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Nainital microlensing survey – long-term photometric study of two novae in M 31

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Abstract. Two classical novae were detected in the disk of M 31. The photometric observations were taken in Cousins *R* and *I* bands during the four year Naini Tal Microlensing Survey which was being carried out during 1998–2002 with the aim of detecting microlensing events in the direction of M 31. The first nova, NMS-1, which had an outburst in 2000 and was monitored before the outburst as well as after, showed an R-magnitude of 17.2 on 2000 October 20, and a fast decline of 0.11 mag/day. For the second nova NMS-2, outburst at peak was not detected; however, this nova was observed during the declining phase in 2001. The rate of decline of NMS-2 suggests that either it was a slow nova or we started monitoring it at late phase of its outburst. In the follow-up observations which were carried out from 2-m Hanle telescope in 2004-2005, we find that both the novae have reached their pre–outburst level flux, though the R_c-I_c color could be slightly different.

Keywords : individual galaxies: (M 31) – nova, cataclysmic variables

1. Introduction

Cataclysmic variables are binary systems with a white dwarf as the primary and a lower mass main sequence secondary star. Classical novae are a subclass of cataclysmic variables where a Roche lobe filling semi–detached donor transfers matter to the white dwarf, forming an accretion disc. A fraction of this matter gets deposited on the surface of the white dwarf. It is possible that this accreted matter becomes degenerate and when the temperature is sufficient to ignite the hydrogen on the surface, a runaway thermonuclear outburst can occur releasing enormous amount of energy due to which a sudden brightening of the star and ejection of the accreted

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matter occurs. The light curves of the different kinds of novae as well as their spectra could provide crucial information on the evolution of close binary stars. In the context of Supernovae Ia, the rapidly declining luminous novae, which are believed to consist of massive white dwarf primaries, are important. Specially, if a bright nova happens to show rapid decline (2 mag decline over time period of the order of 10 days) and also a repeated outburst at time scales of a decade, it could be a potential progenitor candidate for Supernova Ia explosion (e.g. Starrfield et al. 1988)

Due to recent activity to detect microlensing events towards M 31 e.g. AGAPE (Ansari et al. 1997, 1999), Columbia-VATT (Crotts & Tomaney 1996), POINT-AGAPE (Auriére et al. 2001; Paulin-Henriksson et al. 2003), WeCAPP (Riffeser et al. 2001), MEGA (de Jong et al. 2004), Nainital Microlensing Survey (Joshi et al. 2001, 2005) and Angstrom (Kerins et al. 2006), this galaxy has been an important extragalactic target to detect classical novae. Recently, Cao et al. (2012) have reported optical light curves of 29 novae in M 31 observed during the 2009 and 2010 observing seasons. So far, more than 800 novae have been detected in M 31 (Shafter et al. 2011 and references therein) since the pioneering work of Hubble (1929). However, very few follow–up studies of photometry of the novae have been reported. We had detected two novae in the four year Nainital Microlensing Survey (Joshi et al. 2004). Here we report our follow-up work on these two novae. Our aim is to see if the novae reached their pre–eruption flux level and if there is a change in colour compared to the pre-eruption state.

The paper is organised as follows: in Section 2, we present the observations and analysis. The light curves are discussed in Section 3 and results are summarised in Section 4.

2. Data

Cousins R and I band photometric observations of the M 31 disk centered at $\alpha_{2000} = 0^h43^m38^s$; $\delta_{2000} = +41^\circ09'.1$, were obtained with the 1-m Sampurnanand Telescope (ST) at Manora Peak, Nainital, India. The observations of $\sim 6' \times 6'$ field of M 31 disk was carried out with a small 1k×1k CCD in 1998-1999 observing season and a larger 2k×2k was used to observe a $\sim 13' \times 13'$ field during the next three observing seasons. The total integration time during our survey ranges from ~ 30 minutes to 2 hours each night. Follow-up photometric observations were made using FOSC mounted on the 2-m Himalayan Chandra Telescope (HCT), India in imaging mode which covers $\sim 10' \times 10'$ field. Observations in R and I bands were made on a total of 19 nights during 2004–2005. Due to time constraints, it was not possible to observe the target field in both the filters each night; so we put an observing priority on the R band. The average seeing during the observations was ~ 2.2 arcsec. An overview of the observational log is given by Joshi et al. (2003).

