Absolute Magnitudes and Distances of Recent Novae

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Abstract Using photometric data from the American Association of Variable Star Observers, peak absolute magnitudes and distances of some novae discovered in 2009 were calculated using the maximum-magnitude-rate-of-decline (MMRD) relationship. As these novae were only discovered recently, their distances have not been reported using any other method. In view of this, several older novae have been subjected to similar MMRD analysis. Their distances were then compared with other published work which used different methods of estimation. The distances found in this work correlate well, thus giving confidence in the estimates for the recent novae and the MMRD analysis.

1. Introduction

The relationship between the peak absolute magnitude, M_v, of a nova and its rate of decline of brightness from the maximum can be expressed by the following:

1. Nonlinear $M_v - t_2$ relation (Della Valle and Livio 1995; Downes and Duerbeck 2000).

$$M_v = -7.92 - 0.81 \arctan \left[\frac{1.32 - \log t_2}{0.23} \right] \quad (1)$$

$$M_v = -8.02 - 1.23 \arctan \left[\frac{1.32 - \log t_2}{0.23} \right] \quad (2)$$

2. Classical "linear" $M_v - t_2$ relation (Cohen 1985; Downes and Duerbeck 2000).

$$M_v = -(10.70 \pm 0.30) - (2.41 \pm 0.23) \log t_2 \quad (3)$$

$$M_v = -(11.32 \pm 0.440) - (2.55 \pm 0.323) \log t_2 \quad (4)$$

3. Conditional "linear" $M_v - t_2$ relation (Downes and Duerbeck 2000).

$$M_v = \begin{cases} -(10.79\pm0.92)-(1.53\pm1.15)\log t_2 & , \log t_2 < 1.2 \\ -(8.71\pm0.82)-(1.03\pm0.51)\log t_2 & , \log t_2 \geq 1.2 \end{cases} \tag{5}$$

4. Classical "linear" $M_v - t_3$ relation (Schmidt 1957; Downes and Duerbeck 2000).

$$M_v = -11.75 - 2.5\log t_3 \tag{6}$$

$$M_v = -(11.79\pm0.56)-(2.54 \pm 0.35)\log t_3 \tag{7}$$

5. Conditional "linear" $M_v - t_3$ relation (Downes and Duerbeck 2000).

$$M_v = \begin{cases} -(11.26\pm0.84)-(1.58\pm0.78)\log t_3 & , \log t_3 < 1.5 \\ -(8.13\pm1.26)-(0.56\pm0.68)\log t_3 & , \log t_3 \geq 1.5 \end{cases} \tag{8}$$

where t_2 and t_3 are the time taken for the brightness of nova to decline by 2 and 3 magnitudes from its maximum, respectively. Both parameters can be extracted from the light curve of a nova. With absolute magnitude, the distance, D (in kiloparsec, kpc), of a nova can be found by using the following equation.

$$D = 10^{0.2(mv - Mv + 5 - Av)} \tag{9}$$

where m_v is the peak apparent magnitude of the nova and A_v is the interstellar extinction coefficient.

2. Analysis flow and results

At the time of writing there were five novae discovered in 2009: V5581 Sgr, V5582 Sgr, V1213 Cen, V5583 Sgr, and V2672 Oph. Observational data recorded at AAVSO for the first two novae were inadequate and hence were left out of this work. The remaining three novae were subjected to the following analysis flow to determine their peak absolute magnitude and distance. Three older novae, V351 Pup, V4633 Sgr, and V2467 Cyg, were used as references.

1. Collect data from AAVSO
2. Curve-fit data and extract light curve parameters
3. Calculate absolute magnitudes, M_v
4. Refer or estimate extinction coefficients, A_v
5. Calculate distances, D

2.1. Curve-fit observational data

Raw data downloaded from AAVSO were minimally processed. Only "visual" and "V" type observations were considered. "Fainter-than" observations were not considered. All three novae are fast (Downes and Duerbeck 2000) and their light curves past maximum brightness fitted very well to an exponential function in this general form.

$$m_v = P_1 - P_2^{\ exp(-P3t)} \qquad (10)$$

where m_v represents the observed brightness in magnitude and t is the time in Julian date. Parameters P_1, P_2, and P_3 are extracted from the data using non-linear least squares method. Figures 1 through 4 plot the function m_v with data of each of the 2009 novae and the old nova V4633 Sgr.

