The investigation of TT Arietis at the beginning of its present active state

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Abstract. Results of an extended program of optical monitoring and simultaneous and quasi-simultaneous optical observations of TT Ari, begun in 1985 in order to support the EXOSAT X-ray observations of this object in its active state are presented.

The object was observed on August 21/22, 1985 both in X-ray and optical wavelengths. Optical photometric and some spectroscopic data were obtained at more than 10 observatories.

The measurements were taken up immediately after the return of TT Ari to its active (high) state ($m \sim 10.75$) after having been more than 5.5 years in the very low state ($m \sim 13$-16). The transition from low to present high state occured in $\sim$100 days with a mean brightening rate of 0.04 mag. day^{-1}. The long-time optical light curves as well as detailed orbital curves obtained and at around times of X-ray measurements and data on the stability of the photometric period are presented and discussed.

Key words: Stars: novae and cataclysmic variables

1. Introduction

TT Arietis, now thought to be an accreting (magnetic?) white dwarf in a low-mass binary, has been discovered as a variable star by Strohmeier et al. (1957) and was first taken as an eclipsing binary. The (at that time) extraordinary character of the object has been found independently of each other by Huth (1960)

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(long-term irregular optical variability of a blue star), Herbig (1961) (weak diffuse Balmer emission lines), Götz and Wenzel (1962) (featureless strong blue continuum in objective prism spectrum), and Smak and Stepień (1969) (rapid periodic, quasiperiodic and irregular brightness fluctuations photoelectrically observed in 1961/1962). Additional photometric and, especially, spectroscopic investigations in the following years confirmed the star as a close "nova-like" binary, the orbital period of which amounts to about 3.3 hours. Cowley et al. (1975) published the first extensive analysis of the system. They already had problems when trying to reduce spectroscopic and photometric data (e.g. Smak and Stepień 1975) with one and the same period, a question which has been discussed until quite recently (e.g. Thorstensen et al. 1985).

The first (short) X-ray observations of TT Ari were obtained in the course of a survey of cataclysmic variables by means of the Einstein satellite by Cordova et al. (1981) in the range 0.16 to 4.5 keV. Besides, TT Ari proved to be the strongest source of their program of 12 objects. A more extended observational series with the Einstein satellite was performed by Jensen et al. (1983) in July 1980 simultaneously with observations in the optical range, and by EXOSAT in December 1983 and January 1985 (in Dec. 1983 the X-ray intensity was below the limits of detection) by Beuermann (1985). All these observations were performed during low, very low or transitional states of the long-term light-curve (Hudec et al. 1984).

The long-term behaviour of the photometric period was not studied adequately, as yet. The problem consists in the large range of the variability of the shape of the light curve. Thus the epochs of light maxima and the light minima are determined with low accuracy. As the photometric period is very short there is a problem in counting of epochs. Therefore only middle-term range changes of the photometric period were studied (Smak and Stepień 1975, Sztajno 1979, Udalski 1988, Volpi et al. 1988). They did find medium-term changes. There is not clear to which extent these variations are influenced by the variations of the light curve shape.

The present paper is a highly condensed and slightly supplemented version of the preprint Wenzel et al. (1986), to which the reader is expressly referred. The preliminary results were published by Hudec et al. (1987). A part of the original observing material was already published, and the rest is deposited at Sonneberg Observatory.

We have performed numerous optical observations as a support for the X-ray EXOSAT observation. Preliminary results on X-ray data were given by Hudec et al. (1987). These are given in more detail in Hudec et al. (1992) (this volume). The analysis of the optical flickering periodicity will be given by Schult (1992).

2. The optical data

2.1. The long-term light curve

An extended optical monitoring schedule, based mainly on the photographic observations within the framework of the then existing "Interkosmos" program was established (Table 1, where in the column Notes the photometric region, and the exposure time or the integration time are given). Archival plates (Hudec 1985) were used, too. In Fig. 1a the continuation of the long-term lightcurve of Hudec et al. (1984) is presented. The magnitudes of the comparison stars are given by Fuhrmann (1981) for the previous lightcurve and Götz (1985) for the present one. There is a slight systematic difference between the two systems.

