Publication Year	2016
Acceptance in OA	2020-08-25T15:06:21Z
Title	The variable V381 Lac and its possible connection with the R CrB phenomenon
Authors	Rossi, C., Dell'Agli, Flavia, DI PAOLA, Andrea, Gigoyan, K. S., Nesci, R.
Publisher's version (DOI)	10.1093/mnras/stv2824
Handle	http://hdl.handle.net/20.500.12386/26823
Journal	MONTHLY NOTICES OF THE ROYAL ASTRONOMICAL SOCIETY
Volume	456

Monthly Notices
of the
ROYAL ASTRONOMICAL SOCIETY

MNRAS **456,** 2550–2557 (2016) doi:10.1093/mnras/stv2824

The variable V381 Lac and its possible connection with the R CrB phenomenon

C. Rossi,[1]⋆ F. Dell'Agli,[1]⋆ A. Di Paola,[2] K. S. Gigoyan[3] and R. Nesci[4]

[1]*Dipartimento di Fisica, Università di Roma 'La Sapienza', P.le Aldo Moro 5, I-00185 Roma, Italy*
[2]*INAF – Osservatorio Astronomico di Roma, Via Frascati 33, I-00040 Monte Porzio Catone (RM), Italy*
[3]*V. A. Ambartsumian Byurakan Astrophysical Observatory (BAO) and Isaac Newton Institute of Chile, Armenian Branch, Byurakan 0213, Aragatzotn province, Armenia*
[4]*INAF/IAPS, via Fosso del Cavaliere 100, I-00133 Roma, Italy*

Accepted 2015 November 30. Received 2015 November 30; in original form 2015 August 24

ABSTRACT

We have performed new medium resolution spectroscopy, optical and near-infrared photometry to monitor the variability of the asymptotic giant branch (AGB) carbon star V 381 Lac. Our observations revealed rapid and deep changes in the spectrum and extreme variability in the optical and near-infrared bands. Most notably we observed the change of Na I D lines from deep absorption to emission, and the progressive growing of the [N II] doublet 6548–6584 Å emission, strongly related to the simultaneous photometric fading. V381 Lac occupies regions of Two Micron All-Sky Survey and *Wide-field Infrared Survey Explorer* colour–colour diagrams typical of stars with dust formation in the envelope. The general framework emerging from the observations of V381 Lac is that of a cool AGB carbon star undergoing episodes of high mass ejection and severe occultation of the stellar photosphere reminiscent of those characterizing the RCB phenomenon. Comparing the spectral energy distribution obtained with the theoretical model for AGB evolution with dust in the circumstellar envelope, we can identify V381 Lac as the descendant of a star of initial mass $\sim 2\,\mathrm{M}_{\odot}$, in the final AGB phases, evolved into a carbon star by repeated Third Dredge Up episodes. According to our model, the star is moderately obscured ($\tau_{10} \sim 0.22$) by dust, mainly formed by amorphous carbon (∼80 per cent) and SiC (∼20 per cent), with dust grain dimensions around ∼0.2 and 0.08 μm, respectively.

Key words: stars: emission line – stars: individual: V381 Lac – stars: late-type – infrared: stars.

1 INTRODUCTION

Among the asymptotic giant branch (AGB) stars, a small fraction of carbon-rich stars show an extreme variability reminiscent of the hotter R CrB supergiants, e.g. Feast, Whitelock & Marang (2003) and Whitelock, Feast & Marang (2006). Erratic optical variability with large amplitude and dramatic spectral changes are the main signatures of these stars: the fast decline of several magnitudes in luminosity is interpreted as caused by enhanced mass-loss events. The very extended atmospheres produce the ejection of clouds (puffs) where carbon-rich dust condense in grains. The extinction events are attributed to these dust clouds in our line of sight: either a dust cloud is passing between the photosphere and us, or a sudden very strong ejection of dust by the star itself takes place. Colour changes also occur, being the object redder when fainter. The photometric changes have spectacular spectroscopic fallout: molecular and atomic lines develop in emission during the fading to turn back in absorption when the star recovers the bright state (Clayton 1996; Whitelock et al. 2006).

Besides the optical variations, the infrared excess is a well-known characteristics of the RCB and of their cooler counterpart, the DY Per stars, showing a spectrum more similar to that of an ordinary N AGB-type supergiant (see e.g. Clayton 1996; Feast et al. 1997). The advent of several infrared satellites improved the wavelength coverage of the energy distribution and stimulated the use of mid-infrared colour–colour diagrams to select new candidates (Miller et al. 2012; Tisserand 2012; Tisserand, Clayton & Pilecki 2013; Lee 2015). Differences and similarities have been extensively discussed and categorized although the behaviour of strongly variable AGB stars makes them difficult to be identified unless located in well monitored fields, while scattered observations can yield to misclassification of possibly interesting objects.

The case of V381 Lac (also known as FBS 2213+421) is paradigmatic. Over the years, the star has been subject to periods of high luminosity and of rapid, severe obscuration episodes. Classified as a Dwarf Nova by Dahlmark (1996) and by Hoard et al. (2002) on the basis of the photometric variability, then as an M5–M6 star by

---

⋆E-mail: corinne.rossi@uniroma1.it (CR); flaviadellagli@gmail.com (FDA)

Published by Oxford University Press on behalf of the Royal Astronomical Society

Gigoyan et al. (2006) from a low dispersion objective-prism plate of the First Byurakan Survey (FBS; Markarian et al. 1989), it was finally recognized as a Carbon star by Gigoyan et al. (2009). To clarify its nature, we started since 2012 a photometric and spectroscopic campaign and collected the available data from literature and public catalogues. This paper is organized in the following way: in Section 2, we describe the observational material. In Section 3, we analyse the flux variability, the spectroscopic changes and the position of V381 Lac in several infrared colour–colour plots. In Section 4, we present a possible interpretation of the spectral energy distribution (SED) on the basis of our evolutionary models for dusty carbon-rich stars. In Section 5, we discuss the last event of strong flux variation and draw our conclusions.

