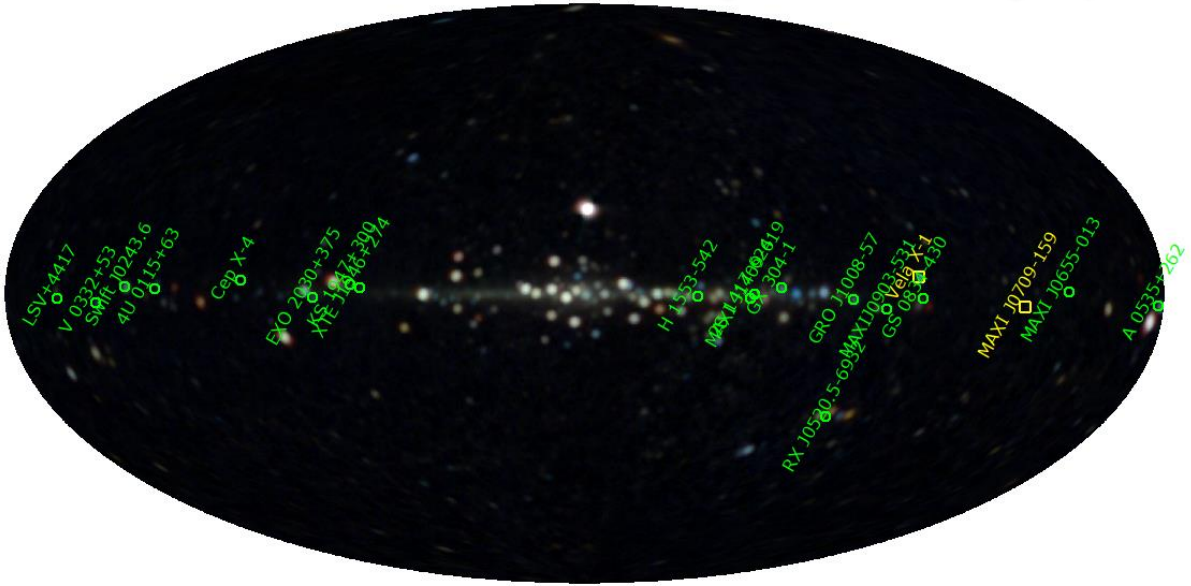
MAXI X-ray monitoring of transient high-mass X-ray binary pulsars



T.Mihara, T.Yamamoto, T.Takagi, F.Yatabe, K.Makishima (RIKEN), M.Nakajima (Nihon-U.), V.Doroshenko (Tuebingen), C.Malacaria (ISSI),S.Pike (UCSD)

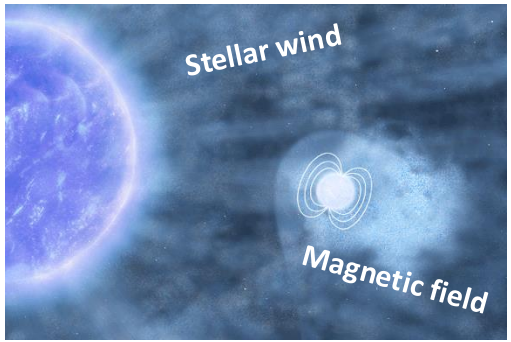
Mutsumi Sugizaki
(Kanazawa-U)

Outline

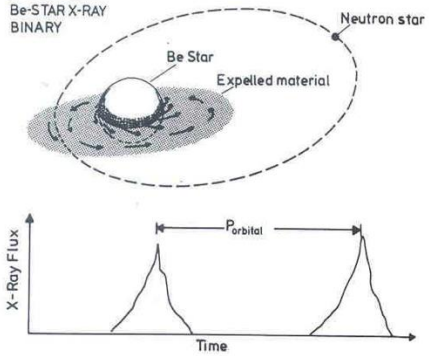
- Be X-ray binary pulsars (BeXB)
  - Luminosity – spin-up relation
    - Accretion-torque models, NS physical parameters
- Supergiant X-ray binary pulsars (SgXB)
  - Vela X-1
  - MAXI J0709-159
    - Supergiant Fast X-ray Transient (SFXT) or evolved BeXB?
- Summary

Two HMXB subclasses

	Supergiant X-ray binary	Be X-ray binary
Binary comp.	OB superginat + NS (pulsar)	Be star + NS (pulsar)
Circumstellar medium	Wind fed (clumpy?)	Be disk
X-ray activity	Persistent (classical) or short transient (SFXT) Large variabilities and flares	Outbursts lasting for a week (type-I) to a few months (type-II)
Pulsar spin-up/down	Unpredictable spin-up/down like random work	Spin-up correlated with X-ray luminosity



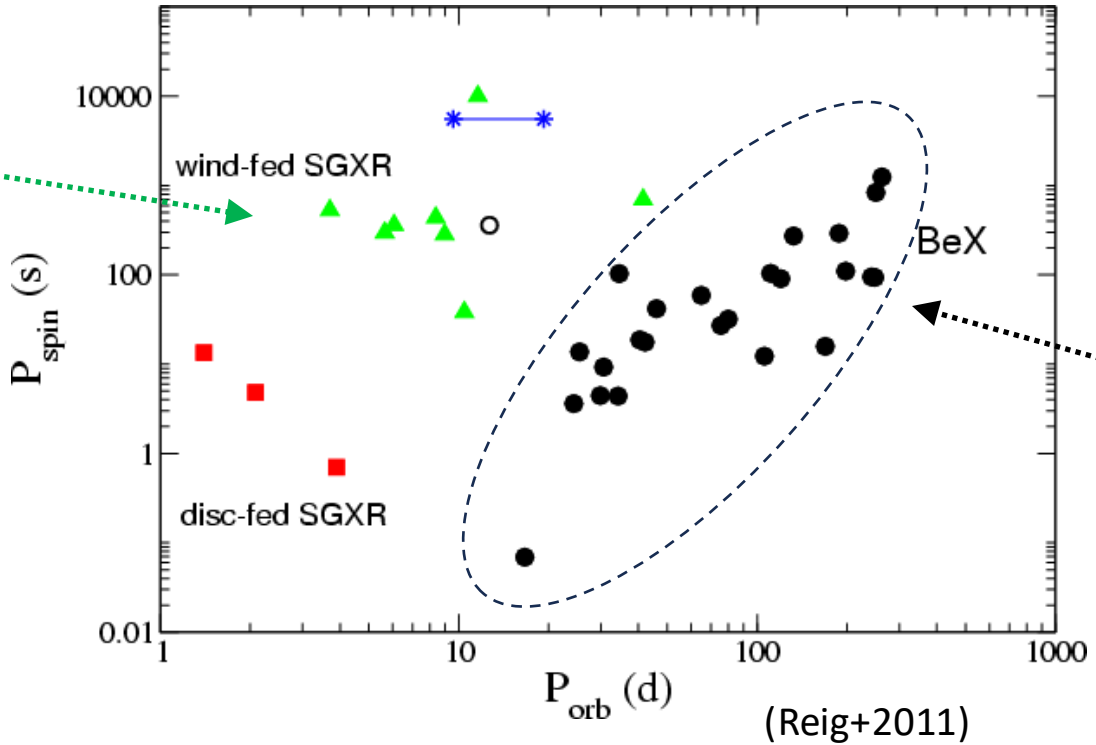
(figure from Bozzo+2011)



