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The relation between the long-term X-ray and optical activity of the polar AM Her (RX J1816.2 + 4952)

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ABSTRACT

We analyze the relation between the long-term (1996–2009) activity of the polar AM Her in the optical and hard X-ray spectral regions. We investigate the mean values of the intensities in the individual high-state episodes. We made use of the ASM/*RXTE* observations for a time-series analysis of the long-term variations in the 1.5–12 keV band. The optical data came from the AFOEV database. We reveal a complicated relation between the optical ($I_{\rm O}$) and hard X-ray intensity ($I_{\rm X}$). We argue that our observations cannot be explained by the variations of the orbital modulation in the high-state. Also, the precession of the spin axis of the white dwarf or asynchronous rotation of this object are unlikely in our case. We show that the basic properties of the emitting region (s) is (are) established in the early phase (several days long) of the high-state episode but they are not reproduced for every episode. The increase of the mass transfer rate from the donor that switches the polar from the low to the high-state also establishes a division of the emission released during the accretion process into various spectral regions that is valid only for a given episode. These results enable us a better understanding of the multifrequency behavior of polars on long time-scales.

1. Introduction

Polars are cataclysmic variables (CVs) with a strongly magnetized white dwarf (WD) accretor (e.g. Hack and la Dous, 1993; Warner, 1995). Streaming matter is threaded through the accretion column (s) onto the spot (s) at the magnetic pole (s) of the WD because the strong magnetic field of the WD prevents formation of an accretion disk. This transferring matter is usually the dominant source of radiation in the optical and hard X-ray spectral regions in the high-state. Since the accretion disk is missing, the variations of the mass transfer rate onto the WD, $\dot{m}_{\rm c}$, (i.e. without any possible fraction of the matter outflowing from the system) are rapidly reflected in the luminosity of the polar. The matter falling onto the WD forms an accretion column above its surface. This column is a source of radiation via several mechanisms. Cyclotron emission is dominant in the optical and UV bands while the medium and hard X-ray emission is due to bremsstrahlung. Soft X-ray excess, probably caused by the thermal emission from the surface of the WD heated by the impact of matter, can be present in some polars (e.g. Warner, 1995). The observations simultaneously obtained in the optical and hard X-ray bands enable us to investigate the relation between the individual emission mechanisms.

AM Her (RX J1816.2 + 4952) is the prototype of the category of polars (e.g. Hack and la Dous, 1993; Warner, 1995). It is known to display large-amplitude long-term variations that are manifested by alternating high and low states of optical brightness (e.g. Hudec and Meinunger, 1976; Wu and Kiss, 2008). These variations are accompanied by changes of the X-ray intensity (e.g. Matt et al., 2000). Several interpretations of these episodes of high and low states have been presented. Livio and Pringle (1994) and Hessman et al. (2000) explained them in terms of variable coverage of the inner Lagrangian point L1 on the donor by starspots. On the other hand, Wu and Kiss (2008) proposed that these states are due to variations in the magnetic field configuration in the system; the magnetic field of the WD thus plays a key role in regulating $\dot{m}_{\rm c}$. It is an open question as regards the X-ray long-term activity of this system and polars generally. This is caused by the weak X-ray signal of such objects, which makes their monitoring very difficult. AM Her itself was observed by Heise et al. (1985) to display a complicated activity on long time-scales with two accretion modes in the high-state. It is thus very interesting to study the activity of such a system.

2. Observations

The optical light curve of AM Her was made from data accumulated in the international AFOEV database operated in Strasbourg, France. They appear very suitable for our purpose. The reason is that monitoring of CVs is very often conducted by the associations of amateur observers. These observations are mostly visual but

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they are quite numerous and come from a large number of observers. Visual data, if treated carefully, can thus be very useful for analyzing long-term activity. Accuracy even better than 0.1 mag can be achieved by data averaging, which is quite sufficient for analyzing these large-amplitude variable objects. The bandpass of the eye sensitivity is similar to Johnson *V* filter. Only the segment of the visual data, for which the ASM/*RXTE* X-ray observations are available, was used here. AFOEV data already marked as unreliable or as limits in the original file were rejected. Further, several observations deviating strongly from the neighboring points in the light curve were rejected. To smooth the light curve, all remaining observations were binned into one-day means. This suppressed the noise considerably, but also averaged out flickering and orbital modulation (e.g. Kafka and Hoard, 2009). This suppression of fast variability does not influence our results because the amplitude of long-term changes (transitions between the high and low states) is much larger.

AM Her has been monitored in the X-ray band by ASM/*RXTE* (Levine et al., 1996) (<http://xte.mit.edu/>) since the beginning of 1996. AM Her is one of a very few CVs detected by ASM/*RXTE*. Only one-day means of the sum band intensities I_X (1.5–12 keV) were used for our analysis to increase the signal-to-noise ratio. This binning is sufficient because our analysis concentrates on the long-term activity, hence on the features in the light curve on the timescale of days and longer. Modified Julian Date, used by *RXTE*, was transformed into Julian Date to make it compatible with the optical data. Hereafter, it is used in the form of JD–2 400 000.

3. Data analysis

The long-term optical light curve of AM Her contemporaneous with the ASM data consists of 1920 data points (one-day means) spanning an interval of 5097 days. Its full (peak-to-peak) amplitude was more than 2 mag during the interval used for our analysis. Several episodes of these high and low state were observed.

