V463 Scuti (Nova Sct 2000): Rapidly Evolving Nova with a Prominent Premaximum Halt

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Abstract

We summarize photometric and spectroscopic observations of V463 Scuti (Nova Sct 2000), which was originally thought to be a red variable. The spectrum taken on 2000 March 16.81 UT showed prominent emission lines with a FHWM of 990 km s$^{-1}$ (H$\alpha$). The light curve shows a conspicuous premaximum halt lasting at least for 24 d, and a late-phase flare-like maximum. The nova then started rapidly fading at a rate corresponding to $t_2 = 15 \pm 3$ d. Long premaximum halts have been considered as a unique character of the “slowest” novae. The present observation, however, suggests that the long premaximum halts are not a unique character of the slowest novae, but a more general phenomenon spreading over a wider range of nova speed classes than has been previously believed. A recent interpretation of premaximum halts requires that the conditions of thermonuclear runaway was only marginally satisfied. Since such conditions are more difficult to meet in rapidly evolving novae, V463 Scut would provide an unique opportunity in testing this interpretation. The early post-outburst spectrum showed co-existence of FeII lines and some forbidden lines, which suggests that substantial amount of material may have been ejected before the observed optical maximum. The impact of the modern global network (VSNET) on confirmatory processes of transient objects is briefly discussed.

Key words: astrometry — stars: individual (V463 Scuti) — stars: mass-loss — stars: novae, cataclysmic variables

1. Introduction

Classical novae outbursts are thermonuclear runaways (TNR, Starrfield, Sparks 1987, Starrfield 1999, Starrfield et al. 2000) on a mass-accreting white dwarf in cataclysmic variables (CVs) [for a general review of CVs, see Warner 1995]. Observational distinction of classical novae is usually done spectroscopically. Classical novae can be easily distinguished from other high-amplitude variable stars by the presence of broad emission lines often accompanied by a P Cyg-type profile.

Such a distinction, however, is sometimes difficult especially when the detection of a new object on a photograph or a CCD image was done at later times. Difficult conditions are also easily met when discovery alert is not timely distributed. In some cases, researchers are obliged to distinguish novae from other objects only with limited information. For example, only 50% of the reported novae in Duerbeck (1987) (up to 1986) were spectroscopically confirmed. Some objects later turned out to be Mira-type stars (e.g. Zhao et al. 1994) or large-amplitude dwarf novae [see Kato et al. (2001) for a review of such objects]. Early spectroscopic confirmation based on a secure perspective of a newly discovered object is therefore a necessary condition for modern nova studies. The condition has been greatly improved by the advent of the global...
network of observers, VSNET,¹ which enabled quick dissemination of discovery alerts. The best examples include V1548 Aql = Nova Aql 2001 (Kato, Takamizawa 2001) and V463 Sct = Nova Sct 2000 (this paper), which may have been overlooked with a traditional confirmatory procedure.

2. Discovery

In 2000 March, one of the authors (KH) discovered a new variable star named Had V46. Because of the close presence of an IRAS source (IRAS 18311−1447), this variable star was initially regarded as a Mira-type long-period variable. However, we noticed a small offset of the reported position from the IRAS position. We thereby took CCD images in order to check the identification with the IRAS source. The CCD images taken on 2000 March 14.9 UT showed that the IRAS source is more likely to be identified with a red USNO star at 18h34m02.25, −14◦45′33.6″ (J2000.0) (star A in Figure 1) and an unexpected fading of Had V46. Since Had V46 looked like to be a large-amplitude (probably eruptive) non-red variable star, the object was reported as a possible nova (Haseda 2000). We examined past photographic survey images taken by KT and KH. The object was not recorded down to 14.0 mag on 21 photographs between 1996 May 25 and 1999 November 10. Furthermore, spectroscopic observation by MF revealed the presence of strong broad emission lines, which indicates that Had V46 is indeed a nova (Uemura et al. 2000). The object was given the permanent variable star designation of V463 Sct.

3. Astrometry and Identification

Astrometry of Had V46 was done with Kyoto images taken on 2000 March 14.9 UT and SK’s image taken on March 16.8 UT, with GSC-ACT reference stars. The accurate position of Had V46 was found to be 18h34m03.13, −14◦45′22.4″ (J2000.0, internal error 0′′.2)². Figure 1 shows a comparison of the outburst image and quiescent identification on DSS. The object was not detected on all available DSS images between 1984 August and 1996 September (6 images). The lack of detection of the prenova on these DSS images leads to an upper limit $V \sim 20$ for the quiescent magnitude of V463 Sct (Uemura et al. 2000).

