Astron. Astrophys. 347, L39–L42 (1999)

ASTRONOMY AND ASTROPHYSICS

LETTER

*Letter to the Editor*

# The 1999 outburst of the eclipsing and recurrent nova U Scorpii*

**U. Munari**[1,3], **T. Zwitter**[2], **T. Tomov**[1,3], **P. Bonifacio**[4], **P. Molaro**[4], **P. Selvelli**[5], **L. Tomasella**[1], **A. Niedzielski**[6], and **A. Pearce**[7]

[1] Osservatorio Astronomico di Padova, Sede di Asiago, I-36032 Asiago (VI), Italy
[2] University of Ljubljana, Department of Physics, Jadranska 19, 1000 Ljubljana, Slovenia
[3] CISAS – Center of Studies and Activities for Space, University of Padova "G.Colombo", Italy
[4] Osservatorio Astronomico di Trieste, Via Tiepolo 11, I-34131 Trieste, Italy
[5] CNR-GNA-Osservatorio Astronomico di Trieste Via Tiepolo 11, I-34131 Trieste, Italy
[6] Centre for Astronomy, N.Copernicus University, ul. Gagarina 11, PL-87100 Torun, Poland
[7] 32 Monash Ave, Nedlands, WA 6009, Australia

Received 26 May 1999 / Accepted 15 June 1999

**Abstract.** The spectroscopic and photometric evolution of the 1999 outburst of the eclipsing and recurrent nova U Sco is presented. The photometric evolution closely matches that of the previous events. The FWZI=10,000 km sec$^{-1}$ for emission lines at maximum has decreased to 4000 km sec$^{-1}$ by day +23, with continuous and dramatic changes in the line profiles. No nebular line has become visible and the ionization degree has increased during the brightness decline. A not previously reported and quite puzzling splitting of the emission lines into three components after the first two weeks is outstanding in our spectra. The radiated luminosity is found to be a tiny fraction of that of classical novae for any reasonable distance to U Sco.

**Key words:** stars: individual: U Scorpii – stars: novae, cataclysmic variables

## 1. Introduction

Previous outbursts of U Sco were recorded in 1863, 1906, 1936, 1979 and 1987 (cf. Sekiguchi et al. 1988, hereafter S88). They were all characterized by a very fast evolution ($t_3 \sim 5$ days) and a large amplitude (from $V \sim 18$–$19$ mag in quiescence to $V \sim 8$ mag at maximum). Several others have been quite possibly missed because U Sco lies just 4° from the ecliptic. In the following the comparison will be limited to the 1979 and 1987 events, because these are the only ones for which useful spectroscopic and photometric data have been obtained (S88, Barlow et al. 1981, Williams et al. 1981 and Warner 1995; hereafter B81, W81 and W95 respectively).

The system in quiescence shows eclipses (Schaefer & Ringwald 1995, hereafter SR95) with a period of 1.2305631 days. The bright prospects to derive the masses of the components from spectroscopic orbits have been however hampered by the faintness in quiescence and devoted attempts with 4-m class telescopes have so far provided only contradicting results (Johnston & Kulkarni 1992, Duerbeck et al. 1993, SR95).

Thanks to an immediate notification by the outburst discoverer (P.Schmeer, Belgium) and the VSNET network (cf. http://www.kusastro.kyoto-u.ac.jp/vsnet/), we were able to begin the monitoring of the 1999 outburst within a few hours from the maximum. In this letter we present the results of our all-out spectroscopic campaign and report about the photometric evolution as long as U Sco has remained brighter than V=15 mag. Modeling of the data and additional observations of U Sco once it will have returned to flat quiescence will be presented elsewhere (Selvelli et al. 1999, in preparation). Similarly, a detailed discussion of the reddening as inferred from the interstellar absorption lines visible in our Echelle spectra will be addressed in detail elsewhere (Munari and Zwitter 1999, in preparation).

## 2. Observations

A journal of the spectroscopic observations is given in Table 1. In this paper the dates are counted from the outburst maximum brightness $V = 7.6$ mag occurred on JD=2451235.062 (cf. IAU Circ. 7113).

