Novae: I. The maximum magnitude relation with decline time (MMRD) and distance

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March 2017

Abstract

The origin and calibration of the maximum absolute magnitude relation with decline time (MMRD) for novae, first derived by Zwicky (1936b), empirically validated by McLaughlin (1940) and widely used to estimate distances to classical novae and the near-constancy of the absolute magnitude of novae, 15 days after optical maximum, suggested by Buscombe & de Vaucouleurs (1955) are revisited in this paper and found to be valid. The main results presented in the paper are: (1) A physical derivation of the MMRD based on instantaneous injection of energy to the nova system. (2) A significantly better-constrained MMRD: $M_{V,0} = 2.16 \pm 0.16 \log_{10} t_2 - 10.804 \pm 0.117$ using a two step calibration procedure. (3) It is shown that the MMRD is one of the best distance estimators to novae available to us and that accuracy of the distances is predominantly limited by an underestimated peak apparent brightness. (4) It is shown that the same MMRD calibration is applicable to novae of all speed class and to both Galactic and extragalactic novae. (5) It is shown that the absolute magnitudes of novae with $2.4 \leq t_2 \leq 86$ days have a smaller scatter on day 12 ($M_{V,12} = -6.616 \pm 0.043$) compared to day 15 following optical maximum.

We reiterate the need for homogenised high fidelity spectrophotometric data in optical bands on classical and recurrent novae in outburst to effectively utilise the potential of the MMRD and $M_{V,12}$ in determining their luminosities and distances.

Keywords

Classical novae, recurrent novae, MMRD, absolute magnitude, light curves, emission line widths, distance to novae.

1 Introduction

It is now well-established that novae are stellar binaries consisting of a white dwarf known as the primary and a gaseous companion star known as the secondary which is either a main sequence star, a sub-giant or a red giant star. Novae are classified into three types - classical novae for which only one major outburst has been recorded, recurrent novae for which more than one major outburst has been recorded and dwarf novae which show low amplitude frequent outbursts. During an outburst in classical and recurrent novae, the quiescent system can brighten by 8 – 20 magnitudes in a day or so whereas a dwarf nova system brightens by 2 – 6 magnitudes in a short time. The physical mechanism responsible for the brightening of dwarf novae is believed to be different from that for classical and recurrent novae. While classical and recurrent novae show evidence for ejection of matter by the white dwarf, no such evidence has been found for dwarf novae.

Estimating distances to astronomical objects has always been a difficult task. Distances to novae are also difficult to estimate and suffer from large uncertainties which in turn lead to uncertainties in the intrinsic luminosity of novae outburst when estimated by using the distance. Several methods have been employed to estimate distances to classical novae and these have been explained in McLaughlin (1942). Expansion parallax, intensities of Calcium lines, Galactic rotation contribution to the velocities of interstellar Calcium lines, reddening with distance etc are some methods which have been used to estimate distances to novae. A reliable distance estimator which is often used is the observed angular expansion of ejecta shells around old classical novae along with their expansion velocities although this can only be used for novae for which the explosion has left behind a detectable shell. Distances are also estimated using the maximum (absolute) magnitude relation with decline time (MMRD) and it has been remarkably successful as a statistical tool since the uncertainties in the peak absolute magnitude and distance estimate for a given nova are found to be large. In this method, the peak luminosity of the nova outburst can be estimated without knowing the distance to the nova. The distance is then determined using the maximum luminosity and the observed peak apparent brightness of the nova. However the MMRD needs to be calibrated before it can be used to estimate the peak absolute magnitudes of novae.

That a relation between decline time and maximum luminosity should exist for novae outbursts was first suggested by Zwicky (1936b) under the assumption that there is an instantaneous release of energy in a nova explo-
sion. Zwicky found that the peak visual luminosity can be inferred from both the ejecta velocity and expansion-luminosity relation (Zwicky 1936a) and the decline time of luminosity relation (Zwicky 1936b) which he then combined to get a life-expansion relation. However there were errors in these relations which were pointed out and corrected by McLaughlin (1940) who also presented empirical evidence in support of the corrected relation. In the corrected MMRD, the most luminous nova outbursts are the fastest ones i.e. novae in which the decline in luminosity is most rapid. Since then the relation has been widely calibrated (e.g. Arp 1956; Schmidt 1957; McLaughlin 1960; Cohen 1985; della Valle & Livio 1995; Downes & Duerbeck 2000) and used as a distance estimator. While the importance and potential of the MMRD for estimating distances has been widely appreciated, its physical origin continues to baffle us. To understand and possibly rectify this, we explored a physical treatment based on the original assumption of rapid injection of energy which we find works remarkably well in deriving the life-expansion relation and the MMRD. A two-step calibration procedure using available observational data on novae results in a more reliable MMRD. Novae are classified into two main speed classes namely fast (or flashing) and slow based on their rate of decline (Gerasimovic 1936). Since decline rates of novae of different speed classes are not same, Buscombe & de Vaucouleurs (1955) explored the possibility that their light curves would intersect on some day following the optical maximum and presented evidence for the same. With more data now available, we revisit this in the paper. We use the data on classical, recurrent and dwarf novae in our Galaxy from the following papers in literature: McLaughlin (1960); Cohen & Rosenthal (1983); Cohen (1985); Warner (1987; 1995); Downes & Duerbeck (2000); Schaefer (2010); Strope et al. (2010); Schwarz et al. (2011). Data on extragalactic novae are used from Arp (1956); Rosino (1964); Pritchett & van den Bergh (1987); Shara et al. (2016).

2 The MMRD

In this section, we discuss the physical origin of the MMRD for classical (and recurrent) novae, devise a better method to calibrate it based on Zwicky’s suggestion and then use the relation to estimate the peak absolute magnitude of several novae.

2.1 The origins of the MMRD

The MMRD, originally referred to as the life-luminosity relation was first suggested and derived by Zwicky (1936b) under the assumption of instantaneous release of energy in a nova outburst. ‘Life’ here refers to the decline time. He derived the life-luminosity (peak absolute magnitude $M_0$) relation as:

$$M_0 = -5\log(\Delta m) + \text{constant}$$

where $t_{\Delta m}$ is defined as the time in which the nova is brighter than $M_0 + \Delta m$. Based on the observational data available at that time, Zwicky suggested that $\Delta m$ should be taken to be 2 or 3. Hence $\Delta m = 1$ should also work if data quality and temporal sampling are sufficient. He also obtained the expansion-luminosity relation between the ejecta velocity $\Delta v$ and $M_0$ as:

$$M_0 = -5\log(\Delta v) + \text{constant}$$

The above two expressions were combined to obtain a relation between observables (Zwicky 1936b) i.e. the life-expansion relation:

$$\log(t_{\Delta m}) = \log(\Delta v) + \text{constant}$$

Zwicky (1936b) calibrated this relationship using some of the available data in 1936 and then transferred it to Equation 1 to estimate the peak absolute magnitude and noted that this relation would be useful in determining the distance to a nova. However he combined data on novae and supernovae which resulted in an error in calibration of the relation. Thus, Zwicky deduced that slow novae are intrinsically more luminous than fast novae which was contrary to results from observations of novae. This calibration error was explained and resolved by McLaughlin (1940) who also provided a calibration of the relation in Equation 3 from observational data on novae. Thus, while Zwicky found a direct relation between the $t_{\Delta m}$ and $\Delta v$, observations were explained by an inverse relation (McLaughlin 1940). Using the velocity displacements $V$ of the principal series of absorption lines as representative of the ejecta velocity, McLaughlin (1940) found that

$$\log V = 3.19 - 0.49 \log t$$

Moreover from observational data on novae, McLaughlin (1940) arrived at three important conclusions on spectral and light curve evolution of novae which, like the MMRD, have stood the test of time and been borne out by subsequent observations. These were: (1) that the observed spectral stage of a nova depends on the light curve evolution; (2) that the decline time is inversely proportional to the square of the velocity of the principal spectrum (Equation 4); and (3) that velocity of the diffuse enhanced spectrum is generally twice the principal spectrum velocities. McLaughlin (1960) and Gaposchkin (1957) presented extensive summaries and interpretation of the photometric and spectroscopic data in the optical bands on novae.

2.2 The physical origin of the MMRD

Here we revisit the origin of the MMRD using simple physical arguments. We start with the original assumption under which Zwicky (1936b) derived the life-luminosity relation (Equation 1) namely that most of the energy in a nova outburst is released in a short time. This assumption is validated by the extremely rapid rise ($\sim$ day) in the optical emission to maximum ($\sim 10^8$ to $10^9$ times increase in quiescence luminosity) detected in classical and recurrent novae. We then derive the life-expansion and life-luminosity relations. We, especially, note that the relation between the expansion velocity and decline time
that was empirically found by McLaughlin (1940) naturally follows from the physical arguments presented here. We proceed as follows.

The total energy $E_{\text{tot}}$ released in the cataclysmic thermonuclear explosion on the white dwarf is immediately released in the form of kinetic energy imparted to the matter overlying it in the relatively lower density envelope on the surface of the degenerate white dwarf. This, in a general case, can lead to two physical manifestations - a macroscopic bulk motion which accelerates and ejects matter and a microscopic random motion component which leads to localized motions of the constituent atoms and molecules in the ejecta. Due to the first component, the ejecta starts to expand and we refer to this energy component as $E_{\text{kin}}$. Due to the second component, the ejecta material can get collisionally ionized and start radiating. We refer to this radiating energy component as $E_{\text{rad}}$. Both are a result of the kinetic energy imparted to the ejecta by the explosion. So larger is $E_{\text{tot}}$, larger are $E_{\text{kin}}$ and $E_{\text{rad}}$ although they need not be in equipartition. Thus, just after the explosion:

$$E_{\text{tot}} = E_{\text{kin}} + E_{\text{rad}}; \quad E_{\text{kin}} \propto E_{\text{rad}} \quad (5)$$

In rest of this discussion, we are concerned with the parameters near peak optical emission when the optical depth of the ejecta becomes one as it expands, soon after the outburst. Thus the quantities like luminosity and ejecta velocity used below refer to values at or close to the peak optical emission. More energetic the outburst, faster will be the expansion of the ejecta. The maximum kinetic power will be proportional to the kinetic energy imparted to the nova ejecta which leads to its expansion. Thus,

$$L_{\text{kin}} \propto E_{\text{kin}} = \frac{1}{2} m_{\text{ej}} v_{\text{ej}}^2; \quad L_{\text{kin}} \propto v_{\text{ej}}^2 \quad (6)$$

where $v_{\text{ej}}$ is the expansion velocity of the ejecta of mass $m_{\text{ej}}$. For now we assume that there is no systematic effect of variation in $m_{\text{ej}}$ on $L_{\text{kin}}$ although we are aware that the range of $m_{\text{ej}}$ can lead to a scatter on the MMRD. This and several other arguments are motivated by the apriori information that the MMRD has been supported by observational data on novae. We, thus, probe the physics behind MMRD with appropriate assumptions where required.

The maximum radiative energy of the nova will determine its radiative luminosity which is often estimated to be close to the Eddington luminosity at the peak of the optical light curve. Given $E_{\text{rad}}$, we can estimate $L_{\text{rad}}$ by dividing the former by the time during which the nova radiates close to its peak luminosity. Since we do not know this time, another way to get a lower limit to $L_{\text{rad}}$ is to divide the energy by $t_2$ which is the time taken by the light curve to fall by 2 magnitudes from the peak. Another way to understand this is that the average luminosity of the nova when it is brighter than $M_{\text{V,0}} + 2$ can be estimated by dividing the maximum radiated energy by $t_2$. This gives a lower limit to the peak luminosity. Thus if $E_{\text{rad}}$ is a constant, then this means that $L_{\text{rad}}$ will be larger for faster novae.

$$L_{\text{rad}} > \frac{E_{\text{rad}}}{t_2}; \quad L_{\text{rad}} \propto t_2^{-1} \quad (7)$$

For practical purposes, we use the proportionality relation. For now, we assume no systematic relation between $E_{\text{rad}}$ and $L_{\text{rad}}$ exists and also note that if the derivation and calibration of MMRD presented here succeed in explaining observations, then it would give strong support to Equation 5. Equation 7 then results in the life-luminosity relation or the MMRD since the peak absolute magnitude is:

$$M_0 = -2.5 \log_{10} L_{\text{rad}} + K \text{ or } M_0 = -2.5 \log_{10} t_2^{-1} + K_1 \quad (8)$$

This is different from Equation 1 which Zwicky (1936) had derived. From Equations 5, 6, 7 for the rapid induction of energy in the nova system, we have:

$$L_{\text{kin}} \propto L_{\text{rad}}^2 \text{ i.e. } v_{\text{ej}}^2 \propto t_2^{-1} \quad (9)$$

This is the relation that McLaughlin (1940) had deduced (see Equation 4) from observations of the principal spectrum lines and the light curve as mentioned in the previous subsection. Equation 9 gives the life-expansion relation i.e.

$$\log_{10} t_2^{-1} = 2 \log_{10} (v_{\text{ej}}) + A_2 \quad (10)$$

This equation is different from what Zwicky (1936b) had derived as given in Equation 5. Since larger volumes of data are now available to determine the constants in the expression, we can write the life-expansion relation in a more general form:

$$\log_{10} t_2 = A_1 \log_{10} (v_{\text{ej}}) + A_2 \quad (11)$$

where $v_{\text{ej}}$ can be determined from the widths of emission lines recorded near optical peak. From Equation 9 we can write $L_{\text{rad}} \propto v_{\text{ej}}^2$ which then gives us the expansion-luminosity relation as follows:

$$M_0 = -2.5 \log_{10} v_{\text{ej}}^2 + K_2 = -5 \log_{10} v_{\text{ej}} + K_2 \quad (12)$$

This equation is similar to Equation 2 that Zwicky (1936b) had derived. The match with observations, as we demonstrate in the next sections, suggest that the physical treatment of the energetics of a nova explosion presented here and the assumptions implicit in deriving these encapsulate the macroscopic properties of a nova explosion.