2 OBSERVATIONAL MATERIAL

2.1 Optical photometry and spectroscopy

Between 2012 July and 2015 September, we obtained simultaneous photometric (*B*, *V*, *R*, *i*) and spectroscopic data with the 152 and 182 cm telescopes of the Bologna and Asiago Astronomical Observatories, equipped with the BFOSC and AFOSC (Bologna/Asiago Faint Object Spectrometer And Camera); spectral range is 3900–8500 Å, dispersion 3.9 Å pixel^{-1} and resolution of about 10 Å. All the spectra were corrected for the atmospheric extinction and normalized at the same wavelength. One photometric point was also obtained with the Roma University telescope (TACOR) and one was kindly obtained for us by the Associazione Romana Astrofili (ARA; http://ara.roma.it) association with the 37 cm telescope in Frasso Sabino. The data were reduced by means of standard IRAF[1] procedures.

To study the photometric history of V381 Lac, we have downloaded from Mikulski Archive for Space Telescopes (MAST) and analysed the digitized images available from First Palomar Observatory Sky Survey (POSS I), Second Palomar Observatory Sky Survey (POSS II) and Quick-V surveys in the *B*, *V*, *R* and *I* bandpasses. Well-sampled light curves were obtained from the Northern Sky Variability Survey (NSVS)-ROTSE telescope (Wozniak et al. 2004) and the AAVSO[2] archive. In the archives of Asiago Observatory, we examined the plates of the field, obtained between 1967 and 1969; only an upper limit of $B = 17.7$ mag could be derived. We will not mention these plates anymore. We also re-analysed the objective prism spectrum visible in the plate of the Digitized First Byurakan Survey (DFBS), now accessible from the Italian Virtual Observatory (http://ia2.oats.inaf.it/). The spectrum, showing the deep absorption bands typical of a carbon star, is presented in Fig. 1. From this spectrum, we derived approximate magnitudes in the *B* and *R* filters following the same criteria of the DFBS automatic pipeline (Mickaelian et al. 2007). We summarize the archive and our recent optical data in Table 1; typical errors are $\sim$0.07 mag for the Loiano, Asiago and Frasso Sabino, 0.1 mag for TACOR.

2.2 Infrared photometry

We obtained photometric observations in *J*, *H* and *K* bands at the 1.1 m AZT-24 telescope located at Campo Imperatore (Italy) equipped with the imager/spectrometer SWIRCAM (D'Alessio et al. 2000), based on a 256×256 HgCdTe PICNIC array. From the archives, we have also retrieved the data from Two Micron All-Sky Survey (2MASS; Skrutskie et al. 2006), *IRAS* (Moshir et al. 1990), *Wide-field Infrared Survey Explorer* (*WISE* Cutri et al. 2013), *AKARI* (Murakami et al. 2007) and converted fluxes to magnitudes according to the prescriptions of Tanabe et al. (2009) and of the IRAS Explanatory Supplement (1988) for *AKARI* and *IRAS*, respectively. Recent and archive magnitudes are reported in Table 2. We do not report the very uncertain value of the *WISE* 4.6μ magnitude.

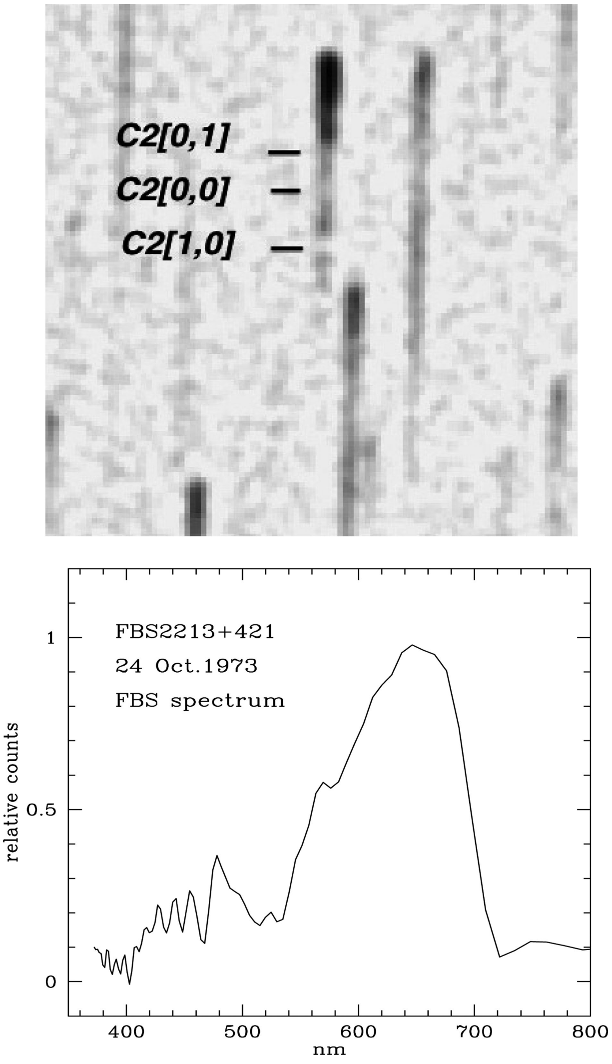

Figure 1. Top: two dimensional section of the FBS plate No 932. The digitization of V381 Lac shows a strong red head and allowed us to identify the deep absorption bands of the C$_2$ from top to bottom at 5636, 5165and 4737 Å, respectively. Bottom: wavelength calibrated spectrum; the central deep depression is partly due to the lower sensitivity of the plate emulsion.

