Acta Polytechnica CTU Proceedings **2**(1): 81–85, 2015 doi: 10.14311/APP.2015.02.0081

Activity of the Polar AM Her (RX J1816.2+4952): A Short Review

V. Šimon[1,2], A. Henden[3]

[1] *Astronomical Institute, Academy of Sciences of the Czech Republic, 25165 Ondřejov, Czech Republic*

[2] *Czech Technical University in Prague, FEL, Prague, Czech Republic*

[3] *AAVSO, 49 Bay State Road, Cambridge, MA 02138, USA*

Corresponding author: simon@asu.cas.cz

Abstract

We show that AM Her displays the transitions between the high and low states with an intermittently existing dominant cycle with length between 400 and 800 days. Moreover, these transitions accumulate in clusters, which produces an additional long cycle after smoothing; a single isolated short episode of the low state does not suggest a break of this cycle. The seasons of existence of the cycle can be controlled by the lifetime of the active regions (e.g. prominences, spots) on the donor. In some high-state episodes, a higher luminosity of the bremsstrahlung emission is not accompanied by a higher optical (cyclotron+stream) emission. Part of the bremsstrahlung emission can be buried in some episodes. Changes of the structure of the accretion region(s) are necessary to explain the variations of the optical and X-ray activity in the high-state episodes of AM Her.

Keywords: cataclysmic variables - polars - activity - emission mechanisms - optical - X-rays - individual: AM Her.

1 Introduction

AM Her is the prototype of polars (e.g. [19]). Its activity is dominated by the large-amplitude long-term variations: alternating high and low states of the optical brightness usually on the timescales of months and years (e.g. [8, 21, 10]). A small accreting region (about 0.1 of the radius of the white dwarf (WD)) near the magnetic pole of this object is the source of radiation and polarization of polar via several processes: cyclotron (accretion column – mainly optical and IR emission), thermal (soft X-rays – surface of the WD heated by the accreting region), bremsstrahlung (accretion column – hard X-rays) (e.g. [19, 15]). The conditions in this region and the mass accretion rate play an important role in governing the observed activity.

2 Long-Term Activity in the Optical Band

Fig. 1a shows the long-term activity of AM Her in the optical band spanning about 32.7 years. The data come from the AAVSO International database (Massachusetts, USA) [6]. The highly variable orbital modulation has a large amplitude mainly in the high state (e.g. [9, 10]), so the character of the long-term activity is less discernible. Fig. 1a therefore shows the HEC13 fit running through the orbital modulation (each point is a smoothed value of brightness in the night of observing).The division between the high and low states is 14.3 mag(V). The properties of the statistical distribution of brightness of the high states strongly evolve with time (Fig. 1cd). The typical high-state brightness is near the middle of the distribution on the magnitude scale in most time segments. The low states often show skewness of brightness toward the brighter magnitudes.

The fuzzy bright edge of the high-state brightness, smoothed over the orbital modulation, in the histogram suggests that the high state is not a uniquely defined level of luminosity of AM Her (Fig. 1cd). It is questionable whether any "unperturbed" state of the system exists et all. A typical strength of the active regions (large loops of magnetically confined gas near the donor due to its magnetic activity [9] and star spots [13, 7]) during the high state is therefore needed (the times of the quite quiescent donor are thus very rare). In the scenario proposed by [21], this statistical distribution also suggests a typical configuration of the magnetic field of the whole system (donor+WD), around which the system balances during the high state of activity.

The brightness of the low states in AM Her often stabilizes at the baseline level. The mass transfer via Roche lobe overflow almost ceases, only clumpy accretion onto the WD from the donor's wind remains [3, 9]. The strong skewness of brightness in Fig. 1cd can emerge if the HEC13 fit runs through the variably recurring brightenings.

Moving averages (MA) of brightness with various filter half-widths Q enable to search for the evolution of the optical activity of AM Her on timescales of several years, significantly longer than the duration of the individual episodes of the high or low states (Fig. 1). The transitions between these states tend to occur in clusters in AM Her. Smoothing then reveals a long cycle because of the variable clustering of the episodes of the low states. Since the borders of these clusters are fuzzy, a smooth profile of the cycle results when MA are applied. A single isolated short episode of the high or the low state does not suggest a break of this cycle since the cycle is caused by the repeating accumulations of these transitions in clusters. Some long cycles thus may not be easily discernible without investigating the variations of the parameters of activity, which MA enable (Fig. 1ab).

