CT Lacertae: Another Long-period Carbon Star with Long-Timescale Variations?

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Received August 11, 2014; revised September 9, 2014; accepted September 9, 2014

Abstract The poorly-studied semiregular-type variable CT Lacertae is a long-period variable of the carbon spectral type, and is also a member of the LPV subclass that exhibits double maxima. More importantly, CT Lac is also undergoing a long-timescale dimming episode spanning the last few thousand days. Analysis of the AAVSO's 45-year visual light curve shows no clear changes in period during the course of its observational history, but current and past changes in mean light and amplitude suggest long-term, observable changes occur in the star itself or in its circumstellar environment. Long-term data are currently too short and sparse to say whether dimming episodes are cyclical as they are in some other long-period carbon Miras and semiregulars, but the ongoing dimming episode could be related to similar events which do recur in other long-period carbon stars like RU Vir and V Hya. CT Lac is an interesting variable and is recommended as a long-term target for both visual and instrumental observation. Increased visual observation is strongly encouraged, as are multicolor photometry and high resolution spectroscopy.

1. Introduction

Asymptotic giant branch (AGB) stars with very long periods (> 550 days) are uncommon; the period distribution of observed Mira variables peaks around 300 days, with a very sharp drop off above 450 days. The reason for this drop off could be a selection effect but is also partly due to their true scarcity. Theoretical studies of AGB stars by Willson and collaborators (Willson 2000) showed that mass loss rates of AGB stars should be maximal when they reach maximum luminosity, after which their mass loss rates become so high that they become optically obscured and undetectable. As an example, S Cas has a period of 612 days and a mass loss rate of 10^{-5} $M_{\odot}$ per year, close to the upper limit for an optically-visible Mira star. Maximum evolutionary luminosity for a Mira star also correlates with the maximum period, and this suggests there is a point beyond which long-period Miras become scarce because obscuration by lost mass overwhelms the optical luminosity, perhaps leaving them as pulsating IR sources (e.g. QX Pup). We selected CT Lac for further study because of its long period as part of a larger study of AGB evolution and behavior focusing on Mira and semiregular variables with long periods, double maxima, and/or period changes.

CT Lac (R.A. 22^{h} 06^{m} 39.93^{s}, Dec. +48° 27' 06.9" (J2000)) was discovered by Morgenroth (1936) and noted as an "irregular" variable. Subsequent spectral surveys showed the star to be a carbon star of late spectral type (Stephenson 1973) while variability surveys found it to be a pulsator with a long period of 562 days. Alksnis (1981) noted the presence of double maxima along with a highly variable light curve from cycle to cycle. The star was observed by Hipparcos and the optical variability is very clear. Price *et al.* (2010) analyzed the COBE/DIRBE near-IR photometry and found no significant variability, but the photometry for this star had low signal-to-noise; the variability is weakly present in period-folded 4.9-µm data, but is very noisy. There has been little work on variability in CT Lac beyond these papers. CT Lac is instead much better known and studied as a bright carbon star, having late R- or N- spectral type with substantial carbon dust absorption and mass loss (Knapp *et al.* 2001).

CT Lacertae has not been historically well-observed by AAVSO observers, but what data exist are very interesting (AAVSO 2014). Notably, the star was followed for several thousand days by the late observer Wayne Lowder (AAVSO observer initials LX), from the late 1960s to the early 1980s, and the star was listed in the *AAVSO Circular* in the 1970s for a time; CT Lac was originally considered to be a potential R CrB variable. Coverage subsequently declined, but the star was picked up again in the late 1990s by Peter Maurer (MPR) and later by Wolfgang Kriebel (KWO). In addition to visual observations, CT Lac is now also a target for a few CCD imagers as well. The full light curve including both visual data and V-band and tri-color green (TG) instrumental data is shown in Figure 1; identification of AAVSO observers and information about the observations is shown in Table 1. All data are freely available from the AAVSO website at http://www.aavso.org/data-download.

