BAV Journal

2023 No. 83 ISSN 2366-6706

Bundesdeutsche Arbeitsgemeinschaft für Veränderliche Sterne e.V.

http://bav-astro.de

The peculiar light curve of S CrB 2022-2023

Matthias Kolb

Wuppertal, Germany

email: mako1997a@gmail.com

Bundesdeutsche Arbeitsgemeinschaft für Veränderliche Sterne e.V.

October 2023

S CrB is a Mira star and was discovered in 1860 by Karl Henke (Marienwerder, Germany). The AAVSO database shows brightness data since 1864. The revised period of the pulsation is 360.1 days, therefore 159 maxima can be identified to a reasonable accuracy. The average maximum brightness (visual and V band) is around 7 mag. The 2022 maximum showed a record brightness of 5.2 mag (Visual, V band: 5.4) which is approx. three sigma above the average brightness. After that, the brightness declined to 13.2 mag, not a record but very faint compared to previous minima. The 2023 maximum is around 8.2 mag which is the second faintest maximum ever and it was an extraordinary flat one. All this can be statistical coincidence, but it is at least an amazing curiosity, if not a hint for more fundamental changes in the state of the star's development.

Introduction

S CrB is classified as an M6e-M8e AGB star with a period of 360 days. The star seems to be a bit under-observed by the variable star observer community. For example, the AAVSO database of Minima and Maxima lists data for 397 long period variables, but S CrB is missing.

Average maximum is around 7 mag, therefore the 5.2 mag observed summer 2022 was quite a big surprise and let to a longer thread in the RSpec-Astronomy forum (Leadbeater et al. 2022, Leadbeater 2022). This discussion was focussed on the spectra of S CrB before during and after 2022 maximum which is not the scope of this work, but triggered the author to monitor S CrB photometrically since then. A statistical analysis of the historical data from the AID (AAVSO International Database) delivered the mean and standard deviation of the maxima and minima, light curve analysis using Fourier transforms with the program VStar (Benn 2012, 2023) confirmed periodicity and gave additional information on potential changes over time.

Observations

Images on approx. 100 days between August 2022 and September 2023 were taken with different equipment, depending on the brightness of the star and weather conditions: Canon 600D with 50mm and 180mm lenses, 500mm refractor with Canon 600D and TS2600MP V, B and I band filters (Baader), remote telescope in Italy using V and B filters. Nearly all observations were transformed from the used filters to the standard bands. Photometric evaluation was done using IRIS, Siril and VPhot (AAVSO).

Fig. 1 shows the light curves for the period July 19, 2022 (shortly after the maximum) until October 10, 2023 from the author's observations. Many more data can be found in the AID of the AAVSO. It is clearly visible that the 2022 maximum is much brighter than the one from 2023, which also shows a more plateau-like shape. The 2021 maximum was "average" around 7.0.

