MAXI results of the Galactic ultra-luminous X-ray pulsar Swift J0243.6+6124

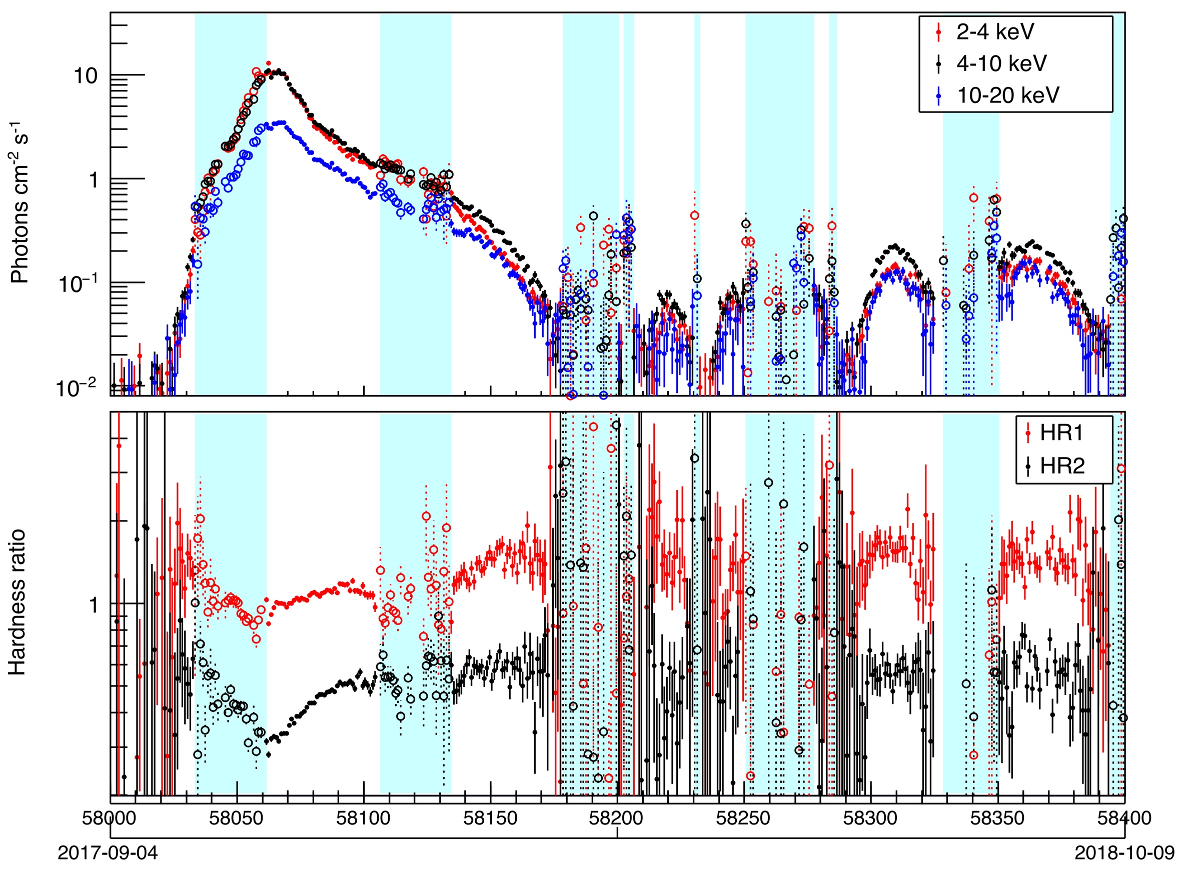
M. Sugizaki, M. Oeda, N. Kawai (Tokyo Tech.), T. Mihara, K. Makishima (RIKEN),
M. Nakajima (Nihon Univ.) and MAXI Team

