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THE VARIABLE CARBON STAR CGCS 6107

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Abstract

The spectroscopic and photometric variability of CGCS 6107 has been studied with four telescopes from 2015 to 2018. The star varied between R=11.4 and 14.2 mag with a time scale of ∼500 days. An appreciable color variation was observed, the star being bluer when brighter. Hα emission was present around maxima. The spectrum is that of an N type giant veiled by a variable dusty envelope.

1 Introduction

Carbon stars on the Asymptotic Giant Branch (AGB) are supposed to be in the last phase of stellar evolution after the Third Dredge-Up and before the ejection of the planetary nebula. Given their evolutionary status they are expected to be variable.

Out of the 6891 stars listed in the Catalog of Galactic Carbon Stars (CGCS, Alksnis et al. 2001), 851 are reported as variables in the General Catalog of Variable stars (GCVS, Samus et al. 2017, CDS B/gcvs): 385 of them have also a period or variability time-scale reported, but only 150 are classified as Miras. The VSX catalog (Watson et al. 2016), updated more frequently, reports much more (1985) variables among the CGCS stars, 957 of them with a quoted period, but only 270 are classified as Miras or likely Miras: it appears therefore that only a minority of the AGB carbon stars are Mira variables.

Automatic surveys with robotic telescopes, dedicated to the detection of transient sources (Supernovae, Gamma Ray Bursts, Near Earth Asteroids, etc.) in large sky areas, contain large amounts of data which can significantly improve our knowledge in this topic: given that this is not the main goal of the science teams operating these telescopes, these large databases are still partially unexplored from this aspect.

We report here the results of our recent study on the variability of the carbon star CGCS 6107, to stimulate the curiosity for strongly variable sources and prompt similar researches in the available databases.

2 CGCS 6107

The star (05:49:32.31 +46:35:57.9, J2000) is a very bright infrared source detected by IRAS, at low galactic latitude in the Auriga constellation ($b = 9.68°$). Its IRAS-LRS spectrum is classified F (Kwok et al. 1997) suggestive of a late spectral type M or C with small amount of circumstellar dust.

It was spectroscopically observed in the optical by Cohen et al. (1996) and classified as C-,4, with a significant Hα emission. It is listed in the CGCS but without any indication of variability. It is not covered by the Sloan DR14[1].

The star is present in the main infrared catalogs: 2MASS (Cutri et al., 2003), WISE, (Cutri et al. 2013), and AKARI (Ishihara et al. 2010). The 2MASS $J-H$;$H-K$ colors of the star are $J-H = 2.10$, $H-K = 1.67$ mag, so it is located well inside the region of the moderately obscured carbon stars, even when small color changes are taken into account, but is not included in the catalog of Infrared Carbon Stars by Chen and Yang (2012).

Only in 2015 the star was pointed out as variable by the Japanese amateur astronomer Shigehisa Fujikawa (2015): spectra taken 3 days after discovery by Munari (2015) with the 122 cm telescope of the Asiago (Pennar) Observatory showed a carbon star spectrum and confirmed the presence of Hα emission.

At the time of writing, the star is listed as variable in the VSX catalog but the variability amplitude is simply given by an upper limit.

3 Photometric observations and calibrations

Soon after Fujikawa's announcement, we started a photometric monitoring of CGCS 6107 with 3 telescopes: the 152 cm of Loiano (Bologna Observatory), the 37 cm of Frasso Sabino (IAU 157) and the 30 cm of Foligno Observatory (IAU K56). The Loiano and Frasso Sabino telescopes were equipped with CCD cameras and Bessell $BVRI$ filters; the Foligno telescope was equipped with a commercial digital camera (DSLR, Nikon D90 up to 2018 and red extended Canon 550D camera afterwards). Loiano and Frasso Sabino provided good quality photometry in a few nights, Foligno allowed a denser monitoring with lower accuracy.

Twenty stars included in the field of view of all the involved telescopes were selected from the UCAC4 catalog to define a comparison sequence, and are listed in Table 1. Aperture photometry was performed using IRAF/apphot[2] with radius equal to the average FWHM of each image.

