UvA-DARE (Digital Academic Repository)

A deep X-ray low state of Am Herculis

De Martino, D.; Gaensicke, B.T.; Matt, G.; Mouchet, M.; Belloni, T.; Beuermann, K.; Bonnet-Bidaud, J.; Mattei, J.; Chiappetti, L.; Done, C.

Published in:
Astronomy & Astrophysics

Link to publication

Citation for published version (APA):
De Martino, D., Gaensicke, B. T., Matt, G., Mouchet, M., Belloni, T., Beuermann, K., ... Done, C. (1998). A deep X-ray low state of Am Herculis. Astronomy & Astrophysics, 333, L31-L34.

General rights
It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use, unless the work is under an open content license (like Creative Commons).

Disclaimer/Complaints regulations
If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please Ask the Library: http://uba.uva.nl/en/contact, or a letter to: Library of the University of Amsterdam, Secretariat, Singel 425, 1012 WP Amsterdam, The Netherlands. You will be contacted as soon as possible.

UvA-DARE is a service provided by the library of the University of Amsterdam (http://dare.uva.nl)

Download date: 25 Jul 2017

Astron. Astrophys. 333, L31–L34 (1998)

ASTRONOMY AND ASTROPHYSICS

LETTER

Letter to the Editor

A deep X-ray low state of AM Herculis

D. de Martino[1], B.T. Gänsicke[2], G. Matt[3], M. Mouchet[4], T. Belloni[5], K. Beuermann[2], J.-M. Bonnet-Bidaud[6], J. Mattei[7], L. Chiappetti[8], and C. Done[9]

[1] Osservatorio di Capodimonte, Via Moiariello 16, I-80131 Napoli, Italy
[2] Universitäts-Sternwarte, Geismarlandstrasse 11, D-37083 Göttingen, Germany
[3] Dipartimento di Fisisca, Universitá degli studi “Roma Tre”, Via della Vasca Navale 84, I-00146 Roma, Italy
[4] DAEC, Observatoire de Paris, Section de Meudon, F-92195 Meudon Cedex, France
[5] Astronomical Institute “Anton Pannekoek”, Kruislaan 403, 1098 SJ Amsterdam, The Netherlands
[6] CEA, DSN/DAPNIA/Service d’Astrophysique, CEN Saclay, F-91191 Gif-sur-Yvette Cedex, France
[7] AAVSO, 25 Birch Street, Cambridge, MA 02138, USA
[8] Istituto di Fisisca Cosmica CNR, Via Bassini 15, Milano, Italy
[9] Department of Physics, University of Durham, South Road, Durham DH1 3LE, UK

Received 2 March 1998 / Accepted 12 March 1998

Abstract. We present a BeppoSAX observation of AM Her during a prolonged low state. The source was observed for ~ 4 hrs at a flux level comparable to previous low states, followed by a rapid (~ 40 min) drop by a factor of ~ 7 to the deepest X-ray low state ever detected. While the active phase X-ray flux is likely to be accretion induced, coronal emission from the secondary may contribute significantly during the inactive phase. The timescale of this dramatic change in the accretion rate is of the order of the dynamical timescale of the secondary star; no available model can satisfactorily explain the evolution of the X-ray flux detected in these BeppoSAX data.

Key words: accretion – binaries: close – stars, individual: AM Her – X-rays: stars

1. Introduction

AM Her, the bright prototype of the *Polars*, contains a magnetic (~ 14 MG) white dwarf which accretes from a late-type main sequence secondary star. The strong magnetic field locks the white dwarf into synchronous rotation with the orbital period and channels the accretion flow towards the magnetic pole of the white dwarf. The accretion region is a strong source of X-ray emission, with the emitted spectrum depending on the mass flow rate. At low mass flow rates, $\dot{m} \leq 30\,\mathrm{g\,cm^{-2}s^{-1}}$, the infalling matter is heated close to the white dwarf surface in a stand-off shock to $\sim 10^8$ K, giving rise to emission of thermal bremsstrahlung and cyclotron radiation. For high mass flow rates, the shock may be buried in the white dwarf atmosphere, and the primary thermal bremsstrahlung is reprocessed into a blackbody soft X-ray emission.