4. Photometry

One of the authors (SK) obtained multicolor photometry with a 25-cm SCT telescope and an AP-7 CCD. The magnitudes were determined using the neighboring Tycho-2 stars. The result is summarized in Table 1. The CCD multicolor photometry covered the fading portion of the light curve. $B−V$’s were between +0.74 and +0.81, and $V−I_c$’s were between +0.90 and +1.11. Both relatively large color indices suggest a significant reddening.

Table 1. CCD multicolor photometry.

| Date (mid UT) | B      | V      | R_c    | I_c   |
|--------------|--------|--------|--------|-------|
| March 16.780 | 12.61  | 11.87  | 11.21  | 10.81 |
| March 17.791 | 12.63  | 11.88  | 11.22  | 10.84 |
| March 24.768 | 13.27  | 12.46  | 11.77  | 11.35 |
| March 31.795 | ⋮      | 14.47  | 13.40  | 13.57 |
| April 3.778  | ⋮      | 14.53  | ⋮      | 13.49 |
| April 8.764  | ⋮      | 14.47  | ⋮      | 13.54 |

No clear systematic color variation was observed during the observation period.

Photographic photometry was performed with twin patrol cameras equipped with a $D = 10$ cm f/4.0 telephoto lens and unfiltered T-Max 400 emulsions, located at two sites in Toyohashi, Aichi (KH) and Saku, Nagano (KT). The passband of observations covers the range of 400−650 nm. The magnitudes were derived against comparison stars selected from a GSC quick-V sequence, whose zero-point adjustment has confirmed using Tycho-2 values. The overall uncertainty of the calibration and individual photometric estimates is 0.2−0.3 mag, which will not affect the following analysis.

Figure 2 shows a light curve drawn from visual observations reported to VSNET, photographic observations, and CCD V-band observations.

5. Spectroscopy

MF obtained two spectra (spectral resolution $R = 450$ at 5500 Å, total exposure time 1080 s) on 2000 March 16.81 UT with the FBSPEC-1 spectrograph attached to a 28-cm telescope at Fuji Bisei Observatory. The data reduction was performed using IRAF package³ and the standard star HR 7596. Figure 3 shows an average of the two spectra. A strong Hα emission line (FWHM = 990 km s⁻¹, refined measurement supersedes the value in Uemura et al. 2000) with a slight hint of P Cyg-type profile (corresponding a velocity of 690 km s⁻¹) was detected. FeII series emission lines and Hβ emission line were also detected. The nova is thus thus confirmed to be an FeII class nova (Williams 1992).

The line identifications are summarized in Table 2. The identifications of forbidden lines ([OI] and [NII]) have been confirmed by a comparison with spectroscopic atlases of novae (Williams et al. 1991; Williams et al. 1994). The Balmer decrement was steep ($F(Hα)/F(Hβ) = 7.9$).

6. Discussion

6.1. Light Curve and Absolute Magnitude

At a first look, the rapid evolution of the light curve around in early March seems to suggest that the brightest observation by KT on March 2 was obtained close to the epoch of the maximum. Following this interpretation,

¹ http://www.kusastro.kyoto-u.ac.jp/vsnet/.

² This value supersedes the one reported in Uemura et al. (2000).

³ IRAF is distributed by the National Optical Astronomy Observatories.
Fig. 1. SK’s outburst image (left, 5 arcminutes square) taken on 2000 March 16.8 UT and the DSS2 quiescent identification (right, 2 arcminutes square) of V463 Sct. North is up and east is left on both images. The nearest USNO star (B in the right image) is about 3” apart from the nova position.