The UCAC4 catalog gives magnitudes in the $r_{\rm Sloan}$ and $i_{\rm Sloan}$ bands, which are somewhat different from the Bessell's ones, and our star is quite red ($R-I \sim 2$), therefore a systematic color term is expected: however there were no stars of comparable colors in the field of view so that we could not compute reliable corrections. We feel this is not critical for the aim of this paper, devoted just to the study of the light curve and of possible color changes of the star, and not to a comparison with theoretical stellar atmosphere models. A linear fit between instrumental and catalog magnitudes provided the calibration curve to evaluate the magnitude of the variable. The slope of the line was always very close to 1.0, as expected for an ideal linear detector. The rms deviation of the comparison stars magnitudes with respect to the fitting line was adopted as true photometric uncertainty of the variable star magnitude. Given the non-standard color separation provided by the

[1] http://www.sdss.org/dr14/
[2] IRAF is distributed by the NOAO, which is operated by AURA, under contract with NSF.

Table 1: Comparison sequence for CGCS 6107.

RAJ2000	DJ2000	V	r_{Sloan}	i_{Sloan}
87.2972	+46.6587	15.011	14.675	14.325
87.3021	+46.5742	16.480	16.065	15.824
87.3159	+46.6300	14.974	14.666	14.386
87.3199	+46.6041	15.571	15.251	14.995
87.3203	+46.5450	14.776	14.306	13.855
87.3346	+46.6278	16.649	16.092	15.913
87.3428	+46.6124	16.144	16.008	15.855
87.3438	+46.6657	14.768	14.239	13.719
87.3502	+46.5741	14.503	14.205	13.931
87.3587	+46.6625	14.290	14.061	13.807
87.3587	+46.5612	15.088	14.811	14.559
87.3836	+46.5586	14.607	14.347	14.060
87.3851	+46.6097	15.209	14.835	14.455
87.3912	+46.6528	14.204	13.992	13.804
87.3993	+46.6128	14.210	13.943	13.652
87.4040	+46.6005	15.809	15.401	15.077
87.4108	+46.6139	15.749	15.439	15.092
87.4122	+46.6229	15.739	15.459	15.180
87.4423	+46.5407	15.542	15.031	14.431
87.4811	+46.6385	15.392	14.713	14.036

DSLR cameras of Foligno, we performed a few nearly simultaneous observations with the Frasso Sabino telescope to establish proper systematic corrections for the V and R bands.

The V and r_{Sloan} magnitudes of our star were always inside, or shortly outside, the range of the comparison stars, while the i_{Sloan} magnitudes were always well outside the range, so these values are extrapolated and less reliable.

4 Light curve

Our photometric data in the V and r_{Sloan} bands are reported in Table 2: column 1 is JD−2,400,000, columns 2, 3, 4 and 5 are magnitudes with their errors, column 6 is the instrument used, coded as follows (FR= Frasso Sabino; EK= Cima Ekar; LO= Loiano; NI= Foligno with Nikon D90; CA= Foligno with Canon 550D). Magnitudes fainter than $V \sim 16$ could not be measured with the 30cm telescope.

A light curve of our star starting from 2014-01-19 can be recovered from the ASAS-SN database (Shappee et al. (2014); Kochanek et al. (2017)[3], which became public only in 2018. These data are taken with an unfiltered FLI CCD camera and tied to Johnson's V-band using the APASS 9 catalog. Below $V \sim 16$, these V magnitudes have uncertainties of several tenths, due to the short exposure times used by the survey.

Fig. 1 reports the ASAS-SN light curve (stars) and our r_{Sloan} light curve (squares) on a common magnitude scale, showing a very good agreement of the overall shape in the common time interval. The source is characterised by very large variations (> 2.5 mag), with a time scale (peak to peak distance) of about 500 days: the variation amplitude is not

[3] `https://asas-sn.osu.edu`

Table 2: Observed magnitudes of CGCS 6107 (all telescopes).