A common characteristic of Polars is a long-term variability in their luminosity, best monitored at optical wavelengths in the prototype AM Herculis itself, where irregular changes in brightness of $\Delta \mathrm{V} \simeq 2-3$ mag (high and low states) are observed on timescales of months. As Polars have no accretion disc, changes in the luminosity directly reflect changes in the mass loss rate of the secondary star. One possible cause for these variations are active regions episodically covering the inner Lagrangian point of the cool star (King & Cannizzo 1998). During high states, the X-ray emission of AM Her is very soft; the accretion is, hence, dominated by high mass flow rates (Gänsicke et al. 1995, hereafter G95). The few X-ray low state observations obtained so far showed AM Her at a low flux level with no noticeable soft component (Fabbiano 1982, hereafter F82; G95). In this *Letter* we report a BeppoSAX observation of AM Her during an optical low state, showing an active phase for ~ 4 hrs, followed by the deepest X-ray quiescence detected so far.

2. Observations

A BeppoSAX (Boella et al. 1997) observation of AM Her was carried out from 1997 September 6, 13:38 to September 7, 3:26 (UT) with the co-aligned Narrow Field Instruments covering the range 0.1-300 keV. The source was detected only by the Low Energy Concentrator Spectrometer (LECS) [0.1-10 keV] and by the two active units of the Medium Energy Concentrator Spectrometers (MECS) [1.3-10 keV], with effective on-source exposures of 9.8 ksec and 24.7 ksec, respectively. Count rates have been extracted from a circular region with a radius of $4^{'}$ in both instruments. Background count rates were extracted from blank sky pointings using the same radius, resulting in $5.6 \times 10^{-3}\,\mathrm{cts\,s^{-1}}$ and $7.0 \times 10^{-3}\,\mathrm{cts\,s^{-1}}$ for the LECS and the MECS, respectively. During the BeppoSAX observa-

Send offprint requests to: D. de Martino

LETTER

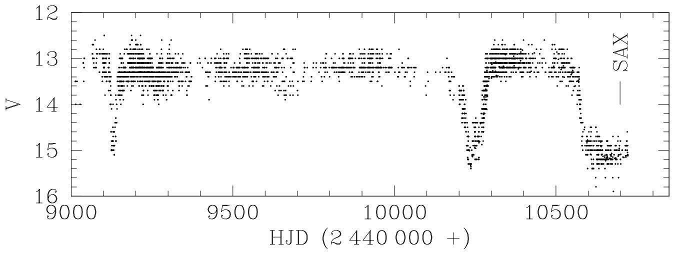

Fig. 1. Long-term optical light curve of AM Her from AAVSO data. The time of the BeppoSAX observation is indicated.

tion, AM Her was in a low state ($V \approx 15.1$ mag; Fig. 1) since ~ 120 d, the longest since three years.

3. Analysis and results

3.1. The X-ray light curve

The background subtracted MECS and LECS light curves of AM Her (Fig. 2) display a striking evolution of the count rates during the BeppoSAX pointing. During the first two satellite orbits, HJD = 2 450 698.1–698.2, the count rate in the MECS detector steeply rises and subsequently falls by a factor ~ 7. Fitting the rise (1st orbit) and the decay (2nd orbit) times with an exponential slope results in $\tau_{\rm rise} = 44\pm^{46}_{14}$ min and $\tau_{\rm fall} = 39\pm^{13}_{8}$ min. The maximum of this burst-like event likely occurred while the satellite was in the earth shadow. A steep rise by a factor ~ 6 is also observed in the LECS count rates, but, due to the shorter on-source time (Fig. 2), the decay has been only marginally covered. A second decay in the MECS count rate is observed during the third satellite orbit (HJD = 2 450 698.22), with a similar timescale as the first decay. The later data show the system at an approximately constant level of $(6.5 \pm 0.8) \times 10^{-3}$ cts s^{-1}and $(6.8 \pm 1.1) \times 10^{-3}$ cts s^{-1}in the MECS and LECS, respectively. We note the X-ray emission of AM Her did not switch off completely. We will refer to the observations obtained before and after HJD = 2 450 698.25 as the *active* and *quiescent* phases, respectively.

