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Absolute spectrophotometry and photometric evolution of Nova Scuti 2005 N.1 (≡ V476 Sct)

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ABSTRACT

Our CCD photometry of Nova Scuti 2005 N.1 shows it to be a fast nova, characterized by $t_2 = 15$ and $t_3 = 28$d, affected by an $E(B - V) \sim 1.9$ mag reddening, appearing at a position $\alpha = 18^{\mathrm{h}}32^{\mathrm{m}}04\overset{\mathrm{s}}{.}753$ (±0.04 arcsec) $\delta = -06°43'34\overset{''}{.}77$ (±0.09 arcsec, J2000) and peaking at $V \sim 11.1$ mag on ∼September 28.1 UT. Absolute spectrophotometry places it within the Fe II class. The profile of emission lines is characterized by a double peak with a velocity separation of 690 km s^{-1} and a width at half intensity of 1200 km s^{-1}. The distance to the nova is 4 ± 1 kpc, and its height above the Galactic plane is $z = 80 \pm 20$ pc. The highly crowded field affects a possible identification of the progenitor, whose pre-outburst magnitude should, however, have been $22 < V < 25$ mag, thus below the limit of photographic surveys. A deep $BVR_{\mathrm{C}}I_{\mathrm{C}}$ photometric sequence is provided to support continued observations of the advanced decline phases.

Key words: novae – cataclysmic variables.

1 INTRODUCTION

Nova Scuti 2005 N.1 (V476 Sct) was independently discovered by Takao (2005) in September 30.522 UT on CCD images taken with a 120-mm f/4 telephoto lens and by Haseda (2005) in September 30.417 on photographs taken with a 120-mm f/3.5 lens. Gilmore & Kilmartin (2005) gave an accurate position of the nova $\alpha = 18^{\mathrm{h}}32^{\mathrm{m}}04\overset{\mathrm{s}}{.}75$, $\delta = -06°43'34\overset{''}{.}3$ (from 111 UCAC-2 stars, mean residual 0.1 arcsec in each coordinate). They remarked how comparison with a Digitized Sky Survey (DSS) red plate from 1988 August 10 shows no obvious precursor, though a star of red mag 17.9 lies 2.7 arcsec to the east of the nova (at a position $\alpha = 18^{\mathrm{h}}32^{\mathrm{m}}04\overset{\mathrm{s}}{.}92$, $\delta = -06°43'33\overset{''}{.}4$).

The nova appeared on a dense stellar field at low Galactic latitude ($l = 24.74$, $b = +1.21$), so progenitor identification is not easy and unique. The star mentioned by Gilmore & Kilmartin does not appear redder than nearby weak-field stars when comparing DSS-1 and DSS-2 plates taken in different bands. It is not included in the Guide Star Catalogue II (GSC2) or USNO-B catalogues, so its proper motion cannot be checked (all field stars within 30 arcsec of the nova are also missing meaningful proper motion information in either right ascension or declination). Although not detected by Two-Micron All-Sky Survey (2MASS), it was recorded in J band by the Deep Near Infrared Survey of the Southern Sky (DENIS) that lists for it $\alpha = 18^{\mathrm{h}}32^{\mathrm{m}}04\overset{\mathrm{s}}{.}94$, $\delta = -06°43'33\overset{''}{.}3$ and $J = 15.62 \pm 0.20$ mag.

Very little is known about this nova that was discovered shortly before becoming lost in the seasonal conjunction with the Sun. Spectroscopic confirmation was reported by Kiss, Bessel & Retter (2005) that identified on October 6.36 UT strong emission lines of hydrogen, oxygen, calcium, magnesium, carbon, and iron, with prominent Hα showing a symmetric profile and full width at zero-intensity (FWZI) > 4000 km s^{-1}. The strongest emission lines included O I 7773, 8446, 9264, Paschen series, the Ca II triplet, and C I 9406 Å, all with FWZI > 2000 km s^{-1}. A later spectroscopic observation was obtained on November 15.11 UT by Perry et al. (2005) that suggested the nova might be still quite early in its spectral development, showing structured emission in the lines of C I, N I, and Fe II with full width at half-maximum (FWHM) of 1600 km s^{-1}. He I lines were just emerging and still very weak, with the strongest lines in the visible and infrared spectrum being those from O I, ascribed almost completely to Lyman β fluorescence.