### 2.3 Calibrating the MMRD

We use the life-luminosity and life-expansion relations of Equations 8 and 11 to calibrate the MMRD. We determine the constants $K_1, A_1, A_2$ from observational data in literature following a two-step procedure. We start with the relation in Equation 11 and use observational data on emission line widths ($\Delta v$) estimated near the optical peak as indicative of the ejecta velocity and $t_2$ to determine the constants $A_1, A_2$. The data on $\Delta v$ and $t_2$ for 51 novae are taken from Schwarz et al. (2011) and these
are plotted in Figure 1 and listed in Table 2 in the Appendix. The ∆v have been estimated from the widths of the Hα or Hβ emission lines near visible maximum (Schwarz et al. 2011). t2 is in days and ∆v is in kms\(^{-1}\). The best least squares fit to the data is obtained when A1 = -0.8655 ± 0.15 and A2 = 3.8276 ± 0.51 which is shown by the line in Figure 1. Thus, the life-expansion relation which encapsulates their inverse relation is:

\[
\log_{10} t_2 = -0.8655(±0.15)\log_{10} ∆v + 3.8276(±0.51)
\]  

(13)

We keep in mind that the signs of the coefficients will be the same when transferred to the \(t_2 \rightarrow \log_{10} t_2\) relation and will change when the MMRD in magnitudes is estimated. The 51 data points used to derive the above relation also includes three novae in the Large Magellanic Cloud (LMC), the very slow nova V723 Cas and recurrent novae.

For the same data shown in Figure 1 we can fit the functional form: \(\log_{10} ∆v = -0.44(±0.08)\log_{10} t_2 + 3.7(±0.09)\) which compares remarkably well with the relation \(\log_{10} V = -0.5\log_{10} t_2 + 3.57\) derived by McLaughlin (1960) using the line shifts of the principal absorption lines. \(t_2\) is in days and ∆v, V are in kms\(^{-1}\). These relations are not very different from Equation 1 obtained in 1940 giving strong support to the correlation which has stood the test of time and has been verified on larger volumes of data. We also fitted the available data on ∆v and t3 for 22 novae listed in Strope et al. (2010). The best least square fit gives the relation \(\log_{10} t_3 = -1.08(±0.28)\log_{10} ∆v + 5.01(±0.95)\). We continue the calibration of the MMRD with Equation 13.

At the end of the first step, we have calibrated the relation between the ejecta velocity and decline time. In the second step, we transfer this to the MMRD in Equation 8 and fine-tune the zero-point i.e. estimate K1. Substituting from Equation 13 and retaining \(\log_{10} t_2\) as the variable, we have \(M_{V,0} = -2.5(-0.8655\log_{10} t_2 + 3.8276) + K_1\) i.e.:

\[
M_{V,0} = 2.16(±0.15)\log_{10} t_2 - 9.57(±0.51) + K_1.
\]  

(14)

This relation with \(K_1 = 0\) along with the one sigma uncertainties are plotted with lines in Figure 2(a). The over-plotted ~60 points show the peak absolute magnitude of several novae in the V band estimated using other methods. These data have been taken from Cohen & Rosenthal (1983), Cohen (1985), Downes & Duerbeck (2000), Schaefer (2010). There is clearly an offset between the peak absolute magnitudes predicted by the fit as shown by the lines and the data since we have set \(K_1 = 0\). To estimate \(K_1\), we used the same data plotted in Figure 2(a) since these have been carefully estimated in most cases for calibrating the MMRD. We then fixed the rate of change in \(M_{V,0}\) with \(\log_{10} t_2\) i.e. the coefficient of \(\log_{10} t_2\) to 2.16 as given in Equation 13 and started with the initial guess of -9.57 for the intercept. The best least squares fit is the following and which is shown in Figure 2(b) along with 1σ errors:

\[
M_{V,0} = 2.16(±0.15)\log_{10} t_2 - 10.804(±0.117).
\]  

(15)

The fit from Equation 15 in Figure 2(b) is remarkably good and the scatter on the determination of the absolute magnitude is less than 0.5 magnitudes especially for fast novae. That the MMRD presented here is the best calibrated and reliable relation is demonstrated by comparing with the MMRD calibrations that exist in literature:

1. \(M_{V,0} = -11.5 + 2.5\log t_3\) by Schmidt (1957); McLaughlin (1960).
2. \(M_{V,0} = -10.66(±0.33) + 2.31(±0.26)\log t_2\) by Cohen (1985).
3. \(M_{V,0} = -7.92 - 0.81\arctan \frac{1.32 - \log t_2}{0.23}\) by della Valle & Livio (1995).
4. \(M_{V,0} = -11.32(±0.44) + 2.55(±0.32)\log t_2\) and \(M_{V,0} = -8.02 - 1.23\arctan \frac{1.32 - \log t_2}{0.23}\) by Downes & Duerbeck (2000).

Clearly the MMRD calibrated using the two-step procedure has resulted in a well-constrained MMRD. The first step exclusively uses directly observed quantities. The calibration has also used larger datasets than previously employed. Figure 2 demonstrates that a carefully calibrated MMRD can result in well-constrained peak absolute magnitude of a nova and that a single MMRD can be used for all speed classes of classical and recurrent novae. It has helped that we were aware of the success of the MMRD in determining the peak absolute magnitudes of novae in outburst which was not the case in the early days of the MMRD.
Figure 2: Step two in calibrating the MMRD. The data on the peak absolute magnitudes on about 60 novae which have been derived using mostly methods other than MMRD are plotted with a distinct symbol corresponding to one of the references - Cohen & Rosenthal (1983); Cohen (1985); Downes & Duerbeck (2000); Schaefer (2010). (a) The MMRD, after the calibration shown in Figure 1 is transferred via Equation 8, is shown by the solid line. The dashed lines represent the 1σ errors on the MMRD peak absolute magnitudes. Note the offset between the MMRD-determined peak absolute magnitudes and the data. (b) The final calibrated MMRD after determining the correct zero-point. $M_{V,\text{peak}} = 2.16 \log_{10} t^2 - 10.804$ and the dashed lines on either side are the 1σ errors. Note the lower uncertainties on this MMRD compared to (a) and the offset between the data and the fit has now been calibrated.
of change in M
on each dataset is the MMRD-like relation with the same rate for the three types of dwarf novae (Warner, 1995). Overplotted of classical novae (filled circles) (Strope et al., 2010) and do not follow the MMRD. (b) Figure shows the outburst ampli-
Warner (1987, 1995) are shown by the symbols. Dwarf novae shown as the solid line and the data on dwarf novae taken from

Figure 3: (a) The MMRD of Equation 15 for classical novae is shown as the solid line and the data on dwarf novae taken from
Warner (1987, 1995) are shown by the symbols. Dwarf novae do not follow the MMRD. (b) Figure shows the outburst ampli-
tude of classical novae (filled circles) (Strope et al., 2010) and for the three types of dwarf novae (Warner, 1995). Overplotted on each dataset is the MMRD-like relation with the same rate of change in $M_{V,0}$ with $t_2$. The zero-points have been inde-
pendently estimated for the two types of novae. Note the good match between data and MMRD-like relation for both types of novae.

2.4 Dwarf novae

Here we examine the applicability of the MMRD to dwarf novae. In Figure 3(a), we have plotted the data on a few dwarf novae for which both the peak absolute magnitudes taken from Warner (1987) and $t_2$ taken to be double of $t_1$ listed in Warner (1995) were available. The line shows the MMRD of Equation 15. The data on dwarf novae do not follow the same trend as classical novae. In fact the data seems to suggest that there is no trend or that the trend is opposite to that of classical novae. Hence an MMRD with a modified zero-point will not be applicable to dwarf novae. In Figure 3(b), the outburst amplitude $A_n$ is plotted against $t_2$ for a sample of classical novae taken from Strope et al. (2010). A trend similar to the MMRD in terms of the magnitude of the rate of change in brightness with $t_2$ is noticeable in $A_n$. Thus, using the same magnitude of the coefficient of $\log_{10} t_2$ in the MMRD of Equation 15 with a reversed sign, we find the best least squares fit to the data is $A_n = -2.16 \log_{10}(t_2) + 13.68(0.23)$ which is overplotted on the data. The data on dwarf novae taken from Tables 3.1, 3.2 and 3.3 in Warner (1995) for the three types of dwarf novae namely the Z Cam, U Gem and SU UMa are also plotted in Figure 3(b). In this case, the trend followed by the dwarf novae is similar to classical novae and hence just a modified zero-point is required. The best fit ($A_n = -2.16 \log_{10}(t_2) + 4.83(\pm 0.16)$) is overplotted on the data points in the lower part of the figure. The same rate of change in the outburst amplitude with $t_2$ can be suggestive of a common origin of the V band emission in both types of novae. We recall that the original calibration of the MMRD slope was from the fit to the ejecta velocity and $t_2$. The difference between the behaviour in the two panels for dwarf novae might be because both the peak and quiescence absolute magnitudes of dwarf novae have been found to show a relation with the orbital period of the binary (Warner, 1987). In Figure 4(a), the orbital period is plotted against $t_2$ and a correlation between the
two quantities is noticeable so that the novae with longer orbital periods have longer decline times. This has already been pointed out by Warner (1995). From the figure, it is not clear if there is any correlation between $P_{\text{orb}}$ and $t_2$ for the SU Uma class of dwarf novae. In Figure 5(b), the data on classical novae taken from Schwarz et al. (2011) have also been included. No correlation between orbital period and decline time is discernible for classical novae. In Figure 5, the orbital period of the binary and outburst amplitude for dwarf novae are plotted. Data have been taken from Warner (1995). Z Cam dwarf novae seem to show a correlation between $P_{\text{orb}}$ and $A_n$ whereas the U Gem and SU UMa do not (see Figure 6).

The behaviour of the observables plotted in Figures 4 and 5 can give us important insight into the physical processes which could be common or otherwise between classical and dwarf novae and can help enhance our understanding of novae. A quick analysis suggests that some of the differences could be in the energetics of the outburst which are different for classical and dwarf novae. So for example, the outburst could be influenced by the companion star in dwarf novae whereas the companion would play no role in an energetic classical nova outburst. However, this needs to be examined in detail, with available data on these objects before any conclusions are drawn.

2.5 Using the MMRD to estimate $M_{V,0}$

We used the MMRD in Equation (15) to estimate the peak absolute magnitudes of classical and recurrent novae for which $t_2$ is taken from literature and these are shown in Figure 6. Most of the novae have $M_{V,0}$ between $-6$ and $-10$ magnitudes which correspond to peak luminosities $10^{4.17} - 10^{5.17} L_\odot$. We have taken $t_2$ for 51 novae from Schwarz et al. (2011), 93 novae from Strope et al. (2010), 10 recurrent novae from Schaefer (2010) and 35 novae from McLaughlin (1960). The estimated $M_{V,0}$ along with 1σ uncertainties are listed for all these novae in Tables 2, 3, 4, 5 in the Appendix. Several novae are common to the different publications but sometimes listed with different $t_2$. For example, there are 22 common novae in the catalogues by Strope et al. (2010) and Schwarz et al. (2011) and owing to the different listed values of $t_2$ for some novae, different $M_{V,0}$ are determined by the MMRD for the same nova. We have estimated and listed $M_{V,0}$ for the repeat entries also. It is important to homogenise all the data that are available on novae so that the same values determined from light curves and spectra can be universally used and which can help reduce the uncertainties introduced into the peak absolute magnitudes due to varying values of observables used by different astronomers. The median value of $M_{V,0}$ of the $\sim 160$ novae shown in Figure 6 is $-8.5$ magnitudes whereas the mean value is $-8.3$ magnitudes. We recall that the median of the peak absolute magnitudes of 10 novae derived from different distance methods (McLaughlin 1960) are: from nebular expansion method: $-8.1$ magnitudes, from interstellar line intensity: $-7.6$ magnitudes, and from Galactic rotation method: $-7.6$ magnitudes and from the trigonometric parallax: $-7.3$ magnitudes. There is a large distribution ($-7.1$ to $-10.6$ magnitudes) in the peak absolute magnitudes estimated for recurrent novae (blue symbols in Figure 6) since the $t_2$ of the ten recurrent novae range from 1.2 to 50 days (Schaefer 2010). Since recurrent novae are believed to be a possible progenitor channel for SN 1a, it is intriguing that the recurrent novae show a relatively large range in their $t_2$ and hence $M_{V,0}$. The decline times and peak absolute magnitudes of SN 1a are generally observed to be constrained to a narrow range, thus, making them ‘standard candles’.

