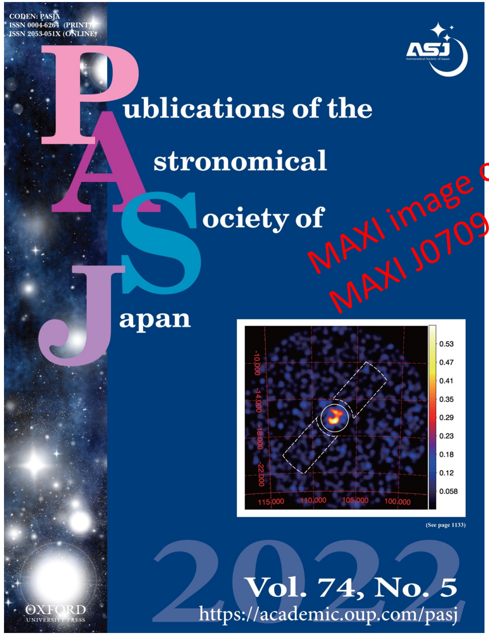
Fast X-ray variability of a new HMXB MAXI J0709-159 / LY CMa observed by MAXI and NICER

MAXI part
Sugizaki+2022, PASJ, Vol.74, 1131

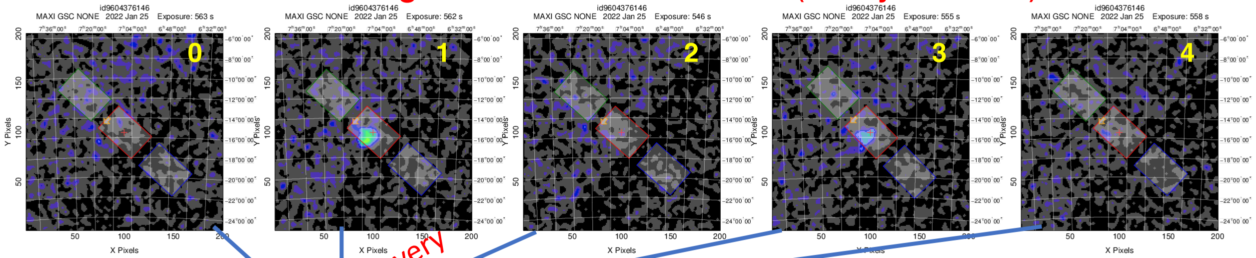


Mutsumi Sugizaki (NAOC)

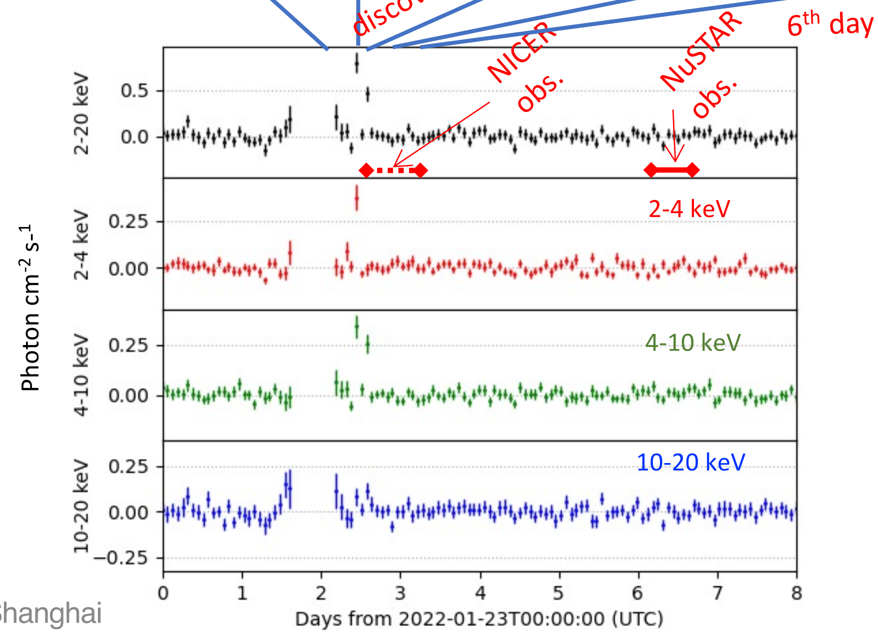
MAXI team, MAXI-NICER collaboration (RIKEN, …)

MAXI J0709-159: Galactic fast X-ray transient

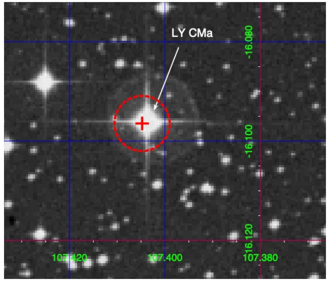
MAXI/GSC 2-20 keV image of each source scan (every 90 min.)