3 DATA ANALYSIS

3.1 Flux variations

From the photometric optical history presented in Table 1, it is clear that two deep minima occurred in 1989 and 2006. On shorter time-scales, variability of $\sim$2 mag are shown by the ROTSE and the AAVSO optical light curve, but no periodicity can be identified (see Fig. 2).

---

[1] IRAF is distributed by the NOAO which is operated by Association of Universities for Research in Astronomy (AURA) under contract with National Science Foundation (NFS).

[2] American Association of Variable Star Observers, url: http://www.aavso.org/vstar/vsots/0100.shtml.

Table 1. Archive and new data in the optical range.

Emulsion/ instrument	Date	JD	*B*	*V*	*R*	*I*
103aO	26 Aug. 1952	243 4250	17.07 (0.14)			
103aE	26 Aug. 1952	243 4250			13.34 (0.13)	
103aF	24 Oct. 1973	244 1979	15.6 0.2		13.3 (0.2)	
IIaD	30 Sep. 1983	244 5607		16.86 (0.10)		
IIIaF	4 Sep. 1989	244 7773			20::	
IIIaF	4 Oct. 1989	244 7803			20::	
IV-N	6 Oct. 1989	244 7805				>20
IIIaJ	29 Sep. 1992	244 8894	21::			
IV-N	20 Sep. 1995	244 9980				15.65 (0.12)
IIIaJ	24 Oct. 1995	244 5014	18.5 (0.3)			
NSVS	May99–Feb00	2451 299-575			12.2–14.3^a	
SDSS	24 May 2006	245 3879	und	und	und	>21.3^b
AAVSO	July–Nov. 2012	2456 109-262	17.5-15.8	15.5-14.0		
BFOSC	18 Jul. 2012	245 6126	17.50	14.95	13.25	
TACOR	14 Oct. 2012	245 6214		13.7	12.4	
F.Sabino	18 Oct. 2012	245 6218	16.09	13.75	12.33	
AFOSC	20 Nov. 2012	245 6251	16.20	13.67	12.20	
BFOSC	28 Nov. 2013	245 6624		17.40	15.61	
BFOSC	17 Dec. 2013	245 6643	19.70	17.65	15.93	14.21
BFOSC	21 Aug. 2014	245 6890	>21.5	19.5	17.85	
BFOSC	13 Sep. 2014	245 6913			18.17	
BFOSC	20 Jun. 2015	245 7194		17.5	15.45	14.32
BFOSC	22 Jul. 2015	245 7225	20.2	17.81	15.75	14.61
AFOSC	06 Sep. 2015	245 7272		19.99	18.50^c	16.87^c

Notes: ^{a}ROTSE Red magnitudes; ^{b}Sloan Digital Sky Survey (SDSS) magnitude; ^{c}converted to Johnson–Cousin system.

Table 2. Recent and archive magnitudes in the infrared range. Wavelengths are in µm. C.I. = Campo Imperatore, K is in 2MASS system. Errors for July 2015 *H* and *K* are 0.15 mag.

Source	Date	1.25	1.65	2.26	3.4	9.0	12	18	22/25	60
2MASS (1)	11-10-1998	13.207	10.196	7.788						
C.I. (2)	21-09-2012	8.96	7.45	6.15						
C.I. (3)	17-12-2013	10.77	8.47	6.54						
C.I. (4)	29-09-2014	12.74	9.65	7.33						
C.I. (5)	22-06-2015	11.13	9.33	7.40						
C.I. (6)	23-07-2015	11.37	9.4	7.6						
IRAS	1983						0.626		−0.17	−0.45
AKARI	2006–2007					1.13		−0.14		
WISE	18-06-2010				4.438		0.365		−0.227	

In the near-infrared, our data show large changes with respect to 2MASS, and also within one year, strongly correlated with the optical photometric and spectroscopic variations. At longer wavelengths, the excursions seem to be smaller on the basis of the data presented in Table 2, obtained at different epochs by different instruments.

3.2 Spectroscopic variations

Our new spectra of V381 Lac at different epochs are shown in Fig. 3. Overall, the spectral changes are strongly correlated with the optical flux and with the sign of its derivative. The spectra obtained during bright phases (1973 and 2012) showed strong absorption bands; in the 2012 spectrum the bands typical of a naked N-type giant, belonging to the Swan system of the C2 and to the red system of CN molecule, could be easily identified. From a comparison with the spectral atlas of carbon stars by Barnbaum, Stone & Keenan (1996), the spectral class of the object was not earlier than N5 subtype. The Na D at 5890–96 Å doublet was strong in absorption. In 2013 December, during a fading phase the continuum was brighter redwards 7800 Å and the veiling started to affect the strength of the photospheric absorption bands. The most interesting features of this spectrum were the Na D doublet which changed to strong emission and a faint emission at about 6582 Å. In summer 2014, the star was even fainter, the emissions were stronger and the second component of the [N II] doublet became visible at 6547 Å. In 2015 June, the star was in a relatively bright phase: only absorption features with sign of veiling were visible in the spectrum, while the evolution of the photometry from June to July indicated a new brightness decline.

Besides the emission of Na D and [N II] during the fading phases, we remark the lack of hydrogen lines either in emission or absorption in all the new spectra, while in 2008, H α was clearly present in absorption simultaneously with the Na D doublet (Gigoyan et al. 2009).