Figure 5: The orbital period is plotted against the outburst amplitude for dwarf novae. Data taken from Warner (1995). A correlation is noted for the Z Cam DN.

Figure 6: Peak absolute magnitude determined from the MMRD using the observed $t_2$ on 51 novae from Schwarz et al. (2011) (crosses), on 93 novae from Strope et al. (2010) (stars), 10 recurrent novae from Schaefer (2010) (squares) and 35 novae from McLaughlin (1960) (circles). The median value of the absolute magnitude distribution is $-8.5$ magnitudes and the mean value is $-8.3$ magnitudes. Most of the novae have a peak absolute magnitude between $-6$ and $-10$ magnitudes.
3 Distances to novae from MMRD

Now that $M_{V,0}$ for a nova has been determined from the MMRD as explained in the previous section, the distance to that nova can be calculated if the peak apparent magnitude in the V band, $m_{V,0}$ of the nova is precisely known. The distance modulus which is useful for quoting extragalactic distances is defined by:

$$m_{V,0} - M_{V,0} = 5\log_{10}(\frac{D}{10}) \text{ magnitudes}$$

where $D$ is the distance to the nova in parsecs, which is generally used for quoting Galactic distances, will be:

$$D = 10^{0.2(m_{V,0} - M_{V,0}) + 1} \text{ pc}$$

If extinction $A_V$ to the nova is known then including it will modify the apparent magnitude in Equation 17 to $m_{V,0} - A_V$ which will reduce the distance estimate. In the following sections, we estimate the distances to the novae for which $M_{V,0}$ has been determined from the MMRD of Equation 15 and $m_{V,0}$ is available. We discuss the results on Galactic and extragalactic novae.

3.1 Galactic novae

Distances estimated from Equation 17 using the MMRD $M_{V,0}$ and $m_{V,0}$ taken for 51 novae from Schwarz et al. (2011), 93 novae from Strope et al. (2010), 10 recurrent novae from Schaefer (2010) and 35 novae from McLaughlin (1960) are shown in Figure 7 and tabulated in Tables 2, 3, 4, 5 in the Appendix. The three novae in LMC from Table 2 are not included in the figure. Many Galactic novae appear to lie beyond 20 kpc and two novae are even placed at a distance of 100 kpc! These large distances for Galactic novae are clearly unrealistic and indicate an error in $M_{V,0}$ or $m_{V,0}$ which is propagated to the distance estimate where it is easily identifiable.

The uncertainty on the distance estimates plotted in Figure 7 reflect the uncertainty in the MMRD-determined peak absolute magnitudes and these appear to be fairly small indicating well-constrained distance estimates especially for novae which have distances smaller than Galactic dimensions. The uncertainty on the peak absolute magnitude and hence distance, assuming $m_{V,0}$ is precise, is smallest for the fastest novae (see Figure 2b)). For example, KT Eridani which has a $t_2 = 6.6$ days, MMRD finds $M_{V,0} = -9(-9.3, -8.8)$ magnitudes and if $m_{V,0} = 5.42$ magnitudes, then it is located at a distance of 7.8(8.7, 7) kpc while V382 Vel which has a $t_2 = 4.5$ days, MMRD finds $M_{V,0} = -9.4(-9.6, -9.2)$ and for $m_{V,0} = 2.85$ magnitudes, it is located at a distance of 2.8(3.1, 2.5) kpc (see Table 2). If the value of $t_2$ is correct to within a day or so then the value of $M_{V,0}$ is likely to be correct for the nova other than the very fast ones since $M_{V,0}$ is estimated from the logarithm of $t_2$. Thus it is more likely that the distance errors result from an erroneous $m_{V,0}$. $m_{V,0}$ could be in error for fast novae if the peak of the optical light curve is missed i.e. the nova is detected post-maximum. In this case, the large distances would have been estimated
3.2 Novae in M31

The MMRD in Equation 15 was used to estimate the peak absolute magnitudes of the novae recorded in outburst in the neighbouring galaxy M31 and the distance modulus was estimated for the novae whose $t_2$ and $m_{V,0}$ are taken from Arp (1956); Rosino (1964). The results are plotted in Figure 8 and tabulated in Table 6 in the Appendix. Arp (1956) found that the novae in M31 and our Galaxy had a similar distribution of peak absolute magnitudes and light curve characteristics. We also recall that Hubble (1929) had concluded from his study which detected 69 new novae in M31 that the mean light curve of novae in M31 was similar to that of Galactic novae. Moreover Hubble (1929) had estimated that the peak absolute magnitudes of novae in M31 were distributed within $\sim$ 4 magnitudes and that the rate of novae were about 30 per year in M31 which we note are similar to what we know for our Galaxy. This would then imply that novae in both galaxies share common physics and the same MMRD would apply to novae in M31 and in our Galaxy. However some subsequent studies in literature have hinted at an independent MMRD calibration for novae in M31. We revisit this issue here using our better calibrated MMRD. In Figure 8(a), $M_{V,0}$ of novae estimated using the MMRD are plotted versus $m_{V,0}$ and since the novae lie at almost the same distance from us, the expected correlation of intrinsically bright novae also appearing brighter in the apparent magnitude is discernible. This is encouraging for the MMRD since $M_{V,0}$ has been estimated from the recorded $t_2$ whereas $m_{V,0}$ has been independently recorded. The plot shows that the distances estimated to these novae against their $t_2$ as shown in Figure 7(b). We note that all the three novae with distance estimated to be $> 80$ kpc are fast with $t_2 < 10$ days. Also most of the novae for which distances $> 20$ kpc are estimated have a $t_2 < 25$ days. This, then, suggests that the recorded value of $m_{V,0}$ could be offset from the actual peak apparent magnitude due to the detection of the nova when it has already started its decline. We examine this further in section 3.4. Interestingly, the larger-than-Galaxy distances ($> 20$ kpc) are estimated for only 2/35 novae listed in McLaughlin (1960) as compared to 25/48 for novae listed in Schwarz et al. (2011), 24/93 for novae listed in Strope et al. (2010) and 6/10 recurrent novae with data taken from Schaefer (2010). Such results have prompted suggestions in literature on limitations of the MMRD, on the requirement of separate MMRD calibration for fast and slow novae; that MMRD is not applicable to recurrent novae. Such hasty conclusions are wrong and are arrived at before ruling out other more obvious reasons. The MMRD of Equation 15 plotted in Figure 2 and the estimated $M_{V,0}$ shown in Figure 6 strongly argue for the applicability of the same MMRD to both classical and recurrent novae irrespective of the speed class as long as an accurate $t_2$ is available. We examine, in detail, the possible reasons for the wrong distance estimates in section 3.4.

![Figure 8](image-url)

Figure 8: The $M_{V,0}$ estimated using the MMRD relation for novae in M31. $t_2$ taken from Arp (1956); Rosino (1964). (a) $M_{V,0}$ is plotted versus the recorded peak apparent magnitude taken from the same two references. (b) The distance modulus is plotted versus the peak apparent magnitude. (c) The distance modulus is plotted versus the peak absolute magnitude for the novae in M31 and six novae in galaxies in the Virgo cluster listed in Pritchet & van den Bergh (1987) and 21 novae in M87 from Shara et al. (2016).
peak absolute magnitudes of most novae in M31 lie between $-6$ and $-9.5$ magnitudes which is similar to novae in our Galaxy as Arp and Hubble had already noted (see Figure 6). The outlier points such as intrinsically bright but apparently faint or vice versa might indicate an error in t$_2$ or m$_V$,0 or are novae for which the scatter on MMRD is larger due to our assumptions in Section 2.2. In Figure 6(b), the distance modulus is plotted which places most of the novae between 24 and 26.8 magnitudes. The mean of the distance modulus estimated for the 57 novae in M31 is 25.01 magnitudes. A quick analysis of the results for M31 shows that there are three novae from Arp’s catalogue which appear as the outliers in Figure 6. One of the outlier points is a bright nova (M$_{V,0}$ $\sim$ $-8.6$ magnitudes) but is recorded to be fairly faint at maximum thus placing it a large distance of 26.8 magnitudes. From examining the light curve of this nova in Arp’s paper (No 4), we find that it was detected before optical maximum. It is hence difficult to understand the cause of such a large distance estimate in terms of observational quantities since both m$_V$,0 and t$_2$ appear correct. We do not comment on it further here but keep it aside for possible future study. The remaining two outlier novae are estimated to be the intrinsically brightest of the sample at M$_{V,0}$ = $-10.2$ magnitudes but do not appear bright enough in m$_V$,0 so that they are placed at a large distance of 25.9 magnitudes. On examining the light curves of these two novae in Arp’s paper (No 1,2), we note that for neither nova which are very fast at t$_2$ = 2 days, the peak apparent magnitude has been observationally recorded. m$_V$,0 has been interpolated in the first case and extrapolated in the second case and hence the possibility of these being underestimated cannot be ruled out. If these three novae are not included then the 25 novae in the Arp sample give a distance modulus of 24.8 magnitudes to M31. It would be premature and hasty to disbelieve the MMRD or cast doubts on the relation based on such rare outlier points when it is found to work well with most novae. In fact, such outlier points should be examined in detail. In Figure 6(c), the distance modulus is plotted against M$_{V,0}$ for the novae in M31 and Virgo cluster. In both cases, we note that the scatter on the distance modulus estimated for faster i.e. brighter novae is larger. 

### 3.3 Novae in Virgo cluster galaxies

Using the recorded t$_2$ in galaxies in Virgo cluster including M87, and assuming that the same calibration of the MMRD applies to these novae, we estimate their peak absolute magnitudes. The MMRD M$_{V,0}$ and distance modulus estimated for these novae are plotted against their recorded peak apparent magnitude in Figures 8(a),(b). The results are listed in Table 7 in the Appendix. The data on t$_2$ and m$_V$,0 for these novae have been taken from Pritchet & van den Bergh 1987; Shara et al. 2016. As in our Galaxy and M31, the peak absolute magnitudes range from $-7$ to $-10$ magnitudes with the somewhat brighter lower limit possibly being dictated by sensitivity owing to the distant nature of the cluster. However the trend shown by the novae in M31 (see Figure 8) of intrinsically bright novae also appearing brighter when their peak apparent magnitude is recorded, is only faintly discernible in the nova in Virgo cluster (see Figure 9). The scatter in the data on novae in Virgo cluster is clearly larger. All the novice lie between distance modulus of 30 ($\sim$ 10 Mpc) and 33.4 ($\sim$ 47.8 Mpc) magnitudes. On examining the light curves of 21 novice in M87 presented in Shara et al. (2016), we find that the light curves of novae numbered 3,4,8,13,18,19,22 appear to be insufficiently sampled and these as noted in the table in the paper, are the faster novice in the sample. The mean distance modulus to M87 after excluding the aforementioned seven novae is 31.3 magnitudes ($\sim$ 18.2 Mpc). If all the 21 novae are used, then the distance modulus to M87 is estimated to be 31.76 magnitudes ($\sim$ 22.5 Mpc). This distance modulus to M87 is very similar to that derived using other distance estimators and we believe gives ample proof to the validity of the MMRD presented here for the novae in Virgo cluster.

From the discussion presented in this section, it appears that a good way to approach the MMRD is to derive the best possible calibration using high quality data on novae mainly in our Galaxy as has been done in this paper. This well-calibrated MMRD can then be used to derive peak absolute magnitudes and distances to nova outburst in our Galaxy and neighbouring galaxies. While it will work on most classical novae, it might give perplexing results for a few novae like the one from Arp’s list of novae in M31. Such cases can then be examined in detail. When outlier novae occur, an error in observed quantities should be suspected before the MMRD is blamed. In literature, there is, sometimes, a tendency to doubt the MMRD before ruling out observational constraints and data limitations which can confuse our understanding of novae instead of improving it. If one can find an easy explanation for the scatter and outliers in the MMRD in observational uncertainty then that should be preferred over doubting the veracity of the relation. The MMRD thus emerges as a reliable estimator of the peak absolute luminosity of the nova given its decline time and subsequently distance given its peak apparent magnitude. Moreover for extragalactic novae, it appears that the distances are best estimated using relatively slow novae with sufficient sampling which would seems to result in more accurate estimates of the peak apparent magnitudes and t$_2$. The peak absolute magnitudes and distances determined from the MMRD appear limited by observational uncertainties and we discuss this more in the next section.

### 3.4 Reasons for large MMRD distances

As noted in section 3.3 several Galactic novae are placed outside the Galaxy when the distance to the nova is estimated using the MMRD-determined M$_{V,0}$ and observed m$_V$,0 (see Figure 7). Either we hastily postulate that these are a new population of novae which lie in the intra-
group medium close to the Milky Way in the local group of galaxies or we investigate possible observational errors that could lead to such incorrect distance estimates. We believe that these novae are inside our Galaxy and that the distance estimates are erroneous. We begin by enumerating the possible causes of errors in the procedure which we then discuss in detail: (1) a calibration error in MMRD, (2) an incorrect \( t_2 \) which we then discuss in detail: (1) a calibration error in MMRD due to the assumptions.

