X-ray Luminosity Versus Orbital Period of AM CVn Systems

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Abstract AM CVn systems are a rare type of cataclysmic variable star consisting of a white dwarf accreting material from a low-mass, hydrogen-poor donor star. These helium-rich systems usually have orbital periods that are less than 65 minutes and are predicted to be sources of gravitational waves. We have analyzed the catalogued x-ray data from the Chandra, XMM-Newton, and The Neil Gehrels Swift Observatory (hereafter referred to as "Swift") to investigate the relationship between x-ray luminosity and the orbital period of AM CVn systems. We find that the high accretion-rate systems which are likely to have optically thick boundary layers are sub-luminous in x-rays relative to theoretical model predictions for the boundary layer luminosity, while the longer orbital period, lower bolometric luminosity systems match fairly well to the model predictions, with the exception of an overluminous system which has already been suggested to show magnetic accretion.

1. Introduction

AM CVn stars are binary systems that have very short orbital periods that range from 5 to 65 minutes. These systems consist of white dwarfs accreting material from a Roche lobe-filling companion star that usually is a lower-mass white dwarf star, but occasionally is a helium star. These systems are expected to be strong sources of gravitational waves (Nelemans *et al.* 2004). In this paper, we discuss the relationship between x-ray luminosity and orbital period for a sample of 28 AM CVn systems. We use the data from XMM, Chandra, and Swift observatories for collecting the x-ray flux and obtaining orbital period values from the literature. Studying the relationship between x-ray luminosity and orbital period can provide insights into the accretion process in AM CVn systems and techniques for searching for more of them.

2. Data and analysis

We collected the x-ray flux from Chandra, XMM-Newton, and Swift for all AM CVn systems listed in Table 1. Using the Chandra Source Catalog (CSC), we collected the flux from 0.5 to 7.0 keV from Release 2.0 (Evans *et al.* 2010). For XMM-Newton, using 4XMM-DR11, we collected the flux from 0.2 to 12.0 keV from Webb *et al.* (2020). For Swift, using the 2SXPS Swift x-ray telescope point source catalogue, we collected the flux from 0.3 to 10.0 keV from Tranin *et al.* (2022). We collected the distances from Gaia parallax measurements corrected for the Gaia zero-point offset, and which used Bayseian analysis to convert the measured parallaxes into inferred distances (Bailer-Jones *et al.* 2021). Using the flux we calculated the x-ray luminosity for each system. We also obtained the orbital periods of these systems from Ramsay *et al.* (2018). For the newly discovered AM CVn system, TIC 378898110, we collected the orbital period, x-ray flux, and the distance from Green *et al.* (2023). In Table 1, we see that a few systems have periods estimated using superhumps. Superhump periods are typically within a few percent of the real periods, which is acceptable for the purposes of comparing luminosities with orbital periods. Using the uncertainty in the distances, we calculated 16% and 84% values for the luminosity. Using these values we made the error bars.

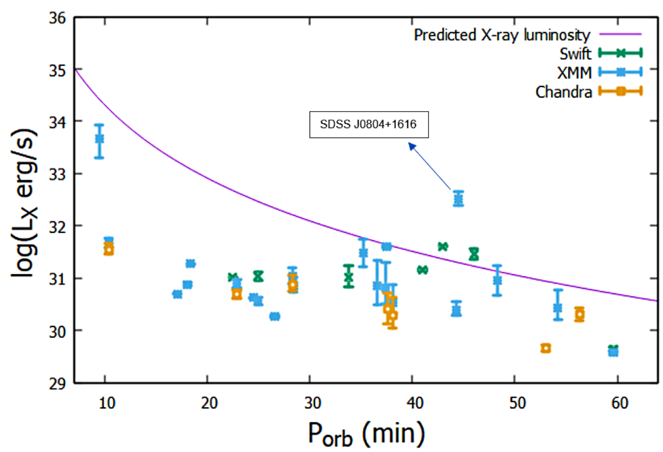

Figure 1. X-ray luminosity versus orbital period of selected AM CVn systems from Table 1.

Our primary analysis involved plotting the x-ray luminosity versus the orbital period for the sample of AM CVn systems. Figure 1 shows a comparison between the observational data and a model prediction for x-ray luminosity from van Haaften *et al.* (2012),

$$L = \frac{GM_a}{2R_a}\cdot\frac{48}{5}\cdot\frac{G^{2/3}}{2c^5}\cdot\frac{M_a(9\pi)^2\cdot 10^{-6}\,M_\odot R_\odot^3}{\left(M_a+\dfrac{9\pi\cdot 10^{-3}\sqrt{\dfrac{M_\odot R_\odot^3}{2G}}}{P_{orb}}\right)^{1/3}}\cdot\frac{(2\pi)^{8/3}}{P_{orb}^{14/3}} \quad (1)$$

where M_a is the mass of the accretor, P_{orb} is the orbital period, and R_a is the radius of the accretor over the observed data. For plotting the predicted x-ray luminosity, we substituted the value of M_a as 0.8 $M_\odot$ from the work by Wong and Bildsten (2021)and

Table 1. AM CVn systems in this study.