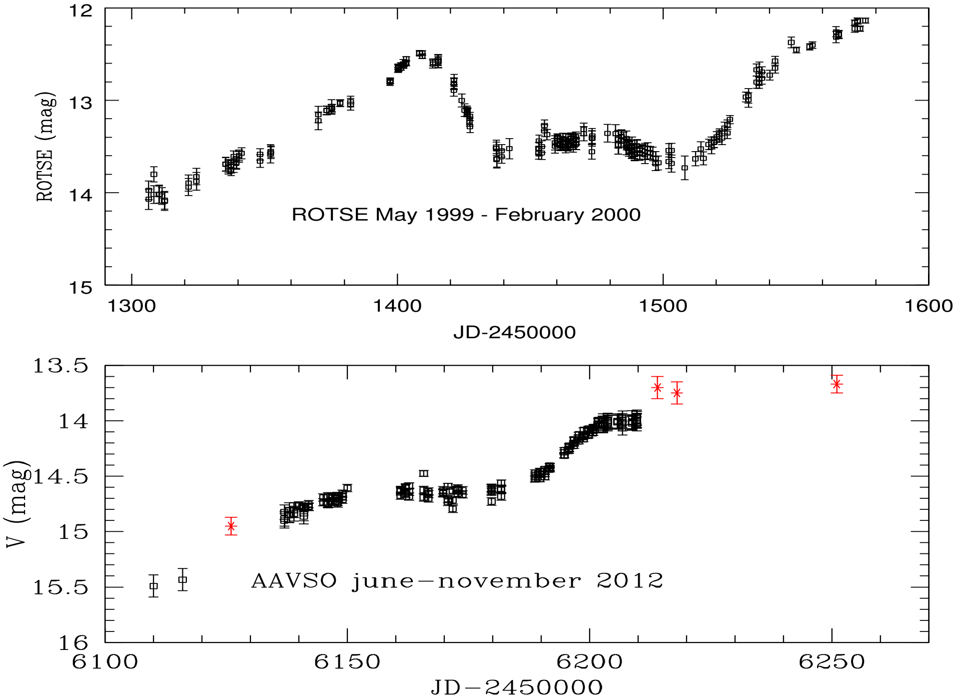

Figure 2. Light curve of FBS2213+421 downloaded from ROTSE and AAVSO archives. The asterisks represent our 2012 data obtained in the same period of the AAVSO data; a small offset between AAVSO V-pre-validated data and our filters is evident.

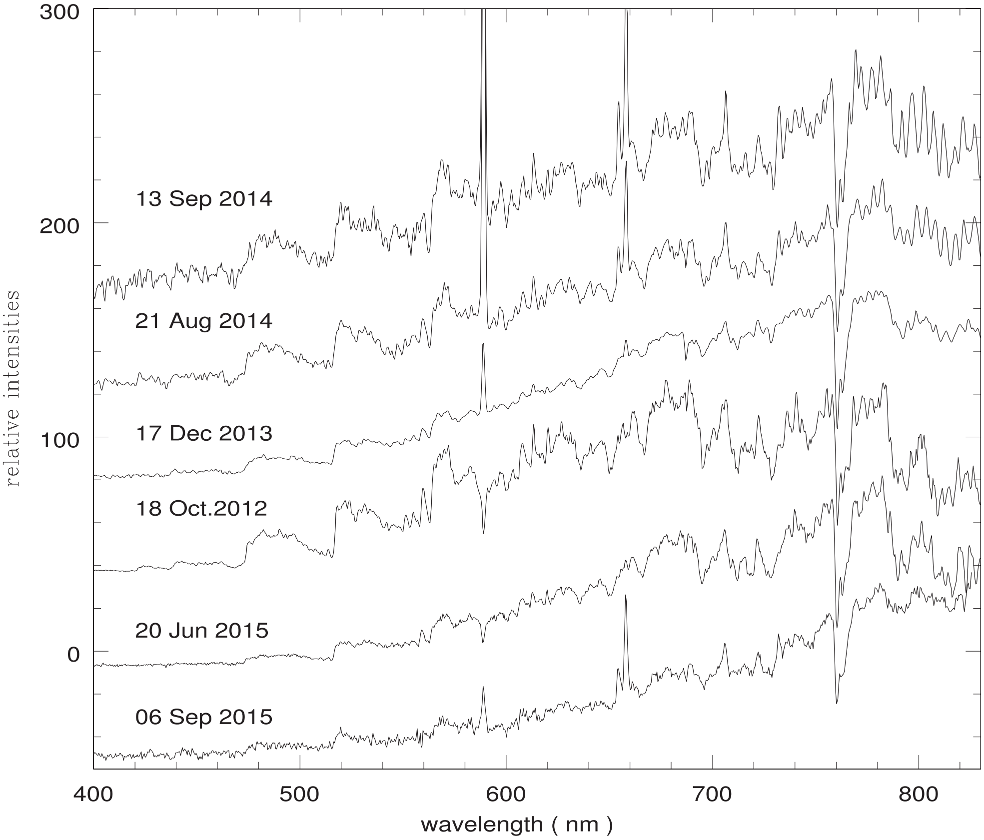

Figure 3. Optical spectra of V381 Lac taken between 2012 and 2015. The *y*-axis represents relative intensities corrected for the atmospheric extinction. The spectra are normalized at 7800 Å. To allow for a better reading, the 2013 and 2014 spectra are shifted upward with respect to the 2012 one; the 2015 spectra are placed at the bottom of the figure.

