X-ray Characteristics of Ordinary and Extraordinary Cataclysmic Variables

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INTRODUCTION: Cataclysmic variables (CVs), in which a white dwarf accretes from a Roche-lobe filling mass donor on or near the main sequence, are an important minority population of X-ray sources throughout the X-ray band. Observations of CVs show that there is still much we do not yet know about the physics of accretion disks, particularly at low accretion rate, and some of the key clues come from X-ray observations. There is also an emerging consensus that CVs are a major contributor to the apparently diffuse X-ray emission from the Galactic bulge and ridge. Past X-ray studies of CVs have been biased towards magnetic CVs, which make up 10–20% of all CVs and are X-ray luminous (10^{31}–10^{33} ergs s^{-1}). However, the majority of CVs are non-magnetic, and those with low (10^{29} ergs s^{-1}) X-ray luminosities may be the most numerous. On the other end of the extreme, there may be a rare subpopulation of CVs with high X-ray luminoisities ($\sim 10^{34}$ ergs s^{-1}). Because they are rare, they are only found several kpc away, often in crowded field. The spatial resolution of *Chandra* can play a key role in establishing the X-ray luinosity function (XLF) of CVs over 5 or more orders of magnitudes in luminosity.

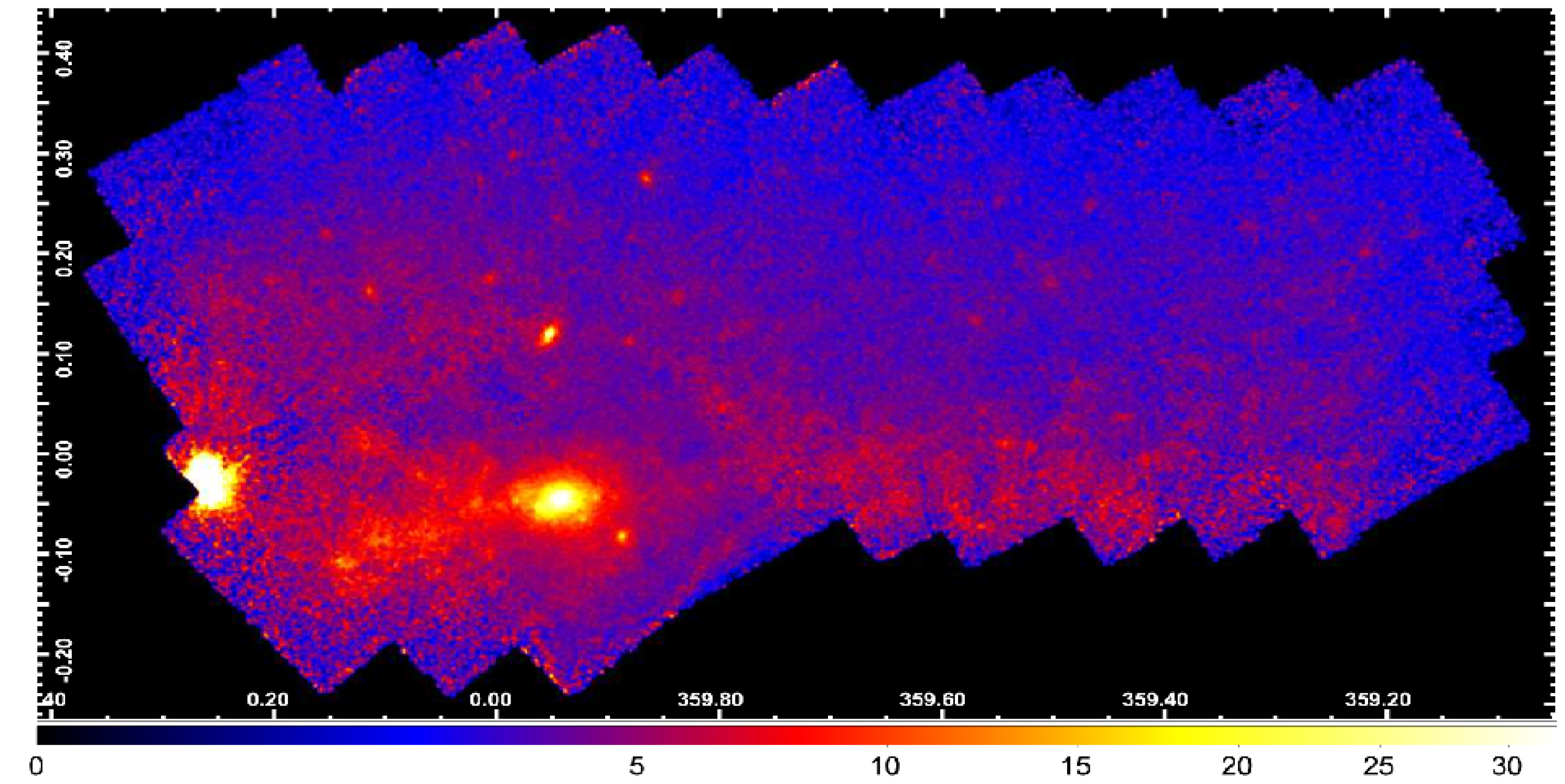


Figure 3 Exposure corrected *NuSTAR* image of the Galactic Center region in the 10–40 keV range; are the hard X-ray emission due to a collection of CVs? (Figure 2 of Hong et al. 2016, ApJ 825, A132

Ordinary CVs

The majority of CVs are dwarf novae, non-magnetic systems in which the accretion rate through the disk is usually low, with occasional outbursts. Well known dwarf novae have typical X-ray luminosities in the 10^{30}–10^{32} range (Figure 1), but this is subject to severe selection effect. We expect that *eRosita* and *Gaia* combined will likely revolutionize our understanding of the XLF of CVs at these luminosities. However, the dominant population of CVs may well be the lowest accretion rate dwarf novae with rare (once per several decades) outbursts. They are X-ray faint ($< 10^{30}$ ergs s^{-1}; Reis et al. 2013, MNRAS, 430, 1994). At the faint end, the point source sensitivity of *Chandra* can play a key role, considering that 10^{29} ergs s^{-1} at 100 pc corresponds to $< 10^{-13}$ ergs cm^{-2}s^{-1}.

Figure 2 The cumulative source distribution (histogram) and the possible power-law X-ray luminosity function of non-magnetic CVs in the solar neighborhood (Figure 6 of Byckling et al. 2010, MNRAS, 408, 2298)