JD	V	err_V	r	err_r	tel
57332	13.54	0.02	11.30	0.02	FR
57367	13.98	0.06	11.70	0.10	NI
57402	14.12	0.06	11.60	0.04	LO
57439	14.56	0.05	12.40	0.20	NI
57449	14.69	0.08	12.50	0.10	NI
57473	15.04	0.06	12.67	0.10	NI
57482	15.12	0.08	12.98	0.10	NI
57492	15.18	0.08	12.80	0.10	NI
57498	15.40	0.10	13.20	0.10	NI
57503	15.40	0.05	13.10	0.10	NI
57507	15.51	0.12	13.20	0.10	NI
57694	15.44	0.04	13.24	0.10	NI
57708	15.35	0.08	13.15	0.10	NI
57735	15.04	0.07	12.85	0.10	NI
57741	15.00	0.07	12.80	0.10	NI
57768	14.89	0.06	12.70	0.05	NI
57774	14.79	0.04	12.67	0.06	NI
57796	14.73	0.04	12.62	0.10	NI
57799	14.73	0.03	12.81	0.09	NI
57799	14.78	0.04	12.40	0.06	LO
57814	14.75	0.04	12.68	0.05	NI
57829	14.70	0.04	12.59	0.08	NI
57840	14.75	0.02	12.47	0.02	FO
57857	14.63	0.06	12.51	0.10	NI
57879	14.70	0.10	12.71	0.07	NI
58085	——	——	14.21	0.07	NI
58093	——	——	14.22	0.10	NI
58106	——	——	14.03	0.10	NI
58109	17.05	0.15	14.03	0.04	FR
58120	——	——	13.90	0.10	NI
58139	——	——	13.70	0.10	NI
58141	16.57	0.03	13.70	0.03	FR
58153	——	——	13.48	0.08	NI
58159	16.32	0.02	13.50	0.03	FR
58164	——	——	13.41	0.09	CA
58186	——	——	13.38	0.09	CA
58200	——	——	13.26	0.08	CA
58202	——	——	13.17	0.07	CA
58212	15.90	0.10	13.19	0.06	CA
58215	15.89	0.04	13.18	0.02	FR
58224	15.70	0.10	13.01	0.06	CA
58229	15.75	0.03	12.86	0.04	LO
58232	15.70	0.10	12.86	0.07	CA

constant, suggesting a classification of Semi Regular rather than of Mira type variability. As mentioned in the Introduction, only a small fraction of the AGB carbon stars shows a regular Mira type light curve, so our finding is not unusual. Similar large amplitude variations, superimposed on longer term trends in the light curve, have been reported also for other carbon stars with strong infrared excess recently studied by our group (see e.g. Gaudenzi et al. 2017; Nesci et al. 2018).

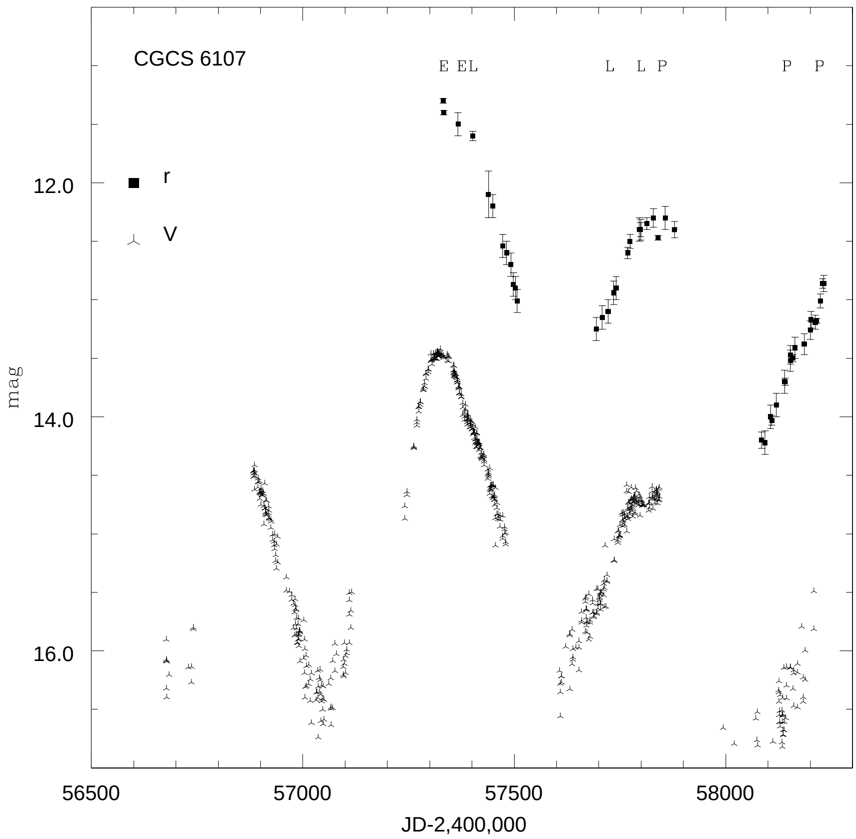

Figure 1. The light curve of CGCS 6107 from our observations in the r band, (squares with error bars) and the ASAS-SN light curve in the V band (stars). Vertical scale in magnitudes. The letters in the upper side mark the dates of the spectroscopic observations listed in Table 5: E=Ekar, L=Loiano, P=Pennar.

