CHANDRA OBSERVATIONS OF THE RECURRENT NOVA IM NORMAE

MARINA ORIO
INAF, Osservatorio Astronomico di Torino, Strada Osservatorio, 20, I-10025 Pino Torinese (TO), Italy; and Department of Astronomy, University of Wisconsin, 475 North Charter Street, Madison, WI 53706; orio@astro.wisc.edu

EMRE TEPEDENLIOGLU
Department of Physics, University of Wisconsin, 1150 University Avenue, Madison, WI 53706; emre@cow.physics.wisc.edu

SUMNER STARRFIELD
Department of Physics and Astronomy, Arizona State University, Tempe, AZ 85287-1504; starrfield@asu.edu

CHARLES E. WOODWARD
Department of Astronomy, University of Minnesota, 116 Church Street SE, Minneapolis, MN 55455; chelsea@astro.umn.edu

AND

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

Received 2004 July 27; accepted 2004 November 3

ABSTRACT

The recurrent nova IM Nor was observed twice in X-rays with the Chandra ACIS-S, 1 and 6 months after the optical outburst. It was not detected in the first observation, with an upper limit on the X-ray luminosity in the 0.2–10 keV range \( L_X < 4.8 \times 10^{30} (d \text{ kpc}^{-1})^2 \text{ ergs s}^{-1} \) (where \( d \) is the distance to the nova). Five months later, a hard X-ray source with \( L_X = (1.4–2.5) \times 10^{32} (d \text{ kpc})^2 \text{ ergs s}^{-1} \) was detected. The X-ray spectrum appears to be thermal, but we cannot rule out additional components due to unresolved emission lines. A blackbody component is likely to contribute to the observed spectrum, but it has bolometric luminosity \( L_{\text{bol}} = 2.5 \times 10^{33} (d \text{ kpc}^{-1})^2 \text{ ergs s}^{-1} \); therefore, it is not sufficiently luminous to be caused by a central white dwarf that is still burning hydrogen on the surface. An optical spectrum, taken 5 months postoutburst, indicates no intrinsic reddening of the ejecta. Therefore, we conclude that the shell had already become optically thin to supersoft X-rays, but nuclear burning had turned off or was in the process of turning off at this time. We discuss why this implies that recurrent novae, even the rare ones with long optical decays like IM Nor, indicating a large envelope mass, are not statistically significant as Type Ia supernova candidates.

Subject headings: binaries: close — novae, cataclysmic variables — stars: individual (IM Normae) — X-rays: stars

1. INTRODUCTION

IM Nor is a recurrent nova (RN) that was observed in outburst in 1920 and again on 2002 January 3 (Elliott & Liller 1972; Liller 2002a). Assuming that the maximum occurred on 2002 January 14 at \( V = 7.84 \) (Liller 2002b, 2002c; note that a successive measurement \( V = 7.66 \) on January 16 was done through fog and had a large error bar), the times to decay by 2 and 3 mag were in the ranges \( t_2 = 21–26 \text{ days} \) and \( t_3 = 45–74 \text{ days} \), respectively (Pearce 2002; Shida 2002). An approximate value \( t_3 \approx 50 \text{ days} \) is derived from the Variable Star Network (VSNET) light curve by Kato et al. (2002). These times are longer than for most RNe, with the exceptions of T Pyx (Webbink et al. 1987, and references therein) and CI Aql (Kiss et al. 2001). The FWHM of the emission lines was 1150 km s\(^{-1}\), indicating moderately high ejection velocities (Dürbeck et al. 2002). IM Nor is the only known RN classified as an “Fe II nova” (see Retter et al. 2002; Dürbeck et al. 2002, and references therein). Another peculiarity is that IM Nor may have ejected significantly more mass than all other RNe except CI Aql (see Retter et al. [2002], and discussion below).

