A simultaneous X-ray and optical study of TT Arietis during its active state. X-ray observations and discussion.

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Abstract. We present results of X-ray observations of TT Ari with the EXOSAT satellite on August 21/22, 1985. This paper represents the second part of the publication of the results obtained with our extended program of optical monitoring and simultaneous optical and X-ray observations of TT Ari. For the first part, which includes optical results, see Wenzel et al. (1992). Optical photometric and partly spectroscopic data were obtained at more than 10 observatories.

The measurements were carried out immediately after the return of TT Ari to its optically active (high) state after being more than 5.5 years in the very low state. The results represent the first detailed simultaneous X-ray and optical study of TT Ari in the high state.

The most important results of our analysis are (i) the mean X-ray flux was found to be surprisingly stable over long time intervals, not changing by more than several tens of per cent and not reflecting the large optical intensity changes between the active and inactive states and (ii) absorption dips were detected in the light curve. The results are discussed from the point of view of the model of the system.

Key words: Stars: novae and cataclysmic variables

1. Introduction

For general information about TT Ari, now thought to be an accreting (magnetic?) white dwarf in a low-mass binary, see Wenzel et al., (1992). For a detailed account about our extended optical program of monitoring TT Ari and gathering quasi-simultaneous and simultaneous optical data of it see Wenzel et al. (1986) and Wenzel et al. (1992).

The EXOSAT X-ray observations of TT Ari, supplemented with optical measurements at 10 observatories, were performed on August 21/22, 1985, immediately after the return of TT Ari to its active state after being in the optically inactive very low state(superminimum) for more than 5.5 years(Hudec et al., 1984, Wenzel et al., 1992). This quite exceptional "superlow" state with a decline down to 16.5 mag superimposed on rather large light variations has resulted in the fact that the active (A) state measurements are more rare than the inactive (I) ones. Actually, no previous X-ray detection of TT Arietis in a genuine A state exists.

We observed TT Ari using LE2 soft X-ray telescope with a channel multiplier array (CMA) as focal detector (de Korte et al., 1981) and the ME medium energy experiment (Turner et al., 1981) on the EXOSAT satellite for 11 hours. The low energy telescope was used with the 3000 lexan and the aluminium/parylene filters. The thin lexan filter was primarily used to monitor the source intensity, while the Al/Pa filter was used to obtain the additional data necessary to achieve broad band spectral information in the soft X-ray band. Half of the medium energy detectors were offset throughout the observation in order to monitor the background. The GSPC detector was also available, but without any source detection. The source was surprisingly faint, resulting in some difficulties in evaluation and analysis of the data.

A review of all published X-ray observations of TT Ari together with our results is presented in Table 1. It is evident (see also Wenzel et al., 1992) that our measurements represent the first detailed X-ray results of this source in a genuine optically high state.

The journal of our LE and ME EXOSAT observations is presented in Table 2 and 3, respectively. It should be noted that the evaluation of the ME data was affected by the failure of the detector C.

The position of TT Ari was estimated from the LE soft X-ray data as follows:

$$\mathrm{RA} = 02^{\mathrm{h}}\ 04^{\mathrm{m}}\ 9.7^{\mathrm{s}}\ ,\ \mathrm{D} = 15^{\circ}\ 03'\ 26.4''\ (1950.0)\ (\mathrm{error}\ 10'')$$

In this paper after the presentation of the journals of X-ray observations, we give in detail measured X-ray fluxes (Section 2) and X-ray light curves (Section 3). The X-ray spectra are given and discussed in Section 4 following by a discussion of the results obtained (Section 5, 6) and the conclusions (Section 7).

2. The X-Ray Fluxes

The LE and ME X-ray count rates detected, in corrected detector counts per second, are given in Tables 2 and 3.

2.1. LE Fluxes

Considering the thermal bremsstrahlung spectrum and Gaunt factor model with $T \approx 10$ keV and $N_H \approx 1\mathrm{x}10^{21}\ \mathrm{cm}^{-1}$, as well as the absorption model by Morrison and McCammon (1983), the average source fluxes at the Earth corresponding to the count rates given in Table 3 are $\approx 10^{-11}$ erg $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ in the (0.05-2) keV energy range or $\approx 2\mathrm{x}10^{-11}$ erg $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ in the same energy range after a correction for interstellar absorption. To make comparisons with previous X-ray observations possible, the average X-ray flux was estimated also in the (0.2-4) keV range and found to be $\approx 1.9\mathrm{x}10^{-11}$ erg $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ at the Earth or $\approx 2.6\mathrm{x}10^{-11}$ erg $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ after a correction for interstellar absorption, respectively. For the energy band (0.15-4.5) keV we get $\approx 2.1\mathrm{x}10^{-11}$ erg $\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ at the Earth and $\approx 2.8\mathrm{x}10^{-11}$ after a correction for interstellar absorption.

Table 1. Review of X-ray observations on TT Ari

Date	Instrument	X-ray flux [erg cm^{-2}s^{-1}] (range in keV)	Mean Spectrum 0)	State Opt. 10) Magnitude
Jan 23/25, 1978 1)	HEAO - 1	$<5\text{x}10^{-11}$ (0.48 – 2.8) not detected		A 9 m $\sim$10.6 2)
July 23, 1979 3)	Einstein IPC	$1.4\text{x}10^{-11}$ (0.15 – 4.5)	kT$\sim$10 ? NH$\sim$1x10^{20}?	m = 10.5 4) A 9 (end) or A 9/I 9 (transition) m = 11.3 9)?
July 19/20, 1980 5)	Einstein IPC Einstein MPC	$2\text{x}10^{-11}$ (0.2 – 4.5) $2.5\text{x}10^{-11}$ (2 – 10)	kT $\geq$ 10 NH$\sim$1x10^{21} kT $\geq$ 10	I 9 m = 11.7
Dec 2, 1983 6)	EXOSAT ME EXOSAT LE	not detected		I 9 m > 13.5
Dec 6, 1983 6)	EXOSAT ME EXOSAT LE	not detected		I 9 m > 13.5
Jan 18, 1985 6)	EXOSAT ME EXOSAT LE	$\sim1\text{x}10^{-11}$ (2 – 10) 7) $\sim1\text{x}10^{-11}$ (0.05 – 2) 7)		I 9 m > 13
Aug 21/22, 1985 8)	EXOSAT ME EXOSAT LE	$9\text{x}10^{-12}$ (2 – 10) $1\text{x}10^{-11}$ (0.05 – 2) (0.2 – 4)	kT = 6$\pm$2 NH=1x10^{21} kT $\geq$ 6 NH=1x10^{21}	A 10 m = 10.75

Remarks to the Table 1:

0) thermal bremsstrahlung spectrum plus Gaunt factor; kT in keV, column density NH in cm−2

1) Cordova et al., 1981

2) Hudec et al., 1984

3) Cordova, Mason and Nelson, 1981. Very short measurment.

4) Immediately before or at beginning of transition from active state I 9 according to Hudec et al., 1984. Photographic measurements indicate that the last active point occured on JD 244 3926 and the first transitional point on JD 244 4116 (date of Einstein measurement JD 244 4078). Wargau et al., 1982 give m_v=11.3 for JD 244 4067 indicating that the transition was already in progress and that the optical estimate given by Cordova, Mason and Nelson, 1981, may be inaccurate.

Table 1. Remarks to the Table 1 (cont.)

5) Jensen et al., 1983
6) Beuermann, 1985
7) estimation based on mean count rates
8) present work
9) magnitude given by Wargau et al., 1981 for July 12, 1979
10) classification of active (A) and active (I) optical states of the system according to Hudec et al. (1984).

Table 2. Journal of EXOSAT LE observations

Date	UT	λ[Å]	Counts s^{-1} +)	Filter
1985 Aug.21	16^h40^m-19^h53^m	6.5-210	0.016±0.002	3000 Lexan
1985 Aug.21	19^h57^m-23^h16^m	6.9- 95 155-310	0.0096 ±0.0014	Al - Pa
1985 Aug.21/22	23^h19^m-02^h59^m	6.5-210	0.014 ±0.001	3000 Lexan

Remark:
+) source intensity corrected for point spread function, sampling dead time, vignetting

Table 3. Journal of EXOSAT ME observations

Date	UT	mean Counts s^{-1} x)	Detector
1985 Aug. 21	16^h18^m-19^h58^m	0.81±0.12	half 1 +)
1985 Aug. 21	20^h09^m-22^h37^m	1.11±0.09	half 2
1985 Aug. 21/22	22^h50^m-03^h03^m	0.68±0.12	half 1

Remarks:
+) a failure of detector *c* occurred during the measurement. The measured flux was corrected for this failure.
x) the count rates (± 1...) are given per detector half for each observation for the energy interval 1 - 20 keV.

