Long-term activity and outburst of the intermediate polar V1223 Sgr

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Abstract

We analyze the character of long-term photometric activity of V1223 Sgr, with paying attention to the previously unresolved features. We detect cycles in both the high/low state transitions and oscillations in the high state. Usually, the high state displays the most stable and the most typical value of the mass transfer rate in this system. The Bamberg photographic data (1964–1970) display an excursion from the lower limit of the high state to an enormously bright state which is not a simple continuation of the typical long-term variations. We interpret the data in the following way. The viscosity alone keeps the disk in steady-state only in the upper limit of the high state, while in lower states the disk consists of two zones – the inner one being kept in the hot state by irradiation by the white dwarf, and the outer one being in the cold state. Burst of the mass outflow from the donor then can temporarily bring the outer zone to the hot state. Our results confirm the scientific importance of astronomical plate archives.

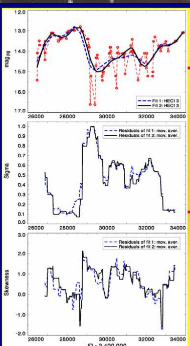
- V1223 Sgr – intermediate polar (IP), orbital period P_{orb} = 0.1402 days (Warner & Cropper 1984), rotational period of the white dwarf (WD) P_{rot} = 746 s (Osborne et al. 1985).
- WD appears to possess a magnetic field weak enough to allow formation of the disk, but the truncation of the inner disk region is larger than thought previously (Beuermann et al. 2004).
- Strong long-term activity with episodes of low states (e.g. Garnavich & Szkody 1988), brief outburst (duration ~6 hr, amplitude ~1.5 mag; van Amerongen & van Paradijs 1989).
- Distance d=500 kpc (Beuermann et al. 2004).

Subjects of our analysis:

- Investigation of the character of long-term photometric activity in the optical.
- Analysis of previously unresolved features.
- Investigation of time behavior, statistical properties of the brightness variations.
- Search for periodicities using a weighted wavelet Z-transform.

Harvard data

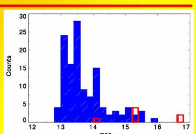
Photographic observations 1931 – 1986 (Garnavich & Szkody 1988)



(a) Fitted light curve. Smooth curves – HEC13 (Vondrak 69, 77; Harmanec) fits with two sets of parameters.

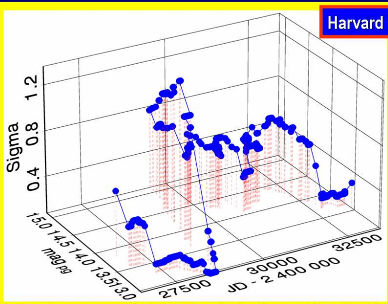
(b) Profile of the standard deviation sigma of the HEC13 fit, smoothed by moving averages.

(c) The same for the skewness of the light curve.



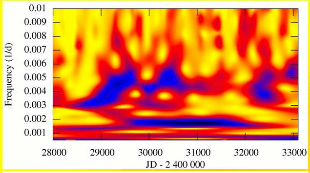
Histogram of the light curve. Typical mag lies in the high state.

Harvard data



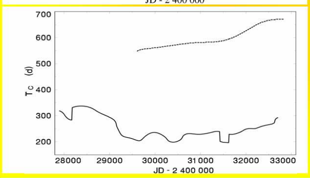
Evolution of mean magnitude and its σ in the Harvard data (the HEC13 fits). σ tends to increase with the decrease of brightness.

Cycles in Harvard data



Weighted wavelet Z-transform (WWZ) of the curve (method of Foster 1996)

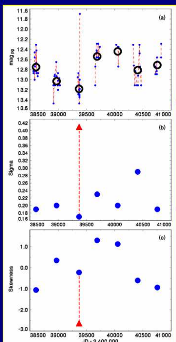
WWZ – determination of period and amplitude of unevenly sampled time series.



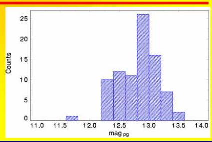
Evolution of the cycle length of transitions between high and low states, T_C, determined by WWZ-transform. This curve represents the maximum or a very high WWZ in each JD. In a part of the interval, two significant values of T_C can be found.

