Insight-HXMT observations of Swift J0243.6+6214 during its 2017-2018 outburst

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Abstract The newly discovered neutron star transient Swift J0243.6+6124 has been monitored by Insight-HXMT on October 10, 2017. Based on the data of the long term observation of the satellite, we calculate the intrinsic spin frequency with the orbital parameters given by *Fermi*/GBM. The 2-150 keV broad-band spectroscopy of both observations revealed that the best-fit model comprised of a TBabs component and a power law with high energy exponential rolloff along with a blackbody component and two gaussian functions for emission lines. Then we calculated the total flux and pulsed flux by spectrum analysis. We check the relationship between flux and the derivative of frequency, we get the power law index is 1.05 ± 0.017 and 0.83 ± 0.0187 respectively. By assuming the distance is 5 kpc, we obtain the peak value of luminosity around $1.1 \times 10^{39}\, erg\, s^{-1}$, the magnetic field is $4.4 \times 10^{13}\, G$. According to this study, we also find the negative transition point of the derivative of frequency which inferred state-changing in the system.

Introduction After the discovery of an outburst showing up of the transient X-ray source Swift J0243.6+6124 around Oct 3, 2017 a broad band observation campaign has been coordinated to monitor this source. Accordingly, these observations resulted in the detection of a spin period of 9.86 seconds and take into consideration of the classification of the the optical counterpart, it was identified as a Be X-ray binary

