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Disk Accretion at 10 Myr: Results from the TW Hydrae Association

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Abstract. We present an analysis of the accretion properties of the members of the TW Hydrae association. The emission line profile of Hα provides explicit evidence of an active accretion flow in 3 out of the 23 observed members of the association; we use radiative transfer models to derive approximate accretion rates for these 3 objects. The resulting accretion rates for the three 10 Myr-old objects ($< 10^{-9}\ M_{\odot}\, yr^{-1}$) are well over an order of magnitude lower than typical values in 1 Myr-old T Tauri stars. The small fraction of TW Hydrae association objects still accreting (13%, compared with $\sim$ 70% in 1 Myr-old regions like Taurus), along with the very small accretion rates, points to significant disk evolution over 10 Myr, providing an important constraint on the timescales for planet formation.

1. Introduction

The TW Hydrae association (TWA) has come to be identified as one of the nearest associations of young stars (de la Reza et al. 1989; Webb et al. 1999; see also relevant articles in this volume), and hence has garnered considerable attention in the past few years with the characterization of its population. Moreover, its age of $\sim$ 10 Myr (Webb et al. 1999) makes it an extremely interesting region with which to study the processes of planet formation, since initial studies have shown that 10 Myr should be the approximate timescale for the dissipation of optically thick circumstellar disks (Strom, Edwards, & Skrutskie 1993).

An important question related to the dissipation of disks is whether gas accretion onto the central star, and hence a reservoir of gas in the disk, can persist for up to 10 Myr, and whether any such older disks show signs of evolution from their younger cousins. The timescale for the dissipation of gas disks is crucial for the formation of giant planets; core accretion models require up to 10 Myr or more to form giant planets (e.g. Bodenheimer, Hubickyj, & Lissauer 2000). The presence of active accretion in any of the TWA members would thus indicate that indeed in some cases, optically thick gas disks do survive for up to 10 Myr. TW Hya itself is already a well-known classical T Tauri star, with attendant accretion disk (Rucinski & Krautter 1983). Extending the initial results presented in Muzerolle et al. (2000), we investigate whether other members of the association also exhibit accretion signatures, and use these signatures to examine evidence of disk evolution.

2. Observations

Optical echelle spectra of 11 TWA members were obtained with HIRES on Keck. The spectral resolution was $\sim$ 8 km s^{-1}, with a wavelength coverage of about 6310 - 8750 Å. This dataset is supplemented with Keck ESI spectra of 4 of the 5 remaining members listed in Webb et al. (1999), the 3 candidates from Sterzik et al. (1999), and 5 of the 8 new candidates identified by Zuckerman et al. (2001). The ESI spectra are of lower resolution (37.5 km s^{-1}), but have a larger wavelength coverage of about 3900 - 10750 Å. Though the resolution is much lower than the echelle spectra, it is still sufficient to resolve line profiles formed in magnetically-mediated accretion flows (FWHM $\sim$ 200 km s^{-1}), where the gas is undergoing ballistic infall onto the star (e.g. Muzerolle, Calvet, & Hartmann 2001). Table 1 lists the objects observed, along with the Hα equivalent widths and FWHM line widths (multiple values indicate measurements from both ESI and HIRES, respectively), and whether the [OI] λ6300 line appears in emission

Table 1. TWA Members Observed

Object	EW(Hα) (Å)	FWHM(Hα) (km s^{-1})	[OI] λ6300?	comments
TW Hya	-238,-165	236,203	*yes*	
TWA 2	-1.8	73	*no*	
Hen 3−600A	-26,-27	150,163	*yes*	double-lined binary
Hen 3−600B	-6.7	96	*no*	ESI only
HD 98800	filled	-	*no*	ESI only
TWA 5A	-9,-7.1	140,112	*no*	double-lined binary
TWA 6	-4.2	142	-	double-lined binary
TWA 7	-5.7	64	-	
TWA 8A	-8.5	68	-	
TWA 8B	-12.5	64	-	
TWA 9A	-3.2	87	*no*	ESI only
TWA 9B	-5.1	72	*no*	ESI only
TWA 10	-7.1,-4.5	73,65	*no*	
TWA 11A	abs.	-	-	
TWA 11B	-3.8	59	-	
TWA 12	-5.3	78	*no*	ESI only
TWA 13A	-1.8	82	*no*	ESI only
TWA 13B	-4.0	84	*no*	ESI only
TWA 14	-12.5	205	*no*	ESI only
TWA 15A	-9.5	85	*no*	ESI only
TWA 16	-3.6	79	*no*	ESI only
TWA 17	-2.7	137	*no*	ESI only, broadened absorption lines
TWA 18	-3.4	102	*no*	ESI only