2 OBSERVATIONS

Low- and medium-resolution spectra of V476 Sct were secured on October 27.8 UT with the AFOSC imager plus spectrograph mounted on the 1.82-m telescope operated in Asiago by INAF Astronomical Observatory of Padova, using a 1.26-arcsec-wide slit aligned along

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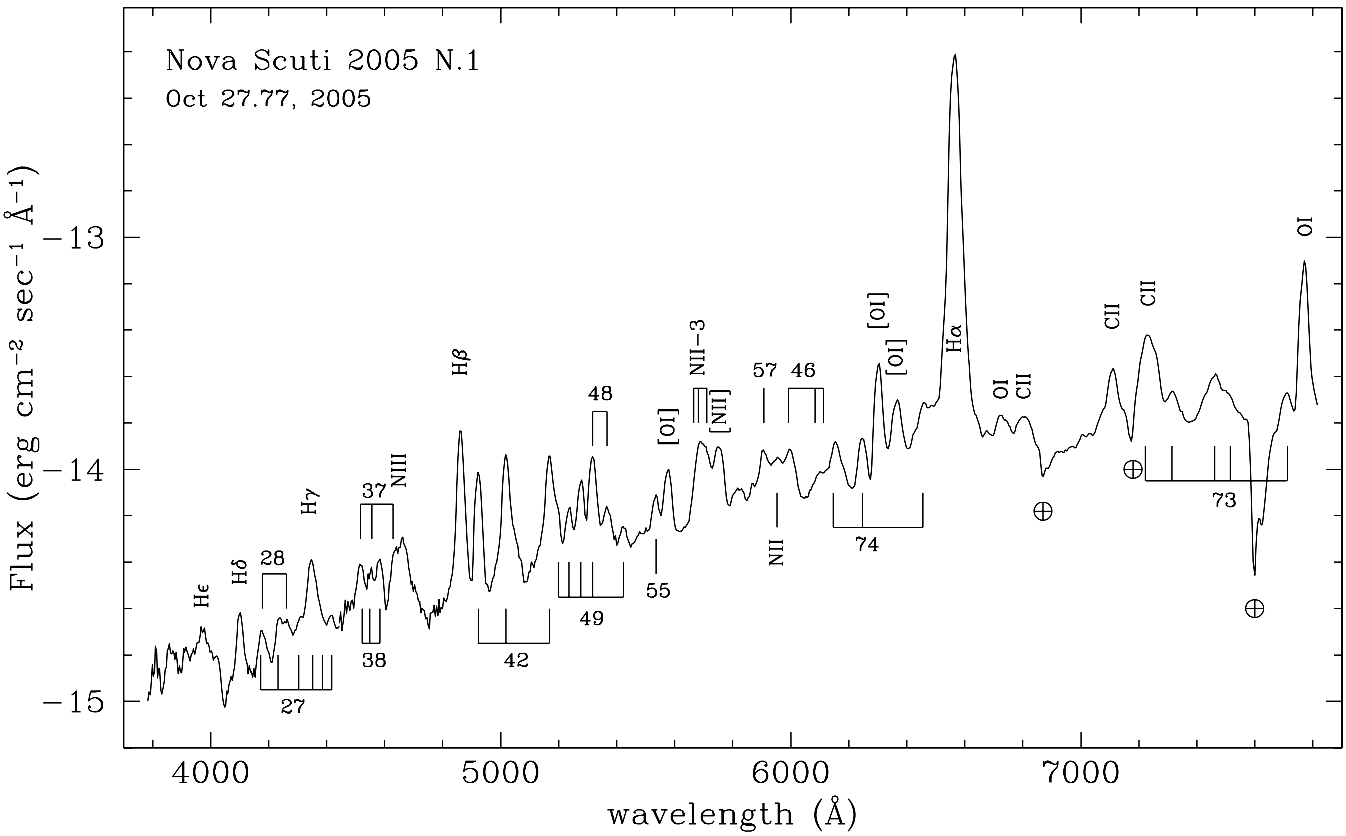