2.2. Extract light curve parameters

Maximum brightness, m_0, and the time of maximum brightness, t_0, of each nova were read off from the light curve. The uncertainties of both parameters due to chart reading were noted down as well. Subsequently, t_2 and t_3 are determined from equation (10). Uncertainties of both parameters were also determined from equation (10) by means of error propagation and variance-covariance matrix obtained during the non-linear least square fitting. Table 1 lists the light curve parameters extracted for the three recent novae of interest and also for the three older novae. The parameters of the three older novae extracted in this analysis are comparable with numbers reported in other work, which are listed for comparison in Table 2.

2.3 Calculate peak absolute magnitude, M_v

Peak absolute magnitudes for each nova were calculated using all equations from all the five $M_v - t_n$ relations listed earlier. Subsequently a final error weighted mean value is calculated. The mean peak absolute magnitude of each nova is listed in Table 3. Values from other work are also listed as reference. The novae were also categorized according to their speed type (Downes and Duerbeck 2000).

2.4. Calculate distance of nova, D

Before the distances of the novae can be calculated, the interstellar extinction coefficient has to be determined. The interstellar extinction coefficient, A_v, can be determined from photometric measurement of the reddening effect of the nova and calculating it from the following equation.

$$A_v = 3.1E(B-V) \qquad (11)$$

Unlike the light curve data, $E(B-V)$ is not readily available from AAVSO or any other sources because the value is specific to that region of the sky where the nova of interest is found. Fortunately there are researchers who have created an interstellar extinction model or map of the whole sky.

A map by Schlegel *et al.* (1998) gives estimates of the maximum extinction on the line of sight in units of $E(B-V)$ or A_v. The map is presented in electronic form and is accessible from:

http://nedwww.ipac.caltech.edu/forms/calculator.html.

Application of the extinction value into the distance, D, equation is straightforward.

Another model considered is the work by Arenou *et al.* (1992) which gives a tridimensional mathematical model of the interstellar extinction. The extinction is modeled as a function of galactic longitude, latitude, and distance from the Sun. In general, the mathematical model is a mixture of quadratic and linear relation with distance.

$$A_v(r, l, b) = \begin{cases} \alpha(l, b)\, r + \beta(l, b)\, r^2 & , r \leq r_0 \\ \alpha(r_0, l, b) + \gamma(l, b)(r - r_0) & , r > r_0 \end{cases} \tag{12}$$

where r is the distance of object, l, b are galactic coordinates, α, β, and γ are coordinate-dependent constants. Since the extinction value is dependent on the distance of the object, the distance of nova, D, is solved numerically.

3. Discussion

There is a big variation in distance due to the values of A_v used. A better estimate of distance can be obtained only if one measures the $E(B-V)$ of the nova. This is especially true for the case of V2672 Oph. The $E(B-V)$ of V2672 Oph was reported to be $+1.6$ (Kato 2009), or A_v ~4.96. This gives an estimate of distance of 9.4 ± 2.3 kpc for V2672 Oph, which is closer to the number obtained with Schlegel *et al.* (1998) in Table 4. The range of distance estimated for V1213 Cen is large as well. It is difficult to narrow down the estimate without any $E(B-V)$ measurement. On the other hand, the distance estimate for V5583 Sgr is more meaningful. It is very likely that V5583 Sgr lies on the other side of the Galaxy since the distance of the Galactic center is ~8 kpc away from the Sun. At this distance, V5583 Sgr lies about $1.1-1.4$ kpc above the Galactic plane. This is not unlikely, as it has been found that the distribution of fast novae exists beyond 1 kpc above the Galactic plane (Burlak 2008). Bulge novae are likely to belong to a spectroscopic class type of Fe II (Della Valle and Livio 1998) while novae that lie near the Galactic disk, like V1213 Cen and V2672 Oph, belong to the He/N class. Table 5 lists the height of the three recent novae with respect to the Galactic plane.

