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The pre-main sequence spectroscopic binary UZ Tau East: Improved orbital parameters and accretion phase dependence[⋆]

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Abstract. We present radial-velocity measurements obtained using high- and intermediate-resolution spectroscopic observations of the classical T Tauri star UZ Tau East from 1994 to 1996. We also provide measurements of Hα equivalent widths and optical veiling. Combining our radial-velocity data with those recently reported by Prato et al. (2002), we improve the orbital elements for this spectroscopic binary. The orbital period is 18.979 ± 0.007 days and the eccentricity is $e = 0.14$. We find variability in the H_α emission and veiling, signposts of accretion, but at periastron passage the accretion is not as clearly enhanced as in the case of the binary DQ Tau. The difference in the behaviour of these two binaries is consistent with the hydrodynamical models of accretion from circumbinary disks because UZ Tau East has lower eccentricity than DQ Tau. It seems that enhanced periastron accretion may occur only in systems with very high eccentricity ($e > 0.5$).

Key words. stars: binaries: spectroscopic – stars: formation – stars: late-type – stars: pre-main sequence – accretion, accretion disks – stars: planetary systems: protoplanetary disks

1. Introduction

UZ Tau was one of the first 11 stars originally identified as members of the class of T Tauri variable stars, and it was also noticed to be a wide pair with angular separation 3.″6 (Joy & van Biesbroek 1944). UZ Tau East and West are a pair of classical T Tauri stars (CTTSs), i.e. very young stars with an emission line spectrum that indicates active mass accretion from a circumstellar disk (Appenzeller & Mundt 1989, Bertout 1989).

UZ Tau E is a CTTS with spectral type M 1, strong H_α emission, strong excess continuum emission at infrared and submillimiter wavelengths (Jensen et al. 1996) and a Keplerian disk (Simon et al. 2000). UZ Tau W is itself a pair with an angular separation of 0.″34 (47.6 AU at 140 pc; Simon et al. 1995). UZ Tau W does not have as strong an infrared excess as E, and it also has much less submillimiter emission (Jensen et al. 1996).

Prior to our observations, UZ Tau E was thought to be a single star. In 1994 we started high-resolution spectroscopic observations of this star and we noticed the radial-velocity variability. Follow-up observations were obtained in several runs. An early report of the orbital parameters of UZ Tau E was given by Mathieu et al. (1996). Prato et al. (2002) obtained radial-velocity measurements of both components of UZ Tau E using near-infrared spectra, and estimated the mass ratio of the system.

After AK Sco (Andersen et al. 1989), GW Ori (Mathieu et al. 1991), DQ Tau (Mathieu et al. 1997), V4046 Sgr (Quast et al. 2000), and RX J0530.7-0434 (Covino et al. 2001), UZ Tau E is only the fifth CTTS known to be a spectroscopic binary. Another CTTS spectroscopic binary, namely KH 15D, has recently been reported by Johnson et al. (2004).

In this paper we present our spectroscopic observations of UZ Tau E obtained from 1994 to 1996. In Sect. 2 we describe the observations. Section 3 contains the main results, including

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[⋆] Based on observations made with the Isaac Newton Telescope, operated on the island of La Palma by the Isaac Newton Group in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias, the ESO 3.6-m telescope at La Silla Observatory in Chile, and the Shane 3-m telescope at Lick observatory in California.

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the orbital solution found using our data and those in the literature. Section 4 provides a discussion of the properties of this spectroscopic binary.

2. Observations and data reduction

Most of the spectroscopic observations presented in this paper were carried out with the 2.5-m Isaac Newton Telescope (INT) equipped with the Intermediate Dispersion Spectrograph (IDS). We used the cameras and gratings listed in Table 1 which provided the full width half maximum (*FWHM*) spectral resolutions given in the same table. We placed both UZ Tau E and W along the same IDS long slit.

The initial identification of radial-velocity variations was made in the analysis of the IDS spectra. In order to confirm the results and to improve the orbital parameters, we supplemented the INT data with observations obtained with the Hamilton echelle at the Shane 3-m telescope at Lick Observatory. We measured the radial velocity of UZ Tau E in a spectrum obtained in 1988, which has been used to derive veiling by Basri & Batalha (1990) and to measure the strength of the lithium resonance line by Basri et al. (1991). Additional observations were obtained at the ESO 3.6-m telescope in January 1996, using the CASPEC echelle spectrograph, and again at Lick with the Hamilton spectrograph in March 1996. Table 1 gives the log of the spectroscopic observations.