An FFT analysis with Period04 (Lenz and Breger 2005) of the ASAS-SN light curve shows a main peak at 543 days, blended with its (fainter) alias at 1083 days; a further peak at 201 days has a low power and is of limited importance in the light curve fit. The period of 543 days is fully compatible with our dataset.

Despite that the star is a semiregular rather than a Mira, we show in Fig. 2 the optical light curve folded with the formal 543 days period. The substantial scatter around phase 0 is mainly due to the variable amplitude of the light curve, as apparent from Fig. 1.

Color indices $(V-r)$ and $(r-i)$ of the star were measured at different flux levels and are collected in Table 3: the star appears markedly redder when fainter.

We have also measured the star magnitudes on historic plates of the DSS, recoverable

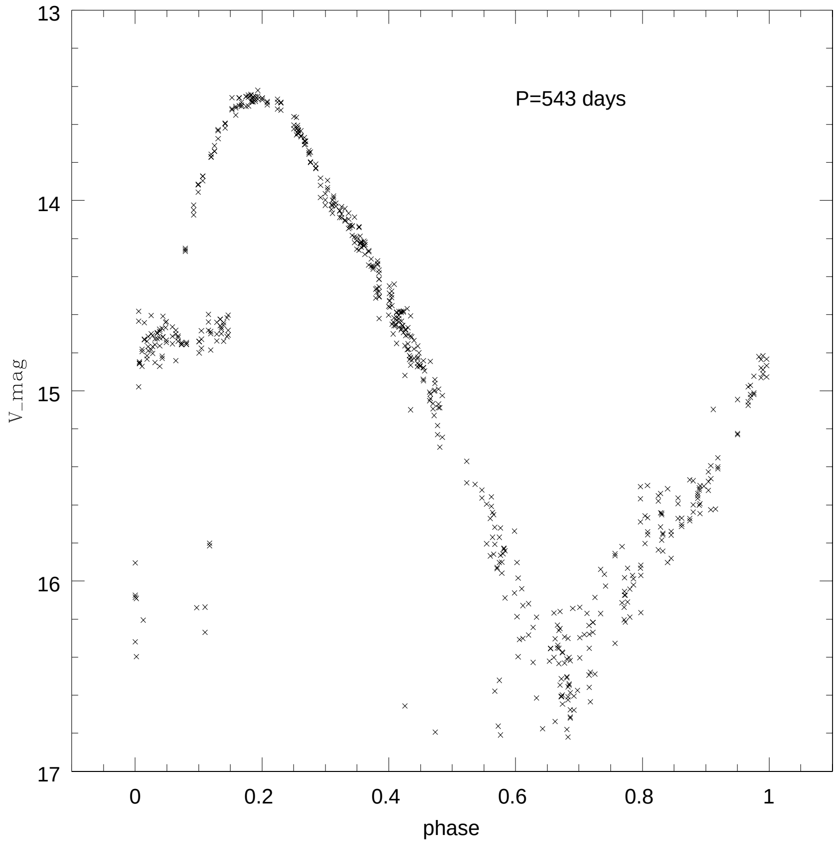

Figure 2. Phased optical light curve of CGCS 6107 from ASAS-SN data folded with the 543 day period.

Table 3: Color indices of CGCS 6107.

Telescope	date	$r_{\rm Sloan}$	$V - r_{\rm Sloan}$	$r - i_{\rm Sloan}$
Frasso Sabino	2015-11-06	11.30	2.24	1.89
Loiano	2016-01-15	11.61	2.50	1.95
Loiano	2016-11-29	12.89	2.60	2.01
Loiano	2017-02-14	12.40	2.38	—-
Frasso Sabino	2017-03-27	12.47	2.28	2.10
Frasso Sabino	2017-12-22	14.04	3.14	2.44
Frasso Sabino	2018-01-23	13.70	2.86	2.37
Frasso Sabino	2018-02-10	13.50	2.82	2.31
Frasso Sabino	2018-04-06	13.18	2.71	2.24
Loiano	2018-04-20	12.86	2.89	2.05

Table 4: Observed magnitudes of CGCS 6107 (all telescopes).

