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Variability of the Hα spectral line in the interacting binary AX Monocerotis

A. Puss[1,2] and L. Leedjärv[1]

[1] Tartu Observatory, EE 61602 Tõravere, Estonia
[2] Tartu University, Department of Physics, EE 50090, 4 Tähe Street, Tartu, Estonia

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Abstract. The interacting binary system AX Mon (K-giant + B(e) star) has been observed at the Tartu Observatory, Estonia, from 1985 to 2000. In the present paper, mostly the behaviour of the hydrogen Hα line from 1996 to 2000 is investigated. We have found that the Hα profiles are variable on time scales from hours to years, with main features appearing around the conjunctions of the stars (K-star in front). Those features include weakening of the main absorption component of the P Cygni like profile and appearance of additional absorption and/or emission components. Occasionally, the Hα line as a whole shifts on the wavelength scale. All those effects seem to occur much stronger at every second conjunction, which we propose to call "strong" conjunctions. We propose that this variability is due to a gas cloud close to the Be star. This cloud is a region, where a stream of matter from the K-giant collides with the circumstellar gas from the Be-star. The mass transfer process seems to have become more unstable than in 1960s. It is possible that a cyclic behaviour of the Hα line with a periodicity of about two orbital periods is present.

Key words. stars: binaries: spectroscopic – stars: emission-line, Be – stars: individual: AX Mon

1. Introduction

AX Mon (HD 45910, SAO 113947, GC 8442, MWC 145) is known as an interacting binary system, with orbital period of 232.5 days, consisting of a K-type giant and a B-type hot star. For the components, spectral types in the ranges K0-M2 III and B0.5-B6 II-V, respectively, have been proposed by various authors. From extensive observations of optical spectra Cowley (1964) deduced spectral type K0 III + B3 V, while the observations of ultraviolet spectra have yielded K0 III + B2 III (Sahade et al. 1984). It is evident, that the AX Mon system contains large amounts of circumstellar matter. It is possible that the AX Mon system is just at the end of the dynamically unstable phase of mass exchange (Harmanec 1974). During this phase the mass-losing star became the less massive component. Such a configuration generates spectra and light curves of complicated character, which makes it more difficult to find exact parameters of the components of the system. In the process of investigating spectral lines it has become evident, that around the time of conjunction of the stars (K-star in front) there appear narrow absorption lines of ionized metals (mostly Fe II) and hydrogen Balmer lines (Hγ, Hδ). This phenomenon is explained by a gaseous stream from the K-star to the B-star, projected in front of the B-star (Cowley 1964). Photometric measurements show that a nearly 0.5 mag dip exists in the U light curve close to phase 0.75. This is interpreted as attenuation of the hot-star light by a dense circumstellar gas cloud (Elias et al. 1997).

In the present paper we analyze spectroscopic observations of AX Mon, performed at Tartu Observatory, Estonia.

Section 2 gives an overview of observational data and results from the literature and describes our observations.

In Sect. 3 we discuss the analysis and possible explanations of the observational data. Section 4 gives the disscussion and Sect. 5 the conclusions.

Send offprint requests to: A. Puss, e-mail: alar@aai.ee

2. Observations

2.1. Observational history

AX Mon system was for the first time mentioned when Fleming (1898) noted that it had bright hydrogen lines in the spectrum. In 1921 Humason and Merrill included AX Mon in a list of B stars with bright Hα. Merrill (1923) and Plaskett (1923, 1927) independently observed AX Mon. They found that the spectrum is variable. Most pronounced phenomenon in the photographic region was occasional appearance of a shell spectrum of ionized metals and variable hydrogen lines with one or more components. Guthnick & Prager (1930) found irregular light

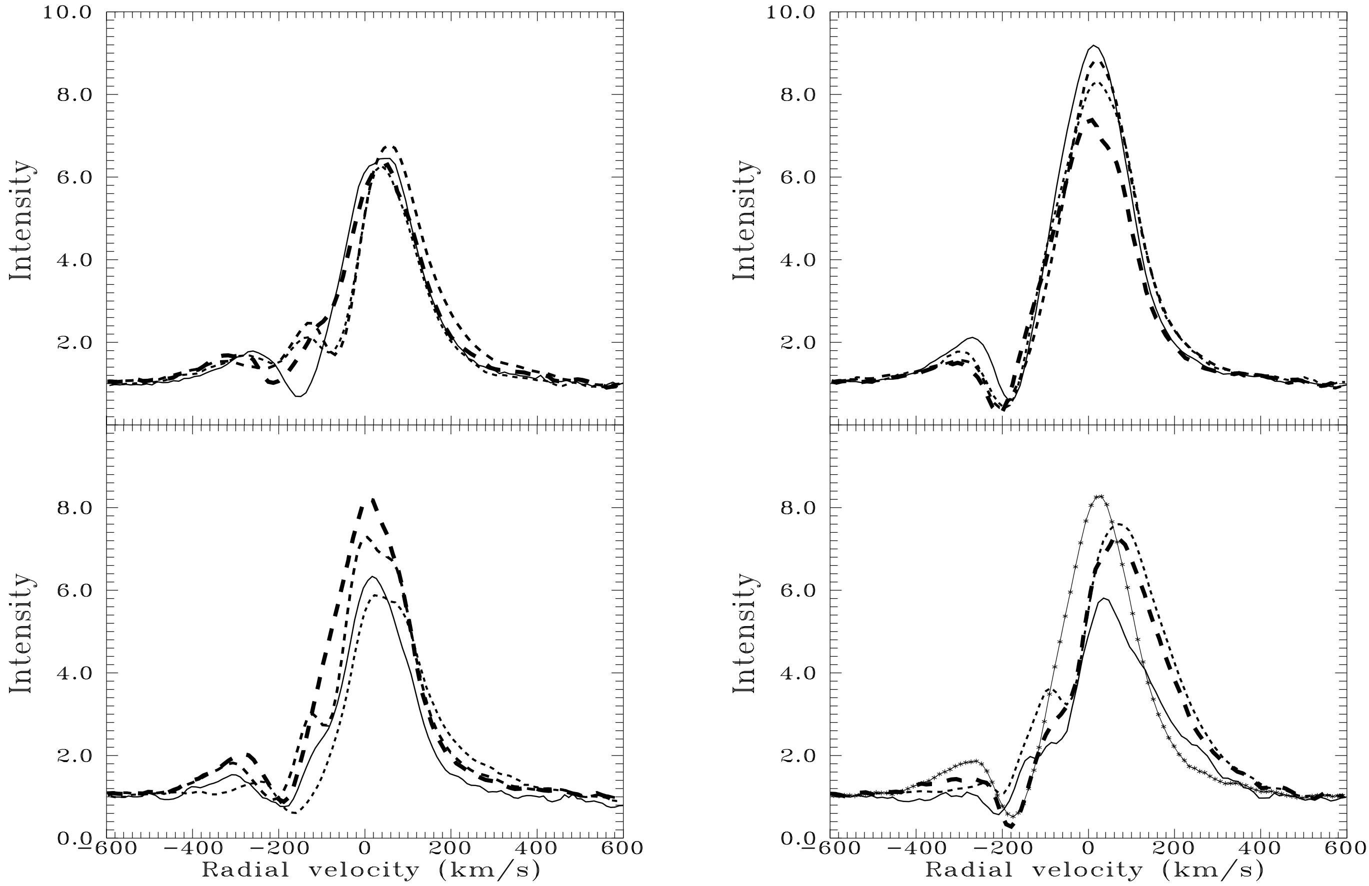

Fig. 1. Hα profiles around different orbital phases. Upper left panel: around the phase 0.0 (solid line: phase 0.943; dotted line: phase 0.976; short-dashed line: phase 0.014; long-dashed line: phase 0.026). Lower left panel: around the phase 0.2 (solid line: phase 0.209; dotted line: phase 0.179; short-dashed line: phase 0.177; long-dashed line: phase 0.168). Upper right panel: around the phase 0.5 (solid line: phase 0.462; dotted line: phase 0.500; short-dashed line: phase 0.469; long-dashed line: phase 0.502). Lower right panel: around of the phase 0.75 (solid line: phase 0.761; dotted line: phase 0.757; dashed line: phase 0.752; solid line with asterisks: phase 0.763).

variations fluctuating between 6.7 and 6.9 magnitudes. Plaskett (1927) detected a periodicity of about 235 days in the displacements of the hydrogen lines (both in emission and in absorption). Struve (1943) concluded from the spectra, that if any periodicity exists, it probably lasts only for a short time. Merrill found in 1945 from high-dispersion spectra weak absorption lines characteristic of a late-type star. From these lines Merrill (1952) found an orbital period of 232 days.