IDS data reduction was done with IRAF[1] routines in the same manner as described in Martín et al. (1992). Hamilton data reduction was made with IDL routines as explained in Basri & Batalha (1990). CASPEC data reduction was carried out with the echelle package in IRAF. The data were unbiased and flatfielded before extracting the spectrum. Wavelength calibration was performed using a ThAr lamp spectrum obtained the same night.

3. Results

Using the IDS spectra we measured radial velocities for UZ Tau E by cross-correlation with the spectra of UZ Tau W observed simultaneously (the slit was aligned with the visual binary axis). After several tests, we found that the spectral region between 640 nm and 650 nm gave the most precise radial velocities. Figure 1 displays one example of the spectral region that we used for cross-correlating the spectra of UZ Tau E and W. Table 2 lists the radial velocities measured in our spectra. These velocities are heliocentric, and relative to an assumed heliocentric radial velocity for UZ Tau W of 19.3 km s^{-1}. The radial-velocity error bars were obtained from the cross-correlation fit given by the IRAF task fxcor.

We also measured Hα equivalent widths and optical veiling in the IDS spectra, and we provide the values in Table 2. We did not measure these quantities in the echelle spectra (from CASPEC and Hamilton) because their resolution is much higher than that of IDS. It is well know that equivalent width measurements are affected by the spectral resolution. Moreover, we only have a few echelle spectra, and hence they do not contribute significantly to the study of the variability of H$_\alpha$ emission and veiling as a function of orbital phase. Nevertheless, in Table 2 we do quote the veiling measured by Basri & Batalha (1989). Our Hα equivalent widths are estimated to be accurate within 10% at a 3σ confidence level.

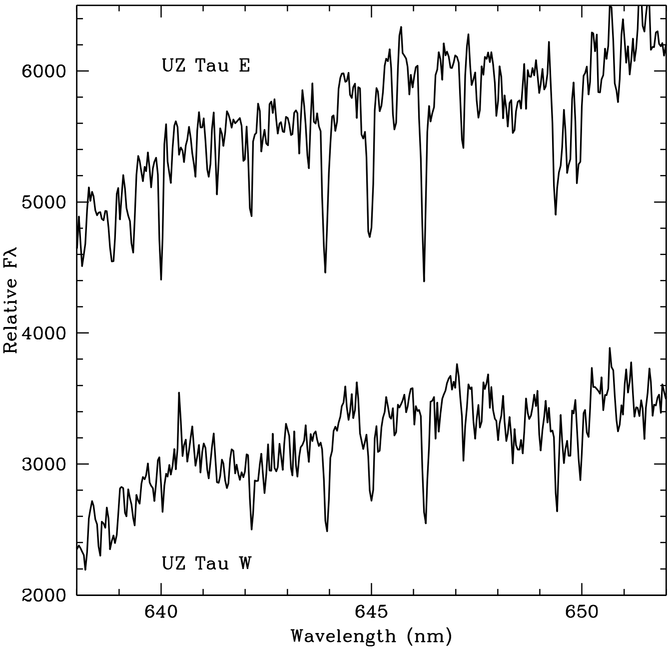

Fig. 1. Zoom on the IDS spectral region that we used for measuring radial velocities. These IDS spectra of UZ Tau E and W were obtained on 20 Nov. 1995.

The veiling at a given wavelength (denoted as v$_\lambda$) is defined as the ratio of the excess flux to the photospheric flux. As a consequence, we have measured veiling as the ratio of two equivalent widths, i.e. $v_\lambda = EW(\mathrm{LiI})_\mathrm{phot}/EW(\mathrm{LiI})_\mathrm{obs} - 1$, where $EW(\mathrm{LiI})_\mathrm{obs}$ is the observed equivalent width of the lithium doublet at 6708 Å. We could not obtain a value of veiling for the spectrum at JD = 49 972.730 using this method, because the spectral range of it did not include the lithium feature. Thus, the value given in Table 2 was obtained from the same spectral region as was used for the radial velocity measurements. We artificially veiled the spectrum of UZ Tau E obtained at JD = 50 040.528 by a small amount until we found a good match. We used $EW(\mathrm{LiI})_\mathrm{phot}$ = 720 mÅ, obtained by Basri et al. (1991). This value is close to the photospheric lithium equivalent width typical of early M-type T Tauri stars (Martín 1997). While the absolute veiling depends on this assumption, we note that our main interest is to measure the variability of the relative veiling as a function of orbital phase. The error bars in the veiling values were obtained in the same manner as explained in Basri et al. (1991).