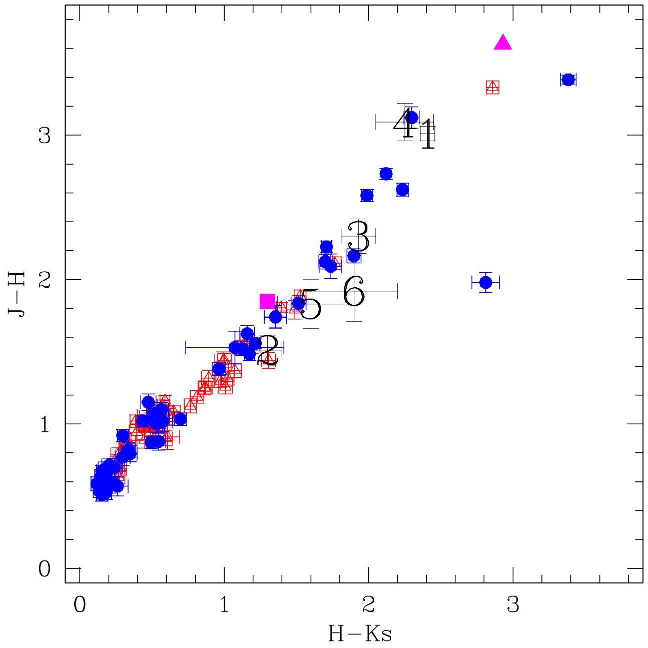

Figure 4. Colour–colour near-infrared diagram in the 2MASS system; the positions of V381 Lac are indicated by the black numbers. Blue filled circles are the FBS carbon stars, red open triangles are carbon stars from other data set. Theoretical model 1 (magenta square) and model 2 (magenta triangle) are also overimposed.

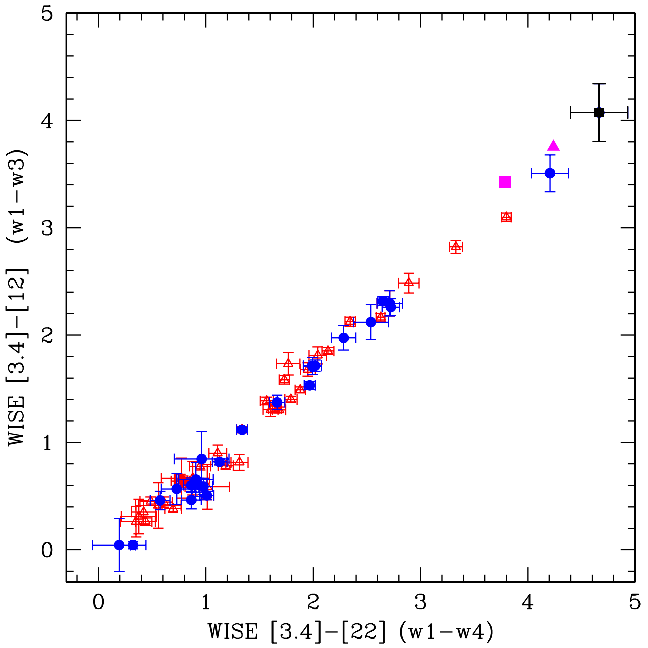

Figure 5. *WISE* w1–w3 versus w1–w4 colour–colour diagram for the sample of carbon stars reported in the text. V381 Lac is the uppermost black square. Theoretical model 1 (magenta square) and model 2 (magenta triangle) are also overimposed.

3.3 Infrared diagrams

We located our star in the classical colour–colour diagram $J - H$ versus $H - K$ to study its evolution with luminosity (e.g. Bessel & Brett 1988; Leggett et al. 2002; Cruz et al. 2003). We show the results in Fig. 4 together with those of confirmed carbon stars from FBS and other data set (Alksnis et al. 2001; Mauron 2008; Mauron et al. 2014). The positions of V381 Lac corresponding to the dates reported in Table 2 are indicated by the numbers in black. The very red 2MASS point in 1988 (point 1) is indicative of the presence of a cool envelope. In 2012, during a bright phase, V381 Lac was along the strip of the naked carbon stars (point 2) while one year later, during the optical fading, it was moving again towards the dusty stars region (point 3). In the autumn 2014, when the star was already faint, the colours were again very similar to those of 2MASS (point 4). The magnitudes of Summer 2015 (points 5 and 6) are intermediate between maximum and minimum. Two points corresponding to the theoretical models described below are also indicated.

At longer wavelengths, we have checked the colours of V381 Lac in diagrams involving the *IRAS*, *WISE* and *AKARI* magnitudes; some of them are very efficient in discriminating dust enshrouded stars (see fig. 8 in Nikutta et al. 2014, fig. 4 in Tisserand 2012, and fig. 3 in Nesci et al. 2014). In the lack of the 4.6μ flux in the *WISE*-2013 data base, we have traced the possible colour–colour diagrams using the three remaining filters. An example is given in Fig. 5: V381 Lac is represented by the red symbol in the region occupied by obscured carbon stars.

We have tried anyway to get more information from *WISE*, locating V381 Lac in the classical diagram $[4.6]-[12]$ versus $[12]-[22]$ used by Tisserand (2012). That paper is based on the *WISE* Preliminary release (Cutri et al. 2011) suffering of several problems of calibration. We have applied the appropriate corrections to the magnitudes of V381 Lac according to fig. 3 of Tisserand (2012); when this release is used V381 Lac has the following colours $[4.6]-[12] = 2.60 \pm 0.13$, $[12]-[22] = 0.75 \pm 0.08$. In the *WISE*-2013 release, the magnitude [4.6] is reported in red (not reliable), the other magnitudes also changed, while the colours remain similar; taking into account the large uncertainties in the new release too, we consider the above-reported colours still acceptable, that locate the star in the zone populated by known RCB stars in fig. 6 of Tisserand (2012).

Similar indications are derived from the other possible *WISE* diagrams and from the diagrams involving *AKARI* data, taken when the star was in a faint phase. From the *IRAS* magnitudes computed according to the definition of van der Veen & Habing (1988) the colours of V381 Lac are: $[12]-[25] = -0.796$ and $[25]-[60] = -1.60$ in region VII of their fig. 5(b), populated by stars with evolved carbon-rich circumstellar shells, in agreement with the previous results.