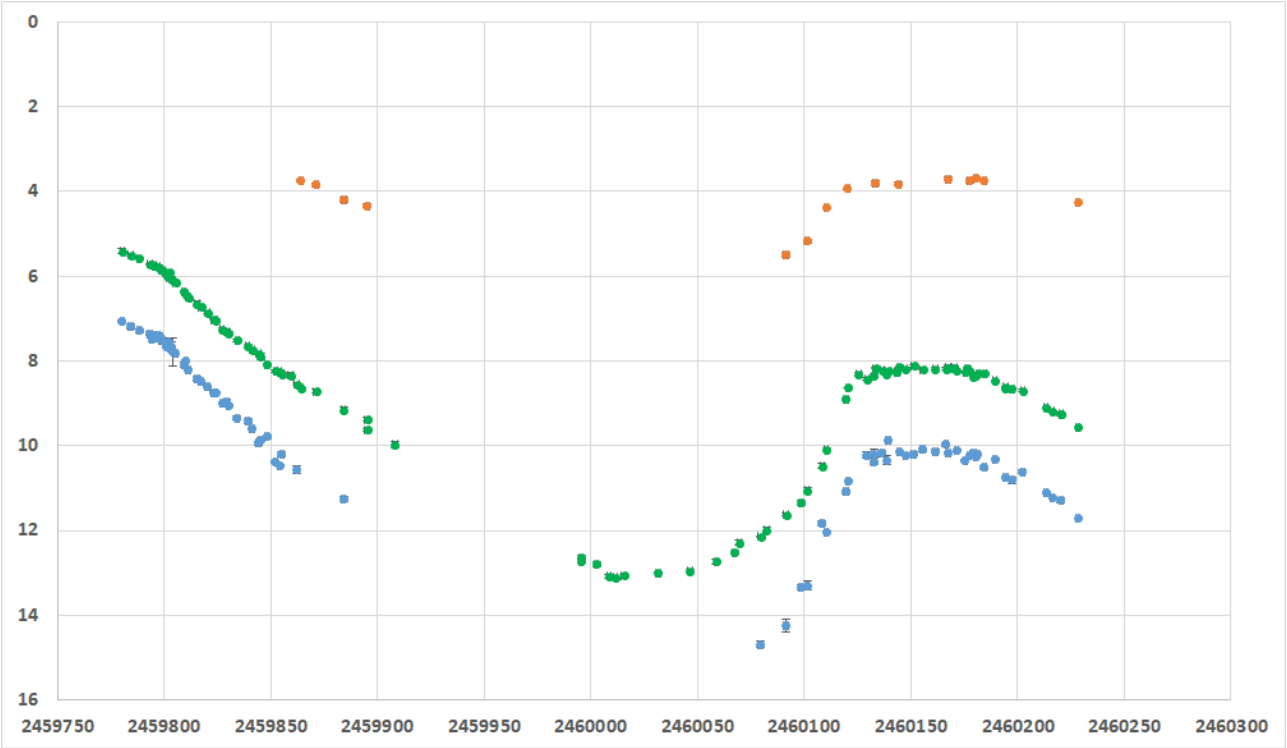

Fig. 1: V (middle), B (bottom) and I (top) magnitudes for S CrB between July 19, 2022 and October 10, 2023 from the author (obs. code KMWA)

Data analysis

The statistical analysis of more than 45.000 visual and V band data generated by several hundred AAVSO observers (Kloppenborg 2023) between 1864 and today is shown in Tab. 1. The number of data points per period is increasing with time, but specifically between 1886 and 1900 only a limited number of observations were available. The analysis was done manually and in some cases the data points may not be very accurate, but the task was not to go to the second decimal but understand the variability of the maximum brightness well enough to assess the 2022/2023 maxima. Coverage of V band data is limited to 13 years, but these data match reasonably well the visual observations for the maxima. The V minima are typically less faint by 0.5 up to even 1 mag in V band compared to the visual data. The information about the minima should be taken with more care therefore.

	Visual	V band
Mean mag	**6.9**	**7.07**
σ	**0.5**	**0.66**
Min	**5.2**	**5.37**
Max	**8.5**	**8.10**
2022 max σ	**+3.2**	**+2.57**
2023 max σ	**-2.6**	**-1.55**
Count	**159**	**16**

Tab 1: Statistical data for visual and V band observations of the light-curve maxima. When comparing the standard deviations, the much smaller number of years covered in the V band should be considered.