Swift J0243.6+6124 (Swft J0243) is a new Be/X-ray binary pulsar discovered on October 3, 2017. The source was first identified as a new X-ray object by the Swift BAT survey. The coherent pulsation with the ~9.86 s period was confirmed by the Swift XRT observation and the Fermi-GBM pulsar analysis. The MAXI all-sky survey had also recognized the X-ray activity, but could not resolve the source from the known nearby X-ray object, LS I +61 303. After the discovery, the source has been observed by many X-ray satellites. X-ray monitoring by MAXI, Swift, Fermi/GBM revealed that the outburst continued for more than 4 months, and the flux reached over 5 Crab at the peak. On the other hand, the recent GAIA result suggests the source distance to be ~7 kpc, meaning that the X-ray luminosity reached the 10 times of the Eddington luminosity (10 L_{EDD}) at the peak. We performed detailed MAX-GSC data analysis taken at around the flux peak, using the Fermi/GBM pulsar ephemeris. X-ray spectra in the 2-30 keV band were largely approximated by power-law functions with a higher-energy cutoff and an iron-K emission line, which is typical in X-ray binary pulsars. The results clarified the spectral softening due to the flux increase, as observed by NICER and Fermi/GBM. The folded pulse profiles show the energy-dependent change due to the intensity. We also investigated the relation between the luminosity and the spin-up rate and found that the positive correlation close to the proportionality smoothly extends up to the 10 L_{EDD}. Assuming the accretion-torque model proposed by Ghosh & Lamb, the surface magnetic filed is estimated to be in a order of 10^{12} G.

1. Light curves and hardness ratios by MAXI GSC

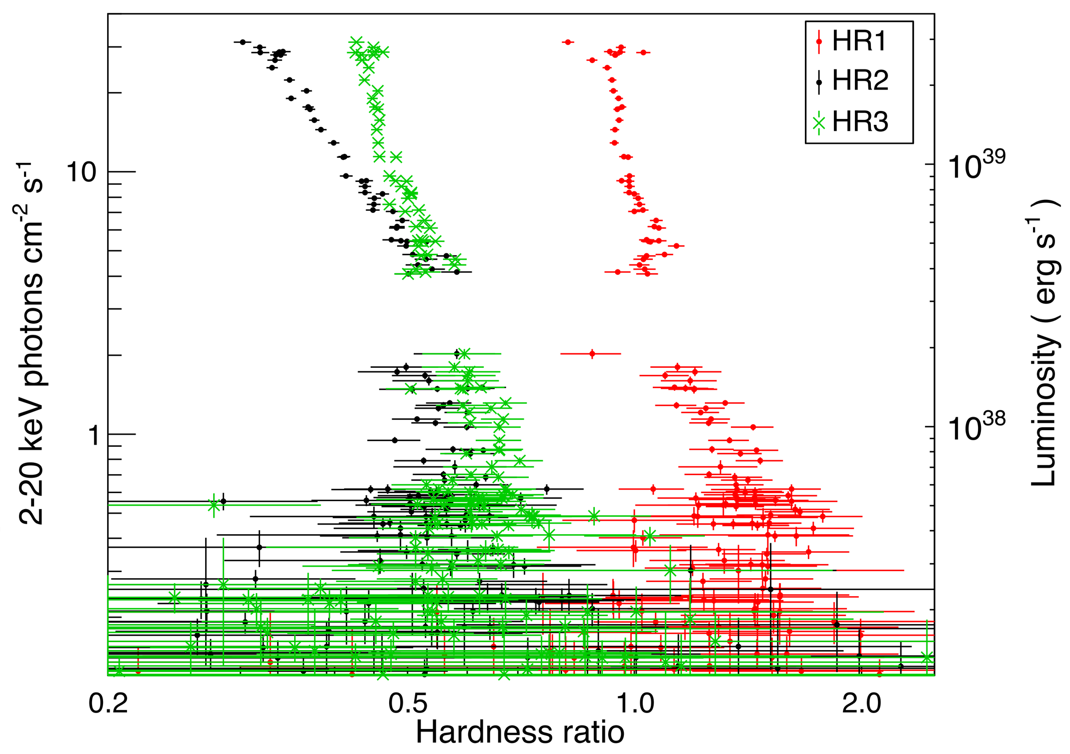
Swift J0243 X-ray light curves obtained by MAXI GSC in 2-4 keV, 4-10 keV, and 10-20 keV bands from 2017 September to 2018 July for about a year.
Data in shaded area were taken by degraded GSC instruments which have large systematic uncertainty.