We combined our radial-velocity data with those of Prato et al. (2002) to improve the orbital parameters of the binary system. We used the ORBIT program (Forveille et al. 1999) to find the best orbital solution to the data, which has a chi-square value of 192. The results of the best orbital fits to the data are given in Table 3 and are shown in Fig. 2. We note that the radial velocity point of Prato et al. (2002) obtained at JD = 2 452 311.2 significantly increased the error bars in the

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[1] The IRAF package is distributed by the National Optical Astronomical Observatories.

Table 1. Observing log.

UT date	JD (+2 400 000)	Instrument	Exp. (s)	Wav. range (nm)	*FWHM* (Å)
30 Nov. 1988	47 495.735	Hamilton echelle	2000	510–870	0.2
16 Oct. 1994	49 641.672	IDS/500 mm/R600	420	593–674	2.4
6 Aug. 1995	49 936.723	IDS/235 mm/R1200	1200	653–673	1.6
7 Aug. 1995	49 937.730	IDS/235 mm/R1200	1200	653–673	1.6
8 Aug. 1995	49 938.727	IDS/235 mm/R1200	1200	653–673	1.6
9 Aug. 1995	49 939.730	IDS/235 mm/R1200	1200	653–673	1.6
12 Sep. 1995	49 972.730	IDS/500 mm/R1200	600	625–665	0.8
19 Nov. 1995	50 039.495	IDS/500 mm/R1200	1000	635–674	0.8
20 Nov. 1995	50 040.528	IDS/500 mm/R1200	900	635–674	0.8
21 Nov. 1995	50 041.415	IDS/500 mm/R1200	900	635–674	0.8
21 Nov. 1995	50 041.696	IDS/500 mm/R1200	900	635–674	0.8
22 Nov. 1995	50 042.433	IDS/500 mm/R1200	900	635–674	0.8
22 Nov. 1995	50 042.665	IDS/500 mm/R1200	900	635–674	0.8
30 Nov. 1995	50 051.401	IDS/500 mm/R1200	1200	635–674	0.8
12 Jan. 1996	50 095.449	IDS/235 mm/H1800	1250	624–677	1.1
31 Jan. 1996	50 113.572	CASPEC	1800	553–773	0.2
3 March 1996	50 145.653	Hamilton echelle	2000	510–870	0.2

Table 2. Spectroscopic data for UZ Tau E.

JD(+2 400 000)	RV (km s^{-1})	$EW(H_\alpha)$ (Å)	v_λ	Phase
47 495.735	7.3 ± 1.2		0.70 ± 0.25[1]	0.81
49 641.672	4.9 ± 4.8	112.1	0.89 ± 0.20	0.88
49 936.723	34.9 ± 4.1	57.5	0.46 ± 0.20	0.43
49 937.730	36.8 ± 4.1	53.8	0.54 ± 0.20	0.48
49 938.727	32.5 ± 4.1	34.6	0.66 ± 0.20	0.53
49 939.730	28.6 ± 4.0	37.4	0.20 ± 0.20	0.58
49 972.730	22.2 ± 3.1	43.5	0.40 ± 0.20	0.33
50 039.495	15.1 ± 3.3	36.6	0.46 ± 0.15	0.84
50 040.528	6.0 ± 3.0	45.8	0.38 ± 0.20	0.90
50 041.415	7.7 ± 3.1	53.0	0.41 ± 0.15	0.95
50 041.696	5.0 ± 2.7	52.6	0.50 ± 0.15	0.95
50 042.433	3.8 ± 2.7	47.9	0.50 ± 0.20	0.00
50 042.665	2.8 ± 2.5	46.7	0.50 ± 0.20	0.00
50 051.401	36.7 ± 3.0	54.6	0.76 ± 0.20	0.47
50 095.449	12.7 ± 4.1	47.6	0.71 ± 0.15	0.79
50 113.572	15.6 ± 2.6			0.74
50 145.653	29.5 ± 3.0			0.44

[1] Veling value from Basri & Batalha (1990).

Table 3. Orbital parameters for UZ Tau E.