Emulsion	band	date	mag
103a-E	r	1952-12-21	12.6
QuickV	V	1983-01-14	16.4
IIIaF	r	1989-10-05	16.4
IIIaF	r	1989-10-29	16.2
IV-N	i	1996-11-03	12.2
IV-N	i	1999-10-13	12.3

from the Space Telescope Science Institute, using our comparison sequence. The calibration curve was markedly non linear, so we could not measure the B magnitude with our UCAC4 sequence because well outside the range. The results for the V, r_{Sloan}, i_{Sloan} filters are collected in Table 4 and confirm the variability of the star in the past.

In the infrared the star was observed for 3 years (from 1990-02-09 to 1993-04-15) with weekly sampling by the DIRBE instrument (Smith et al. 2004; Price et al. 2010) on board the COBE satellite, in the 3.6 μm and 4.9 μm bands. The star was not classified as variable in the DIRBE catalog (Price et al. 2010) according to the strict criteria adopted, but an eye inspection of the data suggested a possible variability. B.J. Smith kindly confirmed to us that no contamination by nearby sources was present for this star, so we made an independent analysis of the published data and we built the light curves at 3.5 and 4.9 μm applying a running mean of 5 consecutive measures: the result is shown in Fig. 3.

A peak-to-peak amplitude of about 1.3 mag is evident, with a time scale of about 500 days, similar to the optical one. The amplitude is similar to that measured for the 'bona fide' variables of similar periods in the Price et al. (2010) catalog.

A deeper analysis of the IR light curves in each band and of the averaged (3.5 and 4.9 μm) fluxes with the FFT technique shows several peaks in the power spectrum with comparable intensities and significantly different phases: for the averaged curve the peaks are around 558, 254, 133, 105, and 76 days (see Fig.4). The presence of so many peaks with similar power suggests a rather noisy pattern in the light curve: actually a single period is quite inadequate to reproduce its overall shape. The actual variability range and time scale are therefore ill-defined from these data. We recall that CGCS 6107 is near the detection limit of the DIRBE instrument, and some details of the light curve might be of instrumental origin. In the spectral energy distribution, the average DIRBE fluxes fit well between the 2MASS (1.25, 1.65, and 2.2 μm) and the AKARI (9 and 18 μm) values.

5 Spectroscopic observations

Spectra of the star were taken at different dates with the Asiago (Cima Ekar 182 cm and Pennar 122 cm) and the Loiano 152 cm Observatories, with luminosity levels ranging from r = 11.4 to 13.7 mag; data reduction was performed with the standard IRAF procedures. The observations log is given in Table 5: column 1 is the telescope, column 2 the date, column 3 the spectral resolution in Å, column 4 the r magnitude at the time of observation, column 5 the Hα equivalent width in Å. These last values are strongly affected by the