Time evolution of hardness ratios (HRs)
HR1 = 4-10 keV / 2-4 keV
HR2 = 10-20 keV / 4-10 keV.



HR-intensity diagrams for 3 HRs of
HR1 = 4-10 keV / 2-10 keV
HR2 =10-20 keV/ 4-10 keV
HR3 = 8-16 keV / 4-8 keV.
The ordinate on the right-side vertical axis represents the luminosity scale calculated from the source distance of 7 kpc and the average spectrum.

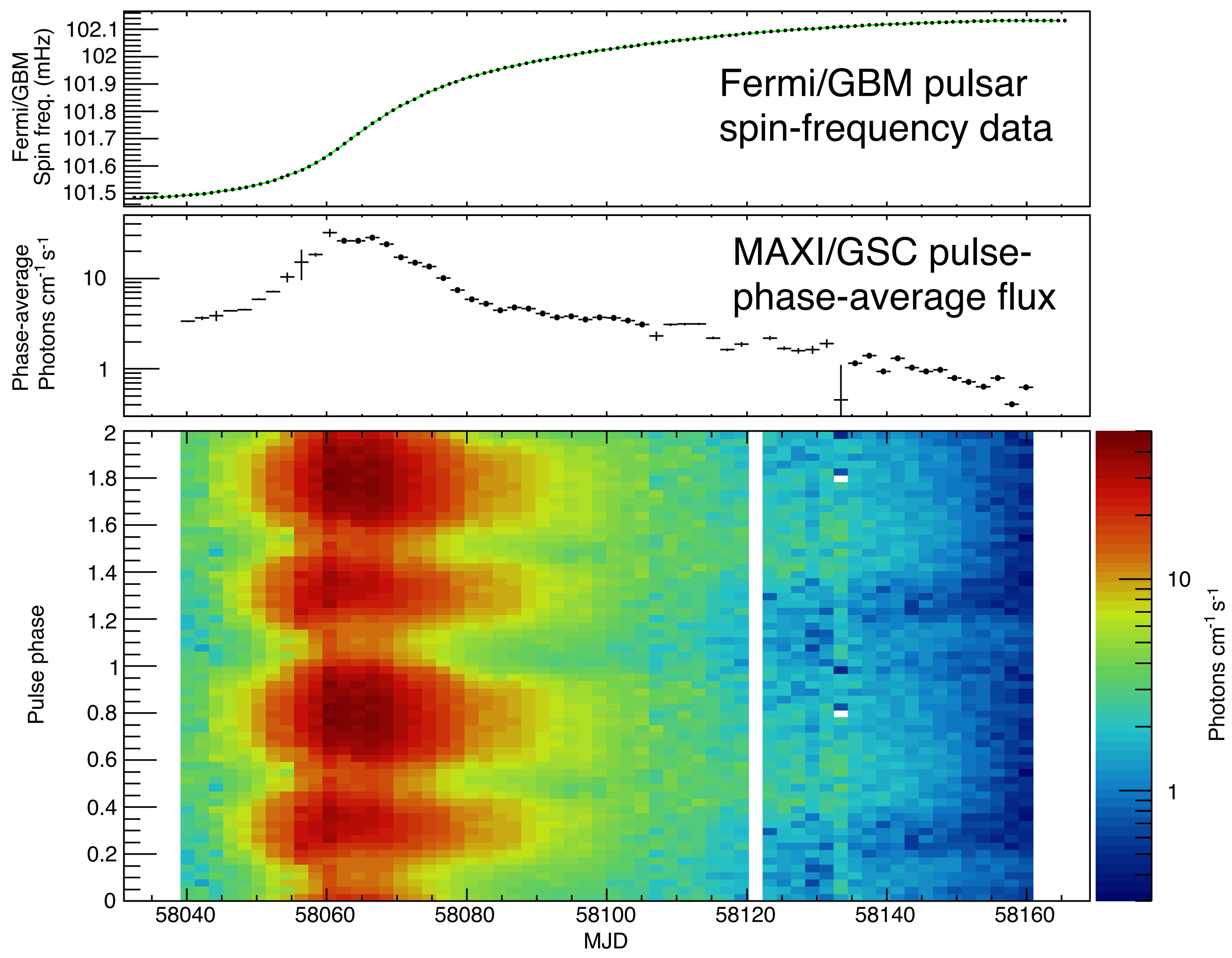
All of the three diagrams show the negative correlations, as reported by Wilson+2018.
The detail profiles are different among the energy bands.