Figure 1. The absolutely fluxed low-resolution spectrum of Nova Scuti 2005 N.1 observed on 2005 October 27.77 UT. The ordinate scale is logarithmic to emphasize visibility of weaker features. Emission-line identification is provided. The lone numbers indicate Fe II multiplets.

the parallactic angle. Absolutely fluxed low-resolution spectrophotometry was obtained over 3505–7815 Å with a dispersion of 4.2 Å pixel^{-1}. The flux calibration was achieved via observations at different airmasses of the spectrophotometric standard HR 7596 (=58 Aql) from Hamuy et al. (1992, 1994). The spectrum is presented in Fig. 1, with our line identifications superimposed, and its bluest (and noisiest) part trimmed. Higher-resolution emission-line profiles were observed with holographic grisms over short wavelength intervals covering the Hα and O I 8447 Å lines (6390–7045 Å at 0.6 Å pixel^{-1}, and 8265–9165 Å at 0.9 Å pixel^{-1}, respectively). The velocity profile of both lines is presented and compared in Fig. 2. The spectra can be obtained in electronic form from http://ulisse.pd.astro.it/novasct2005n1/.

CCD B, V, R_C, I_C photometry of the nova (reported in Table 1) was obtained with the 1.0-m Ritchey–Chrétien telescope of the US Naval Observatory, Flagstaff Station on October 30.10 UT. A Tektronix/SITe 2048 × 2048 K thinned, backside-illuminated CCD was used. The telescope scale is 0.6763 arcsec pixel^{-1}, with a total field of view of around 23 × 23 arcmin^2. Typical seeing was ∼2 arcsec. Aperture photometry was performed with routines similar to those in DAOPHOT (Stetson 1987). A 9-arcsec extraction aperture with concentric sky annulus was commonly used. The photometric calibration has been performed on Landolt (1983, 1992) equatorial fields, selected for wide colour and airmass range. The USNO-FS observations have been used to derive a photometric calibration sequence around V476 Sct, which is presented in Fig. 3. The sequence is close to the photometric system defined by Landolt's equatorial standards, and covers a wide range in both magnitude and colour. Hopefully, it will promote observations of the advanced decline phase when the nova re-emerges from conjunction with the Sun during the spring of 2006 as well as encourage those with access to plate archives to search for valuable historical data on the progenitor.

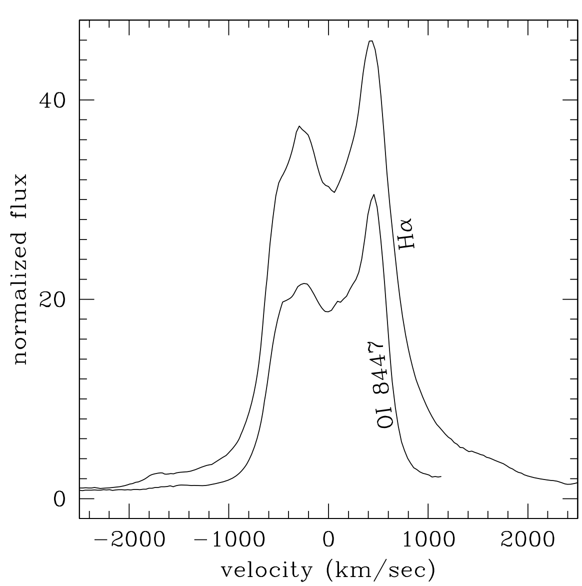


Figure 2. Resolved Hα, O I 8446 and Ca II 8542 Å emission profiles of Nova Scuti 2005 N.1 observed on 2005 October 27.74 UT. The continuum is normalized to 1.0. The profile for Ca II is expanded in ordinate by three times for better visibility.

Table 1. Our BVR_CI_C CCD photometry of Nova Scuti 2005 N.1.

