V383 Sco – a post-AGB star periodically eclipsed by pulsating M type supergiant

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(Conferense poster. Submitted on 14.03.2012; Accepted on 15.04.2012)

Abstract. A summary of our efforts to study in more details one of the longest period eclipsing binaries V383 Sco is presented. Historical photometric observations as well as recent photometry and spectroscopy are used. Our results suggest that V383 Sco could be a high-velocity bulge/bar system containing a post-AGB supergiant eclipsed by a pulsating M supergiant.

Key words: stars: binaries: eclipsing – stars: circumstellar matter – stars: mass-loss – stars: oscillations – Galaxy: kinematics and dynamics

1 A forgotten star

V383 Sco was discovered as an eclipsing binary by Henrietta Swope (1936). She observed three consecutive eclipses at the beginning of the XX^{th} century. The orbital period of the system (13.35 yrs) is one of the longest known. Initially V383 Sco was classified as a ζAur type eclipsing variable. Popper (1948) has estimated the spectral type of the primary as F0 Ia. Later the object was forgotten for decades.

2 Recent photometry and spectroscopy

We combined ASAS-3 V and I photometry (Pojmański 2004), covering the last eclipse of V383 Sco in 2007-2008 (Fig. 1), with archival photometry of three minima observed before 1930 to obtain new ephemeris: $JD_{\rm midecl} = 2415482(\pm41) + 4875.9(\pm8.5) \times E$. We were not able to phase the light curve correctly with this ephemeris because the eclipses duration and contact moments vary at different epochs.

Assuming that these changes could be caused by pulsations of one of the V383 Sco components we analyzed the low-amplitude brightness variations best visible in the ASAS-3 observations outside the eclipse. Applying Fast Fourier Transformation to the ASAS-3 photometric data outside the eclipse we found a period of $198\overset{d}{.}8 \pm 4.8$ for the low amplitude variations (Fig. 1).

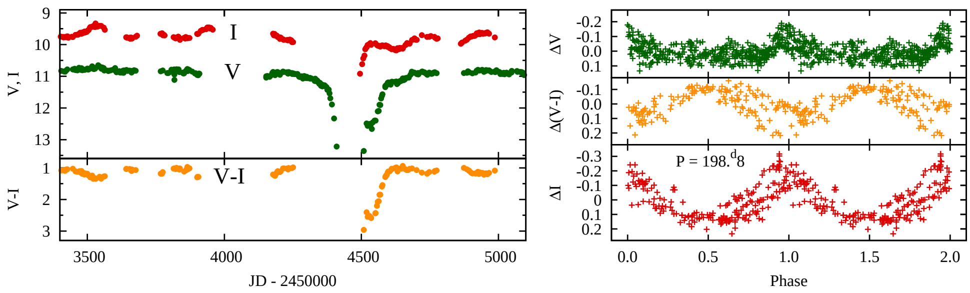

Fig. 1. *Left*: The V and I band light curves as well as the $V-I$ color index observed around the 2007-2008 eclipse of V383 Sco. *Right*: The V-band (top), $V-I$ (middle) and I-band (bottom) light curves outside of eclipse phased with a period $P_{\rm pul} = 198\overset{\rm d}{.}8$. The amplitude of the variations observed in I band appeared to be much greater than in V.

An ephemeris of selected maxima from the V and I-band light curves obtained using a linear fit to the $O-C$ residuals ($JD_{\rm maxPul} = 2452544.8(\pm 2.9) + 198.8(\pm 0.4) \times E_{\rm p}$), perfectly coincides with the pulsations period calculated using the Fourier analysis.

A low-resolution spectrum (LRS) of V383 Sco ($R \simeq 1000$) was obtained at SAAO on 31 October 2009. The spectrum is dominated by early F type absorptions and a relatively weak Hα emission. Traces of molecular bands are well visible in the red part. The best fit model spectrum was obtained for a superposition of F0 I and M1 I spectra reddened by $E_{\rm B-V} = 0.53$.