### 1. Calibration error in MMRD:

Such an error should lead to incorrect estimates of \( M_{V,0} \) for most novae except the ones which coincidentally fall in the region of the MMRD common to the erroneous MMRD and correct MMRD. Considering we have used data measured on 51 novae to determine the relation \( \Delta V \to t_2 \) which finds resonance in the relation derived by McLaughlin (1969) builds confidence in our result regarding the rate of change of the peak absolute magnitude with decline time. Moreover, further calibration has been done using the peak absolute magnitudes of novae determined from independent methods. The MMRD thus arrived at in Equation 15 and shown in Figure 2(b) is found to fit the peak absolute magnitude \( \to t_2 \) data taken from several carefully compiled catalogues. Moreover, the distance estimates to many novae using the MMRD \( M_{V,0} \) are well within Galactic dimensions. Thus, we have several reasons to believe that the calibration of the MMRD presented here is fairly reliable and not responsible for the large distance estimates.

\[ M_{V,0} = \text{peak absolute magnitude of nova outburst} \]

\[ t_2 = \text{decline time of nova outburst} \]

\[ \Delta V = \text{difference in peak magnitudes of nova outburst} \]

2. Incorrect \( t_2 \): Since \( M_{V,0} \) is estimated from the logarithm of \( t_2 \), the effect of a small error in the decline time will not result in a large error in \( M_{V,0} \) of a nova. Only a large fractional error \( \Delta t_2 / t_2 \) will translate to a large error in the peak absolute magnitude of a nova outburst. We consider the effect of an error in \( t_2 \) on fast novae such as U Sco which has a recorded \( t_2 = 1.2 \) days (Table 1) for which the MMRD predicts \( M_{V,0} = -10.6(-10.8,-10.5) \) magnitudes. For example, if we incorrectly recorded the \( t_2 \) of U Sco to be 2.4 days then the MMRD will give \(-10.0 \) magnitudes for the peak brightness and if the error was larger such that \( t_2 = 5 \) days is recorded, then the MMRD will predict \( M_{V,0} = -9.3 \) magnitudes. If the peak apparent magnitude is correctly recorded for this nova, then this kind of error in which the peak absolute brightness is underestimated will result in an incorrect smaller distance estimate to the nova. If on the other hand, the decline time is incorrectly recorded to be faster say \( t_2 = 0.5 \) days, then the MMRD gives \( M_{V,0} = -11.45 \) magnitudes and for a correctly recorded \( M_{V,0} \), such an error will result in the nova being placed at a wrong larger distance to compensate for its recorded faintness.

We now consider the effect of an error on \( t_2 \) for slow novae. Let’s take the case of V723 Cas for which the decline time \( t_2 = 263 \) days. The MMRD predicts that the peak brightness of the nova outburst would be \( M_{V,0} = -5.6(-6.1,-5.1) \) magnitudes. Suppose the \( t_2 \) is incorrectly recorded to be 270 days in which case the MMRD will determine its peak brightness to be \( M_{V,0} = -5.55 \) magnitudes which is an error of only 0.05 magnitude and is well within the MMRD uncertainty. Now if the \( t_2 \) was incorrectly recorded to be 500 days, the MMRD will give \( M_{V,0} = -4.97 \) magnitudes. Thus, when an error in \( t_2 \) leads to a larger value then it will lead to an underestimate of \( M_{V,0} \) and if \( M_{V,0} \) has been correctly recorded, than this will result in a smaller-than-actual distance to the nova being estimated. On the other hand, if the error in \( t_2 \) is in the other direction, i.e., if instead of 263 days, the \( t_2 \) is recorded to be 50 days, then the MMRD will give a \( M_{V,0} = -7.1 \) magnitudes. Such an error in \( t_2 \) where \( M_{V,0} \) gets overestimated by the MMRD will lead to an erroneously large distance estimate for the nova if \( M_{V,0} \) is correct. It appears that the effect of an error in \( t_2 \) for slow novae is likely to be smaller than the errors in \( t_2 \) of faster novae especially with the improved widespread observing facilities which would ensure that only a small error in \( t_2 \) occurs. However large errors in \( t_2 \) leading to incorrect
distance estimates to slow novae are not entirely impossible is demonstrated by the case of the nova V2295 Oph which recorded an outburst in 1993 and has a recorded decline time of $t_2 = 9$ days (Table 5). The MMRD gives $M_{V,0} = -8.7(-9.0, -8.5)$ magnitudes and a distance of 40.6 kpc, which has to be wrong, is estimated using the recorded $m_{V,0}$. The light curve of this nova is flat-topped (see Figure 13(b)) and such novae are generally slow with $t_2 > 100$ days. If we assume that V2295 Oph is of the same nature and hence a slow nova then it has been detected well after it was at its peak brightness. Hence $t_2$ has been grossly underestimated and its peak brightness has been overestimated. This error in $M_{V,0}$ has then propagated into its distance estimate so that the faint $m_{V,0} = 9.3$ magnitudes which was recorded is compensated by placing it at a distance of 40.6 kpc. If we assumed that the correct $t_2$ was 100 days then $M_{V,0} = -6.48$ magnitudes and the distance to the nova would be 14 kpc which would be within Galactic dimensions. Thus, for V2295 Oph, a large error in $t_2$ appears to be the reason for its large distance estimate.

The above examples of fast and slow novae underline the logarithmic dependence of $M_{V,0}$ on $t_2$ so that only large fractional errors on $t_2$ have a perceptible effect on $M_{V,0}$ estimated from the MMRD and consequently distance to the nova. Thus it appears that while an incorrect $M_{V,0}$ from the MMRD might be responsible for the unrealistic distances for a few novae, it is unlikely to explain the same for so many novae. In Figure 10 the $M_{V,0}$ estimated from the MMRD is plotted against the epoch of the nova outburst for the novae listed in [McLaughlin 1960; Strope et al. 2010]. It is interesting to note that several bright novae $M_{V,0} < -10$ magnitudes have been detected since 1960 while none were detected before 1960 in the samples plotted here.

2. Incorrect $m_{V,0}$: An error in the peak apparent magnitude can result from dust extinction or if the nova is detected after optical maximum when the brightness is declining. Dust extinction will be most severe for the novae located in the Galactic plane especially close to the Galactic centre where it can be as large as $2 - 3$ magnitudes. This can introduce an error in the distance estimate if left uncorrected. An $m_{V,0}$ left uncorrected for extinction will always lead to a larger distance estimate to novae for a given $t_2$. This could be an important contributor to the wrong distances to several novae located towards the Galactic centre region.

The second important and as we show below a more frequent error in $m_{V,0}$ arises from missing the optical peak of the nova light curve. Due to the rapid rise to maximum, several novae are detected when they are already on the decline after the optical peak. In absence of any information on when the optical peak might have occurred, the best we can do is assume that the first detected point indicates the maximum apparent magnitude of the nova or if

Figure 10: The figure shows the distribution of $M_{V,0}$ estimated by the MMRD against the outburst epoch for the novae listed in [McLaughlin 1960; Strope et al. 2010]. Note the detection of several novae brighter than $-10$ magnitudes after 1960.

Figure 11: (a) The $m_{V,0}$ is plotted with the outburst epoch of a nova from two catalogues to show that few novae with $m_{V,0} < 2$ have been detected in the last fifty years as compared to 1900 to 1950. The horizontal line is drawn at 2 magnitudes. (b) The MMRD distances are plotted versus the outburst epoch and shows a peculiar correlation. Notice that post-1990 the distances to several novae are estimated to be $> 20$ kpc and that the scatter on distances is larger for novae which recorded an outburst post-1960. The horizontal line is plotted at 20 kpc.
the detection of data points, allow one can interpolate and use an appropriate value for the $m_{V,0}$. However in both cases, we have to accept that there is a high probability of unknown errors in the values which will lead to the peak apparent brightness being underestimated. If a correct $t_2$ is recorded, the detected faintness will be attributed to the nova being located at a larger distance. We also note that the detection of a fast nova after the optical peak might not result in a large error in $t_2$ but can cause a large error in the value of the peak apparent brightness. The magnitude of error in $m_{V,0}$ will depend on how soon after the optical maximum the nova is detected and its speed. For example, if a nova is detected couple of days following optical peak then the error on $m_{V,0}$ will be larger for a fast nova then it will be for a slow nova. Moreover as with the extinction error, the incorrect estimate of $m_{V,0}$ is always in the same direction i.e it always underestimates the peak apparent brightness of the nova so that its peak appears fainter than it should based on its intrinsic brightness and actual distance. This means that when this incorrect $m_{V,0}$ is combined with the MMRD $M_V$, then the distance to the nova is always over-estimated. The error on distance is never in the other direction since it is not possible to record a brighter apparent magnitude for a nova. Thus an error in $m_{V,0}$ caused either by extinction or post-maximum detection always leads to a faulty larger distance estimate.

In Figure 11, we plot the $m_{V,0}$ against the outburst epoch for the novae listed in McLaughlin (1960); Strome et al. (2010). Assuming these are representative samples, we note that before 1960, several novae with apparent magnitudes brighter than 2 magnitudes have been detected while only one such nova is present in the sample between 1960 and 2005. This paucity of novae with $m_{V,0} < 2$ magnitudes is perplexing. Several fainter novae have been detected post-1960 as seen in Figure 11(a) which can be explained by the improved sensitivity of modern optical telescopes. However if we compare this with Figure 11(b) we find that post-1960, a larger number of brighter novae as estimated by the MMRD using the recorded $t_2$ have also been discovered. Combining these two results, it is obvious that all the bright novae which have recorded fainter apparent magnitudes will be placed at unreasonably large distances. This is demonstrated in Figure 11(b) where the distance to the same sample of novae is plotted against the outburst epoch. The data shows that almost half the novae detected after 1990 (23/48) have MMRD distances estimated to be $> 20$ kpc and that the scatter on the distance estimates of novae which have had an outburst post-1960 is larger. We know of no evidence to the existence of a different type of population of novae having been detected since 1990 and hence believe that such a result suggests that for most of the novae outburst after 1990, the $m_{V,0}$ are underestimated and have led to incorrect distance estimates. It could be that a large fraction of the novae discovered post-1990 are located in the Galactic centre region and hence $m_{V,0}$ is highly extincted or it could be that majority of these novae have been discovered post-maximum and hence the $m_{V,0}$ have been underestimated. The larger scatter in the distance estimates of the novae discovered since 1960 as compared to the novae outbursts which have been pre-1960 could be due to genuine detection of more distant novae owing to better telescope sensitivities. Whether this is the case or whether the uncertainty is larger owing to some observational shortcomings can only be commented on when more information on these is gathered. We find the peculiar behaviour exhibited by the novae as a function of their outburst epoch intriguing and we believe that understanding this should be useful in making further progress.

To illustrate how easy it is to underestimate the optical peak brightness, especially in fast novae, the example of the recurrent nova T CrB ($t_2 = 4$ days) which recorded a peak apparent magnitude of 2.5 magnitudes during its outburst in 1866 and a peak apparent magnitude of 3.5 magnitudes in its 1946 outburst (Schafer, 2010), is instructive. Since recurrent novae have shown similar light curve behaviour in all outbursts, the peak apparent magnitude of 2.5 magnitudes obtained from 1866 is likely the best estimate of $m_{V,0}$ for T CrB that we have. This demonstrates how easily a one-magnitude error can be introduced in the peak apparent magnitude of a nova outburst especially for classical novae for which this facility of recurrent outbursts allowing the correct peak apparent magnitude to be determined is not available. We can only ensure that all novae are detected before or near the pre-maximum halt so their peaks are well-determined or have to contend with an unknown error in the value of the peak apparent magnitude of a nova outburst and the corresponding error in the distance estimate if estimated from its peak absolute magnitude.

To further demonstrate how an incorrect $m_{V,0}$ is leading to the unrealistic distance estimates to novae, we reproduce some light curves from Strope et al. (2010) which these authors have mainly derived from the large volumes of useful data collected by the American Association of Variable Star Observers (AAVSO) and augmented by other sources of data in literature, if required.

