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R.H. Becker and F.E. Marshall

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National Aeronautics and
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Goddard Space Flight Center
Greenbelt, Maryland 20771

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R.H. Becker[1] and F.E. Marshall
Laboratory for High Energy Astrophysics
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

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.

[1] Also Dept. Physics & Astronomy, Univ. of Maryland

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 date 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 x 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 novae 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 ± .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 $N_H = 1 \times 10^{20}$ 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 RR Pic, are high inclination systems (Walker 1963, Vogt 1975) and they too are at best 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 Lx. In Figure 2, we have plotted the rate of decay of the nova outburst vs. Lx 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 Lx 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 novae speed class would be supportive of models for novae outbursts which relate accretion rates with the novae speed class.

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TABLE 1. X-RAY SURVEY OF OPTICAL NOVAE

SOURCE	DISTANCE (pc)	DATE OF OBSERVATION (DAY OF 1979)	X-RAY POSITION (1950)[c] RA DEC	H o	M '	S "	IPC cts/s[d] (.15-4.5 keV)	X-RAY INTENSITY[e] (erg cm^{-2} s^{-1})	Lx (erg s^{-1})
V603 Aql	376[a]	265		18 00	46 31	22.6 50.1	.279 ± .013	7.53×10^{-12}	1.28×10^{32}
T Aur	830[a]	264	---------------				< .0068	$< 1.84 \times 10^{-13}$	$< 1.5 \times 10^{31}$
CP Lac	1340[a]	348	---------------				< .0122	$< 3.3 \times 10^{-13}$	$< 7.1 \times 10^{31}$
V841 Oph	860[b]	265		16 -12	56 48	41.1 23.7	.019 ± .005	5.13×10^{-13}	4.55×10^{31}
GK Per	470[a]	239		03 43	27 43	48.2 39.1	.178 ± .016	4.80×10^{-12}	1.27×10^{32}
RR Pic	480[a]	298		06 -62	35 36	09.7 17.5	.031 ± .005	8.37×10^{-13}	2.31×10^{31}
CP Pup	700[a]	328		08 -35	09 12	51.7 28.5	.060 ± .006	1.62×10^{-12}	9.53×10^{31}
V1059 Sag	1370[b]	295		18 -13	59 14	01.2 10.7	.014 ± .005	3.78×10^{-13}	8.51×10^{31}
CK Vul	380[b]	324	---------------				< .0067	$< 1.8 \times 10^{-13}$	$< 3.1 \times 10^{30}$

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[a] McLaughlin, D.B. 1960

[b] McLaughlin, D.B. 1945

[c] Errors of ~ 1 arc min

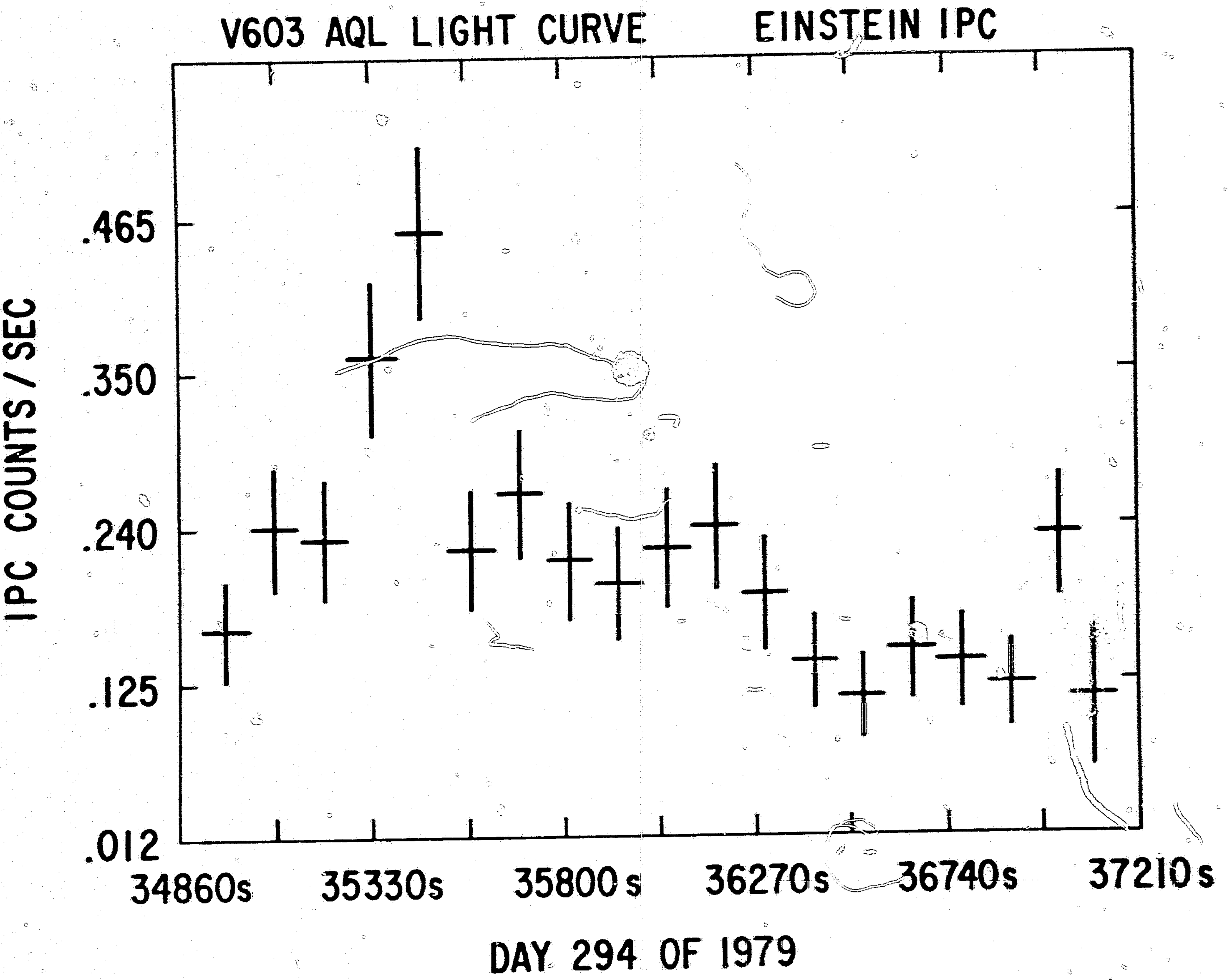
[d] Upper limits are 2σ. Errors are 1σ.