The basic steps of image processing which include bias subtraction, flat fielding, masking of bad pixels and cosmic ray removal were performed using IRAF[1]. All the images were aligned with respect to a reference frame and pixel sizes were rescaled to match the target field which

[1]Image Reduction and Analysis Facility (IRAF) is distributed by the National Optical Astronomy Observatories,

was observed with two different telescopes and using two different-sized CCDs. Photometric magnitudes were calibrated using the deep UBVRI photometry of about 4,00,000 stars carried out by Massey et al. (2006) using the 4-m KPNO telescope.

3. Novae light curves

We identified two novae in the disk of M 31, one in the 2000-2001 and other in the 2001-2002 observing seasons, which are named as nova NMS-1 and nova NMS-2 respectively, where NMS is the acronymn of Nainital Microlensing Survey. We have carried out a detailed photometric analysis of the two novae when these were sufficiently bright for PSF photometry. A detailed study of the individual novae is carried out in the following sub-sections.

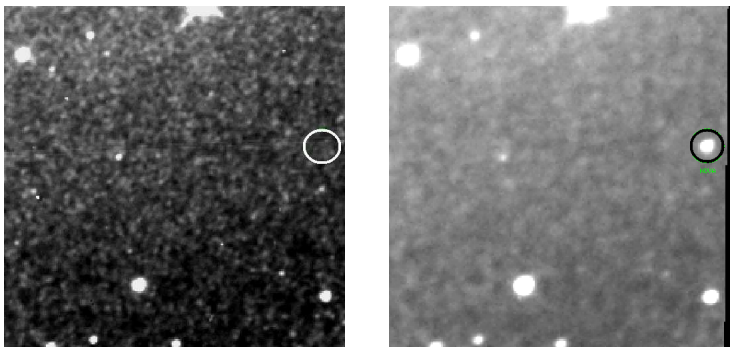

Figure 1. A 2 arcmin wide subset of two different R band images taken on 2000 January 11, (left panel) and 2000 October 20 (right panel). North is at the top and East is to the left. The left image shows no star at the position marked by a circle while the right image shows a star (nova NMS-1) of $R \sim 17.2$ mag at that position.

3.1 Nova NMS-1

The nova NMS-1 lies at $\alpha_{2000} = 00^h42^m57^s.1$ and $\delta_{2000} = +41°07'15''.7$. It was earlier reported in IAU circular by Donato et al. (2001). When we started the observations at 18:54 UT on 2000 October 18, the nova was still brightening. In Fig. 1, we have shown two images where NMS-1 was at the unresolved phase and at maximum brightness. The photometry of this outburst has been carried out using PSF profile fitting technique. Since it was very bright during the early phase of its outburst when we started observations on 2000 October 18, we have carried out photometric reduction of each individual image taken on the first few nights. The light curve of nova NMS-1

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Table 1. *R* band Photometric measurements of the nova NMS-1.

JD-2450000	R (mag)	error (mag)
1474.329861	21.643	0.232
1486.059027	21.756	0.171
1487.131944	21.593	0.152
1488.121527	21.770	0.175
1492.121527	21.368	0.104
1836.287705	18.631	0.052
1836.292006	18.582	0.031
1836.299725	18.528	0.042
1836.307363	18.576	0.047
1838.213467	17.124	0.018
1838.218759	17.104	0.015
1838.224270	17.124	0.014
2269.080473	20.509	0.179
2276.108960	20.480	0.205

is shown in Fig. 2. The brightness of the nova increased by about 1.53 mag in *R* band and 1.44 mag in *I* band from from 2000 October 18–20. From a comparison of individual image taken on 2000 October 20 it appears that we have captured nova NMS-1 during the peak brightness of the outburst phase. The change in brightness after 2000 October 20 was followed by an almost exponential decay. The rate of decrease in brightness from its peak value (t_2) was estimated to be about 0.11 mag/day suggesting a fast nova outburst which peaked at about $M_R(\max) \leq -7.96$ and $M_I(\max) \leq -8.02$ mag assuming a distance modulus of 24.49 for the M 31 and the R and I band extinction of 0.63 mag and 0.47 mag respectively (Joshi et al. 2003). The star was found to have a brightness of about 21.5 magnitude at the quiescent phase, but a slight increase in flux was observed in *R* band images taken in the observing season 2001-2002. R band flux appeared to decrease by more than a magnitude over a time scale of few weeks time of about 80 days after the outburst, and it increased by almost similar amount a year later, over a time scale of 100 days. While the change in *R* magnitude may have resulted due to larger photometric uncertainty at the magnitude fainter than 21 mag in the Nainital data, systematic errors of more than 1 mag is not very likely. The photometric measurements of NMS-1 is given in Table 1 as a sample and a full table can be downloaded from the online version or from the authors.