Another interesting observation from V2672 Oph is the mass of the white dwarf that is responsible for the nova. If the peak absolute magnitude in V band is assumed to be approximately equal to its magnitude in B band and according to the mass – magnitude relation below (Livio 1992), it is interesting to note that the mass of white dwarf of V2672 Oph (at ~1.38 solar mass) is very close to the Chandrasekhar limit. The Chandrasekhar limit sets the theoretical maximum mass of a white dwarf to ~1.4 solar masses.

$$M_B^{max} \sim M_v^{max} = -\, 8.3 - 10.0 \log \left(\frac{M_{WD}}{M_{\odot}} \right) \tag{13}$$

4. Conclusions

Absolute magnitudes and distances of three recent novae were found to a good degree of confidence by exploiting the relationship between maximum magnitude and rate of decline of classical novae and published papers on older novae. All three recent novae are fast with recent two likely to be located on the other side of the Galaxy.

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Table 1. Light curve parameters of novae.

Nova	m_0	t_0	t_2	t_3
V351 Pup	6.4 ± 0.5	0.0 ± 0.5	11.1 ± 5.5	27.2 ± 12.5
V4633 Sgr	7.6 ± 0.3	0.0 ± 0.5	19.5 ± 4.7	42.9 ± 11.2
V2467 Cyg	7.4 ± 0.5	0.0 ± 0.5	9.0 ± 3.6	17.8 ± 5.6
V1213 Cen	8.2 ± 0.5	0.0 ± 0.5	6.6 ± 2.8	15.3 ± 8.0
V5583 Sgr	7.0 ± 0.3	0.8 ± 0.5	4.5 ± 1.2	8.8 ± 1.7
V2672 Oph	10.0 ± 0.5	0.0 ± 0.5	1.0 ± 0.7	2.0 ± 0.7

Table 2. Comparison between parameters extracted (*c*) from curve fit and reported (*r*) by others.

Nova	$t_2(c)$	$t_2(r)$	$t_3(c)$	$t_3(r)$	Reference
V351 Pup	11.1 ± 5.5	10	27.2 ± 12.5	26	Downes and Duerbeck (2000)
V4633 Sgr	19.5 ± 4.7	19 ± 3	42.9 ± 11.2	42 ± 5	Lipkin *et al.* (2001)
V2467 Sgr	9.0 ± 3.6	7.6 ± 3.0	17.8 ± 5.6	14.6 ± 3.5	Poggiani (2009)

Table 3. Calculated (c) and cited (r) peak absolute magnitude of recent and older novae.

Nova	Type	$M_v(c)$	$M_v(r)$	Reference
V351 Pup	fast	–8.5 ± 0.3	–8.0 ± 0.4	Downes and Duerbeck (2000)
V4633 Sgr	slow	–7.7 ± 0.3	–7.7 ± 0.5	Lipkin *et al.* (2001)
V2467 Sgr	fast	–8.8 ± 0.2	–8.8 ± 0.3	Poggiani (2009)
V1213 Cen	fast	–9.1 ± 0.1		
V5583 Sgr	fast	–9.3 ± 0.1		
V2672 Oph	fast	–9.8 ± 0.1		

Table 4. Distances of novae in kpc.