We show light curves of 18 novae (10 in Figure 12 and 8 in Figure 13) with the figures copied from Strope et al. (2010). In Figure 12(a), light curves of four novae are declining right from detection whereas T CrB shows some flattening at the top. In Figure 12(b), light curves of QU Vul and CP Pup seem to be flattened at the top whereas the remaining three novae show a decline from detection. We work with the obvious reasoning that the $m_{V,0}$ is correctly estimated from a light curve with a flat top whereas for the declining light curves, there is a possibility of $m_{V,0}$ being underestimated. Thus, the distances to novae with a flat top light curve should be smaller and well within Galactic dimensions whereas for the declining light curves, the distance estimates could be larger. We find that the correlation between a flat topped light curve and a small distance estimate well within Galactic dimensions is very good. Thus, of the novae in Figure 12(a), T CrB is placed at a distance of 2.5 kpc whereas the other four novae with declining light curves are placed beyond 20 kpc. For the novae in Figure 12(b), the two flat-topped novae QU Vul and CP Pup have the smallest distance estimates of
Estimated its $M$, of a large error in its estimated $t$ that the large distance estimate to V2295 Oph is a result $M$ days (Strope et al., 2010) and the the MMRD-determined V849 Oph and BT Mon are 295 days, 140 days and 118 other three flat-topped novae in Figure 13(b) ie DO Aql, V849 Oph, V4633 Sgr and LZ Mus are 12.4 kpc, 4.6 kpc, 1.1 kpc, 12.9 kpc and 39.9 kpc. In Figure 13, all the eight novae show flat-topped light curves and hence a correct $M_V$, of most novae lie $0$ between $10$ magnitudes (see Figure 6) ie novae radiate at sub-Eddington to Eddington luminosities at its peak. The life-luminosity and life-expansion relations are derived assuming there is an instantaneous injection of the excess energy to the system. These relations might give incorrect $M_V$, if used for novae which show rapid multiple peaks like Nova Herculis (Zwicky, 1936b). This might especially be the case if the successive peaks occur within the timeframe of $t_2$. Thus, if there is continuous injection of energy or several energy injection episodes in a nova then it is possible that the MMRD will not be able to give a correct estimate of its peak luminosity and this would constitute a limitation of the MMRD. However whether this does happen in novae needs to be verified on actual data once the observational data are made error-free. An- other limitation might arise from the assumptions that we made in section 2.2 while deriving the MMRD mainly that (1) the mass of the ejecta $m_{ej}$ and (2) the maximum ra-

**Figure 12:** Light curves of 10 novae. Figure copied from Strope et al., 2010. (a) Note the declining light curves from start for the novae (except T CrB) which can result in an incorrect $m_{V,peak}$. The MMRD distances to T CrB, V4643 Sgr, V4160 Sgr, V3890 Sgr, V4739 Sgr are 2.5 kpc, 31.2 kpc, 27 kpc, 27.8 kpc, 29.6 kpc respectively. (b) The light curves of QU Vul and CP Pup are flat when detected, rest show declining light curves and possibly incorrect $m_{V,0}$. The estimated distances to HS Sge, QU Vul, CP Pup, V4633 Sgr and LZ Mus are 12.4 kpc, 4.6 kpc, 1.1 kpc, 12.9 kpc and 39.9 kpc.

Limitation of the MMRD: As mentioned earlier and seen from Figure 2, the same MMRD relation (Equation 15) is capable of predicting the peak absolute magnitudes of all kinds of Galactic novae: fast, slow, recurrent, classical and extragalactic novae. As demonstrated in the previous points, the distance estimates are mainly limited by errors on either the peak amplitude $m_{V,0}$ which is often difficult to catch due to the extremely fast nature of the rise in nova brightness and occasionally $t_2$. Thus, as stated at the beginning of this section, till we are able to remove these shortcomings on the observed quantities, it is premature to comment on the limitations of the MMRD. The MMRD peak absolute magnitudes of most novae lie between $-6$ and $-10$ magnitudes (see Figure 3) ie novae radiate at sub-Eddington to Eddington luminosities at its peak. The life-luminosity and life-expansion relations are derived assuming there is an instantaneous injection of the excess energy to the system. These relations might give incorrect $M_V$, if used for novae which show rapid multiple peaks like Nova Herculis (Zwicky, 1936b). This might especially be the case if the successive peaks occur within the timeframe of $t_2$. Thus, if there is continuous injection of energy or several energy injection episodes in a nova then it is possible that the MMRD will not be able to give a correct estimate of its peak luminosity and this would constitute a limitation of the MMRD. However whether this does happen in novae needs to be verified on actual data once the observational data are made error-free. Another limitation might arise from the assumptions that we made in section 2.2 while deriving the MMRD mainly that (1) the mass of the ejecta $m_{ej}$ and (2) the maximum ra-
V2295 Oph in the paper and find that its decline time $t_{\text{rad}}$ is 5.7 kpc, 5.7 kpc, 7.7 kpc and 40.6 kpc. We discuss the case of 4 Intersection of novae light curves
Since there are novae of different speed classes, there is a possibility that their absolute magnitude light curves might intersect on a particular day after maximum. Knowing the expected value of the absolute magnitude of novae on that particular day would be useful in estimating the distance to the nova. Recognising the potential of such an occurrence, Buscombe & de Vaucouleurs (1955) examined the light curves of 11 novae of several speed classes and found that their absolute magnitudes showed minimum scatter about 15 days post-maximum. They estimated a mean absolute magnitude of $-5.2 \pm 0.1$ magnitudes on day 15. Here we revisit the estimate using data available on a larger number of novae. We used data on eight novae from Cohen (1985) and 28 novae from Downes & Duerbeck (2000) for which $t_2$, $M_{V,0}$ and $M_{V,15}$ are made available in the papers. The $t_2$ and $M_{V,15}$ listed in these papers are listed in columns 3, 4 of Table 1. There are six common novae in the two lists. As can be seen from Table 1, the $M_{V,15}$ listed in Cohen (1985) range from $-4.8$ to $-8.85$ magnitudes and range from $-4.8$ to $-7.4$ magnitudes as listed in Downes & Duerbeck (2000). This indicates that there exists a large dispersion in $M_{V,15}$ and we explore the possibility of reducing it so that its usage as a distance diagnostic can be increased. Moreover we can use our improved MMRD calibration to get a more reliable estimate of $M_{V,15}$. We proceed as follows.

We used the $M_{V,0}$ and $M_{V,15}$ listed in the papers to estimate the difference in the amplitude of the star in 15 days and this is listed under $dM_{15}$ in column 5 of Table 1. We also estimated $M_{V,0}$ from the MMRD relation in Equation 15 using the $t_2$ from the papers and these are listed in column 6 of Table 1. We, then, estimated $M_{V,15}$ using our MMRD $M_{V,0}$ and $dM_{15}$ and these are listed in column 7 of Table 1. The $M_{V,15}$ estimated in this way lies between $-4.5$ and $-6.8$ magnitudes for the 36 datapoints. From comparing columns 4 and 7 of Table 1 we note that the two estimates of $M_{V,15}$ - one from the papers and other estimated by us using the MMRD $M_{V,0}$ differ for several novae. In Figure 13(a), we plot the $M_{V,15}$ estimated from our MMRD-determined $M_{V,0}$ and in (b) the $M_{V,15}$ listed in Cohen (1985); Downes & Duerbeck (2000) with decline time. An obvious difference between the two plots is the lower scatter on $M_{V,15}$ for a given $t_2$ in Figure 13(a) as compared to (b). Moreover, a trend is discernible in (a) such that $M_{V,15}$ is fainter for fast novae, increases for not-so-fast novae and again drops for slow novae. We believe that the more accurate estimates of $M_{V,0}$ from our well-calibrated MMRD has allowed this behaviour of novae in the $M_{V,15} - \log_10 t_2$ plane to be recognised. An analysis of Figure 13(a) indicates that fast novae fade rapidly,
Table 1: The absolute magnitudes of novae on day 15. The first eight entries are from [Cohen 1985] and the next 28 are from [Downes & Duerbeck 2000]. $dm_{15}$ indicates the change in the nova brightness in magnitudes 15 days after peak brightness. In the last two columns, the $M_{V,0}$ and $M_{V,15}$ ($M_{V,0} + dm_{15}$) estimated using the $t_{2}$ listed in column 3 and our MMRD calibration are tabulated.

| Nova     | $t_{2}$ | $M_{15}$ | $dm_{15}$ | $M_{0}$ | $M_{15}$ |
|----------|--------|----------|-----------|--------|---------|
| D & D 2000 |        |          |           |        |         |
| Nova     | $t_{2}$ | $M_{15}$ | $dm_{15}$ | $M_{0}$ | $M_{15}$ |
|----------|--------|----------|-----------|--------|---------|
| V1229 Aql | 18.0   | -4.8     | 1.8       | -8.1   | -6.3    |
| V500 Aql | 20.0   | -8.85    | 1.5       | -8.0   | -6.5    |
| V1500 Cyg | 2.4    | -5.1     | 4.15      | -10.0  | -5.8    |
| V446 Her | 5.0    | -5.55    | 3.15      | -9.3   | -6.1    |
| V533 Her | 26.0   | -6.6     | 1.1       | -7.7   | -6.6    |
| DK Lac   | 19.0   | -7.35    | 2.0       | -8.0   | -6.0    |
| XX Tau   | 24.0   | -6.75    | 1.3       | -7.8   | -6.5    |
| LV Vul   | 21.0   | -5.25    | 1.5       | -7.9   | -6.4    |

Figure 14: Absolute magnitude on day 15 after outburst maximum versus $t_{2}$. (a) $M_{V,0}$ estimated from the MMRD in Equation 15 and $M_{V,15}$ estimated from this using $dm_{15}$ from column 5 in Table 1 is plotted versus $t_{2}$. A trend is discernible in the plot followed by all novae except the nova plotted at $-4.5$ magnitudes and $\log_{10} t_{2}$ ~ $0.8$. (b) $M_{V,15}$ for the same nova taken from [Cohen 1985] (green boxes) and [Downes & Duerbeck 2000] (red circles) are plotted. Notice the comparatively larger scatter in this plot.

In other words, the absolute magnitude of novae of different speed classes might show lower scatter on a day other than day 15. To explore removing the systematic variation in Figure 14(a), we estimated the mean rate of change in the absolute magnitude over 15 days after optical peak i.e. $dm_{15}/15$. This is plotted in Figure 15(a) for the 36 datapoints. We then used this rate to estimate the absolute magnitudes of the novae on days 14, 13 and 12 following outburst to check if the absolute magnitudes matched better on any of these days. Figure 15(b) shows their brightness has dropped to $\sim -5.5$ magnitudes by day 15 while the somewhat slower novae have faded to $\sim -6.5$ magnitudes and the really slow novae show the smallest change in their peak brightness in 15 days and are already fainter to begin with. Moreover, another inference which emerges from this figure is that the scatter could be reduced and a better estimate of the near-constant absolute magnitude can be obtained, if we could remove this trend.
the expected absolute magnitudes on day 12 after outburst estimated as above. The systematic trend has been removed and M_{V,12} of 32/36 datapoints lie between −6.2 and −7.0 magnitudes. For comparison, the M_{V,15} that we had estimated was between −5.4 and −6.8 magnitudes for the same 32/36 points. Clearly, the scatter on the absolute magnitude on day 12 is less than on day 15. The mean value of the expected absolute magnitude on day 12 using data on 24 novae is:

$$M_{V,12} = -6.616 \pm 0.043 \text{ magnitudes}$$

We have excluded data on four novae while estimating the mean - the three slowest novae and the outlier near log_{10}t_2 ∼ 0.8 from the 28 novae listed in Downes & Duerbeck (2000). This is because the three slowest novae are fainter than or close to −6.616 magnitudes at maximum and hence do not adhere to this relation which is also obvious from Figure 15(b). The fourth outlier nova is clearly an exception which needs to be examined further and hence has been excluded from the mean. It is important to mention that this M_{V,12} is expected to be valid only for novae whose t_2 lie between 2.4 days and 86 days. This method will obviously not work for novae fainter than −6.616 magnitudes i.e. very slow novae with t_2 > 86 days. For comparison, the mean M_{V,15} estimated from the data on the same 24 novae listed in column 7 of Table 1 and shown in Figure 15(a) is −6.22 ± 0.07 magnitudes and is also applicable to novae with t_2 between 2.4 and 86 days.

Thus, M_{V,12} provides a robust alternative to M_{V,15} for estimating the distance to novae with 2.4 ≤ t_2 ≤ 86 days, since it requires M_{V,12} which might be easier to record with higher accuracy than is M_{V,15} for these novae. For the slowest novae (t_2 > 86 days) which fade slowly, m_{V,0} can be accurately recorded and the distance can be easily estimated from the M_{V,0} determined from the MMRD.

Remarkably, a better calibrated MMRD has enabled the determination of a better day after outburst maximum when light curves of novae belonging to several speed classes intersect and a better estimate of M_{V,12}. This, then, also provides strong evidence to the validity of and the better calibration of the MMRD presented in the paper. M_{V,0} and M_{V,12} appear to be the best distance estimators to most novae which allow us to calculate the distance soon after the nova outburst. We end by listing the M_{V,15} from literature:

1. Mean M_{V,15} = −5.2 ± 0.1 magnitudes which was found to be applicable for novae in our Galaxy, LMC and M31 by Buscombe & de Vaucouleurs (1955).
2. Mean M_{V,15} = −5.6 ± 0.45 magnitudes by Cohen (1985).
3. Mean M_{V,15} = −6.05 ± 0.44 magnitudes by Downes & Duerbeck (2000).
4. M_{V,17} = −6.06 ± 0.23 magnitudes and M_{V,20} = −6.11 ± 0.34 for novae in M87 by Shara et al. (2017).

These show a larger scatter than M_{V,12} = −6.616 ± 0.043 magnitudes and M_{V,15} = −6.22 ± 0.07 magnitudes for novae with 2.4 ≤ t_2 ≤ 86 days that we estimate using the MMRD M_{V,0}.