3.2 Nova NMS-2

The nova NMS-2 shown in Fig. 3 lies at $\alpha_{2000} = 00^h43^m03^s.3$ and $\delta_{2000} = +41^\circ12'10''.8$. It was earlier reported in IAU circular by Li (2001). Since this nova was situated at the edge of the target field, it could not be observed during most of our observations. When we started

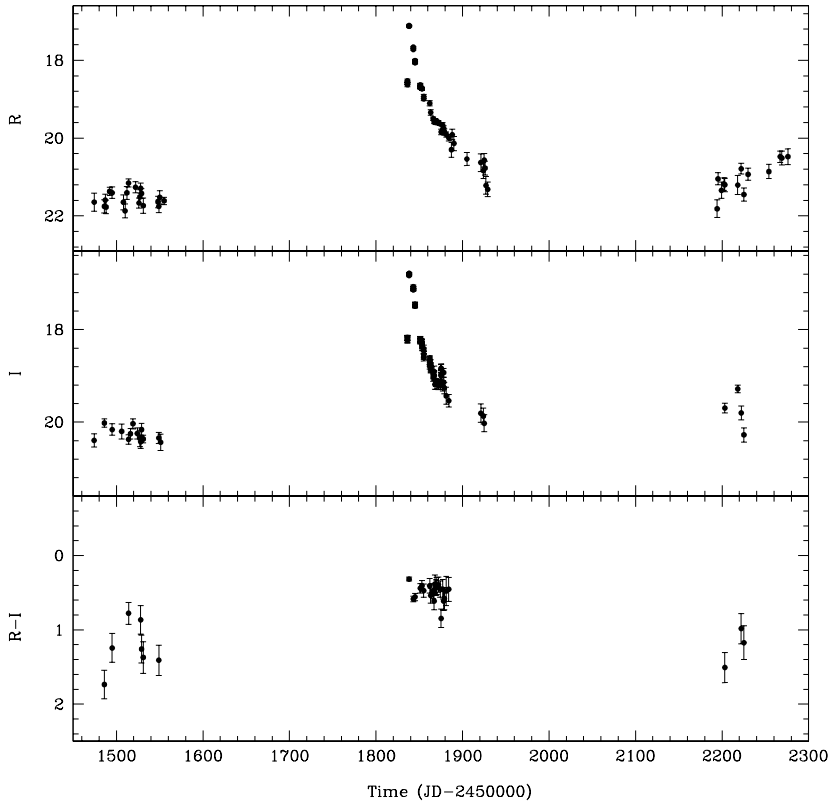

Figure 2. The R_c, I_c and color of NMS-1.

observations on 2000 October 12, for the 2001–2002 observing season, NMS-2 was already in the descending phase of brightness. A variation of more than 1.5 mag in *R* band is seen in first 35 days of its observations (see Fig. 4). Since we do not have any information of its maximum brightness, we could not determine the speed class of NMS-2. The brightest magnitude of the nova NMS-2 in our observations is estimated to be ∼ 17.42 mag and 17.21 in *R* and *I* bands respectively. It is seen in the figure that even during the descending phase, we do not have enough coverage and hence we are unable to say definitely if there is a plateau or an increase in the flux around day JD2452250. The problem is somewhat acute when we analyse the R_c-I_c color. A follow-up photometric observations of NMS-2 from the 2-m HCT suggests that NMS-2 was a R∼20.5 mag star which was also captured earlier at this brightness level during the 1998–1999 and 1999–2000 observing season of our microlens project using the 1-m ST. The *R* band photometric measurements of NMS-2 is given in Table 2 as a sample and a full table in both *R* and *I* bands can be downloaded from the online version or from the authors.

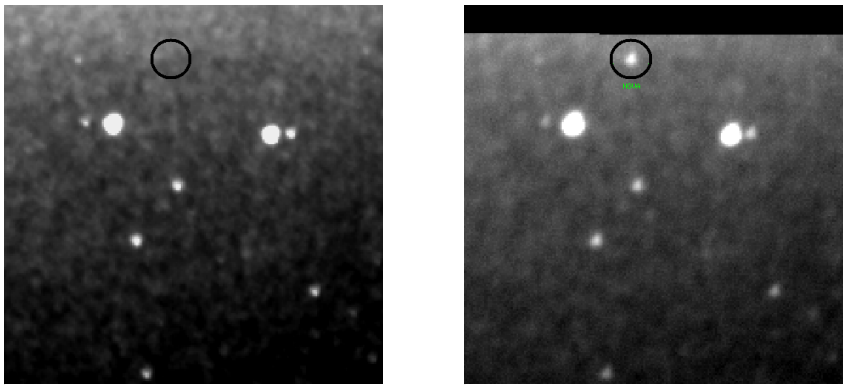

Figure 3. A 2 arcmin wide subset of two different images taken on 2001 January 17 (left panel) and 2001 October 19 (right panel). The North is at the top and East is to the left. The left image shows no star at the position marked by a circle while right image shows a star (nova NMS-2) of $R \sim 17.7$ mag at that position.