Date	MJD	V	I_C	$B-V$	$V-R_C$	Telescope
September 24.13	3637.63	<15.1				ASAS
September 28.09	3641.59	11.09 ±0.04				ASAS
October 01.02	3644.52	11.36 ±0.07				ASAS
October 11.02	3654.52	12.83 ±0.07				ASAS
October 13.07	3656.57	13.08 ±0.08				ASAS
October 16.78	3660.28	13.51 ±0.03				Cembra
October 27.77	3671.27	14.14 ±0.07		1.82 ±0.06		Fig. 1 spectrum
October 28.78	3672.28	14.12 ±0.04	10.71 ±0.02			Cembra
October 29.78	3673.25	14.18 ±0.05	10.71 ±0.01			Cembra
October 30.10	3673.60	14.20 ±0.03	10.74 ±0.03	1.83 ±0.04	2.00 ±0.03	USNO-FS

Astrometry was performed on these USNO-FS images using SLALIB (Wallace 1994) linear plate transformation routines in conjunction with the UCAC2 reference catalogue. Our position for the nova is

$$\alpha = 18^{h}32^{m}04\overset{s}{.}753\,(\pm 0.04\,\text{arcsec})$$
$$\delta = -06^{\circ}43'34\overset{''}{.}77\,(\pm 0.09\,\text{arcsec}) \quad (1)$$

in agreement and with twice the precision of the Gilmore & Kilmartin (2005) determination.

CCD V, I_C photometry on V476 Sct was secured from a private observatory near Cembra (Trento), Italy, housing a 28-cm Schmidt–Cassegrain telescope equipped with a SBIG ST-9XE CCD, with a 1.47 arcsec pixel^{-1} scale and a total field of view of 12.5 × 12.5 arcmin^2. A 9-arcsec extraction aperture with concentric sky annulus was used. The data reduction has been performed in a standard fashion with MAXIM-DL. The photometric data have been calibrated against the photometric sequence in Fig.3 and are listed in Table 1.

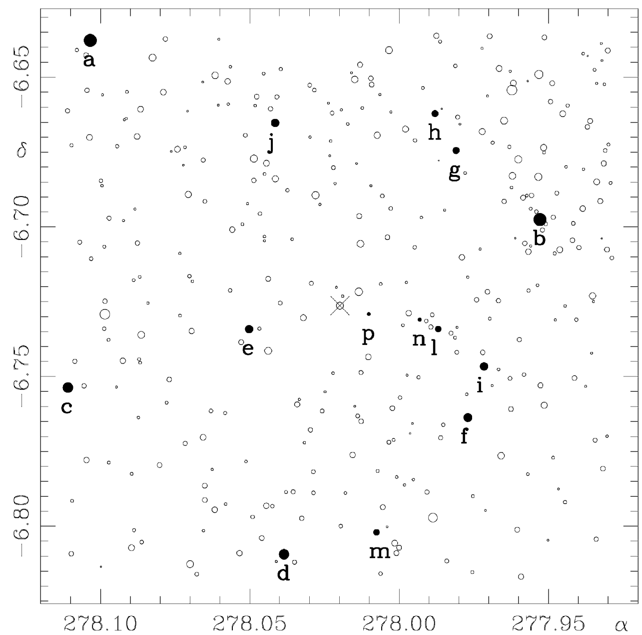
CCD V photometry of the nova was also obtained on several nights at Las Campanas Observatory (Chile) by the All Sky Automated Survey (the ASAS, Pojmanski 2002. See also http://archive.princeton.edu/∼asas/). The ASAS observations reported in Table 1 have been calibrated against the photometric sequence in Fig. 3.

3 PHOTOMETRIC EVOLUTION

The V-band light curve of V476 Sct is presented in Fig. 4 using our data in Table 1. The negative $V < 15.1$ mag detection on September 24.13 and the overall shape of the light curve suggest that the September 28.09 $V = 11.09$ observation has been secured at the light curve maximum or close to it, and we will adopt it throughout this paper. No other accurate CCD data exist in the literature to better map the earliest phases of the outburst development so to refine the estimate of timing and brightness of maximum. As a guess on their uncertainty, below we will assume that the true maximum could have occurred up to a day earlier and 0.2 mag brighter.

The nova decline times are $t_2 = 15$ and $t_3 = 28$ d, values typical of the class of *fast novae*. Using the relation of Warner (1995) on observed nova amplitudes versus t_2, an amplitude between 11 and 14 mag is expected (depending on the inclination to the line of sight of the orbital plane), for a brightness of the progenitor in the range $22 \leqslant V \leqslant 25$.