2.2. ME Fluxes

TT Arietis was also detected by the ME experiment at a mean 2-20 keV count rate of (0.81±0.06) cts s^{-1} in the 4 argon detectors pointed at the source (area $\approx$ 750 cm^2; for details see Table 3). The ME observations were carried out using a standard mode in which data with full energy resolution from all ME detectors are accumulated with a time resolution of 10 s. Four of the ME detectors were offset mechanically by 2° in order to obtain simultaneous background measurements. The offset detectors were interchanged between observations 1, 2 and 3, respectively (see Table 3). The background subtraction was performed using the offset half count rate, after a correction for the observed difference between the halves during the source-free slew periods. The mean X-ray flux was estimated $\approx$ (7±2) x 10^{-12} erg cm^{-2} s^{-1} in the (2-10) keV energy range.

3. The X-ray light curves

The soft (LE) and hard (ME) X-ray light curves covering more than 3 orbital periods were obtained.

3.1. The LE light curves

The count rate recorded as a function of time integrated in 400 (800) second bins is illustrated in Figs. 2, 3 and 4 .

Although the source proved to be faint, a test based on the use of a test box without any source has indicated that the larger structures seen in the light curves of TT Ari may be considered as real. Although the X-ray energy flux is low, a test using a test box without any source has resulted in the fact that the average residual intensity was of the order of $\approx$ 0.3 x 10^{-2} cts s^{-1} at the time of our measurement and the scatter does not exceeded $\approx$ 0.02 cts s^{-1} in amplitude. Hence, some of the structures visible in the X-ray light curve such as the 3 maxima seen in the LE light curve for the observation 1 which reach $\approx$ 0.05 cts s^{-1} as well as flickering are real (for the flickering also the comparison with optical data proved the reality). On the other hand, the fluctuations seen at minima ($\approx$ 0.01 cts s^{-1} or lower) are to be considered as scatter only.

We see that the soft X-ray light curve of TT Ari is rather complicated in the A state, far from what would be expected from the varying aspect of the hot polar cap at the base of the accretion column.

The following variations in the soft X-ray light curves of TT Ari are:

- cycle-to-cycle non-periodic variations without an obvious modulation with the spectroscopic or photometric period. X-ray flux modulation up to $\approx$ 70%.
- intensive X-ray flickering related to optical fluctuations (see Wenzel et al., 1992 and Section 5.2). X-ray flux modulation up to $\approx$ 90%.

- possible absorption events (dips) lasting 5-15 minutes. X-ray flux modulation up to ≈ 100% - full decrease.

Although correlation of X-ray to optical flaring exists (see Section 5.2), there is no confirmation of the photometric or spectroscopic variation in our X-ray data; the X-ray light curve resembles the optical curve after subtracting of the photometric variation (Wenzel et al., 1986 and 1992).

3.2. The ME light curves

The source proved to be very faint in the ME detector, less than 1 cts s^{-1} and thus making detailed interpretation of the curves extremely difficult. The data could, however, be used to get some spectral information.

3.3. The dips

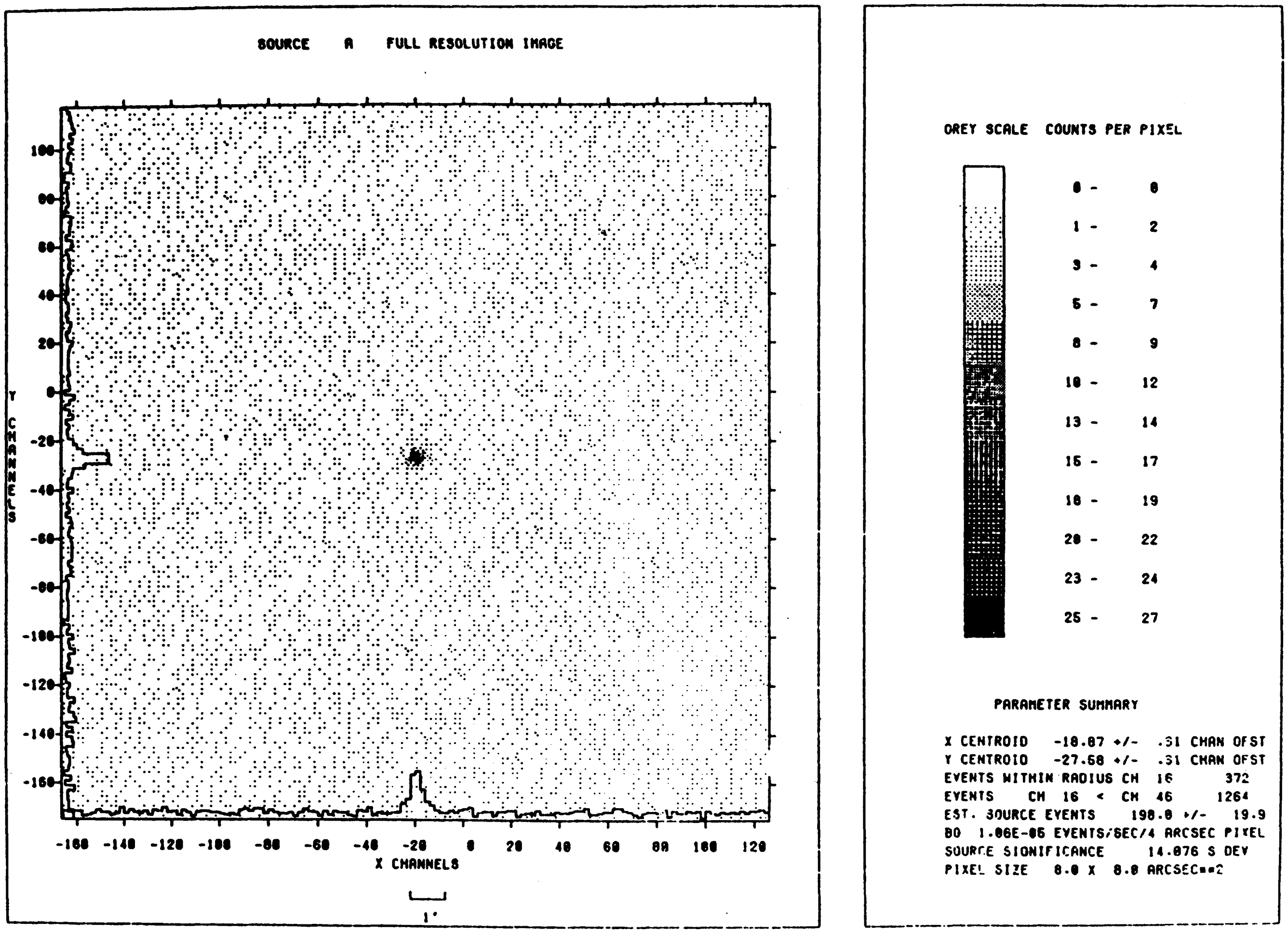
The evaluation of the LE data has resulted in the appearance of at least 2 possible X-ray dips (absorbing events) in the light curves, lasting between 5 and 15 minutes and having no obvious relation to the phase of the spectroscopic (orbital) variation.

The first dip occurred at nearly $16^h\ 50^m$ UT, August 21, the second at nearly 0^h UT, August 22 (Figs. 2 and 4).

Both the well pronounced dips appeared at the photometric period (according to Wenzel et al., 1992) phases 0.12 and 0.85, respectively, suggesting the possibility that the dips may occur near the photometric phase of 0. These dips were not seen - or are much less defined - in the ME data suggesting the energy -dependence of the events. On the other hand, the dips are also present in the optical data (see the optical dip at 0^h UT, which is correlated to the X-ray dip at the same time, in Wenzel et al., 1992 and Section 5.4).

The presence of analogous dips in the orbital light curve was already pointed out by Jensen et al. (1985) in both X-ray and optical light; their dip observed by the Einstein satellite lasted nearly 17 minutes but was not seen in other orbital cycles. This dip was also observed in optical light, but there it was shorter and delayed. Our optical data taken at the Sonneberg Observatory for the night 21/22 August, 1985 (see Wenzel et al., 1992) show clearly that the optical dip correlated to the ≈ 0^h UT X-ray absorption event is not a minimum between 2 peaks of flicker activity, but a real absorption dip below the average shape of the optical light curve.

These dips are probably due to the decrease of the photoelectric absorption by either mass stream between the components of the system or the accreting column, in line with the hypothesis that the photometric period is caused by the different viewing of the 'hot spot' (emitting region) and the maximum occurs when we are facing the top. This agrees well with our result that the dips occur nearly at Max. ± 0.2 in phase (we have observed the dips at 0.12 and 0.85; Jensen et al. (1983) at 0.21.



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PARAMETER SUMMARY

X CENTROID   -18.07 +/-  .31 CHAN OFST
Y CENTROID   -27.68 +/-  .31 CHAN OFST
EVENTS WITHIN RADIUS CH  16       372
EVENTS     CH  16  <  CH  46      1264
EST. SOURCE EVENTS     198.0 +/-   19.9
BO  1.06E-06 EVENTS/SEC/4 ARCSEC PIXEL
SOURCE SIGNIFICANCE      14.076 S DEV
PIXEL SIZE   8.0 X  8.0 ARCSEC**2
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Figure 1. Full resolution image of TT Ari, LE experiment. The X-ray source was detected at 14 σ level.