(MS+2022)

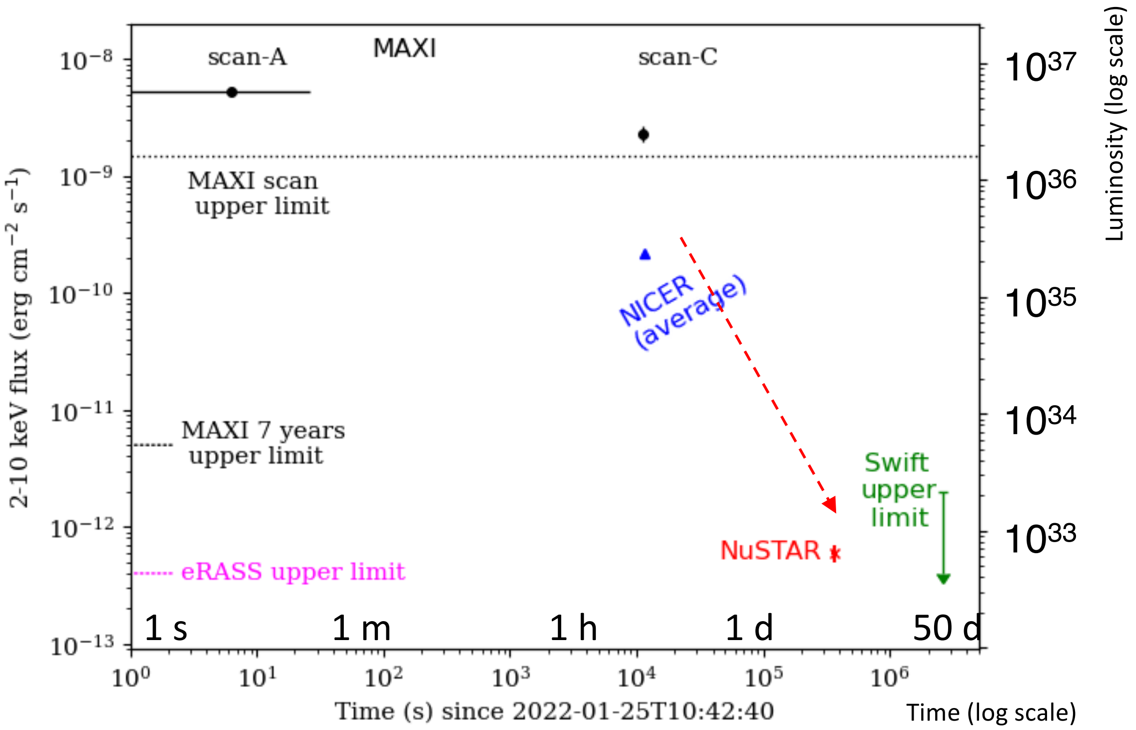


- MAXI/GSC discovered a new transient on 2022 Jan. 25. The significant signals were detected only at the 1st and 3rd scans.The 3rd scan was only in > 4 keV.
- By NICER and NuSTAR follow-up observations, optical countarpart, LY CMa (Be star) at 3 kpc was identified.



DSS optical image
Nustar error circle

Light curve for long-term (~50 days) activity



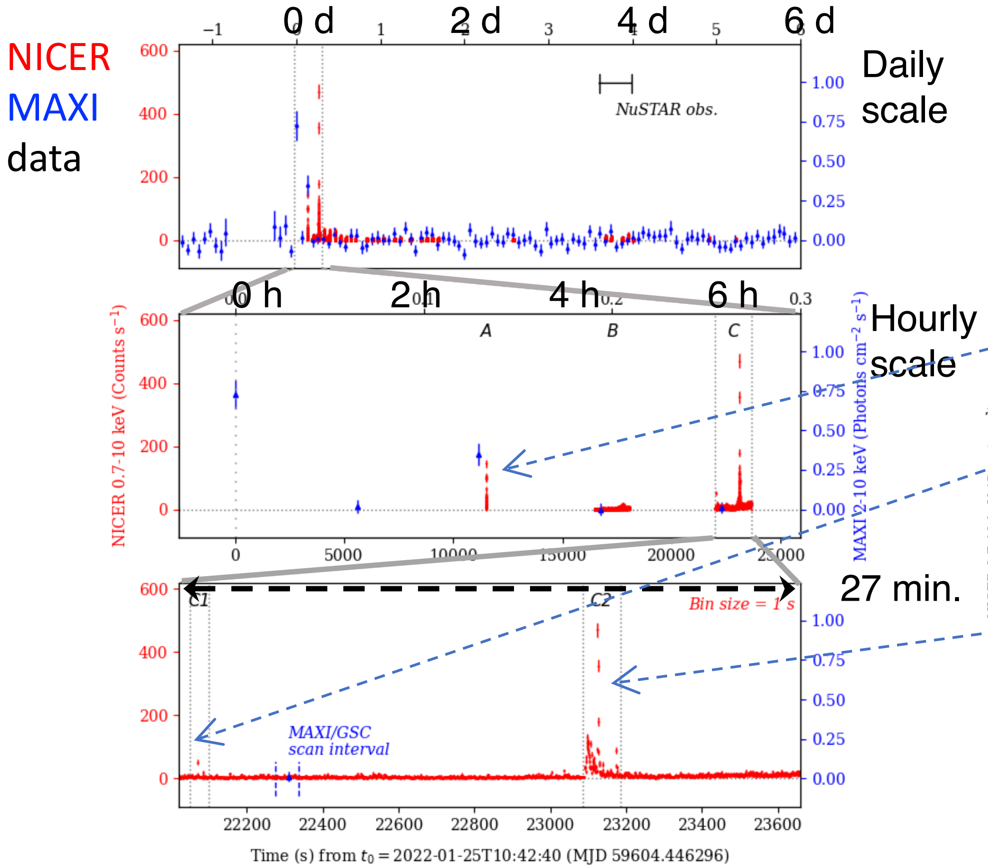
(MS+2022)