Finally, using the archive and our more recent data we have traced the SED for V381 Lac reported in Fig. 6. In the infrared, the *AKARI* data are well aligned with the *WISE* and *IRAS* ones, indicating a smaller variability of the source in the mid-infrared. To avoid confusion, we do not plot the 2015 June and July fluxes. These points overlap quite well those of 2013 December when we caught the star during a fading phase. Although in summer 2015 no emission was visible in the spectrum, from the comparison of June and July photometry we argued that a similar evolution was globally occurring. Our guess was confirmed by the data obtained in September. In Fig. 6, we include these last points which correspond to the minimum brightness we have recorded so far.

4 THEORETICAL MODELS

Following the pioneering exploration by Ferrarotti & Gail (2006), various research groups worked on the description of dust formation

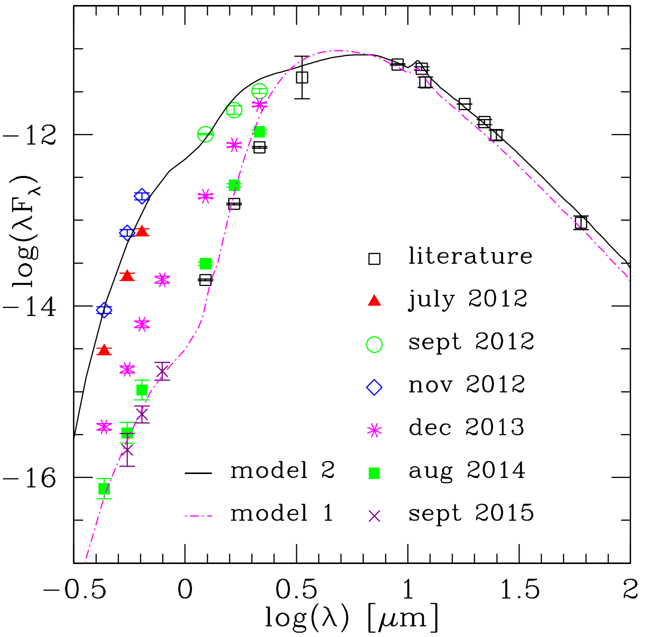

Figure 6. SED of V381 Lac. Fluxes are in SI units. The literature data are from 2MASS, *AKARI*, *IRAS*, and *WISE* catalogues. The best-fitting models (see Section 4 for the maximum (magenta dashed line) and minimum (black solid line) obscuration phases are over imposed.

in the winds of AGBs (Nanni et al. 2013; Ventura et al. 2014). In a recent paper, Dell'Agli et al. (2015) addressed the evolution of the infrared colours of AGB dusty models. In the present paper, we compare the observations of V381 Lac with the predictions of these models, to give a possible theoretical characterization of this star.

4.1 The model

The evolution from the pre-main sequence to the end of the AGB phase was calculated by means of the ATON code for stellar evolution (see Ventura & D'Antona 2009, and references therein). The range of masses investigated is $1\,\mathrm{M}_\odot \le M \le 8\,\mathrm{M}_\odot$, assuming a chemical composition in the range $0.008 \le Z \le 0.018$ ($Y = 0.26$). The convective instability is treated according to the full spectrum of turbulence description, developed by Canuto & Mazzitelli (1991). For carbon stars, we use the mass-loss rate by Wachter et al. (2008). For low-mass models ($1.25 \le M/\mathrm{M}_\odot \le 3$), the Third Dredge Up (TDU) drives the bottom of the envelope to regions previously touched by 3α nucleosynthesis; the consequent increase in the surface carbon content eventually leads to the C-star stage. This paper is focused on a carbon star and for this reason, we have applied only the models with mass below $3\,\mathrm{M}_\odot$. The wind surrounding AGBs is assumed to be accelerated by radiation pressure on dust particles. The growth of dust grains is described by condensation of gas molecules in the wind impinging on the already formed grains. The relevant equations can be found, e.g. in Ferrarotti & Gail (2006). For a given AGB evolutionary time, the location (and temperature) of the inner dust region boundary, the density stratification, the relative percentages of the different dust species (i.e. SiC versus AmC), the optical depth and the dust grain size are calculated self-consistently by our wind AGB models (Ventura et al. 2014 and references therein) and then used as inputs for the DUSTY code (Ivezic, Nenkova & Elitzur 1999). The interest reader will find detailed description of the computation in Dell'Agli et al. (2015).

Table 3. Physical properties of the central object and of the circumstellar dust of V381 Lac, obtained by the comparison with models.

Properties	V381 Lac	
Star		
L (L$_\odot$)	8000–10 000	
$T_{\mathrm{eff}}(K)$	2500	
M_{MS} (M$_\odot$)	2	
M (M$_\odot$)	1	
Dust		
Properties	model 1	model 2
T$_{\mathrm{dust}}(K)$	1000	600
τ_{10}	0.22	0.08
a_{SiC} (μm)	0.08	0.08
a_{C} (μm)	0.18	0.18

4.2 Comparison and results

In Fig. 6, we can clearly distinguish different phases of obscuration that are particularly evident at optical and near-infrared wavelengths.

Using colours and SED, we identify V381 Lac as the descendant of a star of initial mass ${\sim}2\,\mathrm{M}_\odot$, in the final AGB phase, after the effects of repeated TDU episodes turned it into a carbon star. Models of smaller mass can be ruled out by the present analysis, because they never reach the observed degree of obscuration. The gradual increase in the surface carbon favours a considerable expansion of the external regions (Ventura & Marigo 2009, 2010) and the consequent decrease in the effective temperature, which drops to ∼2500 K. These conditions favour the formation of great amount of dust, mainly solid carbon, with smaller percentages of SiC. The SED of the star during the heavily obscured phase is nicely reproduced (model 2 in Fig. 6) by our $2\,\mathrm{M}_\odot$ model, in the evolutionary stage when the mass is reduced to $1\,\mathrm{M}_\odot$. The dust layer is formed close to the star and has a temperature around 1000 K. Dust is composed by ∼80 per cent of solid carbon and ∼20 per cent of silicon carbide, with grain sizes of $a_{\mathrm{C}} \sim 0.18$ μm and $a_{\mathrm{SiC}} \sim 0.1$ μm, respectively. The optical depth at 10 μm is $\tau_{10} \sim 0.22$. The formation of solid carbon increases the emission in the continuum. The presence of a significant percentage of SiC, evident from the feature at ∼11.9 μm in both models, is confirmed by the slight increase in the flux of the [12] band with respect to the other *WISE* bands.