Classical novae are thought to be recurrent over timescales \( \geq 1000 \text{ yr} \), while RNe undergo interoutburst periods of only \( < 100 \text{ yr} \). This seems to be the result of a more massive white dwarf (WD), and in some cases higher mass accretion rate, than in the average classical nova system (see early work by Fujimoto [1982] and Prialnik et al. [1982] for the dependence of interoutburst time on physical parameters of the system). RNe are interesting as possible progenitors of Type Ia supernovae (SNe Ia). A list of publications on the subjects includes Starrfield et al. (1985, 1988), Livio & Truran (1994), Della Valle & Livio (1996), and Hachisu & Kato (2001). There are basically two types of RNe, long-period systems hosting a red giant and typical cataclysmic variables with only a slightly evolved secondary. For the latter group, orbital periods seem to be either very short compared to other novae (2–3 hr) or quite long (10–24 hr). IM Nor has a short orbital period, 2.46 hr (Woudt & Warner 2003).

Novae at quiescence are X-ray sources because of accretion, but they are faint (Orio et al. 2001). After an outburst, they turn into more luminous X-ray sources, initially because of shocks in the ejected shell (e.g., in colliding winds or phenomena between ejecta and circumstellar matter). Thermal bremsstrahlung emission is detected at temperatures in the range 0.1–10 keV, and at late phases emission lines have also been detected in the 0.2–1.0 keV energy range. The X-ray luminosity in the 0.2–10 keV range is \( L_X = 10^{33}–10^{35} \text{ ergs s}^{-1} \) (see Orio [2004] for a review). If the central WD keeps on burning unejected hydrogen,
which has interesting implications related to the final fate of nova systems, then novae appear as luminous supersoft X-ray sources with bolometric luminosities in the range $L_X = 10^{36} - 10^{38}$ ergs s$^{-1}$. The WD atmosphere is extremely hot ($T_{\text{eff}} \geq 2 \times 10^5$ K) and directly observable when the ejecta become optically thin to supersoft X-rays.

In this case, the atmospheric absorption edges and many narrow and crowded absorption lines are detected and, for the most luminous objects, can be resolved with grating observations in X-rays (e.g., Ness et al. 2003). In the Galaxy only $\approx 20\%$ of all classical and recurrent novae were observed as supersoft X-ray sources for more than a few months (see Orio 2004). The length of the supersoft X-ray phase is an indication of the amount of hydrogen fuel left over after each outburst; hence the likelihood that the WD mass grows toward the Chandrasekhar limit. The nature of SN Ia progenitors is still an open question, but single degenerate close binary systems, and among them especially RNe, are thought to contribute significantly to the SN Ia rate (e.g., Starrfield et al. 2004). If not all the accreted material is ejected, and the WD mass grows after repeated outbursts, RNe can be considered the most likely progenitors of SNe Ia among novae and cataclysmic variables (CV) (it is crucial, however, to estimate the abundances because one needs to rule out the possibility that eroded WD material, instead of freshly accreted material, is being burned).

