Baltic Astronomy, vol. 18, 1–8, 2009

OPTICAL EVOLUTION OF THE OUTBURST OF THE SYMBIOTIC NOVA V4368 SGR = WAKUDA'S PECULIAR STAR

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Received 2009 May 14; accepted 2009 June 2

Abstract. We present the complete V band light-curve of the outburst of V4368 Sgr over the 16 years elapsed since its onset in 1993, and provide also its B–V, R_C–I_C and V–I_C colors from CCD observations. Recent absolute spectrophotometry of the star is compared with earlier similar data. V4368 Sgr remained stable at optical maximum around $V = 10.26$ mag for four years, from 1995 to 1998, and since then very smoothly and slowly declined to $V = 11.65$ mag in 2009, still a whole 10 mag brighter than in quiescence, when it was below the ~ 21.5 mag threshold of DSS-I ESO/SERC J and R plates. The spectrum over the last 15 years has kept its low ionization character, while the overall intensity of the emission lines (Balmer, He I, [O I], Fe II and [Fe II]) has increased by ~ 10 times. This has been accompanied by a corresponding increase in intensity of the nebular continuum which has now almost overwhelmed the emission from the fading outbursting star. As at the time of maximum brightness, the emission lines in 2009 are still very sharp and with no P-Cyg absorption flanking them, indicating that mass loss from V4368 Sgr is keeping very low or absent, and no fast wind from the outbursting star has so far emerged.

Key words: stars: novae – stars: binaries: symbiotic, individual (V4368 Sgr)

1. INTRODUCTION

V4368 Sgr (also known as "Wakuda's peculiar star") was discovered on 1994 March 4 at $V \sim 10.7$ mag by M. Wakuda (cf. Hirayama 1994). According to results summarized in IAUC 5961, inspection of various photographic material collected before the discovery showed the object being already at this level of brightness since at least 1993 March 29, but fainter than 12.5 mag through 1992. The progenitor is not visible on DSS-I ESO/SERC J and R plates (limiting magnitude ~ 21.5), which sets the outburst amplitude to $\Delta V > 11$ mag. Hazen (1994) examined 272 blue Harvard plates imaging the field of V4368 Sgr, distributed from 1888 to 1989 with a few gaps, and found no evidence of the star to a limiting magnitude of 14.5 (or, in some cases, considerably fainter). Grebel et al. (1994) examined 20 Sonneberg patrol plates taken between 1984 and 1988 and did not find the star to a limiting magnitude of 17. On 667 additional Sonneberg plates with limiting

Table 1. Our BVR_CI_C CCD photometry of V4368 Sgr with respect to the local photometric sequence calibrated by Henden & Munari (2001). The last column identifies the telescopes (see Section 2). Total error budgets are less than 0.014 mag on all these data.

Heliocentric JD	and date	V	B–V	V–I_C	R_C–IC	Telescope
2454288.483	2007 07 06.483	11.406		1.008		R030
2454301.494	2007 07 19.494	11.379	0.715	1.009		R030
2454585.943	2008 04 29.443	11.548	0.733			R120
2454600.320	2008 05 13.820	11.552	0.755			R120
2454604.879	2008 05 18.379	11.586	0.739			R120
2454651.514	2008 07 04.014	11.613	0.773	1.093		R030
2454668.449	2008 07 20.949	11.671		1.093		R030
2454676.491	2008 07 28.991	11.682	0.733	1.093	0.293	R120
2454688.420	2008 08 09.920	11.685	0.725	1.056	0.317	R120
2454716.366	2008 09 06.866	11.615	0.677	1.064	0.365	R120
2454730.301	2008 09 20.801	11.622	0.719	1.031	0.331	R120
2454739.264	2008 09 29.764	11.655	0.754	1.066	0.323	R120
2454939.588	2009 04 18.088	11.602		1.062		R030
2454943.603	2009 04 22.103	11.664	0.755	1.082		R030
2454944.642	2009 04 23.142	11.673	0.739	1.085	0.328	R120
2454946.583	2009 04 25.083	11.696	0.764	1.100		R030
2454946.645	2009 04 25.145	11.694	0.747	1.119	0.366	R120
2454956.579	2009 05 05.079	11.647	0.714	1.074		R030
2454959.607	2009 05 08.107	11.640	0.723	1.065	0.325	R120

magnitudes between 12 and 14, taken between 1926 and 1948 and between 1950 and 1983, the object was always invisible.