High resolution spectra have been obtained with the Echelle spectrograph mounted at the Cassegrain focus of the 1.82 m telescope which is operated by Astronomical Observatory of Padova on top of Mt. Ekar, Asiago (Italy). The detector was a Thomson THX31156 CCD with 1024×1024 pixels, 19 $\mu$m each, and the slit width was set to $1''.5$. The multi-order Echelle spectra have been successfully processed into single dispersion ones by using spectra of some unreddened A0 V stars close to U Sco and observed under identical conditions (inter-comparison of

*Send offprint requests to*: U. Munari (munari@pd.astro.it)

* Based on observations collected with the telescopes of the European Southern Observatory at La Silla, Chile and of the Padova & Asiago Astronomical Observatories (Italy)

**Table 1.** Journal of the spectroscopic observations. $\triangle t$ = days since maximum brightness (see text); $JD_{\odot}$ = $JD_{\odot}$ – 2451200; $\Phi$ = orbital phase from SR95; *Tel.* = telescope code ($a$ = Asiago 1.22m + B&C +CCD; $b$ = Asiago 1.82m + Echelle +CCD; $c$ = ESO NTT + EMMI); *disp.* = dispersion (in Å/pixel) around H$\alpha$; *FWZI*= full width at zero intensity for the H$\alpha$ profile (H$\beta$ for the first spectrum).

| date (1999) | UT | $JD_{\odot}$ | $\triangle t$ (days) | $\Phi$ | Tel. | disp. (Å/p) | range (Å) | FWZI (km $s^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| 26 Feb | 04:52 | 35.703 | 0.64 | 0.93 | a | 1.20 | 4665-4960 | 9625 |
| 27 Feb | 04:30 | 36.688 | 1.63 | 0.73 | b | 0.19 | 4550-8750 | 9532 |
| 28 Feb | 04:13 | 37.676 | 2.61 | 0.54 | b | 0.19 | 4550-8750 | 9273 |
| 01 Mar | 03:40 | 38.653 | 3.59 | 0.33 | b | 0.19 | 4550-8750 | 9280 |
| 02 Mar | 03:38 | 39.652 | 4.59 | 0.14 | b | 0.19 | 4550-8750 | 9036 |
| 16 Mar | 03:21 | 52.641 | 17.58 | 0.69 | b | 0.19 | 6580-6590 | 5109 |
| 16 Mar | 09:58 | 53.917 | 18.85 | 0.73 | c | 1.00 | 3975-6640 | 4850 |
| 17 Mar | 09:12 | 54.885 | 19.82 | 0.52 | c | 1.00 | 3975-6640 | 4654 |
| 19 Mar | 02:31 | 56.607 | 21.54 | 0.92 | b | 0.19 | 6580-6590 | 4310 |
| 19 Mar | 03:17 | 56.639 | 21.58 | 0.94 | a | 2.34 | 4055-6990 | 4285 |
| 20 Mar | 02:37 | 57.611 | 22.55 | 0.73 | b | 0.19 | 6580-6590 | 4020 |

**Table 2.** Visual magnitudes of U Sco during the 1999 outburst. $JD_{\odot}$ = $JD_{\odot}$ – 2451200; † = pre-outburst observations from VSNET archives; $*$ = data from IAU Circ. 7113.

| $JD_{\odot}$ | V | $JD_{\odot}$ | V | $JD_{\odot}$ | V | $JD_{\odot}$ | V |
|---|---|---|---|---|---|---|---|
| 30.275† | <13.7 | 37.317 | 9.5 | 42.374 | 11.7 | 51.342 | 13.8 |
| 32.328† | <13.7 | 37.356 | 9.5 | 43.351 | 12.1 | 53.323 | 13.8 |
| 33.480† | <14.3 | 38.344 | 9.9 | 44.269 | 12.6 | 54.344 | 14.1 |
| 33.600† | <13.1 | 39.340 | 10.5 | 44.379 | 12.5 | 59.308 | 14.3 |
| 34.540† | <14.3 | 39.379 | 10.6 | 45.322 | 12.9 | 63.301 | 14.4 |
| 34.694* | 9.5 | 40.310 | 11.3 | 46.299 | 13.1 | 64.302 | 14.5 |
| 35.062* | 7.6 | 40.373 | 11.2 | 47.341 | 13.1 | 65.297 | 14.7 |
| 35.125* | 8.0 | 41.311 | 11.5 | 48.299 | 13.1 | 67.315 | 15.0 |
| 36.294 | 9.2 | 41.377 | 11.6 | 48.389 | 13.3 | | |
| 36.378 | 9.2 | 42.310 | 11.6 | 49.276 | 13.7 | | |

the similarly processed A0 V star spectra shows the rectification and joining technique to be accurate to better than ∼3%). The gaps in the red/near-IR visible in the spectra of Fig. 2 are caused by non overlapping Echelle orders.