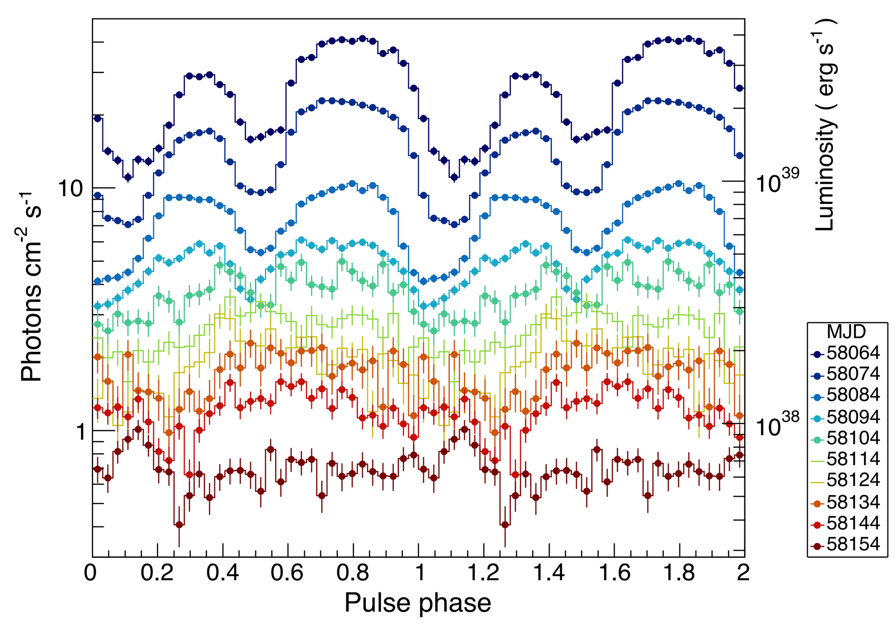
2. Pulsar analysis using Fermi/GBM ephemeris data

MAXI GSC event data are folded with the pulsar spin period measured by the Fermi/GBM pulsar project (Wilson+2018). The period changes between the Fermi/GBM measurements are interpolated by the cubic-spline function.

Time evolution of the obtained MAXI-GSC 2-20 keV pulse profile during the outburst from MJD 58040 to 58160.
The transition from the simple sinusoidal double-peak to the broad single-peak at around MJD 58120 during the outburst decay phase is confirmed.



Sample of MAXI-GSC 2-20 keV pulse profiles for every 10 days during the outburst decay phase.

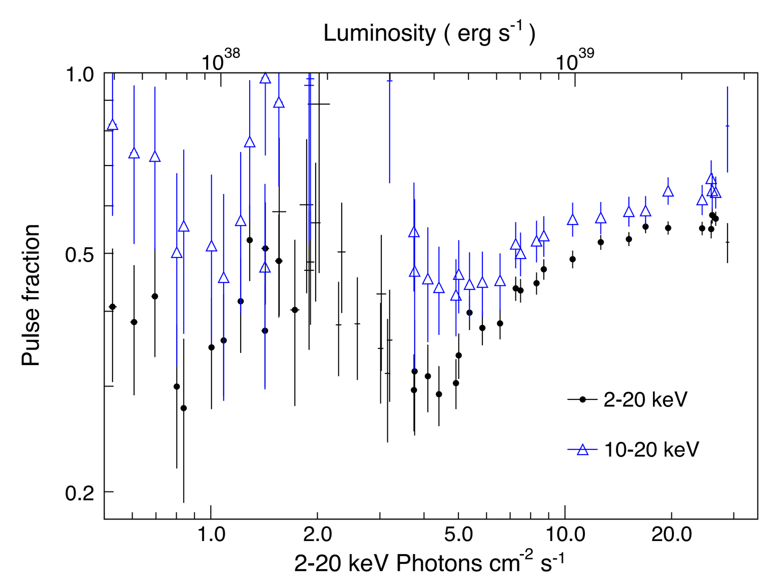


Pulsed fraction f,

$$f = \frac{I_{max} - I_{min}}{I_{min}}$$

against X-ray intensity.

f is larger in the higher energy band.

