

Novae as a Class of Transient X-ray Sources

K. Mukai^{1,2}, M. Orio^{3,4,5} and M. Della Valle^{5,6}

ABSTRACT

Motivated by the recently discovered class of faint (10^{34} – 10^{35} ergs s⁻¹) X-ray transients in the Galactic Center region, we investigate the 2–10 keV properties of classical and recurrent novae. Existing data are consistent with the idea that all classical novae are transient X-ray sources with durations of months to years and peak luminosities in the 10^{34} – 10^{35} ergs s⁻¹ range. This makes classical novae a viable candidate class for the faint Galactic Center transients. We estimate the rate of classical novae within a 15 arcmin radius region centered on the Galactic Center (roughly the field of view of *XMM-Newton* observations centered on Sgr A*) to be ~ 0.1 per year. Therefore, it is plausible that some of the Galactic Center transients that have been announced to date are unrecognized classical novae. The continuing monitoring of the Galactic Center region carried out by *Chandra* and *XMM-Newton* may therefore provide a new method to detect classical novae in this crowded and obscured region, and may test the completeness of the current understanding of the nova populations.

Subject headings: stars: novae, cataclysmic variables — Galaxy: center — X-rays: binaries

¹CRESST and X-ray Astrophysics Laboratory, NASA/GSFC, Greenbelt, MD 20771; mukai@milkyway.gsfc.nasa.gov

²Department of Physics, University of Maryland, Baltimore County, 1000 Hilltop Circle, Baltimore, MD 21250

³Department of Astronomy, University of Wisconsin, 475 North Charter Street, Madison, WI 53706; orio@astro.wisc.edu

⁴INAF – Osservatorio Astronomico di Padova, Vicolo dell' Osservatorio 5, I-35122 Padova, Italy

⁵Kavli Institute of Theoretical Physics, UC Santa Barbara, California 93106

⁶INAF, Osservatorio Astrofisico di Arcetri, Largo Enrico Fermi 5, 50125 Firenze, Italy; massimo@arcetri.astro.it

1. Introduction

Recently, several groups have reported their detections of relatively faint X-ray transients in the *Chandra* and *XMM-Newton* observations of the Galactic Center region (Porquet et al. 2005; Sakano et al. 2005; Munro et al. 2005). No direct distance measurements are available for these objects so far, but they are presumed to be located at the distance of the Galactic Center, based mostly on their distributions on the sky. With this assumption, the inferred luminosities of these transients are in the 10^{34} – 10^{35} ergs s $^{-1}$ range. The authors of these studies claim that such a luminosity is too high for cataclysmic variables (CVs), semi-detached binaries in which the accreting object is a white dwarf. Instead, they argue for neutron star or black hole accretors based solely on the luminosity. However, the Galactic Center transients are sub-luminous compared to the known transient populations of black hole or neutron star binaries (Sakano et al. 2005; Munro et al. 2005), requiring a new population (see, e.g., King & Wijnands 2006).

The accretion driven X-ray luminosities of CVs are indeed insufficient to explain the Galactic Center transients. Non-magnetic CVs X-ray luminosities in the range 10^{30} – 10^{32} ergs s $^{-1}$, with the highest value of 3×10^{32} ergs s $^{-1}$ for V603 Aql (Baskill et al. 2005). Magnetic CVs, the intermediate polars (IPs), are more luminous in 2–10 keV X-rays, with estimated luminosities often exceeding 10^{33} ergs s $^{-1}$ (Sazonov et al. 2006). With the possible exception of the outbursts of the unusual IP, GK Per, (it reached 1.3×10^{34} ergs s $^{-1}$ during its 1996 outburst; Hellier et al. 2004), IPs are also not likely candidates for the Galactic Center X-ray transients.

However, the above discussion is incomplete because it is limited to the accretion driven X-ray luminosities of CVs. In reality, CVs can generate higher X-ray luminosities through nuclear fusion, which is a more efficient source of energy than accretion onto a white dwarf. Indeed, classical novae have been known to emit 2–10 keV X-rays at luminosities exceeding 10^{34} ergs s $^{-1}$. We present below a summary of X-ray properties of classical as well as recurrent novae.