X-ray activity for 50 days by MAXI/GSC, NICER, NuSTAR, Swift

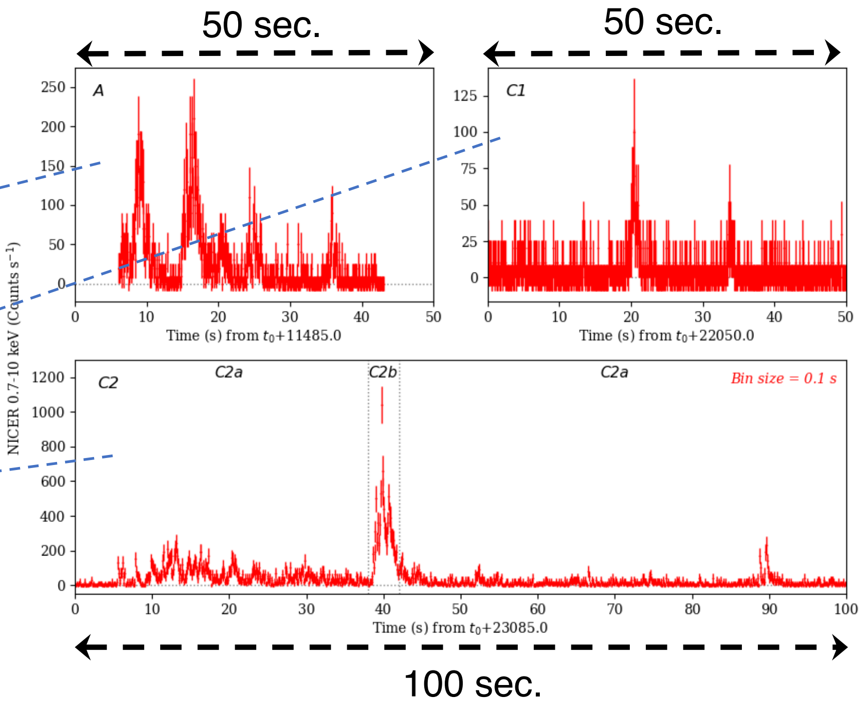
Past activity upper limit by MAXI/GSC, eROSITA

- Outburst ended only in ~6 hours.
- A new Suergiant Fast X-ray Transient (SFXT) ?

NICER Light curve 3 to 6 hours after discovery

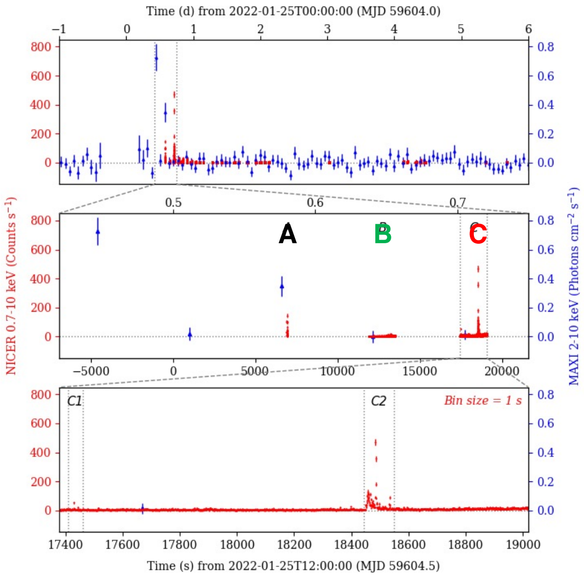


- Sporadic flares, ~3 bright flare in 6 hours
- *Lx* ~ 10^{36}-10^{37} erg s^{-1} at peak
- Flare duration < 100 sec each

