A&A 461, 943–947 (2007)
DOI: 10.1051/0004-6361:20066110

Astronomy & Astrophysics

The emission line galaxy TV Reticuli[⋆] *(Research Note)*

Evidence for an ultraluminous supernova

L. Schmidtobreick[1], C. Tappert[2], H. Horst[1,3], I. Saviane[1], and C. Lidman[1]

[1] European Southern Observatory, Casilla 19001, Santiago 19, Chile
e-mail: `lschmidt@eso.org`
[2] Departamento de Astronomía y Astrofísica, Pontificia Universidad Católica, Casilla 306, Santiago 22, Chile
[3] Zentrum für Astronomie, ITA, Universität Heidelberg, Albert-Überle-Str. 2, 69120 Heidelberg, Germany

Received 26 July 2006 / Accepted 10 October 2006

ABSTRACT

Aims. TV Ret was classified as a cataclysmic variable due to an outburst observed in 1977. We intended to confirm this classification and derive some basic properties of the system.
Methods. Low resolution optical spectra were obtained for a spectral classification of the object.
Results. We find that the object is not a cataclysmic variable but an emission line galaxy with a redshift $z = 0.0964$. An R-image taken in very good seeing conditions shows that the object is extended.
Conclusions. We show that TV Ret is a blue dwarf galaxy, probably compact, with an absolute magnitude of $M_B = -17.5$, a metallicity of 0.12 solar, and an average temperature of 1.3×10^4 K. The line ratios place it among the H II galaxies, although close to the border of the Seyfert 2s. The outburst, which was observed in 1977, could thus be explained by a supernova explosion. However, with an absolute magnitude around $M_B = -21$, it was an extremely bright one.

Key words. stars: dwarf novae – stars: individual: TV Ret – galaxies: dwarf – galaxies: starburst – galaxies: active

1. Introduction

TV Ret was reported by Kinman et al. (1991), who were observing lightcurves of RR Lyr stars in the outer halo of the Large Magellanic Cloud. In one of the objects, which was named R1 in their list, they noticed an increase in brightness, which they interpreted as a possible dwarf nova outburst, and thus classified the object as a cataclysmic variable. As such, it was added in the 72nd name-list of variable stars as TV Ret (Kazarovets & Samus 1995), and entered the catalogue of cataclysmic variables (Downes et al. 2001).

We performed spectroscopic observations in order to confirm this classification. Surprisingly, the object turned out to be a narrow emission-line galaxy of nearly 0.1 redshift. This class of galaxies consists of two different types: starburst or H II-galaxies and the narrow-emission line AGNs, which are either Seyfert 2 galaxies or LINERs.

In the first case, the emission lines origin in gas that is photoionised by young, hot OB stars present in the star-forming regions. In the case of AGNs the emission lines are formed in the Narrow Line Region which is comprised of clouds ionised by radiation from the central engine of the galaxy. Several empirical methods have been developed to distinguish between these two ionisation mechanisms, mainly by comparing the line-ratios in the spectrum (see e.g. Baldwin et al. 1981; Veilleux & Osterbrock 1987; Dessauges-Zavadsky et al. 2000).

We attempt such a distinction and also derive the physical parameters of the galaxy such as size, luminosity, metallicity, and gas temperature and density.

2. Observations and data reduction

The observations were performed on 2003-09-26 and on 2004-11-19 using EFOSC2 (Buzzoni et al. 1984) at the 3.6 m telescope at La Silla, Chile. In Table 1 the observational parameters are summarised.

The standard reduction of the data was performed using IRAF. The bias was subtracted and the data were divided by a flat field, which was normalised by fitting Chebyshev functions of high order. The spectra were optimally extracted (Horne 1986). Wavelength calibration yielded a final resolution of 1.1 nm FWHM for the 2003 data and 1.2 nm FWHM for the 2004 data. Flux calibration was performed only for the 2003 spectrum, using the spectrophotometric standard LTT 7379 which was observed with an airmass difference of 0.05.

For all further analysis, if not especially indicated, the MIDAS package and self-written routines were used.