2. Novae as X-ray Transients

A white dwarf accreting at below the critical rate will undergo a thermonuclear runaway and becomes a classical nova, once a sufficient amount of fresh fuel has been accumulated (Townsend & Bildsten 2005 and references therein). A classical nova releases enough energy ($\sim 10^{45}$ ergs) to eject a shell of up to $\sim 10^{-4} M_{\odot}$ at a typical velocity of 1000 km s $^{-1}$. Classical novae are seen as spectacular optical transients that brighten by over 10 magnitudes, reaching

peak brightness as high as $M_v = -9$. By definition, a classical nova has only been observed to go into an outburst once, although they are thought to repeat with a recurrence period of well over 1,000 years. A recurrent nova is a closely related system that has been seen to undergo multiple thermonuclear runaways; it is thought that a recurrent nova must have a high mass white dwarf accreting at a high rate.

Novae are transient X-ray, as well as optical, sources. Imaging X-ray observations of classical novae weeks to months after visual peak have revealed at least two kinds of X-ray emissions (Orion 2004). Of these, the supersoft emission peaks in the EUV/soft X-ray range with little or no flux above 1 keV. We do not discuss supersoft emission further in this paper, since many works that focus on this aspect of novae are already in print, and because supersoft emission is easily absorbed by interstellar medium and is unobservable from the Galactic Center region.

The other component is inferred to be from shocks within the ejected shell, although they are spatially unresolved within the first few years. The X-ray spectrum of the shell component can be modeled as optically thin thermal emission with temperatures in the 1–10 keV range in the early stages. The line-rich emissions detected in some novae at a later stage are also likely to be from the shell, although they become too soft to be observable from the Galactic center region. We present a summary in Figure 1 compiled from literature, as detailed below.

The first unambiguous detection of the shocked shell X-rays was achieved for V838 Her (Nova Herculis 1991) with *ROSAT* PSPC 5 days after visual maximum (Lloyd et al. 1992). Using their flux estimates and an estimated distance of 3.4 kpc (Lynch et al. 1992), we obtain an unabsorbed 0.2–2.4 keV luminosity of $0.7\text{--}10 \times 10^{34} \text{ erg s}^{-1}$ for V838 Her, the two numbers corresponding to the high ($kT \sim 10 \text{ keV}$) and low ($kT \sim 0.75 \text{ keV}$) temperature fits that Lloyd et al. (1992) obtained. The 2–10 keV luminosity of V838 Her is highly uncertain and requires an extrapolation of the soft X-ray spectrum, which in turn is poorly determined. Later *ROSAT* observations (1 and 1.5 year after the outburst) did not detect V838 Her.

V1974 Cyg (Nova Cygni 1992) was observed multiple times with *ROSAT*; these data are fully described by Balman et al. (1998). To summarize, shell X-rays were detected starting with the first *ROSAT* observation on day 63 and remained detectable on day 653. The temperature declined from $\sim 10 \text{ keV}$ to below 1 keV over the first 6 months, accompanied by a decline in intrinsic absorption. The peak 0.2–2.4 keV luminosity was $\sim 10^{34} \text{ erg s}^{-1}$ on day 147 for an estimated distance of 1.9 kpc (Rosino et al. 1994). V1974 Cyg presumably peaked in the 2–10 keV earlier than on day 147, since the temperature was decreasing.

In addition, V351 Pup (Nova Puppis 1991) was observed with *ROSAT* 16 months after

the outburst (Orio et al. 1996). It was substantially brighter than V1974 Cyg at the same time after outburst, possibly exceeding 10^{34} ergs s $^{-1}$. It was probably considerably fainter in the 2–10 keV band than in the *ROSAT* band, however, since the plasma temperature was estimated to be in the range $0.75 \text{ keV} < kT < 1.22 \text{ keV}$. Many more novae were observed with *ROSAT* at various times after the outburst, which are summarized in Orio et al. (2001a). The *ROSAT* 0.2–2.4 keV luminosities of V838 Her, V1974 Cyg, and V351 Pup are shown in red in Figure 1 and are labeled N1, N2, and N3, respectively.