Della Valle & Livio (1996) argued that the specific contribution of RNe to the SN Ia rate is not high. The discovery of IM Nor and of another RN, CI Aql, in outburst in 2001, may change these conclusions. A long decay time is thought to indicate a large envelope mass. In both these two unusual RNe, the empirical relationship between $t_2$ and ejected mass $M_{\text{env}}$ of Della Valle et al. (2002) yields $M_{\text{env}}$ of order of $10^{-4} M_\odot$. Theoretically, Hachisu et al. (2003) estimate instead an envelope mass $M_{\text{env}} = 8 \times 10^{-6} M_\odot$ for CI Aql. In the models, for reasons that are not clear yet, an order-of-magnitude smaller $M_{\text{env}}$ is commonly predicted than is inferred from the observations (e.g., Gehrz et al. 1998). However, even this lower theoretical value is much higher than those estimated for most other RNe. If the retained mass after the outburst was a significant fraction of the ejected amount, then these two objects may be representative of a class of RNe that accumulate enough material on the WD, despite ejection during outbursts, to grow toward the Chandrasekhar mass in a time that is sufficiently short to have an impact on the SN Ia rate. This class probably includes T Pyx, whose outbursts do not seem to be recurrent any more on a fixed timescale but are also very long lasting. For comparison, U Sco, a non–red-giant RN system in which the decline of the optical light curve was instead very rapid, ejected only about $10^{-7} M_\odot$ (Williams et al. 1981). U Sco appeared as a supersoft X-ray source already 20 days after the outburst (Kahabka et al. 1999). This rapid evolution indicates a massive WD, which ejects little accreted mass but still retains part of it after the outburst. U Sco was not observed again in X-rays, so there is no estimate of the total amount of retained mass. Optical studies suggest, however, that only a small amount of mass was ejected, just what is required to trigger the nova explosion on a massive WD (Starrfield et al. 1985). If part of the envelope is retained after RN outbursts, then the RNe with unusually large envelope masses are of great interest for SN Ia theories because their WDs may grow rapidly to reach the Chandrasekhar mass.

Despite the unusually large optical luminosity, which is thought to indicate ongoing thermonuclear burning, T Pyx has not been detected as a supersoft X-ray source (Greiner et al. 2003), but it was observed only about 30 yr after the last outburst. Since the optical light curve of CI Aql evolved slowly ($t_3 = 30 \pm 1$ and $t_3 = 36 \pm 1$ days; Kiss et al. 2001), X-ray observations were done only less than a year and a half after the outburst, with the working hypothesis that the evolution in X-rays would be as slow as in the optical and that H burning would also last longer. However, X-ray emission was only detected from the ejecta and not from the central source (Greiner & Di Stefano 2002).

2. THE FIRST CHANDRA OBSERVATION

We asked to perform Chandra ACIS-S X-ray observations of IM Nor at much earlier epochs than those done for CI Aql, approximately 1 and 6 months postoutburst. The first observation was done during the Director’s Discretionary Time (DDT) with the comparison with U Sco in mind. The second observation was done in the framework of an accepted Target of Opportunity (ToO) program, based on the optical spectrum having become nebular (see § 3).

The date of the first observation was 2002 February 12, almost 4 weeks after optical maximum, with an exposure of 5630 s. The data were analyzed with the CIAO software for Chandra data analysis. One month postoutburst, U Sco had already become an X-ray supersoft source, and all observed novae were X-ray sources owing to shell emission (see Orio 2004). IM Nor, however, was not detected in this early observation, with an upper limit on the ACIS-S count rate of 0.0014 counts s$^{-1}$ in the 0.2–10 keV range. The value of the equivalent column density of neutral hydrogen, $N_H$, in the direction of the nova obtained from the NH program included in NASA’s FTOOLS (based on the maps of Dickey & Lockman 1990) yields an average $N_H = 8.15 \times 10^{21}$ cm$^{-2}$ in a cone of 1° radius in the direction of the nova, although there is a rather large uncertainty. Assuming a blackbody at $T = 30$ eV (e.g., Orio & Greiner 1999), and conservatively a rather large value $N_H = 10^{22}$ cm$^{-2}$ (which would imply some intrinsic absorption of the ejecta), this limit in the count rate translates into an upper limit to the X-ray flux at 0.2–10 keV, $F_X < 10^{-14}$ ergs cm$^{-2}$ s$^{-1}$. The flux upper limit is instead $F_X < 4 \times 10^{-14}$ ergs cm$^{-2}$ s$^{-1}$, assuming a thermal plasma at $kT = 3$ keV and $N_H = 10^{21}$ cm$^{-2}$ (appropriate for nebular X-ray emission after 1 month; e.g., Mukai & Ishida 2001). These fluxes correspond to X-ray luminosity $L_X = 1.2 \times 10^{32} (d~\text{kpc}^{-3})$ and 4.8 $\times 10^{32} (d~\text{kpc}^{-3})$ ergs s$^{-1}$, respectively.