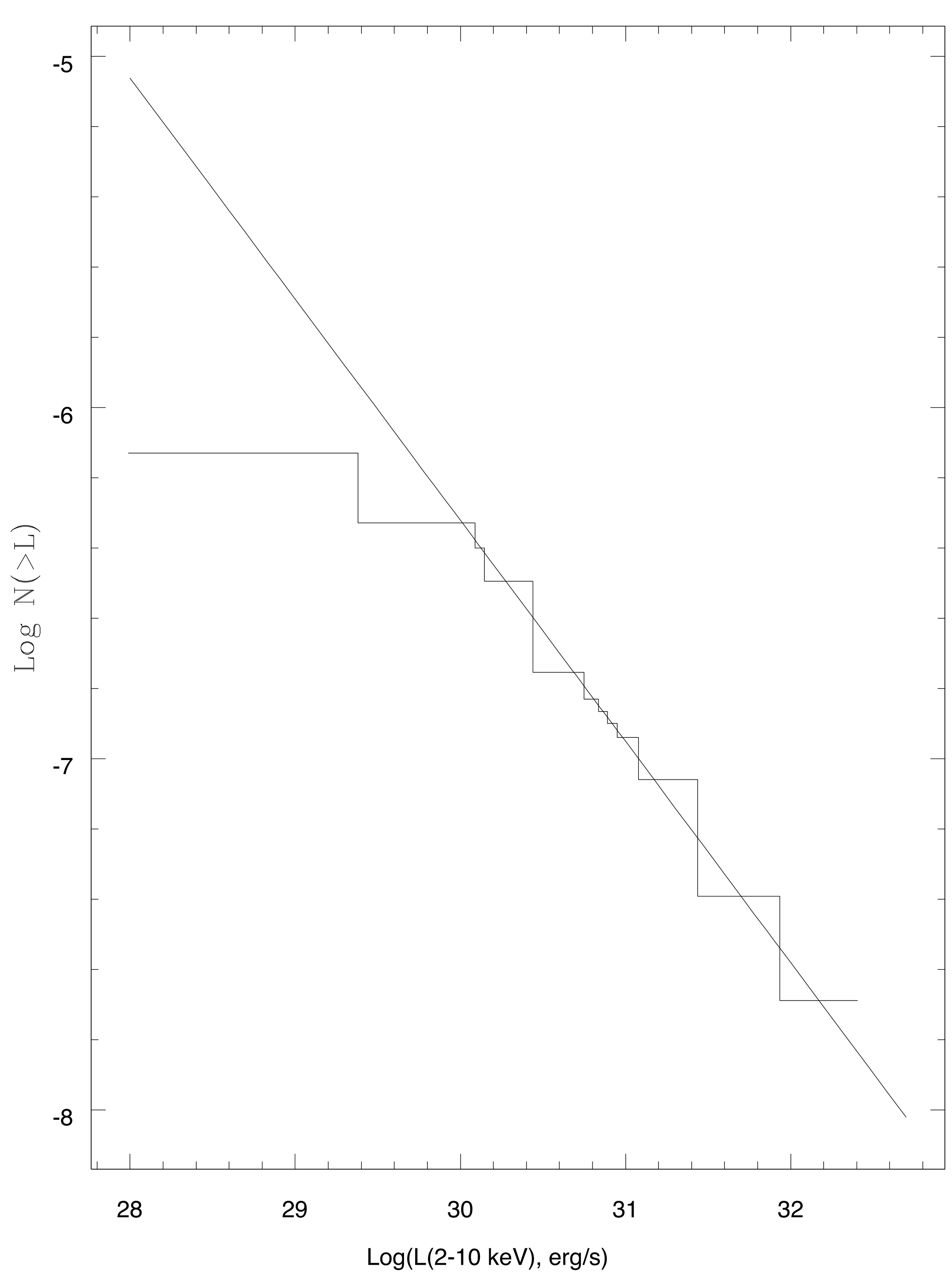