5 Conclusions

In this paper, the maximum (absolute) magnitude relation with decline time (MMRD) for novae has been revisited in terms of its physical origin and calibration using observed parameters. The main points of our study can be summarised to be:

- We derive the life-expansion relation and the MMRD. We start with a rapid one-time injection of energy to the nova system which is manifested in form of kinetic energy imparted to the outer layers of the white dwarf. This energy input causes the outer layers to be set in bulk outward motion as the ejecta and also ionized so that the ejecta starts radiating. The assumptions in this derivation are: (1) instantaneous injection of energy (2) m_{ej} is same for all novae (3)
Novae: I. The MMRD

We calibrate the MMRD using a two-step procedure wherein the first step exclusively uses directly observed quantities of emission line widths (proxy for expansion velocity) and time the nova takes to decline by two magnitudes ($t_2$) from maximum. This step quantifies the rate of change in peak absolute magnitude ($M_{V,0}$) with $t_2$. In the second step, the zero-point of the MMRD is fine-tuned using carefully derived values of $M_{V,0}$ and $t_2$ for novae from literature. The fully calibrated MMRD is $M_{V,0} = 2.16(\pm0.15)\log_{10}t_2 - 10.804(\pm0.117)$ which has the lowest uncertainty of all the relations which exist in literature.

The new MMRD calibration is used to estimate $M_{V,0}$ of the novae in our Galaxy, in M31 and in M87 and most novae are found to lie between $-6$ and $-10$ magnitudes. The novae in M31 give a distance modulus of 24.8 magnitudes and those in M87 give a distance modulus of 31.3 magnitudes for the parent galaxy. The range of distances estimated for Galactic novae using the MMRD range from very close by to $\sim 100$ kpc, the latter are unrealistic and hence wrong.

We investigate the reasons for such large distances to several Galactic novae being estimated on using the MMRD $M_{V,0}$ and the measured peak apparent magnitudes $m_{V,0}$. We show that the major and frequent cause of error is an incorrect estimate of $m_{V,0}$ due to several novae being detected when their brightness is already on the decline. The MMRD is not responsible for the discrepant distances. Our work lends strong support to the validity of the MMRD and the importance of an accurate calibration.

The near-constancy of the absolute magnitude of several novae on a particular day after outburst maximum is revisited. Our study concludes that the scatter on the absolute magnitude of novae with $2.4 \leq t_0 \leq 86$ days is the least on day 12 after maximum and this is $-6.616 \pm 0.043$ magnitudes. Our MMRD was used to estimate $M_{V,0}$ from which $M_{V,12}$ was found. This work gives independent evidence to the MMRD presented in the paper being well-calibrated and a reliable estimator of the peak absolute magnitudes of novae.

We, thus, conclude that the MMRD is indeed a very powerful method for estimating the peak luminosities of nova outbursts and hence distances to novae. However the MMRD should be used to determine the distance to a nova only if an accurate $m_{V,0}$ is recorded which will generally be true for novae detected before they start their decline. The distances to other novae can be determined from $M_{V,12}$ and $m_{V,12}$ if an accurate value of the latter is available.

It might be possible to use the MMRD, with an independent calibration, to determine the peak luminosities of other classes of transients if they are suspected to share the same physics as the nova outburst especially the instantaneous energy input which throws out an ejecta which starts shining.

We end by suggesting a few ways in which we can improve the utility of the MMRD and also gradually minimize the observational uncertainties so that we might then be able to examine the extent of the phase space in which the MMRD remains valid:

1. By uniformising the data on $t_2$ for all novae. This can be possible if we can converge on the best methodologies for estimating $t_2$. Since a coarsely determined $t_2$ has been sufficient for the MMRD, one of the possible methods would be to fit the observed visual light curve up to the point that it has declined by 6 magnitudes or more with a polynomial and find $t_2$ from the fit. This would then smooth over the small wiggles that are sometimes seen superposed on the smooth brightness decline. If such software is made available, for example, on the AAVSO website so that users can use it to estimate $t_2$ then it can lead to uniform results for a given nova for all users. Alternatively, AAVSO can fit the data on all novae in its database and make $t_2$ available to all users.

2. A similar argument applies to determining $m_{V,0}$. Since novae show a variety in the shape of the light curves near maximum, it is important to derive a robust algorithm for determining $m_{V,0}$ which can then be universally accepted and can lead to reducing the observational uncertainty on these parameters. We note that unlike $t_2$, the peak luminosity that a nova outburst achieves will be the largest reliable value of $m_{V,0}$ that we record so that it might not require any fitting of the light curve. However it might require uniformising of the data that might exist in different research papers or websites observed in different wavebands and making the same data on a nova available at all locations for universal use. It is important to present actual data and avoid making any extrapolations on the data.

3. While it is useful to collect data on a large number of novae, it should not lead to compromising the quality of the data. In fact, high fidelity spectrophotometric data on fewer novae is preferable to lower fidelity data on several novae.

The MMRD, suggested by Zwicky [1936b], correct calibrated and observationally supported by McLaughlin [1940] and other scientists remains valid. Novae of several speed classes are also found to evolve to a near-constant luminosity several days after outburst maximum due to their different rates of decline as was suggested by Buscombe & de Vaucouleurs [1955]. These remain important insights into the nova phenomena.
Acknowledgements

I gratefully acknowledge use of ADS abstracts, arXiv e-prints, AAVSO data, gnuplot, LaTeX, Wikipedia and Google search engines enabled by the internet in this research.

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Appendix

In the Appendix, we present tables in which the peak absolute magnitudes of novae in outburst determined from the MMRD that we obtain in the paper with the decline time $t_2$ taken from literature are listed. For the extragalactic novae in the M31 and Virgo cluster, the distance modulus are estimated and listed. For ease of referral, each table corresponds to the set of novae for which the $t_2$ and $m_{V,0}$ are taken from a particular reference or couple of references.

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Table 2: Using the MMRD relation calibrated in the paper to estimate the peak absolute magnitude and then distance to novae. Data on $t_2$, $\Delta v$ and $m_{v,0}$ are taken from Schwarz et al. (2011). These data were used in the step one of the calibration. The bracketed quantities in columns 6 and 7 indicate the $\sigma$ error on the absolute magnitude and distance to the nova. All the novae have an outburst recorded between 1982 and 2010.

| No | Nova       | $m_{v,0}$ | $t_2$ | $\Delta v$ | M$v,0$ | D   |
|----|------------|-----------|-------|------------|--------|-----|
| 1  | CI Aql     | 8.83      | 32.0  | 2300       | -7.6   | 18.9 |
| 2  | GQ Mus     | 7.20      | 18.0  | 1000       | -8.1   | 11.4 |
| 3  | IM Nor     | 7.84      | 50.0  | 1150       | -7.1   | 9.9  |
| 4  | KT Eri     | 5.42      | 6.6   | 3000       | -9.0   | 7.8  |
| 5  | LMC 2000   | 11.45     | 9.0   | 1700       | -8.7   | 109.3|
| 6  | LMC 2005   | 11.50     | 63.0  | 900        | -6.9   | 48.2 |
| 7  | LMC 2009a  | 10.60     | 4.0   | 3000       | -9.5   | 104.9|
| 8  | RS Oph     | 4.50      | 7.9   | 3330       | -8.9   | 4.7  |
| 9  | U Sco      | 8.05      | 1.2   | 7600       | -10.6  | 54.5 |
| 10 | V1047 Cen  | 8.50      | 6.0   | 840        | -9.1   | 33.5 |
| 11 | V1065 Cen  | 8.20      | 11.0  | 2700       | -8.6   | 22.4 |
| 12 | V1187 Sco  | 7.40      | 7.0   | 3000       | -9.0   | 18.9 |
| 13 | V1188 Sco  | 8.70      | 7.0   | 1730       | -9.0   | 34.3 |
| 14 | V1213 Cen  | 8.53      | 11.0  | 2300       | -8.6   | 26.1 |
| 15 | V1280 Sco  | 3.79      | 21.0  | 640        | -7.9   | 2.2  |
| 16 | V1291 Sco  | 8.80      | 15.0  | 1800       | -8.3   | 25.9 |
| 17 | V1309 Sco  | 7.10      | 23.0  | 670        | -7.9   | 9.8  |
| 18 | V1494 Aql  | 3.80      | 6.6   | 1200       | -9.0   | 3.7  |
| 19 | V1663 Aql  | 10.50     | 17.0  | 1900       | -8.1   | 53.6 |
| 20 | V1974 Cyg  | 4.30      | 17.0  | 2000       | -8.1   | 3.1  |
| 21 | V2361 Cyg  | 9.30      | 6.0   | 3200       | -9.1   | 48.4 |
| 22 | V2362 Cyg  | 7.80      | 9.0   | 1850       | -8.7   | 20.4 |
| 23 | V2407 Cyg  | 6.70      | 7.0   | 950        | -9.0   | 13.7 |
| 24 | V2408 Cyg  | 7.40      | 10.0  | 1000       | -8.6   | 16.2 |
| 25 | V2491 Cyg  | 7.54      | 4.6   | 4860       | -9.4   | 24.1 |
| 26 | V2487 Oph  | 9.50      | 6.3   | 10000      | -9.1   | 51.9 |
| 27 | V2575 Oph  | 11.10     | 20.0  | 560        | -8.0   | 65.9 |
| 28 | V2576 Oph  | 9.20      | 8.0   | 1470       | -8.9   | 40.8 |
| 29 | V2615 Oph  | 8.52      | 26.5  | 800        | -7.7   | 17.8 |
| 30 | V2670 Oph  | 9.90      | 15.0  | 600        | -8.3   | 42.9 |
| 31 | V2671 Oph  | 11.10     | 8.0   | 1210       | -8.9   | 97.9 |
| 32 | V2672 Oph  | 10.00     | 2.3   | 8000       | -10.0  | 101.0|
| 33 | V382 Nor   | 8.90      | 12.0  | 1850       | -8.5   | 29.8 |
| 34 | V382 Vel   | 2.85      | 4.5   | 2400       | -9.4   | 2.8  |
| 35 | V407 Cyg   | 6.80      | 5.9   | 2700       | -9.1   | 15.4 |
| 36 | V458 Vul   | 8.21      | 7.0   | 1750       | -9.0   | 27.8 |
| 37 | V459 Vul   | 7.57      | 18.0  | 910        | -8.1   | 13.6 |
| 38 | V4633 Sgr  | 7.80      | 19.0  | 1700       | -8.0   | 14.7 |
| 39 | V4643 Sgr  | 8.07      | 4.8   | 4700       | -9.3   | 30.2 |
| 40 | V4743 Sgr  | 5.00      | 9.0   | 2400       | -8.7   | 5.6  |
| 41 | V4745 Sgr  | 7.41      | 8.6   | 1600       | -8.8   | 17.3 |
| 42 | V477 Sct   | 9.80      | 3.0   | 2900       | -9.8   | 82.2 |
| 43 | V5114 Sgr  | 8.38      | 11.0  | 2000       | -8.6   | 24.4 |
| 44 | V5115 Sgr  | 7.70      | 7.0   | 1300       | -9.0   | 21.7 |
| 45 | V5116 Sgr  | 8.15      | 6.5   | 970        | -9.0   | 27.5 |
| 46 | V5558 Sgr  | 6.53      | 125.0 | 1000       | -6.3   | 3.6  |
| 47 | V5579 Sgr  | 5.56      | 7.0   | 1500       | -9.0   | 8.1  |
| 48 | V5583 Sgr  | 7.43      | 5.0   | 2300       | -9.3   | 22.1 |
| 49 | V574 Pup   | 6.93      | 13.0  | 2800       | -8.4   | 11.6 |
| 50 | V597 Pup   | 7.00      | 3.0   | 1800       | -9.8   | 22.6 |
| 51 | V723 Cas   | 7.10      | 263.0 | 600        | -5.6   | 3.4  |

* - marks the Galactic nova for which a distance > 20 kpc has been estimated.
### Table 3: Using the MMRD relation calibrated in the paper to estimate the peak absolute magnitude and then distance to novae. Data on \( t_2 \) and \( m_{V,0} \) are taken from McLaughlin (1960). The bracketted quantities in columns 6 and 7 indicate the 1\( \sigma \) error on the absolute magnitude and distance to the nova.