3. CAVEATS FROM THE OPTICAL SPECTRUM

Optical spectra of IM Nor were obtained on 2002 April 29.40 UT on the NOAO Cerro Tololo Inter-American Observatory (CTIO) Blanco 4 m telescope using the Ritchey-Chretien spectrograph (f/7.8) with the Blue Air Schmidt camera and the Loral thinned 3K × 1K format CCD (Woodward et al. 2002). A 527 line mm$^{-1}$ grating (KPGL3) resulted in a dispersion of 1.91 Å pixel$^{-1}$. All spectra were obtained with a 1.3 wide slit and a UV (WG360; 3600 Å) blocking filter to reduce second-order contamination in the red. Complete details of observational and reduction techniques can be found in Skillman et al. (2003). One of three spectra is shown in Figure 1.

3.1. The Reddening

Because of the contamination of the H$\alpha$ line by the [N ii] line and of H$\gamma$ by the [O iii] line, we can only estimate the value of $E(B-V)$ with very large uncertainty. Measuring the equivalent width of the Na i line at 5890 Å yields an approximate value $E(B-V) \approx 1.1$ using the empirical relationship of Della Valle & Duerbeck (1993), but we caution that another empirical
relationship given by Barbon et al. (1990) yields only $E(B - V) \approx 0.50$. Following Ryter et al. (1975) we obtain $N_{\text{H}} \approx 7.4 \times 10^{21}$ cm$^{-2}$ in the first case and only $N_{\text{H}} \approx 3.4 \times 10^{21}$ cm$^{-2}$ in the second. In any case, these values do not exceed the one indicated by Dickey & Lockman (1990), and therefore we do not find evidence of intrinsic nebular reddening. This conclusion is definitely strengthened by the ratio of H$\alpha$/H$\beta$, which is known to be 0.26 in stationary conditions (when this ratio depends only on the recombination ratio). Intrinsic nebular reddening would cause a lower value to be measured. This ratio in our case is instead 0.51, which implies that optical depth effect and collisions changed the recombination ratios, and that we were able to observe the spectrum in which such effects occur. We came to the conclusion that intrinsic nebular reddening is absent and should not be added to the interstellar value. In other words, the nebular material was already optically thin at the date of this observation.

3.2. Can We Determine the Distance?

The distance to IM Nor is not known, and the distances to RNe in general are difficult to evaluate. For a classical nova, having an estimate of the reddening and of $t_2$, we should be able to derive the distance from the maximum magnitude versus rate of decline relationship (MMRD). However, even if some RNe, such as T CrB, RS Oph, and V745 Sco, seem to follow the MMRD, Warner (1995) notes that for T Pyx the MMRD yields $d = 1$ kpc, while the nebular parallax indicates $d = 1.5$ kpc. Moreover, observations of RNe in M31 (Capaccioli et al. 1989) and the LMC (Capaccioli et al. 1990) show that they are often 1–2 mag fainter than predicted by the MMRD. Woudt & Warner (2003) also note that the light curves of both CI Aql and IM Nor are different from these of classical novae, and that a correction to the MMRD relationship must be necessary. Adopting the MMRD of Della Valle & Livio (1995), but subtracting 1 mag from the value of the absolute magnitude at maximum, and using $E(B - V) = 1.1$, we obtain a distance range 3.8–4. kpc for $t_2 = 21 – 26$ days; however, with $E(B - V) = 0.50$ obtained with the Barbon et al. relationship, we obtain 1.5–1.6 kpc. Since IM Nor was a RN with a relatively massive envelope and did not eject as little mass as U Sco, the correction to the MMRD may be even much less than 1 mag, and an absolute upper limit can be considered $d = 6.4$ kpc, obtained without correction to the MMRD. 1.5–6.4 kpc is a large range, so we will continue to parameterize the luminosity as a function of the distance.