3. Results

3.1. Classification

In Fig. 1 the flux-calibrated spectrum observed in 2003 is plotted. The spectrum is clearly dominated by strong emission lines. The continuum matches the spectral energy distribution (SED)

[⋆] Based on observations collected at the European Southern Observatory, La Silla, Chile.

Table 1. All observations obtained for this investigation listed with their date, the telescope/instrument combination, the used grism and slit width, and the exposure time.

Date	Telescope/Instrument	Grism/Slit	Exp. time [s]
2003-09-26	3.6 m/EFOSC2	Gr#4/1.0″	1800
2004-11-19	3.6 m/EFOSC2	Gr#11/1.0″	3×900

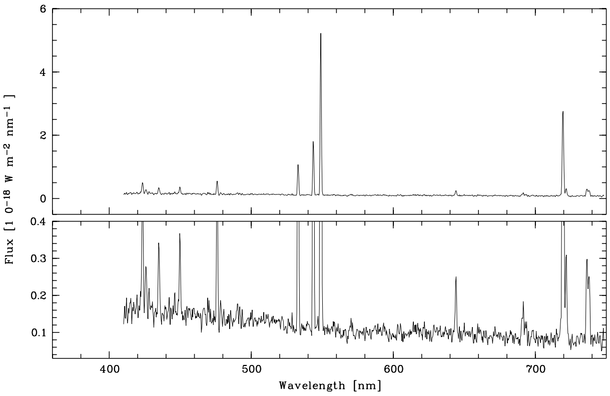

Fig. 1. The flux-calibrated spectrum of TV Ret taken in September 2003. The *upper plot* shows the full intensity range; in the *lower plot* the intensity range has been decreased to better display the weak emission lines and the slope of the continuum.

of a late A or early F type star; the corresponding temperature is $T_{\rm eff} = 7500$ K. In Fig. 2, the normalised spectrum from 2004 is plotted, which shows the same emission lines as the 2003 spectrum and an additional line at 408.9 nm, which was outside the spectral range of the 2003 data. Both spectra show clearly that the object is not a cataclysmic variable, as the typical emission lines for this kind of object are not present at their rest wavelengths. Instead, we find several strong emission lines, which turned out to be redshifted Balmer lines as well as O I, O III, N II, S II, and Ne III. The properties of these lines are given in Table 2. We averaged the individual shifts of these lines to find the redshift of the object as $z = 0.0964(2)$.

The redshift, which indicates an extragalactic object, as well as the strength of the ionised lines, are best interpreted if we assume the object to be an emission line galaxy, which, however, is unresolved in previous images. In Fig. 3, a 3×3 arcmin R-image is plotted, obtained under good seeing conditions of 0.6 arcsec. In this image, the object appears extended and slightly elongated. The size can be estimated to about 0.7×0.9 arcsec.

3.2. Physical properties of the galaxy

For all further calculations, we use the standard flat cosmology with $\Omega_{\rm M} = 0.27$ and $H_0 = 72\,{\rm km\,s^{-1}\,Mpc^{-1}}$ (Spergel et al. 2003).

From $z = 0.0964(2)$ we derive the angular size distance $D_{\rm ang} = 358$ Mpc. Thus, assuming that we see most of it, the size of the galaxy is 1.2×1.6 kpc, which matches the size of a rather small dwarf galaxy.

The magnitude of TV Ret is given as $B = 20.5$ (Kinman et al. 1991). The absolute B-magnitude can be derived using

$$M_B = B - 5 \log D_{\rm lum} + 5 - K \quad (1)$$

with the luminosity distance calculated as $D_{\rm lum} = 430$ Mpc, and the k-correction $K = -2.5 \log\left((1+z)^{-1} L_{\lambda(1+z)^{-1}} / L_\lambda\right)$ (e.g. Oke & Sandage 1968). We use the slope $L_{401\ {\rm nm}}/L_{440\ {\rm nm}} = 1.15$ as derived from the spectrum plotted in Fig. 1, and derive the absolute magnitude of the galaxy as $M_B = -17.5$. This value is typical of massive dwarf galaxies (see e.g. Melisse & Israel 1994) and thus confirms the above classification. However, the surface brightness of $\sigma_B = 20.0\,{\rm mag/arcsec^2}$ is rather high.