The spectroscopic information so far published refers only to the early phases of the outburst evolution of V4368 Sgr. Bragaglia et al. (1995) presented a high quality, absolutely fluxed 332–901 nm spectrum and high resolution emission line profiles from an Echelle spectrum, both obtained during July of 1994. An Echelle spectrum of a similar resolution was recorded in April of 1994 by Wallerstein (1996), while uncalibrated low-resolution spectral observations for March of 1994 were presented by Grebel et al. (1994). On these pre-maximum spectra V4368 Sgr displayed an absorption spectrum closely resembling an F5 supergiant. The only prominent emission lines were Hα, Hβ, Ca II far-red triplet and Fe II (multiplets 41, 42, 48 and 49). Weak emissions from He I and neutral and ionized metals were discernible only on high S/N Echelle spectra. The expansion velocities of the circumstellar material and the outward motion of the pseudo-photosphere were found to be very low, of the order of 30 km/s. The appearance of V4368 Sgr did not changed much at the time of maximum V brightness, as illustrated by the spectra of 1995 and 1996 presented by Munari & Zwitter (2002).

The very slow photometric evolution, the absence of significant mass ejection, the sharpness and presence of a central reversal in the emission profiles of Balmer lines, and the overall spectral appearance led Grebel et al. (1994) to classify V4368 Sgr as a symbiotic nova. Symbiotic novae are extremely rare objects, with about ten so far observed to erupt in our Galaxy, the most famous being probably AG Peg, RR Tel and HM Sge (cf. Kenyon 1986). A further dozen were already in outburst at the beginning of their recorded history, so the occurrence of their outbursts went undocumented (Munari 1997), the most famous probably being Hen 2-104 (the Southern Crab, Corradi et al. 2001) and H 1-36 (Allen 1983).

Table 2. Annual averages of the visual brightness estimates of V4368 Sgr collected by one of us (A.J.). The second column gives the mean JD of the observations, the fourth – the error of the mean (ϵ) for $<\mathrm{m_{vis}}>$, and the last column – the number of estimates collected in the given year.

yr	<JD>	$<\mathrm{m_{vis}}>$	ϵ	N_T
1994	2449472	10.77	0.02	27
1995	2449919	10.25	0.05	4
1996	2450276	10.25	0.04	6
1997	2450652	10.27	0.03	36
1998	2451006	10.29	0.02	56
1999	2451359	10.43	0.02	64
2000	2451731	10.53	0.03	52
2001	2452078	10.65	0.03	65
2002	2452443	10.86	0.04	55
2003	2452829	11.04	0.04	45
2004	2453182	11.03	0.06	23
2005	2453539	11.08	0.05	27
2006	2453893	11.19	0.05	26
2007	2454281	11.37	0.04	28
2008	2454614	11.60	0.02	28
2009	2454924	11.65	0.06	6

There are conspicuous differences between classical and symbiotic novae. A classical nova is typically composed by a white dwarf orbited by a lower mass cool companion (not dissimilar from K or M main sequence stars). Their orbits are close and the orbital periods range from a few hours to a few days. The white dwarf components of classical novae accrete at low rates and their outbursts last for a few weeks to a few months, with significant mass ejection ($10^{-4/-5}$ $M_{\odot}$) and outflow velocities from several hundreds to some thousands km s^{-1}.

In symbiotic novae the donor star is a cool giant (frequently a Mira) feeding mass to the white dwarf companion at rates which are several orders of magnitude higher than in classical novae. In symbiotic novae, orbital periods are decades of years long (the shortest one being probably the 13.5 yr displayed by PU Vul, Kolotilov et al. 1995), the outbursts last for decades or even centuries (Kenyon 1986; Munari 1997), and there is no significant and protracted mass loss from the system, with emission lines generally keeping a sharp profile through the whole outburst.