4. THE SECOND CHANDRA OBSERVATION

IM Nor was detected in X-rays when it was observed again for 4930 s with the ACIS-S 6 months after the outburst, on 2002 May 31. We knew that the nebula was optically thin to supersoft X-rays by this time, but the X-ray source was neither “supersoft” nor very luminous. Further LETG grating observations guaranteed for the ToO program in case of a bright nova were not scheduled because only very low signal-to-noise ratios (S/N) would have been achieved. The hard X-ray emission most likely originated in the ejected nebula (see Orio 2004, and references therein). The measured count rate was 0.267 ± 0.008 counts s$^{-1}$, a factor of 30 higher than for CI Aql 16 months after the outburst. The observations span about 59% of the orbital period, but we cannot detect nor rule out variability on timescales shorter than the observation time. The background corrected count rate varies only within a 2 $\sigma$ error.

In Figure 2 we show the Chandra ACIS-S X-ray spectrum and one possible model fit (see Table 1 and discussion below). At this stage IM Nor was a harder X-ray source than CI Aql, which is expected for an earlier cooling stage of the shell. We fitted the spectrum with several models available in the XSPEC software package (Arnaud 1996). In Table 1 we give the main parameters of the spectral fits and the value obtained for the reduced $\chi^2$. We let $N_{\text{H}}$ vary as a free parameter. If the spectral fit yields $N_{\text{H}} \leq 8.2 \times 10^{21}$ cm$^{-2}$, we consider the result consistent with only interstellar absorption. The power-law model does not give a good fit with reasonable parameters (we obtain a slope $\alpha = 3.6$ and $\chi^2$/dof = 1.5, where dof is degrees of freedom). We also used five thermal plasma models included in XSPEC. Using only one component, we obtain a relatively reasonable fit with the bremsstrahlung model of XSPEC, which yields $\chi^2$/dof = 1.2. This fit yields $N_{\text{H}} = 2.6 \times 10^{21}$ cm$^{-2}$, which does not indicate intrinsic absorption of the ejecta. X-ray fluxes $F_X$ and luminosity $L_X$ are measured in the 0.2–10 keV range. The observed flux is $F_X = 1.34 \times 10^{-12}$ ergs cm$^{-2}$ s$^{-1}$, corresponding to an unabsorbed flux $F_X = 2.10 \times 10^{-12}$ ergs cm$^{-2}$ s$^{-1}$ and to $L_X = 2.5 \times 10^{32}$ (d/1 kpc)$^2$ ergs s$^{-1}$.

One of the models’ parameters used in XSPEC is a constant “$N$”, which is a function of the distance $d$ to the source. For the bremsstrahlung model, $N = 3.02 \times 10^{-15} / (4 \pi d^2 EM)$, and for the MEKAL, VMEKAL, and Raymond-Smith models.
\[ N = 10^{-14}/(4\pi d^2 \text{EM}) \], where \( \text{EM} = \int n_e n_i \, dV \) is the emission measure, and \( n_e \) and \( n_i \) are the electron and ion density, respectively, integrated over the volume of the nova shell. In first approximation, we assumed \( \text{EM} = n_e^2 \nu \), where \( \nu \) is the volume of the shell. Since the velocity of the ejecta was around 1000 km s\(^{-1}\) (Durbeck et al. 2002), at the date of the observation \( \nu \simeq 8.75 \times 10^{45} \text{ cm}^3 \). Electron densities in the ejecta 6 months after the outburst are known to be in the range \( 10^{5} \) to a few \( 10^{6} \), implying a reasonable value for the electron density, \( n_e \approx 6.3 \times 10^{4} \text{ cm}^{-3} (d/1 \text{ kpc})^2 \), if all of the shell is emitting X-rays. We note, however, that the filling factor was only about 1/10 for V382 Vel (Della Valle et al. 2002) and probably much lower for Ty Pyx (Shara et al. 1997).