(figure from van den Heuvel 2014)

Orbital Period P_{orb} vs Spin Period P_{spin} (Corbet diagram)

In SgXBs, P_{orb}-P_{spin} correlation is not clear



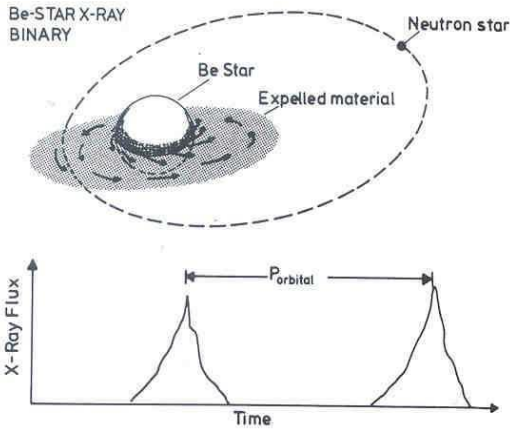
(Reig+2011)

In BeXBs, P_{orb}-P_{spin} correlation suggets pulsars spin up due to mass accretion from donar (Be) stars.

Be X-ray binaries (BeXB)

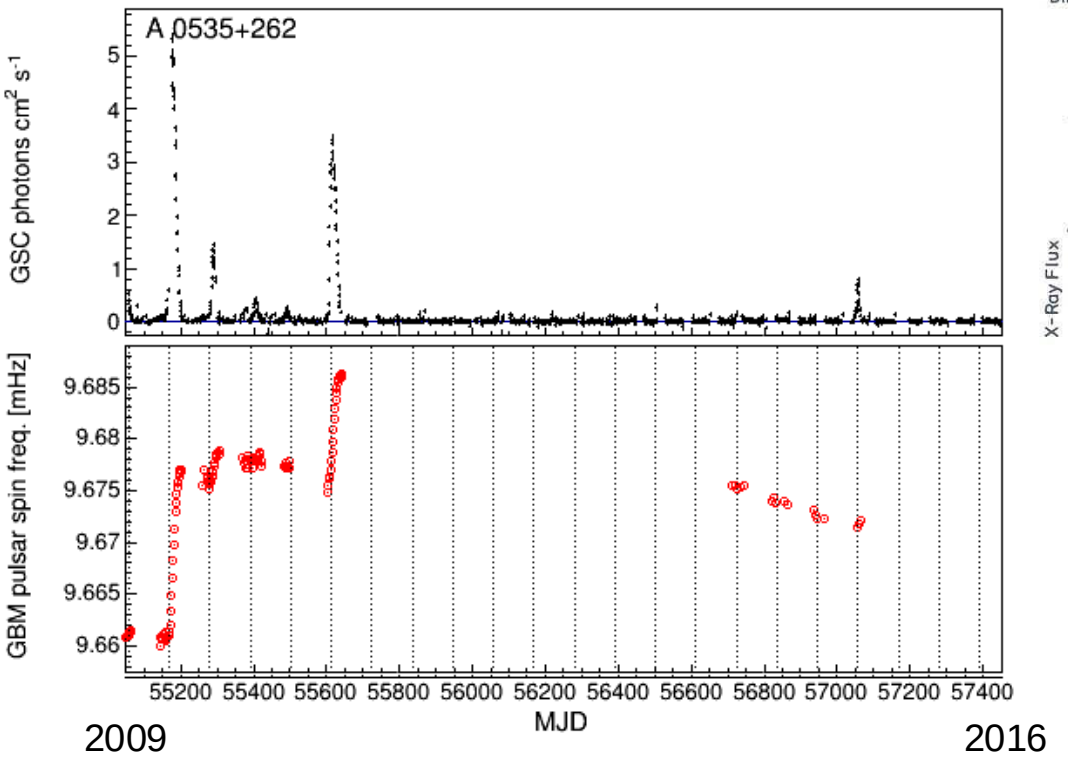
BeXB X-ray outburst vs pulsar spin-up
A typical sample: 1A 0535+262

(fig. from van den Heuvel 2014)



MAXI/GSC 2-20 keV light curve

Fermi/GBM spin-freq. change



X-ray outbursts occurr when the NS pulsar passes through the Be circumstellar disk.