Table 2. *R* band Photometric measurements of the nova NMS-2.

JD-2450000	R (mag)	error (mag)
1498.048611	20.529	0.146
1548.133634	20.873	0.113
1841.231642	20.234	0.160
1870.117819	20.278	0.174
1874.110830	20.539	0.174
2202.154928	17.697	0.017
2202.164698	17.701	0.018
2202.174351	17.712	0.017
2202.176427	17.711	0.017
2202.211732	17.733	0.015
2203.151492	18.020	0.020
2203.161288	18.053	0.020
3332.197118	20.460	0.151
3333.154534	20.799	0.207

4. Summary

The main aim of the 'Nainital Microlensing Survey' was to search for microlensing events in the direction of M 31. However, the vast amount of data also enabled us to identify a substantial number of variable stars and optical transients in the disk of M 31. Two novae were detected during the monitor (NMS-1 and NMS-2). During the outburst, the nova NMS-1 was observed from 2 days prior to its optical maxima, and its initial rapid decline could be captured well to

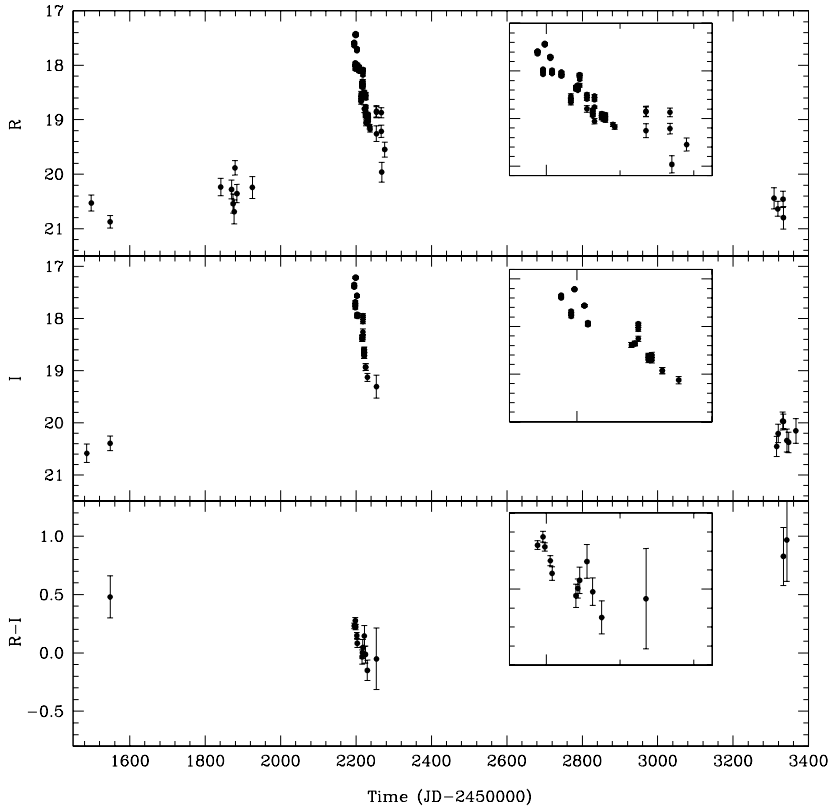

Figure 4. The R_c, I_c and color of NMS-2.. The lightcurves between days JD 2452198 and 2452280 are expanded in the inset.

establish that it was a fast nova. The nova NMS-2, could be monitored only during the declining phase of its brightness, but not during the peak. Follow-up observations were carried out for these two novae. NMS-1 was monitored during 2001–02 with the ST, but our field of view did not allow us to monitor it with HCT. We monitored NMS-2 in 2004-2005 from 2-m HCT and the star could indeed be identified at ∼ 21 mag in its quiescence phase. Its R-I color does indeed remain high (∼ 1 mag) during this phase.

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