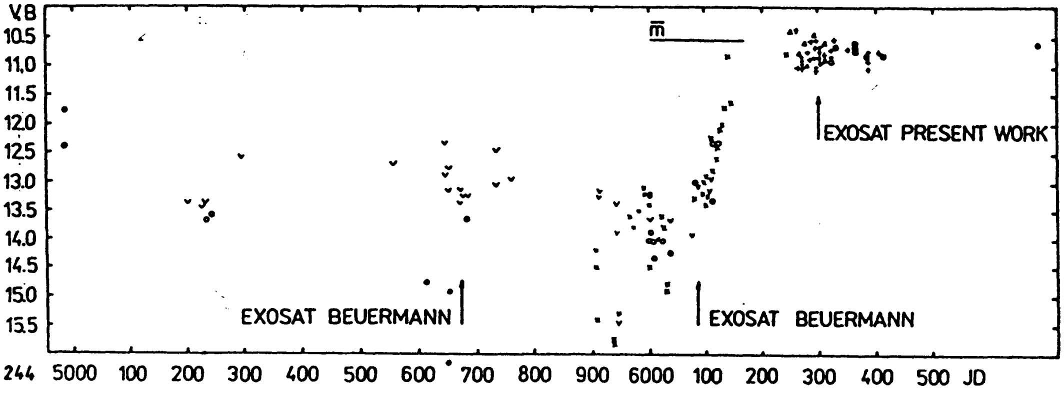

Figure 1. a: The optical long-term light curve of TT Ari between JD 244 5000 and 244 6500 showing also the times of EXOSAT observations. The average active state brightness derived from previous active states is indicated by a line at m=10.55. The open circles represent the results of measurements on Sonneberg sky patrol plates ("V" are upper limits), + represent Sonneberg astrograph data, △ are the estimations of small observatories and amateurs, x present visual observations by Bortle and Verdenet (1984a, 1984b, 1985a, 1985b) and Mattei et al. (1985), □ measurement by Beuermann and Weissieker (1985).

We see that the object was in a very low state from about JD 2444116 to 6120. This unusually low (down to ~ 16 mag) and unusually long (~ 2000 days) minimum is exceptional: none of the previous nine inactive states observed in this object since 1928 exceeds ~ 13 mag, and the duration of 750 days. It is believed that in contrast to the common low states, during which the accretion flow is only moderately reduced, during the "superminimum" the accretion was very low, chaotic and probably had been ceasing completely for some intervals (Shafter et al. 1985, Hudec et al. 1984). The failure to detect X-ray emission during the very low state (Beuermann 1985) is in agreement with this assumption.

Observatory	Instruments	Sort of observations	Notes	
1 Abastumani	AZT-14 A	phe. phot.		Q
	0.7 m Meniskus	spectrosc.	24 min.	Q
2 Bucuresti	0.5 m Reflector	phe. phot.	b,v	S Q
3 Budapest-Piszkéstetö	0.5 m Cassegrain	phe. phot.	UBV 8 s and 10 s	S Q
4 Jena-Grossschwabhausen	0.9 m Cassegrain	phe. phot.	B,	S
5 Kleť	0.85 m Maksutov	pg. phot.	m_{pg}	S Q M
6 Ľvov	0.5 m Reflector	phe. phot.		Q
7 Ondřejov	various	pg. phot.	m_{pg}, V	S Q M
8 Skalnaté Pleso	0.6 m Reflector	phe. phot.	B 20 s	L
	0.3 m Refractor	pg. phot.	m_{pg} 12 min.	Q
9 Sonneberg	0.6 m Cassegrain	phe. phot.	BV 16 s	S Q
	various	pg. phot.	5 - 40 min.	S Q
10 Sverdlovsk	0.6 m Reflector	high-speed phe. phot.	no filter 1.2 s	Q
11 Small and amateur observatories	various	pg. phot.	m_{pg}	Q M
		vis. phot.	m_v	S Q M