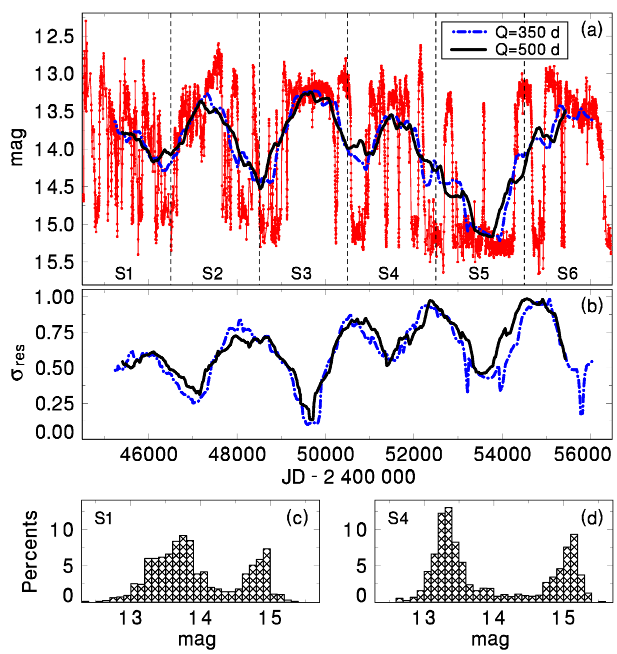

Figure 1: **(a)** The long-term activity of AM Her in the optical band (AAVSO data [6]). HEC13 fit runs through the orbital modulation. The mapping is divided into segments. The smooth lines represent the moving averages (MA). **(b)** Residuals of the MA. **(c, d)** Examples of the strikingly different statistical distributions of brightness. See Sect. 2 for details.

Search for the cycle-length in the transitions between the high and low states from Fig. 1a was carried out also with the weighted wavelet Z-transform (WWZ) developed by [1]. This method enables one to determine the period and amplitude of unevenly sampled time series. WWZ indicates whether or not there is a periodic fluctuation at a given time at a given frequency f (Fig. 2a).

The WWZ-transform really finds that the transitions between the states are not quite chaotic. A dominant cycle in the transitions really exists. However, the cycle-length of the transitions is not stable and this cycle is not conclusively detected in some time segments. Fig. 2b shows the best cycle-length, determined from f that has the biggest value of WWZ at a given time (only the segments in which the amplitude is larger than 60 percent of its peak value in the investigated range of f). In summary, this cycle is characteristic only for a limited time segment. It is intermittent and unstable in length. Moreover, the WWZ-method shows also another temporarily existing shorter cycles in Fig. 2a. For comparison, the cycles of 178 d, 1836 d, 830 d and 1520 d were found by Fourier analysis by [11].

The differential rotation of the lobe-filling donor (modeled by [18]) can influence the position of the above-mentioned active regions on the donor with respect to the L1 point. The breaks of the cycle of the transitions between the high and the low states in AM Her can be caused by a limited lifetime of the above-mentioned active regions connected with the activity of the donor.

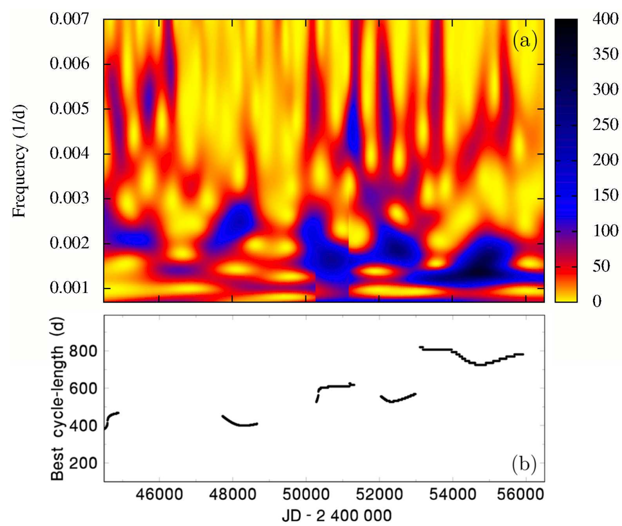

Figure 2: **(a)** WWZ-transform of the light curve of AM Her from Fig. 1a. **(b)** The best cycle-length. See Sect. 2 for details.