The colour at t_3 is $B - V = +1.8$, which suggests a high reddening affecting the nova as expected by its low Galactic latitude and large distance towards the central region of the Galaxy. van den Bergh



	B	(±)	V	(±)	B–V	(±)	V–R_C	(±)	R_C–I_C	(±)
a	11.03	0.03	10.52	0.03	0.51	0.03	0.34	0.03	0.40	0.03
b	11.07	0.03	10.48	0.03	0.58	0.03	0.32	0.03	0.38	0.03
c	12.87	0.03	12.20	0.03	0.67	0.03	0.41	0.03	0.51	0.03
d	13.99	0.03	12.32	0.03	1.67	0.03	0.94	0.03	0.95	0.03
e	14.44	0.03	13.71	0.03	0.72	0.03	0.42	0.03	0.59	0.03
f	14.98	0.03	13.38	0.03	1.56	0.03	0.89	0.03	0.87	0.03
g	15.43	0.03	14.57	0.03	0.87	0.03	0.51	0.03	0.56	0.03
h	15.67	0.03	14.68	0.03	1.00	0.03	0.61	0.03	0.65	0.03
i	15.71	0.03	13.75	0.03	1.96	0.03	1.10	0.03	1.06	0.03
j	15.89	0.03	13.66	0.03	2.24	0.04	1.38	0.03	1.47	0.03
l	16.27	0.03	14.99	0.03	1.28	0.04	1.01	0.03	1.19	0.03
m	17.21	0.03	14.93	0.03	2.28	0.06	1.34	0.03	1.30	0.03
n	17.88	0.05	16.72	0.05	1.16	0.08	0.70	0.05	0.76	0.05
p	18.76	0.06	16.88	0.06	1.88	0.20	0.78	0.07	1.03	0.05

Figure 3. BVR_CI_C photometric comparison sequence around Nova Scuti 2005 N.1 (indicated by the cross) calibrated against Landolt's equatorial standards.

& Younger (1987) derived an intrinsic colour $(B - V)_o = -0.02 \pm 0.04$ for novae at t_2. There is no direct colour measurement of the nova at t_2 but, given the slow spectral evolution implied by the similar description of the spectral appearance by Kiss et al. (2005) on October 6, Fig. 1 on October 27 and Perry et al. (2005) on

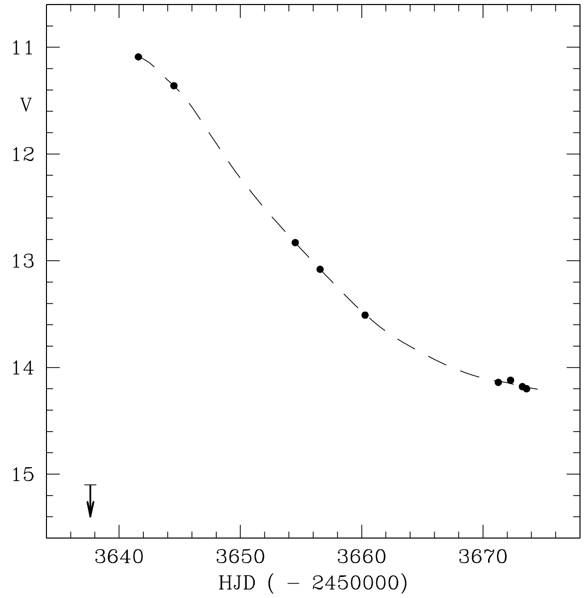


Figure 4. The V-band light curve of Nova Scuti 2005 N.1 from CCD observations in Table 1. The dashed curve is a hand-drawn fitting.

November 15, for the sake of discussion we assume $B-V=+1.8$ to be valid also at t_2, which would set the reddening to $E(B-V)=1.8$. Perry et al. (2005) estimated $E(B-V)=2.0$ from intensity ratio of O I lines. In this paper, we therefore adopt $E(B-V)=1.9 \pm 0.1$. The equivalent width of the diffuse interstellar band at 6614 Å (barely noticeable at the compressed scale of Fig. 2 on the red wing of the Hα profile) is 0.42 (±0.02) Å, a very large value. According to Herbig (1995) data, this is fully supportive of a massive reddening affecting the nova.

