Observing the Peculiar Nova V838 Mon

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Presented at the 91st Annual Meeting of the AAVSO, October 26, 2002; revised February 13, 2003

Abstract The peculiar nova V838 Mon has been monitored since its initial outburst in January 2002. The light curve shows several separate outbursts—a month-long hump in January, followed by a rapid 4-magnitude rise in February, two minor brightenings in March and April, and a final decline in May. This paper will discuss the current state of the nova itself, the remarkable light-echo around it, and offer some suggestions as to how amateurs can continue to monitor the object over the coming seasons.

1. Introduction

V838 Mon (J2000 coordinates: $07^h\,04^m\,04\overset{s}{.}81$ $-03°\,50'\,50\overset{''}{.}9$) is a peculiar nova that was discovered by Brown (2002) in early January 2002. Bedient (2002) was able to obtain early rise photometry from the Stardial automatic system, showing that the outburst must have started near January 1. It has been followed extensively from the ground by both professionals and amateurs, along with several epochs of Hubble Space Telescope (HST) imaging and spectroscopy.

The nova is considered peculiar because of its unusual light curve and its red color (both at maximum and particularly later in the outburst). However, the most peculiar aspect of the nova is the light-echo shell that formed around it. This light-echo is the reflection of the outburst light off of circumstellar material. This material must have been ejected from the star over the past few millennia, forming a number of concentric shells of dust. As the outburst progressed, the light from the outburst is reflected from the dust; since the outburst had a definite peak, you can follow that peak as light-travel time moves it through the surrounding shells.

This paper describes the light curve and some of the light-echo features because both aspects of the nova can be monitored by small telescopes with CCD cameras. In order to obtain high-quality results, some changes in the way aperture photometry is normally performed will be discussed.

2. Light Curve

The V-band and I_C-band light curves for V838 Mon are shown in Figure 1. These curves are a combination of data from Sobotka *et al.* (2002), Crause *et al.* (2003), Kimeswenger *et al.* (2002b), Kolev *et al.* (2002), Goranskii *et al.* (2002), Munari *et al.* (2002a), and Price *et al.* (2002), along with new data (especially after JD 2452380) from the USNO Flagstaff Station (NOFS) 1.0-m telescope. Due to the brightness of the nova, both professional and amateur measures have similar quality, and in fact amateur observations were essential in covering the rapid rise of the large February outburst.

After an initial rise to 10th magnitude, V838 Mon started to decline. Around February 2, 2002, Kimeswenger *et al.* (2002a) discovered a major outburst, culminating in a four-magnitude rise to a sharp visual peak around magnitude 6.5. In March, another rise to 7th magnitude occurred, and then in April, a final rise to 7.5mag occurred before the star went into a final decline. By the time it was lost in evening twilight around mid-May, 2002, V838 Mon was at 15th magnitude. After returning to the morning sky, V838 Mon appeared to have stabilized around $V = 16$.

The light curve is quite different at other wavelengths. Figure 1, for example, also shows the behavior in the Cousins I_C passband. Here, the late-time peaks (March and April) were much brighter than the sharp February peak. The second-season photometry as described by Munari *et al.* (2002a) shows a linear increase in magnitude at the red wavelengths. This is a classic case in which unfiltered photometry gives unusable results since there is so much difference in light-curve shape depending on wavelength.

Spectroscopy in Fall 2002 by Desidera and Munari (2002) and Wagner *et al.* (2003) shows a composite spectrum. In the blue region, the nova looks like a reddened B star. In the red region, the nova is a *very* cool star, approximately M10 in type, with many molecular bands. This composite nature has never been seen before, and will affect wide-band photometry of the nova and especially transformations onto the standard system. These problems will be discussed later.

3. Light Echo

After the February *V*-band peak, a light echo was seen by Henden *et al.* (2002), spreading rapidly and reaching a 35-arcsec diameter by the end of April. A time sequence of this early expansion can be seen in Munari *et al.* (2002a); later evolution of the expansion is shown in a 4-panel color series in *Astronomy* magazine (Gay 2003). The expansion then slowed down to about 0.1–0.2arcsec/day, but continues to grow at the present time.

Bond *et al.* (2002a) used HST to observe V838 Mon on April 30; the *B*-band image from that visit is shown in Figure 2. The important feature of this image is that there are several concentric rings around V838 Mon. As mentioned before, these are thought to be shells of dusty material ejected by previous outburst episodes over the past few thousand years. CCD images give a two-dimensional view of the light travelling through a three-dimensional cloud, thus making it hard to interpret the structure.

Since it takes longer for light to reflect off the backside of a spherical shell compared with material in front of the nova, Bond *et al.* (2002b) predict that the light echo should start filling in before the event ends. An *R*-band image taken on

October 31, 2002, with the NOFS 1.55-m telescope is shown in Figure 3, demonstrating how the light-echo has changed over the intervening months since the HST May visit.