Fig. 3 shows the active and quiescent MECS and LECS count rates folded with the linear polarization ephemeris (Heise & Verbunt 1988). During the active phase, the count rates in both instruments show a deep minimum at $\phi \approx 0.1$. A second minimum, less pronounced and structured, is observed at $\phi \approx 0.42 - 0.55$, followed by a steep rise. During quiescence, the poor statistics prevents the detection of an orbital modulation. The minimum observed at $\phi_{\rm mag} \approx 0.1$ is a recognized stable feature in the X-ray light curve of AM Her, both in high state (G95; Beardmore & Osborne 1997) and in low state (F82; G95), interpreted as the eclipse of the accreting pole by the white dwarf. The second minimum at $\phi_{\rm mag} \approx 0.42 - 0.55$ observed in the MECS data is, however, not straightforward to understand. The GINGA hard X-ray light curve of AM Her during high state shows a quasi-sinusoidal modulation, possibly with a small plateau shortly before $\phi_{\rm mag} = 0.5$ (Beardmore & Osborne 1997). A substantial short-term variability, observed in the GINGA data, could also be present in our data and con-

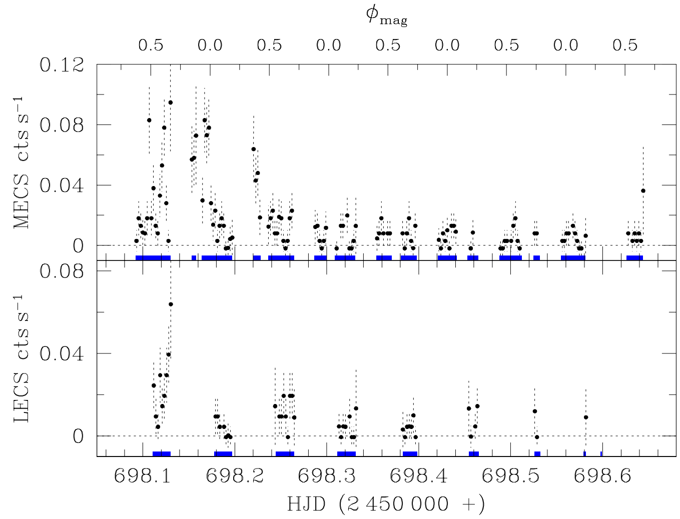

Fig. 2. MECS (upper panel) and LECS (lower panel) light curves of AM Her, binned in 200 sec. The on-target times are indicated by shaded areas at the bottom of each panel. The top axis gives magnetic phases. Count rates below zero are due to the uniform background subtraction.

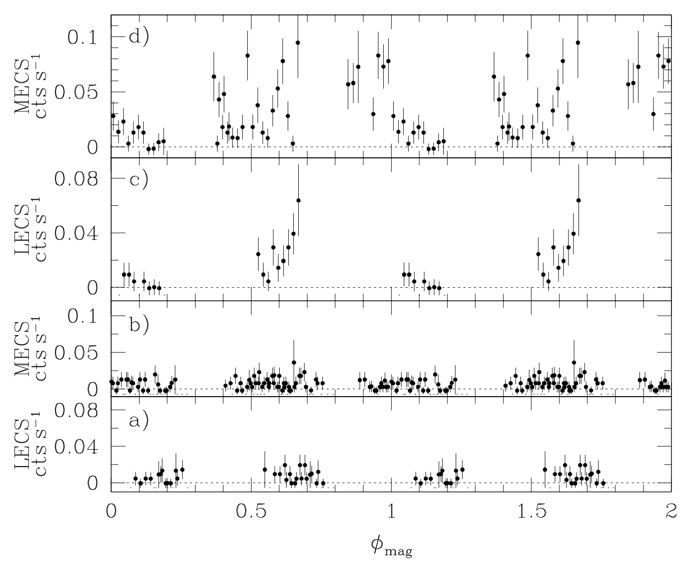

Fig. 3a–d LECS and MECS count rates, binned in 200 sec, during the quiescent phase (**a** and **b**, respectively) and during the active phase (**c** and **d**, respectively).