The shell X-rays from V382 Vel (Nova Velorum 1999) were detected with *Beppo-SAX*, *ASCA*, and *RXTE* (Mukai & Ishida 2001; Orio et al. 2001b). The spectra again showed the same softening trend seen for V1974 Cyg, requiring both kT and N_H to decrease over the first several months. It appears to have maintained a luminosity (using a slightly revised distance estimate of 1.7 kpc; Della Valle et al. 2002) of over $\sim 3 \times 10^{34}$ ergs s $^{-1}$ for at least 40 days. The Fe $K\alpha$ complex was seen to be weak compared to the best-fit, solar abundance plasma model. The cause of this is a puzzle, since strong and broad Fe lines are seen in the optical (Della Valle et al. 2002). The measured 2–10 keV luminosities of V382 Vel are shown as black X’s in Figure 1, along with the initial *RXTE* upper limit, and are labeled N4.

Although many *XMM-Newton* and *Chandra* observations concentrate on the super-soft phase of the novae, there are some that shed light on the hard X-ray emission. Unfortunately, many of these data are yet to be published in peer-reviewed journals. Among the exceptions, the study of Nova LMC 2000 (Greiner et al. 2003) deserves a special mention, since the distance estimate for this nova is more accurate than those for typical Galactic novae (1σ error $\sim 20\%$ when the maximum magnitude–rate of decline relationship is used; Della Valle & Livio 1995). The estimated bolometric luminosity of Nova LMC 2000 was 5×10^{34} ergs s $^{-1}$ 17 days after maximum, and 2×10^{34} ergs s $^{-1}$ on day 51. These points are shown as black +’s in Figure 1 and are labeled N5.

Of the other novae observed with *XMM-Newton* or *Chandra*, the *XMM-Newton* detections of V2487 Oph (986 and 1187 days after outburst; Hernanz & Sala 2002) are thought to be of accretion driven X-rays, and hence we do not include these in Figure 1. More recently, V4633 Sgr has been detected with *XMM-Newton* (934, 1083, and 1265 days after outburst; Hernanz & Sala 2007). The authors favors a shell origin, although cannot completely exclude accretion origin, either. In Figure 1, we have included the first of the three detections (N6; the other two are at similar levels but with larger error bars), noting, however, that we have used the unabsorbed 0.2–10 keV luminosity reported by Hernanz & Sala (2007). The spectral model consists of a soft and a hard component, so the 2–10 keV luminosity should be somewhat lower. In general, we believe there is potentially a great value in a systematic

study of hard X-ray emission from novae in the *XMM-Newton* and *Chandra* data that have not yet been explored.

Although less sensitive than *XMM-Newton* and *Chandra* observations, the *Swift* survey of classical novae (Ness et al. 2007) provides a useful check. Note that their Figure 16 contains both the soft and hard X-ray luminosities and is intended mainly to show the typical duration of the supersoft phase. To show the history of the shell X-rays, we have taken the observed *Swift* XRT count rate from Ness et al. (2007) and estimated the 2–10 keV luminosity. Since none of the *Swift* observations are deep enough to enable spectroscopy of the shell X-rays, we have used a single conversion rate of 6.24×10^{-14} ergs cm $^{-2}$ s $^{-1}$ (2–10 keV) per 1 *Swift* XRT cts ks $^{-1}$, appropriate for a $kT=5$ keV bremsstrahlung observed through $N_H = 1 \times 10^{22}$ cm $^{-2}$. We exclude from the Ness et al. (2007) compilation novae that are dominated by the supersoft emission, objects observed >1 year after the outburst, and V1047 Cen for which no distance estimate is given. The remaining objects (LMC 2005, V5116 Sgr, V1663 Aql, V1188 Sco, V477 Sct, V476 Sct, and V382 Nor) are shown in blue in Figure 1 (as N7, N8, N9, NA, NB, NC, and ND).