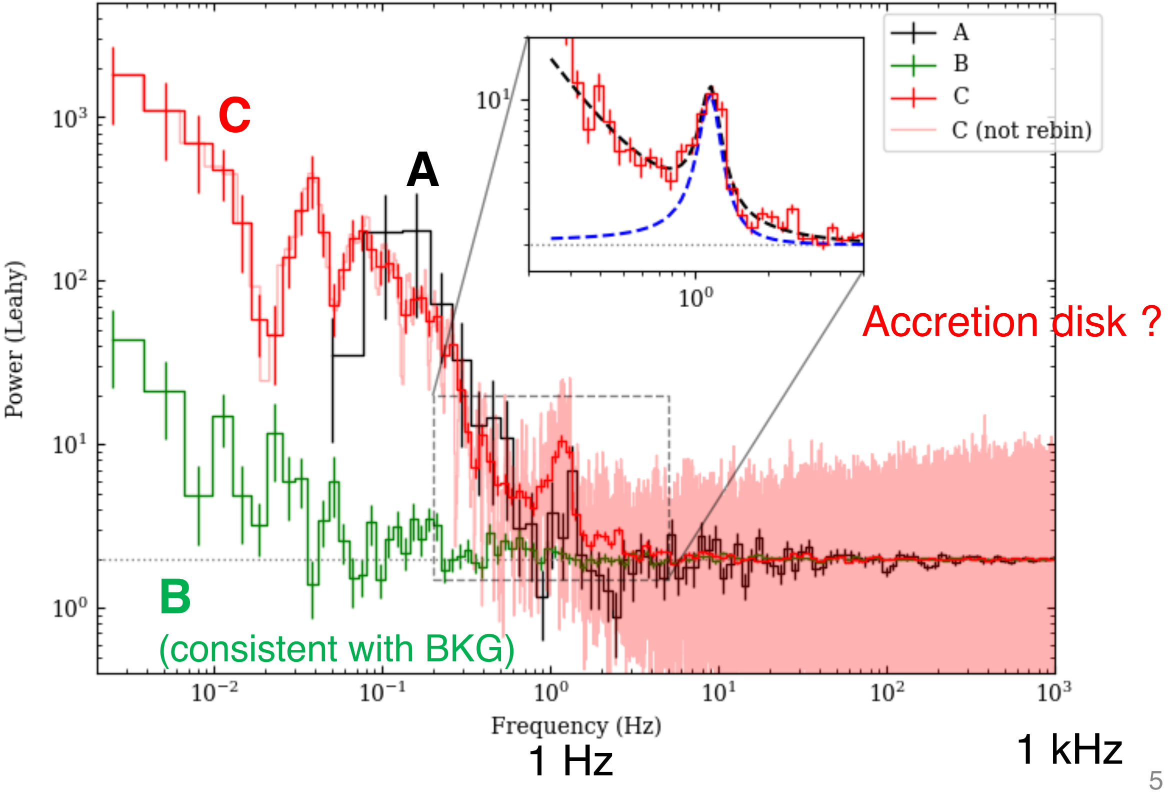


Variability power density spectrum (PDS)

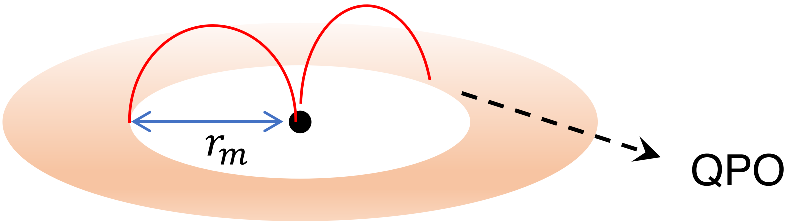
NICER observation
3 good time intervals **A** **B** **C**



QPO-like feature in GTI-C
Lorentzian $\nu_0 = 1.15\ \mathrm{Hz}$ $\Delta = 0.11\ \mathrm{Hz}$ $(Q \sim 5)$



Quasi-Periodic Oscillation (QPO) in HMXB pulsrs



Magnetoshere (Alfven) radius

$$r_m = 2.7\times10^8 \left(\frac{\zeta}{1.0}\right)\left(\frac{M_{NS}}{1.4M_\odot}\right)^{1/7}\left(\frac{R_{NS}}{10\ \mathrm{km}}\right)^{10/7}\left(\frac{B_s}{10^{12}\ \mathrm{G}}\right)^{4/7}\left(\frac{L_X}{10^{37}\ \mathrm{erg\ s^{-1}}}\right)^{-2/7}\ \mathrm{cm}$$