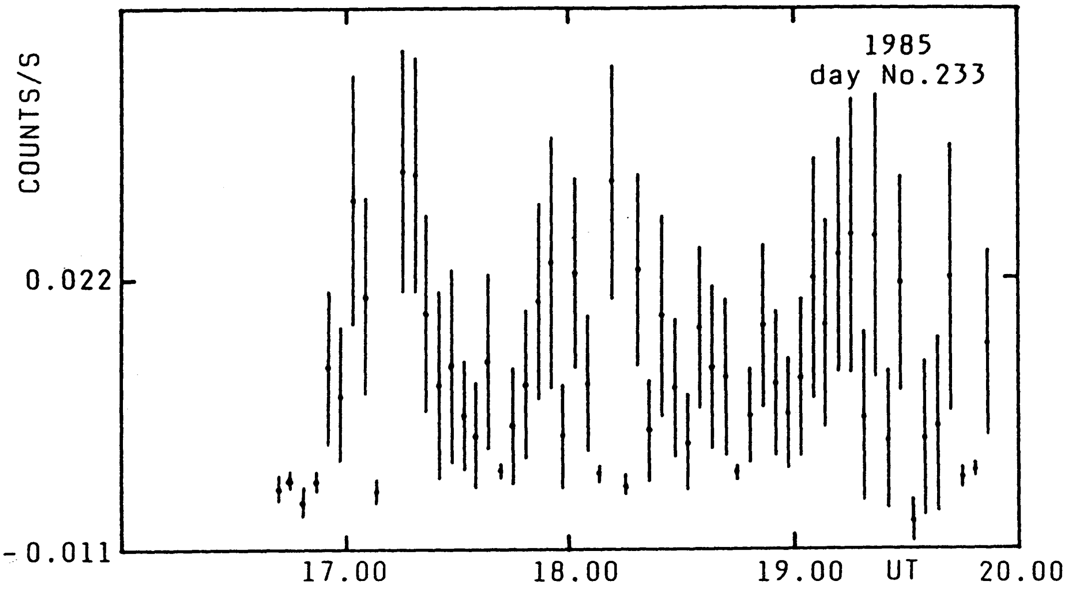

Figure 2. X-ray light curve, LE experiment, observation 1. Day 233 = August 21st, 1985.

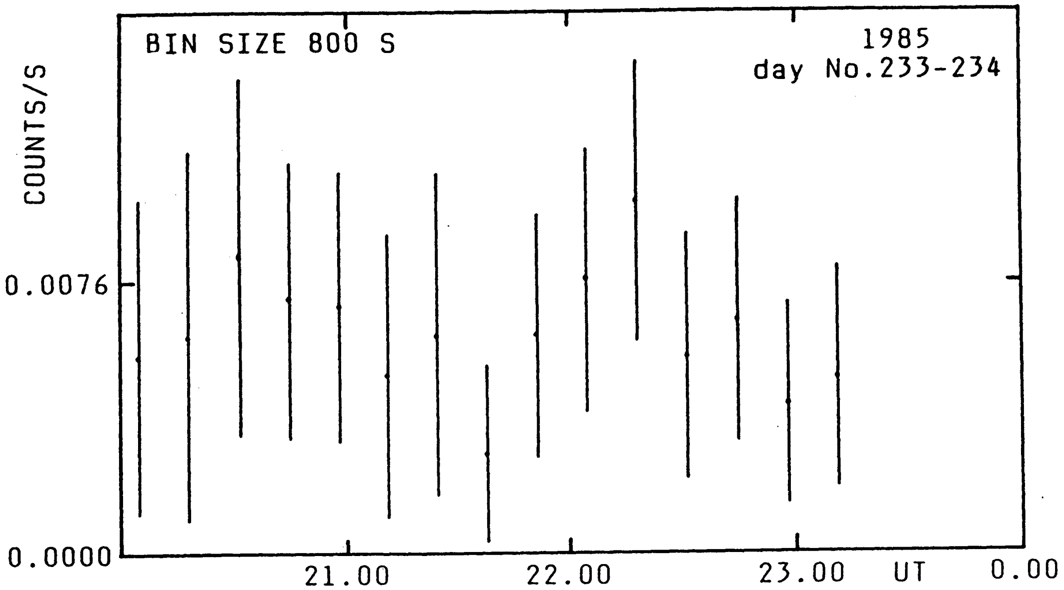

Figure 3. X-ray light curve, LE experiment, observation 2, bin size 800 s. Day 233 = August 21st, 1985.

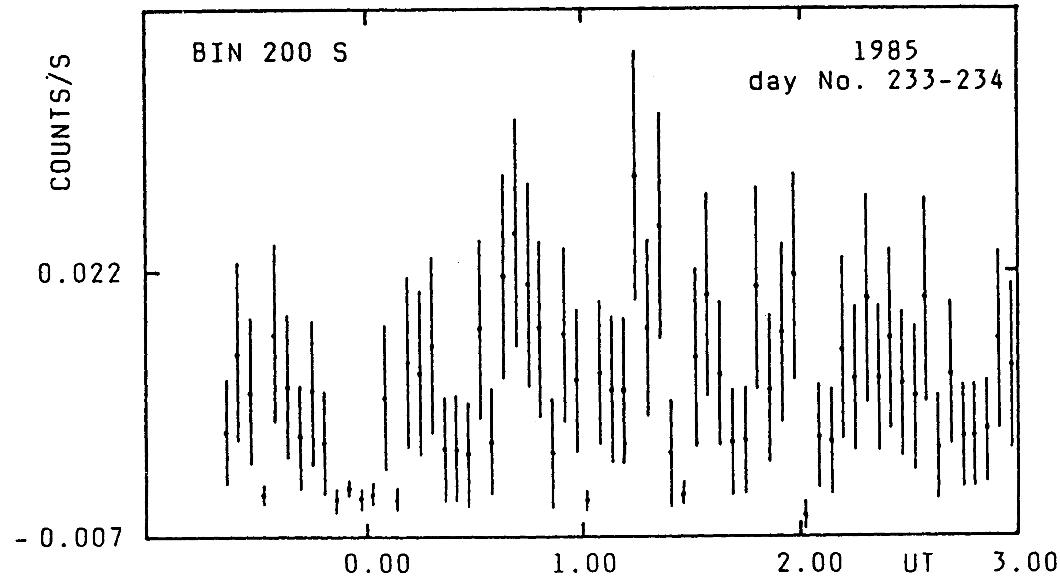

Figure 4. X-ray light curve, LE experiment, observation 3, bin size is 200 s. Day 233 = August 21st, 1985.

The correlation with optical dips will be given in more detail in Section 5.4. Some more dips were observed in optical data, but these observations are contaminated by artifacts (e.g. Hudec et al., 1989, and Tremko et al., 1991). As already mentioned, the absorption dips seem to occur near the maximum of the photometric variation. However, there may also be a hypothetical recurrence of the dips of $7^h\ 12^m$ or $3^h\ 36^m$ (resulting from the separation between both dips seen in the EXOSAT LE data). To verify this possibility, the data given by Jensen et al. (1983) were examined for the presence of other dips of the same period. Unfortunately, no other dip was found in the Einstein data because the times of possible events coincide with the gaps in the data.

Considering the accuracy available for obtaining the value of a possible dip recurrence period, the time interval between our dips and the dip observed by Jensen et al. (1983) is too large to allow confirmation or exclusion of the possible recurrence period.

3.4. The periods

Both LE and ME data were examined for possible periods and quasiperiods using the period search programs within the EXOSAT interactive analysis system. Possible periods were searched for in the interval from 100 to 13000 seconds.

The raw count rate of TT Arietis was found not to be clearly modulated with the photometric period. We have calculated the power spectra of the time series binned in 50 to 100 intervals.