3 Optical and Hard X-Ray Intensities in the High States

In AM Her, increase of the mass transfer rate from the donor (giving rise to a high-state episode) also establishes specific division of the emission into various spectral regions during the accretion process (Fig. 3) (see our analysis in [17] for details). The properties of the emitting region(s) on the WD are established in the early phase of the high-state episode (but not reproduced for every episode) of AM Her. A higher luminosity of the bremsstrahlung emission may not be always accompanied by a higher optical (cyclotron+stream) emission in a given episode of the high state (the intensities in both of these bands were averaged over the orbital period) [17]. This can significantly differ even for two consecutive episodes (Fig. 3bc). This relation of intensities is representative for the whole such episode.

Purely geometric effects (asynchronous rotation of the WD, precession of the WD spin axis) cannot explain the observations – gradual evolution of the X-ray and optical intensities with time would be needed (see [17] for details).

We propose the following scenario. The source of the bremsstrahlung emission is confined to a smaller region than that of the cyclotron emission. Part of the bremsstrahlung emission is buried in some high-state episodes. Since there is no smooth transition of the ratio of the optical and hard X-ray intensities [17], it suggests that the role of several modes of accretion is worth considering.

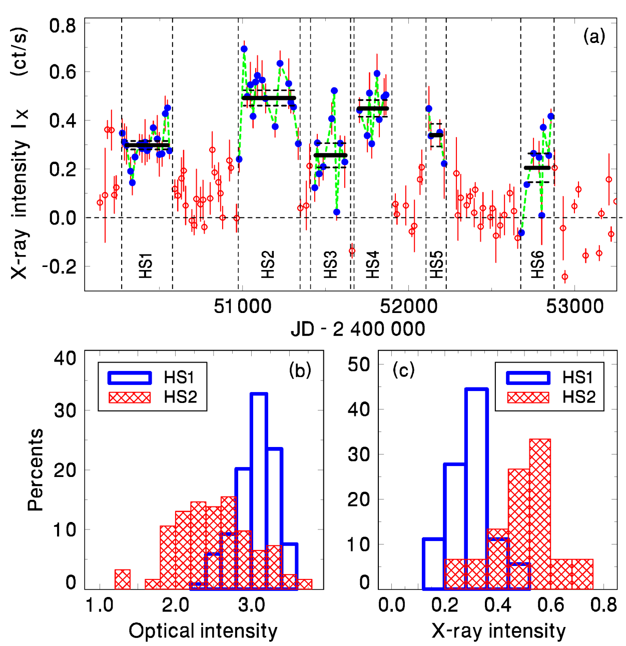

Figure 3: **(a)** Part of the ASM/*RXTE* (1.5–12 keV) [12] light curve of AM Her (15-d means). The mean levels and their standard errors are marked. **(b, c)** Intensities of the optical (AFOEV data, the intensity $I = 1$ for 14.3 mag) and hard X-ray (1.5–12 keV) (ASM/*RXTE* data) emissions in two consecutive episodes of the high state. A higher luminosity of the hard X-ray emission may not be always accompanied by a higher optical emission in a given episode.

4 Role of the Accretion Modes

The orbital modulation of AM Her displays significant changes in both the optical and X-ray spectral regions. Unexpected mode of the X-ray (soft: 0.1–0.31 keV, hard: 1.9–8.5 keV) orbital modulation was observed in two observing runs of the same optical high state by [4]. It suggested a two-pole accretion mode in which the primary pole was the dominant emitter of the hard X-rays while the secondary pole was dominant in the soft X-rays.

The accretion mode is representative only for a given high-state episode of AM Her [14]. A short episode of the high state (but less bright than most other high-state episodes) displayed a single-pole accretion mode with a self-occultation of the primary pole, resulting in a deep primary minimum in the bands between $E = 0.6$ and 10 keV, but no sign of the secondary minimum. The subsequent brighter high state displayed a two-pole accretion mode with a shallow primary minimum in the 2–30 keV band, suggesting the big dimensions of the accretion region. The secondary minimum occurred only in the soft band (1–2 keV), suggesting that the secondary pole is the dominant emitter of the soft X-rays. The same situation as those observed in one of the previous high states by [4], that is the primary pole dominant in the hard X-rays and the secondary one dominant in soft X-rays, thus repeated. Also cyclotron emission undergoes peculiar changes with the accretion mode. In the above-mentioned bright high state observed by [14], cyclotron emission from a region at the primary accreting pole dominated in the V-band [2]. Since a two-pole accretion was determined from polarization of the optical emission for another high-state episode by [20], it suggests that the accretion modes are very unstable in AM Her.