Orbital radius at Kerplerian frequecy ν_K

$$r_K = 1.7\times10^8 \left(\frac{M_{NS}}{1.4M_\odot}\right)^{1/3}\left(\frac{\nu_K}{1\ \mathrm{Hz}}\right)^{1/3}\ \mathrm{cm}$$

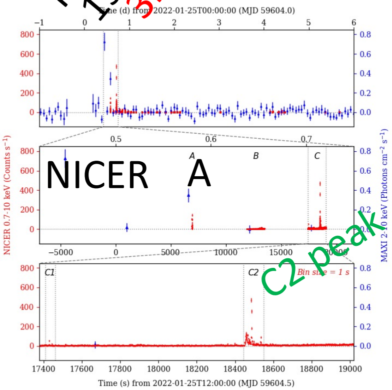
Assuming $r_m = r_K$, $\nu_K = \nu_{\mathrm{QPO}}$ (Keplerian frequency model)

$$B_s = 0.4\times10^{12} \left(\frac{\zeta}{1.0}\right)^{-7/4}\left(\frac{M_{NS}}{1.4M_\odot}\right)^{1/3}\left(\frac{R_{NS}}{10\ \mathrm{km}}\right)^{1/2}\left(\frac{L_X}{10^{37}\ \mathrm{erg\ s^{-1}}}\right)^{1/2}\left(\frac{\nu_K}{1\ \mathrm{Hz}}\right)^{-7/6}\ \mathrm{G}$$

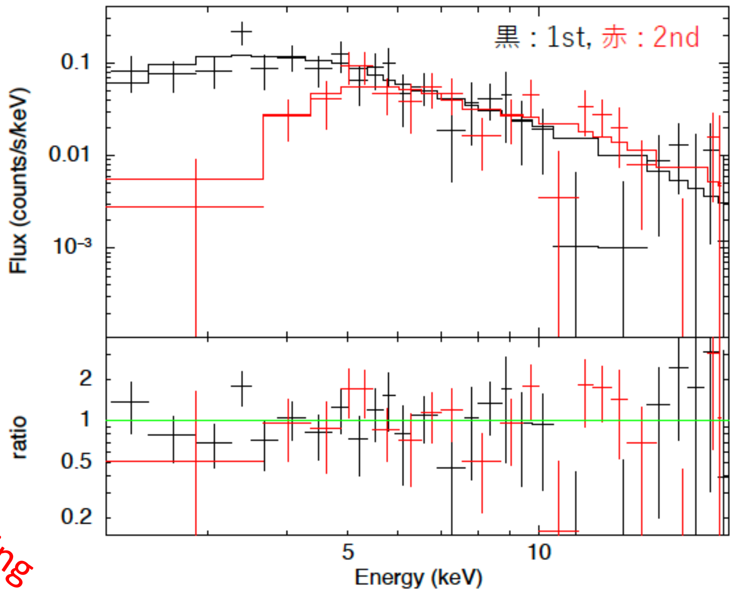
$\sim 0.4\times10^{12}$ G (spherical accertion) $\sim 2\times10^{12}$ G (disk accretion)

X-ray spectrum

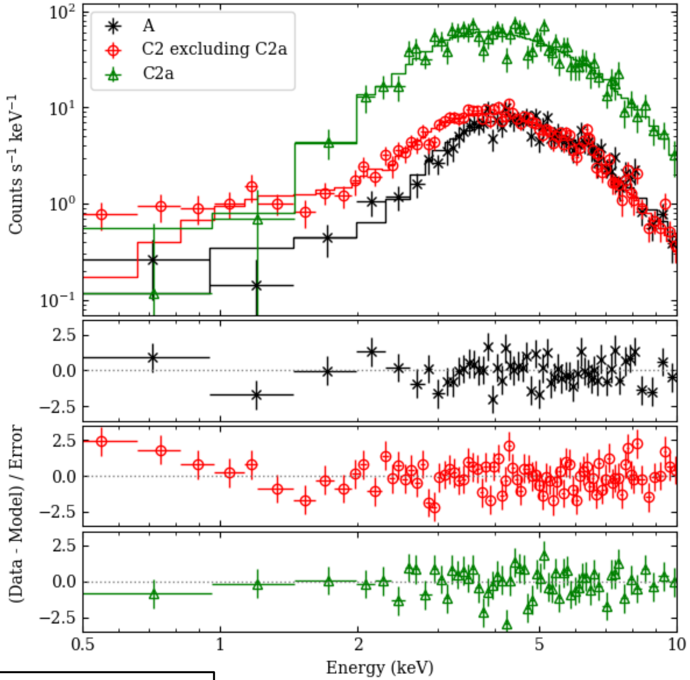
MAXI 1st scan 3rd scan



MAXI/GSC 2-20 keV
1st and 3rd scans (MS+2022)