This brief summary (see also Orio et al. 2001a; Orio 2004) suggests the following regarding the X-rays from shocked shells in classical novae. These hard X-rays from the ejected shells appear to be a nearly universal feature of classical novae. Between ~ 10 day past visual maximum to months or years past maximum, they are usually strong X-ray sources, often exceeding 10^{34} ergs s $^{-1}$. The existing data suggest variations in the duration and peak luminosity from nova to nova. The case of V382 Vel suggests that there is a delay in hard X-ray turn-on of classical novae compared to the optical peak. The range of plasma temperatures in the ejecta decrease from 20–30 keV at hard X-ray turn-on, to $\simeq 1$ keV in a few months (e.g., Lloyd et al. 1992; Mukai & Ishida 2001). Within 1–2 years the nebula may have a rich line spectrum, emitting mostly below 1 keV (e.g., Ness et al. 2003, 2005). Of the novae discussed above, the time for the hard component of the X-ray emission to cool was about 6 months for the two fast novae (Balman et al. 1998; Mukai & Ishida 2001), but was longer (over 18 months) for slow novae with massive ejecta (Orio et al. 1996; Greiner et al. 2003), potentially exceeding the duration of the supersoft phase. However, the gradual decrease in temperature means that duration of novae as >2 keV X-ray sources are effectively shorter than the total duration of novae as shell X-ray sources.

Even less is known of the X-ray emission from recurrent novae. IM Nor (R1) was not detected 1 month after the outburst and was only a moderately strong ($\sim 2 \times 10^{32}$ [d/1 kpc] 2 ergs s $^{-1}$) source 6 month past maximum (Orio et al. 2005). The hard component of CI Aql (R2) was detected 34 and 95 days after the outburst at about 7×10^{30} ergs s $^{-1}$ (Greiner & di Stefano 2002) using the distance of 2.6 kpc (Lynch et al. 2004). In contrast, RS Oph (R3)

reached a luminosity in excess of $>10^{35}$ ergs s $^{-1}$ shortly after the outburst peak (Sokoloski et al. 2006; Bode et al. 2006). In Figure 1, we plot only the early *Swift* data for RS Oph; *RXTE* measurements are similar. The fast turn-on and high luminosity of RS Oph is due to the existence of M giant wind, which provides an additional mechanism for X-ray production not available in classical novae, whose mass donors are on or near the main sequence. The relative paucity of X-ray data on recurrent novae reflects the fact that recurrent novae are much rarer than classical novae. In the rest of the paper, we will therefore concentrate on classical novae, but the possibility of an RS Oph-like transient near the Galactic Center region should be kept in mind.

3. Novae As Galactic Center Transients?

As our summary shows, novae are a known class of X-ray transients with peak luminosities above 10^{34} ergs s $^{-1}$. Thus, they should be considered as a candidate class in discussing Galactic Center transients. In fact, novae are the only known class of transients with the right characteristics, as the known neutron star and black hole transients have much higher peak luminosities.

Classical novae can be found both in a relatively young population (e.g., the Galactic disk) and in the older population (e.g., the Galactic bulge). Della Valle & Duerbeck (1993) have shown (their Fig. 1) that the distribution of the rates of decline of classical novae in the Milky Way and in M31 perfectly overlap with each other, and both are statistically distinguishable from LMC distribution (which exhibits a predominance of fast rates of decline). Since it is well known from theoretical studies (e.g. Starrfield et al. 1985; Kovetz & Prialnik 1985) that the rate of decline is a tracer of the mass of the white dwarf in the nova system, we can assume that the main bulk of the progenitors of novae in the Milky Way and in M31 originates in the same type of stellar population. Capaccioli et al. (1989) and Shafter & Irby (2001) have demonstrated that novae in M31 are mainly produced in the bulge, therefore in view of what reported above, the same should occur for novae in our Galaxy.

A global Milky Way rate of ~ 24 novae yr $^{-1}$ has been measured by Della Valle & Livio (1994) by scaling from extragalactic nova surveys (Della Valle et al. 1994). An estimate somewhat larger of ~ 35 novae yr $^{-1}$ has been obtained by Shafter (1997) by extrapolating from the current rate of nova discovery in the Galaxy (about 4–5 novae yr $^{-1}$) and by Darnley et al. (2006) based on microlensing survey of M31. In the following we will adopt as an “educated” guess a global rate of 30 novae yr $^{-1}$, and estimate the rate of novae in a region of the sky within 15 arcmin of the Galactic Center. This is roughly the field of view of *XMM-Newton* EPIC observations centered on Sgr A*.