Extensive spectroscopic investigations of AX Mon were performed by Cowley (1964). A summary of her results is as follows:

(1) Hydrogen lines exhibit P Cygni-like profiles corresponding to expansion velocities of approximately 200 $\mathrm{km\,s^{-1}}$. They can undergo rapid variations. Usually Hγ and Hδ lines were investigated. They have frequently multiple components which are usually seriously blended, and which are variable in various ways, especially the high-velocity components.

(2) Around the conjunction of the stars, or little before that (mostly between phases 0.7 and 1.1) a metal rich shell spectrum appears with sharp absorption lines of Fe II, Ti II, Cr II, Mn II, Ni II. Its duration is variable. Lines have maximal intensities approximately at phase 0.92. (Phase 1.0 corresponds to superior conjunction of the B-star.) This phenomenon is interpreted by a mass transfer stream from the K-giant to the B-star, moving at about +25 $\mathrm{km\,s^{-1}}$.

(3) Broad He I absorption lines form in the vicinity of the B-star. The width of the lines makes it difficult to determine the B star orbital velocity. Cowley connected broad lines to rapid rotation of the B star.

(4) The semi-amplitudes of the radial velocities of the B star were estimated from the Hα and Hβ emission lines (with some difficulty). The most accurate estimate is for the K-star from neutral metallic absorption lines. From the Hα emission line a mass ratio of $M_{\rm K}/M_{\rm B} = 0.4$ has been determined. The inclination of the orbit is estimated to amount to about 65° (there are different estimates ranging from 50° to 80°). With these assumptions the masses $M_{\rm B} = 8.6\ M_\odot$ and $M_{\rm K} = 3.4\ M_\odot$ were derived as well as the semi-major axis of the orbit: $a \sin i = 2.53 \times 10^8$ km $= 1.69$ AU.

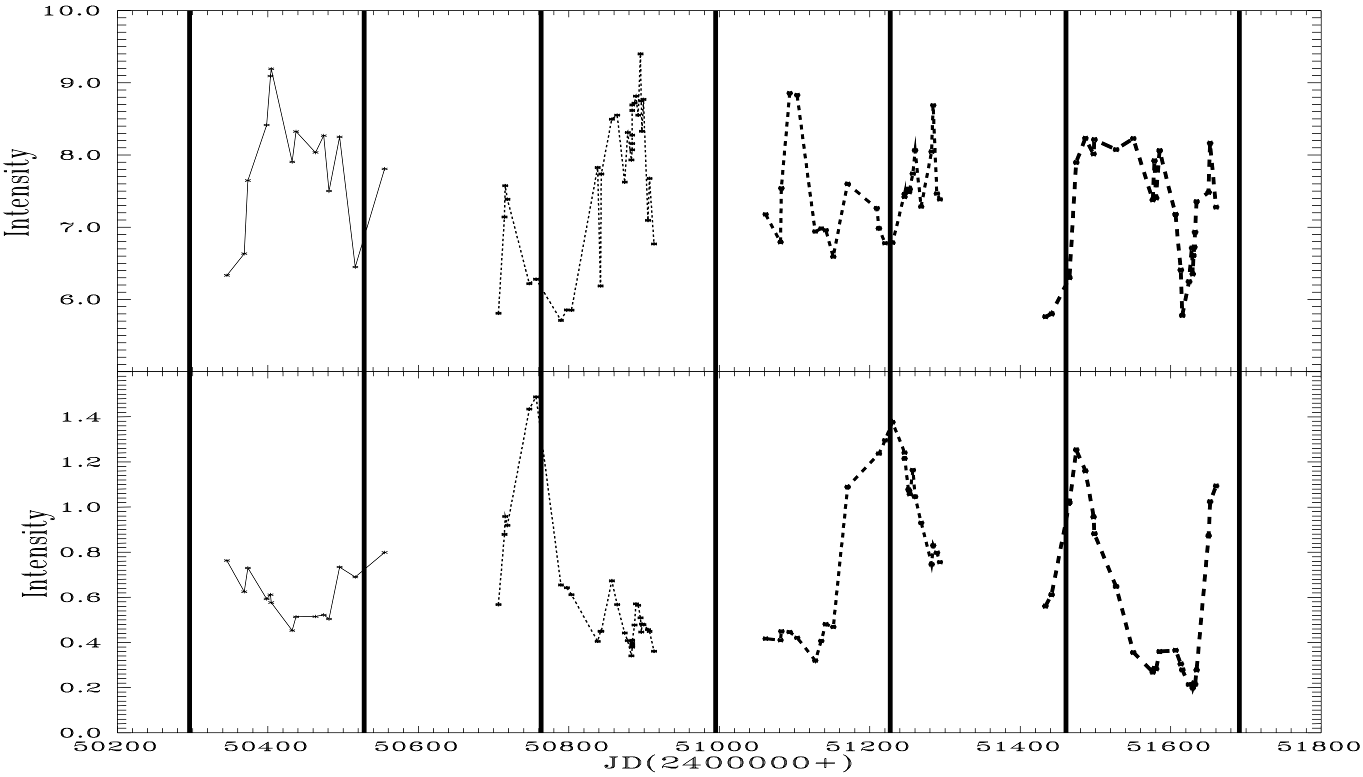

Fig. 2. Intensities of the Hα main emission (upper panel) and absorption components (lower panel). Solid line - from Sept. 1996 to Apr. 1997; dotted line – from Sep. 1997 to Apr. 1998; short-dashed line – from Sep. 1998 to Apr. 1999; long-dashed line – from Sep. 1999 to Apr. 2000. Vertical lines – times of the conjunctions (K-star in front).

Harmanec (1974) proposed that AX Mon is just at the end of the dynamically unstable phase of mass exchange. Therefore, the initially more massive mass-losing star has become the less massive component. In the same work he proposed that the orbital period of the system should rapidly increase. Maštenova (1989) analysing neutral metallic lines of the K-star concluded that the orbital period of the system was still 232.5 days. Consequently, an increase of the orbital period was not confirmed.

The paper by Peton (1974) treats *UBV* photometry and spectroscopic observations in the photographic region during 11 years. Peton states, that there exists two absorbing envelopes: an exterior shell of hydrogen and an interior metal rich shell. Photometric variations on three different timescales were found: very short variations (≤4 hr); short variations (>1 day); long-time variations (≤3 yr). Peton estimated an orbital inclination $i = 79°$. In spite of the small orbital eccentricity, tidal effects might be present. Peton preferred to use an orbital phasing from the periastron passage (If $F_{\rm p} = 0$, then $F_{\rm c} = 0.285$).

Sahade et al. (1984) and Sahade & Brandi (1985) obtained IUE (184–323 nm and 116–213 nm) spectra at the phase $F_{\rm c} = 0.380$. They determined the B-star temperature to be about 20 000 K and estimated a spectral class B2 III. Also, based on the Mg II absorption at 280 nm, they confirm the presence of a large amount of circumstellar matter.

Danezis et al. (1991) performed similar analyses of IUE spectra.