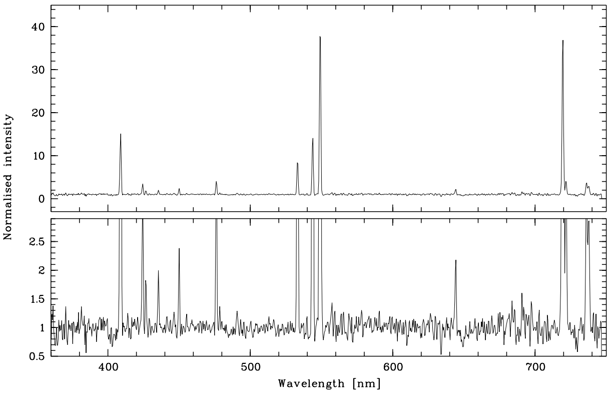

Fig. 2. The spectrum of TV Ret taken in November 2004 with the continuum normalised to unity. The *upper plot* shows the full intensity range; in the *lower plot* the intensity range has been decreased to better display the weak emission lines.

3.2.1. Starburst or AGN?

A more detailed classification of the galaxy can be done by analysing the emission lines. Apart from the features at 478.5 nm and 737 nm, which are clearly blends of [O I] and [SII 673.1]/[SII 671.7] respectively, the lines are not resolved within our resolution of 1.1 nm, and therefore are narrow-emission lines. Thus, TV Ret could be either an H II galaxy or a narrow-line AGN. We use the flux-ratio of the different emission lines to find the mechanism by which the emission lines are produced following the method described by Veilleux & Osterbrock (1987).

To have a comparable data set, we also determined the reddening in the same way as these authors, using the Hα/Hβ flux-ratio and the Whitford reddening curve parameterised by Miller & Mathews (1972). We measure $F({\rm H}\alpha)/F({\rm H}\beta) = 3.25$. If we assume a starburst galaxy with a recombination value $I({\rm H}\beta)/I({\rm H}\alpha) = 2.85$, the reddening is $E(B-V) = 0.13$. If we assume an AGN with $I({\rm H}\beta)/I({\rm H}\alpha) = 3.1$, we find a rather low value of $E(B-V) = 0.05$. For both cases, the dereddened flux values are listed in Table 2. Although the dereddened flux values are different, the logarithms of the line ratios used for the classification are similar (see Table 3). This is expected, as the line ratios were chosen for being insensitive to the reddening, i.e. are close in wavelength.

We compared the line ratios of the forbidden lines (see Table 3) with the values given by Veilleux & Osterbrock (1987), i.e. their Figs. 1–6. In all these diagnostic diagrams, TV Ret lies close to the border between AGNs and H II region-like objects, which is mainly due to the high value of [O III]λ500.7/Hβ. In [O III]/Hβ versus [N II]/Hα and [O III]/Hβ versus [S II]/Hα, it lies on the side of the H II region-like objects, while for [O III]/Hβ versus [O I]/Hα it lies on the side of the AGNs.

Comparing the line ratios with the diagnostic diagrams of Dessauges-Zavadsky (2000) yields similar conclusions. We can definitely exclude that TV Ret is a LINER, but it is on the border between the Seyfert 2 and the starburst galaxies, although the latter appears slightly more likely.

Table 2. Observed wavelengths, equivalent widths, and FWHM of all identified emission lines in the 2002 and 2003 spectrum of TV Ret. For 2003 the line flux is also given. Note that the uncertainty of the line flux describes the uncertainty of the relative flux in the line and does not include the photometric error. The line flux has been dereddened using the reddening laws for H II regions and for AGNs (see text for details).