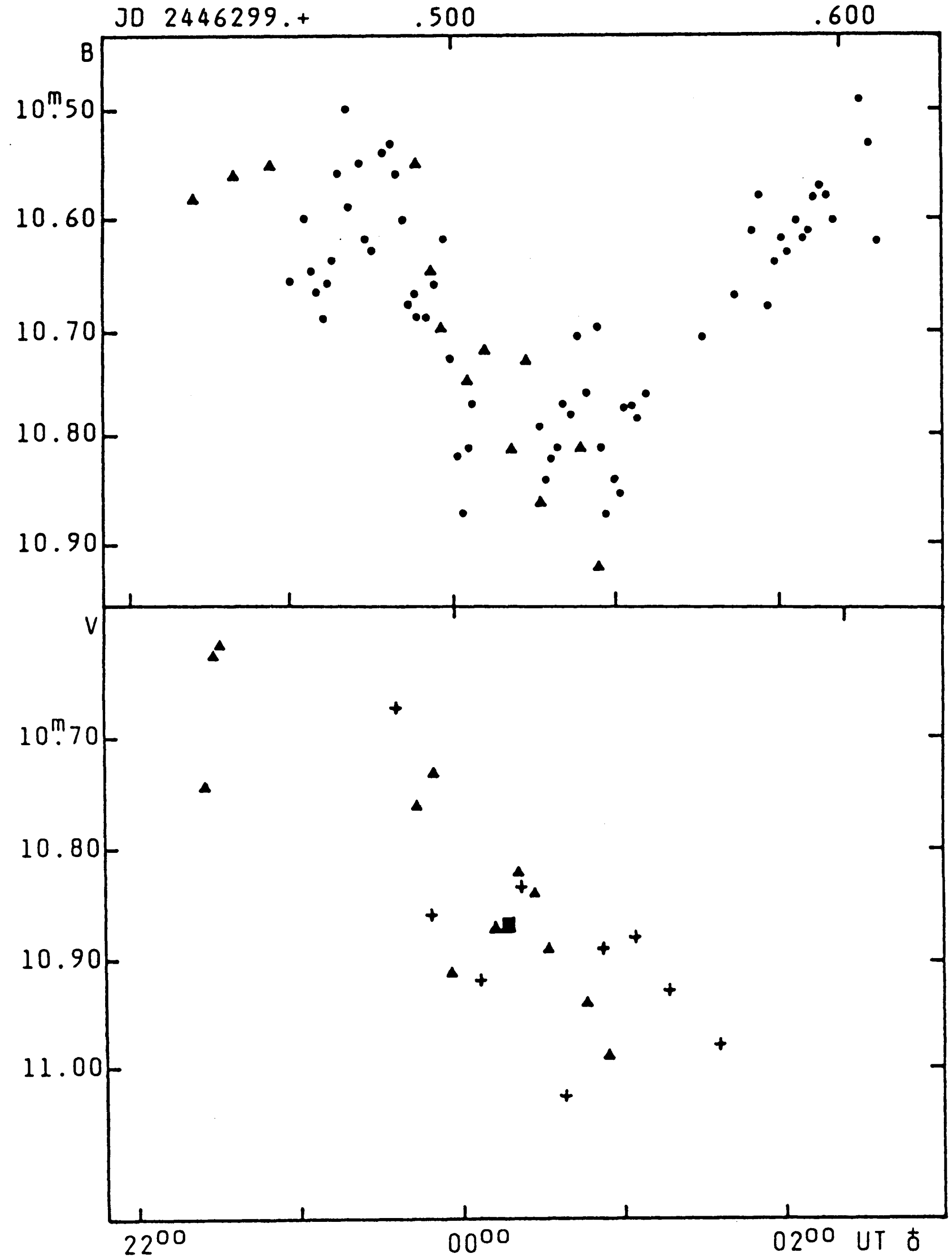

Figure 5. The simultaneous optical light curve corresponding to the X-ray curve plotted in Fig. 2. Points = Sonneberg photoelectric photometry, triangles = Bucuresti photoelectric photometry (corrected), crosses = Ondřejov photographic photometry (corrected). For more details and more simultaneous optical data see Wenzel et al. (1986, 1992).

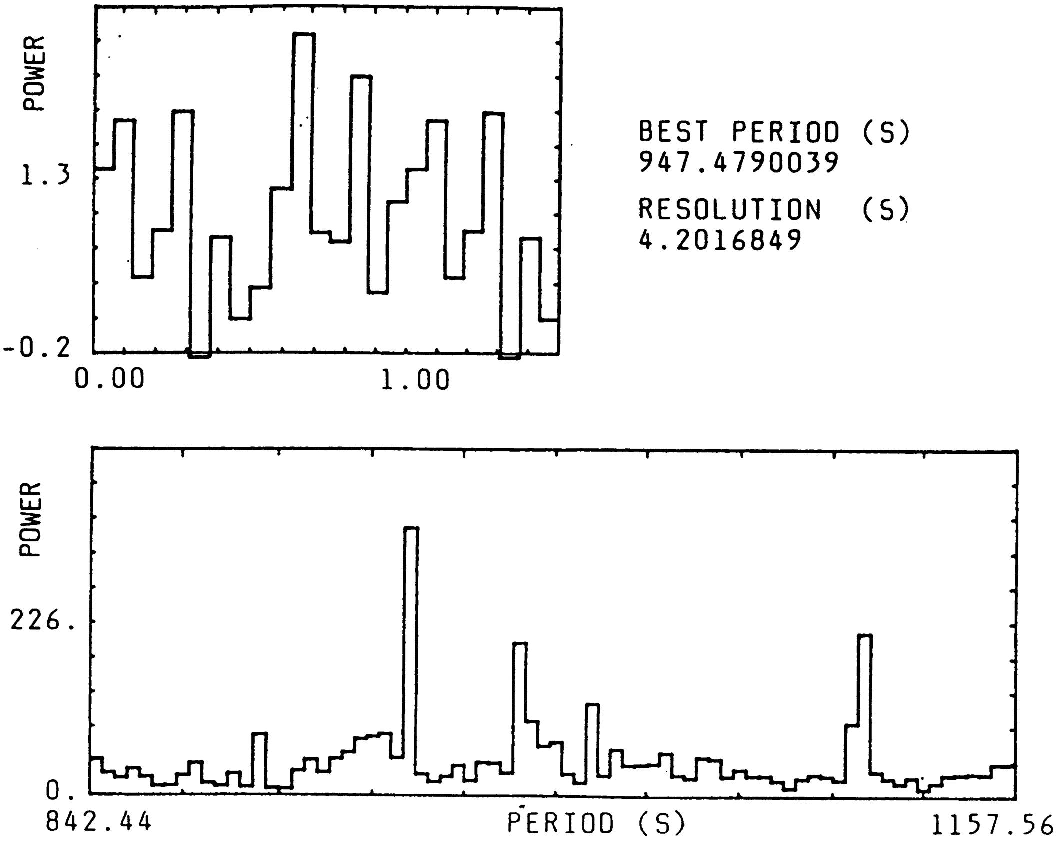

Figure 6. a) Periodogram based on the ME data, observation 1, for the range 840-1160 s, showing the peak corresponding to the possible quasiperiod 947 s.

No strict periodic phenomenon was found for the data set. Quasiperiodic variations were found to have periods close to 3600 and 1900 seconds (non-flickering changes) and 1000 and 500 s (flickering). For individual power spectra see Figures 6, 7 and 8. The interval on the X-axis is divided into 10 equal parts (Figs. 6,7,8).

4. The X-ray spectra

The LE and ME data were used to determine the spectral properties of the source.

4.1. The LE spectral information

Although the grating was not available for the 1985 spectral measurements using the LE telescope, some constraints can be derived from the ratio of count rates

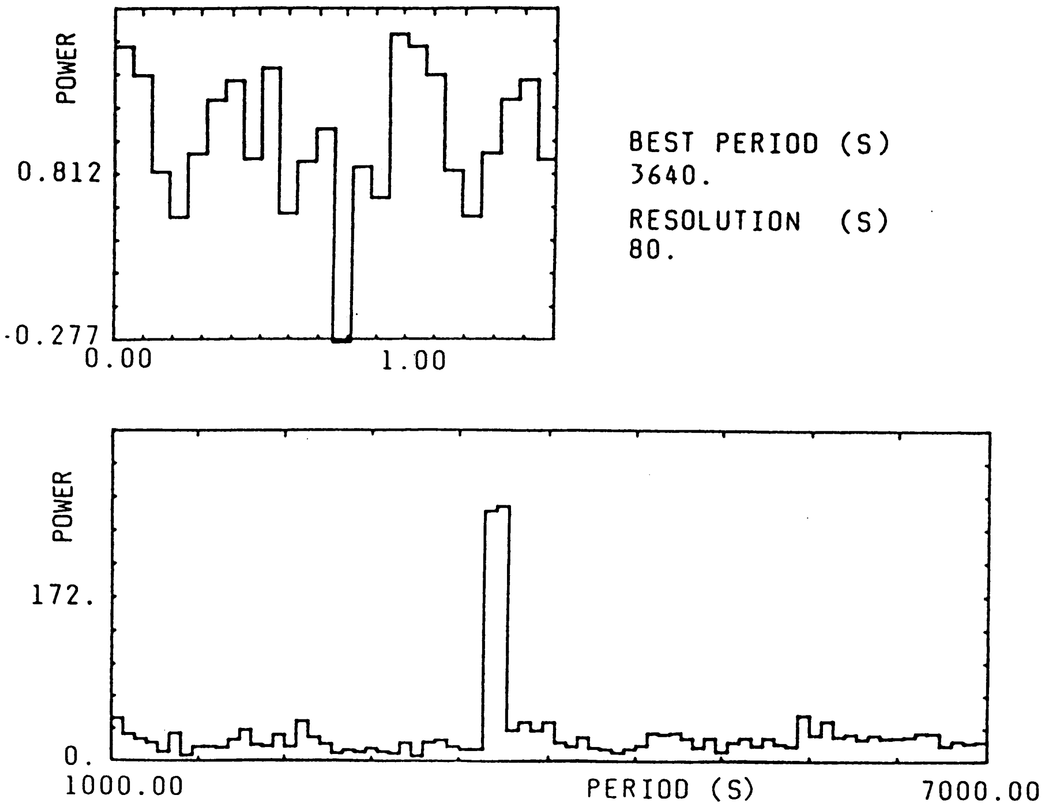

Figure 6. b) Periodogram based on the ME data, observation 1, for the range 1000-7000 s, showing the peak corresponding to the possible quasiperiod 3640 s.