The light curve of V4368 Sgr has never been presented in the literature, nor new spectroscopic data collected after 1996 have been published. The aim of this paper is to present the complete light curve of the outburst and the recent spectral data.

2. OBSERVATIONS

2.1. Photometry

All our CCD observations of V4368 Sgr were accurately reduced and color-corrected against the local $UBVR_{\mathrm{C}}I_{\mathrm{C}}$ sequence of Henden & Munari (2001). The results are listed in Table 1. The formal global errors (adding quadratically the

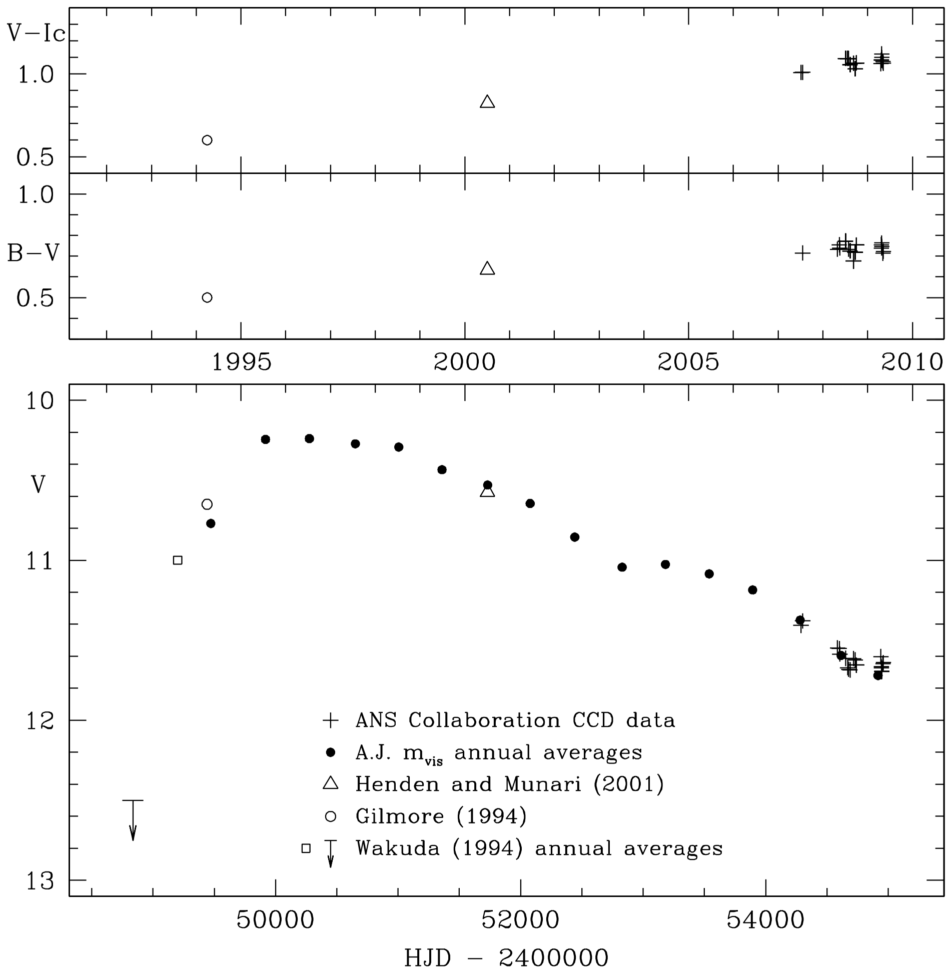

Fig. 1. Light curve in the V passband and B–V and V–I_C color evolution of V4368 Sgr.

