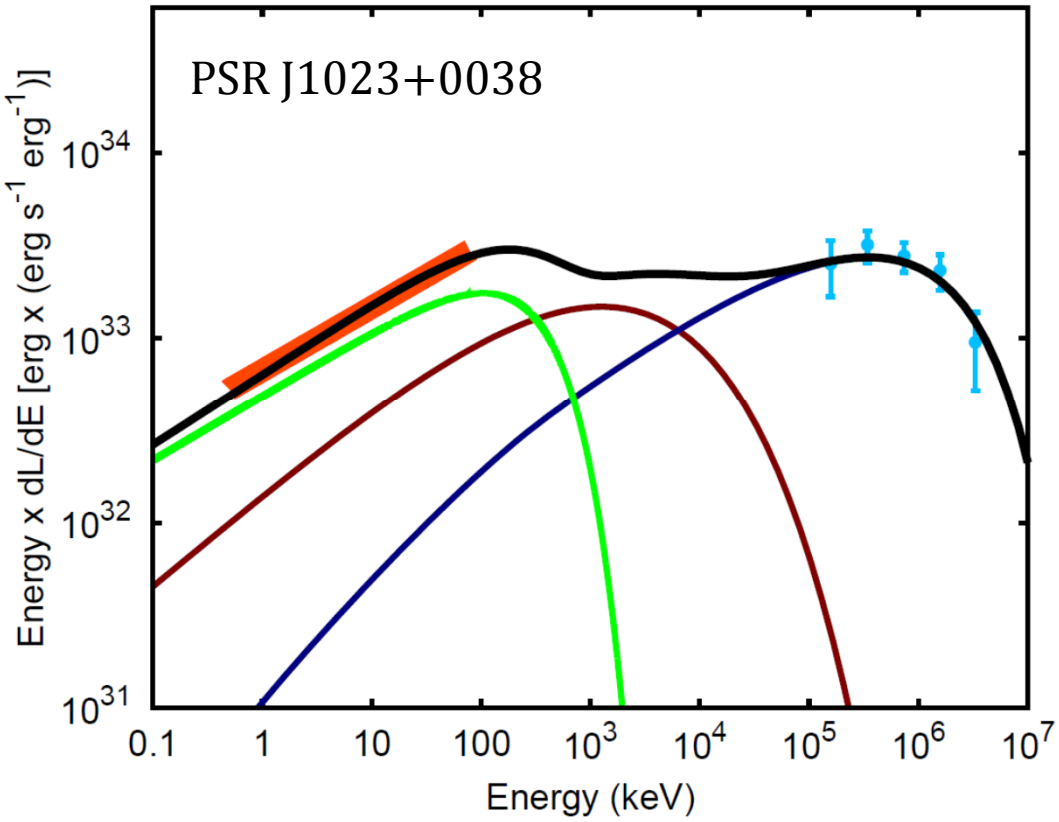
Takata et al. (2014)

Origin of γ-rays: Propeller Mechanism?



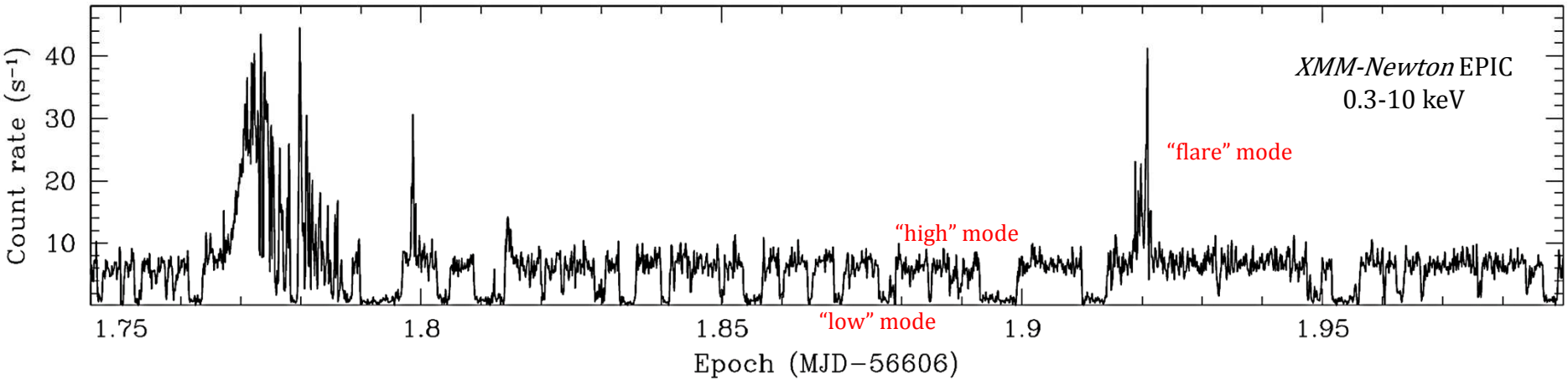
Lii et al. (2014)

Papitto & Torres (2015)



Transitional Millisecond Pulsars

- Lack of radio pulsar emission when accreting – enshrouding or quenching due to accretion?
- Flat-spectrum radio continuum emission – jet-like outflow?
- X-ray mode switching – emptying and refilling of inner accretion disk or interruptions in low-level accretion?
- X-ray/optical flares – enhanced accretion onto neutron star?
- GeV γ-ray emission – intra-binary shock or propeller ejection?



Conclusions

- Transitional MSPs (tMSPs): only known variety of γ-ray-emitting low-mass X-ray binaries

- Only 3 *bona fide* tMSPs identified so far

  ⇒ Necessary to extend the sample of transitional MSPs

- At present, only PSR J1023+0038 in low-luminosity accreting state - plus 1RXS J154439.4–112820

- Detailed behavior of tMSP accreting state is telling us something important about disk/magnetosphere interactions and jet production

  ⇒ Further multi-wavelength studies of known tMSPs are essential