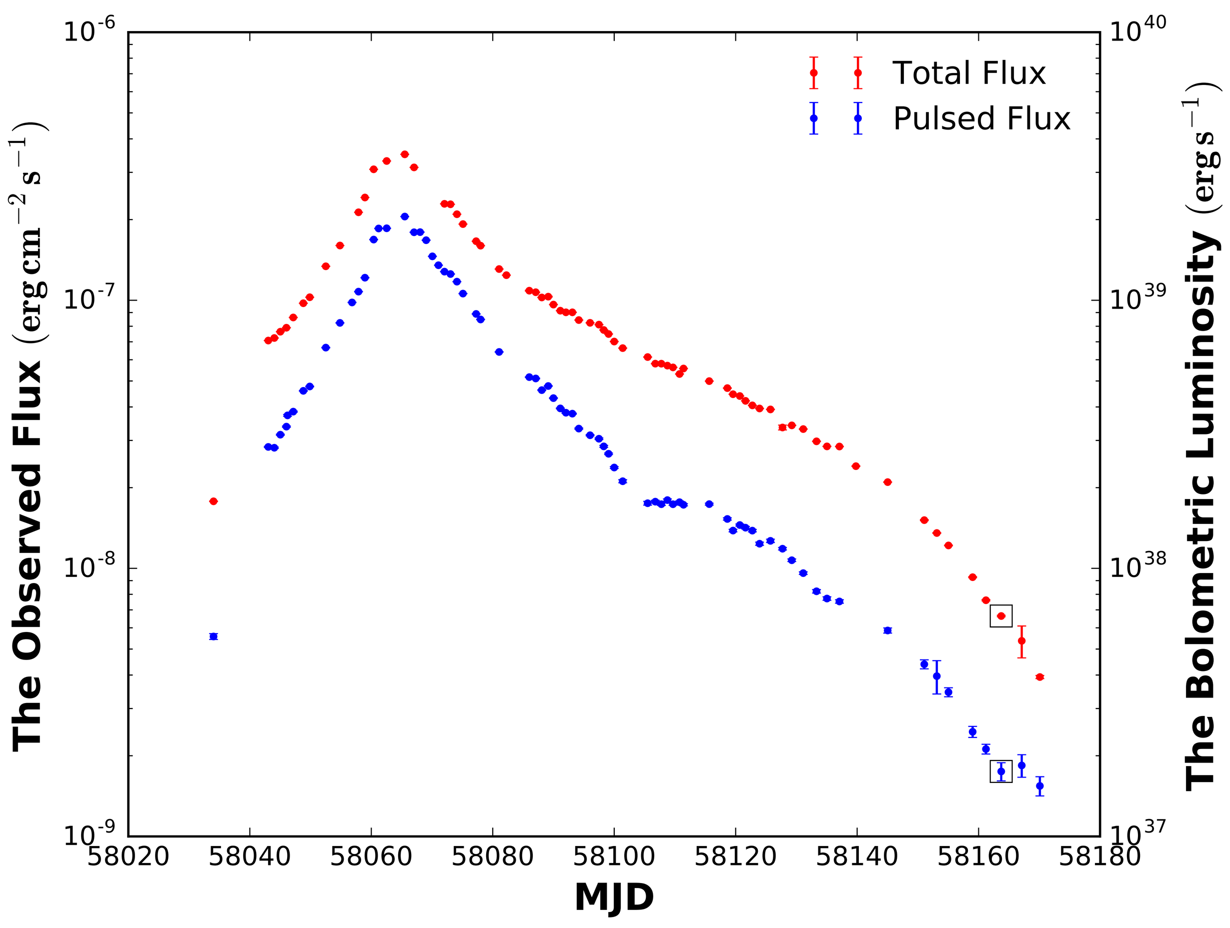

Figure 1: The observed flux and bolometric lumonosity covering from 2 to 150 keV. The red dot shows the total flux and the blue dot shows the pulsed flux each of these was calculated by fitting the spectrum of three payloads of Insight-HXMT simultaneously. And the luminosity was derived by assuming the distance of $5kpc$.

Data Swift J0243.6+6124 was observed by Insight-HXMT which was operated in pointed observation mode starting at 2017 October 7, and each observation about 10ks is scheduled every 1-2 days. To obtain a long term timing variation of the pulsar, we use a large mount of data from MJD 58,033 to MJD 58,112 with net exposure time of ~835 ks.

The data were reduced following standard procedures using the Insight-HXMT data analysis software package HXMTDAS v2.01. X-ray spectral analysis was performed in 2-150 keV range using XPSEC version 12.10.0. And for timing analysis, the arrival time was corrected to Solar System Barycenter(SSB).

