X-Ray Spectroscopy and Photometry of the long-period polar AI Tri with *XMM-Newton*

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Abstract

Based on *XMM-Newton* observations, covering for the first time uninterruptedly a complete binary orbital period, we present our spectroscopic and photometric analysis of the long-period magnetic cataclysmic variable AI Tri. More than about 70% of the binary orbit are dominated by soft X-ray emission from the heated surface of the White Dwarf with a highly variable flaring light curve. The associated spectral component can be described in good approximation by a mildly absorbed blackbody component with $kT_{\rm bb} = 35.8^{+1.5}_{-1.5}\,{\rm eV}$ and $N_{\rm H} = 3.66^{+0.43}_{-0.47}\cdot 10^{20}\,{\rm cm}^{-2}$. In addition, weaker hard X-ray emission is visible nearly all the time. The hard spectral component, originating from the diffuse hot plasma in the post-shock accretion column, is described by a MEKAL model with a mean temperature of $kT_{\rm Mekal} = 13.5^{+5.4}_{-2.5}\,{\rm keV}$ and three times solar abundance. The ultraviolet light curve obtained with OM has a similar shape but a higher amplitude than the optical light curves during high states of accretion. In contrast to that, the EPIC/PN X-ray light curve shows a broad dip in the soft X-ray regime during the bright phase, which can be interpreted as self-absorption in the accretion stream. Phase-resolved spectral modeling supports the picture of one-pole accretion and self-eclipse.

White Dwarfs in Magnetic CVs

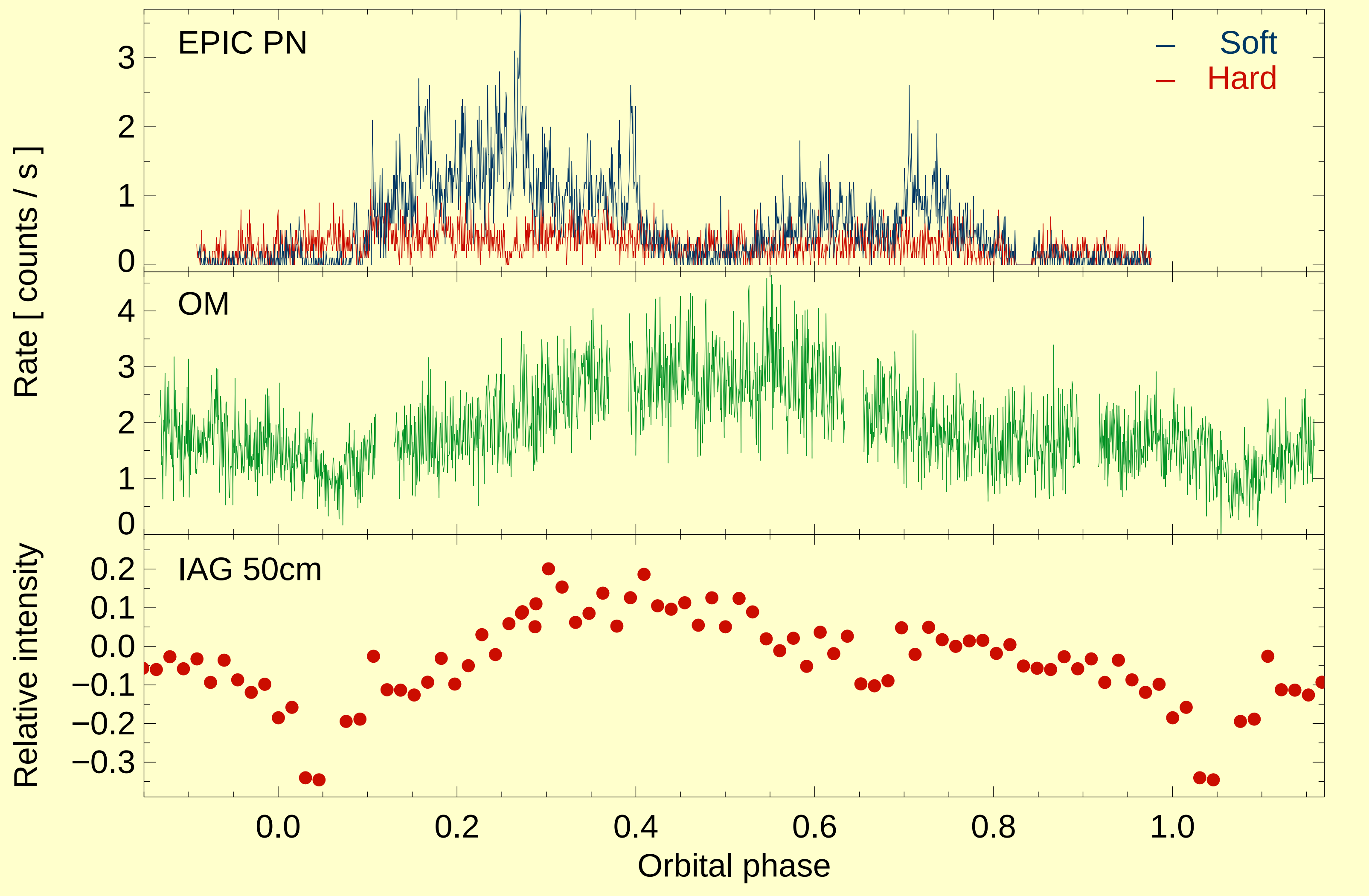
Magnetic Cataclysmic Variables (MCVs) may be called "children" of the era of X-ray astrophysics, as their vast majority has been discovered in recent X-ray surveys. They consist of an accreting White Dwarf, accompanied by a late type secondary filling its Roche lobe and donating mass to the primary. Influenced by the strong magnetic field ($7-230\,{\rm MG}$) of the primary, the accretion stream follows the magnetic field lines and reaches the White Dwarf in the immediate vicinity of its magnetic poles. The accreted material, decelerated above the primary's surface and heated to about $10^8\,{\rm K}$, forms a strong shock in the flow. The flux maximum of the emitted radiation lies in the hard X-ray regime, whereas the heated surface of the White Dwarf is mainly seen in the soft X-ray or UV, producing a quasi-blackbody component in the spectrum. Several systems show an unexpected dominance of soft over hard X-ray emission, which is believed to be linked to a high magnetic field, when cyclotron emission becomes the main cooling process (e. g. Beuermann & Burwitz 1995). A remarkable soft X-ray excess is shown by AI Tri. Its $P_{\rm orb} = 4.6\,{\rm hrs}$ is one of the longest known among MCVs; $B = 38 \pm 2\,{\rm MG}$ and $V = 18^{\rm m} - 15.5^{\rm m}$ are typical for this class (Schwarz et al. 1998).