	September 2003						November 2004	
Transition	$\lambda_{\rm obs}$ [nm]	$-W$ [nm]	$F[10^{-18}$ W m$^{-2}]$	$F_{\rm SB\,dered}$	$F_{\rm AGN\,dered}$	$100 \cdot F_{\rm SB\,dered}/F_{\rm H\beta}$	$\lambda_{\rm obs}$ [nm]	$-W$ [nm]
$\rm H_\alpha$	719.47	46.0	3.51(3)	4.55	3.85	285(10)	719.42	46.1
$\rm H_\beta$	532.97	10.5	1.08(2)	1.60	1.24	100(4)	533.16	9.0
$\rm H_\gamma$	475.97	3.5	0.46(2)	0.72	0.54	45(3)	476.14	3.4
$\rm H_\delta$	449.76	1.8	0.26(5)	0.42	0.31	26(6)	450.01	1.4
$\rm H_\epsilon$	434.94	1.8	0.26(2)	0.42	0.31	26(3)	435.48	1.2
$\rm H_8$	425.83						426.68	
[S II]: 673.1	737.81	3.1	0.24(2)			15(2)	737.58	
[S II]: 671.7	736.36	3.7	0.29(2)	0.68	0.58	18(2)	736.20	6.8
[N II]: 658.4	721.70	3.6	0.28(3)	0.36	0.31	23(3)	721.64	3.9
[O I]: 630.0$^{(1)}$	691.20	2.3	0.17(2)	0.22	0.19	14(2)		1.6
He I: 587.56	644.12	2.2	0.20(2)	0.27	0.22	17(2)	644.20	2.0
[O III]: 500.7	548.95	47.2	5.23(2)	7.61	5.97	477(15)	549.04	50.4
[O III]: 495.9	543.69	16.0	1.73(2)	2.53	1.98	159(6)	543.82	17.1
[O III]: 436.3	478.53	0.6	0.07(1)	0.11	0.08	7(1)	478.57	0.5
[Ne III]: 386.8	423.44	3.1	0.48(3)	0.78	0.57	49(4)	424.42	3.0
[O II]: 372.7						169(15)	408.93	16.2

(1): Blend of several O I lines.

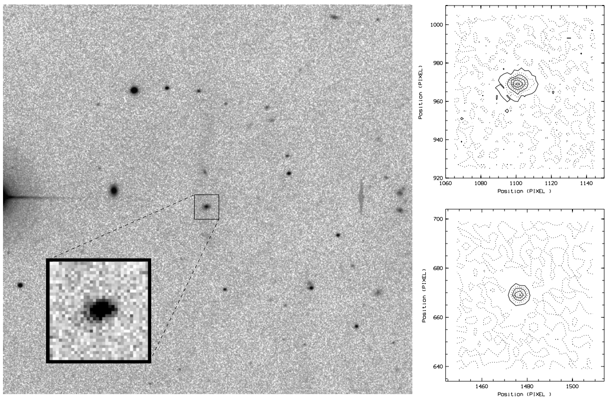

Fig. 3. The *R*-band acquisition image shows the 3 × 3 arcmin surroundings of TV Ret (*in the centre*) and a zoom on the object; north is up, east is left. With the good seeing of 0.6″ the object appears clearly extended. On the right side, the contours of TV Ret (*upper plot*) and a star for comparison are plotted.

Table 3. The logarithm of the line ratios is given for the two reddening laws, starburst (SB) and AGN, as derived from Hα/Hβ. The forbidden line fluxes correspond to the following transitions: O III: 500.7 nm, N II: 658.3 nm, S II: 671.6 + 673.1 nm, and O I: 630.0 nm.

	$\log\frac{\rm [O\,III]}{\rm H\beta}$	$\log\frac{\rm [N\,II]}{\rm H\alpha}$	$\log\frac{\rm [S\,II]}{\rm H\alpha}$	$\log\frac{\rm [O\,I]}{\rm H\alpha}$	$\frac{\rm H\alpha}{\rm H\beta}$
SB	0.68	–1.10	–0.83	–1.32	2.85
AGN	0.68	–1.09	–0.82	–1.31	3.10

Table 4. Physical parameters of the HII galaxy.