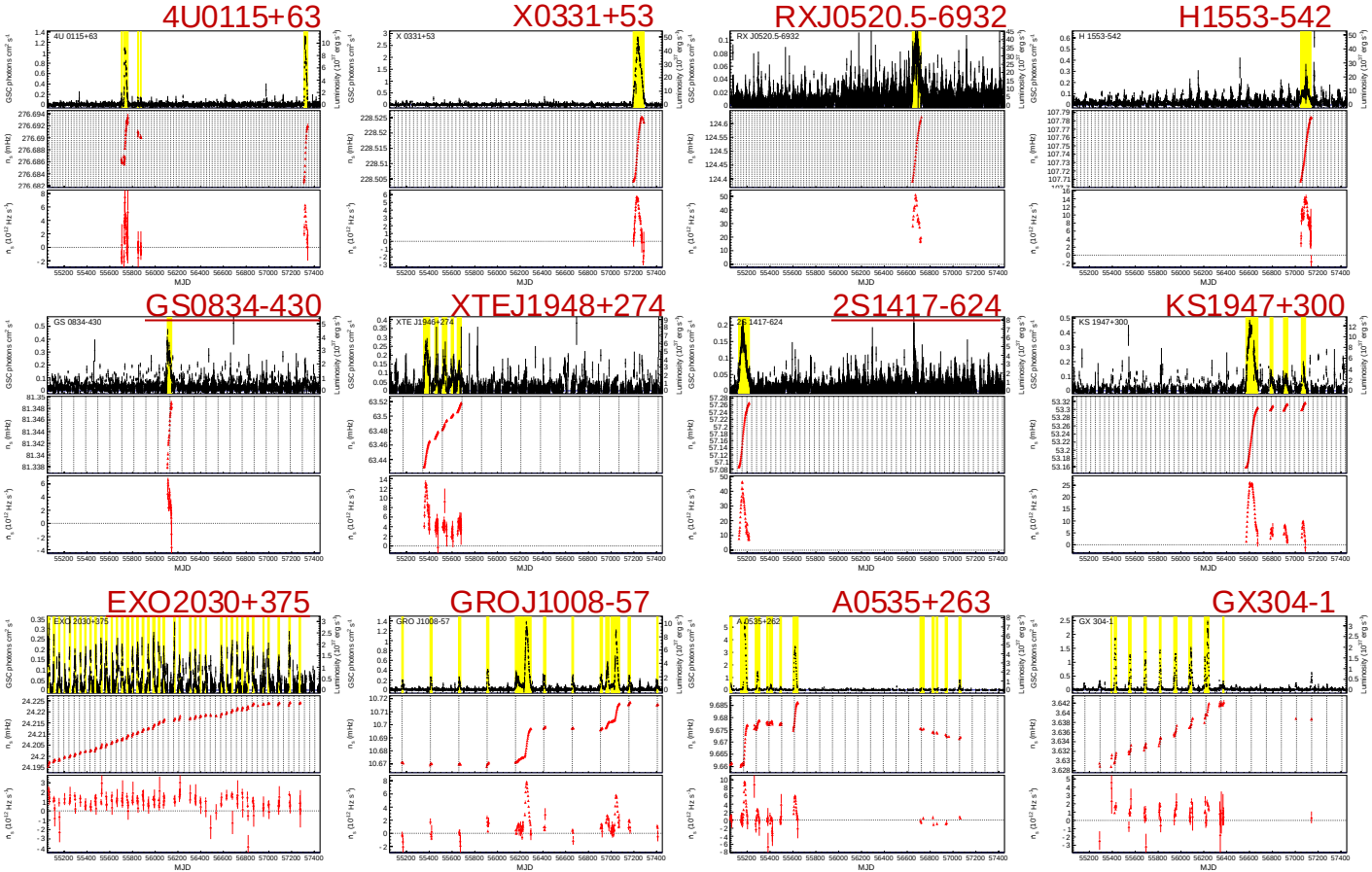
(Nakajima+2013 , poster)

MAXI & Fermi 7 years (2009-2016) data of 12 BeXB Pulsars

X-ray flux

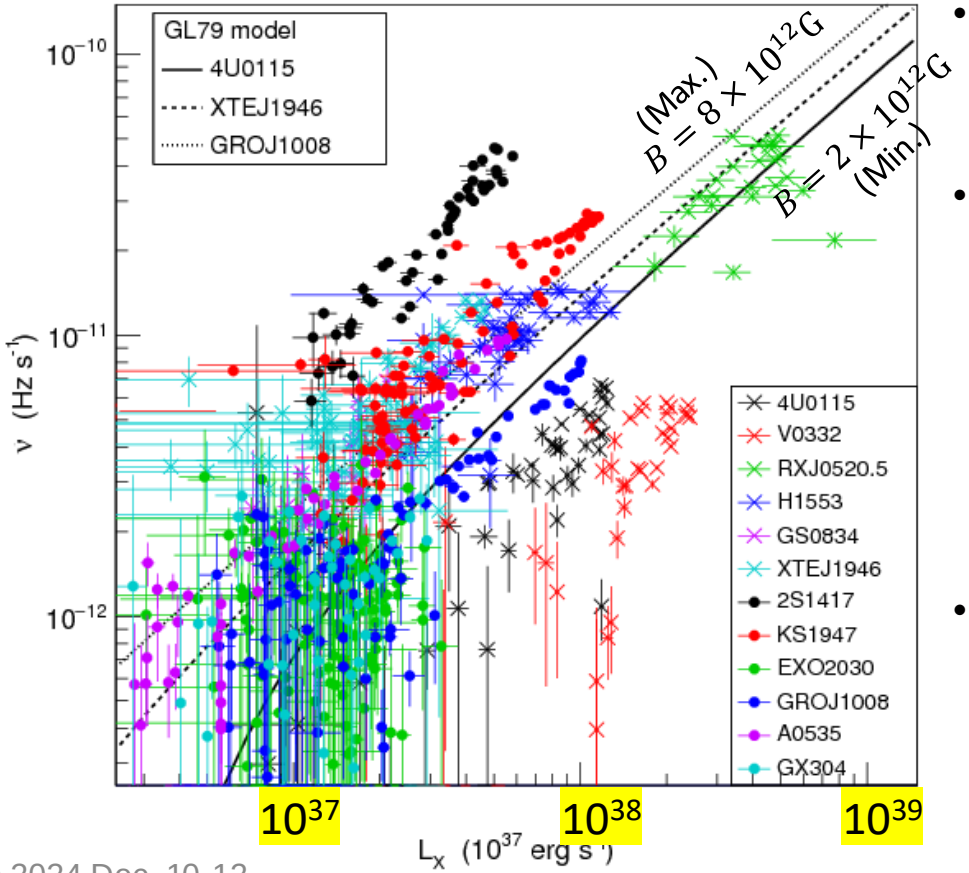
spin-frequency

fdot



(MS+2017)

Luminosity – spin-up relation (vs. Ghosh & Lamb model)



- Positive correlation in all the 12 Be XBPs.
- $\dot{\nu}$-to-L coefficient differ by a factor ~ 3 from the GL model (assuming M=1.4M_{sun}, R=10km, B_s from E_{cycl}).

$$\nu_{obs} = 0.3\sim3\ \nu_{GL}$$

- The average of 12 objects agrees with the GL79 model.

