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An X-Ray Survey of Nine Historical Novae

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SEPTEMBER 1980

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ABSTRACT

The Einstein Observatory Imaging Proportional Counter has been used to search for X-ray emission from nine nearby historical novae. Six of the novae have been detected with estimated X-ray intensities between 1 - 4 keV of $10^{-13}$ - $10^{-11}$ ergs/cm$^2$-s, comparable to the intensities of previously detected cataclysmic variables. The X-ray intensity of one of the novae, V603 Aql, varies over times of several hundred seconds. The data suggest a correlation between the decay rate of the historical outburst and the current X-ray luminosity. Alternatively, the X-ray luminosity may be related to the inclination of the binary system.

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I. INTRODUCTION

Classical novae are a subset of cataclysmic binary systems whose defining characteristics are based on their eruptive behavior (for review see Payne-Gaposchkin 1957, Gallagher and Starrfield 1978). Detailed studies of classical nova binary systems, both before and after outburst, show they are qualitatively similar to other cataclysmic binary systems such as dwarf novae. It is now accepted that these phenomena are the result of mass transfer from a late-type companion onto a white dwarf through an accretion disk. X-ray emission is expected from the release of gravitational energy from material falling onto the surface of the white dwarf. X-ray emission has been detected previously from several dwarf novae, nova-like objects, and one classical nova (Cordova, Mason and Nelson 1980 and references therein). In light of some of these observations as well as the prediction of X-ray emission from classical novae (Tylenda 1977), a survey of nearby classical novae was undertaken.

II. THE EXPERIMENT AND THE SURVEY

The observations were made with the imaging proportional counter (IPC) on the Einstein Observatory. A detailed description of the IPC can be found in Giacconi et al. (1979). To summarize, the IPC produces an X-ray image of a ~ 1 sq. deg. field with ~ 1 arc min angular resolution. The image is sorted into 8" pixels. After determining the intensity of the non-X-ray background for a given observation, localized variations above this background are analyzed for statistical significance and spatial distribution. Each event detected by the IPC undergoes a pulse height analysis so that in principle the energy spectrum of each detected source can be estimated. In addition, each X-ray event is time tagged so that variability of the X-ray intensity can be studied.

For the purpose of this survey, nine nearby classical novae were selected from the catalog compiled in Payne-Gaposchkin (1957). These are listed in
Table 1 along with the data of each observation and the estimated distance to each system. This survey is not complete and the individual objects do not make up a homogeneous class of novae. Since there has been very little information available on the X-ray behavior of classical novae, the primary purpose of these observations was to provide some indications for future lines of research.

Each object was observed for $1-3 \times 10^3$ sec without regard to binary phase. In light of the nature of cataclysmic variables, all these data should be considered as snapshots of what may be highly variable behavior.

III. OBSERVATIONS

The averaged X-ray properties for each of the nine novae, i.e. the X-ray position if detected and the measured counting rate or 2σ upper limit are given in Table 1. Six of the nine objects have been positively detected, both on the basis of positional coincidence with the optical nova and a statistically significant counting rate. Upper limits for the remaining three sources have been calculated by summing the counts at the optical nova position.

All of the detected sources have been examined for time variability and spatial extent, although only two objects, GK Per and V603 Aql, provided enough photons for meaningful analysis. The light curve for V603 Aql is shown in Figure 1. The nova V603 Aql appears to have experienced a short-lived flare lasting ~ 200 s during which the X-ray intensity doubled. The intensity of GK Per remained constant throughout its observation. All the X-ray images were consistent with that of a point source.

The time-averaged spectra for each source was also examined. All the spectra were relatively hard. The calculated hardness ratio (counts above 0.55 keV to counts below 0.55) ranged from $2.2 \pm 0.9$ for RR Pic to $>23$ for GK Per, similar to values determined by Cordova et al. (1980) for other cataclysmic variables in general and GK Per specifically. A spectral form
must be adopted in order to convert IPC cts into an X-ray intensity. Since
the data are consistent with a hard thermal component as observed in other
cataclysmic variables (Swank 1979, Cordova and Riegler 1979) we will assume a
nominal 10 keV thermal bremsstrahlung spectrum with N_H = 1 x 10^{20} \text{ cm}^{-2}, as was
done by Cordova et al. (1980) in her study of cataclysmic variables. As
Cordova pointed out, the derived X-ray intensities are relatively insensitive
to these assumptions. The intensities are given in Table 1.

IV. DISCUSSION

With a sample of 11 old novae (includes observations of DQ Her and V533
Her from Cordova et al. (1980)) it is feasible to attempt to correlate L_X with
other observables. Cordova et al. (1980) has suggested that the lack of X-ray
emission from DQ Her may be a geometric effect from the high inclination of
the binary system. Indeed, two other old nova systems, T Aur and RRPic, are
high inclination systems (Walker 1963, Vogt 1975) and they too are at least
weak X-ray emitters; while the low inclination system V603 Aql (Kraft 1964) is
one of the most luminous. (However, we note that recent observations by
Boggess et al. 1980 indicate V603 Aql may actually be an eclipsing system.)

Additional determinations of i are needed to strengthen this possible
correlation between L_X and inclination. Lambert et al. (1980) has suggested
that i of a nova system is strongly correlated with the nature of the UV
spectra of cataclysmic variables in general and old novae in particular,
supporting the likelihood that geometric effects could be very important.

Cordova et al. (1980) noted that the only two old nova which pulse
optically, DQ Her (Walker 1956) and V533 Her (Patterson 1979), both lack X-ray
emission. Assuming that the pulsations are indicative of high magnetic
fields, it is possible that X-ray emission is being suppressed in favor of
cyclotron radiation (Lamb and Masters 1980). If so, then L_X may be an
indicator of the white dwarf magnetic field.