Quantity	Value	Notes
T(OIII)	$13\,400^{969}_{938}$ K	
n(SII)	239^{433}_{177} cm^{-3}	
$\rm O^{++}/H^+$	$(7.02 \pm 0.19) \times 10^{-5}$	average λ5007 and λ4959
$\rm O^+/H^+$	$(2.39 \pm 0.90) \times 10^{-5}$	λ3727
O/H	$(9.41 \pm 0.92) \times 10^{-5}$	TOT
12 + log (O/H)	7.97 ± 0.04	
$\rm N^+/O^+$	$(9.87 \pm 6.48) \times 10^{-2}$	
log (N/O)	-1.01 ± 0.22	
N/H	$(2.36 \pm 2.44) \times 10^{-6}$	
$\rm S^+/H^+$	$(5.69 \pm 0.28) \times 10^{-7}$	average λ6716 and λ6731

3.2.2. Temperature and metallicity

For a first indication, we compared the line ratios with the models of Ferland & Netzer (1983) and Evans & Dopita (1985), which are overplotted on the diagnostic diagrams of Veilleux & Osterbrock (1987), and find a metallicity of 0.1 times solar and an ionisation temperature of 45 000 K.

A more sophisticated computation of the abundances have been done following the so-called direct method (e.g. Osterbrock 1989). The [OIII] region electron temperature $T_{\rm e}$, electron density $n_{\rm e}$, and abundances were computed using tasks within the NEBULAR package of IRAF. The temperature was computed using the [OIII] lines ratio (4959 + 5007)/4363, and the density using the [SII] line ratio 6716/6731. Using these values for $T_{\rm e}$ and $n_{\rm e}$, the ionic abundances were computed with the IONIC task, with central wavelengths, line ratios and errors taken from Table 2. The total oxygen abundance was computed as $\rm O/H = O^{++}/H^+ + O^+/H^+$, i.e. neglecting the usually small contribution from $\rm O^{+3}$ (Skillman & Kennicutt 1993). In the case of sulfur, the abundance was computed as $\rm S/H = ICF \times (S^+ + S^{++})$, with the ionisation correction factor (ICF) computed as $\rm ICF = [1 - (1 - O^+/O)^{\alpha}]^{-1/\alpha}$. This expression for the ICF was first proposed by Stasinska (1978) with $\alpha = 3$, but we used the value $\alpha = 2.6$ which reproduces Garnett's (1989) photo-ionisation models better in the range $\rm O^+/O > 0.2$. Nitrogen abundances were computed assuming $\rm (N/O) = (N^+/O^+)$, and then using the nitrogen to oxygen ratio in the equation $\rm (N/H) = (N/O) \times (O/H)$.

In Table 4, the derived parameters are listed for TV Ret. We find that the average metallicity is about 0.12 solar, in agreement with the values derived from the model of Ferland & Netzer (1983). The gas temperature derived from the [OIII] lines is $1.3(1) \times 10^4$ K, the density derived from the [S II] lines is about 240/cm^3. These values again confirm TV Ret as an H II galaxy.

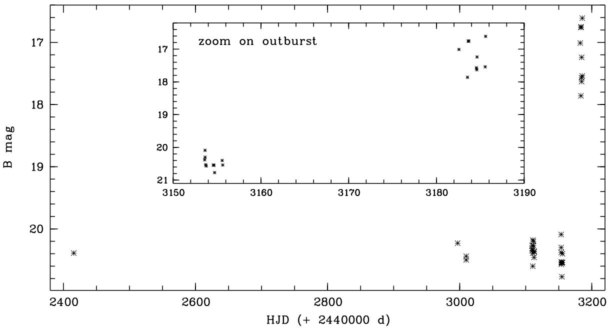

Fig. 4. The B-magnitude of TV Ret plotted against the heliocentric Julian Date. The data are taken from Table 5 of Kinman et al. (1991). The smaller plot is a zoom on the last 40 days, when the outburst happened.

3.3. The outburst

The reason for the classification of TV Ret as a cataclysmic variable was the outburst that the object underwent in February 1977 and that was observed over several days (Kinman et al. 1991). In Fig. 4, the B-magnitudes and heliocentric Julian Date that they give in Table 5 are plotted. They estimated the outburst amplitude as $\Delta m = 3.8$ mag. Note that there is no tight observational constraint on the duration of the outburst. The rise happened between JD 2 443 156 and JD 2 443 182, and hence lasted 26 days at the most. However, the decline was not observed, and thus the actual duration of the outburst is unknown. We can only say that the object is back in quiescence during our observations 26 years later.