AX Mon has been observed with the Einstein X-ray satellite in the 0.1−1.4 KeV range (Guinan et al. 1984), but AX Mon was not proven to be an X-ray source. This may be due to the lack of hot plasma, or due to large amount of interstellar absorption.

Dougherty et al. (1994) have revealed an excess infrared radiation from a near-IR survey. This excess is caused by the presence of the cool giant in the AX Mon system.

Extensive multiwavelength observations and modelling of AX Mon have been performed by Elias et al. (1997). The main results are as follows:

1) Contrary to Cowley's (1964) interpretation, the broad He I lines are not connected to the B-star's rapid rotation. They rather originate from circumstellar gas clouds.

2) Specified parameters of the K-star: $v_{\rm rot} \sin i$ = 20 km s^{-1}; $T_{\rm eff} = 4500$ K; $M_{\rm K} = 4.49\ M_\odot$; $R_{\rm K} = 120\ R_\odot$; $M_{\rm bol} = -4.28$.

3) The same for the B-star: $T_{\rm eff} = 20\,000$ K; $M_{\rm B} = 13.57\ M_\odot$; $R_{\rm B} = 14.1\ R_\odot$; $M_{\rm bol} = -6.35$.

4) The parameters of the system: semi-major axis $a = 417\ R_\odot = 1.93$ AU; inclination $i = 50°$; distance from Earth $r = 1.3$ kpc; mass ratio $q = 0.331$; $M_{\rm bol} = -6.5$; $M_V = -5.0$; $V = 6.8$.

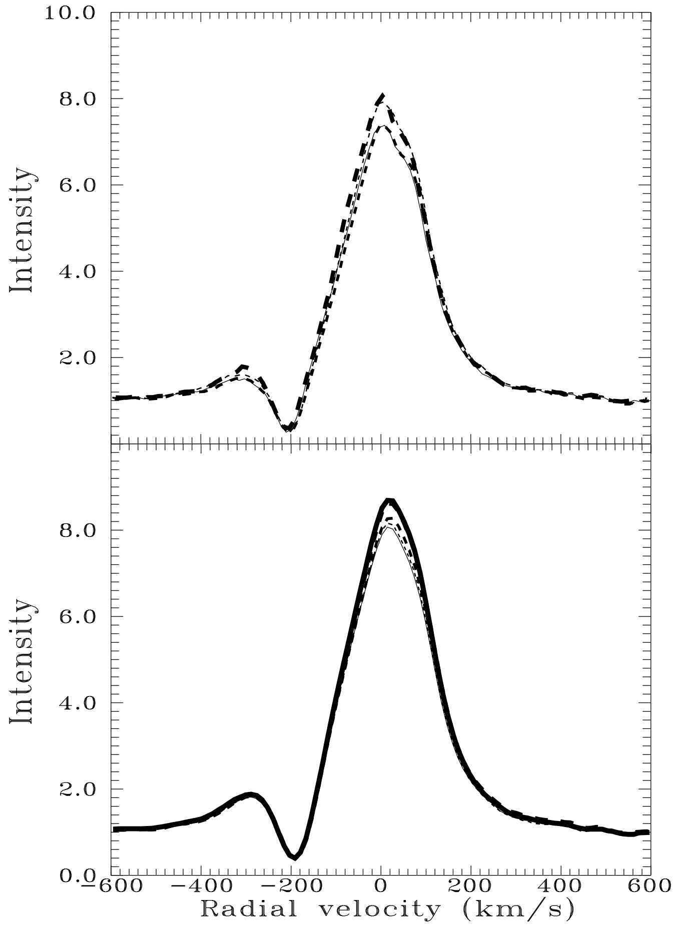

Fig. 3. Upper panel: example of the variability of the Hα line on a time scale of few days. Solid line – 01.02.2000; dotted line – 03.02.2000; short-dashed line – 05.03.2000; long-dashed line – 10.03.2000. Lower panel: Strengthening of the Hα main emission component during 1.5 hours at 11.03.1998 (five 10-minute exposures).

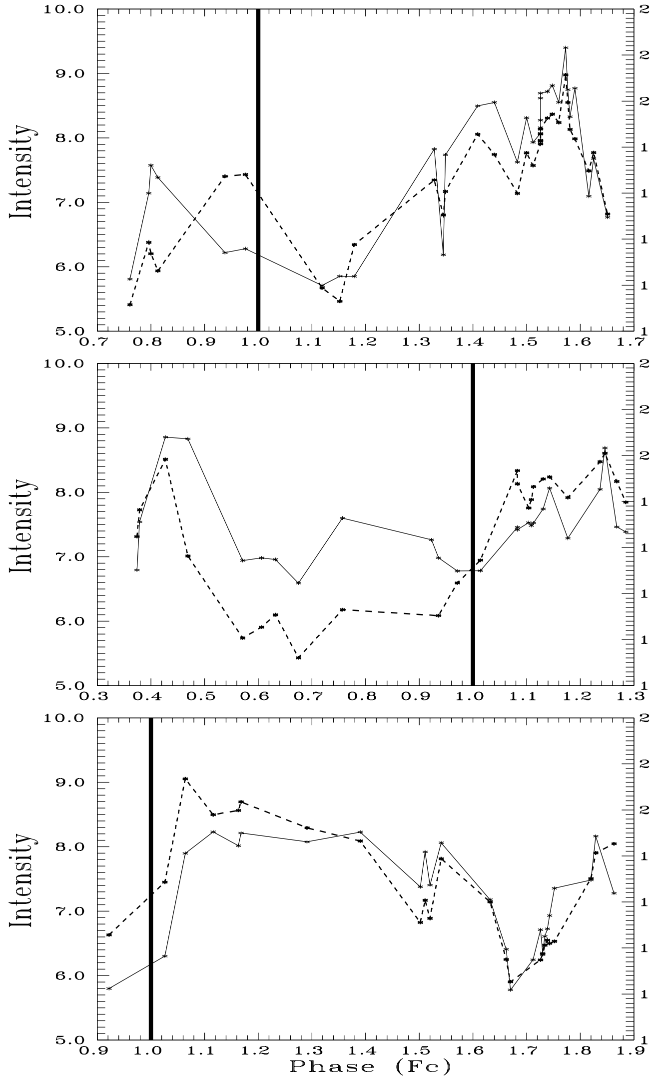

Fig. 4. Intensities of the Hα main and secondary (blue) emission components. Solid line – main component (left ordinate scale); dashed line – secondary component (right ordinate scale). Upper panel – Sep. 1997 to Apr. 1998; mean panel – Sep. 1998 to Apr. 1999; lower panel – Sep. 1999 to Apr. 2000. Vertical lines – times of the conjunctions (K-star in front).

5) A large gas cloud exists near the B-star, with dimensions similar to the B-star radius. The cloud generates a 0.5 mag dip in the U magnitude near phase 0.75 (computed from conjunction). The cloud may arise, when the stream from the K-star swings around the B-star, falls back and intersects its earlier trajectory. An alternative explanation: the stream impacts a pre-existing disk around the B-star. (We prefer the second scenario.)

In our earlier work (Puss & Leedjärv 1997) spectral investigations of AX Mon from 1985 to 1997 were presented. We examined mostly Hα, Hβ and Hγ lines, and metallic, mostly Fe II lines. The results were:

1) The variations of the Balmer lines are caused largely by the variability of the extent and the physical characteristics of the B star envelope;

2) The large scatter in the characteristics of Fe II lines indicates that they could arise in several locations, e.g. in the hot star's envelope and in the stream of matter between the K giant and the B star.

2.2. Our observations

Spectroscopic observations of AX Mon have been carried out at the Tartu Observatory, Estonia, since 1985. The spectra obtained until early 1997 have been described and analyzed in Puss & Leedjärv (1997). The most regular and homogeneous set of CCD observations starts in 1996. In the present paper we concentrate mostly on the spectra in the Hα region, recorded between 1996 and 2000, with some reference to the earlier spectra and to other spectral regions.