2. Time-series analysis

Though sparse, the AAVSO data clearly show the cycle-to-cycle variability, and its overall behavior places CT Lac in the semiregular category. To quantify the variability, we analyzed the unaveraged visual data from 1968 to late 2008, omitting subsequent data that show the significant drop in mean magnitude. Early data also show some decline in maximum magnitude—from $m_{vis} = 9.5$ to 10.5—but less substantially than the decline from 2008 to 2014. We used an

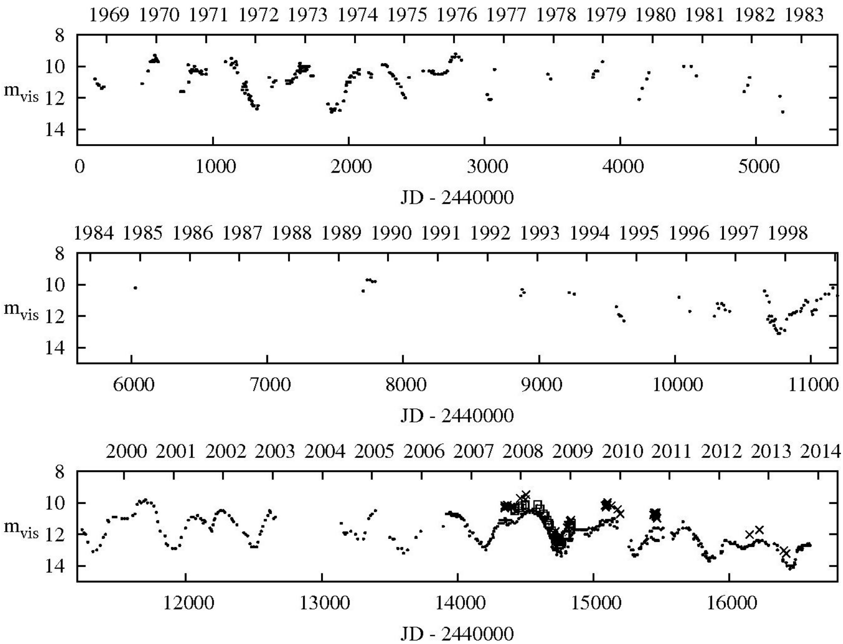

Figure 1. AAVSO light curve for CT Lac, 1968 to mid-2014: filled circles, visual data; open squares, tri-color green data; crosses, V-band data. The star has been well-observed visually for the past 15 years. This period has been characterized by a fading of the star's mean brightness by about two magnitudes.

Table 1. Observers of CT Lac through 2014 August 1.

Observer (AAVSO Obs. code)	*Obs. band*	*Min(MJD)*	*Max(MJD)*	*No. of Obs.*
Maurer (MPR)	Visual	50685	56871	281
Kriebel (KWO)	Visual	53939	56870	194
Lowder (LX)	Visual	40134	46029	164
Morelle (MEV)	Tricolor G	54420	54841	47
O'Connor (OCN)	Visual	43467	51044	41
Arminski (AAM)	Johnson V	54348	55470	38
Bichon (BIC)	Visual	53145	54089	28
Bortle (BRJ)	Visual	41643	42167	14
Sharpe (SHS)	Visual	54413	54765	5
Holmberg (HGUA)	Johnson V	56151	56420	4
Ford (FD)	Visual	40820	40951	2
Bueno (BUO)	Visual	42149	—	1