(MS+2017)

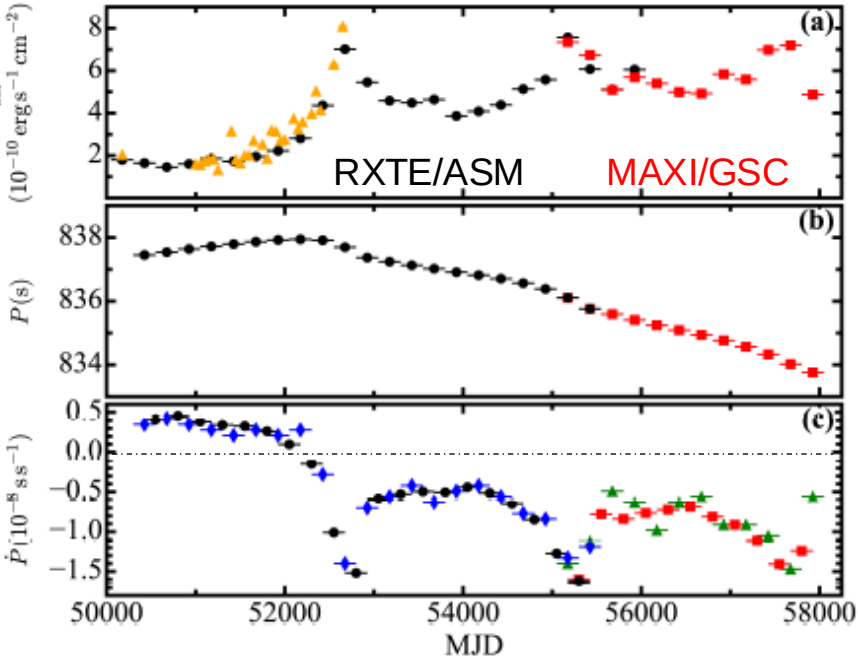
X Persei

Slow spin P_{spin} = 835 s, Relatively low Lx~10^{34} ergs/s,
Moderate variability, Dist. = 0.81 kpc

X-ray light curve

Spin period P

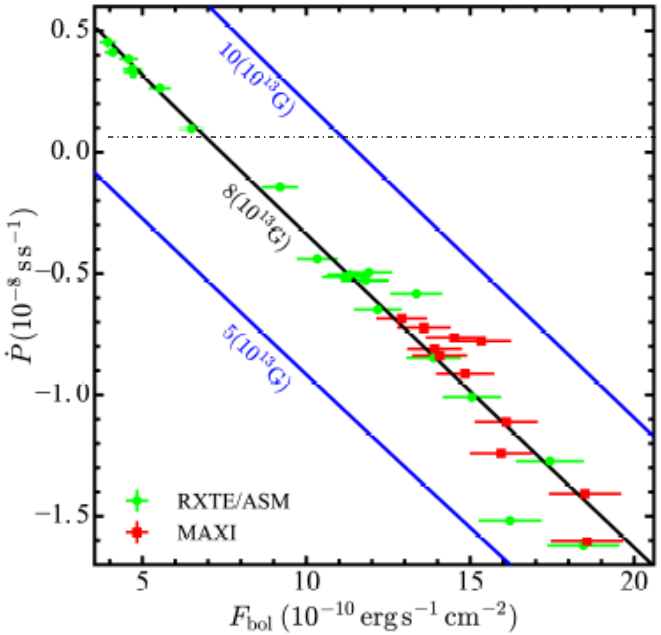
Pdot



1996 — 2017

21 years

Luminosity – Pdot relation



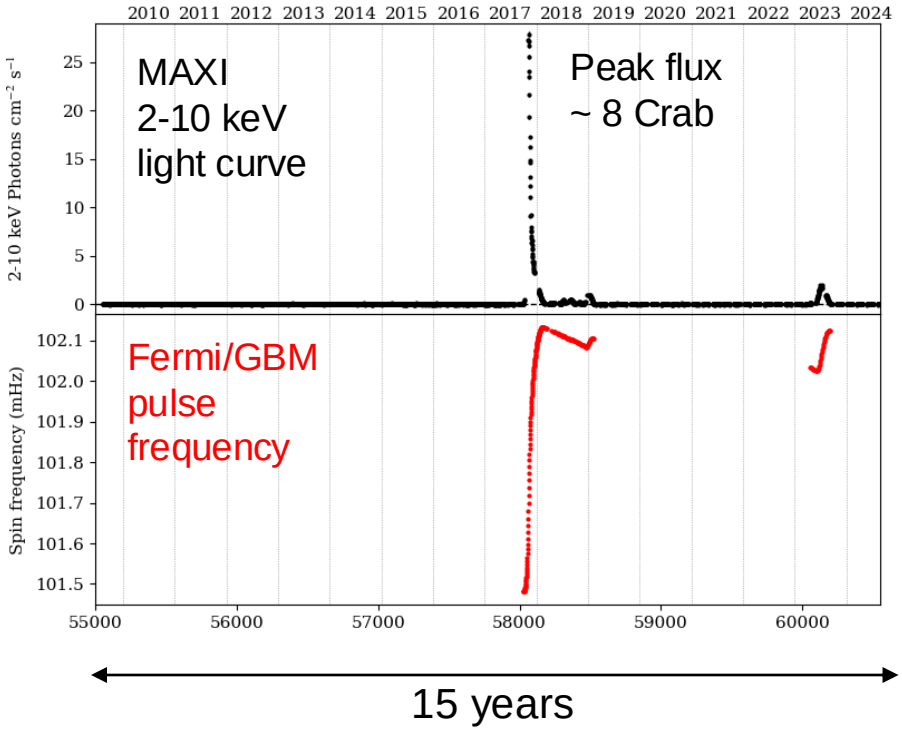
(Yatabe+2018)

GL model suggests $M \sim 2.0 M_{\rm sun}$,
$R \sim 12.9$ km, $B = 8 \times 10^{13}$G.

Record-breaking bright BeXB outbursts

Swift J0243.6+6124 (ULX in our Galaxy)