We have found an additional parameter, the speed class of the nova
outburst, which appears to correlate with $L_x$. In Figure 2, we have plotted the rate of decay of the nova outburst vs. $L_x$ for the ten old novae for which this is known. We find that the four most luminous old novae were all "fast" novae, while those old novae with the severest upper limits were all "slow" novae. If this apparent correlation is true, then $L_x$ is the first observable quantity in post-outburst novae which "predicts" (after the fact) the speed of the nova outburst.

Qualitatively, the optical light curves of all novae are similar. Quantitatively, the light curves show significant differences in the rate of decrease following maximum, i.e., the speed of the outburst. Calculations based on hydrodynamic models for novae indicate that the speed of the outburst depends on both the CNO abundance in the white dwarf (Sparks, Starrfield, and Truran 1978) and the mass of the white dwarf envelope (Taam and Faulkner 1975). In the first case, Sparks et al. found that higher CNO abundances resulted in faster nova outbursts. Taam and Faulkner found that lower envelope mass at the time of the outburst also led to faster outbursts. More recently, Shara, Prialnik, and Shaviv carried out calculations varying both CNO abundances and envelope masses, and came to the same conclusion for CNO abundances near solar and envelope masses from $\sim 10^{-6}$ to $\sim 10^{-3}$ solar masses. These results have shown how the speed of the nova depends on the condition of the envelope at the time of the outburst.

The correlation between $L_x$ and outburst speed therefore relates the envelope at outburst to the X-ray emission between outbursts. Pringle and Savonije (1979) have shown that for a given white dwarf mass and radius, $L_x$ is approximately proportional to the accretion rate until the accretion rate is so large that the system becomes optically thick for X-rays. Thus for a group of novae, $L_x$ should be correlated with the accretion rate. In this context, we note that Taam (1977) showed that higher accretion rates onto the white dwarf lead to a higher envelope temperature and hence to a "premature"
thermonuclear runaway and therefore a lower envelope mass at the moment of outburst. Similarly, Starrfield and Sparks (1979) have compared the interval between outbursts to the diffusion time of heavy elements in the white dwarf envelope and concluded that high accretion rates will lead to higher CNO abundances at the time of outbursts. In effect, higher accretion rates result in the conditions hypothesized to result in fast novae.

In summary, this X-ray survey of old novae suggests several lines of inquiry. There is some support for correlations between Lx and both the inclination of the binary system and the speed class of the nova outburst. Currently, the inclination of most old nova systems is unknown and further optical observations could help confirm or deny the correlation with inclination. Secondly, the X-ray survey should be extended to additional old novae, again with the aim to confirm or deny either of the suggested correlations. A correlation between Lx and nova speed class would be supportive of models for nova outbursts which relate accretion rates with the nova speed class.

We wish to thank Jean Swank and Ron Taam for useful discussions. We thank F.R. Harnden for discussions concerning IPC analysis software. Special thanks go to Dr. Joseph Ashbrook for providing his unpublished light curve for CK Vul.
REFERENCES


Starrfield, S. and Sparks, W.M. 1979, BAAS 11, 663.


<table>
<thead>
<tr>
<th>SOURCE</th>
<th>DISTANCE (pc)</th>
<th>DATE OF OBSERVATION (DAY OF 1979)</th>
<th>X-RAY POSITION (1950)</th>
<th>IPC cts/s (0.15-4.5 keV)</th>
<th>X-RAY INTENSITY (erg cm⁻² s⁻¹)</th>
<th>Lx (erg s⁻¹)</th>
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<tr>
<td>V603 Aql</td>
<td>376a</td>
<td>265</td>
<td>18 46 22.6</td>
<td>0.279 ± 0.013</td>
<td>7.53 x 10⁻¹²</td>
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<td>T Aur</td>
<td>830a</td>
<td>264</td>
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<td>&lt; 0.0068</td>
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<td>CP Lac</td>
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<td>348</td>
<td>----------------------</td>
<td>&lt; 0.0122</td>
<td>&lt; 3.3 x 10⁻¹³</td>
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<td>V841 Oph</td>
<td>860b</td>
<td>265</td>
<td>16 56 41.1</td>
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<td>4.55 x 10³¹</td>
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<td>GK Per</td>
<td>470a</td>
<td>239</td>
<td>03 27 48.2</td>
<td>0.178 ± 0.016</td>
<td>4.80 x 10⁻¹²</td>
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<td>RR Pic</td>
<td>480a</td>
<td>298</td>
<td>06 35 09.7</td>
<td>0.031 ± 0.005</td>
<td>8.37 x 10⁻¹³</td>
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<td>CP Pup</td>
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<td>328</td>
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<td>295</td>
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<td>CK Vul</td>
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<td>----------------------</td>
<td>&lt; 0.0067</td>
<td>&lt; 1.8 x 10⁻¹³</td>
<td>&lt; 3.1 x 10³⁰</td>
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</tbody>
</table>

- McLaughlin, D.B. 1960
- McLaughlin, D.B. 1945
- Errors of ~ 1 arc min
- Upper limits are 2σ. Errors are 1σ.
- Conversion to intensity assumes a 10 keV thermal bremsstrahlung spectrum.
FIGURE CAPTIONS

Figure 1 - X-ray light curve for classical novae V605 Aql from UGC observations.

Figure 2 - Current X-ray luminosity vs. historical rate of decline for classical novae. Values for decline rates come from Payne-Gaposchkin (1957) except for V533 Her and CK Vul which were calculated based on light curves from Chincarini (1964) and Joseph Ashbrook (private communication) respectively. Upper limits to Lx for DQ Her and V533 Her are from Cordova et al. (1980).