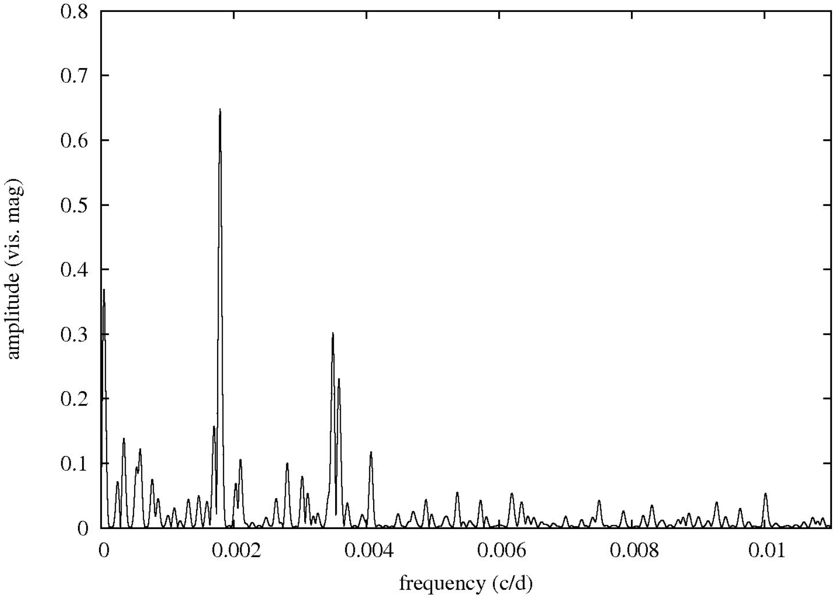

Figure 2. Fourier transform of CT Lac visual data 1968 to 2008 for the low frequency portion of the tested frequency range; frequencies above 0.005 c/d do not show any statistically significant signals and so we only show frequencies up to 0.01 c/d (P = 100 days). A list of signficant peaks is given in Table 2. The peak with amplitude > 0.35 magnitude near zero frequency is an artifact of the change in mean light early in the light curve, which typically causes low-frequency power. The frequency of that peak yields a period longer than the span of the data, and is not periodic.

Table 2. Significant peaks in the Fourier amplitude spectrum of CT Lac, 1968–2008.

Frequency $\times 10^{-3}$ *c/d*	*Amplitude Visual mag.*	*Phase rad.*	*ID*
1.7915(7)	0.65(13)	–0.16(3)	f_0
3.492(1)	0.30(13)	–2.61(7)	f_1
3.583(2)	0.23(13)	+0.86(9)	$2f_0$
1.701(3)	0.16(13)	+2.95(13)	f_2
4.067(4)	0.12(13)	+2.55(17)	f_3

Note: *Uncertainties were calculated using the formulae of Lenz and Breger (2005) for the ideal case, and assuming mean photometric uncertainties of 0.2 magnitude. Phases are relative to the temporal center of the data, JD 2447466.5.*

iterative, discrete Fourier transform code that uses the method of Roberts *et al.* (1987) to compute the Fourier spectrum for frequencies between 0 and 0.05 c/d. We show the Fourier spectrum in Figure 2, and provide a table of significant frequencies in Table 2.

We find the dominant frequency during the 40 year span to be $f_0 = 0.0017915$ c/d, corresponding to a period of 558.2 days, slightly different from the current VSX (Watson *et al.* 2014) value of 562 days. We also clearly detect the first Fourier harmonic of the dominant signal (twice the main frequency) at $2f_0 = 0.003583$ c/d (P=279.1 days). Along with this, we also detect a second peak at slightly lower frequency than the second harmonic, $f_1 = 0.003492$ c/d (P=286.3 days). This peak is clearly resolved and separate from the $2f_0$ component, and so it is almost certainly a real feature. There is a weak peak adjacent to f_0, having frequency $f_2 = 0.001701$ c/d, and the sum of this frequency and the f_0 yields f_1 exactly. Finally, we note another peak with frequency $f_3 = 0.0040670$ c/d, with very marginal statistical signifigance. We do not see statistically significant peaks at higher Fourier harmonics of the dominant frequency f_0 beyond $2f_0$.