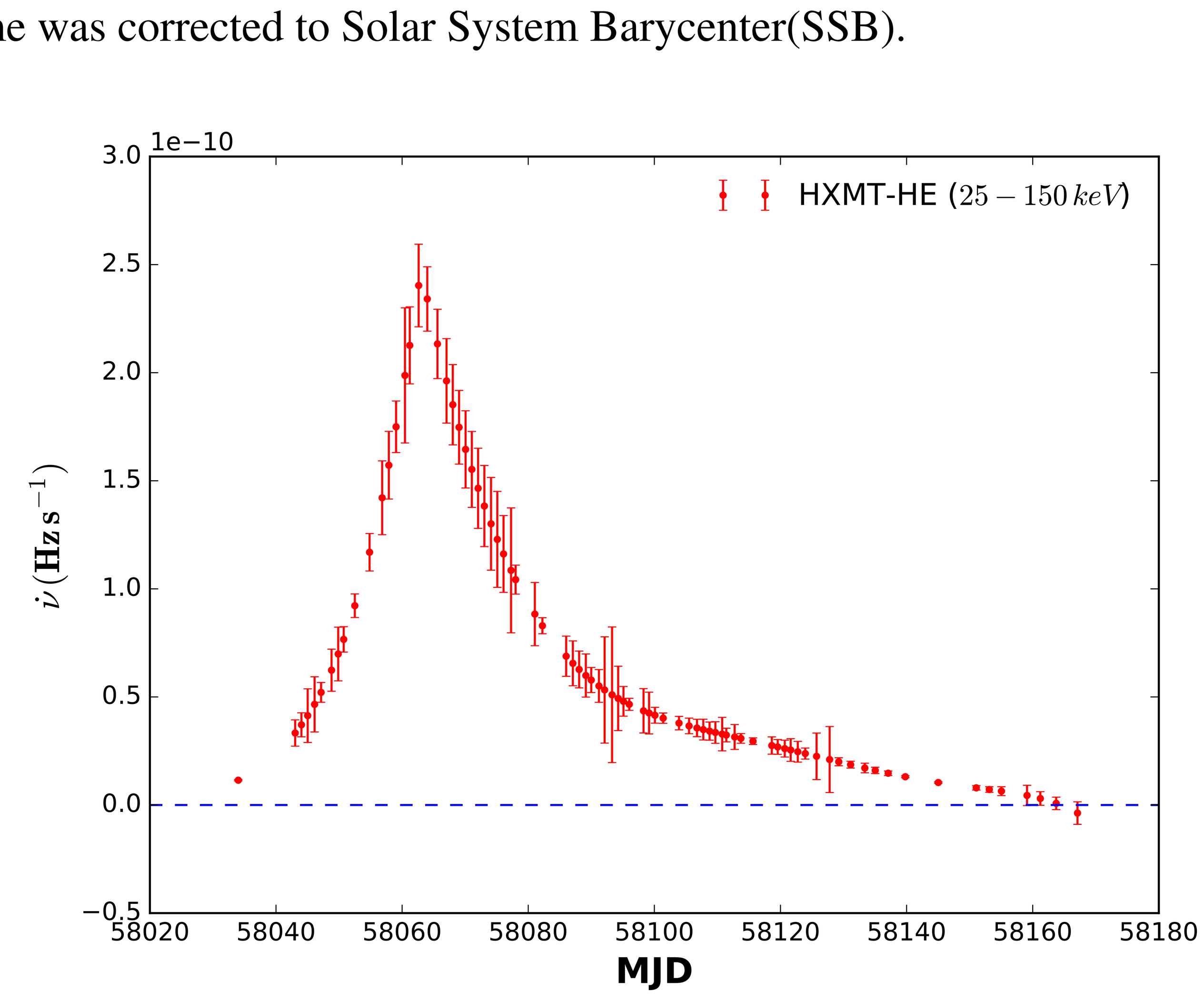

Figure 2: The frequency derivative variance vs time. We search the observed frequency by correcting the arrival time of every events by SSB and consider the Doppler effects of the orbital motion of the binary system by the result of *Fermi*/GBM Pulsar Project .

Results The observed spin frequency was searched in the observed light curves by using the standard maximum Pearsion χ^2 technique. Considering the Doppler effects, we calculate the frequency in the pulsar's rest frame. And then we calculate the spin-up rate from the adjacent observations and present in Fig. 2.

The derivative of the intrinsic frequency is closer to zero at the beginning of the giant outburst. And it goes up rapidly to the maximum value. The decrease brunch of the curve can be divided into three parts. The first parts is decrease quickly and the second is fall slightly, finally become negative values.