tribute to the structured shape of the secondary minimum in the MECS light curve. A second minimum at $\phi_{\rm mag} \approx 0.5$ is also observed in the soft X-rays (G95), likely due to photoelectric absorption in the accretion stream. However, it is very unlikely that absorption can account for the deep second minimum in the MECS 2–10 keV light curve. We conclude that, while the minimum observed at HJD = 2 450 698.2 is consistent with being due to the eclipse of the accreting pole, the initial rise and the decline at HJD = 2 450 698.22 are likely due to intrinsic X-ray luminosity variations (cfr. Sect. 4).

3.2. The X-ray spectrum

Spectral fitting was performed separately for the active and quiescent phases. No soft blackbody component is required by the data being the LECS+MECS spectra fitted with a thermal plasma (Raymond-Smith) model with solar abundances, assuming an interstellar hydrogen column density of $N_{\rm H} = 9 \times 10^{19}\,{\rm cm}^{-2}$ (G95). The relative normalization of the two instruments was left free to allow for a residual mismatch in the absolute calibrations and the different time coverage. For the quiescent phase this parameter resulted to be completely unconstrained and was, therefore, fixed to unity. The fits are acceptable for both phases, $\chi^2_{\rm red} < 1$, resulting in $kT_{\rm RS} = 5.8\pm^{3.9}_{1.8}$ keV for the active phase and in a lower limit $kT_{\rm RS} \geq 3.6$ keV for the quiescent phase (quoted errors refer to the 90% confidence level). The temperature derived for the active phase spectrum is significantly lower than the typical value for the high state (∼13.5 keV, Beardmore et al. 1995), but is broadly consistent with the 9 keV temperature derived from the low state Einstein observations in August 1980, when AM Her was at $V \sim 14.5$ mag (F82). In Table 1, we list for the active phase the 2-10 keV and the bolometric fluxes for Raymond-Smith models at 5.8 keV, at 9 and 20 keV, the latter for comparison with the low state ($V \sim 14.9$ mag) observed in September 1990 during the Rosat All Sky Survey (G95). The 9 keV thermal bremsstrahlung model fitted to the Einstein spectrum (F82) resulted in a 0.4 – 4 keV bright phase flux of $48 \times 10^{-13}\,{\rm ergs\,cm^{-2}s^{-1}}$, which converts into a bolometric flux of $120 \times 10^{-13}\,{\rm ergs\,cm^{-2}s^{-1}}$, somewhat higher than that obtained by G95 ($80 \times 10^{-13}\,{\rm ergs\,cm^{-2}s^{-1}}$) for an assumed 20 keV thermal bremsstrahlung spectrum fitted to the ROSAT PSPC data. The bolometric fluxes derived from the BeppoSAX active phase spectrum (Table 1) are of the same order of magnitude as those given by F82 and G95, thus indicating that the active phase corresponds to the normal low-state activity while the quiescent phase represents the deepest X-ray low state observed so far. As shown in Table 1, the resulting quiescence bolometric flux is a factor ~ 8 lower than any X-ray flux of AM Her hitherto reported.

We finally note that the lack of detection of a soft component is consistent with the previous 1980 and 1990 low states. An upper limit can be obtained including a 29 eV blackbody in the fit, as derived from high state ROSAT data (G95). No improvement in the fit is achieved, and we constrain $F_{\rm bb}/F_{\rm RS} \leq 2$. However, the BeppoSAX data alone do not allow us to assess the eventual presence of substantial blackbody emission in the EUV.