Recent estimates of the ratio $\text{nova_rate(disk)}/\text{nova_rate(bulge)}$ range between 0.25 up to 0.40 (Capaccioli et al. 1989; Della Valle et al. 1992, 1994; Shafter & Irby 2001). By assuming from Ratnatunga & van den Berg (1989) a surface for the Galactic disk of 850 kpc^2 and a typical scale height of 100 pc for disk novae (Della Valle & Livio 1998), the density of nova outburst in the Milky Way disk is $\rho_{\text{rmdisk}} = 0.4\text{--}0.7 \times 10^{-10} \text{ novae pc}^{-3} \text{ yr}^{-1}$. Assuming the distance from the Sun to the Galactic Center of 8 kpc, one can find that the rate of disk novae within 15 arcmin of the Galactic center is only $5 \times 10^{-4} \text{ novae yr}^{-1}$. That is, we can exclude a disk nova identification for any Galactic Center X-ray transients as highly unlikely.

More uncertain is the estimate of the nova density in the bulge. Let us assume (from Figure 1 of Della Valle & Livio 1998) that most bulge novae are located within 400 pc from the Galactic plane. From Figure 2 of Shafter (1997) we can assume (rather optimistically) that most bulge novae occur within the first kpc from the Galactic center. Under these assumptions, we find that bulge novae are distributed within a prolated ellipsoid with a density of $\sim 3 \times 10^{-8} \text{ novae pc}^{-3} \text{ yr}^{-1}$. The line of sight region within 15 arcmin of the Galactic center encompasses a volume of $\sim 35^2 \text{ pc}^2 \times \pi \times \leq 1000 \text{ pc} = 3.8 \times 10^6 \text{ pc}^3$. The expected number of bulge nova in this volume is therefore of order $\sim 0.1 \text{ novae yr}^{-1}$.

The majority of these novae go undiscovered. During the 1978–1993, the average rate of discovery was 3.3 yr^{-1} (Liller & Mayer 1987). Even though the rate of discovery may have increased in recent years (about 6 yr^{-1} are reported in IAU Circulars since 2001), this still leaves of order 25 classical novae every year that are undiscovered. We expect that the undiscovered novae are preferentially located in crowded regions and/or behind high interstellar extinction. Both problems are extreme in the Galactic Center region. Therefore, optical observations are unlikely to yield a complete census of the novae in the Galactic Center region, although a wide area IR monitoring should be able to do so.

There have been observations of the Galactic Center region roughly every 6 months with *XMM-Newton* for roughly 2 years between 2000 Sep and 2002 Oct, out of which three transients were discovered (Porquet et al. 2005; Sakano et al. 2005). To this, we add 1 year as a representative duration of novae as a Galactic Center X-ray transients (i.e., bright enough and hard enough to be detectable if they were placed at the Galactic Center; the precise value one adopts affects the following numbers only slightly). With this assumption, these *XMM-Newton* observations should have been sensitive to novae that peaked optically between 1999 Sep and 2002 Oct, or a period of 3 years. Combined with the above estimate of 0.1 novae per year within 15 arcmin of the Galactic center, roughly the field-of-view of *XMM-Newton* EPIC cameras, we predict these observations should have detected 0.3 novae as X-ray transients. If this is the true expectation value, there is a 26% chance that at least

one of the Galactic Center transient is a nova according to Poisson distribution (4% chance that two or more were novae).

Most optimistically, then, one or two of the *XMM-Newton* discovered could have been unrecognized novae. On the other hand, it may well be the case that none of these transients are novae. Novae are poorer candidates for the *Chandra* transients, given the strong concentration of *Chandra* transients near Sgr A* (Muno et al. 2005). However, given the uncertainties involved both in the nova rate and the transient rate, we consider it advisable to keep novae in mind, particularly as regular monitoring of the Galactic Center region continues (Wijnands et al. 2006).