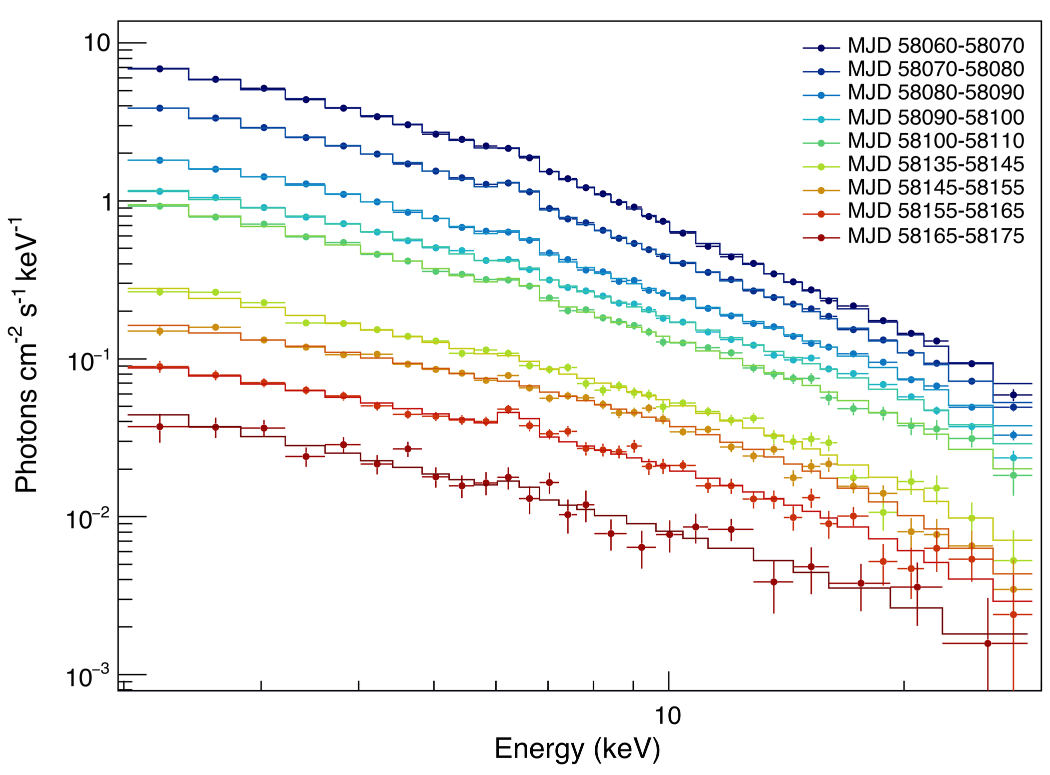


3. X-ray spectra

X-ray spectra were extracted for 10-day intervals from the outburst peak. They fitted well to a model consisting of a cutoff power-law plus a blackbody (BB) and a gaussian for Fe-K line (Gaus),