4. Discussion

4.1. The origin of the X-rays

The BeppoSAX observation reported here has revealed an unprecedented large variation in the X-ray emission of AM Her, showing short activity event followed by the deepest X-ray low state ever detected so far. Since we lack of information on whether the source was in a sustained active state before our BeppoSAX pointing, which would clearly indicate accretion-induced X-ray emission, we explore the possibility that the X-ray flux observed during both active and quiescent phases was due to the secondary star only.

Table 1. 2-10 keV and bolometric Raymond-Smith model fluxes for the active (A) and the quiescent (Q) phase at the given temperatures.

Phase	$kT_{\rm RS}$ [keV]	$F_{\rm RS}(2-10\,{\rm keV})$ $[10^{-13}\,{\rm ergs\,cm^{-2}s^{-1}}]$	$F_{\rm RS}({\rm bol})$
A	5.8	18	36
A	9.0	19	39
A	20.0	19	50
Q	5.8	2.4	4.8
Q	20.0	2.5	6.5

Active phase: The secondary star has been observed to be active at optical wavelengths. A large and rapid ($\sim$ 1 hr) brightening has been detected in AM Her during a low state in 1992 (Shakhovskoy et al. 1993), with the typical morphology, sharp rise and slow decay, of a stellar flare. We, therefore, compare the timescales, energetics and emission measure of the active X-ray phase with those of flares in dMe and RS CVn stars. A thorough compilation of X-ray flares is provided by Pallavicini et al. (1990), mainly based on EXOSAT LE data. Stellar flares show a wide variety of timescales and energetics, and the active phase of AM Her falls into the large flares category, with an increase of flux of $\gtrsim 7$. However, the morphology of this $\sim$ 4 hr active phase, with a rather slow exponential rise ($\gtrsim$ 44 min), and a double-humped decay with similar time scales, differs from that of typical flares. Moreover, the temperature is higher than typical flare temperatures of $1.7 - 3.4$ keV. Also, the average luminosity in the 0.05–3 keV band, $1.4 \times 10^{30}\,{\rm ergs\,s^{-1}}$assuming a distance of 91 pc (G95), is at the high end of the peak luminosities of stellar flares, $10^{27} - 10^{30}\,{\rm ergs\,s^{-1}}$, observed with the EXOSAT LE experiment. The same holds for the integrated luminosity in the same band, 1.4×10^{34} ergs, which compares with $3 \times 10^{30} - 1 \times 10^{34}$ ergs for stellar flares. Only the derived volume emission measure $1.4 \times 10^{53}{\rm cm}^{-3}$, is comparable to those of stellar flares. Therefore, the discrepancies in the characteristics of the active phase in AM Her from those of stellar flares, along with the coincidence of the $\phi_{\rm mag} \approx 0.1$ minimum in the phase-folded light curve with the eclipse of the accreting pole, strongly suggest that the X-ray emission detected by BeppoSAX during the active phase is due to accretion.

Quiescence: The quiescent X-ray flux is the lowest observed so far in AM Her and could be due to coronal emission from the secondary. Although we cannot constrain the quiescence temperature, the lower limit of 3.6 keV is higher than typical coronal temperatures (~ 250 eV–1.7 keV). However, assuming $kT_{\rm RS} = 5.8$ keV, the luminosity in in the soft X-ray bands of EXOSAT and Einstein is $\sim 2 \times 10^{29}\,{\rm ergs\,s^{-1}}$, which is about the observed luminosity of late-type main sequence stars (Pallavicini et al. 1990; Eracleous et al. 1991). Therefore, unless the secondary in AM Her is unusally inactive, coronal emission significantly contributes to the quiescent X-ray flux of AM Her, even though the temperature might suggest the presence of an accretion induced component.

