Chandra Observations of Old Novae

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Abstract. We present highlights of *Chandra* observations of two old novae, DQ Her and V603 Aql, with the main aim of improving our understanding of the underlying binary decades after their respective nova eruptions. In DQ Her, we find a partial X-ray eclipse; it is likely that we observe photons scattered in an accretion disk wind. The X-ray spectrum of V603 Aql suggests an origin in multi-temperature plasma; while the low energy lines suggest modest density, the 6.4 keV Fe Kα line suggests that the hard continuum arises in a compact emission region. We also report on our searches for nebular X-ray emission around these old novae.

INTRODUCTION

X-ray observations of old novae are useful in selecting magnetic systems, in constraining the total accretion rate, and potentially in inferring the abundances of the accreting and/or ejected materials. With the increasing capability of X-ray satellites, we can now observe fainter systems or obtain detailed light curves and spectra of brighter systems. Here we present our *Chandra* observations of DQ Her and V603 Aql. The former is X-ray faint, while the latter is among the X-ray brightest old novae known, although both were among the brightest novae of the 20th century.

DQ HER

DQ Her is the prototype of a subclass of magnetic CVs, "Intermediate Polars" (IPs) or "DQ Her type systems" [1]; unlike most members, however, DQ Her is not a strong X-ray source as seen from Earth. It was undetected with *Einstein* [2], with an upper limit of 3×10^{30} ergs s^{-1}. Since DQ Her is a deeply eclipsing system in the optical, its white dwarf (presumed primary X-ray emission site) is likely hidden from our view at all times. DQ Her, however, was detected with *ROSAT* at $\sim 4.0\times10^{30}$ ergs s^{-1} [3]. A deep eclipse was not observed, hence these detected X-rays are not from the immediate vicinity of the white dwarf. So what is the origin of the observed X-rays?

We observed DQ Her with *Chandra* ACIS-S in imaging mode (i.e., without a grating) from 2001 July 26 13:00 UT – July 27 02:31 UT and again from 2001 July 29 17:09 UT – July 30 02:27 UT, for a total good time of 69 ksec. We detect a moderately strong

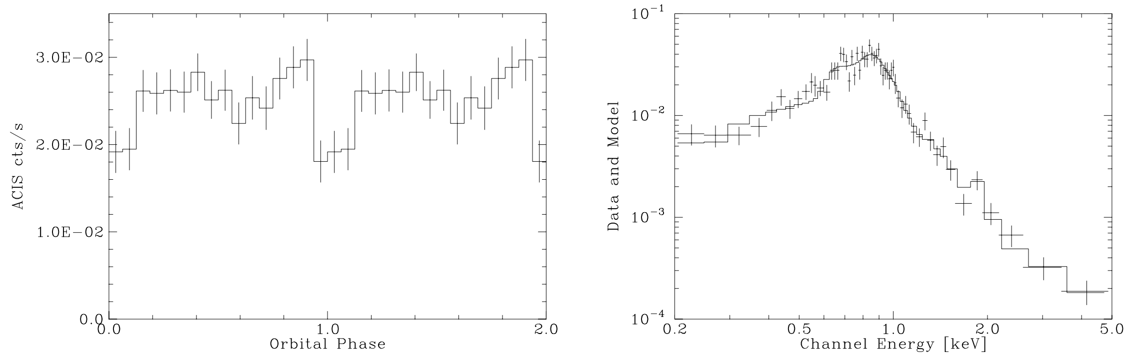

FIGURE 1. (Left) The X-ray light curve of DQ Her, folded on the orbital period (two cycles are shown for clarity). (Right) The X-ray spectrum of DQ Her, as observed with *Chandra* ACIS-S, plotted with a 2-component model (power law plus a kT$\sim$0.6 keV thermal plasma model) folded with the ACIS-S response.

(0.025 cts s^{-1}, or $\sim 3^{30}$ ergs s^{-1}) point source at the optical position of DQ Her in these observations. The light curve, folded on the orbital ephemeris of [4], clearly shows a partial eclipse, lasting a little over 0.1 in phase and about 30% deep; the spectrum shows a bump around 0.8–1.0 keV, characteristic of plasma emission with lines of O, Ne, and Fe at these energies (Figure 1). The partial eclipse is a signature of an extended emission region. Materials that are $\sim$11 white dwarf radii above the orbital plane should remain uneclipsed, given the known system geometry, suggesting a vertical extent at least this much. These observations are consistent with the idea that the observed X-rays have been scattered in an accretion disk wind, similarly to OY Car in superoutburst [5]. The presence of an accretion disk wind in DQ Her has been inferred from UV observations [6], even though DQ Her lacks a boundary layer. The fact that there is a significant partial X-ray eclipse in DQ Her makes it different from other wind-scattered X-ray sources such as OY Car and UX UMa [7], and may be an indication of differences in their wind structures.

V603 AQL

V603 Aql is among the X-ray brightest old novae both in intrinsic luminoity (in excess of 10^{32} ergs s^{-1}) and in terms of flux at Earth [8]. We therefore observed V603 Aql with *Chandra* HETG with ACIS-S from 2001 April 19 17:36 UT – April 20 11:53 UT for a total of 64 ksec, to obtain the highest quality X-ray spectrum of an old nova to date.