contribution of the Poissonian noise, color transformations and residuals in the dark/flat/bias corrections) are always less than 0.014 mag for all data points in Table 1. The observations were collected with the following two ANS Collaboration telescopes. **R030**: a 0.30 m Meade RCX-400 f/8 Schmidt-Cassegrain telescope operated in Cembra (Trento, Italy) by AAVC. The CCD is a SBIG ST-9, 512×512 array, 20 μm pixels, the scale 1.72″/pix, and a field of view of 13′×13′. The B filter is from Omega and the VI_C filters from Custom Scientific; **R120**: a 0.42 m f/5.4 Newton telescope operated in Bastia (Ravenna, Italy) by ARAR. It has an Apogee Alta 260e CCD Camera, 512×512 array, 20 μm pixels, the scale 1.83″/pix, and a field of view of 16′×16′. It is used in combination with BVR_CI_C filters from Schuler.

One of us (A.J.), since the discovery of V4368 Sgr outburst, has been collecting estimates of its visual magnitudes with a 0.32 m Newtonian reflector located in Nelson (New Zealand). The comparison sequence for observations collected since

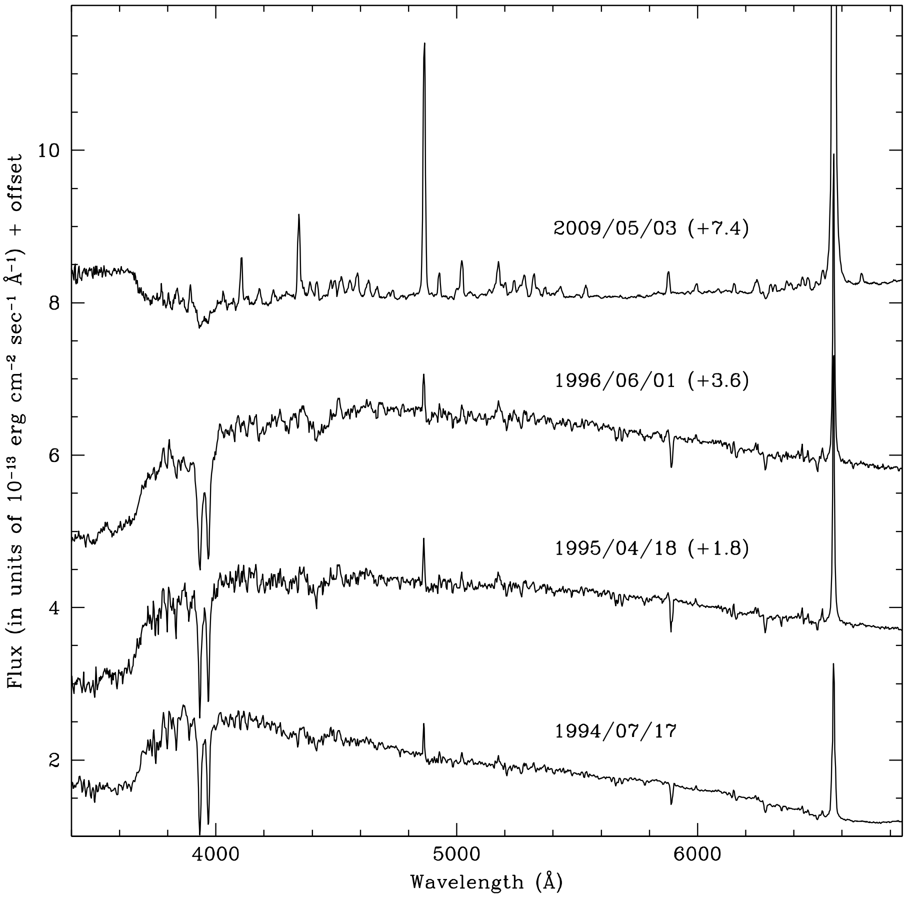

Fig. 2. Spectroscopic evolution of V4368 Sgr. The 1994 spectrum is from Bragaglia et al. (1995), the 1995–1996 ones are from Munari & Zwitter (2002).