Table 1. Participating observatories

Remarks: S - simultaneous, Q - quasisimultaneous, M - monitoring

It is noteworthy that after returning to the state of activity, the mean brightness of TT Ari during July-September 1985 was ~ 10.75 mag, whereas the average level of the brightness for the active states in the past was somewhat higher ~ 10.55 mag (Figs. 1a, 1b), the correction for the new comparison star magnitudes were taken into account (Götz 1985). The subsequent observations (Fig. 1b) indicate that since JD 244 6480, the object seems to have been undergoing a small brightening towards the nominal mean brightness of ~ 10.55 mag. We note that the difference between B and V is of the order of ~ 0.05

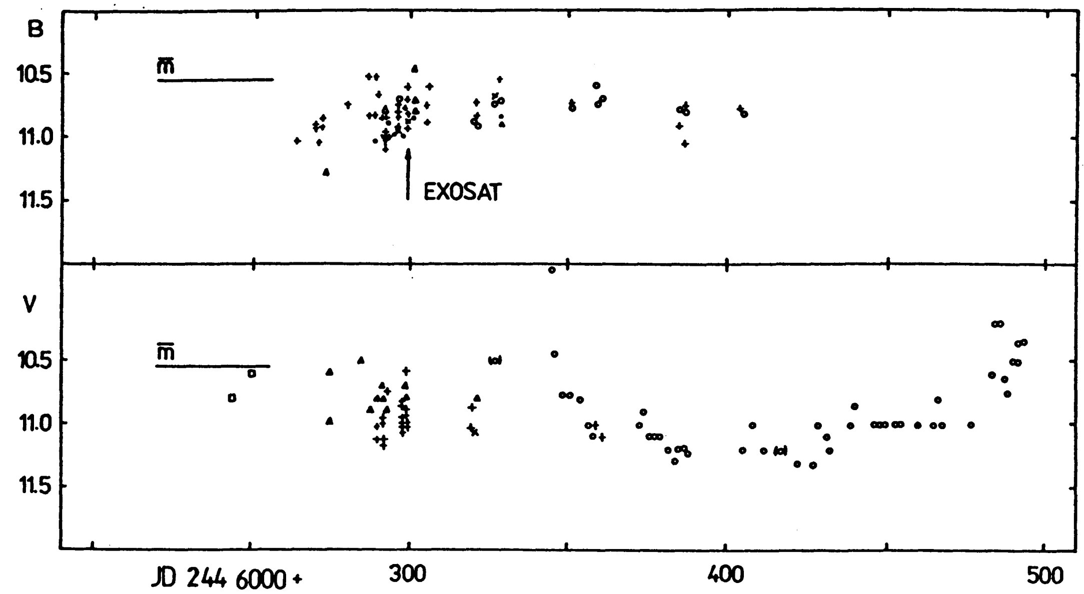

Figure 1. b: The detailed optical long-term light curve of TT Ari around the time of X-ray observations (JD 244 6200 to JD 244 6500). o represent measurements on Sonneberg sky patrol cameras.

B light curve: + Sonneberg astrographs, x Sonneberg Schmidt camera, △ Skalnaté Pleso astrograph, • Kleť Maksutov camera and small observatories.

V light curve: x Sonneberg Schmidt camera, + Ondřejov cameras, △ Czech amateurs, □ Verdenet and Grzelczyk +0.6 mag. The average active state is also indicated, by two straight lines.

mag for the active state (see Table 3) and ∼+0.1 mag for the superminimum (Shafter et al. 1985) and thus lower than the mean error of photographic and visual observations; therefore it was not necessary to distinguish between m_V and m_B in some cases (Fig. 1a). The long-term lightcurve for the time around the date of the X-ray observations is in detail given in Fig. 1b. Except the brightening detected in V since JD 244 6480, there is no significant deviation from the usual long-term behaviour of the system in active state as described by Hudec et al. (1984), characterized by day-to-day variations by a few tenths of a magnitude and low-amplitude changes without any evidence for long-term periodic brightness variations in a greater than 1 day range.