The 1.5 meter telescope and the Cassegrain grating spectrograph have been used. From 1996 to early 1999, the SpectraSource Instruments CCD camera HPC-1 (Tek 1024 × 1024 chip, pixel size 24 × 24 μm, Peltier cooled) has been used. Since March 1999 the spectra have been obtained with the cryogenically cooled CCD

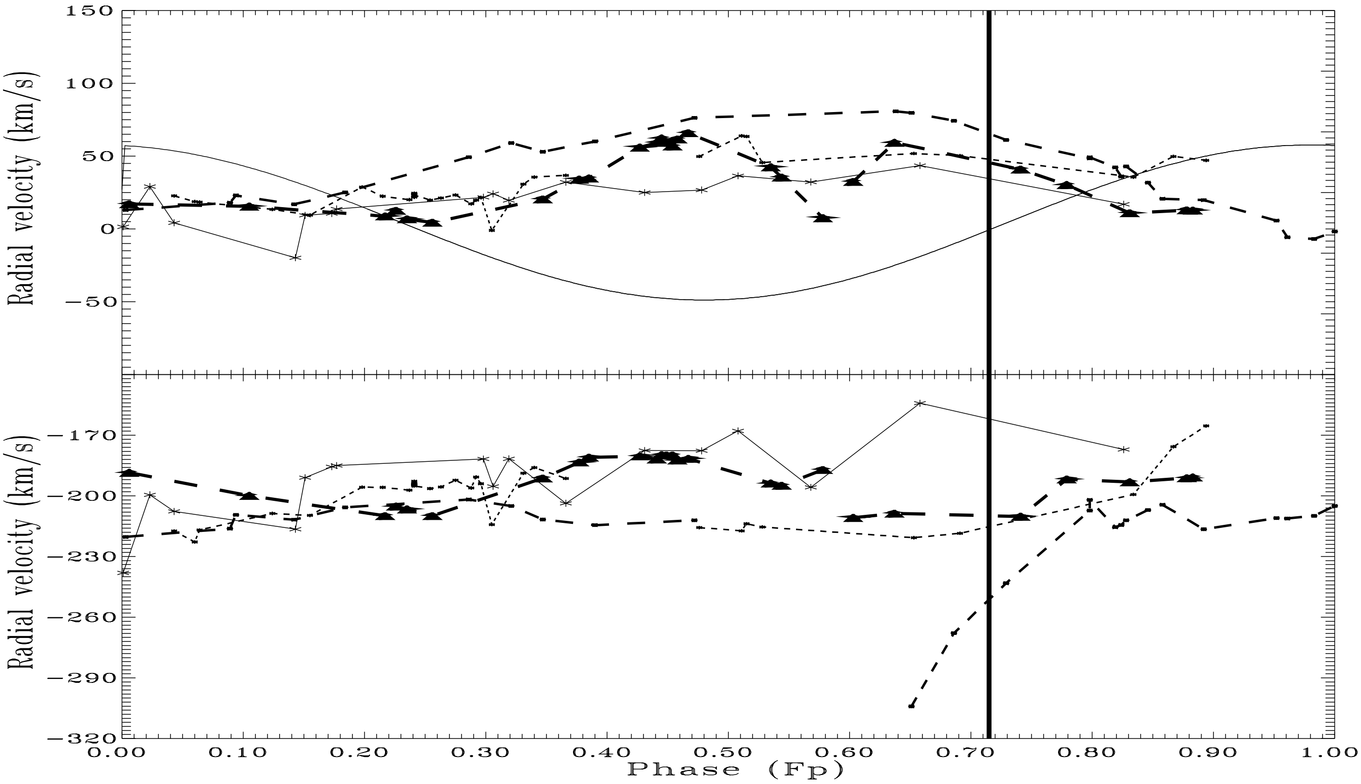

Fig. 5. Hα radial velocities depending on the orbital phase. Upper panel – main emission component; lower panel – main absorption component. Solid lines with asterisks: from Sep. 1996 to Apr. 1997; dotted lines: from Sep. 1997 to Apr. 1998; short-dashed lines: from Sep. 1998 to Apr. 1999; long-dashed lines with triangles: from Sep. 1999 to Apr. 2000. Solid curve in the upper panel indicates the radial velocity curve of the K-star. Solid vertical line: moment of the conjunction (K-star in front).

camera ORBIS-16 (also SpectraSource Instruments, Tek 512×512 chip, pixel size 24×24 μm). Altogether 97 spectra of AX Mon in the Hα region have been recorded, most of them (from 6490 to 6610 Å) with a linear dispersion ∼12 Å mm^{-1} or 0.2 Å pix^{-1}. A few spectra with lower dispersion (28 Å mm^{-1}) also have been obtained. In addition, some spectra in the blue spectral region (Hβ, Hγ) have been obtained.

Preliminary reduction of the CCD spectra (subtracting the dark frame and sky background, flat-fielding) has been performed using the ESO MIDAS package. The spectrum of a star usually occupies 6–12 rows in the CCD frame. The readings in each row have been divided by the weights obtained from the vertical (y-direction) cross-section of the spectrum. The final one-dimensional spectrum is computed as a median value of those weighted rows, thereby excluding cosmic ray spikes and other random noises.

In further reduction of the spectra we used the software package KASPEK, developed and modified by Annuk (1986, and private communication) at the Tartu Observatory. For a wavelength calibration, the spectrum of a Ne-Ar (until October 1999) or Th-Ar (from October 1999 onward) hollow cathode lamp has been recorded together with all the stellar spectra. The wavelength-calibrated spectra have been normalized to the continuum. The KASPEK package has been used also for measurements of radial velocities, equivalent widths and other quantities from the normalized spectra.

3. Analysis of the spectra

3.1. The Hα line: Profiles, intensities, velocities

In Fig. 1 we present Hα profiles of AX Mon at phases of about 0.5, 0.75, 0.0 and 0.2 from 1996 to 2000 in four different orbital cycles, respectively. Phases are computed from the conjunction of the stars (K-star in front). Very generally speaking, the Hα lines show a P Cygni profile with the main emission component at about +20 km s^{-1} and an absorption component at about −200 km s^{-1}. Actually, however, in most cases we can detect emission blueward of the P Cygni absorption component. Thus, the Hα profiles of AX Mon resemble those of Be-stars, with V/R mostly less than 0.3. The Hα profile is quite smooth around phase 0.5, while more details in the Hα profile appear at the time closer to the conjunction.

Intensities of the main emission and absorption components depending on time are given in Fig. 2. Weakening of the main absorption around zero-phase is well visible, but during different conjunctions the time scales and intensity of the weakening are different.

Figure 1 shows, that the Hα main emission component is strongest around phase 0.5, weakest around conjunction,

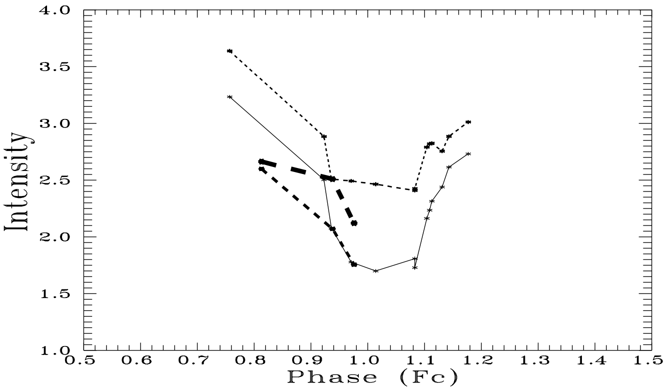

Fig. 6. Intensities of the additional emission/absorption components over the two observed "strong" conjunctions (1999 and 1997). Solid line: intensities of the absorption component around JD 2 451 227; dotted line: intensities of the emission component around JD 2 451 227; short-dashed line: intensities of the absorption component around JD 2 450 762; long-dashed line: intensities of the emission component around JD 2 450 762.