Fig. 2. Light curve of V463 Sct drawn from visual observations reported to VSNET (dots), photographic observations (open circles: KH, filled circles: KT), and CCD V-band observations (open squares).
Fig. 3. Spectrum of V463 Sct taken on 2000 March 16.81 UT. The unit in flux is erg s$^{-1}$ cm$^{-2}$ Å$^{-1}$, calibrated using the standard star HR 7596. The flux of the upper (thin line) spectrum has been multiplied by 5 in order to show weak lines. A strong H$\alpha$ emission line (FWHM = 990 km s$^{-1}$) with a slight hint of a P Cyg-type profile is clearly seen. FeII series emission lines and H$\beta$ emission line are also detected.

we obtain $t_2 = 6$ d based on KT’s subsequent observations using the same system. This value would indicate that V463 Sct belongs to very fast novae (Duerbeck 1987). By applying a recent calibration between the rate of decline and absolute magnitude at maximum (della Valle, Livio 1995), we obtain the maximum $M_V = -8.9 \pm 0.5$. Since photographic observations and visual observations have been confirmed to agree within $\sim 0.3$ mag, we can then safely adopt apparent maximum magnitude of $V = 9.9$. By adopting a mean $B - V$ of $+0.75$ during the early decline phase and the intrinsic color $B - V = -0.02 \pm 0.04$ for novae 2 mag below the maximum (van den Bergh, Younger 1987), we obtained $E_{B-V} = +0.8 \pm 0.1$. The observed constancy of the $B - V$’s during the observation precludes a possible effect of a reddening pulse which occurs in some novae around their optical maxima (van den Bergh, Younger 1987). Using the generally adopted relation $A_V = 3.1E_{B-V}$ and $E_{B-V}$, we can derive a distance modulus of $16.3 \pm 0.6$. This value is, however, too large to accept.

The other interpretation is that the “maximum” caught on March 2 is better understood as a delayed flare-like maximum sometimes seen in very slow novae [e.g. HR Del (Terzan 1970, Terzan et al. 1974, Drechsel et al. 1977), V723 Cas (Ohsima et al. 1996, Munari et al. 1996, Iijima et al. 1998), V1548 Aql (Kato, Takamizawa 2001), and DO Aql (Vogt 1928, Beyer 1929)]. The measured line width (FWHM $= 990$ km s$^{-1}$) seems to support this analogy [the FWHMs of V1548 Aql and V723 Cas were reported to be 1100 and 600 km s$^{-1}$, respectively (Shemmer 2001, della Valle et al. 1995)]$^4$. The flat portion of the light curve around $V = 12.0$, following the first positive detection $\sim 24$ d before March 2, is reasonably interpreted as a premaximum halt. The exact duration of the premaximum halt was not determined because of the lack of observations (around the solar conjunction) between 1999 November 10 and 2000 February 6. On 1999 November 10, the object was fainter than $V = 14.0$. Following this interpretation, the linear portion of the later evolution of the light curve would better represent the characteristic decline rate. The linear decline rate since March 2 has been estimated to correspond to $t_2 = 15 \pm 3$ d. If we adopt $t_2 = 15$ and the relation in della Valle, Livio (1995), $M_V$ becomes only 0.5 mag fainter than the case of $t_2 = 6$ d, which yields a still unacceptably large distance modulus of $15.8 \pm 0.6$. These estimates suggest that the speed of the linear decline part is not a useful indicator of the absolute magnitude of this nova.

The lack of large color changes during the fading stage seems to preclude a possibility of a dust-forming episode.

$^4$ A care, however, should be taken to make a direct comparison of line widths derived at different stages of outbursts. One should be also careful in interpreting the velocity in V463 Sct because a higher velocity component could have been undetected in the present low-resolution spectra.
scientific to exclude the possibility of a CV-type recurrent
Mikolajewska 1999). The present upper limit is insuffi-
images, however, precludes the possibility of a red giant
than +2). This limit and the non-detection on 2MASS
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part of a classical nova (e.g. Warner (1986) showed that
upper limit is reasonable for a CV-type quiescent coun-
terpart down to
erably affected. The absence of a quiescent optical coun-
(see Duerbeck (1981) for representative color changes).
The nova is located on the edge of Lynds 387. The large
interstellar absorption suggests that the nova is behind
this molecular cloud.

6.2. Quiescent Counterpart
Since there is a considerable uncertainty in estimating
the decline rate, we have adopted $M_V = -7.7$ (typical
maximum absolute magnitude for classical novae) as in
(Liller, Mayer 1987). Even if we adopt an extreme value
of $M_V = -8.9$, the following discussion will not be consid-
erable affected. The absence of a quiescent optical coun-
terpart down to $V \sim 20$ corresponds to an upper limit of
$M_V = 2$ ($M_V = 1$ for the $M_V$ (max) = -8.9 case). This
upper limit is reasonable for a CV-type quiescent counter-
part of a classical nova (e.g. Warner (1986) showed that
most of post-outburst classical novae show $M_V$ fainter
than +2). This limit and the non-detection on 2MASS
images, however, precludes the possibility of a red giant
secondary, as in symbiotic (recurrent) novae (Anupama,
Mikolajewska 1999). The present upper limit is insuffi-
cient to exclude the possibility of a CV-type recurrent
nova (Hachisu, Kato 2001).