Star System	P_{orb} (min)	Log (x-ray luminosity) (erg/sec) XMM	Chandra	Swift	Distance (parsec) Best Estimate	b_{pc} (16%)	B_{pc} (84%)
V407 Vul	9.5	33.66	—	—	4813.76	3214.56	6584.68
ES Cet	10.4	31.67	31.55	—	1786.57	1612.83	2013.34
AM Cvn	17.1	30.7	—	—	300.02	297.24	303.06
SDSS J190817.07+394036.4	18.1	30.88	—	—	968.33	935.96	1004.87
HP Lib	18.4	31.28	—	—	277.91	275.38	280.4
TIC 378898110	20.5	—	—	31.02	309.3	307.5	311.1
CX361	22.9	30.9	30.69	—	963.45	878.92	1058.7
CR Boo	24.5	30.63	—	—	349.55	344.79	353.67
KL Dra	25	30.56	—	31.04	907.92	829.11	985.06
V803 Cen	26.6	30.27	—	—	284.08	279.26	290.12
YZ LMi	28.3	31.04	30.89	—	815.72	694.03	994.31
CP Eri	28.4	30.86	—	—	725.62	623.87	874.06
V406 Hya	33.8	—	—	31.02	753.68	616.76	966.01
SDSS J173047.59+554518.5	35.2	31.49	—	—	1317.93	977.98	1771.03
V558 Vir	36.6 (sh)	30.86	—	—	1548.05	1015.78	2692.72
SDSS J124058.03-015919.2	37.4	30.81	—	—	764.3	544.51	1358.88
NSV1440	37.5 (sh)	31.6	—	—	1861.73	1814.65	1917.21
SDSS J172102.48+273301.2	38.1	30.54	30.29	—	674.02	510.86	997.94
V493 Gem = ASASSN-14mv	41 (sh)	—	—	31.15	247.06	240.59	253.23
QX Eri = ASASSN-14ei	43 (sh)	—	—	31.61	256.89	253.71	259.87
SDSS J152509.57+360054.5	44.3	30.4	—	—	538.6	469.63	639.85
SDSS J080449.49+161624.8	44.5	32.51	—	—	998.97	865.22	1184.42
SDSS J141118.31+481257.6	46	—	—	31.46	452.01	397.95	502.2
SDSS J090221.35+381941.9	48.3	30.96	—	—	709	512.44	976.22
SDSS J120841.96+355025.2	53	—	29.66		210.7	198.89	223.64
SDSS J164228.06+193410.0	54.2	30.42	—	—	554.84	432.7	824.24
SDSS J155252.48+320150.9	56.3	—	30.31	—	422.52	369.72	481.38
SDSS J113732.32+405458.3	59.6	29.58	—	29.64	209.06	199.36	218.5

Notes: b_{pc} and B_{pc} refer to the lower and upper limit in the uncertainty in the the distances, respectively; (sh) indicates that the orbital period was derived from superhumps.

that the luminosity generated in the boundary layer is one-half of the total accretion power, and that all of the boundary layer luminosity goes into x-rays and the evolution of ultra-compact binaries by Nelemans *et al.* (2004); van Haaften *et al.* (2012).

We conduct a Spearman's rank correlation test for the sources that have the orbital period greater than 30 minutes, yielding a correlation coefficient of –0.48235 with a two-tailed p-value of 0.05846. This suggests a marginally significant association between the two variables. If we exclude the system SDSSJ0804+1616 and re-run the test, we obtained rs = –0.575, with a two-tailed p-value of 0.02494, again marginally significant.

Our findings also indicate that, at short orbital periods, the accretion rates are high enough to keep the system in a state at which the system is constantly accreting material from its companion star at a very high rate, where the boundary layer is optically thick. In this regime, the x-rays produced at the white dwarf surface are thermalized into UV photons, leading to suppression of the x-ray emission, as seen in transient outbursts in dwarf novae (Wheatley *et al.* 2003).

Two systems stand out as overluminous relative to the trend of sources at similar orbital periods. One is V407 Vul, the shortest period object, which is a direct impact accretor (Marsh and Steeghs 2002), which may lead to a higher fraction of its accretion power coming out in x-rays. The other is SDSS J0804+1616, which shows a strong magnetic field for the accretor, which may drive its orbital evolution to be faster than that due to gravitational radiation (Maccarone *et al.* 2023).

3. Conclusion

In conclusion, we observe that AM CVn systems with short orbital periods have x-ray luminosities below those from literature model predictions, but which, in hindsight, should have been anticipated given the expectation that bright systems will have optically thick boundary layers. We find a clear anti-correlation between x-ray luminosity and orbital period for the longer orbital period systems, in agreement with the theoretical expectations for the accretion process in these systems.

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