The Raymond-Smith model without additional components does not yield a good fit (\( \chi^2/\text{dof} = 2.5 \)). With the MEKAL model we could fit the spectrum only by allowing the metallicity parameter, \( Z \), to vary. We find a reasonable fit with a very low value, \( Z \approx 0 \). To better test the effect of the chemical composition, we tried the VMEKAL and the VRAYMOND models, which include abundances of several elements. We allowed the abundances of He, C, N, O, Ne, Mg, Ca, Fe, and Ni to vary freely. We obtained the best fits in both models with enhanced C and O and with depleted Fe. The most outstanding abundances are \( C/\text{O} = 160 \), \( N/\text{N} = 188 \), and \( \text{Fe}/\text{Fe} \approx 0 \) for VMEKAL, and close values were obtained using VRAYMOND. With VRAYMOND, the fit is slightly improved with \( \text{He}/\text{He} \leq 0.002 \), but low He abundance is not required fitting with the MEKAL model. These results are surprising (especially for iron, because IM Nor was an Fe II nova) but not conclusive. First of all, it is possible to fit the spectrum even better with solar abundances by adding an additional component (see below). Moreover, there may be nonionization equilibrium conditions (see discussion by Mukai & Ishida [2001] for Nova V382 Vel, for which iron was not detected in the X-ray spectrum).

As a next step, we tried fitting composite models. We added a blackbody component to the thermal plasma and obtained the best fit of all (\( \chi^2/\text{dof} = 0.95 \); see Fig. 1). The blackbody fit at \( T_{bb} = 70 \text{ eV} \) is obtained with a constant proportional to the bolometric luminosity and inversely proportional to the distance, and in our fit \( L = 2.5 \times 10^{31} (d/1 \text{ kpc})^2 \text{ ergs s}^{-1} \) (note that \( T_{bb} \leq 60 \text{ eV} \) is ruled out by the spectral fits). This value of the bolometric luminosity, for any value of the distance, is orders of magnitudes lower than those observed for supersoft X-ray sources (see review by Orio 2004). Thus, a blackbody component is likely to exist, but we are not observing the atmospheric emission of a significant portion of the surface of a hot, hydrogen-burning WD. The residuals in the fits (see Fig. 1) are suggestive of emission lines, like those observed previously for nova V382 Vel (Burwitz et al. 2002). Additional narrow Gaussian components at \( \approx 1 \text{ keV} \) and \( \approx 1.2 \text{ keV} \), at which residuals appear in the model fit, do not fit the data. Adding a Gaussian component at 1.94 keV (possibly due to a Ni xvi line) to the bremsstrahlung model, we improved the fit to some extent, although we did not improve it further by adding more Gaussian components. The low spectral resolution prevents a very thorough investigation of how emission lines may be altering the observed spectrum. All the spectral fits in Table 1 yield unabsorbed flux \( F_X = (1.2-2.4) \times 10^{-12} \text{ ergs cm}^{-2} \text{ s}^{-1} \), and \( L_X = (1.4-2.9) \times 10^{37} (d/1 \text{ kpc})^2 \text{ ergs s}^{-1} \). From the values of the emission measure, we derive electron density \( n_e \approx 10^{5} - 10^{6} \text{ cm}^{-3} \) for \( d \approx 4 \text{ kpc} \), if all the shell volume is filled.

We also tried fitting a two-component thermal plasma, the last in Table 1, which could originate in different clumps or layers of the ejected nebula and therefore be differently absorbed. Using the Raymond-Smith model for both, we find a heavily absorbed component at low temperature, filling a fraction of at least 1/10 of the ejected shell. The absorbed flux in this model would be \( 1.8 \times 10^{-12} \text{ ergs cm}^{-2} \text{ s}^{-1} \), corresponding to the high unabsorbed flux \( F_X = 6.1 \times 10^{11} \text{ ergs cm}^{-2} \text{ s}^{-1} \). However, the conclusions we derived from the optical spectrum rule out this component because of the high value \( N_{HI} = 3.2 \times 10^{22} \text{ cm}^{-2} \).