Bamberg data

Photographic observations (1964 – 1970)
Camera 100/610 mm, field size 13°, exp. time 60 min, emulsion Gevaert 67A50 (close to B)

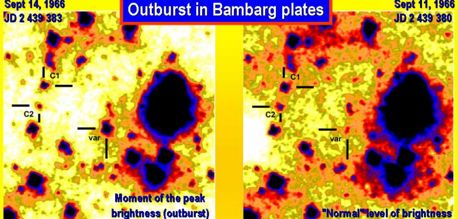


(a) Light curve. Closed circles – individual obs. Large open circles – annular averages. Largely deviating point in JD 2 439 383 is not included in the mean.
(b) Annular averages of the standard deviation σ (filled circles). Triangle denotes the value of σ with the point in JD 2 439 383 included.
(c) Annular averages of skewness of the light curve.

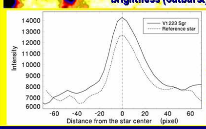


Histogram of the light curve.

Outburst in Bambarg plates

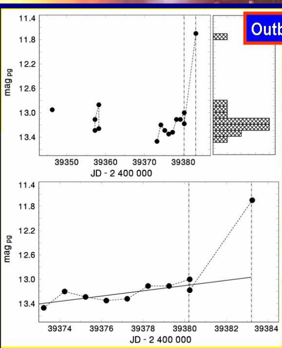


V1223 Sgr is abbreviated as "var".
Reference stars are labeled as "C1" and "C2".
North is at the top, east to the left.



Comparison of the profile of V1223 Sgr in outburst with the reference star C1
Slice is in the East-West direction.
Both profiles are very similar to each other – the outburst of V1223 Sgr is not caused by artifact.

Outburst in Bambarg plates



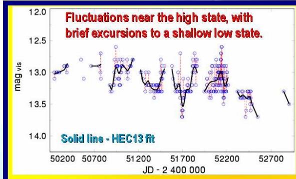
Segment of the Bamberg data around the largely deviating point in JD 2 439 383.
Two dashed vertical lines denote the time separation between the deviating point and the preceding brightness level.

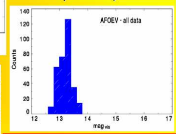
The linear fit of the preceding "quiescent" level and its extrapolation to the moment of the deviating point are included in the bottom panel.

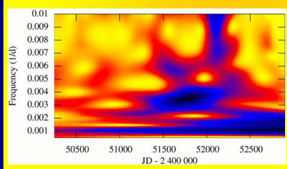
Statistical distribution confirms the striking deviation of the point from the other data.

AFOEV light curve

Visual observations
AFOEV database, Strasbourg, France
ftp: // cdsarc.u-strasbg.fr/pub/afoev)







Weighted wavelet Z-transform (WWZ) of the curve (method of Foster 1996)
WWZ – determination of period and amplitude of unevenly sampled time series.

RESULTS

- Level of brightness above which the disk is thermally stable is about 13.0 – 13.5 mag (fluctuations above this level are usually gradual and low-amplitude). Statistical distributions of brightness suggest that the most probable state is the high state. Excursions from it occur with the decreasing probability of achieving the deepest low states.
- Thermal instability has to be considered in the models by Beuermann et al. (2004) . The high state displays the smallest fluctuations which grow with the decrease of brightness. High state is thermally stable, the state below it is thermally unstable. The disk must be stabilized by irradiation when V1223 Sgr is below the upper level of the high state.

- The levels below the upper level of the high state suggest that the disk is thermally stabilized, i.e. the cooling front is halted inside the disk. In absence of this stabilization, the propagation of the cooling front would continue and bring the entire disk to the cold state, and hence the brightness would fall substantially.
- Point of enormously high brightness in 1966 – this event is not caused by a simple transition to the high state or a simple continuation of the typical long-term variations, because it lies far above the gradual increase from the preceding level. Also the segment after the following seasonal gap starts with an increase to the brighter level of the high state,which strengthens the episodic nature of the brightening in 1966.
- Proposed mechanism for outburst: The disk consisted of two zones, the inner being kept in the hot state by irradiation by the WD, and the outer one in the cold state. Burst of the mass outflow from the donor then temporarily brought the outer zone from the cold to the hot state.

- Fluctuations of brightness on day-to-day time scale are significantly smaller than those of the high/low state transitions.
- Cycles in the long-term brightness variations: Sequence of low states displays a prevailing cycle-length of about 250 days in the Harvard data. This is in good agreement with the cycle of ~280 days in the fluctuations near the high state seen in the AFOEV data. Occurrence of these low states and fluctuations is therefore not quite random. This casts problems to the star spot scenario, in which random occurrence of these transitions and fluctuations is expected. The cycle, but not strict periodicity also rules out the asynchronous rotation of the donor as the cause of the transitions.
- Our results confirm the scientific importance of astronomical plate archives. They enable to study the evolution of objects during very extended time intervals, which cannot be provided with any other type of the recent instrumentation.