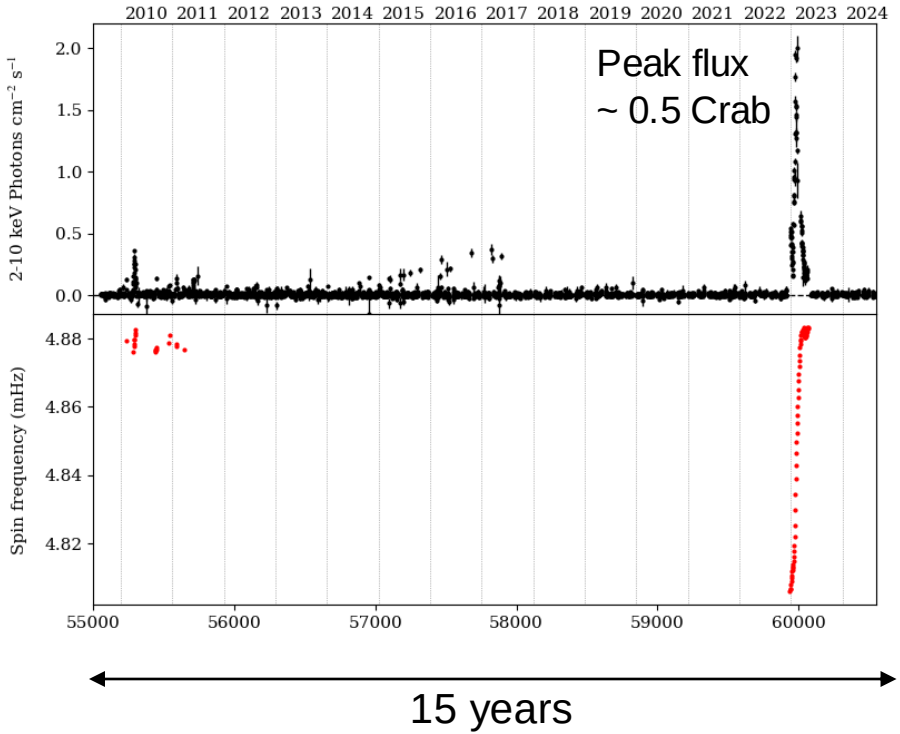
P_{spin}= 9.8 sec.



15 years

LS V +44 17 (aka RX J0440+4431)

P_{spin}= 205 sec.

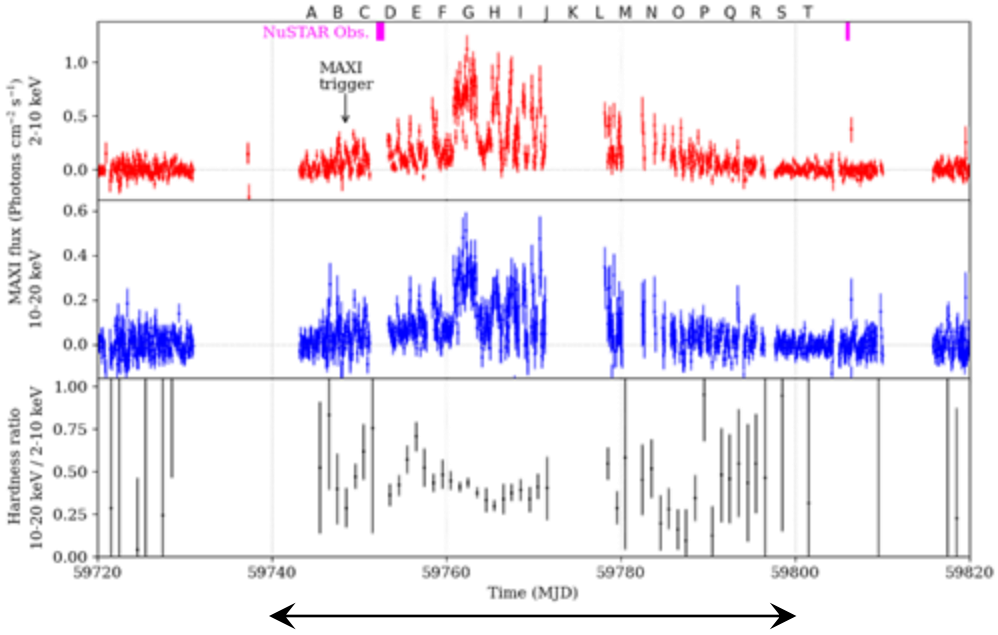


15 years

New discovered BeXB MAXI J0655-013

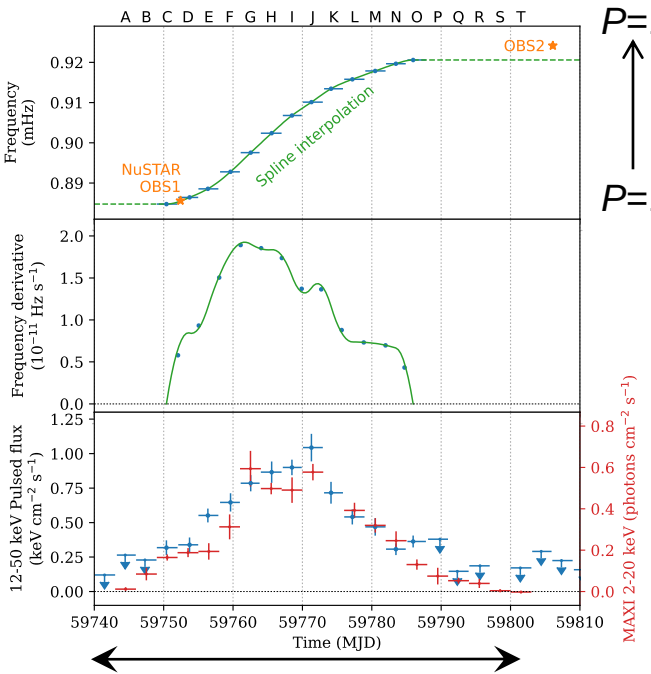
- Very long P_{spin} = 1130 sec. pulsation was discovered by NuSTAR (Pike's talk)