Element	Value
Period	18.979 ± 0.007 days
Gamma	14.9 ± 1.2 km s^{-1}
K1	15.5 ± 2.0 km s^{-1}
K2	58.2 ± 5.7 km s^{-1}
ecc	0.14 ± 0.05
omega	$217^{o}.9 \pm 30.1$
$T_{\mathrm{periastron}}$	2 451 314.09 ± 1.66 JD
M 1 $\sin^3(i)$	0.60 ± 0.16 $M_\odot$
M 2 $\sin^3(i)$	0.16 ± 0.04 $M_\odot$
$a1 \sin(i)$	0.02675 AU
$a2 \sin(i)$	0.10056 AU

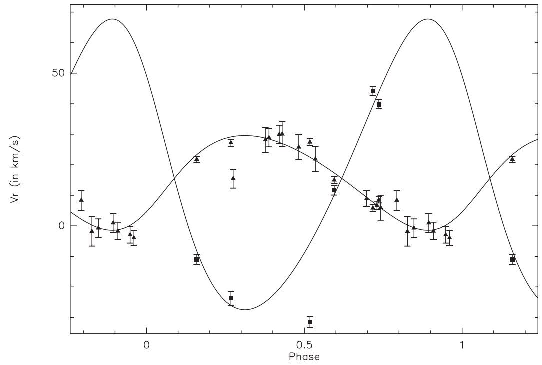

Fig. 2. Phased radial velocity data for UZ Tau E. The triangles represent the primary star and the squares represent the secondary star (from Prato et al. 2002). The curves represent our best fit for these data.

orbital elements and decreased the quality of the orbital fit. When this point was removed from the dataset, the chi-square value of the best orbital fit was 87, and the estimated masses of the components were changed significantly. In particular, the mass ratio q changed from 0.26 to 0.31. More radial velocity points for the secondary of UZ Tau E are clearly needed to improve the confidence of the mass estimates.

4. Discussion

The emission line spectrum, optical veiling, spectral energy distribution and millimeter emission of UZ Tau E are different facets of an accretion disk. Valenti et al. (1993) derived a mass accretion rate of 3×10^{-7} $M_\odot$ yr^{-1} using blue low-resolution spectroscopy. In order to maintain such an accretion rate, circumbinary material must be flowing across the binary orbit.

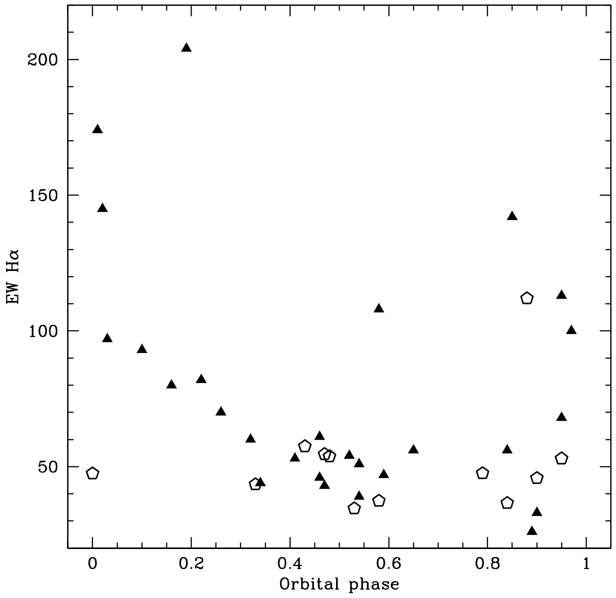

Fig. 3. Phased H_α emission data for UZ Tau E (open pentagons) compared with DQ Tau (filled triangles, from Basri et al. 1997).

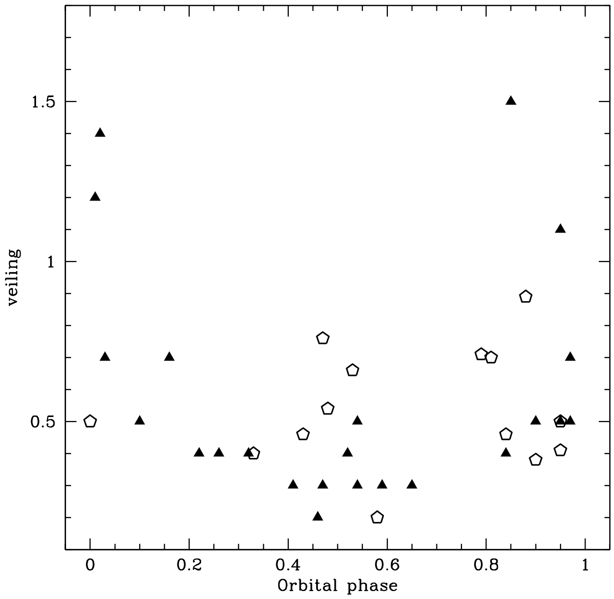

Fig. 4. Phased veiling measurements for UZ Tau E (open pentagons) compared with DQ Tau (filled triangles, data from Basri et al. 1997).