Observation and Data Reduction

With *XMM-Newton*, we have obtained a $20\,{\rm ksec}$ exposure during a high state of AI Tri in August 2005. Simultaneously, the UV light curve at an effective wavelength of $231\,{\rm nm}$ has been measured with the UVM2 filter and the optical monitor used in timing mode. Light curves, spectra and images have been extracted making use of the *XMM-Newton* Software Analysis System. Large parts of the exposure are strongly affected by soft proton flares, excited by high solar activity. An analysis of the temporal, spatial and spectral variability of the background has shown that, owed to the high signal of the source, data quality is mainly sufficient for the analysis. Only the latest time interval of the observation where the satellite reaches the Van Allen radiation belt had to be excluded.

In addition, optical V-band and white light observations were performed during seven nights between November 2006 and March 2007 at the Göttingen 50 cm, the 1.2 m MONET/North (Texas), and the Tübingen 80 cm telescopes, when AI Tri was seen in high state and intermediate high state at an estimated brightness between $V = 16\overset{\rm m}{.}5 - 15\overset{\rm m}{.}5$. For data reduction and photometry, we have used TRIPP (Schuh et al. 2003) and Midas routines.

X-ray, UV and optical light curves



Background subtracted and barycentrically corrected EPIC/PN, ultraviolet OM and optical V-band light curves. The red curve in the upper panel shows the variations of the high ($E \geq 0.5\,{\rm keV}$), the blue one those of the low energy component ($E \leq 0.5\,{\rm keV}$). The optical data, obtained at the Göttingen 50 cm telescope in November 2006, has been plotted twice for clarity.