Nova	$A_v(1)$	D(1)	$A_v(2)$	D(2)	D(r)	Reference
V351 Pup	4.20	1.4 ± 0.4	1.46	4.9 ± 1.3	4.7 ± 0.6	Orio *et al.* (1996)
V4633 Sgr	1.30	6.3 ± 1.2	0.71	8.3 ± 1.6	2 – 10	Ikeda *et al.* (2000)
V2467 Sgr	20.24	0.0 ± 0.0	2.00	7.0 ± 1.7	1.5 – 4	Tomov *et al.* (2007)
V1213 Cen	6.72	1.3 ± 0.3	1.89	12 ± 3		
V5583 Sgr	1.29	9.9 ± 1.5	0.76	13 ± 2		
V2672 Oph	5.02	9.2 ± 2.2	1.69	42 ± 10		

Table 5. Heights of novae, z (in kpc), above the Galactic plane.

Nova	*Type*	*b*||	*z(1)*	*z(2)*
V1213 Cen	disk	–1.4	0.03 ± 0.01	0.3 ± 0.1
V5583 Sgr	bulge	–6.4	1.1 ± 0.2	1.4 ± 0.2
V2672 Oph	disk	2.5	0.4 ± 0.1	1.9 ± 0.5

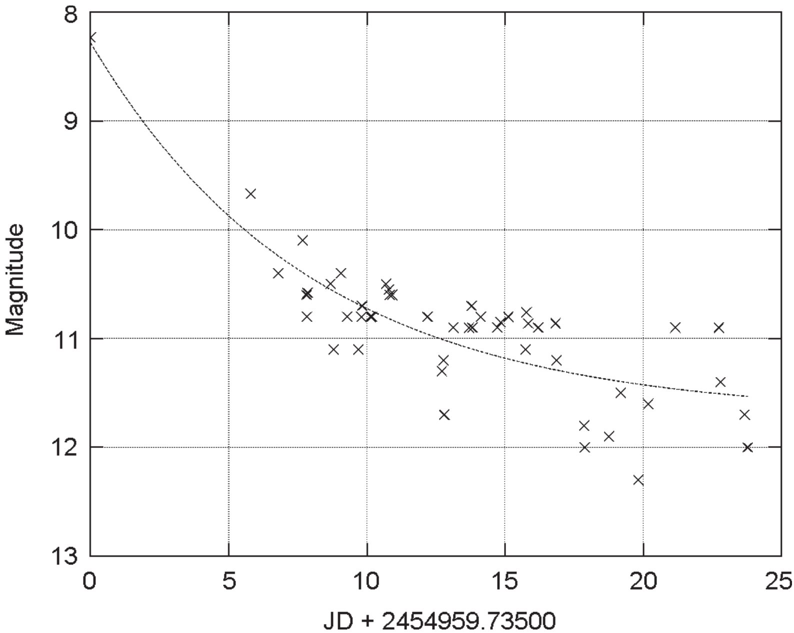

Figure 1. Light curve of V1213 Cen. Dashed line shows the fit of function m_v.

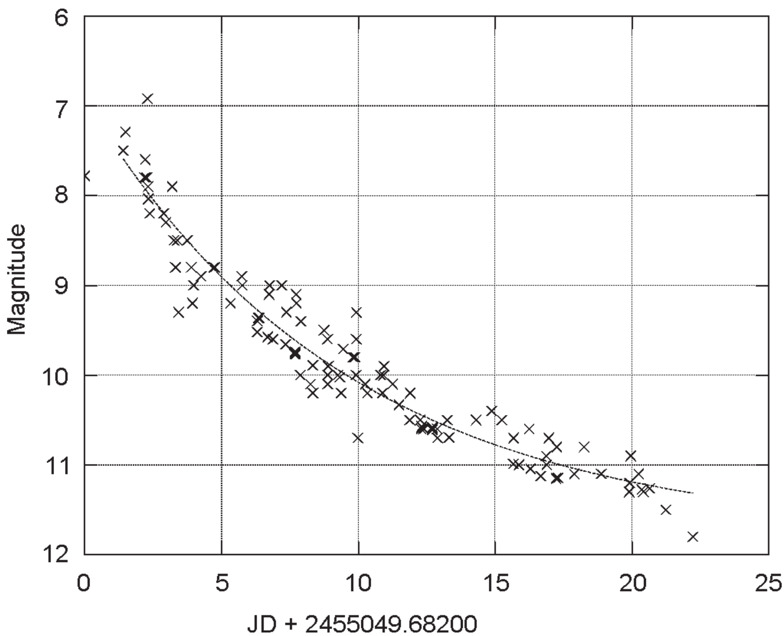

Figure 2. Light curve of V5583 Sgr. Dashed line shows the fit of function m_v.