NICER 0.5-10 keV
A, C2 ex peak, and C2 peak



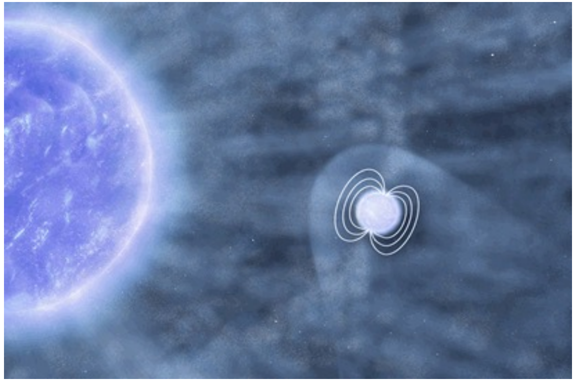
Model: (ISM + CSM absorption) * (power law + iron-K line)
Photon index $\Gamma \sim 2(\pm 1)$
CSM absorptino $N_{\mathrm{H}} \sim 10^{22} - 10^{23}$ cm^{-2} changed with time

Typical X-ray spectrum of HMXBs

What kind of HMXB is MAXI J0709-159 ?

- Observed features
  - Short duration (< 6 hours) activity
  - Sporadic flares (3 bright ones in 6 hours)
  - Rapid (<1 sec) variability
  - Luminosity reaching ~ 1×10^{37} erg s^{-1} at peak
  - Power-law ($\Gamma\sim2$) spectrum with CSM absorption N_H changing ~ 10^{22} – 10^{23} cm^{-2} with time

  Similar to SFXT rather then Be binary



(Figure from Bozzo+2011)

- What is the compact object?

  Probably, magnetized NS.

- Where does the fast variability ~1 Hz come from?

  If it is Keplerian rotatoion period at the NS magnetoshere radius, B~10^{12} G

Problems

- Why is it so different from classical HMXB (pulsars)?
- Spin period?
- (Orbital period?)

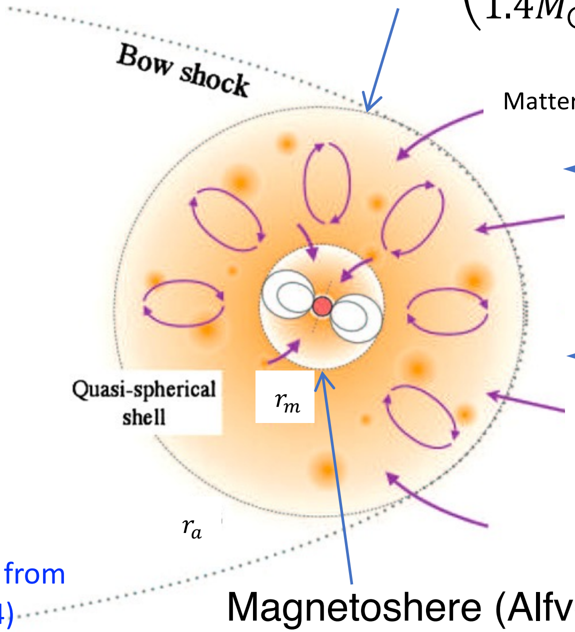
Back up

Clumpy wind-accretion scenario

Accretion (Bondi) radius

$$r_a = 3.7\times10^{10}\left(\frac{M_{NS}}{1.4M_\odot}\right)\left(\frac{v_w}{10^8\ \mathrm{cm\ s^{-1}}}\right)^{-2}\ \mathrm{cm}$$

Wind velocity
$v_w = 10^8\ \mathrm{cm\ s^{-1}}$



(Illustration from Enoto+2014)

Clump scale from $t_{outburst} = 10^4$ s

$$r_{cl} = 10^{12}\left(\frac{v_w}{10^8\ \mathrm{cm\ s^{-1}}}\right)\left(\frac{t_{outburst}}{10^4\ \mathrm{s}}\right)\ \mathrm{cm}$$