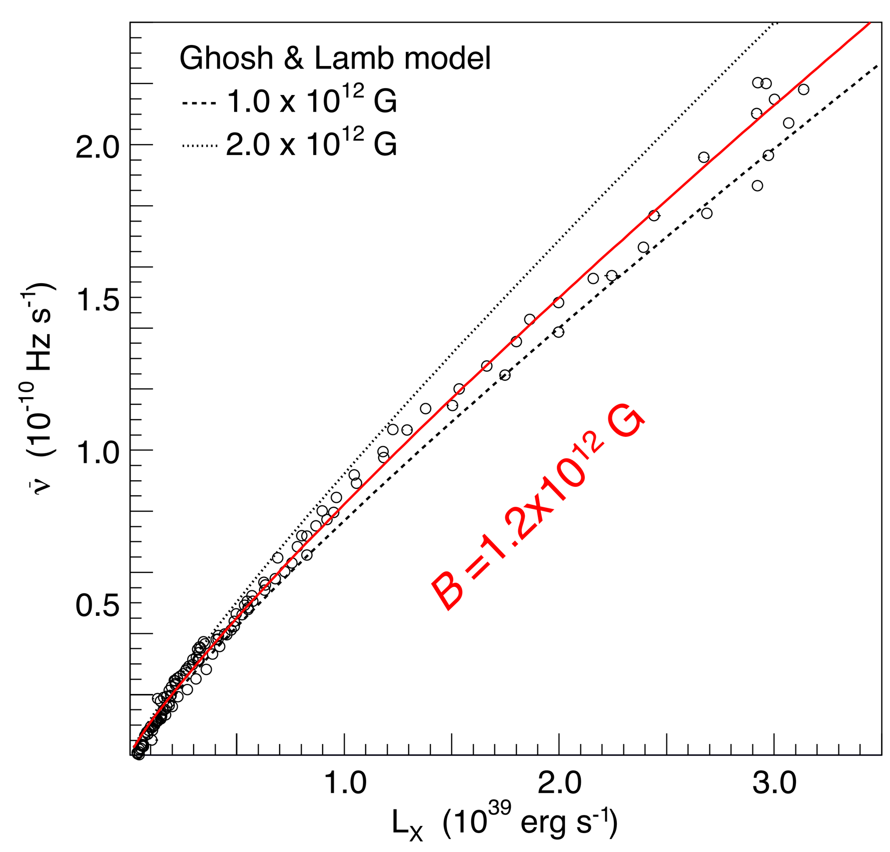
$$F(E) = AE^{-\Gamma} \exp\left(-\frac{E}{E_C}\right) + BB + Gaus,$$

which is typical in X-ray binary pulsars.
The figure shows the unfolded photon spectra. The spectral softening due to the flux increase is seen.



4. Luminisity – spin-up relation

The luminosity – spin-up relation extracted from the MAXI/GSC X-ray light curve, spectra, and the Fermi/GBM pulsar data. The source distance of 7 kpc is employed from the GAIA DR2.
The figure compares the observed relation with those expected from the Ghosh & Lamb 1979 model with the canonical neutron-star (NS) mass (1.4 solar mass), radius (10 km), and the surface magnetic fields B=1x10^{12}, 2x10^{12} G. The best-fit suggest B=1.2x10^{12} G.



5. Summary

Swift J0243.6 is considered as the first Galactic ultra-luminous X-ray pulsar which exhibits the extraordinary large luminosity (>10 L_{EDD}), from the X-ray flux and the source distance determined by GAIA. Using the MAXI GSC monitoring data and the Fermi/GBM pulsar ephemeris, we confirmed and found the following facts,

1. Spectral softening due to the flux increase in the high-luminosity regime above the critical luminosity L_{crit}~ L_{EDD}, as observed by NICER and Fermi/GBM (Wilson+2018)
2. Pulse-profile transition from the single-peak to the double-peak at around the critical luminosity (Tsygankov+2018, Wilson+2018).
3. X-ray spectra represented by a cutoff power-law plus a blackbody and a gaussian for the Fe-K line.
4. The positive correlation between the luminosity and spin-up rate, smoothly extended up to the maximum of ~ 10 L_{EDD}. Assuming the canonical NS mass (1.4 solar mass), radius (10 km), and the Ghosh & Lamb 1979 disk-accretion model, the best-fit function suggests B=1.2x10^{12} G.

As for points 1. and 2, the similar results have been observed in other Galactic XBPs. These behaviors are interpreted as the transition between two mass-accretion regimes dominated by Coulomb collision and radiation, respectively. Although the estimated L_{crit} suggests a possible strong magnetic filed of B~10^{13} G, it requires several assumptions (Tsygankov+2018, Wilson+2018). The points 3. and 4. are typical in XBPs. Thus, the difference to cause the extraordinary large luminosity is still under debate. We consider further detailed data analysis and observations.