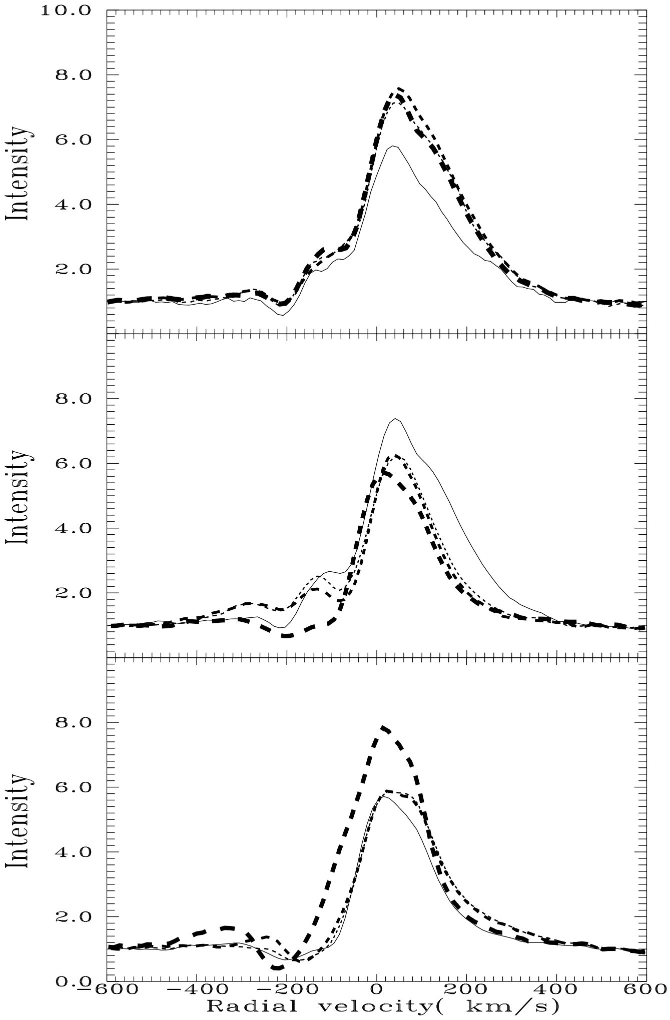

Fig. 7. Hα profiles, obtained around the "strong conjunction" JD 2 450 762 1997. Upper panel: solid line: phase 0.761; dotted line: phase 0.796; short-dashed line: phase 0.800; long-dashed line: phase 0.813. Middle panel: solid line: phase 0.813; dotted line: phase 0.938; short-dashed line: phase 0.976; long-dashed line: phase 1.119. Lower panel: solid line: phase 1.119; dotted line: phase 1.152; short-dashed line: phase 1.179; long-dashed line: phase 1.328.

and in the meantime also somewhat variable in intensity. Figure 2 also presents the intensity of the Hα main emission component. To a certain extent there exists a local minimum close to the conjunction, but this phenomenon is not clearly periodical. The intensity of the emission component mostly seems to be irregularly variable, therefore it is possible, that such a minimum is an incidental case. Changes in the intensity of the main emission component can be fast, in a time scale of a few days, or even of a few hours (see Fig. 3).

The weaker secondary (violet) emission component (not to mix up with additional component in blue edge of the main (red) emission component, see later!) of Hα is variable similarily to the main emission component (see Fig. 4). This is a hint that in the AX Mon system a variable disk or disk-like structure, exists.

Figure 5 shows radial velocities of the Hα main emission component depending on the phase. The dependency varies from cycle to cycle indicating that a region, where the line arises, has no permanent extent. Sometimes this region seems to be concentrated closer to the B-star, the velocity curve is then approximately in opposite phase with that of the cool star. Sometimes the Hα radial velocity is almost independent of the orbital phase, which means that the region, where the Hα emission line arises, has moved further away from the B-star.

The Hα absorption component is also variable. Often, the component as a whole shifts together with the blue edge of the main emission component. In Fig. 5, lower panel, radial velocities of the Hα main absorption component depending on the orbital phase are shown. But here we cannot find a clear phase dependency. Radial velocities of the Hα secondary, blue emission component are poorly determined, because of its large width.

Figure 1 also shows that around the time of the conjunction additional emission and/or absorption components arise in the blue wing of the Hα main emission component. Their duration differs from cycle to cycle and is correlated with the duration of the weak intensity of the Hα main absorption component. In Fig. 6 we present the trend of the intensities of additional components in two different cycles. In both cases the intensities of emission and absorption components drop until the conjunction. Unfortunately, we have no spectrum with additional Hα components immediately after the conjunction in 1997. The first spectrum has been obtained one month later, in phase 0.119 after conjunction. However, from Fig. 7, middle panel, we are able to draw some conclusions. It seems that additional components of Hα weaken after the conjunction, until being fused and associated with the stronger main absorption component of the Hα. However, two orbital periods later, the situation after the conjunction is different (see Fig. 8, right). In this case additional components do not disappear immediately after the conjunction, but their intensities begin to increase. Eventually, they seem to be associated with the blue edge of the main emission component of Hα, which becomes wider.

3.2. "Strong" and "weak" conjunctions

If we consider all the Hα spectra obtained during the observing period from 1996 to 2000, it seems that the effects in connection with conjunction of the stars are alternately stronger and weaker. In the case of a "strong conjunction" weakening of the Hα main absorption component lasts longer and reaches greater intensity. Then, also additional absorption/emission components appear in the blue edge of the Hα main emission component. In the case of a "weak conjunction" weakening of the main absorption component is not so intense and it may remain below the continuum level. In this case we do not find additional absorption/emission components. With some reserve we can consider the conjunctions at JD 2 450 297, JD 2 450 762, JD 2 451 227, JD 2 451 692 as "strong" and those at JD 2 450 529.5, JD 2 450 994.5, JD 2 451 459.5 as "weak".

This idea acquired some confirmation by the observed cyclically shifts of the edges of the Hα main emission component (see Fig. 10), although this process is not very regular:

1) Around $F_c \approx 0.5-0.6$ a reddening of the violet wing (with weakening of the line);

2) Around $F_c \approx 0.7-0.8$ a reddening of the red wing (with strengthening of the line);

3) Around $F_c \approx 0.9-1.0$ a blueing of the red wing (with weakening of the line);

4)Around $F_c \approx 0.2-0.3$ a blueing of the violet wing (with strengthening of the line).

We have measured radial velocities of the points of the Hα profile at the intensity level 3.5 (continuum level = 1.0). The "four-phase cycle" mentioned above becomes evident at times with "strong conjunctions" as at JD 2 450 762 and JD 2 451 227 (see Fig. 8 for the conjunction around JD 2 451 227). For the orbital periods with "weak conjunction" this cycle is not so distinctive. However, some problems exist. If our supposition is true, in May 2000, JD 2 451 692, a "strong conjunction" should have taken place. The two first parts of the expected cycle are well visible in Fig. 10, but then a discrepancy appears. In the phase interval 0.752–0.863 the red edge of Hα is shifting to the blue. This is somewhat earlier than supposed. But at the same time the blue edge shifts to the blue too (see Fig. 9), which is in contrast with earlier "strong conjunctions", when shifting of the blue edge has taken place after the conjunction. This shift of the blue edge to the blue "ahead of time" arises suspicion that during the present "strong conjunction" also additional components will not appear. Unfortunately, more observations of the AX Mon system were made impossible by the sunset glow. Thus, there is no strict proof, that "strong" and "weak" conjunctions appear alternately.