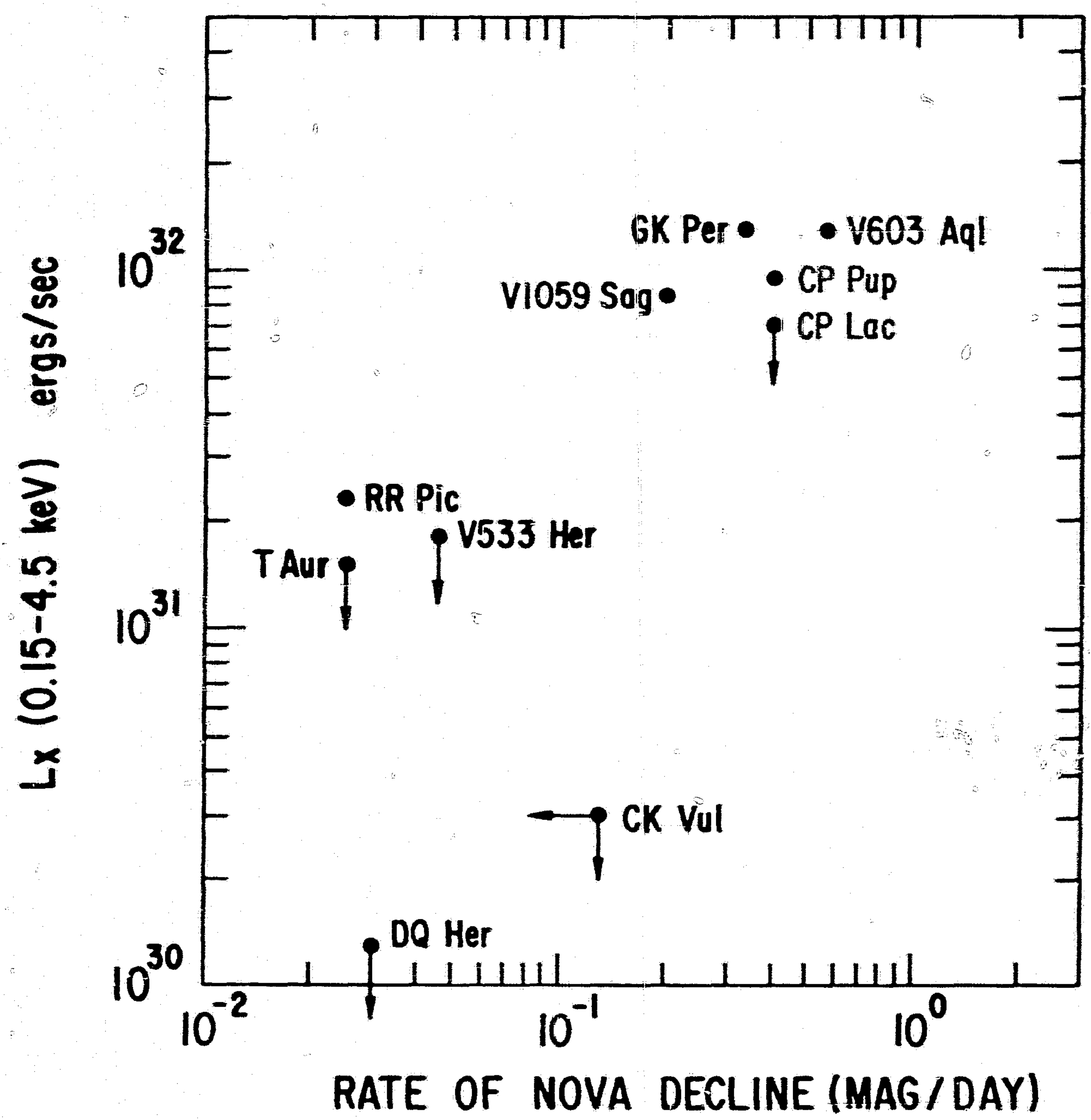
[e] Conversion to intensity assumes a 10 keV thermal bremsstrahlung spectrum.

FIGURE CAPTIONS

Figure 1 - X-ray light curve for classical novae V603 Aql from IPC 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).


V603 AQL LIGHT CURVE
EINSTEIN IPC
IPC COUNTS / SEC
.465
.350
.240
.125
.012
34860s
35330s
35800 s
36270s
36740s
37210s
DAY 294 OF 1979


GK Per
V603 Aql
CP Pup
V1059 Sag
CP Lac
RR Pic
V533 Her
T Aur
CK Vul
DQ Her
10^{32}
10^{31}
10^{30}
Lx (0.15-4.5 keV) ergs/sec
10^{-2}
10^{-1}
10^{0}
RATE OF NOVA DECLINE (MAG/DAY)