Using the Cohen (1988) relation between absolute magnitude and t_2 rate of decline, the nova absolute magnitude is $M_V=-7.9$ (an identical value is found using the Schmidt 1957 relation for t_3), which corresponds to a distance of 4.2 ± 0.5 kpc (in this and later error estimates, we will assume an uncertainty of 0.2 mag in $V_{\rm max}$, 0.1 mag in $E(B-V)$, 1 d in t_2 and t_3). The t_2 relation by Capaccioli et al. (1989) and della Valle & Livio (1995) would instead give $M_V=-8.4$ corresponding to a distance of 5.3 ± 0.5 kpc.

Buscombe & de Vaucouleurs (1955) suggested that all novae have the same absolute magnitude 15 d after maximum light. There are several calibrations of this absolute magnitude at 15 d past maximum: $M^V_{15}=-5.2\pm0.1$ for Buscombe & de Vaucouleurs (1955), $M^V_{15}=-5.60\pm0.43$ for Cohen (1985), $M^V_{15}=-5.23\pm0.16$ for van den Bergh & Younger (1987), $M^V_{15}=-5.38$ for van den Bergh (1988), and $M^V_{15}=-5.69\pm0.14$ for Capaccioli et al. (1989). Since $(B-V)_\circ \sim 0.0$ at $t=15$ d (cf. Warner 1995), it can be derived $M^V_{15}=-5.85$ according to Schmidt (1957), $M^V_{15}=-5.74\pm0.60$ for Pfau (1976) and $M^V_{15}=-5.50\pm0.18$ for de Vaucouleurs (1978). The nova brightness 15 d after maximum light was $V_{15}=13.1$ (12.9 if the maximum occurred one day earlier than estimated) and the corresponding distance estimates average at 3.5 kpc (σ = 0.4 kpc).

Combining above distance estimates from different methods with the above given uncertainties in t_2, $E(B-V)$ and $V_{\rm max}$, we conclude that the nova distance is 4 ± 1, corresponding to a height above the Galactic plane of ∼80 pc.

4 SPECTROSCOPY

Integration of the October 27.8 UT spectrum of Fig. 1, and the B and V magnitudes using the Buser (1978) transmission profiles yields $V=14.14$ (± 0.07) and $B-V=1.82$ (±0.06) mag, which match well the photometric data in Table 1 and Fig. 4, providing confidence in the accuracy of the calibration into absolute fluxes of the spectrum. The spectrum in Fig. 1 shows that the nova had not yet entered the nebular phase at the time of observation (day +30 from maximum), in line with the similar finding of Perry et al. (2005) later on November 15 (day +49).

The spectrum is dominated by Fe II lines, belonging mainly to multiplets 27, 28, 37, 38, 42, 46, 48, 49, 55, 57, 73 and 74, which arguably associate the nova with the 'Fe II' class defined by Williams (1992). Other prominent emission lines belong to hydrogen Balmer and Paschen, N II, N III, O I, [O I], Ca II and C II. The overall appearance of the spectrum resembles that of Nova Scuti 1989 similarly one month past maximum (Williams et al. 1991).

The high-resolution profiles of Hα, O I 8446 and Ca II 8542 Å in Fig. 2 display similar double-peaked profiles with a velocity separation of the peaks amounting to ΔV = 695, 695 and 665 km s^{-1}, respectively. The FWHM of the profiles are 1355, 1170 and 1010 km s^{-1}, respectively. The corresponding expansion velocity ($v_{\rm exp}\sim 600$ km s^{-1}) is somewhat slower than typical for novae with $t_2=15$ d, that have on average $v_{\rm exp}\sim 950$ km s^{-1}. There are, however, other novae characterized by a similar $t_2\sim15$ d and displaying slow expansion velocities: DN Gem with $t_2=17$ d and $v_{\rm exp}\sim 770$ km s^{-1}, V533 Her with 16 d and 580 km s^{-1} or GQ Mus with 15 d and 535 km s^{-1}. The profile in Fig. 2 suggests that the FWZI > 4000 km s^{-1} reported by Kiss et al. (2005) for Hα is probably quite inflated by the blending with Fe II 6456 Å (multiplet 74), far more than accountable by the expected decrease with time of the expansion velocity (e.g. McLaughlin 1960, Warner 1989).

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