Medium dispersion spectra were secured with the B&C+CCD spectrograph at the 1.22 m telescope of the Astronomy Dept., Univ. of Padova, located in Asiago too. The detector was a Wright Instr. CCD camera with a 512x512 pixel, 23 $\mu$m size, UV-coated chip. The slit width was set to 2″.

On March 16th and 17th U Sco was observed with the ESO NTT and the EMMI instrument. The dispersing element was grism #5 on the 16th, and grisms #5 and #2 the following night. A 1″ slit was used on both nights. The seeing was $0''.9$ the first night and $0''.8$ the second. The DA white dwarf HIP 80300 was observed as flux standard on March 17.

Visual estimates of U Sco brightness have been obtained by one of us (AP) with a private 16″ f/4 reflector using the A.Henden (USNO) comparison sequence as distributed by VSNET. The visual estimates are listed in Table 2 and the photometric evolution of the 1999 outburst is compared with those of 1979 and 1987 events in Fig. 1.

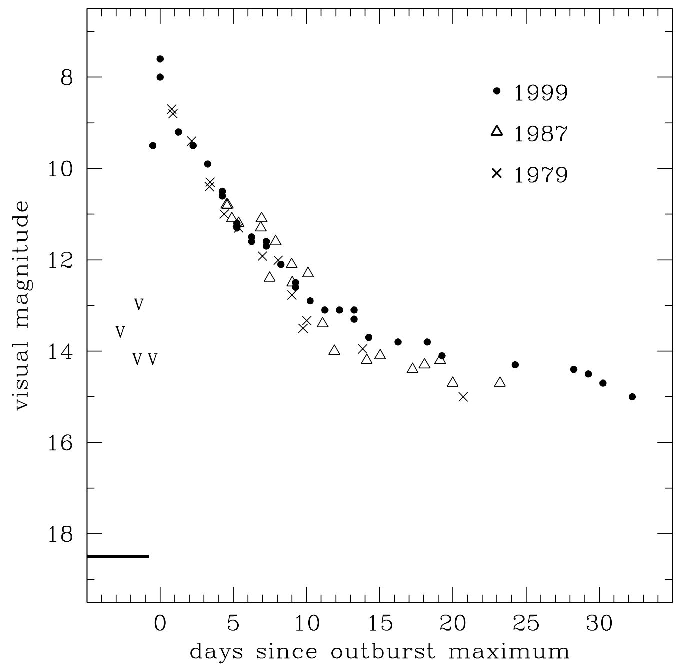


**Fig. 1.** Comparison of the light curves of the last three outbursts of U Sco (data from Table 2, B81 and S88). The thick line is the average brightness in quiescence. Negative detections for 1999 are given as *fainter-than* symbols.

## 3. Photometric evolution

The photometric evolution of the 1999 outburst has followed quite closely that of previous events as Fig. 1 clearly shows. Small differences may be easily accounted for by ($a$) different comparison sequences, and ($b$) a mixture of different observing techniques used by B81 and S88 (visual estimates directly at the eyepiece or on the screen of TV telescope guiding systems, photography, etc.)

With a maximum brightness of $V = 7.6$ on February 25.562, the 1999 outburst has been characterized by a fast decline with $t_2 = 2.2$ and $t_3 = 4.3$ days, very close to the 0.67 mag $day^{-1}$ reported by Payne-Gaposchkin (1957) for the 1863 and 1936 events. The outburst was discovered by P.Schmeer on February 25.194 when he estimated U Sco at $V = 9.5$. This suggests a fast rise to maximum of the order of $\triangle$mag = 5.2 $day^{-1}$, or even faster if the observation at $V = 7.6$ on February 25.562 was actually past the true maximum.