To lower the scatter of the optical observations, to emphasize the slowly varying component of these variations, and to pick out their profile, the optical data were fitted by the code HEC13 written by Harmanec (1992). This code is based on the method of Vondrák (1969, 1977), who improved the original method of Whittaker (Whittaker and Robinson, 1946). The method is based on minimizing the value $Q = F + \lambda^2 S$, where $F = \sum p(y_i - y'_i)^2$ denotes the degree of smoothing (y being the smoothed and y' the observed value of the variable), $S = \sum(\Delta^3 y_i)^2$ is the measure of roughness of the curve, λ^2 is a constant to be selected and defines how much the curve will be smoothed. A full description of the method can be found in Vondrák (1969). This method can fit a smooth curve to the nonequidistant data regardless of their profile. HEC13 makes use of two input parameters, ϵ (in dimensionless units) and ΔT. The quantity $\epsilon = 1/\lambda^2$ determines how "tight" the fit will be, that is, if only the main profile or also the high-frequency variations are to be reproduced. The quantity ΔT is the interval over which data are binned before smoothing. The resulting fit consists of the mean points, calculated to the individual observed points of the curve. This fitting was carried out in the magnitude scale. A set of fits to the optical data with the different ϵ and ΔT was generated and submitted for inspection. The fit with $\epsilon = 1$, $\Delta T = 10$ d was found to satisfy the general profile of the visual light curve (Fig. 1(a)). The individual observed data are not displayed to avoid overcrowding the plot. This fit reproduces the main features of the profile of the optical light curve and suppresses rapid fluctuations. This confirms the reliability of the features in the light curve of AM Her. It is true that this method is somewhat subjective but it enables a compromise between a curve running through all the observed values and an ideal smooth curve. We preferred to use this method because it does not make any assumptions about the profile of the fitted data.

The visual magnitudes of the smoothed light curve were transformed into intensity I_O, setting $I_O = 1$ at 14.3 mag$_O$. The typical standard error of the unsmoothed one-day mean of I_O is about 0.1. The value of 14.3 mag$_O$ lies between the levels of the high and low state (Fig. 1(b)). The times of crossing $I_O = 1$ in the optical light curve are marked by the dashed vertical lines in Fig. 1(b). This enables us to separate the high and low states. Because this separation can be made with a better precision for the optical data than for the ASM observations it is also used for the X-ray data (Fig. 1(c)).

The signal of AM Her detected by ASM/*RXTE* is weak even in the high state. These data therefore need careful evaluation before they are submitted for the analysis. To assess the quality of the data, a set of the light curves for the data with various limiting quoted uncertainty σ_q of the original one-day means was made. It turned out that dividing the measurements according to their σ_q to the groups with $\sigma_q \leqslant 0.25$ ct s^{-1} and $\sigma_q > 0.25$ ct s^{-1} considerably suppressed the noise and improved the appearance of the profile of the light curve. An increase of I_X was observed during optical high-state episodes longer than 60 days.

In the next step, only the one-day means, each of which comprised of at least 21 observations, were used for the X-ray light curve. This further improved the visibility of the high-states in the light curve. Finally, these data were grouped into the 15-day bins. The time of each bin refers to the arithmetic mean of the times of all the observations included and it may not exactly coincide with the center of the mean. An arithmetic mean of I_X and its standard error were calculated for each bin. This curve remained dense enough to distinguish its profile. It consists of 185 data points spanning the interval of 4951 days. It was used for subsequent analysis and is displayed in Fig. 1(c). The typical standard error of the 15-day mean of I_X is about 0.0585 ct s^{-1}. An increase of I_X definitely occurs during optical high-state episodes longer than 60 days. The rise of I_X occurs in the beginning of the optical high-state, with the delay not longer than several days. Notice that this X-ray light curve is even able to show the short episode of the X-ray low state near JD 2 451 700. It corresponds to the short optical low state.

The fact that we did not find any clear dependence of σ_q on I_X can be explained by the character of the X-ray activity of AM Her. In the low state, the observational noise dominates and the system is likely below the detection limit of ASM. A clear decrease of σ_q with the growing I_X can be expected only if I_X remains stable during the time interval over which it is averaged. However, AM Her was observed to display strong orbital modulation in the 2–4 keV and 4–10 keV X-ray bands (Matt et al., 2000). Its amplitude varies considerably on long time-scales (Priedhorsky et al., 1987). As shown in Section 4, the emission in this band was dominant also in the ASM observations.

For comparison, the ASM one-day means of the AM Her data with $\sigma_q \leqslant 0.25$ ct s^{-1} were also fitted by HEC13. A set of fits to these data with the different ϵ and ΔT was generated and submitted for inspection. The fits using $\epsilon = 1$ while ΔT was equal to 25 and 35 days, respectively, yielded the best results. They were in good agreement with each other and satisfied the general profile of the X-ray curve. They were also in good agreement with the 15-day-binned X-ray curve, which was described above. This confirms that propper analysis of the ASM data can yield useful results even for faint X-ray sources if we confine ourselves to the long-term changes and if this source is not located in a crowded field.

Our inspection of the X-ray light curves showed that I_X in the low state of AM Her was very small and likely dominated by noise. We therefore only concentrated on analyzing the optical and X-ray intensities in the high-states. In total, seven well-mapped episodes of the optical high-state were successfully associated with the