in different filters. Using the count rates accumulated in the 3000 lexan and Al-Parylene filters (see Table 2) we obtain a mean "softness" ratio (cts s^{-1} Al-P/3 lexan) of 0.65 ± 0.1 indicating that the bulk of the flux is emitted in wavelengths below $\approx$ 170 Å and thus a not very soft spectrum. Thus the low energy spectrum is not like that of the AM Her objects. These typically have blackbody temperatures of 30-50 eV with $N_H \approx 10^{18}$ - 10^{20} in this energy range (e.g. Heise et al., 1982) and give Al-P/3 lexan count rate ratios of order of 0.1.

Moreover, the X-ray flux was plotted as a function of spectral parameters using program IFFIT in the EXOSAT interactive analysis to analyse the multi-spectral observations. In this process, one of the parameters determining the spectrum was fixed while the other was stepped in a range of values. We have fixed the column density, N_H, at 10^{21} cm^{-2}, which is the value derived from previous measurements (Jensen et al., 1983). This value of N_H corresponds to an admissible temperature range of $T > 6$ keV considering the thermal bremsstrahlung + Gaunt factor model (see Figures 9 and 10). The fact that no significant soft X-ray excess was detected in our data, in line with the results

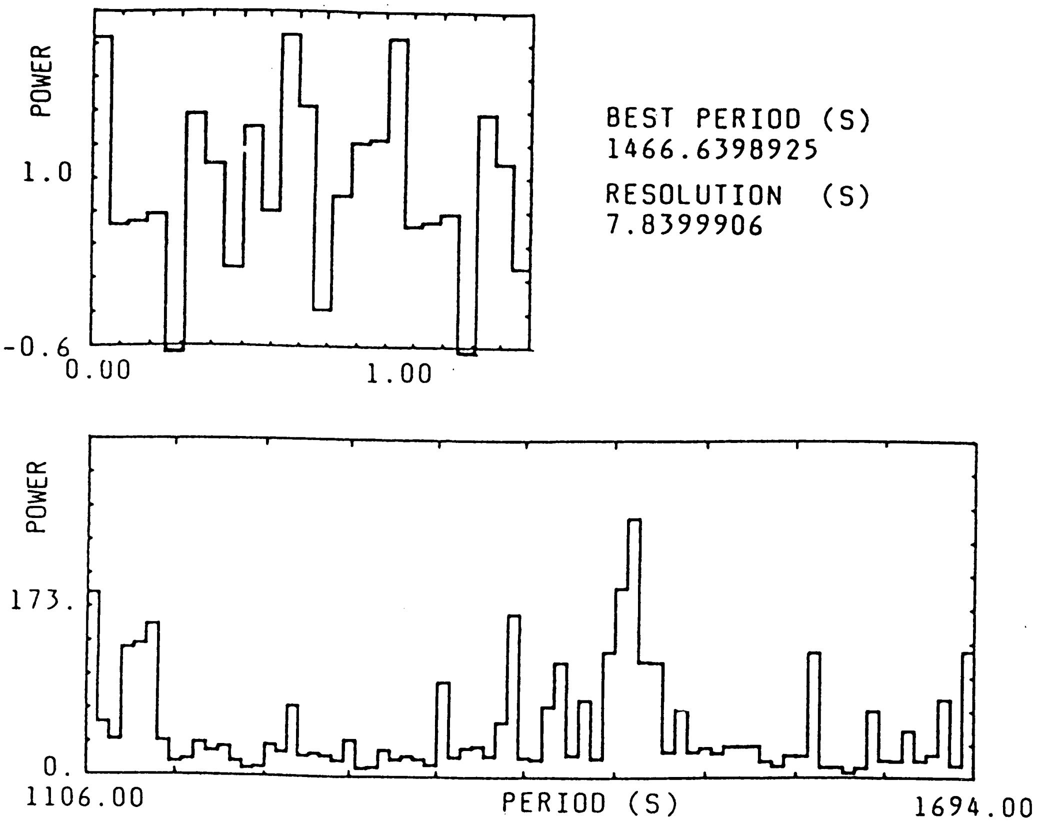

Figure 7. Periodogram based on the ME data, observation 1, for the range 1100-1700 s, showing the peak corresponding to the possible quasiperiod 1470 s.

expected for intermediate polars where a high intrinsic photoelectrical cutoff ($\approx$ 1 keV) generally may prevent any detection of soft X-ray flux ($<$0.1 keV) at all. Thus the soft X-ray component is totaly absorbed in the local cold material and we see only an escaping hard component.

4.2. The ME spectra

The ME spectral data were analysed both with EXOSAT automatic and interactive analysis. The channels of the pulse height analysis 1 to 64 in argon (1 - 20 keV) were taken into account; however, only the channels where a substantial flux was detected (channels 5 to 22) are significant.

An attempt to search for spectral variations was unsuccesfull in the time interval of our observations; however the sensitivity of the observation of weak sources is limited and depends critically on the level and variability of the in-orbit background and the background subtraction philosophy.

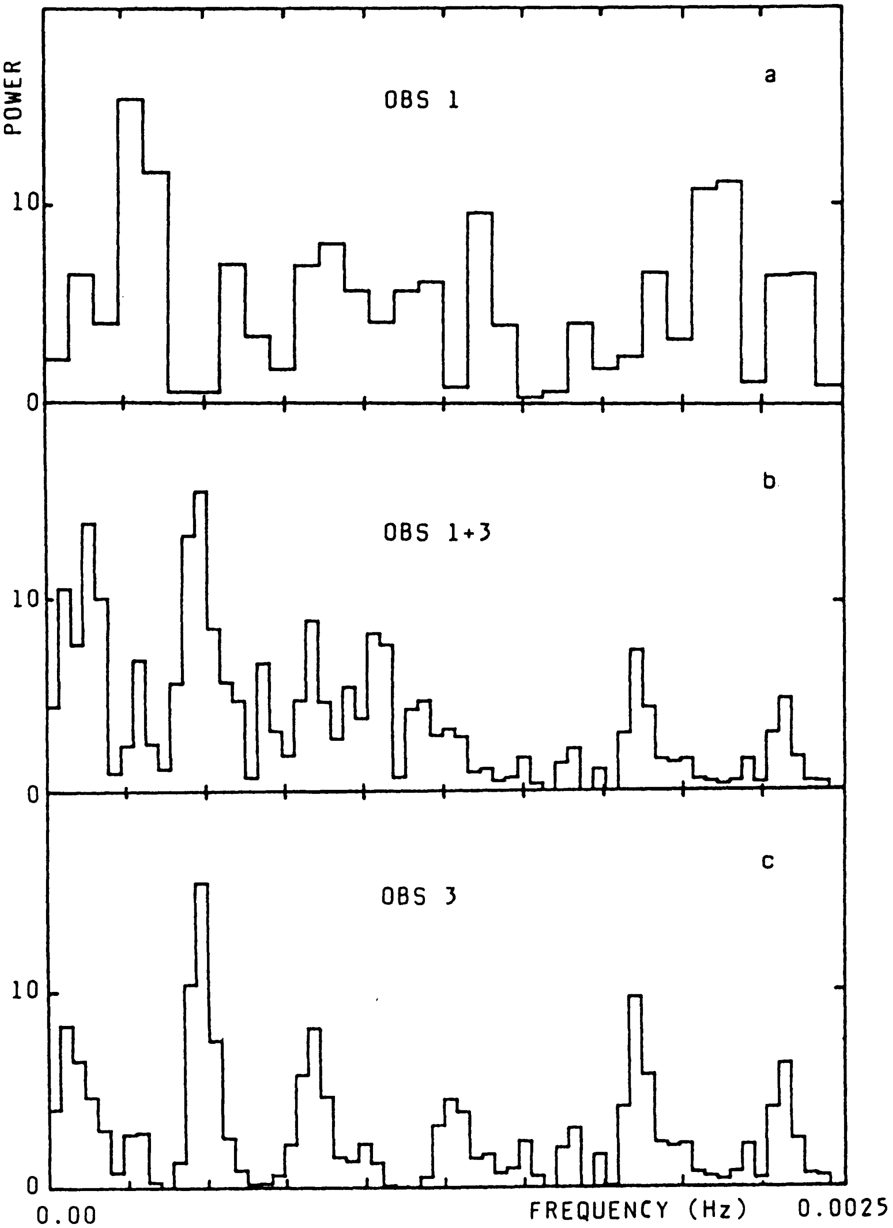

Figure 8. Periodograms based on the LE data sets (SF, FD timing interactive system). a: Observation 1, integration time 200 s, range 0.0000-0.0025 Hz. The largest peak corresponds to 3200 s, the second largest to 460 s.

b: Observations 1+3, integration time 100 s, range as for 8a. The peaks correspond to 6400, 2100 and 1970 s.

c: Observation 3, integration time 100 s, range as for 8a, peaks at 1970, 1190 and 530 s. These quasiperiods probably correspond to the flicker activity, which is not strictly periodic.