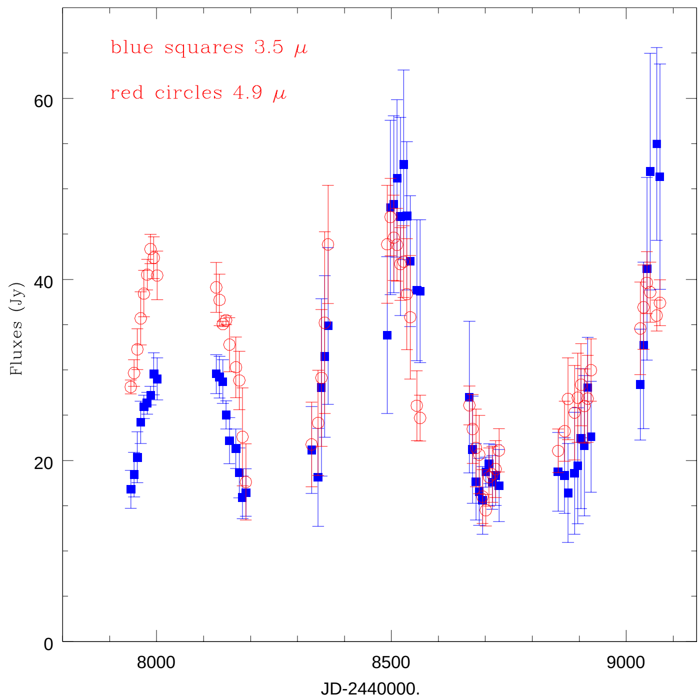

Figure 3. The light curve of CGCS 6107 at 3.5 and 4.9 μm from the DIRBE data after a 5-point running mean. Error bars are the rms deviation form the mean of the averaged points. We remark that these errors are quite large and of very different size in different years. The 4.9 μm data seem of better quality.

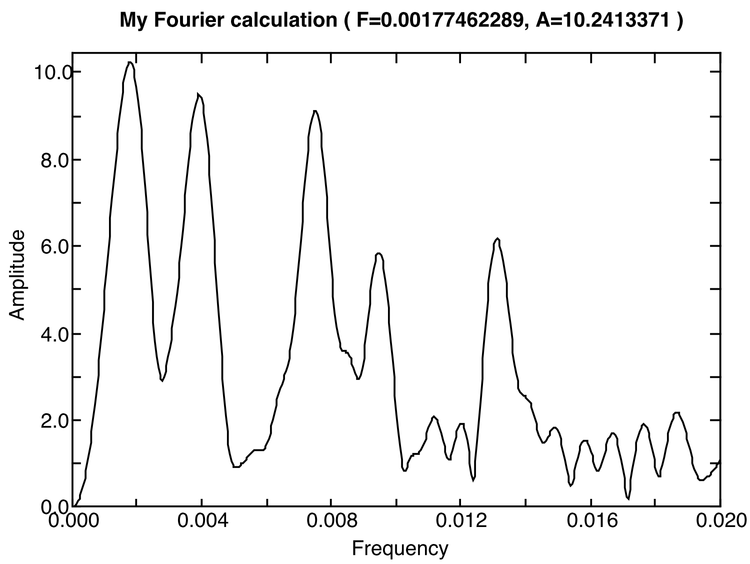

Figure 4. The power spectrum of CGCS 6107 from the DIRBE data: it is evident that several frequencies of similar power are present, indicating a complex structure.

variability of the continuum and typical errors are about 0.3 Å. In the last row we report the data relative to the observation by Cohen et al. (1996) taken with the 100 cm Lick reflector. This spectrum was taken in December 1987 and showed Hα in emission: from the published plot we derived an approximate equivalent width of 7 Å, comparable to our measures.

The dates of our spectroscopic observations are also marked in the bottom of Fig. 1 to better put them in the context of the stellar light-curve.

Characteristic spectra at different epochs are reported in Fig. 5. All the spectra are typical of an N type giant, moderately obscured by dust in the circumstellar envelope, with the blue region strongly underexposed.