To interpret the 2012 observations, when the SED exhibits a smaller degree of obscuration, we assume that the star experienced a phase of smaller mass-loss, during which dust formation was suppressed. In this situation, the radiation emitted from the central object is reprocessed by the dust layer formed during a previous phase of stronger mass-loss, pushed outwards by effects of radiation pressure. In this configuration (model 1 in Fig. 6), the temperature of the dusty layer is ∼600 K, while the composition and dimension of dust grains are preserved together with the properties of the central object. Also, in this configuration the density decrease determines a lower optical depth, $\tau_{10} \sim 0.08$, with a higher emission in the optical. In Table 3, we summarize the main characteristics of the two different phases described by the models.

Figs 4 and 5 show the same models in the 2MASS and *WISE* colour–colour diagrams. The reddest colours correspond to the most obscured phase.

5 DISCUSSION AND CONCLUSIONS

Our observations of V381 Lac confirmed its strong photometric variability and showed a simultaneous coherent behaviour from the optical to the near-infrared. A number of deep minima have been recorded in the last 60 years, most notably in 1989 (POSS II) and in 2006 (SDSS). Although the historic light curve is rather undersampled, no clear sign of periodicity in the occurrence of fading episodes can be derived.

The magnitude changes decrease with increasing wavelengths. In the $J-H$ versus $H-K$ diagram, the star moves along the strip of the moderately obscured AGB carbon stars, being redder when fainter. This is a common behaviour among stars showing erratic variability, and obscuration events. Feast et al. (1997) and Feast (1997) report an extensive description of different phenomenologies and several examples of the evolution in this diagram. The path followed by the colours of our star is substantially the same in spite of the limited number of our points in J, H, K filters.

The spectral variations of V381 Lac are strongly correlated with the optical flux, showing a behaviour reminiscent of RCB stars. At maximum, continuum and spectral features are those of a typical N carbon giant. During decline, the photospheric absorptions are progressively diluted by the veiling due to repeated scattering of the light crossing the soot clouds that eclipse the photosphere. Na D and [N II] doublets go in emission, with increasing intensity as stellar luminosity decreases. These lines, formed in the circumstellar envelope, are likely present with constant flux at all times, but are not visible during maxima, overwhelmed by the bright central object. Extensive descriptions and explanations of these phenomena may be found e.g. in Clayton (1996), Kameswara Rao, Lambert & Shetrone (2006) and references therein. Notably, during a phase of minimum luminosity, corresponding to the maximum emission of Na D and [N II] lines, the molecular absorption bands were strong again (see Fig. 3). A similar behaviour is reported by Lloyd-Evans (1997) in the framework of the RCB model *'... as the cloud gradually dissipates the photospheric spectrum returns to normal long before the re-attainment of maximum light'*.

In the 2008 spectrum, H α was clearly present in absorption; the spectrum appears veiled but the photometric phase at that time is unknown.

In the more recent spectra, hydrogen lines have never been observed neither in emission, nor in absorption, while, in similar stars, hydrogen is sometimes observed in emission during dimming. V381 Lac shows a high level of activity, this suggest a high frequency of gas ejection from the central star, which can be responsible for a wide variety of variability between successive events, similarly to what happens e.g. in DY Per (Alksnis et al. 2002).

The 2008 features still remain an open question: only a frequent monitoring with simultaneous photometric and spectroscopic observations can help in clarifying this difficult scenario.

Based on the fit of our theoretical models with the SED, V 381 Lac is a carbon star with an initial mass $\sim 2\,\mathrm{M}_{\odot}$ during the last pulses of the AGB phase. The central object with a luminosity around $8 \times 10^3 \leq L/\mathrm{L}_{\odot} \leq 10^4$ and effective temperature $T_{\mathrm{eff}} \sim 2500$ K, is losing the external envelope with a high rate ($\dot{M} \sim 1.5 \times 10^{-4}\,\mathrm{M}_{\odot}\,\mathrm{yr}^{-1}$) producing a dense carbon-enriched wind. This condition favours the formation of SiC and amorphous carbon in the circumstellar envelope with a grain size of ~0.08 and ~0.18 µm, respectively. The dusty layers enshroud the star, obscuring the stellar radiation in the optical bands. Phases of lower mass-loss rate are followed by a decrease in the dust production and a consequent increase of the optical emission.

We cannot exclude the possible presence of a companion of V381 Lac, capable to trigger strong mass-loss events like in the case of V Hya, where the obscuration phases do not occur with regular timing (Olivier, Whitelock & Marang 2001). We still do not have enough observing material to settle this issue: again, a long-term spectroscopic(at high resolution) and photometric monitoring would be necessary to this purpose.

ACKNOWLEDGEMENTS

This study is based on observations collected with the Cassini Telescope at Loiano station of the INAF-Bologna Astronomical Observatory, and with the Copernico Telescope of the INAF-Padova Astronomical Observatory. We thank the staff of the Asiago and Loiano observatories for the allocated time and excellent support for the observations. This research has made use of the SIMBAD data base, operated at CDS, Strasbourg, France; the 2MASS data base, which is a joint project of the University Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology; the data from the *WISE*, which is a joint project of the University of California, Los Angeles and the Jet Propulsion Laboratory/California Institute of Technology; the NSVS created jointly by the Los Alamos National Laboratory and University of Michigan; the AAVSO International Database contributed by observers worldwide. We finally wish to thank our referee G. Clayton for his valuable suggestions which contributed to improve the quality of the paper.