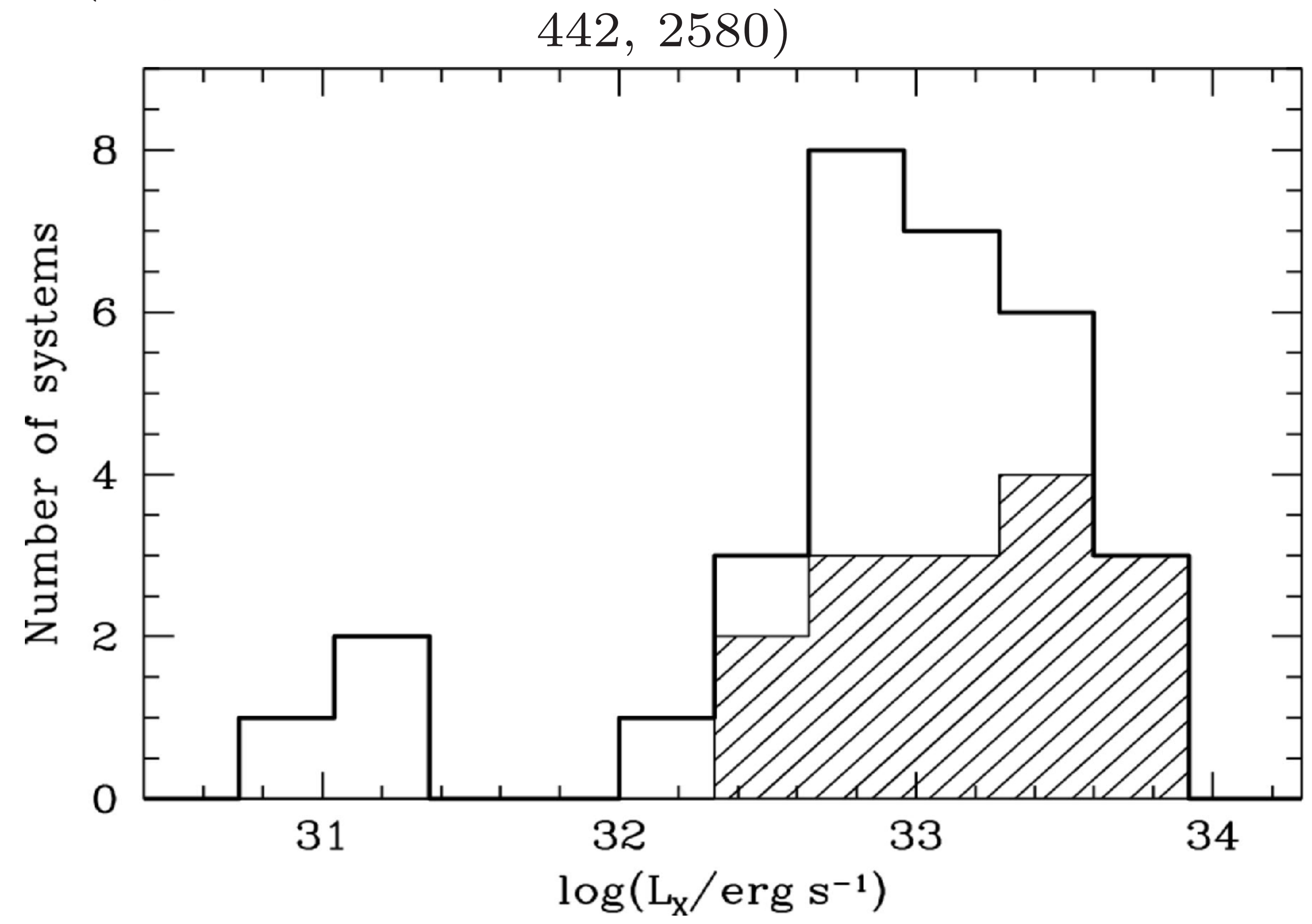