In fact, we can turn this argument around. There is a possibility that the present estimate of the Milky Way nova rate ($\sim 30 \text{ yr}^{-1}$) is underestimated, because optical monitoring is ineffective in the crowded, high extinction regions around the Galactic Center. The degree of central concentration of bulge novae is unknown; if there is an additional population of novae found preferentially near the Galactic Center, we would not know it from optical data. The continuing search for faint X-ray transients in the Galactic Center region can therefore be considered an important complementary method for discovering classical novae that are otherwise not recognized. Since the Galactic Center region is already regularly monitored with sensitive X-ray observatories for other purposes, it makes sense to utilize the existing data for this purpose.

4. Conclusions

Classical and recurrent novae are a known class of transient X-ray sources that reach luminosities in the $10^{34} - 10^{35} \text{ ergs s}^{-1}$ range. The shell X-ray phase of novae may last months to several years, although they probably soften as they age, gradually making them less conspicuous above 2 keV.

Novae have the right spectral and temporal characteristics to explain a subset of the faint Galactic Center transients that have been detected with *Chandra* and with *XMM-Newton* in recent years. If the existing literature accurately reflects the rate of X-ray transient near the Galactic Center, then the known population of classical (and recurrent) novae are probably a small, but not negligible, contributor to the overall transient population.

Muno et al. (2005) have argued that dynamical processes may lead to a high space density of X-ray binaries within 1 pc of the Galactic Center. That is, the concentration of X-ray emitters is forcing considerations of a new population of objects not seen elsewhere in the Galaxy. We propose that any such studies include white dwarf binaries, since Galactic

Center specific processes could produce an additional population of novae beyond disk and bulge novae that are currently known.

Chandra and *XMM-Newton* have been monitoring the Galactic Center region more or less regularly over the last ~ 8 years. Even at 0.1 novae per year within 15 arcmin of the Galactic Center, it is probable that a nova will be detected as 2–10 keV X-ray transient soon, if one hasn't been already. A concurrent infrared monitoring campaign will be required, however, to prove beyond a reasonable doubt that a particular X-ray transient is due to a classical nova.

REFERENCES

- Balman, S., Krautter, J. & Ögelman, H. 1998, *ApJ* 499, 395
- Baskill, D. Wheatley, P.J. & Osborne, J.P. 2005, *MNRAS*, 357, 626
- Bode, M.F., O’Brien, T.J., Osborne, J.P., Page, K.L., Senziani, F., Skinner, G.K., Starrfield, S., Ness, J.-U., Drake, J.J., Schwarz, G., Beardmore, A.P., Darnley, M.J., Eyres, S.P.S., Evans, A., Gehrels, N., Goad, M.R., Jean, P., Krautter, J. & Novara, G. 2006, *ApJ*, 652, 629
- Capaccioli, M., Della Valle, M., D’Onofrio M. & Rosino, L. 1989, *AJ*, 97, 1622
- Darnley, M.J., Bode, M.F., Kerins, E., Newsam, A.M., An, J., Baillon, P., Belokurov, V., Calchi Novati, S., Carr, B.J., Créz’e, M., Evans, N.W., Giraud-Héraud, Y., Gould, A., Hewett, P., Jetzer, Ph., Kaplan, J., Paulin-Henriksson, S., Smartt, S.J., Taspras, Y. & Weston, M. 2006, *MNRAS*, 369, 257
- Della Valle, M., Bianchini, A., Livio, M. & Orio, M. 1992, *A&A*, 266, 232
- Della Valle, M. & Duerbeck, H. 1993, *A&A*, 271, 175
- Della Valle, M., Rosino, L., Bianchini, A. & Livio, M. 1994, *A&A*, 287, 403
- Della Valle, M. & Livio, M. 1994, *A&A*, 286, 786
- Della Valle, M. & Livio, M. 1995, *ApJ*, 452, 704
- Della Valle, M. & Livio, M. 1998, *ApJ*, 506, 818
- Della Valle, M., Pasquini, L., Daou, D. & Williams, R.E. 2002, *A&A*, 390, 155
- Greiner, J. & di Stefano, R. 2002, *ApJ*, 578, 59
- Greiner, J., Orio, M. & Schartel, N. 2003, *A&A*, 405, 703
- Hellier, C., Harmer, S. & Beardmore, A.P. 2004, *MNRAS*, 349, 710
- Hernanz, M. & Sala, G. 2002, *Science*, 298, 393
- Hernanz, M. & Sala, G. 2007, *A&A*, in press (astro-ph/0704.3166)
- King, A.R. & Wijnands, R. 2006, *MNRAS* 366, L31
- Kovetz, A. & Prialnik, D. 1985, *ApJ*, 291, 812