There have been claims that this is a magnetic system of the IP type, based on polarimetry [9] and on X-ray photometry [10]. However, the former was based on a method which is, for variable sources, susceptible to false detections; on the other hand, [11] established a strict upper limit using a variable-star-safe instrument. Here we examine the claim of X-ray periodicity (Figure 2), using 1st order (dispersed) photons in the *Chandra* HETG data which was taken without interruption (0th order, undispersed, image suffers from a significant pile-up which makes it far less useful for timing analysis). As a comparison, the *Chandra* HETG power spectrum of V1223 Sgr, a typical IP, shows

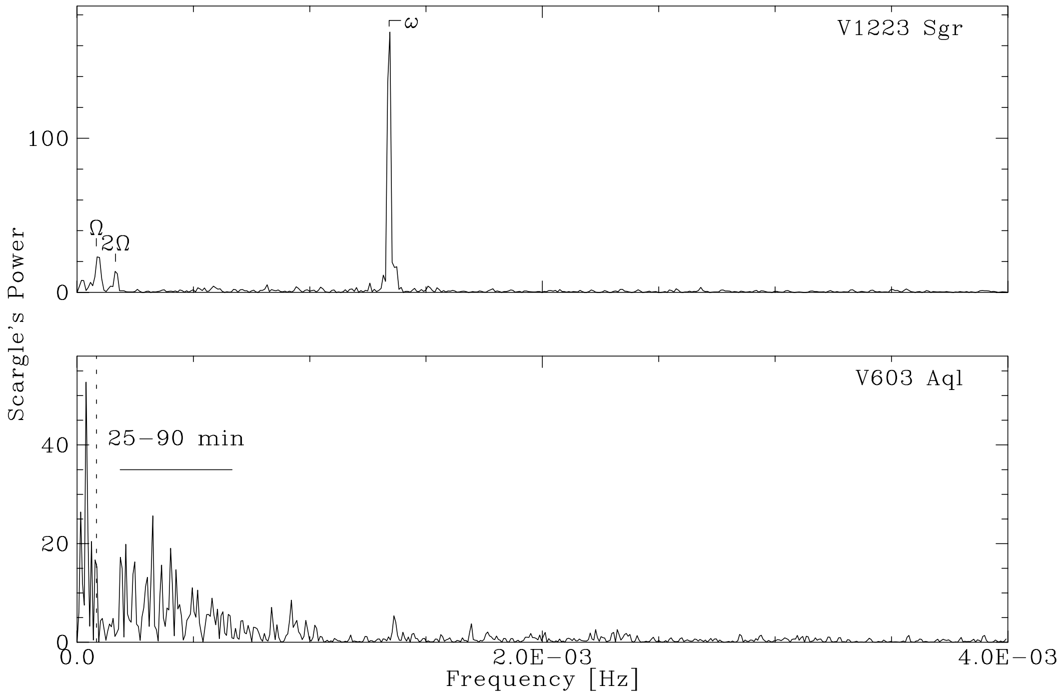

FIGURE 2. Power spectra of the IP, V1223 Sgr (top) and the old nova, V603 Aql (bottom), both from continuous *Chandra* grating observations. The former shows strong peaks at the orbital and spin periods, whereas the latter shows a broad envelope of excess power: the observed X-ray variability is not periodic.

prominent peaks at the orbital and spin periods, and in some harmonics, with little power at other frequencies. In contrast, the power spectrum of V603 Aql contains a number of peaks, roughly in the 20 min – 1 hr range. It is highly unlikely that any combinations of harmonics and sidebands can explain all the peaks, given a single underlying clock. We therefore conclude that V603 Aql shows a strong variability, but not a periodicity, and that there is no evidence to date that it is an IP.

The average spectrum of V603 Aql is rich in emission lines; the simultaneous presence of emission lines of Fe, Si, Mg, Ne, and O is a direct evidence for the multi-temperature nature of the X-ray emitting plasma. In Figure 3, we show details of selected regions of the spectrum. With the superior spectral resolution of *Chandra* HETG, we have been able to resolve the He-like triplets of Ne IX and Mg XI. The presence of the forbidden (f) component in the latter (and perhaps also the former) sets a limit of the density of the line emitting region at $n_e \leq 10^{13}$ cm^3. At the Fe K region of the spectrum, the resolution of HETG is insufficient to rerseoluve the He-like triplets; what we see are the 6.4 keV fluorescent, 6.7 keV He-like, and 6.97 keV H-like components. The H-like comnponent, from kT$\sim$10 keV plasma, is present but significantly weaker than the He-like component (kT$\sim$5 keV). The fluorescent component has an equivalent width of $\sim$150 eV, consistent with reflection from the white dwarf surface that subtends 2π steradians. This implies that the hard X-ray continuum originates in a compact emission re egion, whereas the lower energy lines may originate in a more extended structure.