If this was an outburst in a foreground object, by chance superimposed on the galaxy, we can estimate an upper limit for the brightness of this object. With a $S/N \approx 10$ of our spectra, we would be able to see an object about three times fainter than the galaxy. Since no trace of such a forground object is visible in the spectrum, it must be fainter than ≈22 mag. In that case, the amplitude of the outburst was at least 5.5 mag, leaving two explanations, a dwarf nova or a nova outburst. In the case of a dwarf nova, the object would be in quiescence now, close to 22 mag, but would show strong Balmer emission lines. No emission is found at the restframe wavelength of these lines, making this possibility very unlikely. Note that we cannot refute the possibility of a dwarf-nova super-outburst which would imply that the quiescent object is even fainter, and the Balmer emission are no longer observable. In the case of a nova, the outburst amplitude itself would have been larger, so that the object is not visible in quiescence. However, even faint novae have an absolute magnitude of $M_B = -7$ (e.g. Della Valle & Livio 1995), yielding a lower limit of its distance as 450 kpc and placing it far outside our Galaxy.

In the following, we assume that the outburst originates in the galaxy and is not a chance transient from a foreground object. The luminosity L_{out} of the outburst can then be estimated via

$$\Delta m = -2.5 \log \frac{L_{\mathrm{gal}} + L_{\mathrm{out}}}{L_{\mathrm{gal}}} \tag{2}$$

and thus results in $L_{\mathrm{out}} = 32.1\, L_{\mathrm{gal}}$. The absolute B-magnitude at the maximum is $M_B = -21.3$. While the explanation of a supernova seems natural, the luminosity of the outburst is too high. The brightest supernovae of type Ia have an absolute B-magnitude around $M_B = -19.8$ (e.g. Germany et al. 2004). Even if we allow for a large K-correction of 0.4 mag (e.g. Hamuy et al. 1993), the outburst would still be about 1 mag too bright for a type Ia supernova. Furthermore, supernovae are not known to vary on short time scales. The lightcurve observed by Kinman et al., instead, varies around 0.8 mag and on time scales of hours both during quiescence and during outburst (see Fig. 4). There are however unusual supernovae that are extremely luminous. The brightest one is SN 1999as (Knop et al. 1999), a type-Ic hypernova that reached an absolute V magnitude brighter than −21, i.e. similar to the magnitude that was found for TV Ret. However, the probability for such objects is rather low. Even more extreme are pair-production supernovae (Scannapieco et al. 2005), which can reach $M_B = -21$. However, pair-production supernovae have never been observed and they are thought to occur in environments with metallicities that are several orders of magnitude lower than the metallicity of the host galaxy of TV Ret.

The variation on short time scales indicates a compact source, so an AGN seems more likely. However, they do not generally show such strong variations in the optical. While X-ray variability on short timescales is a common phenomenon in AGNs, optical intra-night variability of up to 10% is only found in luminous Quasars with $M_B < -24.5$ (Gupta & Joshi 2005; Stalin et al. 2005). More extreme variabilities are only exhibited in Radio-loud AGN with ultra-relativistic jets and there is no indication that TV Ret is such an object. Radio and/or X-ray observations of this galaxy would help to decide on the presence of an AGN and thus also on the possible nature of the outburst.

There is a possible third explanation, if we assume that the accuracy of the measurements of Kinman et al. is not the 0.03 mag that they claim, but rather of the order of 0.3 mag. In that case, the short-term variation would not be real and for the outburst magnitude one would have to subtract the average magnitude values of outburst and quiescence magnitudes instead of the extreme values. This would lower the outburst amplitude by 0.4 mag, putting it closer to the possible range of a bright supernova. However, the method that the authors used is well-known and the quoted errors seem reasonable for it. Still, the fact that the variation is also present during the quiescence phase might indicate that it is a scatter in the measurements rather than a real variation. On the other hand, the scatter seems to be slightly larger during outburst, where one would actually expect the higher accuracy. We know of no photometric monitoring of TV Ret after 1977, which would be an important observation. If the short-term variation was confirmed by such measurements, this would be a strong indication for the presence of a compact source, i.e. an AGN. If no variation was detected, the probability would grow that the variation in 1977 is just the uncertainty in the measurements.