- Liller, W. & Mayer, B. 1987, *PASP*, 99, 606
- Lloyd, H.M., O’Brien, T.J., Bode, M.F., Predehl, P., Schmitt, J.H.M.M., Trümper, J., Watson, M.G. & Pounds, K.A. 1992, *Nature*, 356, 222
- Lynch, D.K., Hackwell, J.A. & Russell, R.W. 1992, *ApJ* 398, 632
- Lynch, D.K., Wilson, J.C., Rudy, R.J., Venturini, C., Mazuk, S., Miller, N.A. & Puetter, R.C. 2004, *AJ*, 127, 1089
- Mukai, K. & Ishida, M. 2001, *ApJ*, 551, 1024
- Muno, M.P., Pfahl, E., Baganoff, F.K., Brandt, W.N., Ghez, A., Lu, J. & Morris, M.R. 2005, *ApJ*, 622, L113
- Ness, J.-U., Starrfield, S., Burwitz, V., Wichmann, R., Hauschildt, P., Drake, J.J., Wagner, R.M., Bond, H.E., Krautter, J., Orio, M., Hernanz, M., Gehrz, R.D., Woodward, C.E., Butt, Y., Mukai, K., Balman, S. & Truran, J.W. 2003, *ApJ*, 594, 127
- Ness, J.-U., Starrfield, S., Jordan, C., Krautter, J. & Schmitt, J.H.M. 2005, *MNRAS*, 364, 1015
- Ness, J.-U., Schwarz, G.J., Retter, A., Starrfield, S., Schmitt, J.H.M.M., Gehreles, N., Burrows, D. & Osborne, J.P. 2007, *ApJ*, in press (astro-ph/0703286)
- Orio, M., Balman, S., Della Valle, M., Gallagher, J. & Ögelman, H. 1996, 466, 410
- Orio, M., Covington, J. & Ögelman, H. 2001, *A&A*, 373, 542
- Orio, M., Parmar, A., Benjamin, R., Amati, L., Frontera, F., Greiner, J., Ögelman, H., Mineo, T., Starrfield, S., Trussoni, E. 2001, *MNRAS*, 326, L13
- Orio, M. 2004, in “IAU Colloquium 194: Compact Binaries in the Galaxy and Beyond,” eds. G. Tovmassian & E. Simon, *RevMexAA (Serie de Conferencias)* 20, 182
- Orio, M., Tepedelenlioglu, E., Starrfield, S., Woodward, C.E. & Della Valle, M. 2005, *ApJ*, 620, 938
- Porquet, D., Grosso, N., Burwitz, V., Andronov, I.L., Aschehnabach, B., Predehl, P. & Warwick, R.S. 2005, *A&A*, 430, L9
- Ratnatunga, K.U. & van den Bergh, S. 1989, *ApJ*, 343, 713
- Rosino, L., Iijima, T., Rafanelli, P., Radovich, M., Esenoglu, H. & della Valle, M. 1994, *A&A*, 315, 463

- Sakano, M., Warwick, R.S., Decourchelle, A. & Wang, Q.D. 2005, MNRAS, 357, 1211
- Sazonov, S., Revnivtsev, M., Gilfanov, M., Churazov, E. & Sunyaev, R. 2006, A&A, 450, 117
- Shafter, A.W. 1997, ApJ, 487, 226
- Shafter, A. & Irby B. 2001, ApJ, 563, 749
- Sokoloski, J., Luna, G.J.M., Mukai, K. & Kenyon, S.J. 2006, Nature, 442, 276
- Starrfield, S., Sparks, W. & Truran, J. 1985, ApJ, 291, 136
- Townsley, D.M. & Bildsten, L. 2005, ApJ 628, 395
- Wijnands, R., in't Zand, J.J.M., Rupen, M., Maccarone, T., Homan, J., Cornelisse, R., Fender, R., Grindlay, J., van der Klis, M., Kuulkers, E., Markwardt, C.B., Miller-Jones, J.C.A. & Wang, Q.D. 2006, A&A, 449, 1117