2.2. Spectroscopy

A prism spectroscopy was carried out on 1985 August 20/21 at 22:46 UT (about 16 hours before starting X-ray measurements); total exposure time was 24 min on a photographic plate ORWO ZU 21. The observation was made at an 0.7 m meniscus telescope equipped with an 8° prisma and a dispersion of 16.6 nm/mm at the Abastumani Observatory.The spectrum resembles an O type star with weak hydrogen lines and with emission components, a result which resembles the results of previous spectral observations of TT Ari in active state (e.g. Vojkhanskaya 1983).

2.3. Photoelectric lightcurves

Surrounding the EXOSAT run photoeletric lightcurves over at least a full orbital period each were secured in 13 nights between 1985 August 14/15 and October 20/21 (JD 244 6292.5 to 6359.5) mainly at the telescopes at Sonneberg, Jena-Grossschwabhausen and Budapest-Piszkéstetö observatories. The integration times were 8 s or 10 s with the exception of the Sonneberg series of 1985 August 20/21 and 21/22. In these two nights the integration time of 16 s was applied. As main comparison star served star "c" of the above mentioned sequences, which according to Shafter et al. (1985) has the following brightness: V=10.99 mag, B=11.68 mag, U=11.91 mag. The position of 35 west of TT Ari given by Shafter et al. (1985) means 35 seconds of time (not of arc).

Of special importance are the measurements which were obtained at the same time as the EXOSAT observations of 1985 August 21/22 (Figs. 2 and 3). The state of the system was characterized by a high level of flickering acitivity, whose cycle-length was later determined to 18 ± 5 minutes (Schult 1992). Clearly seen is the 3.2 hours photometrical period, which will be discussed in the next sections. It should be stressed that the shape and the mean level of the lightcurve change from night to night. During the night of EXOSAT observation the shape was "steep", in contrast to "flattened" curves of other nights (see e.g. Wenzel et al. 1986, Roessiger 1987).

In the photoelectric light curves few absorption dips with variable duration and depth were detected. These dips were confirmed in the observations obtained two seasons later (Tremko et al. 1990). Besides the dips in the optical region, the X-ray dips were observed, too. In two cases the dips were confirmed in both the optical and X-ray region. Analogous dips, mostly in X-ray region were detected during long-term observations of EXOSAT satellite, in low-mass X-ray binaries. There is a great variety in the dips properties, both from the same system and for the class as a whole (Mason et al. 1985). The dips are probably the result of an obscuration of the radiation source by a stream of the infalling matter. The dips in TT Ari are not phase dependent neither on the photometric nor on the specroscopic period. (Tremko et al. 1990.) The irregular phase distribution of the dips, the variation in the depth and in the duration could be explained by the shortlived events of the enhanced mass transfer, by the changes in the structure of the obscuring stream, changes in its density and in the position of the stream or by a combination of some of these effects.