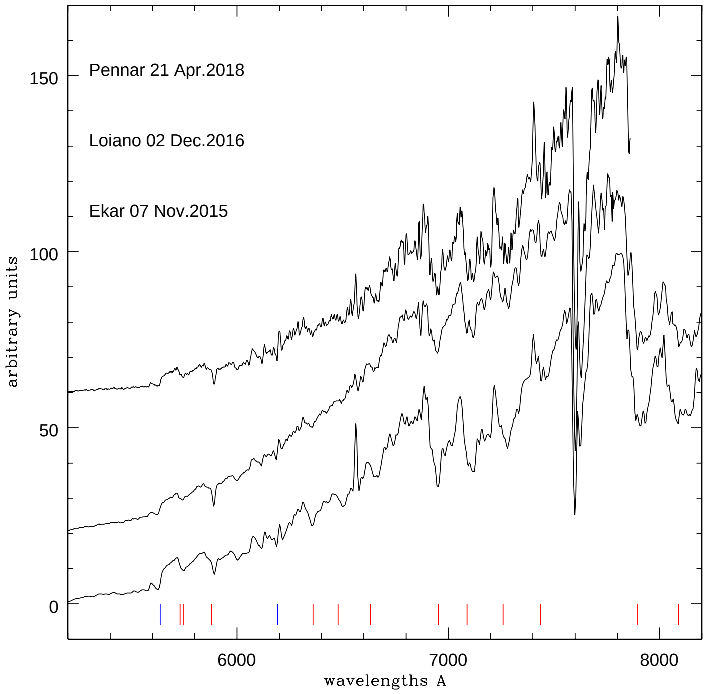

Figure 5. Optical spectra of CGCS 6107 at different dates and luminosities. The y axis represents relative intensities corrected for the atmospheric extinction. The spectra are normalised at 7800 Å. The main molecular bandheads are color-coded: blue = C_2; red = CN. The telluric bands of O_2 and H_2O molecules, overlapped to the CN red system, have not been removed. The spectra are vertically shifted to each other for ease of comparison. From bottom to top: 2015-11-07 (r∼11.4), 2016-12-02 (r∼12.8), 2018-04-21 (r∼13.0).

Red-ward of 5000 Å the molecular absorption bands of C_2 (Swan) and the red system of CN can be easily identified[4]. The 6260 Å of the $C_{13}N_{14}$ is clearly visible in the bright states; the two absorptions of atomic lines of K at 7665, 7699 Å are always visible. The 5889-5895 Å NaD absorption is possibly produced in the circumstellar envelope. The Balmer Hα emission line is also recorded with different intensities in different epochs.

Spectral changes are correlated with the optical flux: the continuum and the strength of Hα and of the absorption bands are always affected by the veiling effect, mainly during

[4]most notably $\lambda\lambda$ 5636, 6122 and 6192 Å of C_2; 5730, 5746, 5878, 6013, 6206, 6360, 6478, 6631, 6925, 7088, 7259, 7437, 7876-7945 and 8150 Å of CN.

Table 5: Spectroscopic observations logbook.

Telescope	date	res. (Å)	r	Hα (Å)
Cima Ekar	2015-11-07	8.0	11.4	−8.3
Cima Ekar	2015-11-15	8.0	11.7	−7.9
Cima Ekar	2015-12-20	8.0	11.7	−7.8
Loiano	2016-01-15	10.0	11.6	−7.2
Loiano	2016-12-02	10.0	12.8	——
Loiano	2017-02-14	10.0	12.4	−4.8
Pennar	2017-04-06	6.9	12.5	−5.6
Pennar	2018-01-27	6.9	13.7	——
Pennar	2018-04-13	6.9	13.0	−5.7
Pennar	2018-04-21	6.9	13.0	−5.9
Lick	1987-12-XX	11	V=17.3:	−7

faint photometric phases. Hα emission was present at the end of 2015, the beginning of our monitoring, when the star was in bright state; it was not present one year later, during a faint state; again the emission was present near the next maximum, disappeared again when faint and rose again during the more recent brightening. In the fainter states (December 2016 and January 2018) the depth of the molecular absorption bands was also reduced, while the equivalent width of the NaD lines in absorption did not vary significantly.

6 Conclusions

We have found that the variability of the carbon star CGCS 6107 is compatible with a quasi regular periodicity on a time scale of about 543 days; the star may be classified as a SR variable because its average magnitude in each cycle is not constant. Historic observations from DSS plates also show large variability.

A definite change of the color indices $(V - r)$ and $(r - i)$ was detected, with the source being bluer when brighter. The Hα line was in emission during maxima while disappeared in the fainter parts of the light curve: this is not unusual among AGB carbon stars. Overall the photometric and spectroscopic properties are similar to those of other variable carbon stars also studied by our group, like BIS 036 (HP Cam) or BIS 184 (Gaudenzi et al. 2017).

The absolute K magnitude of CGCS 6107 may be estimated from the relation (Whitelock et al. 2012):

$$M(K) = -3.69 \times (\log P - 2.38) - 7.18(\pm 0.37)$$

which yields $M(K) = -8.35$: this gives an estimated distance of 4.9 kpc, with a probable range 5.8-4.2 kpc. The total galactic absorption in the K band in the direction of the star is 0.13, much less than the uncertainty on the actual average K magnitude of the star, given its variability.

The Gaia DR2 catalog (Gaia collaboration 2018), just published when we were finishing this paper, gives a parallax of 0.270 (±0.104) mas, corresponding to a distance of 3.7 (−1.0; +2.1) kpc, in fair agreement with our estimate.

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