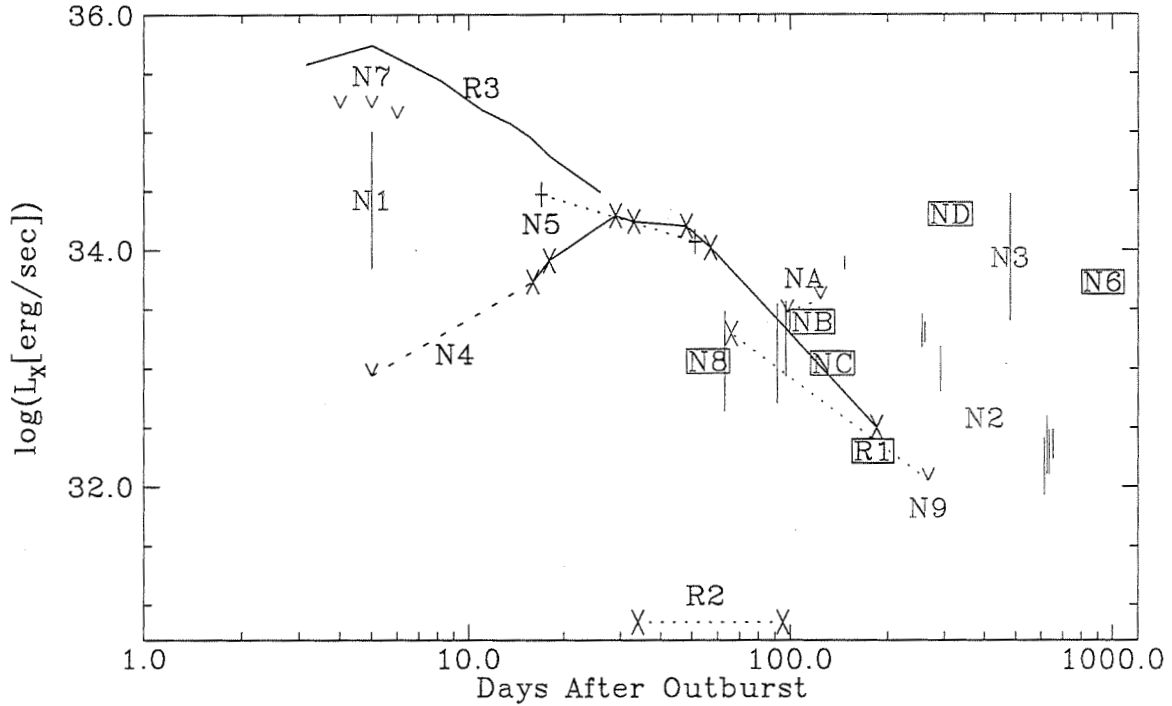


Fig. 1.— Hard X-ray light curves of classical novae, all shown against days since the visual maxima. Black points are generally inferred 2–10 keV luminosities. Blue points are the same estimated from *Swift* XRT count rates, while red points are inferred 0.2–2.4 keV luminosities from *ROSAT* data. Points for any given objects are connected, except that the 11 points for V1974 Cyg are left unconnected for clarity. Upper limits are shown as upside down carets; measurements are shown using a variety of symbols to allow those for different objects (indicated by the object keys, see below) to be distinguished. In 6 cases, object keys themselves, enclosed in boxes, are used to plot measurements. Classical novae plotted are: N1: V838 Her; N2: V1974 Cyg; N3: V351 Per; N4: V382 Vel; N5: Nova LMC 2000; N6: V4633 Sgr; N7: Nova LMC 2005; N8: V5116 Sgr; N9: V1663 Aql; NA: V1188 Sco; NB: V477 Sct; NC: V476 Sct; ND: V382 Nor. Recurrent novae plotted are: R1: IM Nor; R2: CI Aql; R3: RS Oph. See text for details.