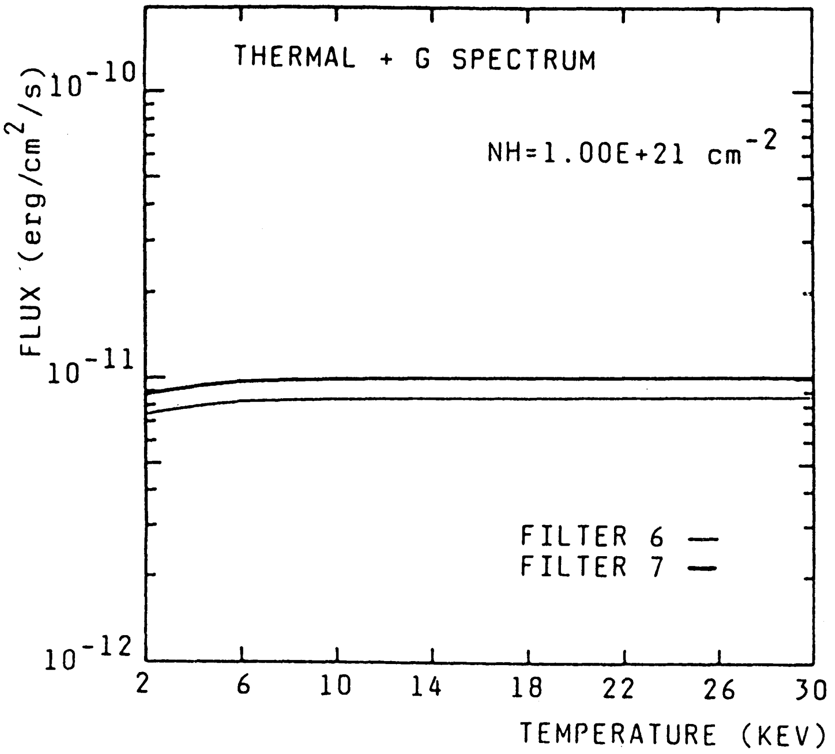

Figure 9. LE spectra. The dependence of the X-ray flux on the temperature for fixed value of $N_H = 1 \times 10^{21}\,\mathrm{cm}^{-2}$ and for the thermal bremsstrahlung + Gaunt factor model. Energy range 0.05 - 3.0 keV.

The best spectral fits can be obtained using the thermal bremsstrahlung + Gaunt factor model

$$E = N_0 \left[e^{-(E/T)} E^{-1} \right] \times e^{-K(E) \times NH} \times \mathrm{Gaunt}\,(E,T)$$

with the normalisation factor $N_0 = 1.5 \times 10^{-3} \pm 0.1 \times 10^{-3}$ ph cm^{-2} s^{-1} keV^{-1} and hydrogen column density $N_H = (3.7 \pm 2.5) \times 10^{21}$ H-atoms cm^{-2} where $T = (6.9 \pm 0.4)$ keV (the 90 per cent confidence limits are $4 < kT < 9$ keV). This agrees well with results obtained for combined LE and ME data.

This confirms that the spectrum of the source can be described reasonably well by a thermal bremsstrahlung model characterized by temperature of ~ 6 keV. The data are quite sensitive, however, to the absorption in the spectrum.

Due to the faintness of the source, the power law shape with a photon index of 2.1 ± 0.3 and $N_H = 1.4 \pm 0.3 \times 10^{22}$ cm^{-2} cannot be definitely excluded, although the fit is worser.

We see that no significant soft X-ray excess was found in our data, in line with results expected for intermediate polars with high absorption. Such excess

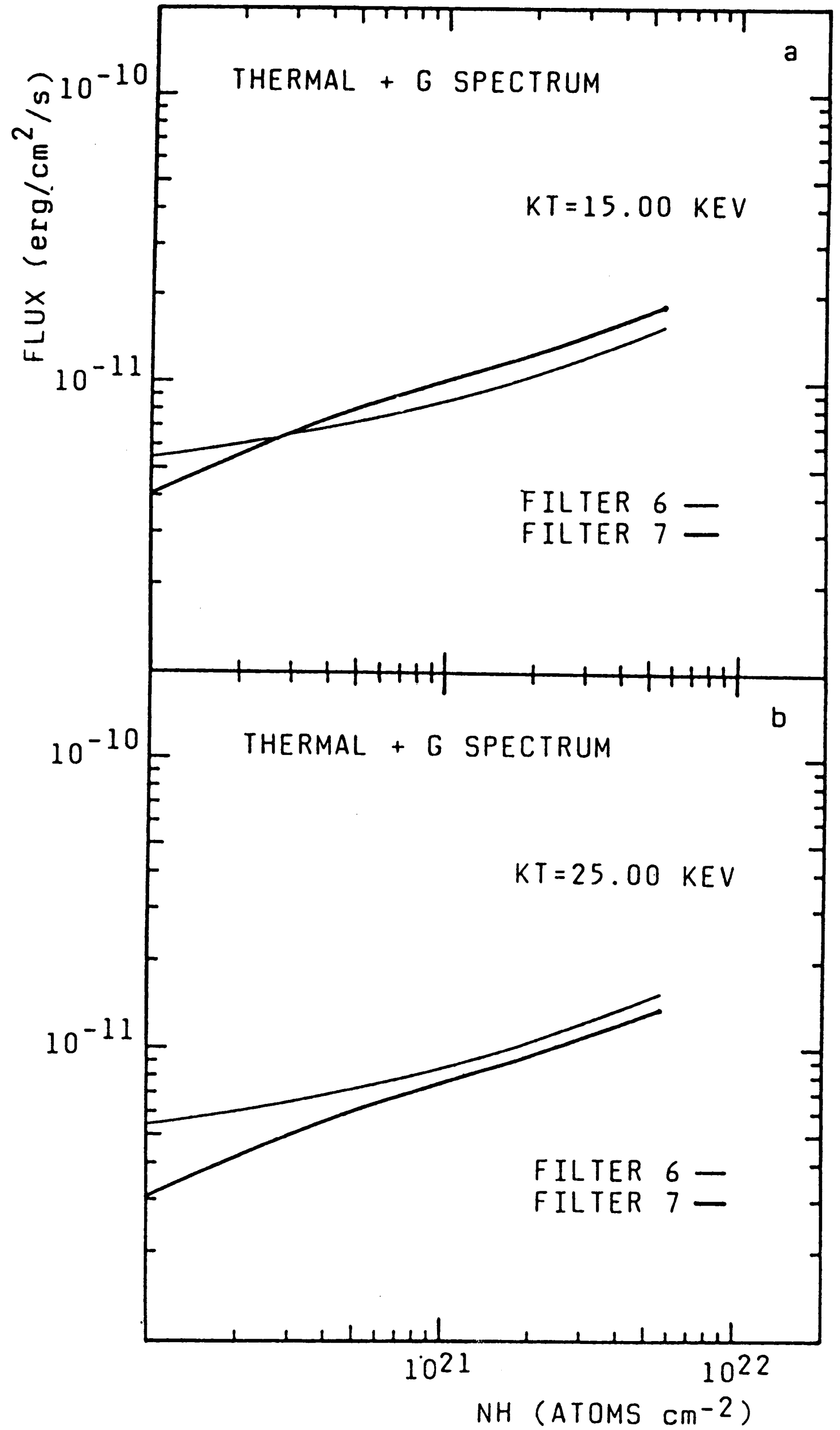

Figure 10. EXOSAT L1, LE spectra. The X-ray flux versus N_H for fixed temperature of 15 keV (10a) and 25 keV (10b). The thermal bremsstrahlung + Gaunt factor model is assumed.