It seems, that the appearance of the additional components in the blue edge of the Hα main emission component is possible, if the blue edge shifts sufficiently to the red. An additional condition is that it should happen around the conjunction, but from cycle to cycle the physical conditions appear to change. Even during different "strong conjunctions" the additional components behave differently (see above).

3.3. Possible explanations

In this subsection we try to find some simple phenomenological explanations for the behaviour of the Hα line in the spectrum of AX Mon.

(1)The main profile of Hα is a mixture of a P Cygni profile and of a profile with two emission components (like in Be-stars).

It is known that P Cygni profile implies a spherically symmetric ejection of matter. Profiles with two emission components indicate on the other hand the existence of a disk-like structure in the system. This may be an accretion disk, formed from the material accreted from the cool star. However, the disk may indicate that the hot component is a Be-star, which ejects material itself.

Figure 4 shows that generally intensities of the Hα main and secondary emission component increase or decrease simultaneously. This confirms the possible presence of a disk. However, because the red component (previously known as the main emission component) is much stronger than the violet, or the secondary component (it is not the additional component!), it may indicate ejection of matter from the whole binary system.

(2) The Hα line is variable, but the main features appear around the conjunction of the stars (see Fig. 1).

Around the conjunction the Hα main absorption component becomes weaker up to the continuum level. Duration and extent of the weakening is different for every conjunctions. Moments, when the absorption component is faintest are not periodic (see Figs. 1 and 2). It is interesting to mention that Hγ and Hδ absorption components become stronger during the conjunctions (Cowley 1964).

Since the effects connected to the conjunction of the stars are associated with the viewing angle, those effects have mainly a geometrical origin. Since the variability of the Hα line varies from cycle to cycle, it suggests changing physical conditions in the AX Mon system.

A possible reason: around the conjunction the Hα absorption component is being suppressed by cloud or clouds between the two stars, which generates the Hα emission. Parameters of the cloud (clouds) are most likely not constant. At shorter wavelengths, this region may not be able

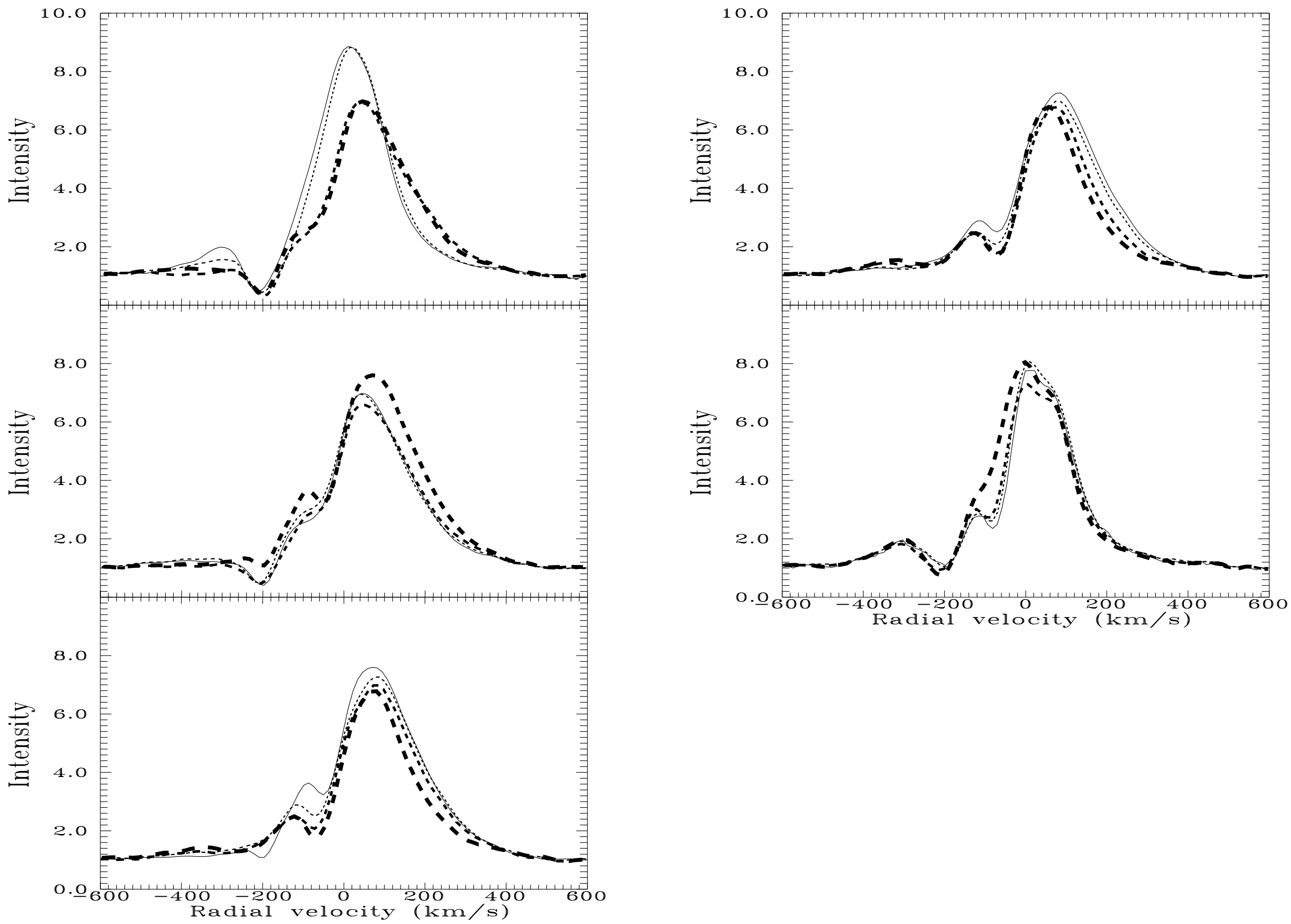

Fig. 8. Hα profiles around "strong conjunction" JD 2 451 227. Upper left panel: solid line:phase 0.427; dotted line: phase 0.469; short-dashed line: phase 0.571; long-dashed line: phase 0.606. Middle left panel: solid line: phase 0.606; dotted line: phase 0.632; short-dashed line: phase 0.675; long-dashed line: phase 0.757. Lower left panel: solid line: phase 0.757; dotted line: phase 0.923; short-dashed line: phase 0.936; long-dashed line: phase 0.971. Upper right panel: solid line: phase 0.923; dashed line: phase 0.936; short-dashed line: phase 0.971; long-dashed line: phase 1.014. Lower right panel: solid line: phase 1.131; dotted line: phase 1.143; short-dashed line: phase 1.177; long-dashed line: phase 1.237.

to generate emission, but only add to the absorption. As a result, the Hγ and Hδ absorption components can become stronger .

(3) Around the conjunction additional absorption or emission components on the blue edge of the Hα main emission component sometimes appear (see Fig. 1). Their evolution in time is different for every conjunction (see Figs. 7 and 8). This phenomenon implies that flows of the matter between the components of the binary system are non-stationary (see (2)). Figure 7 presents the evolution of the additional components in 1997. They influence also the secondary emission component, which evolves parallel to the additional emission component (see Fig. 4). Finally, the latter becomes weaker and fuses with the main absorption component (at the same time also the secondary emission component becomes weaker).

Figure 8 presents the situation two orbital periods later. Here, the additional components vary in a more complex manner. At first, the main absorption component disappears totally, then arises again at very negative radial velocity, about $-305\ \mathrm{km\,s^{-1}}$, moves to the red and becomes stronger. The secondary emission component changes analogously. The additional components last for a longer time.