There is an important negative detection on Feb 25.040 listed in Table 2, when U Sco was found fainter than V=14.3. This is just 22 minutes before central eclipse according to the SR95 ephemeris and 3.7 hours earlier than the $V = 9.5$ outburst discovery by P.Schmeer. Adopting the $\triangle$mag = 5.2 $day^{-1}$ rise rate just estimated, U Sco should have been at $V = 10.3$ mag at the time of the Feb 25.040 negative detection. This seems to suggest that the dimensions of the outbursting WD were still smaller than those of the occulting companion 0.522 days before maximum. However, a different explanation is in order if the SR95 ephemeris should turn out to be no more accurate in 1999

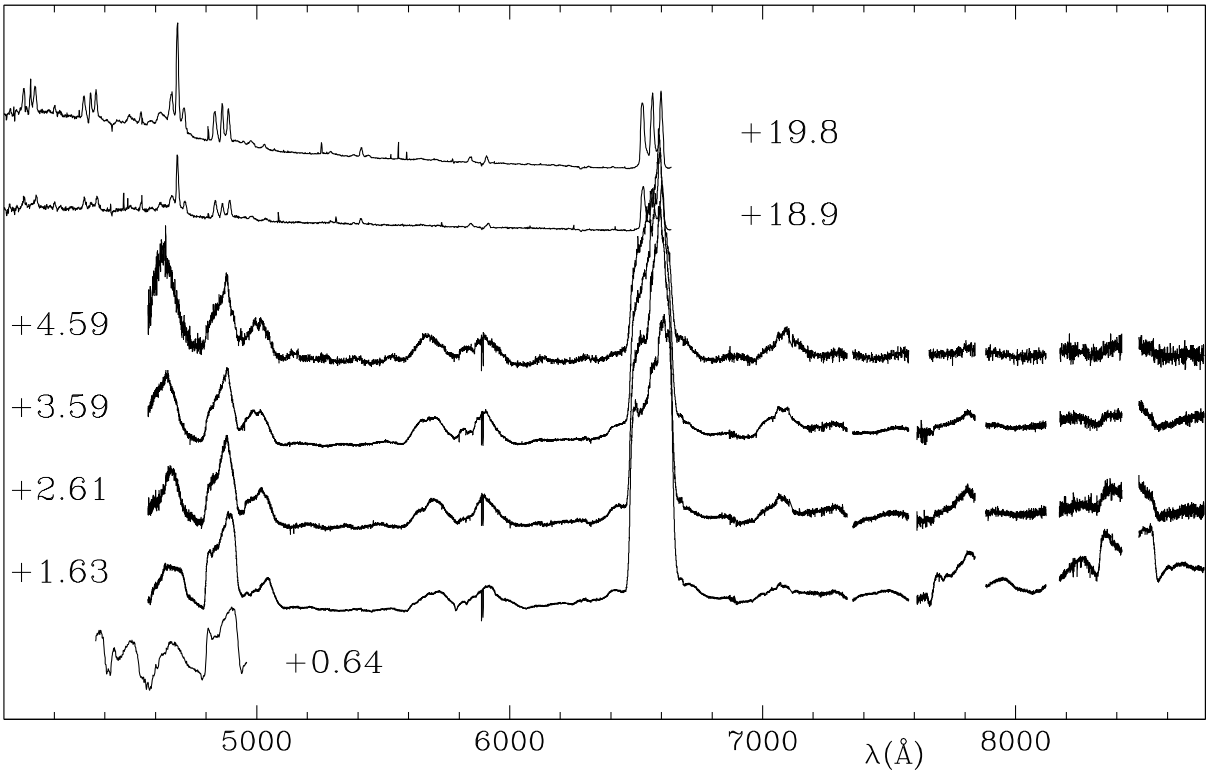


**Fig. 2.** Spectroscopic evolution of the 1999 outburst of U Sco from some of our spectra. Numbers are days since maximum brightness. The spectra are normalized to 1.0 at 5500 Å and shifted to avoid overplotting. H$\alpha$ profiles are plotted on an expanded scale in Fig. 3.

and/or the predicted minima are the eclipse of the hot spot and not those of the WD.