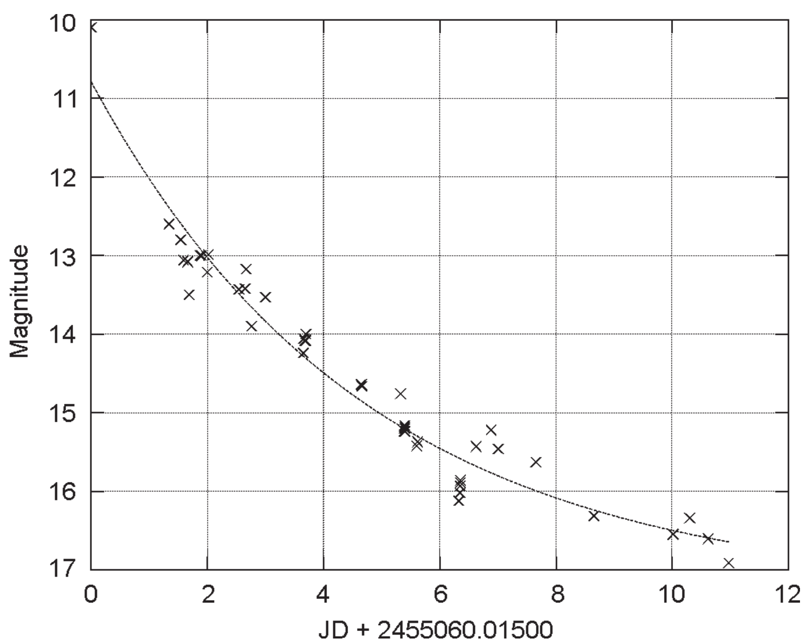

Figure 3. Light curve of V2672 Oph. Dashed line shows the fit of function m_v.

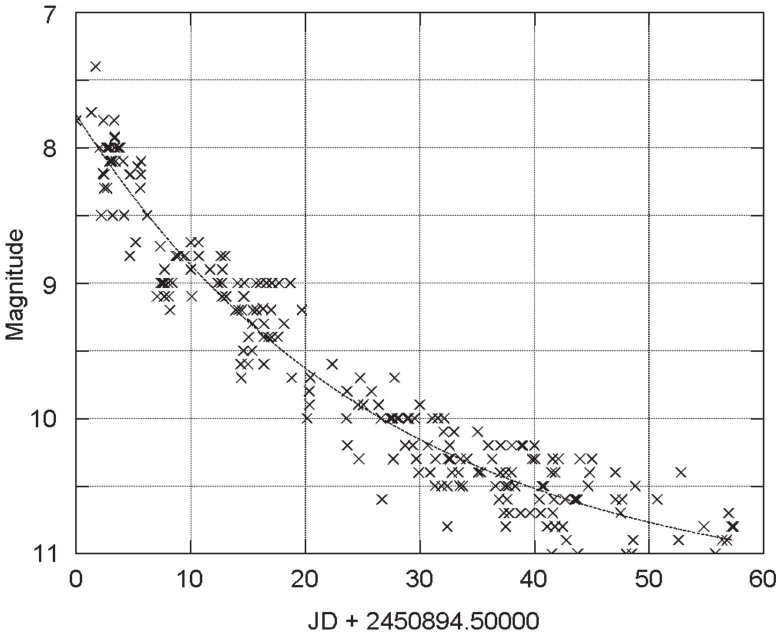

Figure 4. Light curve of V4633 Sgr. Dashed line shows the fit of function m_v.