Roman CCS White Paper

Title Search for faint Cataclysmic Variables at Galactic Bulge

Roman Core Community Survey: *Galactic Bulge Time Domain Survey*

Scientific Categories: *Choose from (descriptions can be found here): stellar physics and stellar types; stellar populations and the interstellar medium*

Additional scientific keywords: *Suggestions for each of the above categories can be found here.*
White dwarf stars, Variable stars

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The Galactic Diffuse X-ray Emission (GDXE; Figure 1, which is apparently diffuse X-ray emission of a low surface brightness along the Galactic Plane in |ℓ|< 45° and |b|<1.5°, has been known since the 1980s (e.g. Worrall et al. 1982). The X-ray emission of the GDXE has an integrated luminosity of $\sim 1\times10^{38}$ erg s^{-1} in the 2-10 keV (Koyama et al. 1986; Valinia & Marshall 1998) and its X-ray spectrum is described by two-temperature thermal plasma (～1 and 5 - 10 keV) and also exhibits Fe K emission lines (e.g. Koyama et al. 1996; Yamauchi et al. 2009, Ebisawa et al., 2005); neutral and/or low ionization state line at 6.4 keV (FeI) as well as highly-ionized iron lines at 6.7 (FeXXV) and 7.0 keV (FeXXVI).

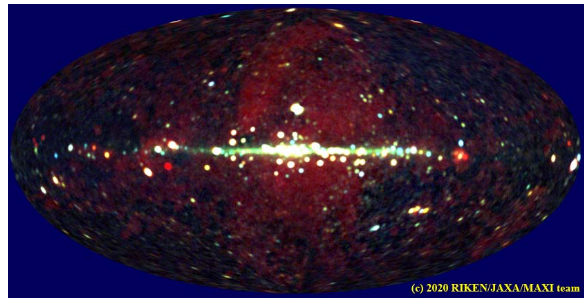

Figure 1 All-sky X-ray image obtained with the Gas Slit Camera (GSC) and Solid-state Slit Camera (SSC) on the Monitor of All-sky X-ray Image (MAXI) in 0.7-1 keV (SSC) and 2-4 keV (GSC) in red, 4-8 keV in green, and 8-16 keV in blue from 2009 to 2020 in Galactic coordinate. Among 1000 bright sources along the Galactic plane, the extended X-ray emission is recognized that is the GXDE.

From these features, the origin of the GDXE has been considered whether truly diffuse emission of a low surface brightness along the Galactic plane or composed of faint unresolved X-ray point sources. Among various X-ray observations carried out, Chandra X-ray Observatory resolved ～88% of the GDXE at the Galactic bulge (ℓ = 0.08°,b = −1.42°) around the Fe K band into faint X-ray point sources down to a flux of 10^{-16} erg cm^{-2} s^{-1} at 2 – 10 keV with the deepest X-ray observation (Revnivtsev et al., 2009). This revealed that the GDXE at Galactic bulge is primarily summed from faint X-ray sources. Several candidates for such sources include magnetic Cataclysmic Variables (CVs; e.g., Yuasa et al. 2012; Hong 2012) and X-ray active stars (e.g. Revnivtsev et al. 2006). More recently, non-magnetic CVs should also be a major population (e.g., Nobukawa et al. 2016, Xu, Wand, and Li 2016). However, it is difficult to constrain the nature of these individual point sources from X-ray data alone due to a lack of X-ray photons (less than 10 photons detected for each source even with the deepest observation).

Then, follow-up observations with longer wavelengths are needed to avoid large extinction toward the Galactic plane. Near-infrared (NIR) observations are more suited than optical observations that can only access CVs within ～2 kpc (Motch et al. 2010). NIR imaging and spectroscopy observations have been carried out for X-ray sources detected on the Galactic plane with Chandra and XMM-Newton (e.g., Laycook et al., 2005, Mauerhan et al., 2009, Morihana et al., 2012), which have a large amount of data at the Galactic plane because they have been operated for more than 20 years. From the follow-up observations, the nature of some of the point sources was revealed individually, which are magnetic-CVs, non-magnetic CVs with high accretion rates, and non-magnetic CVs with low accretion rates (Morihana et al., 2016, 2022). However, the spatial density of CVs estimated from X-ray spectra of the GDXE spectrum, which needs ～10^{-4} - 10^{-5}/pc^{-3} (Yamauchi et al. 2009, Yamamoto et al., 2023), is larger than the theoretically predicted value (e.g., 10^{-6} pc^{-3}; Patterson et al., 1998) and estimated value (3.4×10^{-5}/pc^{-3}; Warwick 2014) from the solar neighborhood. The population evolution model also predicts that most white dwarf binaries will be faint with a low accretion rate (e.g., Howell et al., 2001). Therefore, there are still undiscovered CVs hidden on the Galactic plane.