4. Amateur Contributions

Certainly amateurs were instrumental in following the main outburst of V838 Mon. With a peak brighter than 7th magnitude, few professional telescopes could measure the nova without saturating their detectors. There may be *V*-band measures by observers during the rise to the February peak that have not been reported, so submission to archiving sites like the AAVSO of such data is strongly encouraged. Likewise, since this nova lies in the Monocerotis Milky Way, there may be images taken before outburst that can give information about the precursor during the time immediately preceding the January outburst. Saving those old images can sometimes be important!

During the 2002–2003 and later observing seasons, small telescope observations will be critical. The nova is still bright enough for almost any telescope, and the light-echo is still visible and over an arcminute in diameter, continuing to grow and easy to resolve under even poor seeing conditions.

For photometric measures of the nova itself, remember that the light-echo will influence extractions. If the sky annulus has small radii, the light from the echo will be included in the sky measure and will make the nova photometry fainter than reality. The inner radius needs to be set beyond the edge of the nebula, and the outer radius somewhat larger than that. As the nebula expands, these radii may need to be increased accordingly. Another option is to measure sky somewhere else in your CCD frame rather than concentric to the nova. The light-echo shell needs to be avoided in the nova measures since you want to measure changes in the star.

The object aperture needs to be quite small. Looking at Figure 3, there are some close companions about 4arcsec distant that should be kept outside of the aperture. An aperture size of 7arcsec diameter or less is recommended to avoid these stars, at least in the bluer bandpasses where the nova is faint. If the seeing is poor, you can still use such a small aperture as long as you use the same size aperture on your comparison stars. That keeps the fraction of light the same for both object and comparison, and the photometry will be proper. Looking at both Figures 2 and 3, there is an inner void in the light echo that a small measuring aperture avoids as well. However, if the light echo starts filling in, you will get some unavoidable contribution in your aperture from the inner parts of the nebula. There are methods of removing this extra light, so archive all images for further processing.

Munari *et al.* (2002b) indicate that V838 Mon is now increasing in brightness at the red wavelengths while remaining near quiescence in the blue. This is indicated in Figure 1, showing the monotonic brightness increase in the I_C filter compared with *V*. Recent photometry suggests that this increase is slowly extending into the *V* band. Monitoring the nova on a daily basis, at more than one passband if possible, can confirm this blueward progression and watch for subsequent outbursts. Time-series photometry can check for orbital modulation if this is a binary system, or possibly rotation of the suspected white dwarf component, much like what is done for cataclysmic binaries. You may want to do a time series in one of the bluer bands as well as one in a red band, as they are measuring different phenomena.

The Bessell prescription I_C-band filter has a red tail in its response compared with a true Cousins bandpass. Since V838 Mon is so red, the extended red response of a Bessell filter will make such I_C measures brighter than they should be. Use of the bluer passbands (B, V, R_C) are recommended where possible to avoid this problem. The difference between various I_C filters can be seen in Figure 1 after the beginning of the final decline, where there is more scatter in the I_C light curve.

Due to the composite nature of the spectra for V838 Mon, filter transformation is unusual. Normally, you can use (B-V), (V-R_C), (V-I_C), etc. for your V-band transformation color. However, since the spectra indicate that the U, B, V bandpass energy is coming from the blue star, and the R_C, I_C bandpass energy is coming from the red component, you will get different results for transformed V depending on the color index you choose. For V, it is recommended that you use (B-V) rather than (V-R_C) or (V-I_C) since the V-band flux is primarily from the hotter component. If a simultaneous B-band exposure is not taken, then you should use the nearest published (B-V) value for transforming a V-band measure. Untransformed V measures can be acceptable, if you indicate what your transformation coefficients are or take multiple nights of data so that the researcher can offset your data to match other observers. When transforming R_C or I_C, use (R_C-I_C) for the color index since these passbands are primarily from the cooler component. Unfiltered observations are not very useful since they cannot discriminate between the blue and red components of the composite spectra.

Continued deep imaging of the light-echo shell is also important. HST now has four epochs of observation, with major changes between each set of images. It is unclear whether these changes are due to light-travel effects or whether they are expanding or contracting features when seen at widely spaced time intervals. The possible filling-in of the light echo will be very important to discover and follow. Surface photometry, both wide- and narrow-scale, can follow the color evolution of the light-echo and also map out the three-dimensional surface as features brighten and dim. More distant shells may become illuminated as the outburst light propagates through space. While much of this can be done at professional observatories, small-telescope contributions can give a longer baseline and fill in observing gaps. Surface photometry of an extended object with lots of structure can be difficult, but you can send your calibrated images to a professional for examination. However you look at V838 Mon, it is a gorgeous object that is fun to observe!