Two high resolution spectra (HRS) of V383 Sco (R=84000) were obtained with ESO HARPS spectrograph on 14 and 16 October 2009. Using the UVES library of high-resolution spectra (Bagnulo et al. 2003) we found that the V383 Sco HRS falls somewhere in between A9 I and F2 I spectral classes. Taking into account the close similarity with a spectrum of ε Aur (F0 II-III?, Hoard et al. 2010) obtained outside the eclipse (ELODIE database, Moultaka et al. 2004) an F0 I spectral class can be suggested for V383 Sco.

The absorption spectrum of V383 Sco is dominated by sharp lines of neutral and once ionized metals. Among the most conspicuous and strongest are the absorptions of Fe II, Ti II, Ba II, Sr II, Si II, etc. The Balmer lines appear similar to that in the spectrum of a Be star. Hα presents as two emission components divided by an absorption while in the Hβ profile in addition to the same emission and absorption components wide absorption wings are well visible (Fig. 2).

Simultaneously with the spectra of V383 Sco ($l = 352\overset{\circ}{.}9723, b = -06\overset{\circ}{.}0999$, $z \sim 0.8$ kpc) we obtained a HARPS spectrum (October 15, 2009) of another nearby, poorly studied, long-period ($P \sim 18$ yrs) eclipsing binary V381 Sco ($\sim$A8 II, $l = 354\overset{\circ}{.}2974, b = -03\overset{\circ}{.}8119$, $z \sim 0.4$ kpc). Using the total equivalent width of the IS Na I D_2 line (Fig. 2) and the calibration of Munari & Zwitter (1997) we estimated low limit reddening values $E_{\rm B-V}$ about 0.43 and

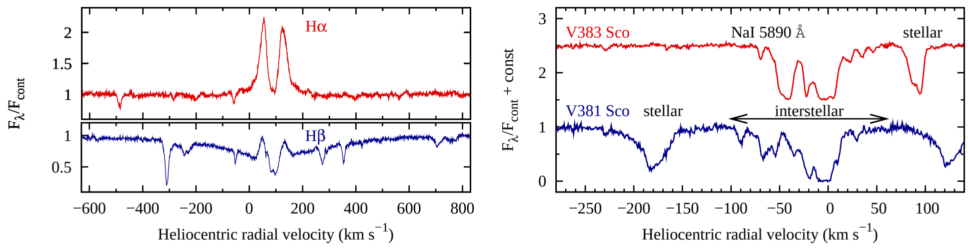

Fig. 2. *Left*: The Hα and Hβ lines in the spectrum of V383 Sco. *Right*: The region around Na I 5890 Å in the HARPS spectra of V383 Sco and V381 Sco. The large difference in the radial velocities of the stellar Na I components in the spectra of two nearby stars is evident.

0.39 (giving distances $7.8^{+1.9}_{-1.5}$ kpc and $5.5^{+1.3}_{-1.1}$ kpc) for V383 Sco and V381 Sco respectively.

The measured radial velocities of both stars are high and very different, 90 km s^{-1} for V383 Sco and -179 km s^{-1} for V381 Sco (Fig. 2). They cannot be caused by orbital motion in such long-period systems but seem to be in agreement with the kinematic model of the Milky-Way center, inconsistent with purely circular motion. Using the model of Weiner & Sellwood (1999, see their Fig. 8) for the inner part of our Galaxy we estimated that V383 Sco is placed about 0.5 kpc behind the galactic center and that V381 Sco is placed about 1 kpc in front of it. Assuming a value of $R_0 = 8.0$ kpc (Sofue et al. 2009) for distance to the galactic center the corresponding distances to V383 Sco and V381 Sco are 8.5 ± 1 kpc and 7 ± 1 kpc, respectively. Which are consistent with the above values within the errors.

3 Possible nature of V383 Sco

To construct the Spectral Energy Distribution (SED) of V383 Sco shown in Fig. 3 we used all photometric data available in the literature (Swope 1936, TYCHO-2, ASAS-3, 2-MASS, AKARI, IRAS). The observed SED can be reproduced by a superposition of a hot F0 I supergiant and a cool M type giant/supergiant, with inclusion of a 500 K black-body to justify the excess in the range up to 18 μm.