| No | Nova    | Outburst year | \( M_{V,0} \) \( t_2 \) | McLaughlin (1960) |
|----|---------|---------------|----------------|-------------------|
| 1  | V606 Aql | 1899          | 6.70 25.0      | -7.6 (-8.1, -7.5) |
| 2  | V604 Aql | 1905          | 8.20 9.0       | -8.7 (-9.0, -8.5) |
| 3  | V603 Aql | 1918          | -1.10 4.0      | -9.5 (-9.7, -9.3) |
| 4  | DO Aql   | 1925          | 8.60 300.0     | -5.5 (-5.9, -5.0) |
| 5  | V356 Aql | 1936          | 7.10 145.0     | -6.1 (-6.6, -5.7) |
| 6  | V368 Aql | 1936          | 5.00 5.0       | -9.3 (-9.5, -9.1) |
| 7  | V528 Aql | 1945          | 7.00 17.0      | -8.1 (-8.4, -7.8) |
| 8  | T Aur   | 1891          | 4.20 80.0      | -6.7 (-7.1, -6.3) |
| 9  | T CrB   | 1866          | 2.00 3.0       | -9.8 (-10.0, -9.6) |
| 10 | T CrB   | 1946          | 3.00 5.0       | -9.3 (-9.5, -9.1) |
| 11 | Q Cyg   | 1876          | 3.00 5.0       | -9.3 (-9.5, -9.1) |
| 12 | V476 Cyg| 1920          | 2.00 7.0       | -9.0 (-9.2, -8.7) |
| 13 | V450 Cyg| 1942          | 7.90 91.0      | -6.6 (-7.0, -6.2) |
| 14 | DM Gem  | 1903          | 5.00 6.0       | -9.1 (-9.4, -8.9) |
| 15 | DN Gem  | 1912          | 3.50 16.0      | -8.2 (-8.5, -7.9) |
| 16 | DQ Her  | 1934          | 1.40 67.0      | -6.9 (-7.3, -6.5) |
| 17 | DI Lac  | 1910          | 4.60 20.0      | -8.0 (-8.3, -7.7) |
| 18 | CP Lac  | 1936          | 2.10 5.0       | -9.3 (-9.5, -9.1) |
| 19 | DK Lac  | 1950          | 5.40 19.0      | -8.0 (-8.4, -7.7) |
| 20 | HR Lyr  | 1919          | 6.50 48.0      | -7.2 (-7.5, -6.8) |
| 21 | V841 Oph| 1848          | 4.30 50.0      | -7.1 (-7.5, -6.8) |
| 22 | RS Oph  | 1933          | 4.30 4.0       | -9.5 (-9.7, -9.3) |
| 23 | V849 Oph| 1919          | 7.40 120.0     | -6.3 (-6.7, -5.9) |
| 24 | GK Per  | 1901          | 0.20 6.0       | -9.1 (-9.4, -8.9) |
| 25 | RR Pic  | 1925          | 1.20 80.0      | -6.7 (-7.1, -6.3) |
| 26 | CP Pup  | 1942          | 0.40 5.0       | -9.3 (-9.5, -9.1) |
| 27 | T Pyx  | 1944          | 7.00 100.0     | -6.5 (-6.9, -6.1) |
| 28 | WZ Sge  | 1913          | 7.20 14.0      | -8.3 (-8.6, -8.0) |
| 29 | WZ Sge  | 1946          | 7.80 18.0      | -8.1 (-8.4, -7.8) |
| 30 | V1059 Sgr| 1898          | 4.90 10.0      | -8.6 (-8.9, -8.4) |
| 31 | V999 Sgr| 1910          | 8.10 220.0     | -5.7 (-6.2, -5.3) |
| 32 | V1017 Sgr| 1919         | 7.00 70.0      | -6.8 (-7.2, -6.4) |
| 33 | V630 Sgr| 1936          | 4.40 4.0       | -9.5 (-9.7, -9.3) |
| 34 | EU Sct  | 1949          | 7.40 20.0      | -8.0 (-8.3, -7.7) |
| 35 | RT Ser  | 1909          | 10.60 40.0     | -7.3 (-7.7, -7.0) |

* - marks the Galactic nova for which a distance > 20 kpc has been estimated.

### Table 4: Using the MMRD relation calibrated in the paper to estimate the peak absolute magnitude and then distance to recurrent novae. Data on \( t_2 \) and \( m_{V,0} \) are taken from Schaefer (2010) The bracketted quantities in columns 7 and 8 indicate the 1\( \sigma \) error on the absolute magnitude and distance to the nova.

| No | Recurrent Nova | \( m_{V,0} \) \( t_2 \) | Schaefer (2010) |
|----|----------------|----------------|-----------------|
| 1  | TPyx           | 6.40 32.0      | -7.1 3.2        |
| 2  | IMNor          | 8.50 50.0      | -7.0 3.4        |
| 3  | CIaql          | 9.00 25.4      | -7.3 5.0        |
| 4  | V2487Oph       | 9.50 6.2       | -9.6 32.4       |
| 5  | U5co           | 7.50 1.2       | -10.7 37.7      |
| 6  | V394CrA        | 7.20 2.4       | -10.2 24.4      |
| 7  | TCrB           | 2.50 4.0       | -9.9 3.2        |
| 8  | RSOph          | 4.80 6.8       | -9.5 2.1        |
| 9  | V745Sco        | 9.40 6.2       | -9.6 14.1       |
| 10 | V38905gr       | 8.10 6.4       | -9.6 7.6        |

* - marks the Galactic nova for which a distance > 20 kpc has been estimated.
Table 5: Using the MMRD relation calibrated in the paper to estimate the peak absolute magnitude and then distance to novae. Data on $t_2$ and $m_{V,0}$ are taken from Strope et al. (2010). The bracketed quantities in columns 6 and 7 indicate the 1σ error on the absolute magnitude and distance to the nova.

| No | Nova   | Outburst year | $m_{V,0}$ | $t_2$ | $M_{V,0}$ | D |
|----|--------|---------------|---------|-------|---------|---|
| 1  | OS And | 1986          | 6.50    | 11.0  | -8.6     | 10.3 |
| 2  | CI Aql | 2000          | 9.00    | 25.0  | -7.8     | 22.7 |
| 3  | DO Aql | 1925          | 8.50    | 295.0 | -5.5     | 6.2  |
| 4  | V356 Aql | 1936    | 7.00    | 127.0 | -6.3     | 4.5  |
| 5  | V528 Aql | 1945    | 6.90    | 16.0  | -8.2     | 10.5 |
| 6  | V603 Aql | 1918    | -0.50   | 5.0   | -9.3     | 0.6  |
| 7  | V1229 Aql | 1970   | 6.60    | 18.0  | -8.1     | 8.7  |
| 8  | V1370 Aql | 1982   | 7.70    | 15.0  | -8.3     | 15.6 |
| 9  | V1419 Aql | 1993   | 7.60    | 25.0  | -7.8     | 11.9 |
| 10 | V1425 Aql | 1995   | 8.00    | 27.0  | -7.7     | 13.9 |
| 11 | V1493 Aql | 1999   | 10.10   | 9.0   | -8.7     | 58.7 |
| 12 | V1494 Aql | 1999   | 4.10    | 8.0   | -8.9     | 3.9  |
| 13 | T Aur  | 1891          | 4.50    | 80.0  | -6.7     | 1.7  |
| 14 | V705 Cas | 1993   | 5.70    | 33.0  | -7.5     | 4.4  |
| 15 | V723 Cas | 1995   | 7.10    | 263.0 | -5.6     | 3.4  |
| 16 | V842 Cen | 1986   | 4.90    | 43.0  | -7.3     | 2.7  |
| 17 | V868 Cen | 1991   | 8.70    | 31.0  | -7.6     | 18.1 |
| 18 | V888 Cen | 1995   | 8.00    | 38.0  | -7.4     | 12.0 |
| 19 | V1039 Cen | 2001  | 9.30    | 25.0  | -7.8     | 26.1 |
| 20 | BY Cir | 1995          | 7.40    | 35.0  | -7.5     | 9.4  |
| 21 | DD Cir | 1999          | 7.60    | 5.0   | -9.3     | 23.9 |
| 22 | V693 CrA | 1981   | 7.00    | 10.0  | -8.6     | 13.5 |
| 23 | T CrB  | 1946          | 2.50    | 4.0   | -9.5     | 2.5  |
| 24 | V476 Cyg | 1920   | 1.90    | 6.0   | -9.1     | 1.6  |
| 25 | V1330 Cyg | 1970   | 9.90    | 161.0 | -6.0     | 15.4 |
| 26 | V1500 Cyg | 1975   | 1.90    | 2.0   | -10.2    | 2.6  |
| 27 | V1668 Cyg | 1978   | 6.20    | 11.0  | -8.6     | 8.9  |
| 28 | V1819 Cyg | 1986   | 9.30    | 95.0  | -6.5     | 14.7 |
| 29 | V1974 Cyg | 1992   | 4.30    | 19.0  | -8.0     | 2.9  |
| 30 | V2274 Cyg | 2001   | 11.50   | 22.0  | -7.9     | 76.0 |
| 31 | V2275 Cyg | 2001   | 6.90    | 3.0   | -9.8     | 21.6 |
| 32 | V2362 Cyg | 2006   | 8.10    | 9.0   | -8.7     | 23.4 |
| 33 | V2467 Cyg | 2007   | 7.40    | 8.0   | -8.9     | 17.8 |
| 34 | V2491 Cyg | 2008   | 7.50    | 4.0   | -9.5     | 25.2 |
| 35 | HR Del | 1967          | 3.60    | 167.0 | -6.0     | 0.8  |
| 36 | DN Gem | 1912          | 3.60    | 16.0  | -8.2     | 2.3  |
| 37 | DQ Her | 1934          | 1.60    | 76.0  | -6.7     | 0.5  |
| 38 | V446 Her | 1960   | 4.80    | 20.0  | -8.0     | 3.6  |
| 39 | V533 Her | 1963   | 3.00    | 30.0  | -7.6     | 1.3  |
| 40 | V827 Her | 1987   | 7.50    | 21.0  | -7.9     | 12.3 |
| 41 | V838 Her | 1991   | 5.30    | 1.0   | -10.8    | 16.6 |
| 42 | CP Lac | 1936          | 2.00    | 5.0   | -9.3     | 1.8  |
| 43 | DK Lac | 1950          | 5.90    | 55.0  | -7.0     | 3.9  |
| 44 | LZ Mus | 1998          | 8.50    | 4.0   | -9.5     | 39.9 |
| 45 | BT Mon | 1939          | 8.10    | 118.0 | -6.3     | 7.7  |
| No | Nova          | Outburst year | Strope et al. (2010) $m_{V,0}$ | $t_2$ | This MMRD $M_{V,0}$ | D kpc |
|----|---------------|---------------|-------------------------------|------|---------------------|-------|
| 46 | IM Nor        | 2002          | 8.50                          | 50.0 | -7.1 (-7.5, -6.8)   | 13.4  |
| 47 | RS Oph        | 2006          | 4.80                          | 7.0  | -9.0 (-9.2, -8.7)   | 5.7   |
| 48 | V849 Oph      | 1919          | 7.60                          | 140.0| -6.2 (-6.6, -5.7)   | 5.7   |
| 49 | V2214 Oph     | 1988          | 8.50                          | 60.0 | -7.0 (-7.3, -6.6)   | 12.4  |
| 50 | V2264 Oph     | 1991          | 10.00                         | 22.0 | -7.9 (-8.2, -7.6)   | 38.1  |
| 51 | V2295 Oph     | 1993          | 9.30                          | 9.0  | -8.7 (-9.0, -8.5)   | 40.6  |
| 52 | V2313 Oph     | 1994          | 7.50                          | 8.0  | -8.9 (-9.1, -8.6)   | 18.6  |
| 53 | V2487 Oph     | 1998          | 9.50                          | 6.0  | -9.1 (-9.4, -8.9)   | 53.0  |
| 54 | V2540 Oph     | 2002          | 8.10                          | 66.0 | -6.9 (-7.3, -6.5)   | 9.9   |
| 55 | GK Per        | 1901          | 0.20                          | 6.0  | -9.1 (-9.4, -8.9)   | 0.7   |
| 56 | RR Pic        | 1925          | 1.00                          | 73.0 | -6.8 (-7.2, -6.4)   | 0.4   |
| 57 | CF Pup        | 1942          | 0.70                          | 4.0  | -9.5 (-9.7, -9.3)   | 1.1   |
| 58 | V351 Pup      | 1991          | 6.40                          | 9.0  | -8.7 (-9.0, -8.5)   | 10.7  |
| 59 | V445 Pup      | 2000          | 8.60                          | 215.0| -5.8 (-6.2, -5.3)   | 7.5   |
| 60 | V574 Pup      | 2004          | 7.00                          | 12.0 | -8.5 (-8.8, -8.2)   | 12.4  |
| 61 | T Pyx        | 1967          | 6.40                          | 32.0 | -7.6 (-7.9, -7.2)   | 6.2   |
| 62 | HS Sge        | 1977          | 7.20                          | 15.0 | -8.3 (-8.6, -8.0)   | 12.4  |
| 63 | V732 Sgr      | 1936          | 6.40                          | 65.0 | -6.9 (-7.3, -6.5)   | 4.5   |
| 64 | V8890 Sgr     | 1990          | 8.10                          | 6.0  | -9.1 (-9.4, -8.9)   | 27.8  |
| 65 | V4021 Sgr     | 1977          | 8.90                          | 56.0 | -7.0 (-7.4, -6.6)   | 15.3  |
| 66 | V4160 Sgr     | 1991          | 7.00                          | 2.0  | -10.2 (-10.3, -10.0)| 27.0  |
| 67 | V4169 Sgr     | 1992          | 7.90                          | 24.0 | -7.8 (-8.1, -7.5)   | 13.9  |
| 68 | V4444 Sgr     | 1999          | 7.60                          | 5.0  | -9.3 (-9.5, -9.1)   | 23.9  |
| 69 | V4633 Sgr     | 1998          | 7.40                          | 17.0 | -8.1 (-8.4, -7.8)   | 12.9  |
| 70 | V4643 Sgr     | 2001          | 7.70                          | 3.0  | -9.8 (-10.0, -9.6)  | 31.2  |
| 71 | V4730 Sgr     | 2001          | 7.20                          | 2.0  | -10.2 (-10.3, -10.0)| 29.6  |
| 72 | V4740 Sgr     | 2001          | 6.70                          | 18.0 | -8.1 (-8.4, -7.8)   | 9.1   |
| 73 | V4742 Sgr     | 2002          | 7.90                          | 9.0  | -8.7 (-9.0, -8.5)   | 21.3  |
| 74 | V4743 Sgr     | 2002          | 5.00                          | 6.0  | -9.1 (-9.4, -8.9)   | 6.7   |
| 75 | V4745 Sgr     | 2003          | 7.30                          | 79.0 | -6.7 (-7.1, -6.3)   | 6.3   |
| 76 | V5114 Sgr     | 2004          | 8.10                          | 9.0  | -8.7 (-9.0, -8.5)   | 23.4  |
| 77 | V5115 Sgr     | 2005          | 7.90                          | 7.0  | -9.0 (-9.2, -8.7)   | 23.8  |
| 78 | V5116 Sgr     | 2005          | 7.60                          | 12.0 | -8.5 (-8.8, -8.2)   | 16.4  |
| 79 | U Sco         | 1999          | 7.50                          | 1.0  | -10.8 (-10.9, -10.7)| 45.8  |
| 80 | V992 Sco      | 1992          | 7.70                          | 100.0| -6.5 (-6.9, -6.1)   | 6.9   |
| 81 | V1186 Sco     | 2004          | 9.70                          | 12.0 | -8.5 (-8.8, -8.2)   | 43.1  |
| 82 | V1187 Sco     | 2004          | 9.80                          | 10.0 | -8.6 (-8.9, -8.4)   | 48.8  |
| 83 | V1188 Sco     | 2005          | 8.90                          | 11.0 | -8.6 (-8.8, -8.3)   | 31.0  |
| 84 | V373 Sct      | 1975          | 6.10                          | 47.0 | -7.2 (-7.6, -6.8)   | 4.6   |
| 85 | V443 Sct      | 1989          | 8.50                          | 33.0 | -7.5 (-7.9, -7.2)   | 16.0  |
| 86 | FH Ser        | 1970          | 4.50                          | 49.0 | -7.2 (-7.5, -6.8)   | 2.1   |
| 87 | LW Ser        | 1978          | 8.30                          | 32.0 | -7.6 (-7.9, -7.2)   | 14.8  |
| 88 | V382 Vel      | 1999          | 2.80                          | 6.0  | -9.1 (-9.4, -8.9)   | 2.4   |
| 89 | LV Vul        | 1968          | 4.50                          | 20.0 | -8.0 (-8.3, -7.7)   | 3.2   |
| 90 | NQ Vul        | 1976          | 6.20                          | 21.0 | -7.9 (-8.3, -7.6)   | 6.8   |
| 91 | PW Vul        | 1984          | 6.40                          | 44.0 | -7.3 (-7.6, -6.9)   | 5.4   |
| 92 | QU Vul        | 1984          | 5.30                          | 20.0 | -8.0 (-8.3, -7.7)   | 4.6   |
| 93 | QV Vul        | 1987          | 7.10                          | 37.0 | -7.4 (-7.8, -7.1)   | 8.0   |