(4) Wings of the main emission component seem to be variable in a "four-phase" cycle (see Sect. 3.2 and Fig. 10). This cycle appears only, when phenomena associated with the conjunction of the stars are stronger (additional Hα components appear, Hα main absorption component becomes weaker). In "weak conjunctions" this cycle does not turn up completely. However, in 2000, when a "strong conjunction" should have happened, the "four-phase" cycle was cut off at the third phase. Actually, the third and the fourth phase took place together! Figure 10 (upper panel) shows that the reddening of the blue edge of the Hα main emission component lasted much shorter

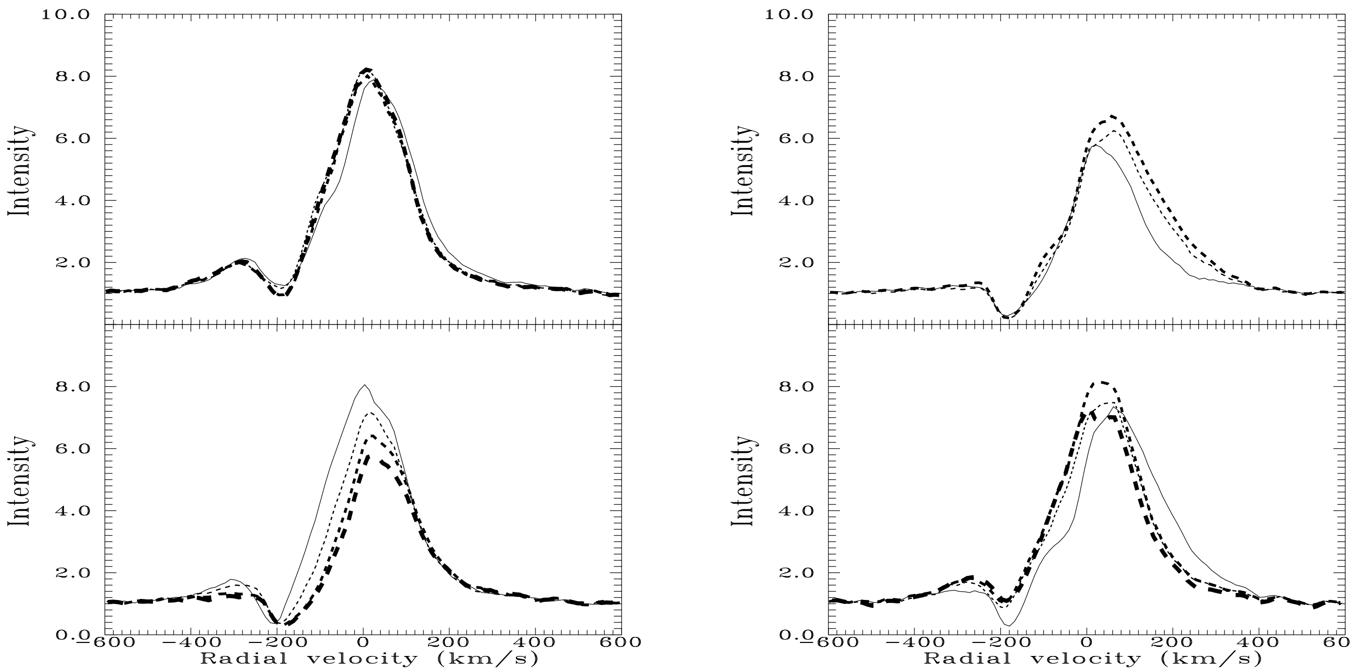

Fig. 9. Hα profiles between the "weak conjunction" JD 2 451 460 and "strong conjunction" JD 2 451 692. Upper left panel: solid line: phase 0.064; dotted line: phase 0.116; short-dashed line: phase 0.163; long-dashed line: phase 0.168. Lower left panel: solid line: phase 0.541; dotted line: phase 0.632; short-dashed line: phase 0.662; long-dashed line: phase 0.670. Upper right panel: solid line: phase 0.670; dotted line: phase 0.712; dashed line: phase 0.726. Lower right panel: solid line: phase 0.752; dotted line: phase 0.820; short-dashed line: phase 0.829; long-dashed line: phase 0.863.

compared with the reddening in other "strong conjunctions" (see also Fig. 9, lower left panel and the right panel). This all indicates again a non-homogeneous distribution of the circumstellar material.

(5) It seems, that all these effects appear more or less alternately. Consequently, we presume that in the AX Mon system a cyclicity could exist in the Hα line with the duration of about two orbital periods (see Sect. 3.2).

4. Discussion

According to Cowley (1964), narrow shell-lines of ionized metals appear in the spectrum of AX Mon near the time of conjunction, and they are interpreted as arising in a stream of matter moving from the K-giant to the hot star at about $+25$ km s^{-1}. At the same time, absorption components of the Balmer Hγ and Hδ lines become stronger. In the present paper, we have shown that around the time of the conjunction of the two stars the Hα line is also variable in quite a complex manner.

At the risk of some oversimplification, we can state that the Hα profiles indicate that in the AX Mon system an extended disk-like envelope exists around the B(e)-star where the Hα emission line originates. On top of the Hα emission variable absorption components are superimposed. Around phase 0.5 (B-star in front) the Hα profile resembles a classical P Cygni profile. During orbital phases closer to the conjunction, the Hα profiles become more complicated: additional absorption components appear, sometimes the "normal" main absorption component disappears at all and the line as a whole shifts on the velocity scale etc. Assuming the orbital inclination $i = 65^0$, the eclipses by the gas cloud (see below) alone cannot explain all the phenomena observed close to the conjunction.

When the orbital motion brings the stars closer to the quadrature (phase 0.75), usually the main emission component of Hα will be distorted by additional absorption(s) at radial velocities ≤ -50 km s^{-1}. Around the same orbital phase (0.75) a 0.5 mag dip in the U light curve has been observed. Elias et al. (1997) explain this drop as due to a gas cloud close to the B-star scattering and/or absorbing light. The absence of dips at longer wavelengths requires a strongly bandpass-specific opacity, which could be caused by the Balmer continuum shortward of the jump and by the many high-order Balmer lines. Most likely it is the same cloud which is responsible for the additional absorption components appearing in the Hα profile near phase 0.75. Relying mostly on the photometric observations by Magalashvili & Kumsishvili (1969), Elias et al. (1997) have found that the 0.5 mag dip in the U bandpass is a persistent feature over at least five orbital cycles. However, our spectroscopic observations show that additional absorption components do not necessarily occur in every orbital cycle (see Fig. 1, upper left panel, Hα profile from January 25, 1997 = JD 2 450 474).

Variations of the Hα profile closer to the conjunction (phase 0.0) and after that also vary from cycle to cycle. As