2000 has been that published by Henden & Munari (2006), i.e. the same as for the CCD observations described above. The earlier visual estimates, that used a preliminary calibration sequence, were also transformed to the same comparison sequence. In Table 2 we present the annual average brightnes values of V4368 Sgr as derived from these visual estimates.

2.2. Spectroscopy

A low resolution, absolutely fluxed spectrum of V4368 Sgr was obtained on 2009 May 3.10 UT with the B&C spectrograph of the INAF Astronomical Observatory of Padova attached to the 1.22 m telescope operated in Asiago by the Department of Astronomy of the University of Padova. The slit, aligned with the parallactic angle, had a width corresponding to 2″ on the sky, and the total exposure time was 40 min. The detector was an ANDOR iDus 440A CCD camera, equipped with a EEV 42-10BU back-illuminated chip, 2048×512 pixels of 13.5 μm size. A 300 ln/mm grating blazed at 5000 Å provided a dispersion of 2.26 Å/pix and a wavelength range extending from 340 to 810 nm.

The accuracy of the absolute fluxes is better than 0.1 mag over the B, V and $R_{\rm C}$ magnitude passbands, as derived by comparing the synthetic magnitudes integrated over the spectrum with the values obtained directly by CCD photometry at similar dates given in Table 1. On the May 3.10 spectrum we indentified and measured 68 emission lines, whose integrated absolute fluxes are listed in Table 3.

Table 3. Integrated absolute fluxes (in units of 10^{-14} erg cm^{-2} sec^{-1} Å^{-1}) of the emission lines identified on the 2009 May 3.10 spectrum of V4368 Sgr presented in Figure 2.

λ (Å)	Ion	Flux	λ (Å)	Ion	Flux	λ (Å)	Ion	Flux
3770.6	H11	19	4713.2	He I	9	5875.7	He I	35
3797.9	H10	18	4730.4	Fe II 43	13	5991.4	Fe II 46	19
3833.6	He I + H9	60	4861.5	Hβ	425	6148.9	Fe II 46, 74	14
3856.1	He I	24	4923.9	Fe II 42	32	6239.4	Fe II 74	35
3889.1	H8	46	5000.7	Fe II 25	23	6300.2	[OI]	10
4026.3	He I	12	5018.4	Fe II 42	58	6318.3	Fe II	10
4101.7	Hδ	77	5051.3	Fe II	9	6366.9	[OI], Fe II 40	14
4122.6	Fe II 28	15	5132.7	Fe II 35	14	6384.0	Fe II	12
4132.1	Fe II 43	3	5169.0	Fe II 42	101	6416.9	Fe II 74	8
4160.6	Fe II 39	6	5184.8	[Fe II] 19	8	6432.7	Fe II 40	23
4178.9	Fe II 28	27	5197.6	Fe II 49	17	6456.4	Fe II 74	23
4233.2	Fe II 27	18	5234.6	Fe II 49	30	6488.8	?	9
4244.7	[Fe II] 21	4	5261.6	[Fe II] 19	21	6516.0	Fe II 40	15
4340.5	Hγ	130	5276.0	Fe II 49	46	6562.8	Hα	2802
4387.9	He I	23	5316.7	Fe II 48, 49	41	6678.1	He I	16
4416.3	[Fe II] 6	20	5333.6	[Fe II] 19	16	7065.2	He I	21
4471.6	He I	27	5362.9	Fe II 48	13	7155.1	[Fe II] 14	14
4489.2	Fe II 37	24	5376.5	[Fe II] 19	3	7308.0	Fe II 73	7
4515.3	Fe II 37	50	5414.1	Fe II 48	6	7320.7	Fe II 73	34
4552.8	Fe II 37, 38	39	5425.3	Fe II 49	17	7462.4	Fe II 73	10
4583.0	Fe II 37, 38	49	5495.8	[Fe II] 17	3	7515.9	Fe II 73	19
4629.3	Fe II 37	40	5503.8	Fe II	3	7711.7	Fe II 73	46
4664.7	Fe II 44	18	5532.4	[Fe II] 17, Fe II 55	21			