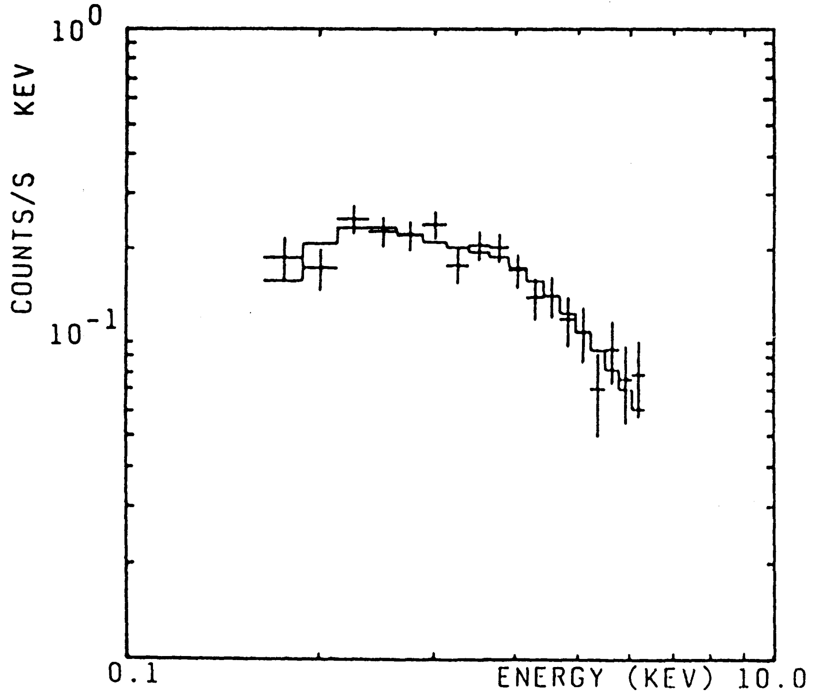

Figure 11. ME X-ray spectrum (counts s^{-1} keV^{-1} versus energy in keV) for integrated observations 1+2+3 (crosses). The plotted curve represents the thermal bremsstrahlung + Gaunt factor model with T = 5.3 keV.

has been previously reported from a number of cataclysmic variable sources (most notably the AM Her stars) in the form of intense ultra-soft components characterised by a blackbody temperature of order of tens of keV . In Figure 11 we show the 'best fit' model (solid line) drawn through the measured incident spectrum processed to remove the background and divided by the instrument response. The combined plot of ME + LE spectra (Fig. 12) is again well fitted by the thermal bremsstrahlung + Gaunt spectrum model.

The spectrum of TT Ari seems to be somewhat softer in the active state (we get kT $\approx$ 7 keV) if comparing with the inactive state (Jensen et al., 1983, give kT $>$ 10 keV) but the difference is not conclusive.

5. Correlation between X-rays and optical light

Having a large amount of correlated optical data, we are able to get correlations between optical light and X-rays in several directions. Let us correlate the X-ray and optical data according to the known types of optical variability (see Wenzel et al., 1986 and 1992).

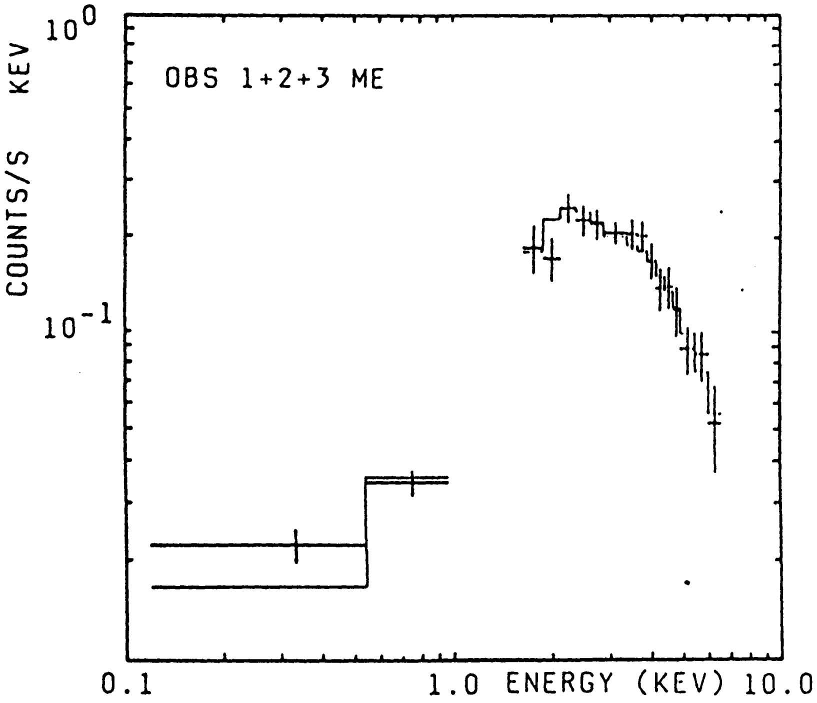

Figure 12. The combined LE + ME spectrum for integrated observations 1, 2 and 3. The plotted curve corresponds to the thermal bremsstrahlung + Gaunt factor model with T = 6.2 keV.

5.1. Photometric period

No obvious modulation of the X-ray light curve with the spectroscopic or photometric period was found, in contrast to the findings of Jensen et al. (1983) during the inactive state of TT Arietis. The active state X-ray light curve resembles the optical one after subtracting the main photometric wave.

5.2. Flickering

During the time of X-ray observations, the star was in the state of a high level of flickering activity both in the optical and X-ray range; it was not, however, highly variable over the time intervals of days within the time span of our optical measurements. The flickering seems to be correlated between the optical and the X-ray data sets. For a majority of detected flickering in the X-ray data, correlated (up to ± several minutes) flickering events can be found in optical light, a result in line with the findings by Jensen et al. (1983) during the inactive state. Although no precise estimation (except for several events well-defined in both ranges) was possible due to the faintness of the object and the used measuring modes in optical light taken into account, an average time delay of ≈ 0.5 to 1 minute can be expected for the flickering activity between X-rays

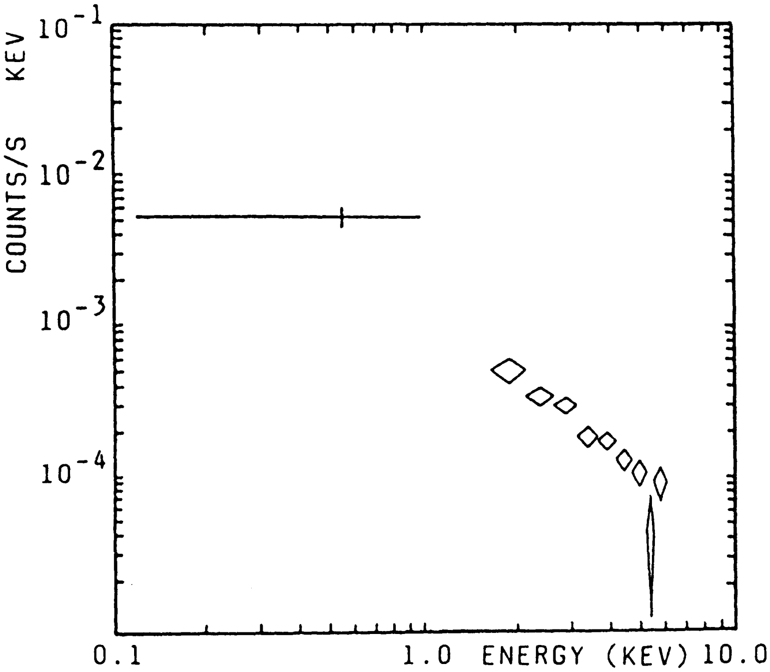

Figure 13. The LE + ME X-ray spectrum for observations 1 + 2 corrected for interstellar absorption.

and optical light, the X-ray events preceding the optical ones. But this delay seems not to be stable for all events, scatter being larger than the measuring errors.

5.3. Non-flickering cycle-to-cycle variations

The LE X-ray data indicate that there probably exist irregular non-flickering variations with typical quasiperiods near 1 hour (cycle-to-cycle) modulated up to 70%. Unfortunately, the simultaneous optical data cover only a smaller part of the full extent of the X-ray data because of the shortness of the night in Central Europe in August.

Due to the faintness of the object, it is, however, difficult to distinguish between the cycle-to-cycle and flickering activity levels. Moreover, the cycle-to-cycle activity was less pronounced during the times of optical measurements, making a detailed analysis difficult. But it seems that analogous changes either do not occur in optical light or are very small.

5.4. The dips

One of the most important results is the presence of absorption events (dips) in both X-ray and optical data. At least 2 (possibly 3) probable absorption events modulated up to 100% and lasting for 5-15 minutes were found in the LE X-ray data set. In the ME data, their presence is possible, but not certain due to the faitness of the source. In each case, the dips are more pronounced in soft (LE data) than in hard (ME data) X-rays. An event simultaneous to one of the X-ray dips was observed in the visible region. Its X-ray counterpart was centered at 23:58 UT and lasted ≈ 10 minutes. The corresponding optical dip was found in the simultaneous optical data set obtained at the Sonneberg Observatory, was centered at 00:02 UT and lasted for ≈ 8 minutes. Unfortunately no optical counterpart could be observed for another dip seen in the X-ray data at 16:46 UT because of the lack of optical data for this day time.