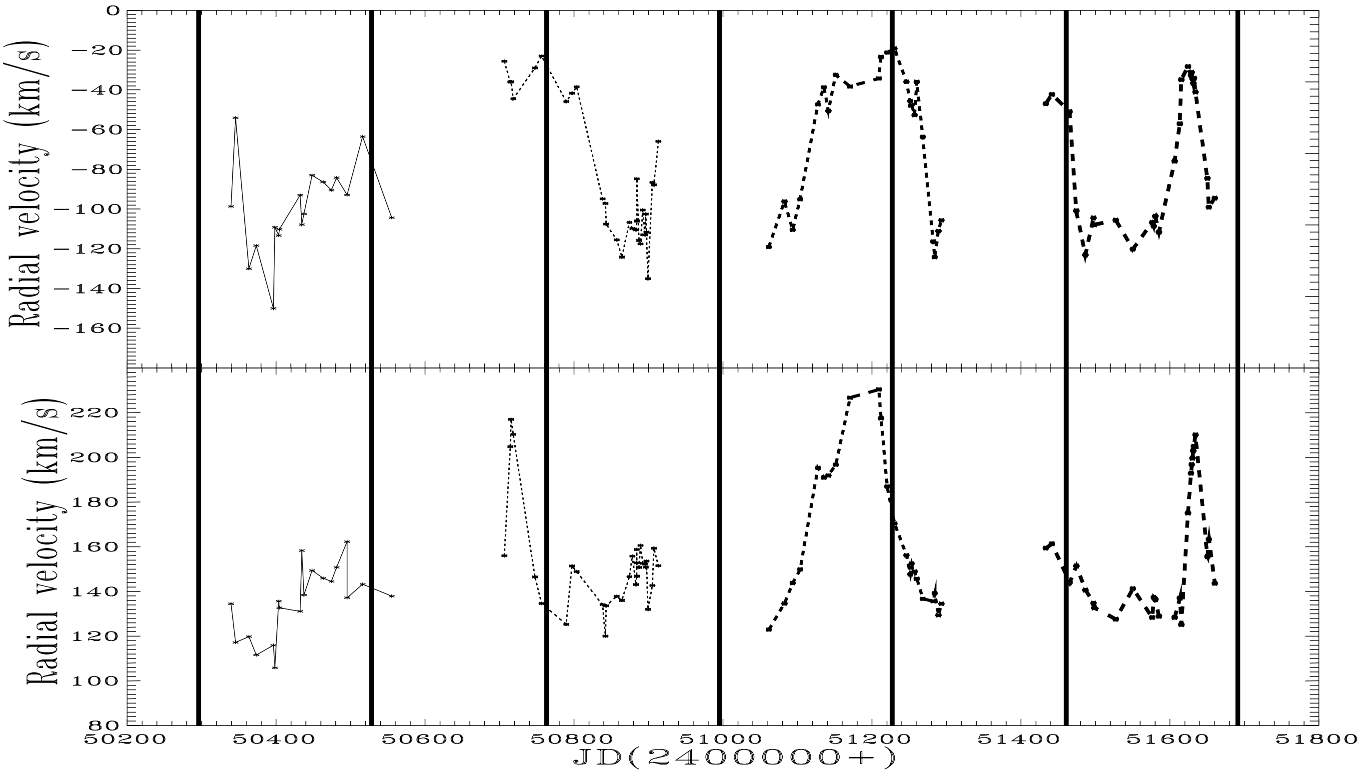

Fig. 10. Radial velocities of the edges of the Hα main emission component at the intensity level 3.5. Upper panel: blue edges; lower panel: red edges. Solid lines: from Sep. 1996 to Apr. 1997. Dotted lines: from Sep. 1997 to Apr. 1998. Short-dashed lines: from Sep. 1998 to Apr. 1999. Long-dashed lines: from Sep. 1999 to Apr. 2000. Vertical lines: times of the conjunctions (K-star in front).

discussed in Sect. 3.2, it seems that so called "strong" and "weak" conjunctions take place alternately. A correlation between the photometric and spectroscopic characteristics is not always present. Assuming that the more or less regular fading of the ultraviolet light of AX Mon around phase 0.75 is persistent up to the time of our observations, we noticed that during photometric constancy, spectroscopic features come and go. This is possible, considering that the attenuating cloud in front of the B-star probably is consisting of many small cloudlets, which may move to-and-fro and with different speeds. The overall extent of the attenuating cloud, which determines the photometric behaviour, remains more or less constant, while the forming of additional absorption components in the Hα profile depends on the prevailing direction and velocity of motion of the cloudlets at any given time. As suggested by Elias et al. (1997), some material can occasionally be blown up high enough to be projected against the B-star's photosphere even at phases rather far away from the conjunction. For example, Fig. 7 in Elias et al. (1997) shows that the main absorption of Hα has been vanished and additional absorption components are present at phase 0.209 (JD 2 449 416). Also, our spectra have shown a somewhat similar Hα profile at phase 0.177 (Fig. 1, lower left panel).

On the other hand, by the absence of simultaneous photometric and spectroscopic data, we cannot be absolutely sure that the photometric behaviour of AX Mon in 1990s has been the same as in 1960s. Referring again to Elias et al. (1997), one can see from their Fig. 2 that during about one year (March 1995 to March 1996), there has been a rather large scatter in the star's brightness in the Strömgren u filter. Although the dip at phase 0.75 is well visible, its duration is much shorter than in the broadband U filter data from 1960s (Fig. 1 in Elias et al. 1997). The difference in the bandwidths of the Johnson U and Strömgren u filters hardly accounts for this discrepancy, as both filters include the Balmer jump. According to our "schedule" of alternating conjunctions, the time interval from March 1995 to March 1996 includes a "weak" conjunction in December 1995. Thus, there is a hint that during "weak" conjunctions the dip in the U magnitude could last shorter as compared to "strong" conjunctions.

Still an intriguing question remains, viz. whether the "strong" and "weak" conjunctions really alternate over longer time intervals, and if so, what the reason might be for this type of variability. A search for a possible physical mechanism which drives gas flows in the AX Mon system with a periodicity of approximately two orbital periods requires understanding of the formation mechanism of the cloud in the vicinity of the B-star.

Elias et al. (1997) put forward two alternative mechanisms for generating the attenuating cloud. The first one: the cloud is the self-intersection "point", where incoming cloudlets from the K-star collide with other cloudlets which have encircled the B-star before. An alternative mechanism is, that the stream from the K-star impacts a pre-existing disk- or shell-structure that orbits the B-star. This structure may consist of matter ejected by the B-star itself. Thus, the hot component could actually be a Be-star.

Be-stars are generally known as rapidly rotating objects which eject matter, mainly in their equatorial plane. This process can be variable on different time scales. Also, it is known that transitions B → Be → Be shell star can occur on a time scale from years to decades. Some time ago Kříž & Harmanec (1975) suggested that all the Be-stars could be members of binary systems being spun up to rapid rotation by mass transfer. This suggestion has not been entirely confirmed by later investigations, for instance, Gies (2000) has presented arguments that most of Be-stars cannot be components of active mass transfer systems. In the AX Mon system, however, a clear evidence of mass transfer can be found. Tarasov (2000) has classified AX Mon as a W Ser type active binary.

5. Conclusions

AX Mon is an interacting binary system in the stage of active mass transfer between the components. Our study of the variability of the Hα emission line has led to the following conclusions:

(1) The Hα profile which is a mixture of a P Cygni profile and of a profile with two emission peaks indicates that an extended gaseous envelope exists around the hot component of the AX Mon system. The hot component is most likely a Be-star and the shape of the envelope might be something intermediate between a spherically symmetric expanding envelope and a flat equatorial disk.

(2) The Hα profiles are variable on time scales from hours to years, with main features appearing around the conjunction of the stars (K-star in front). Those features include weakening of the main absorption component and appearance of the additional emission and absorption components. Also the Hα line as a whole shifts on the wavelength scale in a certain "four-phase" cycle.

(3) There is a rather strong, but still no final evidence that the effects mentioned in (2) reveal themselves at every second conjunction. We propose to call those conjunctions "strong" (at JD 2 450 297, 2 450 762, 2 451 227, 2 451 692), while during "weak" conjunctions (at JD 2 450 529.5, 2 450 994.5, 2 451 459.5) changes in the Hα profile are quite small. This possible cyclicity with a duration of approximately two orbital periods needs further explanation.

(4) The cloud of gas in the vicinity of the Be-star, proposed by Elias et al. (1997) to cause a nearly 0.5 mag dip in the U light curve near the phase 0.75, is responsible also for most of the variations of the Hα profile. This high-density cloud, most likely, arises when the stream of the matter from the K-star collides with the pre-existing disk-like structure around the Be-star.

In order to determine more definitely, which stage of mass transfer is taking place in the AX Mon system, one still needs more observational data in different wavelength regions such as conventional broad-band photometry. A search for a correlation between photometric and spectroscopic properties would give a significant insight into the pattern of the long-term variability. Referring once more to the paper by Elias et al (1997), one can see from their Figs. 1 and 2 that the photometric behaviour of AX Mon was slightly different in the 1960s and the 1990s. There is a possibility that mass transfer in the AX Mon system was quite stable in the 1960s, while in the 1990s more instabilities have set in.

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