MAXI/GSC light curves and hardness ratio



2022 Jun.

Fermi/GBM pulse frequency



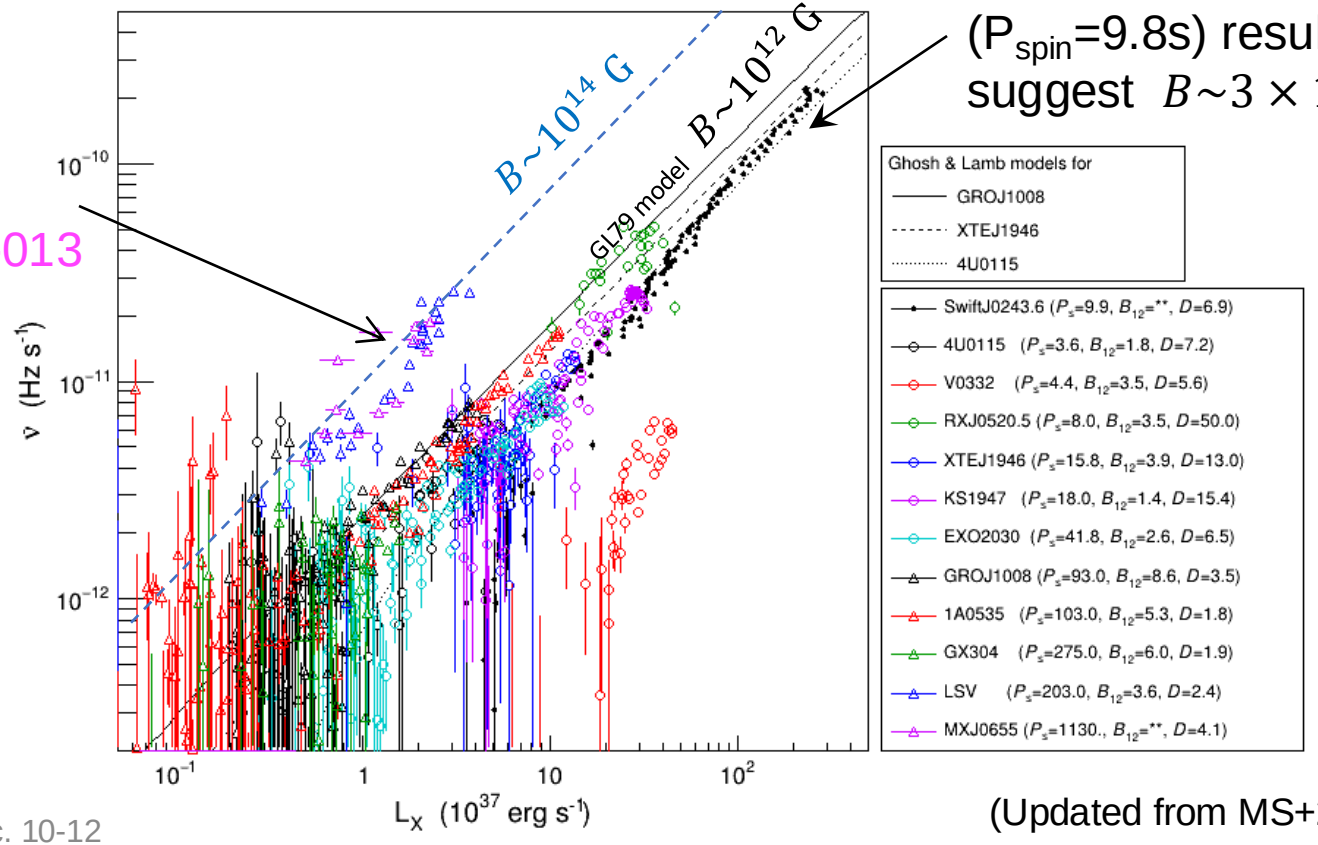
P=1085 s
spin up
P=1129 s

(Pike+2023)

Update luminosity – spin-up relation with newly identified BeXB outbursts

Magnetic field
Very high ?

- MAXI J0655-013 (P_{spin}= 1130 s)
- LS V +44 17 (P_{spin}= 205 s)



Our Swift J0243.6+6124 (P_{spin}=9.8s) results suggest $B\sim3\times10^{12}$ G

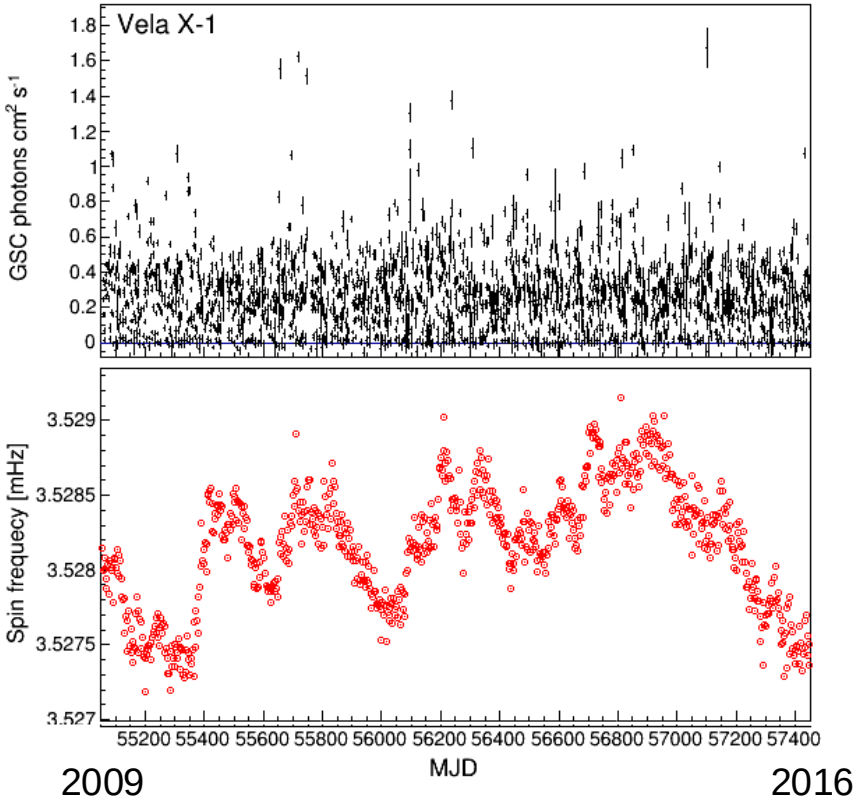
(Updated from MS+2020)

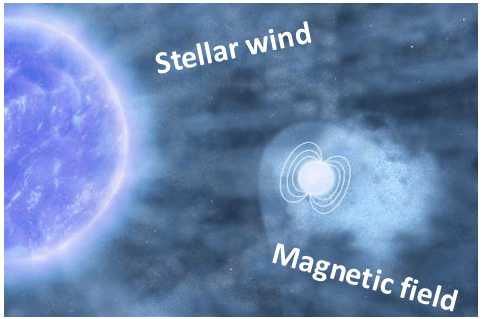
Supergiant X-ray binaries (SgXB)

X-ray activity vs pulsar spin-up/down
SgXB prototype: Vela X-1

MAXI/GSC
2-20 keV
light curve

Fermi/GBM
spin-freq.