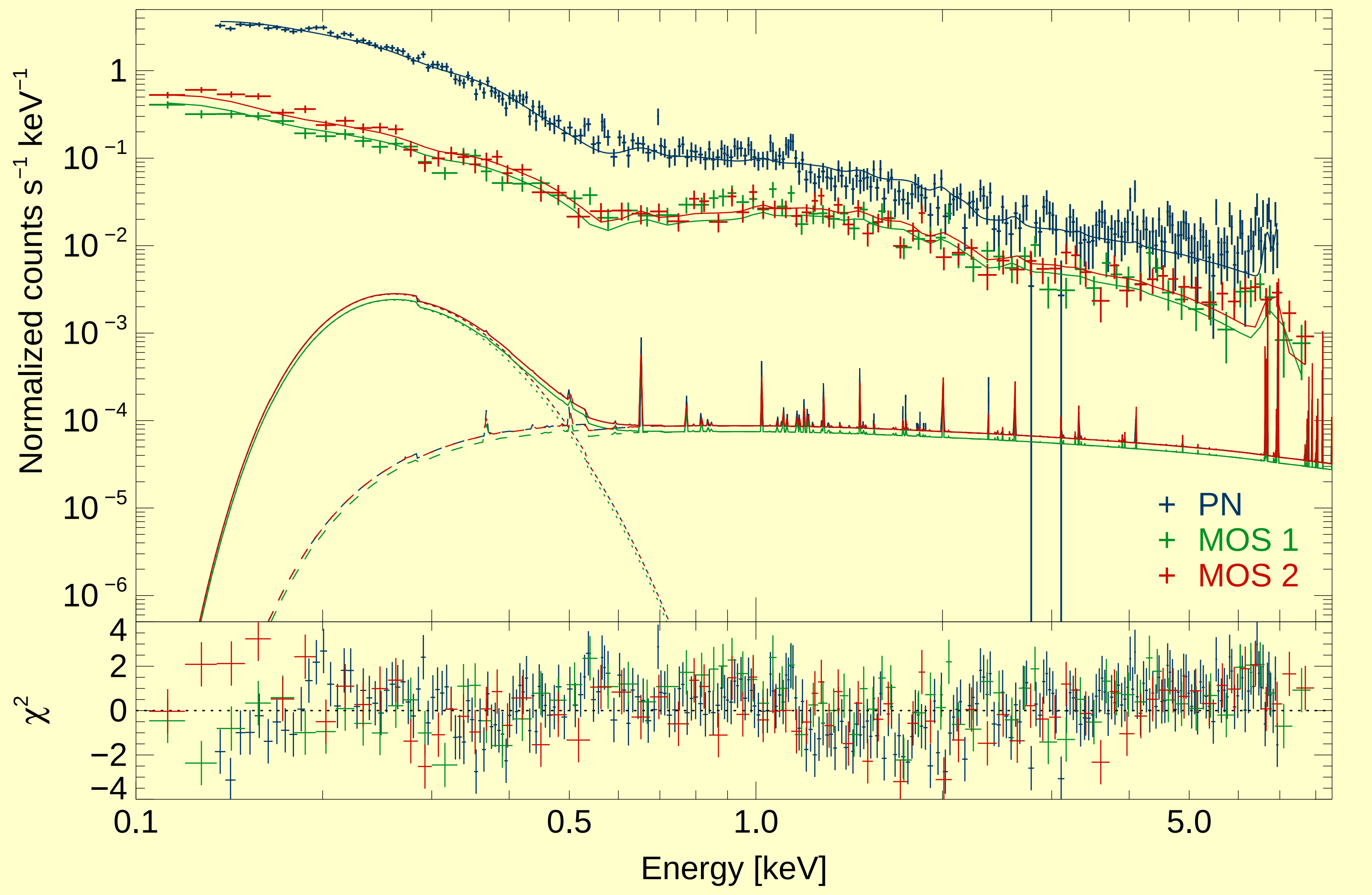
The optical light curve of AI Tri in high state is dominated by the non-sinusoidal variation with orbital period and a slightly asymmetric shape with steeper rise and smoother decline. An irregular pattern of small dips is superposed, with one dip in the midst of the minimum and one close to the maximum of the light curve. Using timings of four new V-band minima mapped between November 2006 and March 2007 and the data published by Schwarz et al. (1998), we determined the improved ephermeris to

$$\mathbf{HJD} = 2451135\overset{\rm d}{.}1217(21) + 0\overset{\rm d}{.}1917453(3) \cdot E \quad .$$

From our 20 ksec *XMM-Newton* exposure, we extracted the first continuous UV and X-ray light curves, covering a full binary orbital period. The ultraviolet light curve, obtained in the UVM2 filter at an effective wavelength of 231 nm, has a similar shape but higher amplitude than our optical light curves during high states of accretion and those presented by Katajainen et al. (2001) and Schwarz et al. (1998).