3. RESULTS

The light curve in Figure 1 illustrates how the outburst of V4368 Sgr has so far evolved *very* slowly and smoothly, as indeed is typical for symbiotic novae. It took two years for V4368 Sgr to rise the last magnitude in brightness, and it remained stable around maximum optical brightness at V = 10.26 mag for four years, from 1995 to 1998. The following decline has been tediously slow, by just ΔV = 1.36 mag in 11 years (1998–2009), or 0.000338 mag day^{-1} on average. The time required to decline by two whole magnitudes (t_2) would be 16 years at the current rate. This would place V4368 Sgr on the t_2 vs. amplitude plane far away from the region occupied by classical novae (cf. Warner 1995) and into that populated by symbiotic novae. Even if the photometric color information available for V4368 Sgr is particularly scarce, the color evolution presented in Figure 1 appears to have been a very slow too. It is consistent with a linear trend characterized by a modest $\Delta\,(B–V)$ = 0.25, $\Delta\,(V–I_{\rm C})$ = 0.5 mag amplitude over the whole 15 yr recorded period.

The spectral appearance of V4368 Sgr in 2009 has changed appreciably since the time it reached maximum optical brightness. The spectra presented in Figure 2 show that the emission lines have increased in intensity by a factor of ~ 10 times, the Balmer continuum has turned into emission and the outbursting star is contributing only a small fraction of the overall optical emission. In fact, the broad absorptions of Ca II H and K and CH (the G-band), so prominent around maximum, have been almost completely outshined by much stronger nebular continuum. Thus the photometric evolution appears so slow because the fading continuum of the outbursting star has been nearly compensated for by the growing intensity of the emission from the circumstellar ionized gas.

The ionization degree did not changed much in 2009 compared to maximum brightness. The main emission lines are in fact still the same Balmer series and Fe II as in 1994–1996, while the He I/Fe II ratio has only slightly increased. One noteworthy difference is the presence in the 2009 spectrum of [Fe II] lines, indicating that now the gas at greater distances and lower densities is contributing to the emission line spectrum.

We plan to continue monitoring of V4368 Sgr in the optical, including high-resolution spectroscopy and absolute low-resolution spectrophotometry. Devoted long wavelength infrared observations are encouraged to confirm the classification of the star as a symbiotic nova by detecting the presence of a cool giant or supergiant donor star in the system. Such a classification is highly probable given the striking similarity between V4368 Sgr and PU Vul (the latter away from eclipses). The two systems share identical spectral appearance at maximum, including high resolution profiles of emission lines (Ivison et al. 1994), a flat maximum lasting for years, a very large outburst amplitude, and a similarly smooth and very slow magnitude and color evolution.

REFERENCES

Allen D. A. 1983, MNRAS, 204, 113
Bragaglia A., Duerbeck H. W., Munari U., Zwitter T. 1995, A&A, 297, 759
Corradi R., Livio M., Balick B., Munari U., Schwarz H. E. 2001, ApJ, 553, 211
Gilmore A. C. 1994, IAUC, No. 5961
Grebel E. K., Duerbeck H. W., Greiner J., Richter G. A. 1994, IBVS, No. 4019
Ivison R. J., Bode M. F., Meaburn J. 1994, A&AS, 103, 201
Hazen M. 1994, IAUC, No. 5976
Henden A., Munari U. 2006, A&A, 458, 339
Hirayama T. 1994, IAUC, No. 5961
Kenyon S. J. 1996, *The Symbiotic Stars*, Cambridge Univ. Press
Kolotilov E. A., Munari U., Yudin B. F. 1995, MNRAS, 275, 185
Munari U. 1997, in *Physical Processes in Symbiotic Binaries and Related Systems*, J. Mikolajewska ed., Copernicus Foundation for Polish Astronomy
Munari U., Zwitter T. 2002, A&A, 383, 188
Wakuda M. 1994, IAUC, No. 5961
Wallerstein G. W. 1996, PASP, 108, 408
Warner B. 1995, *Cataclysmic Variable Stars*, Cambridge University Press