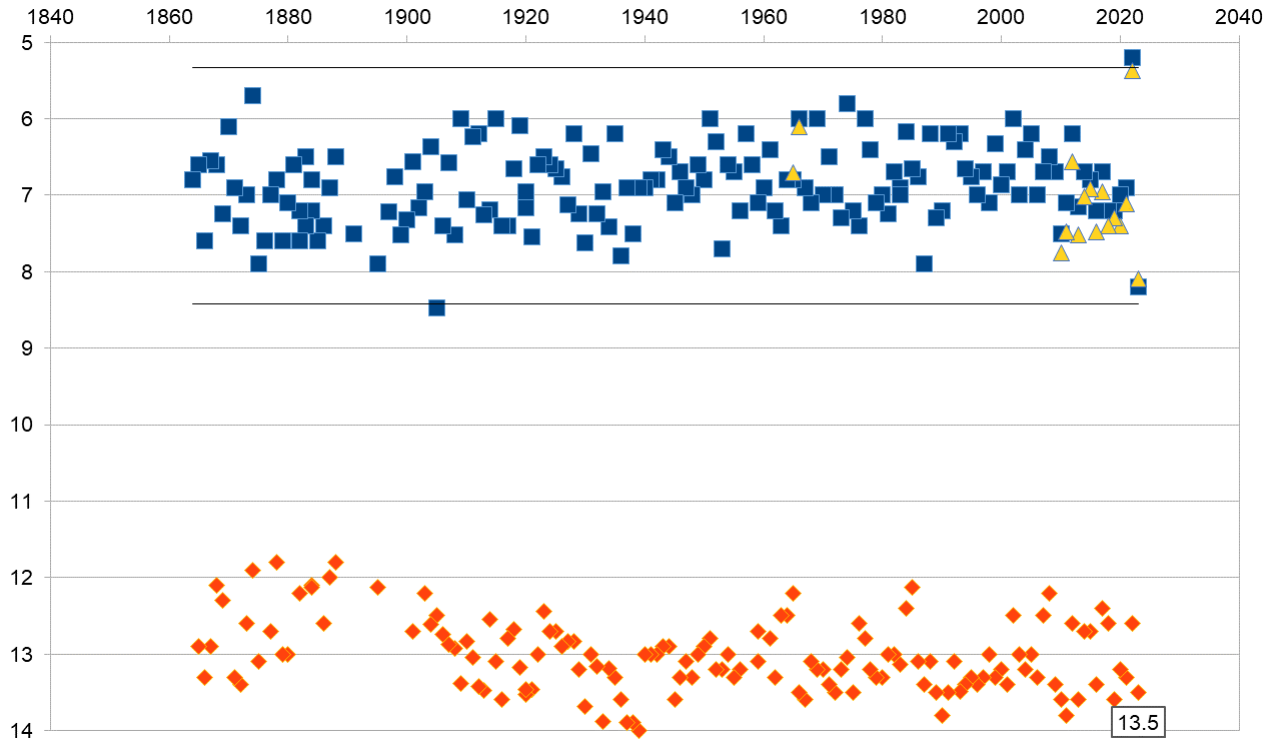

Fig. 2: Brightness at maxima and minima for the time from 1864 to 2023 both visually and V band (yellow, only maxima). The horizontal lines show the 3σ range for the visual data. The exceptional character of the 2022 and 2023 maxima is quite obvious.

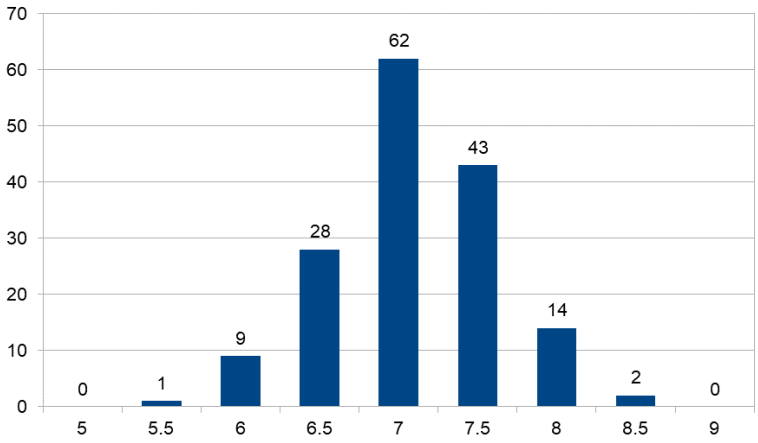

Fig 3: Histogram of the visual magnitude at the maxima. Statistical tests show that this is in line with a normal distribution.