Changes of the structure of the accretion region(s) are necessary to explain the variations of the optical and X-ray orbital modulation in the individual episodes of the high state in AM Her. The accretion modes (single-pole accretion, two-pole accretion) vary with time; they may be characteristic for a given high-state episode, but not for another one. Since the properties of the accretion region at the primary pole largely differ from those at the secondary pole, these changes of the accretion modes contribute to the complicated long-term activity.

The transition from the high to the low state is accompanied by dramatic changes of the size and structure of the cyclotron-emitting accretion region in AM Her (Fig. 4). A decrease of the dimensions of the accretion region(s) during the transition emerges from these facts: the rises and declines between the extremes of brightness (especially of the branches of the primary minimum) become progressively steeper, the amplitude of the modulation increases, the eclipse of the primary pole becomes very prominent. During the final phase of the high-state episode, the properties of the cyclotron-emitting region do not scale exactly with the optical luminosity.

AM Her appears to have the primary accreting region close to the position which is close to the grazing eclipse; a slight increase of its vertical and/or horizontal dimensions (and variable position) can give rise to a highly variable orbital modulation. This is visible not only for the site of the cyclotron emission (Fig. 4), but also for the site of the bremsstrahlung emission which can increase so much that it even becomes temporarily uneclipsed in some high states [16].

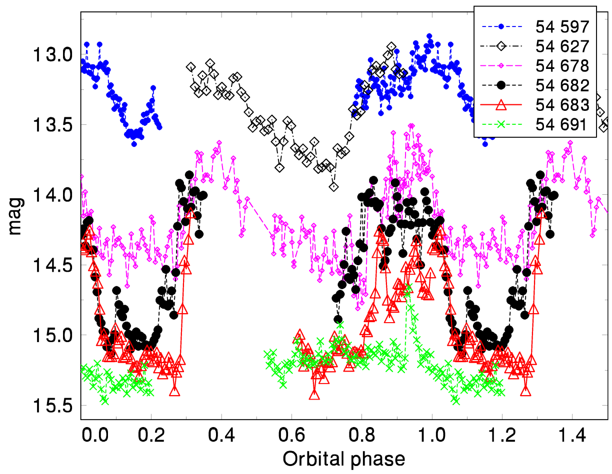

Figure 4: Dramatic changes of the orbital modulation during transition from the high to the low state of AM Her (CCD *V*-band AAVSO data). Time in JD–2 400 000 is given in the legend. The orbital ephemeris of [5] is used.

5 Conclusions

In AM Her, the optical emission displays cycles in the transitions between the high and low states, which are detectable only for the limited time segments. In addition to the intermittent cycle of the transitions, accumulation of episodes of the low states in clusters produces an additional, long cycle of activity. A single isolated short episode of the low state does not suggest a break of this cycle. This has a consequence for the structures and their lifetimes on the donor and/or the changes of the configuration of the magnetic field in the whole system.

The configuration of the accreting matter influences the emission of AM Her in various spectral bands. The accretion modes (single-pole accretion, two-pole accretion) vary with time (from one high-state episode to another). Also the changes of the accretion region(s) and/or accretion modes are necessary to explain the relation between the optical and X-ray emission in the high states.

Acknowledgement

This study was supported by grants 13-33324S and 13-394643 provided by the Grant Agency of the Czech Republic. This research has made use of the observations provided by the ASM/RXTE team, the Swift/BAT team, the AAVSO International database (Massachusetts, USA) and the AFOEV database (Strasbourg, France). We thank the variable star observers worldwide whose observations contributed to this analysis.

We used the code developed by Dr. G. Foster and available at http:// www.aavso.org/winwwz. We thank Prof. Petr Harmanec for providing us with the code HEC13. The Fortran source version, the compiled version and brief instructions on how to use the program can be obtained via http:// astro.troja.mff.cuni.cz/ftp/hec/HEC13/.

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