There is no evidence in the spectral energy distribution for a gap in the accretion disk, but the gap may be masked by a small amount of inflow material (Jensen et al. 1996). These authors infer a circumbinary disk mass of 0.06 $M_\odot$ from the millimeter continuum emission.

The CTTS properties of UZ Tau E can be explained with the model developed by Artymowicz & Lubow (1996) where accretion streams across the binary orbit allow large accretion rates and suppress orbital shrinkage by the flow of high-angular-momentum circumbinary material onto the stars. This model has also been invoked to explain the properties of the CTTS spectroscopic binary DQ Tau. A key prediction of this model is that accretion onto the stars in a binary system is modulated with the orbital phase. For high eccentricy binaries, most of the accretion takes place during periastron passage, but not for orbits with lower eccentricities. Observational support for this prediction was found in DQ Tau, where outbursts of emission lines and veiling were seen during periastron passages, although they were not present one third of the time (Basri et al. 1997; Mathieu et al. 1997). Moreover, in DQ Tau there is a permanent level of accretion going on at all orbital phases.

It is interesting to compare UZ Tau E and DQ Tau. The orbital periods are similar (18.9 and 15.8 days, respectively), but the eccentricities (0.14 and 0.55, respectively) and mass ratios (0.26 and 0.97, respectively) are very different. A comparison between the UZ Tau E and DQ Tau phased H_α emission datasets (without veiling corrections) is presented in Fig. 3. UZ Tau E has a level of permanent mass accretion comparable to DQ Tau as judged from the H_α equivalent width, which is on average 51.7 Å, while in DQ Tau it is 79 Å. However, we have not observed in UZ Tau E any outburst as strong as those seen in DQ Tau. We have one observation at JD = 2 449 641.67 close to periastron passage (phase = 0.88) where we find the strongest H_α emission and largest veiling in our dataset. On the other hand, we do not witness any significant emission or veiling enhancement in the periastron passage from JD = 2 450 039.49 to JD = 2 450 042.66.

In Fig. 4, we present a comparison of the dependence of veiling on orbital phase between UZ Tau E and DQ Tau. The veiling values for DQ Tau have been taken from Basri et al. (1997). The enhanced accretion events sometimes seen near periastron in DQ Tau are not present in our data of UZ Tau E. We conclude that the orbital modulation of accretion in UZ Tau E, if present, is not as clear as in DQ Tau. This could be due to the lower eccentricity of UZ Tau E or to the lower mass ratio of the two components, or to a combination of both parameters. Figure 2 of Artimowicz & Lubow (1996) shows that their hydrodynamical models predict that accretion is much more enhanced at periastron passage in a binary with $e = 0.5$ than in a binary with $e = 0.1$. Hence, the difference in behaviour between these two CTTS binaries is qualitatively consistent with the models.

Few other studies of the orbital dependence of accretion diagnostics in pre-main sequence spectroscopic binaries exist. Alencar et al. (2003) failed to find evidence for enhanced accretion near periastron in the pre-main sequence spectroscopic binary AK Sco which has an eccentricity of $e = 0.47$ and an orbital period of 13.6 days. Stempels & Gahm (2004) also did not find periastron activity in V4046 Sgr, a 2.4 day binary with a circular orbit.

Future studies of UZ Tau E are needed to improve the phase coverage of the accretion diagnostics, and to check the repeatability in its behaviour. More CTTS spectroscopic binaries must be studied to determine observationally the role of the binary parameters on the time dependence of the accretion from the circumbinary disk. Enhanced periastron activity has clearly been seen in DQ Tau only, amongst the 4 pre-main sequence spectroscopic binaries observed so far. DQ Tau has the highest eccentricity among them, and hence it seems that enhanced accretion at periastron may occur only for extremely high eccentricities ($e > 0.5$).

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