Results

The record maximum from 2022 is approx. 3 sigma off the mean maximum brightness, confirming a first analysis from Leadbeater at time of 2022 maximum (Leadbeater, 2022). The distribution of the maxima is compatible to a Gaussian distribution (Kolmogorow-Smirnow, Shapiro-Wilk, Anderson-Darling). We can expect around 3 data points beyond 3 sigma within 1000 data points and we now saw the first one after more than 150 years. Similar for the maximum 2023: 8.2 mag is 2.6 sigma below the mean, only one maximum was fainter, but also this is in line with the normal distribution. The minimum between the two maxima is within the lower quartile. As a result, the decline from the 2022 maximum to the 2023 minimum was approx. 8 magnitudes. This is also a record for this star and belongs to the strongest inner-cycle-amplitudes of Mira stars. The average amplitude of S CrB (taken as the difference between av. Max and av. Min) is 6 mag, but the average semi-amplitude is only around 2.7 mag (see Fig. 4)

The Fourier analysis of the light curve shows a periodicity of 360 days. The Weighted Wavelet Z-Transform (WWZ) analysis (Foster 1996) implemented in VStar shows the development of the periodicity over time: Minor variations are visible, but no significant trend. The semi-amplitudes show a stronger dependence on time, but also no clear pattern, in particular no correlation between period and semi-amplitude over longer time ranges.

In general, with increasing period also luminosity of Mira's increase (Glass, 1981), but this holds for much bigger period changes than the minor variations see in Fig. 4.