Integrating the lightcurve in Fig. 1, the energy radiated in the V band by U Sco during the time covered by the observations in Table 2 can be expressed as

$$E_{\rm V}^{\rm rad} = 2.65 \times 10^{40}\ D^2\ 10^{0.4 \times A_V} \quad {\rm ergs} \tag{1}$$

where $A_V$ is the extinction in magnitudes and $D$ is the distance in kpc. The slope of the continuum in our spectra suggests a color temperature of about $2{\times}10^4$ °K. Assuming for sake of discussion that U Sco has radiated on the average as a Kurucz's model atmosphere with T=20,000 °K and log g = 3.0, we find that the global radiated energy is $\sim 20\times$ that radiated in the $V$ band, so Eq. (1) can be rewritten for the bolometric energy as

$$E^{\rm rad} \sim 5 \times 10^{41}\ D^2\ 10^{0.4 \times A_V} \quad {\rm ergs} \tag{2}$$

For any reasonable distance inside the Galaxy and the extinction generally adopted ($A_V$=0.6, cf. S88), the 1999 outburst of U Sco appears considerably underluminous compared to those of classical novae (cf. W95). The same conclusion was reached by W81 from IUE observations of the 1979 outburst of U Sco.

## 4. Spectral evolution

In comparison to previous outbursts our observations begun much earlier, significantly extended toward later phases and have been performed at a higher resolution and over a broader wavelength range (see Fig. 2).

As for previous outbursts (cf. B81, S88), the spectrum has been characterized by very wide emission lines, with Balmer hydrogen lines being the strongest at earliest phases (in quiescence hydrogen lines are generally absent and mimicked by the Pickering series of HeII, cf. Hanes 1985 and Johnston & Kulkarni 1992).

A feature not reported for previous outbursts (perhaps due to the poorer resolution and looser time coverage) is the monotonic decrease with time of the FWZI (full width zero intensity) of H$\alpha$ (and similarly for the other Balmer lines; cf. Figs. 2 and 3). The values in Table 1 are plotted in Fig. 4 where the linear fit is given by the equation:

$$FWZI(H_\alpha) = 10,030 - 270 \times {\rm days} \quad {\rm km\ sec^{-1}} \tag{3}$$

This linear decrease is difficult to explain in term of ejecta deceleration by circumstellar material because the spectra carry no sign of the typical signatures that characterize the presence of shock fronts (cf. Osterbrock 1989).

The identification of emission lines other than the Balmer ones is complicated by the their large width. Surely present close to maximum are OI 7775 and 8446 Å, HeI 5876 and 7075 Å (the presumably weaker 6678 Å line is nearly lost in the H$\alpha$ wings) and NII 5675. The complex at 5015 Å could be a blend of HeI and NII, and NIII and CIII are probably the main contributors to the blend at ∼4630 Å. The ionization degree has increased during the decline, with HeII 4686 Å becoming visible after the first week from maximum. As for previous outbursts, also this time the nebular lines have not shown up in the late spectra of