The two frequencies f_0 and $2f_0$ are responsible for the main pulsation at 558.2 days, and appear to be stable to within the uncertainties of the data. What is interesting is the presence of f_1 and f_2. The f_1 peak has substantial amplitude, exceeding that of $2f_0$, and is capable of perturbing the light curve. It should create a beat pattern with the $2f_0$ peak, and may be responsible for (or be a manifestation of) the cycle-to-cycle variability. Its origin isn't clear, but the fact that its frequency is the sum of f_0 and f_2 suggests one of two things: that it may be a distinct pulsation mode (e.g. a radial overtone) at a frequency very close to twice that of f_0, or that the variability mechanism responsible for producing f_0 is being modulated in some way that is producing sidelobes. As an example, there are a number of stars (including RV Tauri stars and Type II Cepheids) that show some evidence of "period-doubling" and that could be happening here. Further discussion is beyond the scope of this paper especially given the relatively short span of data, but future analysis of a longer light curve may provide some interesting insight into the cause of such variations.

3. Recent and past behavior: cyclical or not?

As Figure 1 shows, CT Lac is currently undergoing a long-term dimming event that started in the late 2000s. It isn't clear whether the star is in the middle of a cyclical change and will return to its previous mean magnitude within the next decade, or whether some longer-term and more exceptional event is happening. The current change in mean magnitude appears to coincide also with a strong reduction in amplitude; the most recent pulsation cycle (from early 2012 to mid-2013) has a flat-topped shape that only weakly recovered from the preceeding minimum light. The cause of this fading isn't known, but dimming by dust is a likely explanation.

Beyond its being a long-period pulsator, what made CT Lac notable enough for deeper study was this fading behavior. There are other cases of long-period, semiregular and Mira stars of the carbon sub-type that show fading events, with RU Vir and V Hya being two prominent examples. Lloyd-Evans (1997) noted that at least two prominent carbon stars—V Hya (SRa, P = 530d) and R Lep (M, P = 445d)—show modulations in optical emission from C_2 molecules (carbon dust) that are anticorrelated to the optical brightness; the Swan C_2 bands are bright when the star is optically faint. Like those stars, CT Lac is also a carbon star, with some ambiguity as to whether it is of the R- or N-subtype (Eglitis *et al.* 2003 (EEB); Zamora *et al.* 2009). In either case, it is of late type, and C_2 was strongly present in the optical spectrum at the time of the EEB study. What is not known is the variability of the Swan bands, either during individual pulsation cycles or over long periods of time. A contemporary spectroscopic observation and re-measurement of the Swan bands observed by EEB may provide a useful comparison of the C_2 brightness circa 2003 versus now. Such a measurement might make clear whether the current dimming episode is quantitatively similar to those seen in other pulsating carbon stars with long-period supercycles.

Barring further spectroscopy, the most important observational study should be the continued (and increased) observation of CT Lac during the next several years to two decades. The dimming apparent in the light curve from the late 1960s to early 1980s gives a hint that there may be something cyclical in CT Lac's behavior, but current data archives are simply too sparse to make a definitive statement. Past data may be available from plate archives, and we plan to check Harvard plate data once the DASCH (Grindlay *et al.* 2009) public archive includes the Lacerta region. Future observations by both visual observers and instrumental observers will also be required. Visual observers have provided the majority of the existing time-series to date, and these data are fully capable of tracking these long-term variations simply, efficiently, and accurately. Instrumental data would provide additional useful information, especially if Johnson B and V data were taken and properly transformed so that both the overall V-band brightness and the (B−V) color could be accurately tracked with time.

4. Acknowledgements

MT thanks all of the AAVSO observers for providing the observational data that made this study possible. He would also like to point out important contributions to this field by two individuals who have passed on: Wayne Lowder and, very recently, Tom Lloyd-Evans. First, this work would not have been possible at all if Wayne Lowder had not begun observations in the 1960s, and this star is just one among many whose observational histories in the AAVSO archives began with his work. Second, the 1997 paper on carbon star spectra that was cited here is one example among many where Tom Lloyd-Evans helped expand our understanding of variable stars. He respectfully dedicates this paper to both of their memories.

This research has made use of the International Variable Star Index (VSX) database, operated at AAVSO, Cambridge, Massachusetts, USA, and the SIMBAD database and VizieR catalogue access tool, both operated at CDS, Strasbourg, France.

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