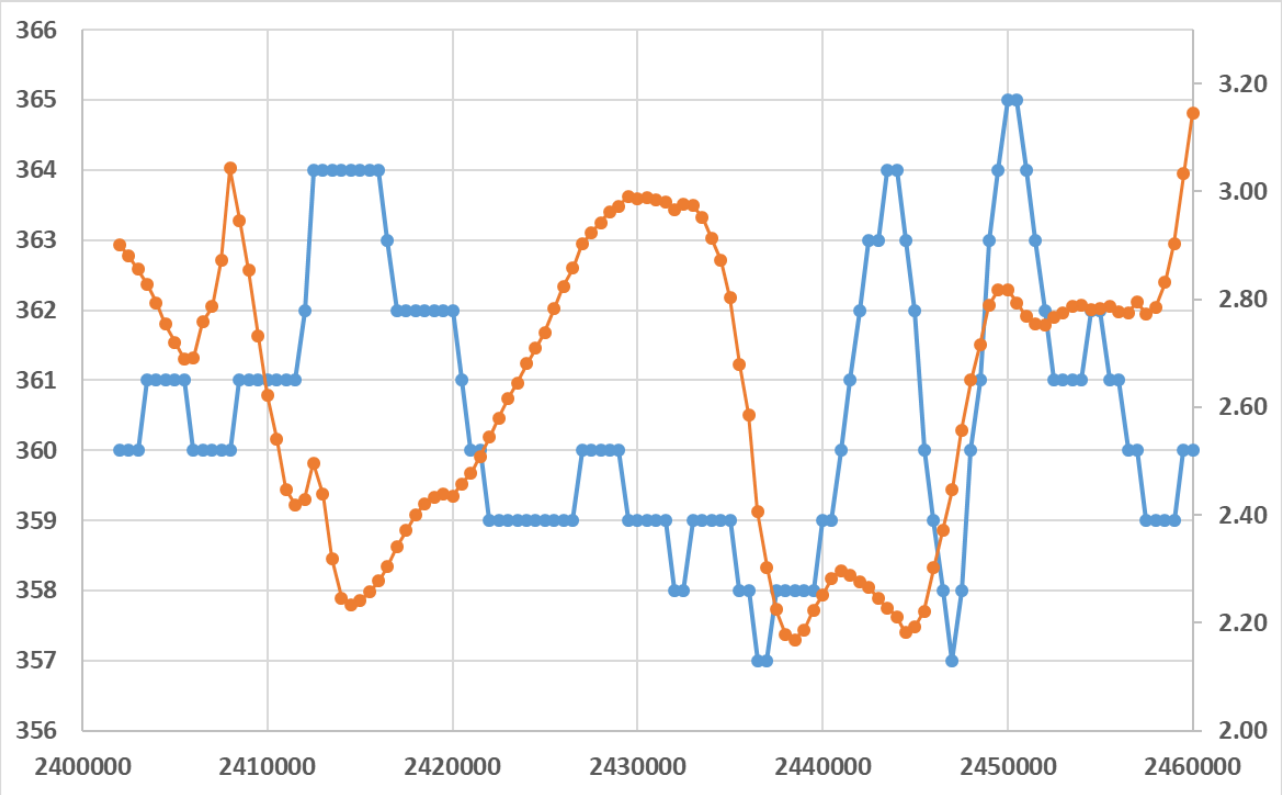

Fig. 4: Period (blue, left axis in d) and Semi-Amplitude (orange, right axis in delta mag) over time using WWZ on all visual observations. Parameters used for WWZ: minimum period 100d, maximum 500d, period step 1d, decay rate 0.001, time divisions 50.

The differences between the three maxima 2021, 2022, 2023 are approximately:

2022-2021: 356 days

2023-2022: 376 days,

which is very long, but the 2023 maximum is hard to define due to a plateau-like shape of the light curve around maximum.

Other bands: As typical for the Mira stars, the amplitudes of S CrB are more pronounced in the blue part of the spectrum compared to the visual and they are much smaller in the red and infrared.

B-V was around 1.6 during the 2022 maximum and 2 during the 2023 maximum, in line with the expected bigger B-V with lower V.

The number of infrared observations in the AID is very low, unfortunately there was no measurement done during the 2022 maximum. The author's I band observations of the 2023 maximum show approx. 3.9 mag but it is not easy to develop an accurate number as no good comparison stars with similar brightness in I are nearby. Based on our data V-I is around 4-4.5 at a V band magnitude of 8-9 mag.

Independent of the data, the impression of the difference of V and I band brightness looking at the photographic images is always amazing. Fig. 5 shows images with both filters on May 17, 2023. The brighter star nearby is HD 136654 (non-variable) with V=6.9, I band data not given, but the J magnitude is 5.98.