The shape of the X-ray light curve is characterized by strong flares and high variability on short time scales, as typical for soft polars. These bright flares occur mainly in the soft energy range during about 70% of the phases, whereas hard X-ray emission is present at a low level during most of the time. This shape is consistent with the ROSAT light curve as described by Schwarz et al. (1998), who interpret the flaring pattern as an indication of blobby accretion.

X-ray Spectroscopy of AI Tri



EPIC spectra extracted from the $20\,{\rm ksec}$ exposure of the magnetic cataclysmic variable AI Tri. The model consists of a mildly absorbed blackbody at $kT_{\rm bb} = 35.8^{+1.5}_{-1.5}\,{\rm eV}$ and $N_{\rm H} = 3.66^{+0.43}_{-0.47}\cdot 10^{20}\,{\rm cm}^{-2}$ and a MEKAL plasma emission with $kT_{\rm Mekal} = 13.5^{+5.4}_{-2.5}\,{\rm keV}$ and $3.35^{+1.39}_{-1.08}$ times solar abundance.

The X-ray spectra of AI Tri obtained with the EPIC PN, MOS1, and MOS2 detectors have been fitted with a multi-component XSPEC model, consisting of an absorbed blackbody, associated with the accretion-heated surface of the White Dwarf, plus bremsstrahlung or cooling plasma emission, representing the diffuse hot plasma in the post-shock region. The best fit ($\chi^2 = 1.48$ for 426 degrees of freedom) has been achieved with a MEKAL emission model (e. g. Mewe et al. 1985; Liedahl et al. 1995). In the soft X-ray range below $0.5\,{\rm keV}$, the spectrum is dominated by a blackbody-like component at $kT_{\rm bb} = 35.8^{+1.5}_{-1.5}\,{\rm eV}$, only slightly affected by interstellar and intrinsic absorption ($N_{\rm H} = 3.66^{+0.43}_{-0.47}\cdot 10^{20}\,{\rm cm}^{-2}$). The energy range between $0.5\,{\rm keV}$ and $8.5\,{\rm keV}$ has been described by MEKAL emission with a mean temperature of $kT_{\rm Mekal} = 13.5^{+5.4}_{-2.5}\,{\rm keV}$ and $3.35^{+1.39}_{-1.08}$ times solar abundance. Our error estimates correspond to the 90% level.

Phase-resolved spectral modeling results in almost identical fits for the two broad maxima in the soft X-ray light curve. No appreciable variation in the hydrogen absorption $N_{\rm H}$ may be noticed between time intervals with soft and hard radiation dominating respectively. The small number of counts during minima of the soft component, however, rules out a reliable fit to the faint-phase emission. Hence it cannot definitely be stated, if $N_{\rm H}$ is mainly of interstellar origin or intrinsic in the system.

Discussion

Our best fit blackbody plus MEKAL model yields the typical parameters of the high-energy distribution of CVs. Using the distance estimate of AI Tri (Schwarz et al. 1998) results in an unabsorbed blackbody luminosity of $L_{\rm bb} = 7.7 \cdot 10^{32} (d/620{\rm pc})^2\,{\rm erg/s}$, an emitting surface area with $R_{\rm bb} \approx 190 (d/620{\rm pc})^2\,{\rm km}$ and a total integrated flux in the spectral fit range of $F_{\rm X} = 1.6 \cdot 10^{-12}\,{\rm erg/s}$ $(0.1 - 10\,{\rm keV})$. The integrated fluxes of the individual model components indicate an approximate flux balance of $F_{\rm bb} : F_{\rm Mekal} \approx 10 : 1$.

Based on the available data, the system geometry remains uncertain. If the minimum in the soft X-ray light curve around phase 0.5 is a persistent feature, the most likely scenario is a one-pole accreting White Dwarf which undergoes a self-eclipse of the accretion region. This interpretation would be consistent with the phasing of the UV and optical light curves as well as the results of our phase-resolved spectroscopic analysis. The permanent hard X-ray emission however, nearly constant over the whole orbital cycle including the faint phase, might also be a sign for the existence of a second independent accretion region in AI Tri. Despite the striking highly variable structure of the high-resolved X-ray light curve, individual accretion events ("blobs") cannot be identified. Further spectroscopic and photometric multi-wavelength observations are inevitable before a definite statement about the geometry of the system can be made.

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