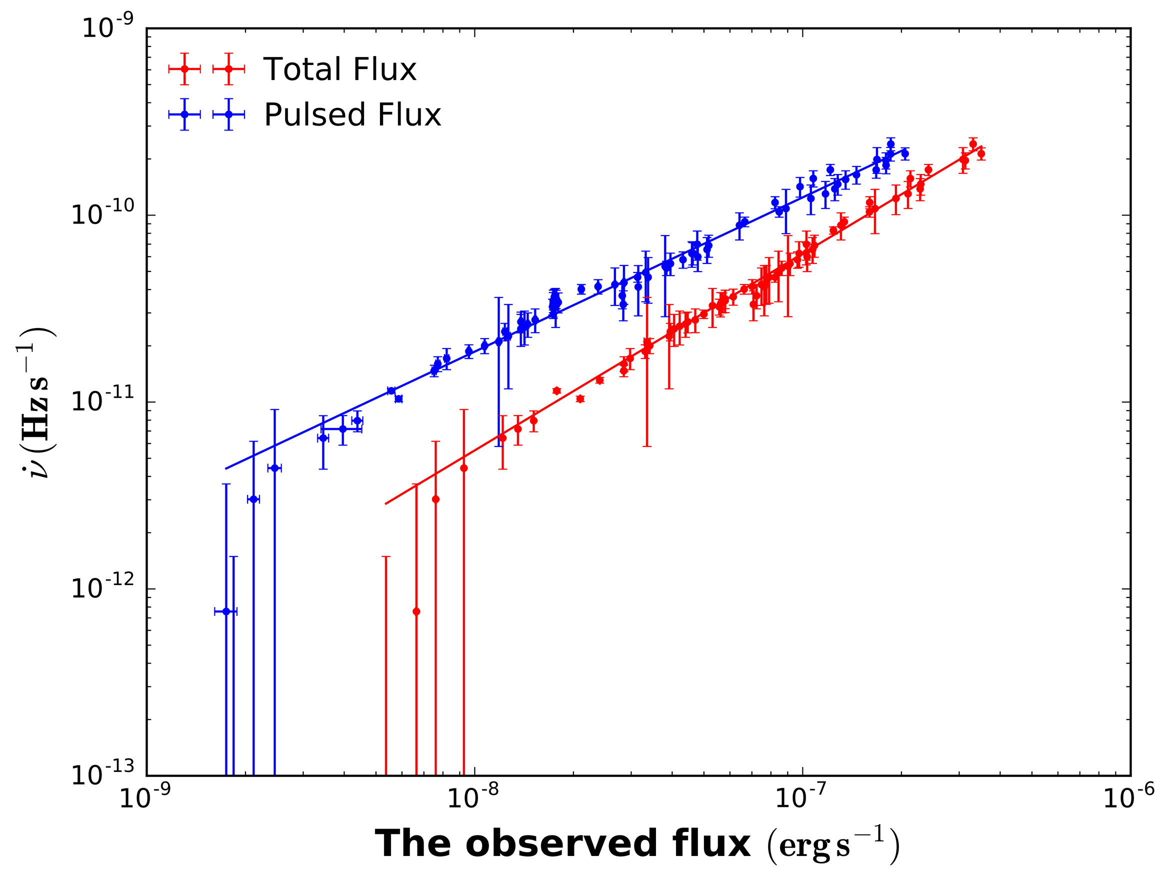

Figure 3: Intrinsic frequency as function of X-ray flux in the 2017-2018 outburst. The data was fitted by $\nu \propto F^{\alpha}$

We find that the derivative of intrinsic frequency is indeed correlated with the observed X-ray flux as presented in Fig. 3. The fitting result shows $\alpha = 1.05 \pm 0.017$.

There are some accretion torque models had been proposed to describe the spin evolution due to the accretion process of a neutron star. The correlation can be presentd by,

$$-\dot{P} = 5.0 \times 10^{-5} \mu_{30}^{\frac{2}{7}} n(\omega_s) R_6^{\frac{6}{7}} M_{NS\odot}^{-\frac{3}{7}} I_{45}^{-1} P_{spin}^2 L_{37}^{\frac{6}{7}} \, (s\, yr^{-1})$$

In the case of Swift J0243.6+6124, we apply $n(\omega_s) \approx 1.4$, because of the slow rotation around $10s$. Meanwhile, we use standard neutron star mass $M_{NS} = 1.4 M_{sum}$ and radius $R_6 = 1$, and then we can get $I_{45} = \frac{2}{5} M_{NS} R_6^2 = 1$, the magnetic moment μ_{30} is calculated as $\mu_{30} = \frac{1}{2} B_{12} R_6^3$. By applying the location of the source is $5\, kpc$ and using the total flux of the source, the maximum value of B_{12} is 4.4×10^1, the maximum luminosity $1.1 \times 10^{39}\, erg\, s^{-1}$. If the pulsed flux is applied and the distance is $10kpc$, the magnetic field B_{12} is 6.4, the luminosity is $2.5 \times 10^{39}\, erg\, s^{-1}$.

In the end part of the giant outburst, the frequency derivative value underwent a transition from positive to negative (the squre shapes in Fig. 2.). It infer that the neutron star reached the equilibrium period and the system start transition to propeller state, meanwhile the neutron star begun throw out the accretion matter in the inner radius of the disk.

Conclusion We analyzed the Insight-HXMT data of Be X-ray pulsar Swift J0243.6+6124 during the during the 2017-2018 outburst. The X-ray luminosity reaches a peak value more than $2.6 \times 10^{38}\, erg\, s^{-1}$ (in $2 - 150\, keV$, $D = 2.5\, kpc$) around MJD58065, that is a few times of NS Eddington luminosity.

We find the state-changing in the end of the outburst, it implies the rotation state of neutron start from spin-up to spin-down, it can be explain by the occurring of propeller effect. And the momentum of neutron star was took away by throwing away the accretion matter in the boundary of magnetic atmosphere.

According to the accretion torque theory, we would expect the spin-up rate increases with the accretion rate ($\dot{\nu} \propto L^{6/7}$). The power law index is $\alpha = 1.05 \pm 0.017$ for total flux and 0.83 ± 0.0187 for pulsed flux. However, the former fitted power-law index is generally greater than the prediction of 6/7 meanwhile the latter index is more close to 6/7. It infer that the accretion torque theory is suitble for the neutron star itself not for the whole binary system.

We also noticed that the magnetic field value will undergoing a drastic change when the estimate value of distance from 2.5 kpc to 5kpc. In fact, when the distance is 2.5 kpc, the magnetic field is $2.6 \times 10^{16}\, G$, when D is 5kpc, B is $4.1 \times 10^{14}\, G$, furthermore, when D is 10 kpc, B is $3.6 \times 10^{13}\, G$. It is so important that fix the distance because the enormous gap of the values of magnetic field derived from variance distance implies different physical characters.