All in all, the reason for the outburst remains a mystery. Too many possible explanations exist, and none of them is really convincing. Unless the original measurements have rather high uncertainties, we can conclude that the outburst was some rare and unusual event that is not comparable with normal sources of variability.

4. Conclusions

We refute the classification of TV Ret as a cataclysmic variable. The object is a narrow-emission line galaxy, probably of H II type, although we cannot rule out the contribution of an AGN to the ionisation field. The size of ≈1.2 kpc and the absolute magnituse of $M_B = -17.5$ places the object among the dwarf galaxies. Assuming that we see most of the galaxy, it is probably a blue compact dwarf with ongoing star formation. The metallicity is 0.12 solar, in agreement with an H II galaxy.

We have no final conclusion concerning the observed outburst. If associated with the galaxy, it is about 1 mag brighter than normal supernovae of type Ia. One would thus prefer to explain the outburst via a foreground transient. However, the two possible explanations – dwarf nova or nova – have their drawbacks as well.

Acknowledgements. This research has made use of the Simbad database operated at CDS, Strasbourg, France. We thank the referee for valuable comments.

References

Baldwin, J. A., Phillips, M. M., & Terlevich, R. 1981, PASP, 93, 5

Buzzoni, B., Delabre, B., Dekker, H., et al. 1984, The Messenger, 38, 9

Della Valle, M., & Livio, M. 1995, ApJ, 452, 704

Dessauges-Zavadsky, M., Pindao, M., Maeder, A., & Kunth, D. 2000, A&A, 355, 89

Downes, R. A., Webbink, R. F., Shara, M. M., et al. 2001, PASP, 113, 764, living edition

Evans, I. N., & Dopita, M. A. 1985, ApJS, 58, 125

Ferland, G. J., & Netzer, H. 1983, ApJ, 264, 105

Garnett, D. R. 1989, ApJ, 345, 282

Germany, L. M., Reiss, D. J., Schmidt, B. P., Stubbs, C. W., & Suntzeff, N. B. 2004, A&A, 415, 863

Gupta, A. C., & Joshi, U. C. 2005, A&A, 440, 855

Hamuy, M., Phillips, M. M., Wells, L. A., & Maza, J. 1993, PASP, 105, 787

Horne, K. 1986, PASP, 98, 609

Kazarovets, E. V., & Samus, N. N. 1995, IBVS, 4140

Kinman, T. D., Stryker, L. L., Hesser, J. E., et al. 1991, PASP, 103, 1279

Knop, R., Aldering, G., Deustua, S., et al. 1999, IAUC, 1728

Melisse, J. P. M., & Israel, F. P. 1994, A&A, 285, 51

Miller, J. S., & Mathews, W. G. 1972, ApJ, 172, 593

Oke, J. B., & Sandage, A. 1968, ApJ, 154, 21

Osterbrock, D. E. 1989, Astrophysics of gaseous nebulae and active galactic nuclei (University Science Books)

Scannapieco, E., Madau, P., Woosley, S., Heger, A., & Ferrara, A. 2005, ApJ, 633, 1031

Skillman, E. D., & Kennicutt, R. C. 1993, ApJ, 411, 655

Spergel, D. N., Verde, L., Peiris, H. V., et al. 2003, ApJS, 148, 175

Stalin, C. S., Gupta, A. C., Gopal-Krishna, G. K., Wiita, P. J., & Sagar, R. 2005, MNRAS, 356, 607

Stasinska, G. 1978, A&A, 66, 257

Veilleux, S., & Osterbrock, D. E. 1987, ApJS, 63, 295

Warner, B. 1995, Cataclysmic Variable Stars (Cambridge University Press)