Using our own, very simple computer code, we made an attempt to model the last eclipse of V383 Sco, taking into account pulsations of the cool star. The best results were obtained for eclipses of a hot star ($R_{\rm hot} = 58 R_\odot$, $T_{\rm hot} = 7500$ K) by a cool component ($\bar{R}_{\rm cool} = 208 R_\odot$, $T_{\rm cool} = 2800$ K) which changes its V and I brightness with amplitudes of $3^{\rm m}.66$ and $1^{\rm m}.75$ respectively (Fig. 3).

The observed properties of V383 Sco can be explained if we suppose that, most probably, the system is composed of a post-AGB F0 supergiant, perhaps in the beginning of its PPN phase, and a cool M supergiant. A system similar to the non eclipsing binary HD 172481, which consists of an F-type post-AGB star and an M type, probably AGB, companion (Reyners &

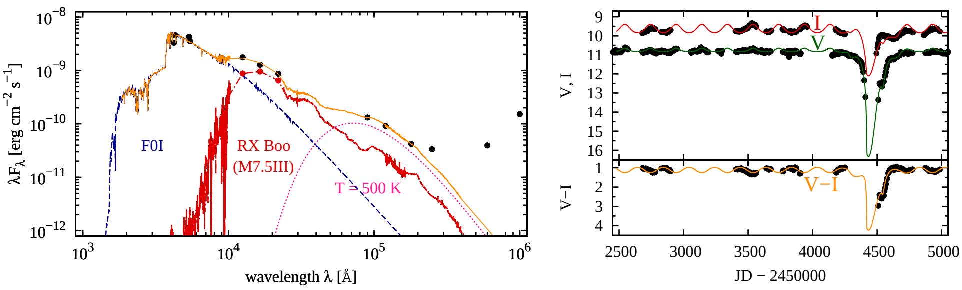

Fig. 3. *Left*: The dereddened SED of V383 Sco (points). The dashed line shows the F0 I type supergiant from 1993 Kurucz Stellar Atmospheres Atlas (Kurucz 1993). The dot-dashed line marks the spectrum of SRb type pulsating star RX Boo. The doted line shows a black-body with T=500 K. The continuous line shows the sum of all 3 components appropriately rescaled to fit to the SED of V383 Sco. *Right*: The synthetic V and I-band light curves and the $V-I$ color index curve, obtained by modeling, are plotted for comparison to the observational photometric data.

Van Winckel 2001). Whitelock & Marang (2001) showed that the cool component in HD 172481 is a Mira type variable with a pulsation period of $312^{\rm d}$.

As arguments in favor of the post-AGB nature of the F0 I component in V383 Sco can be considered: (i) the belonging to the Galaxy bulge/bar structure; (ii) the large radial velocity; (iii) the IR excess observed in the SED; (iv) existence of a very low excitation nebula around the system indicated by O I 6300 Å emission in the HRS with an expanding velocity $\sim$15 km s^{-1} (Gałan et al. 2012).

The hypothesis that the eclipsing object is a pulsating M type giant/supergiant is supported at least by: (i) traces of molecular absorption bands in the V383 Sco spectrum; (ii) reproduction of the observed SED by the superposition a hot F0 I supergiant and a cool M type giant/supergiant; (iii) strong dependence of the eclipse depth on the photometric band, which shows that a cool, very bright object dominates in the near IR; (iv) pulsations, with an amplitude decreasing towards the short wavelengths, which cause changes in the phases of the eclipse contacts; (v) the flattened "bottoms" of the pulsation minima observed in the V band and reproduced by our model (compare Figs. 1 and 3).

Acknowledgements

This study was supported by MNiSW grant No N203 395534 and was financed to DG by the GEMINI-CONICYT Fund, allocated to the project 32080008. WG gratefully acknowledges financial support for this work from the Chilean Center for Astrophysics FONDAP 15010003, and from the BASAL Centro de Astrofisica y Tecnologias Afines (CATA) PFB-06/2007".

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