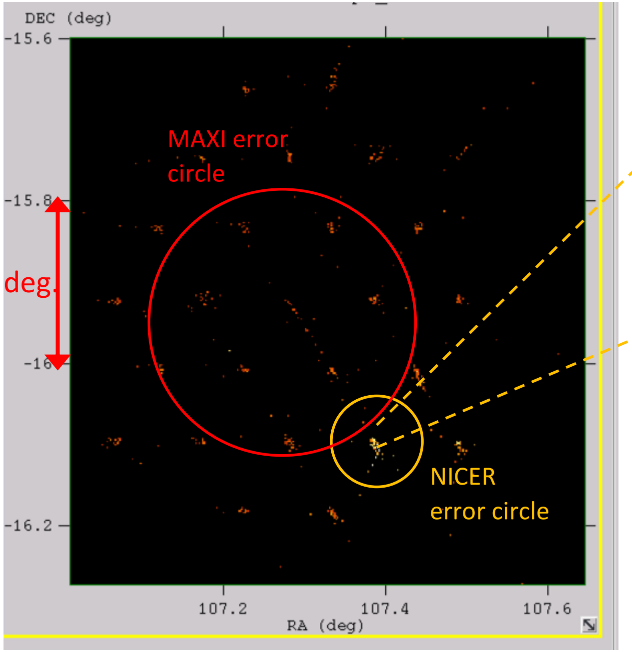
Clump column density N_H estimated from the integrated luminosity = accreted mass, clump radius, accretion radius is roughly consistent with observed $N_H \sim 10^{23}\ \mathrm{cm^{-2}}$.

Magnetoshere (Alfven) radius from QPO 1 kHz

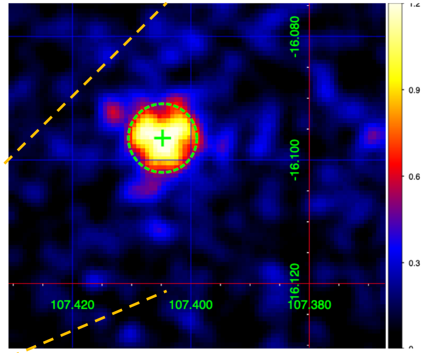
$$r_m = 2.7\times10^{8}\left(\frac{\zeta}{1.0}\right)\left(\frac{M_{NS}}{1.4M_\odot}\right)^{1/7}\left(\frac{R_{NS}}{10\ \mathrm{km}}\right)^{10/7}\left(\frac{B_s}{10^{12}\ \mathrm{G}}\right)^{4/7}\left(\frac{L_X}{10^{37}\ \mathrm{erg\ s^{-1}}}\right)^{-2/7}\ \mathrm{cm}$$

NICER NuSTAR follow-ups and optical identication

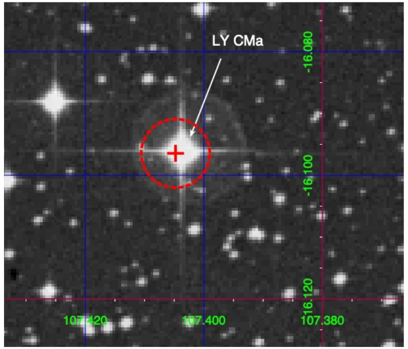
NICER raster scan of MAXI error circle (ATEL#15181)



NuSTAR observation (ATEL#15193)



The source flux observed by NuSTAR was 6x10^{-13} erg s^{-1}, ~10^{-4} of the flaring periods that MAXI observed.



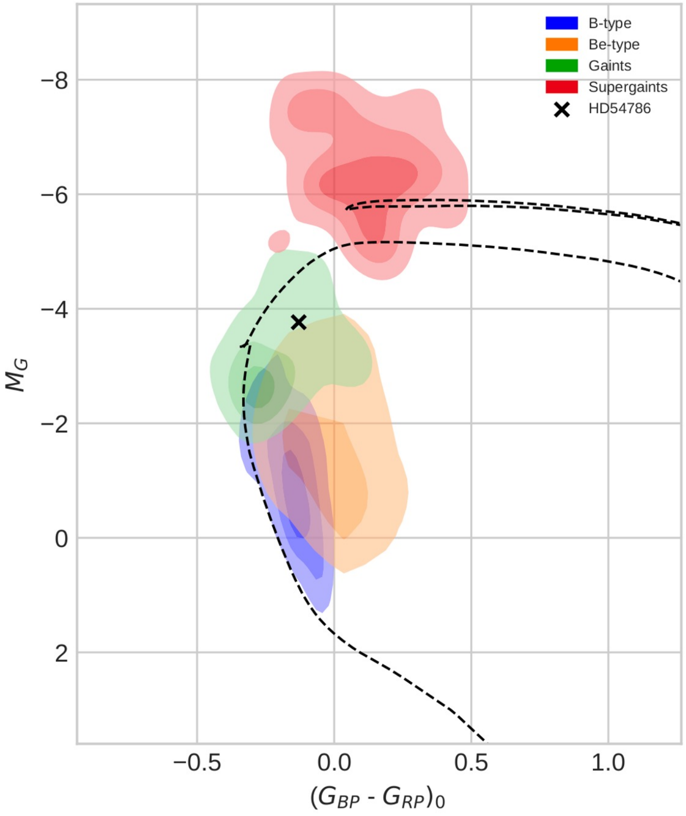
DSS optical image

- Identified as Be star, LY CMa
- Distance: 3.2 kpc (Gaia DR3)