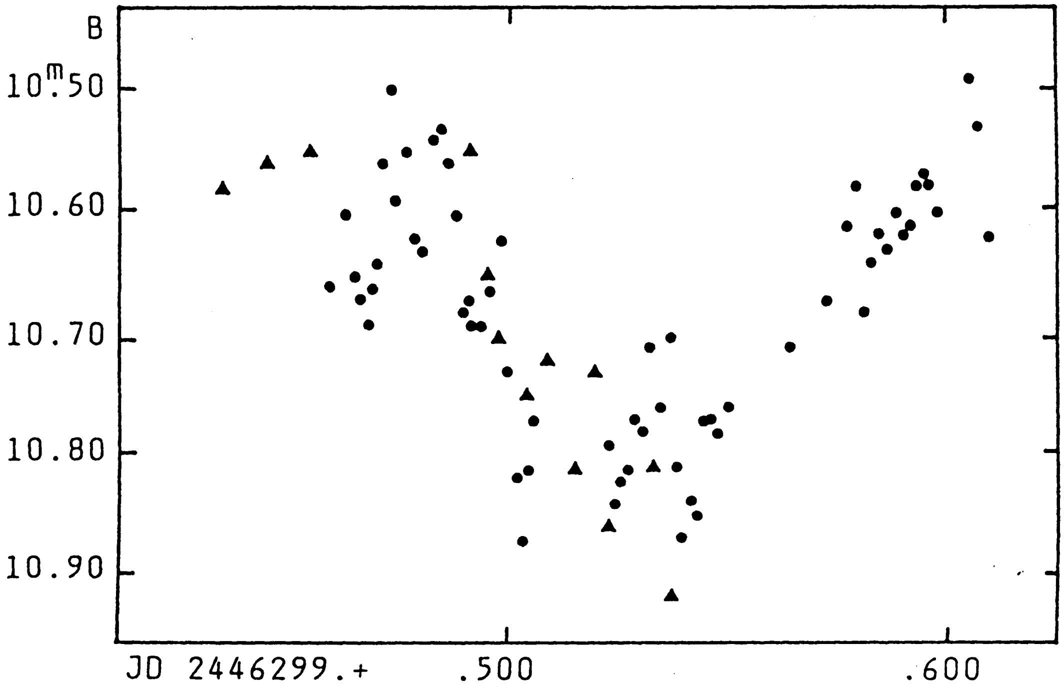

Figure 2. Photoelectric optical B light curve Aug. 21/22, 1985 (simultaneous with EXOSAT observation): points Sonneberg, triangles Bucuresti (corrected).

2.4. Stability of the photometric period

The photometric period P_{ph} found by us by frequency analysis (7.538 cpd= 0.1327 days) is about 7 minutes shorter than the orbital period P_{sp}= 0.1375514 days (Thorstensen et al. 1985). The accuracy of our value is given by the time interval covered by the frequency analysis (t=37 days) and amounts to ± 0.0002 days.

The epochs of maxima derived from our observations together with those excerped from the literature were used for the computation of the photometric elements. These are as follows:

$$\mathrm{Max}_{hel.} = 243\ 7646.665 + 0.^{d}13277100 \times E$$

The light elements derived from the observations spanning over 34 years show the long-term stability of the photometric period. The complete list of the epochs of maxima used for our computation was published in the preprint of Wenzel et al. (1986) and separately by one of the coauthors (Roessiger 1988). Therefore we do not give them here. Roessiger obtained practically the same

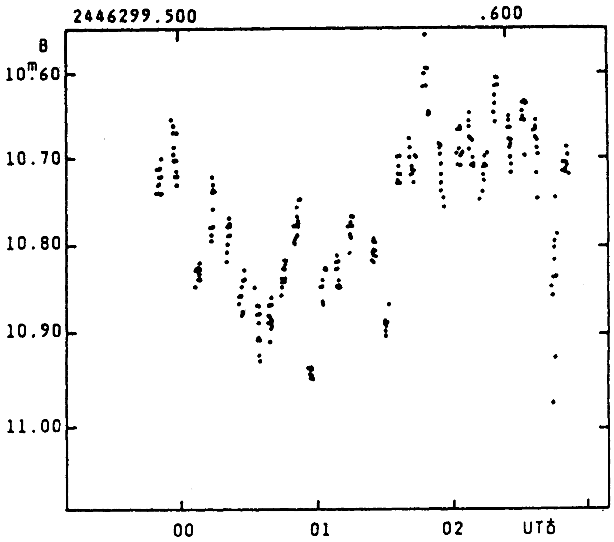

Figure 3. Photoelectric optical B light curve Aug. 21/22, 1985 (simultaneous with EXOSAT observation) from Jena-Grossschwabhausen. Note the effect of differing mode of measuring as compared with Fig. 2.

value for the photometric elements. The slight difference of about 3 sigma comes from the difference in the weighting procedure and by adding one new epoch of maximum.