Figure 2 The X-ray luminosity distribution of IPs detected in the Swift/BAT 70-month survey (Figure 4 of Pretorius & Mukai 2014, MNRAS, 442, 2580)



Many Types of CVs

It is impossible to characterize all CVs with a single XLF. There are many varieties, depending on:

Mass transfer rate: CVs "above the period gap" (orbital period, P, greater than 3 hrs) have a higher secular average mass transfer rate than those below ($P < 2$ hrs). CVs below the gap are far more numerous, since their life time is longer roughly by the ratio of the secular mass transfer rate.

The white dwarf mass: It now appears that most CVs have 0.8 $M_\odot$ white dwarfs (Zorotovic et al. 2012, A&A, 536, A42), and any model of their collective X-ray emission that requires a large population of much lower mass white dwarf systems is suspect.

Magnetic field of the white dwarf: Magnetic white dwarfs strong enough to control the accretion flow often result in efficient X-ray emission, notably for a subclass of magnetic CVs called intermediate polars (IPs). X-ray luminous ($\sim 10^{33}$ ergs s^{-1}) IPs dominate the CV population in the hard X-ray surveys (Figure 2). However, Pretorius & Mukai (2014) also found a separate, low X-ray luminosity population of IPs, whose size is currently unknown.

The X-ray luminous IPs out to a few hundred pc away are suitable targets for in-depth X-ray spectroscopy using *Chandra* HETG. Nearby CVs whose X-ray luminosities are just below this level are better studied using other missions, as their flux level is high enough to cause pile-up in bare ACIS observations but not high enough to obtain high quality grating data.

Collective Contribution to the Ridge and Bulge

It is now widely accepted that CVs make a substantial contribution to the apparently diffuse X-ray emission from the Galactic ridge and bulge, including the hard X-ray (>10 keV) emission now being studied using *NuSTAR* (Figure 3). The spatial resolution of *Chandra* is the obvious key in resolving as many sources as possible.

The study of XLF and space density of various subpopulation of CVs, and of the related population of symbiotic stars, is necessary before we can conclusively answer the question of the origin of the ridge and bulge X-ray emission.

Extraordinary CVs

In recent years, we have discovered several CVs (V2487 Oph, V2491 Cyg, and V2672 Oph) with very high X-ray luminosities. In the best established cases, these are associated with the quiescent (accretion) phase of novae — the thermonuclear runaway of accreted material that eject most, if not all, of the envelope. The properties of these particular novae suggest they harbor massive white dwarfs, perhaps very close to the Chandrasekhar limit. No firm evidence of magnetic white dwarfs has been found.

The high luminosity implies a very high accretion rate: perhaps these are cousins of ordinary CVs with much faster evolution, hence much shorter lifetime, hence similar birth/death rates. Since they are rare and found many kiloparsecs away, in crowded field, they require the spatial resolution of *Chandra* to establish the correct optical identification.

Figure 4 *Chandra* (yellow), radio (magenta) and optical positions (other colors) of the X-ray luminous post-nova V2672 Oph, shown superimposed on the VVV image (Courtesy T. Finzell, MSU)