(MS+2022)

Optical color-magnitude diagram

(Bhattacharyya+2022)



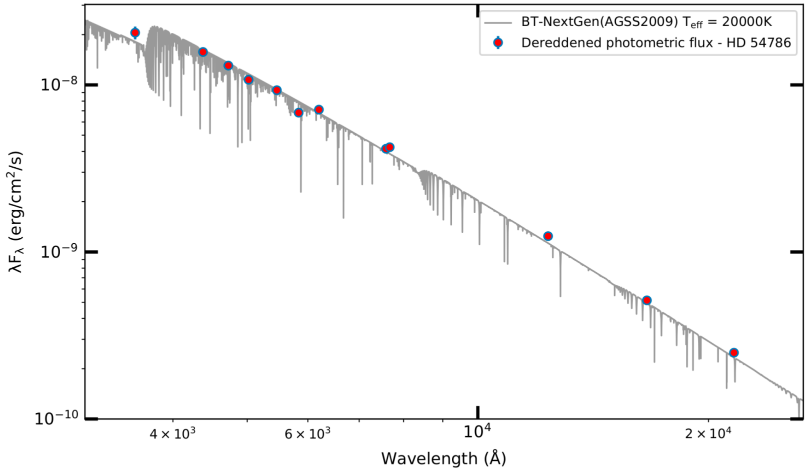


Figure 2. Panel (a): The Gaia CMD of HD 54786 having absolute Gaia G and color corrected (BP-RP) magnitudes available from Gaia Collaboration et al. (2021). The probability distribution (Gaussian fitted at three contour levels) of the B, Be stars, Giants and supergiants are shown in blue, orange, green and red shaded colors, respectively. The black dashed line in the plot represents the isochrone of 60 Myr with V/Vcrit = 0.4 and [Fe/H] = 0 (The top black dashed line is the blue loop part of the same isochrone). Panel (b): In the SED, the flux values of the star HD 54786 is fitted with the theoretical BT-NextGEN(ASGG2009) model at Teff = 20000 K and log(g) = 3, using the chi-squared minimization method.

Optical H-alpha line

(MS+2022)

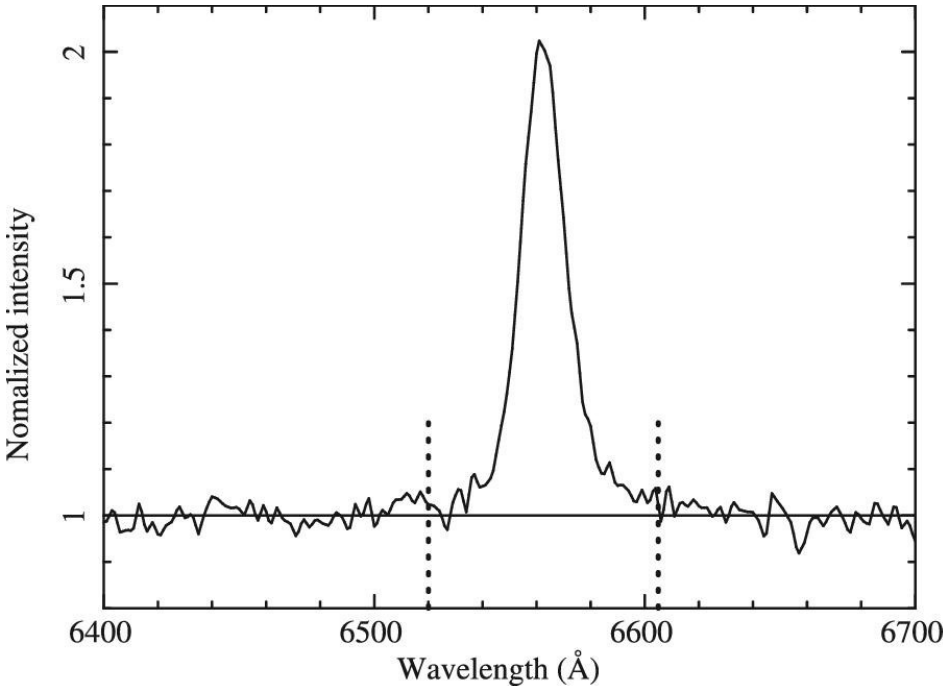


Fig. 9. Optical spectrum of LY CMa obtained by SCAT around the Hα emission line. The intensity scale is normalized by ...

Hardness-intensity diagram