Table 2. Line identifications.

| $\lambda$ | E.W. | ID | $\Delta$ |
|----------|------|----|---------|
| 4516     | -7.5 | FeII (37) | 4515.3 |
| 4555     | -16.1 | FeII (37) | 4555.9 |
| 4579     | -20.9 | FeII (37.38.48) | 4582.8, 4576.3, |
|          |       |           | 4574.8† |
| 4666     | -5.3  | FeII (37) | 4666.8 |
| 4861     | -76.9 | H$\beta$ | 4861.3 |
| 4924     | -27.6 | FeII (42) | 4923.9 |
| 5017     | -38.5 | FeII (42) | 5018.9 |
| 5169     | -50.1 | FeII (42) | 5169.0 |
| 5234     | -9.7  | FeII (49) | 5234.6 |
| 5273     | -13.5 | FeII (49) | 5276.0 |
| 5317     | -20.5 | FeII (48.49) | 5316.8, 5316.6† |
| 5376     | -4.6  | FeII (49) | 5376.0 |
| 5535     | -5.6  | FeII (55) | 5534.8 |
| 5572     | -5.7  | [OI] | 5577‡ |
| 5681     | -10.4 | [NII] | 5679‡ |
| 5756     | -21.4 | [NII] | 5755 |
| 5897     | -3.5, -7.7‡ | NaI | 5890 |
| 6246     | -14.9 | FeII (74) | 6240.1, 6247.6‡ |
| 6299     | -16.9 | [OI] | 6300 |
| 6365     | -4.2  | [OI] | 6364 |
| 6454     | -1.8  | FeII (74) | 6456.4 |
| 6564     | -42.8 | H$\alpha$ | 6562.8 |

* Equivalent width in Å.
† Blended.
‡ Uncertain identification.
§ Decomposed doublet components.

(see Duerbeck (1981) for representative color changes).

Although the origin of the phenomenon is not yet well
understood, it is well known that the duration of a pre-
maximum halt depends on the nova speed class: in slow
novae, the typical duration is a few to several days; in
fast novae, the typical duration is a few hours (Bode,
Evans 1989, p.4). In some slow novae (HR Del, V1548
Aql, V723 Cas, DO Aql, see subsection 6.1 for the refer-
ences), the durations can be up to several months. All
these exceptional slow novae are known to belong to the
“slowest” novae (there is even an argument that V723
Cas may be a symbiotic nova, cf. Munari et al. 1996).
The occurrence of at least 24 d-long premaximum halt in
a rapidly evolving nova (V463 Sct) is quite exceptional.
This observation suggests that the occurrence of a long
premaximum halt and a late-time flare-like maximum is
not a unique character of the “slowest” novae, but a more
general phenomenon spreading over a wider range of nova
speed classes than has been previously believed.

Figure 4 shows a comparison of three recent novae with
a prominent premaximum halt. The data for V463 Sct are
the same as in figure 2. The data for V1548 Aql and V723
Cas are from reports to VSNET. The scales of the axes
are different between the objects. The quick evolution of
V463 Sct is evident.

Friedjung (1992) studied the past spectroscopic obser-
vations of HR Del during its long premaximum stage. Friedjung (1992) showed the presence of an almost sta-
tionary photosphere with very low velocities, unlike for
the majority of classical novae. Friedjung (1992) sug-
gested that the conditions of thermonuclear runaway
was only marginally satisfied in HR Del. This inter-
pretation is compatible with the measured white dwarf
mass in HR Del (0.52 $M_\odot$: Bruch 1982; 0.595 $M_\odot$:
Kwurster, Barwig 1988) combined with models of ther-
monuclear runaways (Prialnik, Kovetz 1995). This inter-
pretation seems to apply to similar very slow novae with
a long premaximum halt and delayed maximum. Orio,
Shaviv (1993) proposed that a premaximum halt may be
explained as an effect of local thermonuclear runaways,
but this possibility has not been examined in more detail.