REFERENCES

Alksnis A., Balklavs A., Dzervitis U., Eglitis I., Paupers O., Pundure I., 2001, Balt. Astron., 10, 1
Alksnis A., Larionov V. M., Larionova L. V., Shenavrin V. I., 2002, Balt. Astron., 11, 487
Barnbaum C., Stone R. P., Keenan P. C., 1996, ApJS, 105, 419
Bessel M. S., Brett J. M., 1988, PASP, 100, 1134
Canuto V. M. C., Mazzitelli I., 1991, ApJ, 370, 295
Clayton G. C., 1996, PASP, 108, 225
Cruz K. L., Reid I. N., Liebert J., Kirkpatrick J. D., Lowrance P. J., 2003, AJ, 126, 2421
Cutri R. M., Wright E. L., Conrow T. et al., 2011, Explanatory Supplement to the WISE Preliminary Data Release. Technical Report, Available at: http://wise2.ipac.caltech.edu/docs/release/prelim/expsup/wise_prelrel_toc.html
Cutri R. M. et al., 2013, CDS Catalog II/328, available at: http://wise2.ipac.caltech.edu/docs/release/allwise/expsup/
D'Alessio F. et al., 2000, in Masanori I., Alan F. M., eds, Proc. SPIE Conf. Ser. Vol. 4008, Optical and IR Telescope Instrumentation and Detectors. SPIE, Bellingham, p. 748
Dahlmark L., 1996, Inf. Bull. Var. Stars, 4329, 1
Dell'Agli F., Ventura P., Schneider R., Di Criscienzo M., Garcia-Hernandez D. A., Rossi C., Brocato E., 2015, MNRAS, 447, 2992
Feast M. W., 1997, MNRAS, 285, 339
Feast M. W., Carter B. S., Roberts G., Marang F., Catchpole R. M., 1997, MNRAS, 285, 317
Feast M. W., Whitelock P. A., Marang F., 2003, MNRAS, 346, 878
Ferrarotti A. D., Gail H. P., 2006, A&A, 553, 576
Gigoyan K. S., Russeil D., 2006, Astrofizika, 49, 91
Gigoyan K. S., Russeil D., Sarkissian A., Sargsyan A. L., 2009, Astrophysics, 52, 451
Hoard D. W., Watcher S., Clark L. L., Bowers T. P., 2002, ApJ, 565, 511
IRAS Catalogs and Atlases vol.1, Explanatory Supplement 1988, in Beichman C., Neugebauer G., Habing H. J., Clegg P. E., Chester T. J., eds, NASA RP-1190, NASA, Washington, D.C.

Ivezic Z., Nenkova M., Elitzur M., 1999, User Manual for DUSTY. Univ. Kentucky Internal report

Kameswara Rao N., Lambert D. L., Shetrone M. D., 2006, MNRAS, 370, 941

Lee C. H., 2015, A&A, 575, A2

Leggett S. K. et al., 2002, ApJ, 564, 452

Lloyd Evans T., 1997, MNRAS, 286, 839

Markarian B. E., Lipovetski V. A., Stepanian J. A., Erastova L. K., Shapovalova A. I., 1989, Commun. Spec. Astrophys. Obs., 62, 5

Mauron N., 2008, A&A, 482, 151

Mauron N., Gigoyan K., Berlioz-Arthaud P., Klotz A., 2014, A&A, 562, A24

Mickaelian A. M. et al., 2007, A&A, 464, 1177

Miller A. A., Richards J. W., Bloom J. S., Cenko S. B., Silverman J. M., Starr D. L., Stassun K. G., 2012, ApJ, 755, 98

Moshir M. et al., 1990, IRAS Faint Source Catalogue, Vizier on line data at CDS catalogue II/156

Murakami H. et al., 2007, PASJ, 59, 369

Nanni A., Bressan A., Marigo P., Girardi L., 2013, MNRAS, 434, 2390

Nesci R., Gaudenzi S., Rossi C., Pezzotti C., Gigoyan K., Mauron N., 2014, in Mišková L., Vítek S., eds, Proc. Astroplate 2014. Inst. Chem. Technol., Prague, p. 91

Nikutta R., Hunt-Walker N., Nenkova M., Ivezić Ž., Elitzur M., 2014, MNRAS, 442, 3361

Olivier E. A., Whitelock P., Marang F., 2001, MNRAS, 326, 490

Skrutskie M. F. et al., 2006, AJ, 131, 1163

Tanabe T. et al., 2009, PASJ, 60, S375

Tisserand P., 2012, A&A, 539, A51

Tisserand P., Clayton G. C., Pilecki B., 2013, A&A, 551, A77

van der Veen W. E. C. J., Habing H. J., 1988, A&A, 194, 125

Ventura P., D'Antona F., 2009, MNRAS, 499, 835

Ventura P., Marigo P., 2009, MNRAS, 399, L54

Ventura P., Marigo P., 2010, MNRAS, 408, 2476

Ventura P., Dell'Agli F., Schneider R., Di Criscienzo M., Rossi C., La Franca F., Gallerani S., Valiante R., 2014, MNRAS, 439, 977

Wachter A., Winters J. M., Schröder K. P., Sedlmayr E., 2008, A&A, 486, 497

Whitelock P., Feast M. W., Marang F., 2006, MNRAS, 369, 75

Wozniak P. R. et al., 2004, AJ, 127, 2436 [On-line Data available at: http://skydot.lanl.gov/nsvs/nsvs.php]

This paper has been typeset from a TEX/LATEX file prepared by the author.