5. CONCLUSIONS

The upper limit on the X-ray luminosity of IM Nor 1 month after the outburst is unprecedented because all classical and recurrent novae that were observed at early postoutburst epochs
showed X-ray emission at $L_X > 10^{32}$ erg s$^{-1}$ earlier than 1 month after the outburst (see review by Ori 2004). Half a year after the outburst, the nova was detected as an X-ray source. Hard X-ray emission from the ejecta, with $L_X \approx 10^{31}$ erg s$^{-1}$, was the dominant component in the X-ray spectrum.

A blackbody component is also likely present in the X-ray spectrum of IM Nor, at high temperature, $T_{bb} \approx 70$ eV, but at such low luminosity, $L_X \leq 2.5 \times 10^{31}(d/1\text{kpc})^2$ ergs s$^{-1}$, that does not fit the observed characteristics of the supersoft X-ray sources in novae, and it is likely to have another origin, possibly a hot spot on the WD surface.

Did we observe IM Nor too early, when the supersoft emitting hot WD atmosphere was absorbed by the intrinsic column density of the ejecta? Even if the spectral fits do not allow us to rule this out completely because of the high value of $N_H$ for the first component of the double Raymond-Smith model in Table 1, the optical spectrum of the nova observed 1 month earlier shows that the ejecta were optically thin 5 months after the outburst. It is very unlikely that we had significant intrinsic absorption even 1 month later. Therefore, nuclear burning switched off, or was in the process of switching off, 6 months after the outburst. It takes about a year to terminate thermonuclear burning completely (D. Prialnik 2004, private communication). The mass-burning rate for stable hydrogen thermonuclear burning in the accreted shell is a few $10^{-7} M_\odot$ yr$^{-1}$, and the burnt mass must be added to the nonburnt mass. There is, in fact, a minimum mass necessary to sustain shell hydrogen burning, which is $M_{\text{min}} \leq 10^{-6} M_\odot$ for the expected WD mass in RNe, $M_{\text{WD}} \geq 1 M_\odot$ (Fujimoto 1982). This implies that the leftover mass after about 80 yr of recurrence time does not exceed $\lesssim (1.1-1.3) \times 10^{-6} M_\odot$.

If 80 yr is the average period between outburst, IM Nor accretes 0.1 $M_\odot$ in about $10^7$ yr, 10 times longer than the typical timescale assumed by Della Valle & Livio (1996) to accumulate this mass in a RN. Since these authors found that, even with an order-of-magnitude shorter timescale, RNe do not contribute significantly to SN Ia explosions, at least assuming the Chandrasekhar mass model for the outburst, RNe like IM Nor, hitherto thought to be the best candidate progenitor, appear to contribute at most in a negligible way to the SN Ia rate. Even if some outbursts were missed notwithstanding the long decline, the conclusion does not change because with such little leftover mass, the interoutburst time would need to be of the order of 1 yr to make IM Nor a “statistically significant” SN Ia candidate. We do not rule out that some RNe may become SNe Ia, but our result strengthens and makes more compelling the conclusion of Della Valle & Livio (1996): the path of a RN to a SN Ia takes such a long time that RNe cannot contribute significantly to the SN Ia rate. At least another class of progenitors other than RNe is needed to explain the observed SN Ia rate.

We are very grateful to H. Tananbaum for granting Director’s Discretionary Time for the first Chandra observation. We wish to thank B. W. Miller (Gemini Observatory) for his assistance in obtaining optical spectra. C. E. W. acknowledges support from NSF grant AST02-05814 for ground-based observations. S. Starrfield receives partial support from NSF and NASA grants to Arizona State University.

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