If the interpretation of Friedjung (1992) also applies to
V463 Sct, the rapid subsequent evolution should meet a
difficulty because rapidly evolving novae would require a
more massive white dwarf (see e.g. Prialnik, Kovetz 1995).
If this marginal condition is met in V463 Sct, this object should have a high mass-transfer rate. The uniqueness of V463 Sct in that it showed both a slow-nova type long premaximum halt and rapid photometric evolution is expected to provide a more stringent test for this interpretation. Future quiescent observation of V463 Sct to determine the white dwarf mass and an accretion rate would therefore provide an unique opportunity in testing the interpretation that premaximum halts reflect a marginally satisfied TNR condition.

6.4. Spectroscopy

The “textbook” development of the optical spectra of novae has been described by various authors (e.g. Payne-Gaposchkin 1957; Bode, Evans 1989, Chap. 1.4; Williams 1992; Williams et al. 1991; Williams et al. 1994). The post-maximum evolution of nova spectra is known to be complex (Williams 1992; Williams et al. 1994). Williams (1992) described that novae at early post-outburst decline can be divided into two classes: FeII novae and He/N novae based on the predominant lines. Williams (1992) reported that FeII novae, to which V463 Sct belongs, tend to have narrower lines (i.e. smaller expansion velocity) and relatively early appearance of [OI] lines. The [OI] (λλ 6300, 6364 Å) lines, however, usually appear later than the evolution of FeII lines. For example, Williams et al. (1994) showed that the [OI] (λλ 6300, 6364 Å) lines were not strong 14 d after maximum in Nova LMC 1991, 11 d after maximum of V351 Pup = Nova Pup 1991, 11 d after maximum of V2264 Oph = Nova Oph 1992 No. 1. All of these novae are fast novae with \( t_3 \) between 8 and 26 d.

A spectrum of V463 Sct is shown in figure 3. According to Williams et al. (1994), it usually takes 20–30 d in fast novae before the [OI] lines become comparable in strength to V463 Sct at this epoch. The early (only 14 d after the March 2 maximum) appearance of these lines in V463 Sct is thus rather exceptional among FeII class novae. The spectrum is also similar to a spectrum of the moderately fast novae V1425 Aql (Nova Aql 1995) taken 50.5 d after the maximum (Kamath et al. 1997), V443 Sct (Nova Sct 1989) 72 d after the maximum (Anupama et al. 1992) and V1819 Cyg (Nova Cyg 1986) 92 d after the maximum (Whitney, Clayton 1989). These comparisons suggest that V463 Sct showed a moderately evolved spectrum only 14 d after the March 2 maximum.

According to Williams (1992), the FeII lines are considered to be formed in high-density winds. Since neutral oxygen is not expected in a homogeneous, high-temperature nebula in a nova, the presence of the [OI] lines is usually considered to be a signature of density inhomogeneities which are sufficiently large to prevent complete ionization (Williams 1992). The presence of the FeII and [OI] lines suggests that substantial amount of material had been ejected. Since the appearance of the [OI] lines in V463 Sct seems to be earlier than in other FeII class novae, the mass ejection responsible for the [OI] lines may have taken place earlier than the March 2 maximum. Since the elapsed time (38 d) since the earliest positive detection (February 6) is comparable to the epochs of appearance of the [OI] lines in fast to moderately fast FeII class novae, the presence of a long premaximum halt may be responsible for this ejection.

The steep Balmer decrement is consistent with a relatively large reddening (subsection 6.1).

6.5. Importance of Rapid Identification

As described in section 2, the nova was original considered as a red variable based on a possible identification with an IRAS source. Such a technique using catalog correlations to screen out large-amplitude red variables among nova candidates has been widely used. The present example clearly demonstrate a caveat of this technique in a very crowded region (V463 Sct indeed lied within an error ellipse of the IRAS source). It is thus highly advisable to check all materials (DSS, 2MASS, past archival photographs) before completely ruling out the possibility of a nova even if the suspect object is close to an IRAS source. Rapid accurate astrometry is confirmed to be very helpful in accurately identifying the counterpart on DSS images, leading to a correct interpretation of a new ob-
ject. Finally, a rapid circulation of discovery information through a world-wide network such as VSNET is proven to be very effective even when the nature of the new object is not clarified. Without such a medium, a chance in making early epoch observations could have been easily lost (for an unfortunate example, see Kato, Fujii 2001) especially in fast novae.

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