LETTER

4.2. Variability of the accretion rate

Identifying the X-ray emission during the active phase as due to accretion leads to the conclusion that we have observed a significant drop of the accretion rate at HJD = 2 450 698.25. We are left with the ambiguity that the observed rise in both MECS and LECS at the beginning of the observation are related to the onset of an accretion event. In the following, we estimate the accretion rates during the active phase as well as an upper limit for the quiescent phase, assuming that also the latter is accretion-induced. The *total* accretion luminosity can be estimated taking into account that about half of the thermal bremsstrahlung and cyclotron radiation emitted from the hot post-shock plasma is intercepted by the white dwarf and re-emitted in the UV, as established for AM Her by G95: $L_{\rm UV} \approx L_{\rm tb} + L_{\rm cyc}$ with $L_{\rm cyc} \approx 2.3\,L_{\rm tb}$. Neglecting the contribution from an undetected soft EUV component, $L_{\rm acc} \approx L_{\rm tb} + L_{\rm UV} + L_{\rm cyc}$. For $kT_{\rm RS} = 5.8$ keV, this translates into a lower limit of $L_{\rm acc} \geq 2.4 \times 10^{31}$ ergs s^{-1} for the active phase, while 3.1×10^{30} ergs s^{-1} is derived for the quiescent phase. Assuming $M_{\rm wd} = 0.6\,M_\odot$ ($R_{\rm wd} = 8.7 \times 10^{8}$ cm), these luminosities imply accretion rates of $\dot{M} \geq 4.1 \times 10^{-12}\,M_\odot\,{\rm yr}^{-1}$ for the active and a factor of 10 lower for the quiescence. Considering the upper limit on a possible soft EUV component (Sect. 3.2), these accretion rates could be higher by a factor of ~ 2. It appears that the normal low state accretion rate, as measured by Einstein, ROSAT, and by BeppoSAX during the active phase, is broadly consistent with that expected from gravitational braking, $3 \times 10^{-11}\,M_\odot\,{\rm yr}^{-1}$ for $P_{\rm orb} = 3.09$ h (Warner 1995). However, the accretion rate during the quiescent phase is at least one order of magnitude below that value, indicating a turn-off of the mass transfer. We stress that, considering the long (~ 9 h) quiescent phase, the observed large decrease in flux is not due to inhomogenous accretion, but to a decrease of the total mass transfer rate.

The puzzling result is the very short timescale, ~ 40 min, on which accretion turns off, remarkably close to the dynamical timescale of the secondary star (Warner 1995). This may be interpreted as a temporary detachment of the secondary from the Roche lobe. King & Cannizzo (1998) discuss possible models for such variations on timescales of ~ 1 d, but none of them seems appropriate for the rapid X-ray turn-off detected by BeppoSAX. On the other hand, if AM Her was in a deep low state also before our BeppoSAX pointing, the observed variability could have been produced by an eruptive mass ejection from the secondary star. Eruptive prominences, extending up to $10 - 20\,R_\star$, are indeed observed in active late stars (Cameron 1991) but with masses of the order of 4×10^{17} g, a factor of ~ 10 lower than the mass accreted on the white dwarf during the active phase. Unfortunately, the knowledge of mass ejections in stars other than the sun is still very scarce, limiting any further comparison.

Our BeppoSAX observation of AM Her has revealed that the mass transfer rate is subject to large variations also during low state. Stellar activity on the secondary appears to be an important, but poorly explored ingredient in understanding the nature of these variations.

Acknowledgements. We acknowledge useful discussions with J. Schmitt, K. Readorn and G. Cauzzi.

References

Beardmore A.P., Done C., Osborne J.P., Ishida M., 1995, MNRAS 272, 749
Beardmore A.P. & Osborne J.P., 1997, MNRAS 290, 149
Boella G. et al. 1997, A&AS 122, 299
Cameron A.C., 1991, MmSAI 62, p337.
Fabbiano G., 1982, ApJ 262, 709 (F82)
Eracleous M., Halpern J., Patterson J., 1991, ApJ 382, 290
Gänsicke B.T., Beuermann K., de Martino D., 1995, A&A 303, 127 (G95)
Heise J., Verbunt F., 1988, A&A 189, 112
King A.R., Cannizzo J.K., 1998, ApJ *in press*
Pallavicini R., et al. 1990, A&A 228, 403.
Shakhovskoy N.M., et al. 1993, Ann. Isr. Phys. Soc. 10, 237
Warner B., 1995, *Cataclysmic Variable Stars* (Cambridge University Press)