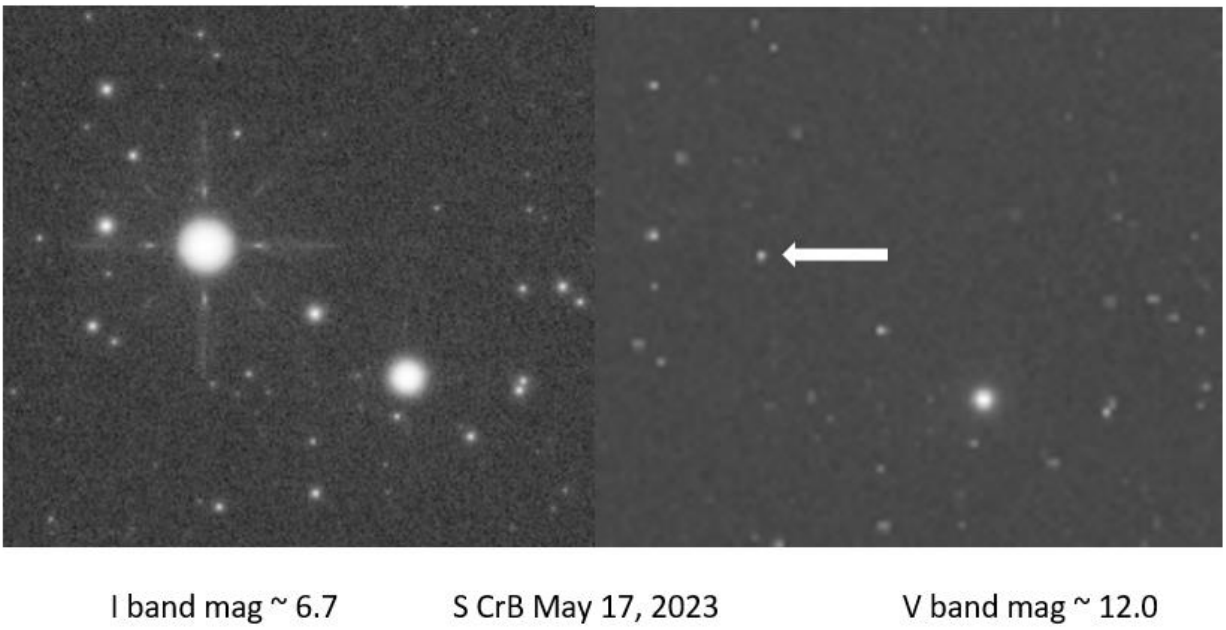

Fig. 5: I and V band lights from May 17,2023.

Discussion

Which physical processes lead to different amplitudes for the same Mira star? And is S CrB a star with a broader standard deviation of the amplitude distribution compared to other Mira's? The author has not found any statistics for the second question yet. To approach the first question we may get some more insight if we look at the work of L. Celis S. (1978): The change in visual or V band brightness can be explained by two factors: The continuum changes due to the pulsation (radius/surface and temperature changes of the photosphere) and increasing / decreasing formation of TiO molecules during the cycle: The more TiO molecules condense, the broader the absorption bands and the fainter the V brigthness. In his work he quantified the impact of both effects on the amplitudes of a sample of Miras. A comparison of different cycles of the same Mira with different amplitudes shows that both effects differ between the cycles.

Even though the bright maximum 2022 and the faint one following 2023 are compatible with a normal distribution of data with a mean of 7 mag and a sigma value of 0.5 mag, the light curve is amazing: *A record bright maximum followed by a record decline and finished by a near-to-record faint maximum with a plateau-like shape.*

Acknowledgements

We acknowledge with thanks the variable star observations from the *AAVSO International Database* contributed by observers worldwide and used in this research (Koppenburg, 2023).

We also acknowledge David Benn for comments on WWZ analysis (private communication).

In addition to the author, the following members of the BAV supported data to the AID since 2022 (indicated in the table below the light curve generated by the light curve generator https://www.aavso.org/LCGv2/): Thorsten Lange, Jörg Neumann, Frank Vohla, Wolfgang Vollmann, Volker Wickert. If, I missed someone, please take my apologies.

References

Benn, D. 2012, "Algorithms + Observations = VStar", JAAVSO, v40, n2, pp.852-866.

Benn, D., Beck, S., Pyatnytskyy, M., Kotnik, C., Lee, S., Weber, A., Dadighat, M., & Camargo, N. (2023). VStar (Version 2.23.0) [Computer software]. https://github.com/AAVSO/VStar

Celis S., L. 1978, Intrinsic Amplitude and Molecular Absorption of Mira Stars, Astron. Astrophys. 63, pp 53-61

Foster, G. 1996, Wavelets for Period Analysis of Unevenly Sampled Time Series, Astron. J., vol 112, p 1709

Glas I.S., Lloyd Evans T., 1981, Nat.291, 303

Kloppenborg, B. K., 2023, Observations from the AAVSO International Database, https://www.aavso.org

Leadbeater, Robin, 2022, The Spectrum of S CrB during the 2022 Record Maximum, British Astronomical Association Variable Star Section Circular, Number 18 Number: 193. pp. 16-17.

Leadbeater, Robin et. al, 2022, Mira S CrB at Very Bright Maximum, RSpec-Astronomy Forum, https://groups.io/g/RSpec-Astronomy