The time variability of CVs is very useful to detect these hidden CVs. The accretion of most CVs occurs via an accretion disk around white dwarfs. For dwarf nova, this accretion disk is thermally unstable, resulting in a quasi-periodic, large-amplitude outburst with a magnitude increase of 2-6 mag over a period as short as a day, which is known as a dwarf nova outburst (e.g., Meyer & Meyer-Hofmeister 1981; Osaki 1989). The outburst interval varies from system to system and depends on the accretion rate and the disk size, for example, some types of dwarf nova such as ER-UMa type outburst every few days, while the other type of dwarf nova such as WZ-Sge type outburst after several decades of quiescence. In addition to this, most CVs are variable, even if they do not show dwarf nova outbursts.

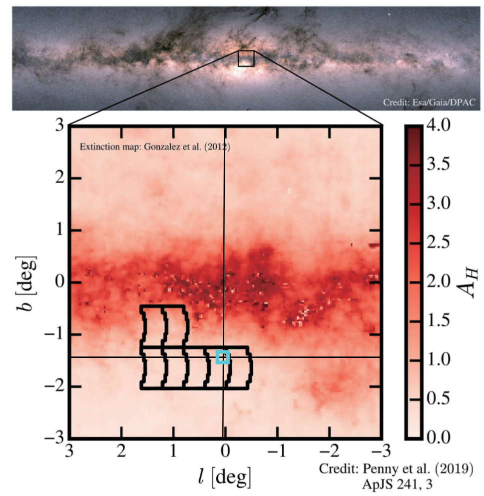

Figure 2 Placement of the Galactic Bulge Time Domain Survey. (Upper image) The inner half of our galaxy in false color with the Galactic Bulge at the center. (Lower image) Seven Galactic Bulge Time Domain fields (black comb-shaped) and the deepest X-ray observation region by Revnivtsev et al. (2009) at the Galactic bulge (cyan box). The background image shows a combination of high stellar density and comparatively low dust extinction.

Moreover, the orbital period, which can obtain from the variability of CVs, is key to understand the evolutionary state of CVs. The orbital period of CVs generally decreases with the evolution from long periods of several hours to short periods (～80 minutes). When the thermal timescale of the companion star exceeds the time required for mass loss, it cannot contract fast enough to maintain thermal equilibrium, and the binary orbit expands to accommodate the star, and the orbital period increases again (e.g., Kolb & Baraffe 19). As the binary system evolves to the period minimum, the mass accretion rate becomes smaller, and brightness goes to be fainter in evolution.

Thus, it is difficult to discover these CVs with short orbital periods and short outburst intervals. Roman Space Telescope is ideal to discover these CVs using time variability because it observes the Galactic bulge region with the FS146 filter at 15-minute intervals. Most of the regions planned to observe by Roman's Galactic Bulge Time Domain have been observed by the Chandra, which has been in operation for more than 20 years, and a huge amount of X-ray data has been accumulated. Especially, since the Chandra Bulge field (Figure 2: cyan box) is the longest X-ray observation (～1Ms) of the GDXE by Chandra and detected thousands of X-ray faint point sources, this region is very useful to search CVs.

We plan to carry out the following steps. First, we select candidate sources of CVs based on X-ray hardness using the X-ray archival data of Chandra. Second, we identify candidate sources with F146 data from Roman Space Telescope and make light curves. Third, we classify sources using the power spectra. If the source is CVs, the power spectrum is considered to have the power of the orbital period plus 1/f fluctuation. On the other hand, a flare star with the same time variability is also possible, but this one is expected to have a flat power spectrum. This allows us to distinguish between CVs and flare stars.