5. Acknowledgements

Based on observations with the NASA/ESA Hubble Space Telescope, obtained at the Space Telescope Science Institute, which is operated by AURA, Inc., under NASA contract NAS5-26555.

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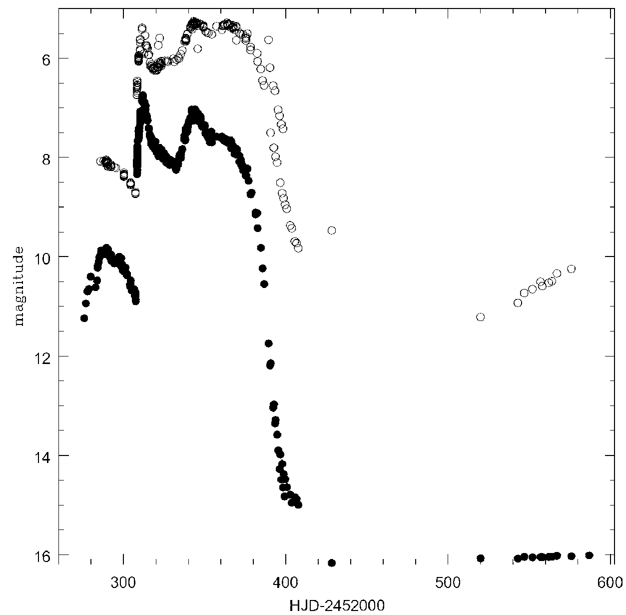

Figure 1. V- and I_c-band light curves of V838 Mon. V-band measures are shown by filled circles; I_c measures are shown by open circles.

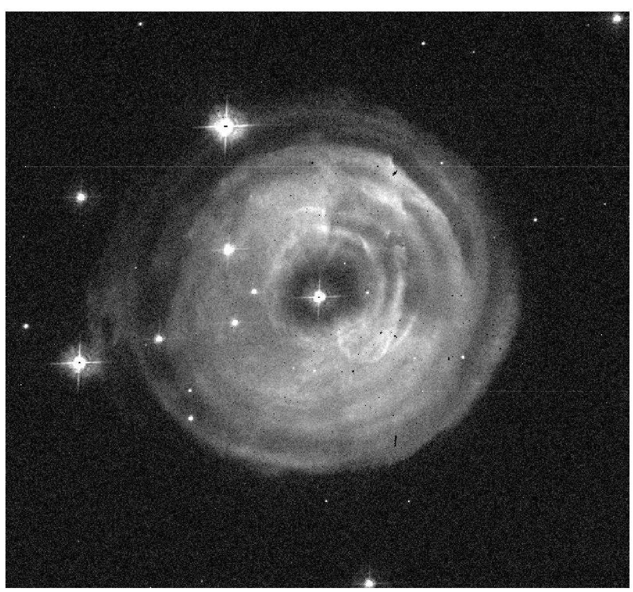

Figure 2. B-band light echo as seen by HST on April 30, 2002. This is approximately 60 arcsec wide, north up and east left, though the field is rotated slightly counter-clockwise due to spacecraft orientation.

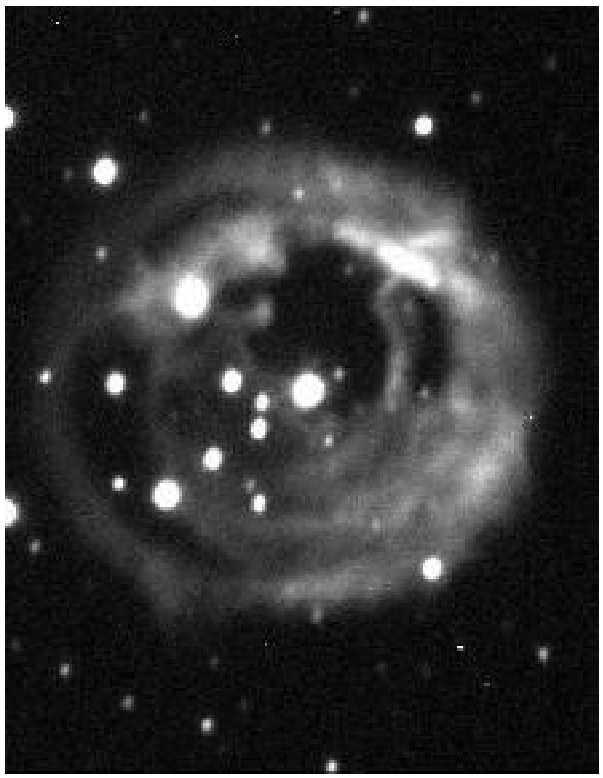

Figure 3. R_c-band light echo image as seen by the NOFS 1.55-m telescope on October 31, 2002. Approximately 2 arcmin high with north up and east left.