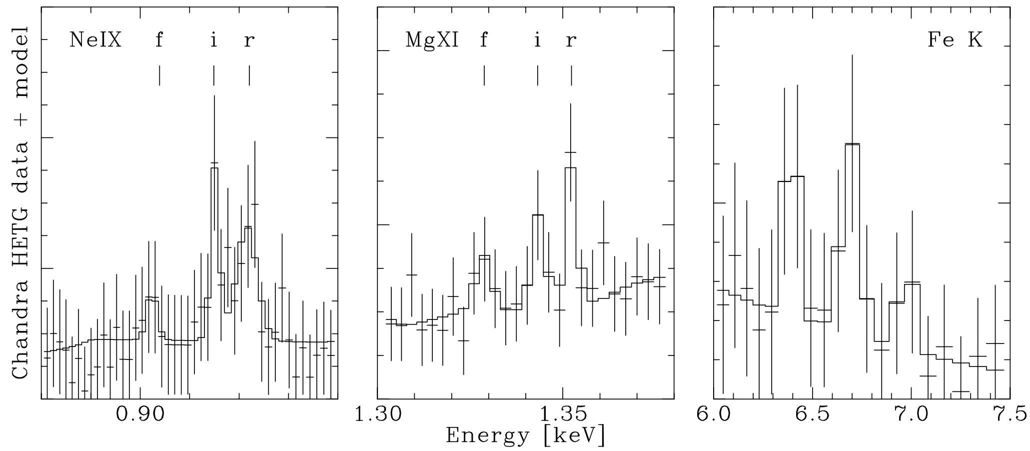

FIGURE 3. Selected X-ray emission lines of V603 Aql. The left two panels show He-like triplets of Ne IX and Mg XI while the right panel shows the Fe K line (∼neutral, He-like and H-like).

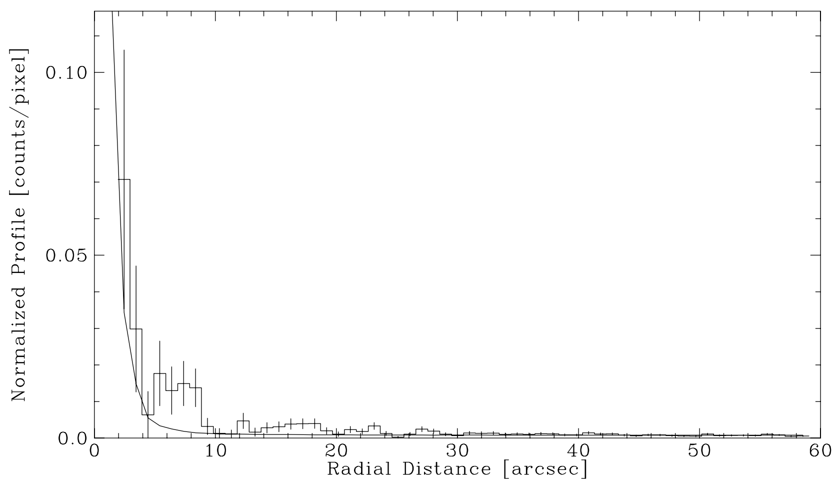

FIGURE 4. The radial profile of the *Chandra* ACIS-S X-ray image of DQ Her in the 0.2–0.5 keV band. The data are plotted as a histogram with errors, while the best-fit model (for 0.3 keV monochromatic X-rays observed on-axis) are plotted as a solid line.

A SEARCH FOR NEBULAR X-RAY EMISSIONS

Finally, the superior imaging resolution of *Chandra* allows a sensitive search for extended emission, such as that seen around GK Per [12]. In Figure 4, we plot the observed radial profile of the *Chandra* image of DQ Her, and the best-fit model based on the known point-spread function (the fit is strongly constrained by the first few points, which are not shown). We detect an excess of counts rougly 10 arcsec away, most prominently at the lowest energies. This excess is most prominent towards NE of DQ Her itself, and is not consistent with a point source. A comparison with a ground-based images of the nova shell [13] suggests a coincidence with an [NII] knot.

Our search for a similar feature around V603 Aql has been inconclusive. This is because we used a grating, which complicates the background and the point-spread-function calibration; and because the central source is much brighter than in DQ Her.

CONCLUSIONS

The majority of X-rays from DQ Her appear to be scattered in the accretion disk wind. Despite its well-credentialed magnetic nature, DQ Her resembles high accretion rate, non-magnetic CVs seen at high inclination. X-ray data may be useful more as a probe of the wind than of the accretion flow immediately around the white dwarf in this system. A small number of X-ray photons ($\sim$30, a few times 10^{28} ergs s^{-1} appear to be from the shell around DQ Her.

The X-ray spectrum of V603 Aql is rich in lines and may contain enough clues to advance our understanding of accretion onto the white dwarf. However, we have not yet learned how to interpret these clues. It may serve as a template for the studies of non-magnetic CVs in general (previous claims that V603 Aql is magnetic were premature, and quite possibly erroneous).

We have presented a flavor of what X-ray observations of quiescent old novae can do. Observations of additional novae with *Chandra* and *XMM-Newton* should be encouraged.

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