$\overline{E}$	$\overline{O-C}$	n
82	$-0^{d}.003$	6
270	+0 .025	3
13999	+0 .004	6
46619	+0 .027	4
48670	−0 .001	3
51165	−0 .009	1
65316	−0 .006	17

Table 2. Mean O−C values

The important task when computing the photometric elements is to avoid the possible mistake in the counting of epochs. Therefore we used the grouped data. We computed the mean value for the groups of epochs of maxima. The time differences between successive intervals are graduated favourably: excluding the first difference they are approximately 2000, 2500, 14000 and 32000 epochs (see

Table 2). Errors in counting the cycles can therefore be minimized. If, for example the smallest value of that difference (2051) is errorneus by ± 1, then an error of 7.10^{-5} days of the assumed period would be introduced and should be visible as a systematic trend in the O-C values of the 1985 photoelectric series which covers about 500 epochs. Similar arguments hold for other differences. Therefore a mean photometric period derived by us should be acceptable for the years considered (1961 to 1985). Trends of a systematic decrease or increase of the period are not recognized. It is true, however, that during restricted intervals (several hundred days) distinct deviations from the mean occur. For example this is evident for the systematically large O-C values of 1962 (though uncertain) and 1978 (the integral light). There are also more or less isolated strong displacements of maxima e.g. E=49312 and 65382 of the list of Wenzel et al. (1986). It is unclear at present whether these deviations are a mere consequence of the strongly changing shape of the lightcurve or are produced by a special behaviour of the system when it is approaching or passing an inactive state (E=65382). The reliability of this finding seems to be supported by the reported "phase jitters" among similar systems. A delay of the optical minimum from −0.006 to +0.002 days within 15 days has been observed in the source H1405-45 after passing a low state (Bonnet-Bidaud et al. 1985).

Obviously the cause for the variability characterized by P_{ph} cannot lie in a "bright spot" created by the initial mass flow. In this case would be $P_{ph} = P_{sp}$. Rather there is a nonsynchroneous rotation of the immediate surroundings of the primary and of the accreted masses canalized there from the gas disk. For forming this accretion column a magnetic field of $\leq 4.10^6$ Oe (Shafter et al. 1985) must obviously be sufficient. Besides there are hints that the conclusions about the magnetic field strenghts in intermediate polars may be in error (King 1985). Position and shape of the accretion column are governed by the changing rate of mass flow and so are the instantaneous cycle length and the shape of the light curve.

Furthermore, a variability of the lightcurve could be caused by a superposition of photometric and orbital periods: The excess radiation originating in the accretion column gives rise to a "reflection effect" at the outer layers of the secondary component, where the period P_b of this phenomenon will be given for the terrestrial observer by $\frac{1}{P_b} = \frac{1}{P_{ph}} - \frac{1}{P_{sp}}$, from which follows $P_b = 3.8$ days.

Semeniuk et al. (1987) had given the value of 3.66 days for the 1966 season. The expected value for this season was 3.76 days. The cause of the difference is the lower accuracy in the determination of the photometric period obtained during one season, only. We showed the long-term stability of the photometric period. Therefore the observed variability of the beat period is actually within the accuracy of the determination of the fundamental periods.

Our series of observations are not sufficient enough for the study of the light curves in dependence of the beat period. Nevertheless a change of steep (or high) maxima (s) and flattened maxima (f) can be noted. For the first ones a

Max. JD (hel.)	Shape	B−V
244 6292.569		
298.561	s	$+0^m.06$
299.474	s	$+0^m.06$
299.603	s	
305.594	f	$0^m.00$
306.510	f	$-0^m.02$
306.642		
307.572	s!	$+0^m.10$
320.462		
320.594		
321.507	s	
327.477	f	$-0^m.04$
328.554		$0^m.00$
335.595	f!	$-0^m.02$
342.505	f	$-0^m.04$
346.484	f	
359.492	s	$+0^m.07$
705.458	f	

Table 3. Maxima of 3.2 hour wave

mean colour index of about $+0.07$ mag and for latter ones -0.02 mag have been measured (see Table 3), the exclamation mark (!) denotes particularly prominent features. Although these findings do not prove the existence of the beat phenomenon, the cyclic change between steep and shallow maxima does not disagree with the cycle length of P_b given above. If it is really the reflection effect which is showing in this way, then for the understanding of the physical processes the colour change of the re-processed radiation as compared with the undisturbed mean seems noteworthy. We note that by frequency analysis we found indications for the presence of a superposition period of 3.2 days whose relation to P_b, however, cannot be ascertained.

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