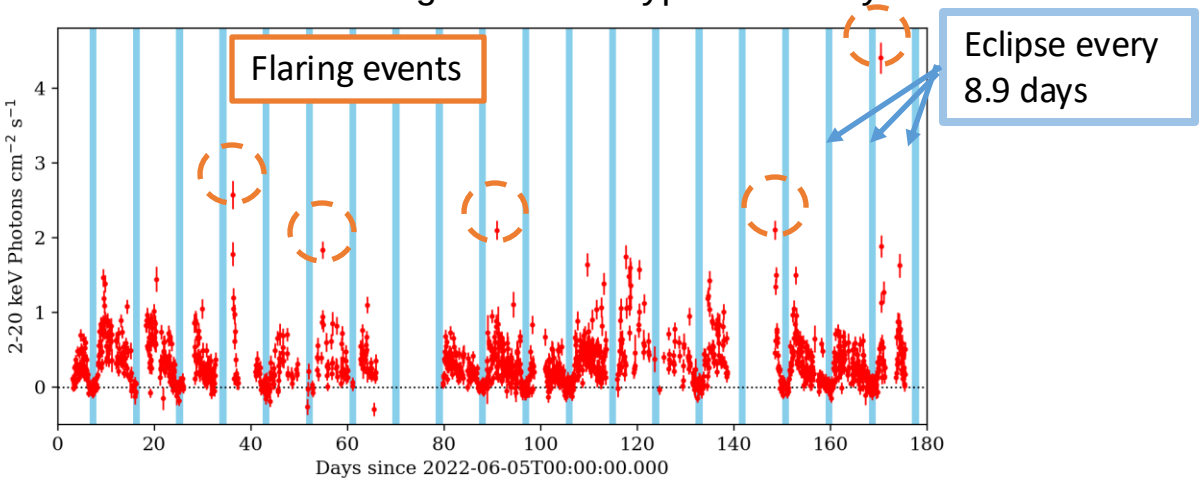


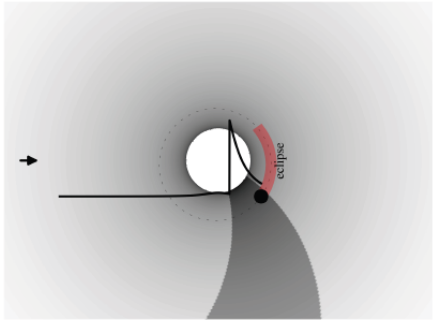


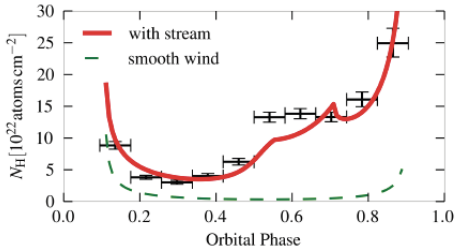
- Correlations between X-ray intensity and pulsar spin-up/down are not clear. The spin-up/down changes look like a random walk.
- The stellar-wind velocity (momentum) will not be negligible.

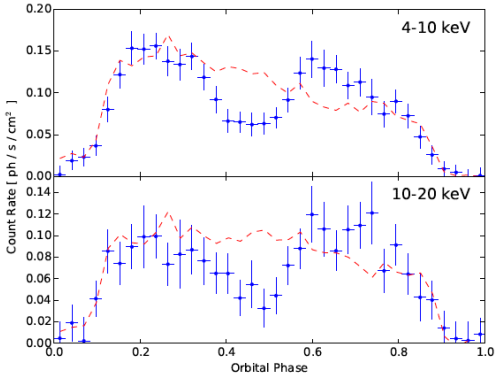
Results of MAXI monitoring Vela X-1

MAXI GSC 2-20 keV light curve for typical 180 days









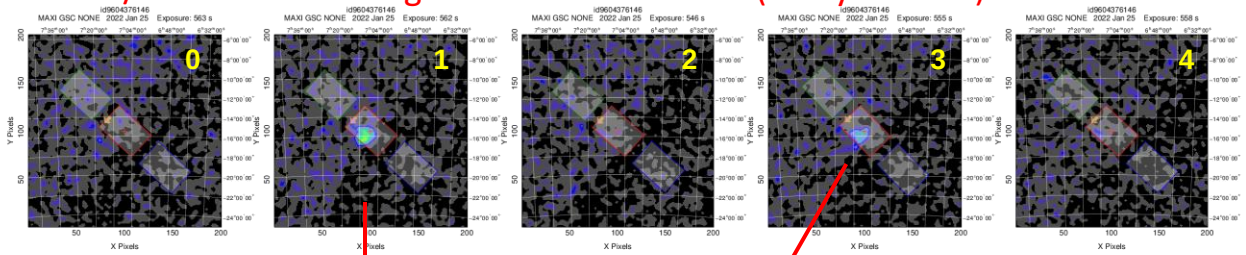
Orbial profiles average for all and double-peaked cycles

- The orbital profile is not always consistent. It sometimes becomes multile-peak. (Malacaria+2016)

- N_H change with orbital phase suggests CSM density profile forming accretion wake (Doroshenko+2013)

MAXI J0709-159: Galactic fast X-ray transient

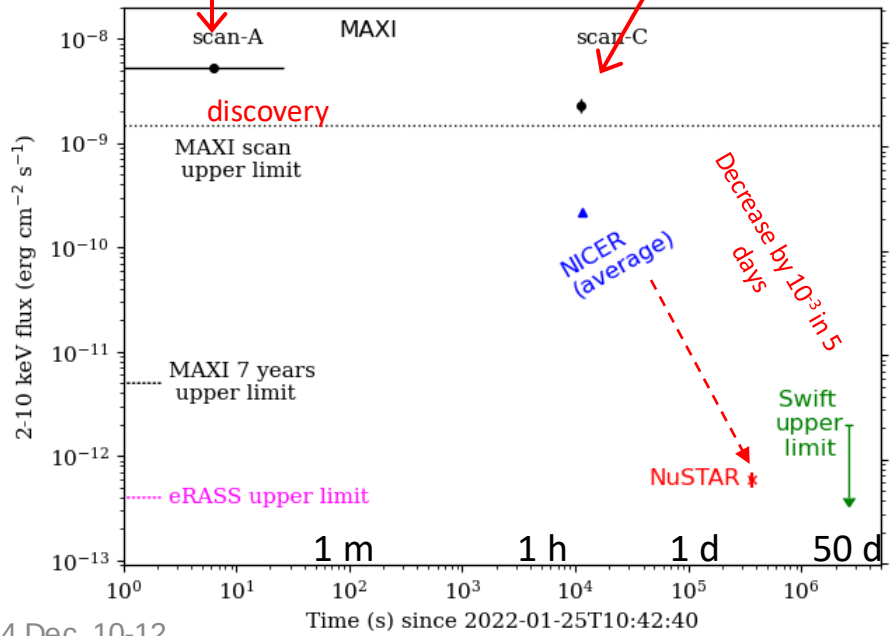
MAXI/GSC 2-20 keV image of each source scan (every 90 min.)