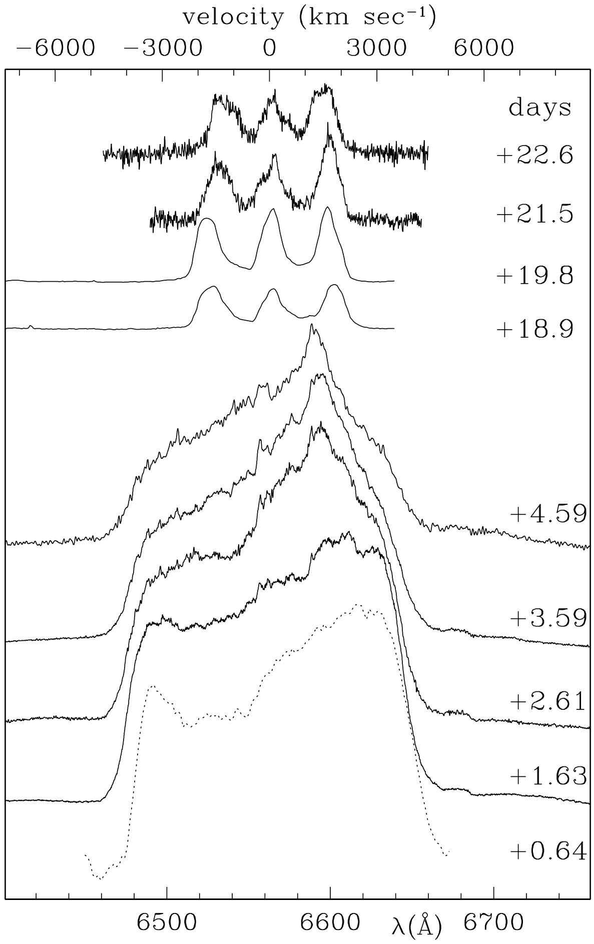


**Fig. 3.** Evolution of the H$\alpha$ profile. The first spectrum (dotted line) is actually a H$\beta$ profile (cf. Fig. 1). The transition from a saddle-like profile at earliest stages toward a more Gaussian-like one and eventually to a triple-peaked shape is evident as it is the continuous decrease in width (cf. Fig. 4).

U Sco, reinforcing the notion that a limited amount of material – if any – has been ejected by U Sco.

The Balmer and O I 7775-8446 Å emission lines showed a saddle-like profile at earliest phases, while other lines presented a more Gaussian-like profile. At *day +3* Balmer and O I lines turned to single-peaked profiles as well. Later evolution has been characterized by Balmer and HeII lines to split into three components with velocity separation of the order of $\pm$1600 km sec$^{-1}$. This triple–peak profile was not observed in the 1987 outburst (cf. S88) and can be perhaps only marginally spotted in the latest H$\beta$ profile presented by B81 for the 1979 outburst.

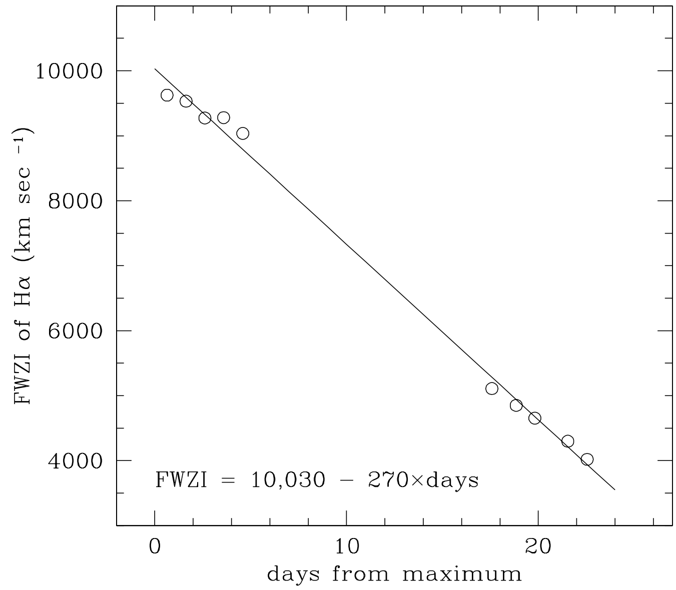


**Fig. 4.** Decrease of the FWZI of H$\alpha$ since outburst maximum.

The eclipsing nature of U Sco prevents an explanation of the triple peaks at later phases (when the ejecta become presumably optically thin) as collimated beams of material ejected at a large angle from the plane of the orbit or of an accretion disc.

The 1979, 1987 and 1999 outbursts spectroscopically resemble each other only in broad terms, with significant differences from eruption to eruption. Such differences might trace large changes from event to event in the optical depth and kinematics of the ejecta. The optical depth must be connected to the amount of ejected material (the velocity and time extent remaining about the same from outburst to outburst), which should in turn depend on the amount of material accreted between successive outbursts.

## References

Barlow M.J. et al. 1981, MNRAS 195, 61 (B81)
Duerbeck H.W., et al. 1993, ESO Messender 71, 19
Hanes D.A. 1985, MNRAS 213, 443
Johnston H., Kulkarni S.R. 1992, ApJ 396, 267
Osterbrock D.E. 1989, Astrophysics of Gaseous Nebulae and Active Galactic nuclei, University Science Books
Payne-Gaposchkin C. 1957, The Galactic Novae, Dover Publ.
Schaefer B.E., Ringwald F.A., 1995 ApJLett 337, L45 (SR95)
Sekiguchi K. et al. 1988, MNRAS 234, 281 (S88)
Williams R.E. et al. 1981, ApJ 251, 221 (W81)
Warner B. 1995, Cataclysmic Variable Stars, Cambridge Univ. Press