* - marks the Galactic nova for which a distance > 20 kpc has been estimated.
Table 6: Using the MMRD relation calibrated in the paper to estimate the peak absolute magnitude and then distance to novae in M31. Data on \( t_2 \) and \( m_{\nu,0} \) are taken from Arp (1956), Rosino (1964). The bracketted quantities in columns 4 and 5 indicate the 1σ error on the absolute magnitude and distance to the nova.

| No \( \text{Arp (1956)} \) | \( m_{\nu,0} \) \( \text{mag} \) | \( t_2 \) \( \text{days} \) | \( M_0 \) \( \text{mag} \) | \( m_0 - M_0 \) \( \text{mag} \) | \( \text{Rosino (1964)} \) |
|---|---|---|---|---|---|
| 1 | 15.70 | 2.0 | -10.2 (-10.3, -10.0) | 25.9 (26.0, 25.7) | 24.30 | 25.0 |
| 2 | 15.70 | 2.0 | -10.2 (-10.3, -10.0) | 25.9 (26.0, 25.7) | 25.2 (25.4, 25.0) |
| 3 | 15.90 | 5.0 | -9.3 (-9.5, -9.1) | 26.8 (27.1, 26.6) | 24.8 (25.0, 24.5) |
| 4 | 18.20 | 10.0 | -8.6 (-8.9, -8.4) | 24.4 (24.7, 24.1) | 24.7 (25.0, 24.5) |
| 5 | 15.90 | 12.0 | -8.5 (-8.8, -8.2) | 24.3 (24.6, 24.0) | 24.7 (25.0, 24.5) |
| 6 | 16.00 | 9.0 | -8.7 (-9.0, -8.5) | 24.6 (24.8, 24.3) | 24.6 (24.8, 24.3) |
| 7 | 15.90 | 13.0 | -8.4 (-8.7, -8.1) | 24.6 (24.9, 24.3) | 24.6 (24.9, 24.3) |
| 8 | 16.00 | 9.0 | -8.7 (-9.0, -8.5) | 25.0 (25.2, 24.7) | 25.0 (25.2, 24.7) |
| 9 | 16.00 | 11.0 | -8.6 (-8.8, -8.3) | 25.2 (25.4, 24.9) | 25.2 (25.4, 24.9) |
| 10 | 16.00 | 7.0 | -9.0 (-9.2, -8.7) | 25.2 (25.4, 24.9) | 25.2 (25.4, 24.9) |
| 11 | 16.10 | 11.0 | -8.6 (-8.8, -8.3) | 24.7 (24.9, 24.4) | 24.7 (24.9, 24.4) |
| 12 | 17.00 | 26.0 | 7.7 (-8.1, -7.4) | 24.7 (25.1, 24.4) | 24.7 (25.1, 24.4) |
| 13 | 16.20 | 12.0 | -8.5 (-8.8, -8.2) | 24.7 (25.0, 24.4) | 24.7 (25.0, 24.4) |
| 14 | 16.40 | 16.0 | -8.2 (-8.5, -7.9) | 24.6 (24.9, 24.3) | 24.6 (24.9, 24.3) |
| 15 | 16.70 | 13.0 | -8.4 (-8.7, -8.1) | 25.1 (25.4, 24.8) | 25.1 (25.4, 24.8) |
| 16 | 17.20 | 29.0 | -7.6 (-8.0, -7.3) | 24.8 (25.2, 24.5) | 24.8 (25.2, 24.5) |
| 17 | 17.50 | 34.0 | -7.5 (-7.8, -7.1) | 25.0 (25.3, 24.6) | 25.0 (25.3, 24.6) |
| 18 | 17.60 | 29.0 | -7.6 (-8.0, -7.3) | 25.2 (25.6, 24.9) | 25.2 (25.6, 24.9) |
| 19 | 17.20 | 33.0 | -7.5 (-7.9, -7.2) | 24.7 (25.1, 24.4) | 24.7 (25.1, 24.4) |
| 20 | 17.40 | 27.0 | -7.7 (-8.0, -7.4) | 25.1 (25.4, 24.8) | 25.1 (25.4, 24.8) |
| 21 | 17.60 | 30.0 | -7.6 (-8.0, -7.3) | 25.2 (25.6, 24.9) | 25.2 (25.6, 24.9) |
| 22 | 17.40 | 43.0 | -7.3 (-7.6, -6.9) | 24.7 (25.0, 24.3) | 24.7 (25.0, 24.3) |
| 23 | 17.80 | 34.0 | -7.5 (-7.8, -7.1) | 25.3 (25.6, 24.9) | 25.3 (25.6, 24.9) |
| 24 | 17.60 | 33.0 | -7.5 (-7.9, -7.2) | 25.1 (25.5, 24.8) | 25.1 (25.5, 24.8) |
| 25 | 18.00 | 47.0 | -7.2 (-7.6, -6.8) | 25.2 (25.6, 24.8) | 25.2 (25.6, 24.8) |
| 26 | 17.80 | 105.0 | -6.4 (-6.9, -6.0) | 24.2 (24.7, 23.8) | 24.2 (24.7, 23.8) |
| 27 | 18.00 | 118.0 | -6.3 (-6.8, -5.9) | 24.3 (24.8, 23.9) | 24.3 (24.8, 23.9) |
| 28 | 18.10 | 118.0 | -6.3 (-6.8, -5.9) | 24.4 (24.9, 24.0) | 24.4 (24.9, 24.0) |
Table 7: Using the MMRD relation calibrated in the paper to estimate the peak absolute magnitude and then distance to novae in Virgo cluster galaxies. Data on $t_2$ and $m_{V,0}$ are taken from [Pritchet & van den Bergh (1987); Shara et al. (2016)]. The bracketed quantities in columns 4 and 5 indicate the $1\sigma$ error on the absolute magnitude and distance to the nova.

| Nova         | $m_0$ (mag) | $t_2$ (days) | $M_0$ (mag) | $m_0 - M_0$ (mag) |
|--------------|-------------|--------------|-------------|-------------------|
| NGC4365a    | 24.36       | 18.0         | -8.1 (-8.4, -7.8) | 32.5 (32.8, 32.1) |
| NGC4472Wa   | 22.74       | 20.0         | -8.0 (-8.3, -7.7) | 30.7 (31.0, 30.4) |
| NGC4472Wb   | 21.75       | 6.0          | -9.1 (-9.4, -8.9) | 30.9 (31.1, 30.6) |
| NGC4472Wc   | 24.44       | 12.5         | -8.4 (-8.7, -8.2) | 32.9 (33.2, 32.6) |
| NGC4472We   | 24.04       | 54.0         | -7.1 (-7.4, -6.7) | 31.1 (31.5, 30.7) |
| NGC4472Eb   | 23.21       | 11.0         | -8.6 (-8.8, -8.3) | 31.8 (32.0, 31.5) |
| Novae in M87 |             |              |              |                   |
| [1]          | 21.84       | 15.2         | -8.2 (-8.5, -8.0) | 30.1 (30.4, 29.8) |
| [2]          | 21.85       | 11.2         | -8.5 (-8.8, -8.3) | 30.4 (30.7, 30.1) |
| [3]          | 22.71       | 2.0          | -10.1 (-10.3, -10.0) | 32.9 (33.0, 32.7) |
| [4]          | 22.28       | 7.7          | -8.9 (-9.1, -8.6) | 31.2 (31.4, 30.9) |
| [5]          | 22.74       | 17.1         | -8.1 (-8.4, -7.8) | 30.9 (31.2, 30.6) |
| [6]          | 22.79       | 11.2         | -8.5 (-8.8, -8.3) | 31.2 (31.5, 31.0) |
| [7]          | 23.61       | 9.3          | -8.7 (-9.0, -8.4) | 32.3 (32.6, 32.1) |
| [8]          | 22.95       | 3.7          | -9.6 (-9.8, -9.4) | 32.5 (32.7, 32.3) |
| [9]          | 23.51       | 22.3         | -7.9 (-8.2, -7.6) | 31.4 (31.7, 31.1) |
| [10]         | 23.57       | 28.9         | -7.6 (-8.0, -7.3) | 31.2 (31.6, 30.9) |
| [11]         | 23.58       | 33.1         | -7.5 (-7.9, -7.2) | 31.1 (31.4, 30.8) |
| [12]         | 23.67       | 6.7          | -9.0 (-9.3, -8.8) | 32.7 (32.9, 32.5) |
| [13]         | 23.74       | 31.5         | -7.6 (-7.9, -7.2) | 31.3 (31.6, 31.0) |
| [14]         | 23.77       | 32.6         | -7.5 (-7.9, -7.2) | 31.3 (31.6, 31.0) |
| [15]         | 23.81       | 30.4         | -7.6 (-7.9, -7.3) | 31.4 (31.8, 31.1) |
| [16]         | 23.83       | 3.8          | -9.6 (-9.8, -9.4) | 33.4 (33.6, 33.2) |
| [17]         | 23.90       | 9.0          | -8.7 (-9.0, -8.5) | 32.6 (32.9, 32.4) |
| [18]         | 23.94       | 36.3         | -7.4 (-7.8, -7.1) | 31.4 (31.7, 31.0) |
| [19]         | 24.07       | 29.9         | -7.6 (-8.0, -7.3) | 31.7 (32.0, 31.3) |
| [20]         | 24.14       | 8.3          | -8.8 (-9.1, -8.6) | 33.0 (33.2, 32.7) |
| [21]         | 24.16       | 8.0          | -8.9 (-9.1, -8.6) | 33.0 (33.3, 32.8) |