A detailed analysis of the dips observed in visible light (Tremko et al., 1991; Hudec et al., 1989) indicate that these events are rare, their duration and their depth change and the dips are neither photometrically nor spectroscopically phase dependent. However, as already mentioned, there is a strong suspicion that some of the visually observed light decreases were caused by artifacts (probably by the absorption of the light in the atmosphere after jetliner flights).

5.5. Search for other correlations

For some types of optical variations known for the TT Ari system (e.g. Wenzel et al., 1986; Hudec et al., 1987; Roessiger and Luthardt, 1992; Schult, 1992) the study of possible correlation with X-rays was not possible because of an insufficient lenght of X-ray data and their insufficient time resolution.

5.6. The long-term behaviour

In the long-term behaviour, the mean optical brightness at the time of coordinated multiwavelength observations corresponds to the active state, while the X-ray brightness remains to be almost constant in comparison with the results reported for the inactive state (Table 1).

6. Discussion

Although a large number of photometric and spectroscopic observations in UV, X-ray and optical light exists, the detailed nature of TT Ari is still unclear.

6.1. Level of activity

From our data we conclude that the central X-ray source of TT Ari was blocked from direct view and that the X-rays observed - probably intrinsically more luminous - were scattered into the line of sight by material above the disk plane.

Reviewing all the available X-ray measurements of TT Ari, it is evident that the mean flux $Fx \approx 2 \times 10^{-11} \mathrm{erg\,cm^{-2}\,s^{-1}}$ (0.2 - 4keV) does not vary more than by a factor of 0.7, not respecting the level of optical activity (where there are changes by a factor of 10). Only for the optical superminimum, the X-ray flux seems to decline to less than 0.25 Fx (while in optical light the change is still by a factor of 100). Thus, the study of TT Ari surprisingly revealed no enhancement of X-ray activity between inactive ($B \approx 11.7 - 13$; see Jensen et al., 1983 and Beuermann, 1985) and active ($B \approx 10.6$) states, in constrast to the results obtained, e.g., for the AM Her system, where the hard X-ray flux is higher by a factor of 10 in the active state (Fabiano, 1982). Thus the significant increase in the accretion does not result in the increase of the X-ray flux.

We conclude that there exists a strongly absorbing structure in the system and that, consequently, the hard X-ray emission is suppressed during higher accretion rates, similar to the decrease of observed hard X-ray during the optical outburts of SS Cyg (Watson et al., 1985). The same absorbing structure may be responsible for the total absorption of the soft X-ray component.

6.2. The dips

In our EXOSAT LE data set, at least two well-pronounced X-ray dips (absorbing events) were detected at 16:48 and 23:58 UT lasting for ~ 10 minutes each, the later of them being confirmed also in optical light. A similar dip lasting for ~ 17 minutes was mentioned also by Jensen et al.(1983) in the Einstein data; they also report an optical dip, but narrower and shifted in time. From the dips observed by Einstein (Jensen et al., 1983) in the 0.2 - 4 keV range and by the LE experiment (0.2 - 4 keV) and from the fact that the dips are not clearly visible in the ME experiment (1 - 20 keV) we conclude that they are energy dependent. Hence they are probably caused by a photoelectric absorption.

The second X-ray dip was confirmed also by optical data. While the X-ray signal was reduced from 23:49 to 00:03 (or 00:08) UT, the correlated optical dip seen in the Sonneberg data (Figure 5) from 00:00 to 00:07 was shorter and delayed. Unfortunately, the optical dip is only marginaly seen in the Jena Observatory data (see Fig. 4 of Wenzel et al.,1986) because of the gap in their data set near this time. As already mentioned, for the first X-ray dip no optical data are available.

From the general model of the TT Ari system it follows that the absorption and scattering are probably caused by either mass stream between the components, by accretion column or by a thickened region of the accretion disc. This is supported by the possible phase dependence of dips mentioned in Section 3.3, considering that photometric variations are caused by changing aspect of the emitting region (hot spot).

The occurrence of two well defined dips in the data set allows to look for a possible recurrency of absorption events. The individual dips are separated by ~ $7^h\ 12^m$. However, we cannot exclude the possibility of the occurrence of another, less pronounced dip having a smaller modulation and being located between these dips, where only less sensitive LE data with Al-parylene filter exist.

Let us add that also in "classical" dipping sources, where the dips are observed to occur periodically, the dip intensity, duration and shape can vary dramatically from cycle to cycle. As an example, for XB 1254-690 the reduction change from $\sim$ 95% in 1-10 keV to less than 20% was observed (Curvoisier et al., 1986). Unfortunately, our data set is too short to confirm whether the dips in the light curve of TT Ari occur periodically or not. If so, then the (hypothetical) recurrence period is $7^h\ 12^m$ or $3^h\ 36^m$, longer than the periods previously known for the source, but remarkably close to the possible optical period of $\sim$ 3.5 hours revealed from the optical data (Wenzel et al., 1992). However, more X-ray and optical data are necessary to confirm this hypothetical recurrency. We have also searched for other possible dips with this speculative period in the data sets obtained by the Einstein satellite (Jensen, 1983) but were unsuccessful due to the gaps in the Einstein data at the critical times.

7. Conclusions

The most important results of our analysis are

- the mean X-ray flux was found to be surprisingly stable over long time intervals, not changing by more than several per cent and not reflecting the large optical intensity changes between the active and inactive states. The only exception seems to be the superlow state before 1985 where the mean flux declined below $\approx$ 25% of the average value (Beuermann, 1985). We conclude that F x is stable within ± 30% for optical changes between ≈ 10.7 and ≈ 13.5 mag (active/inactive state) but vary by ≈ 5 times for optical superminimum ($\approx$ 16 mag).

- absorption dips occur in the light curves.

Reviewing previous and new X-ray measurements of TT Ari, we see that the physical structure of X-ray emitting regions is rather complicated.

We attempted to confirm a suspected dip reccurence period using the data published by Jensen et al. (1983). Unfortunately, all the times offset by Nx 3^h36^m from the dip reported in their data fall into to the data gaps caused by instrumental effects.

On the other hand, the reality of the dips in the X-ray light curves is supported by the coinciding structures at optical wavelengths found for 2 of these events. In both cases (Jensen et al., 1983 and this paper), the decrease in optical event started later and its duration was shorter than in soft X-rays.

It should be noted that the location and properties of the material which causes analogous "dips" in a variety of low-mass X-ray binaries still remains to be unclear.

In our view, the problem of TT Ari can be explained by the existence of (at least) two X-ray emitting regions, present in the active and inactive states but not in superminimum, and (at least) one scattering and/or absorbing region, present in the active state and being identical or related to the enhanced accretion flow to the degenerate component. One of the emitting regions is more compact (hot spot or probably hot polar cap) and the other more extended (corona above and below the accretion disc or a scattering cloud). Then we see both X-ray emissions during the inactive state: the modulated "steady" emission from the compact region, superimposed by flickering from the extended region. Both these emissions are probably forced by the accretion stream. The extended region ("coma") probably gets only a small fraction of the energy dissipated in the accretion disc during its transport to the corona, most of the energy is absorbed and re-radiated. The transport can probably be even blocked or not inversed during the periods of enhanced accretion.

In the superminimum, the accretion stops and, consequently, both the compact region and the hot corona disappear; hence no X-ray emission is detectable.

In the active state, the enhanced mass exchange results in building up a structure which absorbs the radiation or even blocks the central source from direct view. The X-rays observed, probably intrinsically more luminous, are scattered into the line of sight by an absorbing material and/or re-radiated to optical light.

More detailed and more sensitive spectral observations are necessary to distinguish the spectra of both components, steady and flaring. At present, their separation is impossible due to their faintness.

There are some hints that the X-ray flicker may also occur in narrow dips, indicating that the flickering region is situated apart from the blocked region.

There is yet another possible explanation of the observed properties of TT Ari: a combination of both accretion processes (i.e. column and disc)in which the weight of each may vary in time. Then the compact structure would be represented by a column hot spot and the elongated one by a massive disc. In the inactive state, the accretion is more column-like with residual disc only, while in the active state the disc is building up.

This model could explain the apparent lack of orbital modulation in the active state: In the inactive state the compact component is visible and can therefore be seen at a varying aspect; in the active state this central source is blocked. The presence of accreting structure also explains the lack of very soft X-rays.

It is worth mentioning that it is not clear whether a disc exist in the TT Ari system. Although some indications exist (Wargau et al., 1982; Shafter et al., 1985), King (1985) argue that the accretion disc may not form in non-synchronous systems with P< 5 h.

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