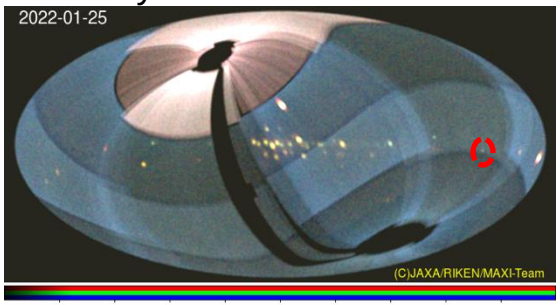
The new transient detected only at 2 scans in 3 hours

(MS+2022)

Light cuve for 50 days (log-log scale)

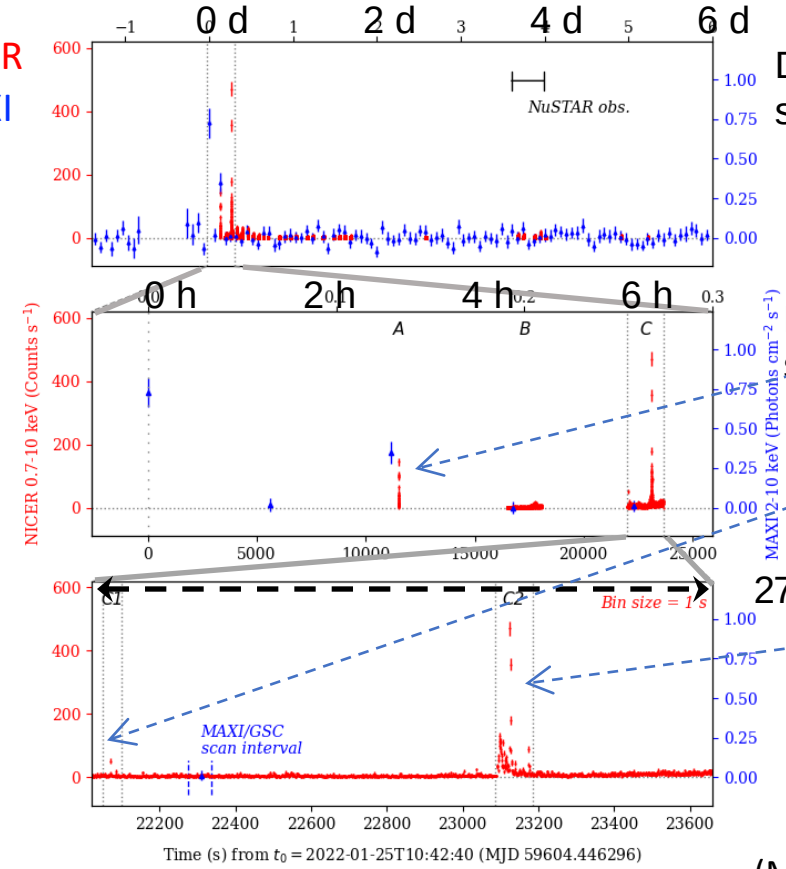


- MAXI/GSC discovered a new transient on 2022 January 25.
- NICER and NuSTAR observations, identifeid optical countarpart, LY CMa (Be star) located at 3 kpc.
- Very short X-ray transient. Supergiant Fast X-ray Transient SFXT?

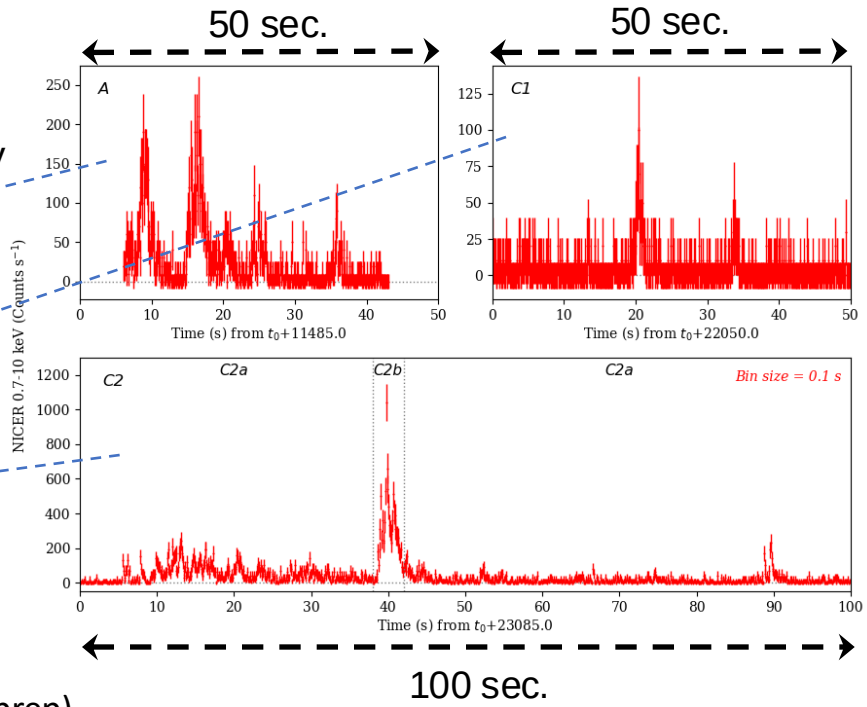


NICER Light curve 3 to 6 hours after discovery

NICER
MAXI
data



- Sporadic flares, ~3 bright flare in 6 hours
- *L*x ~ 10^{36}-10^{37} erg s^{-1} at peak
- Flare duration < 100 sec each



(MS+ In prep)

Summary of MAXI 15-year monitoring HMXB pulsars

- BeXB
  - Luminosity – spin-up relations and accuracy (limits) of their theoretical models are established.
  - Some long period (~ 1000 s) pulsars may have a strong Bs > 10^{13} G
- SgXB
  - Data enables overall analysis of the circumstellar-medium condition ruled by stellar wind and X-ray radiation over the entire orbital phase.
  - A possible SFXT with an evolved Be star

- Prospects in new X-ray missions
  - Wide-field monitor for transient XRB (MAXI → Einstein-Probe, …)
  - Timing (NICER, HXMT, …), Polarization (IXPE, POLIX)
  - Emission/abroption line diagnosis of the CSM (XRISM)