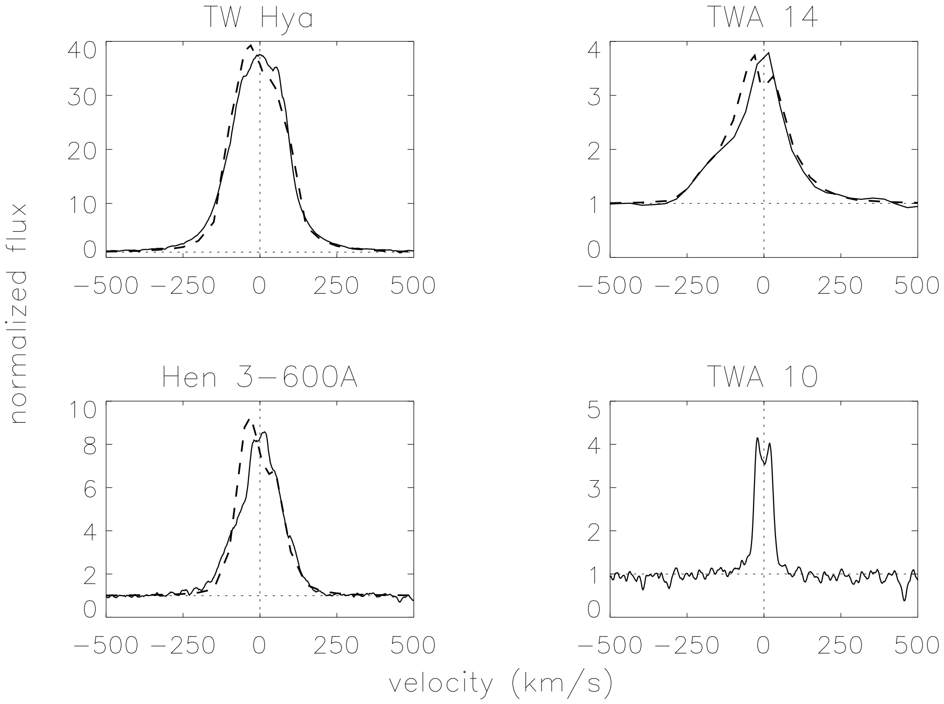

Figure 1. Observed (solid lines) and model (dashed lines) Hα profiles for the three TWA accretors, plus the observed profile of a typical non-accreting object showing chromospheric emission (TWA 10).

3. The Accretors of TWA

Only 3 of the 23 TWA members observed, TW Hya, Hen 3-600A, and TWA 14, show broad, asymmetric Balmer emission line profiles indicative of active accretion. All other objects exhibit narrow (FWHM $\lesssim$ 100 km s^{-1}) and symmetric Balmer line profiles, typical of the chromospheric emission of weak T Tauri stars (a few of these objects are probable spectroscopic binaries, where the photospheric absorption lines are broadened or doubled, in which case the Balmer lines are slightly broader at FWHM $\sim 100 - 140$ km s^{-1}). Two of the three objects with Balmer profiles showing gas infall, TW Hya and Hen 3-600A, also show [OI] λ6300 emission, an indicator of mass outflow seen only in actively accreting young stars; none of the remaining stars observed with ESI show this emission. Furthermore, these two objects exhibit infrared excess emission indicative of circumstellar disks (Jayawardhana et al. 1999a,b)[1]. Finally, TW Hya and TWA 14 exhibit continuum veiling of their photospheric absorption features, with values of 2.4 and 0.2, respectively, at 4400 Å(because Hen 3-600A is a double-lined binary, reliable veiling determinations cannot be made without knowing the stellar properties of each component).

[1]No published infrared observations yet exist for TWA 14.

In order to quantify the accretion activity, we have modeled the Hα line profiles using radiative transfer models of magnetospheric accretion. These models successfully reproduce the observed line emission in typical 1 Myr-old classical T Tauri stars in Taurus (Muzerolle, Calvet, & Hartmann 2001). Muzerolle et al. (2000) have already presented results for TW Hya and Hen 3-600A; see that paper for details. Model comparisons from that paper are shown in Figure 1, along with new results for TWA 14. Note that the stellar parameters for this object are not well-determined; we assume the same distance and age as TW Hya, and, given the similar spectral types, also the same mass and radius. In each of the three accreting TWA members, the model accounts very well for the observed profile shape, width, and strength, with surprisingly small mass accretion rates ($\dot{M} = 5 \times 10^{-10}$ $M_{\odot}\,yr^{-1}$ for TW Hya, and $\dot{M} = 5 \times 10^{-11}$ for Hen 3-600A and TWA 14) compared to typical values measured in 1 Myr-old accretors ($\dot{M} \sim 10^{-8}$). We note that the two HIRES and ESI observations of TW Hya and Hen 3-600A show relatively similar profile shapes and line strengths, with TW Hya showing somewhat stronger blueshifted absorption in the ESI spectrum.

The Hα models can only provide constraints on the mass accretion rate to within about a factor of 5, however, because of uncertainties in the parameterized gas temperature and magnetospheric size (see Muzerolle, Calvet, & Hartmann 2001). A much more definitive measurement of $\dot{M}$ can be made from the luminosity of the UV continuum excess, which is produced in the accretion shock formed as accreting material falls onto the surface of the star. Muzerolle et al. (2000) used the detailed accretion shock calculations of Calvet & Gullbring (1998) to model the UV and optical spectral energy distribution of TW Hya, the only one of the TWA accretors with sufficient UV observations. The resulting value of the accretion rate, $\sim 4 \times 10^{-10}$ $M_{\odot}\,yr^{-1}$, is in good agreement with the Hα models. [2]

4. Accretion at 10 Myr

Due to the similarity of the Balmer emission line profiles of the TWA accretors to those in the well-studied younger objects in Taurus, and the success the accretion models have in explaining these observations, it is clear that the standard disk accretion scenario for low-mass young stars still applies in these older objects. Thus, some stars are able to maintain magnetically-mediated accretion flows, and associated optically thick accretion disks, for at least 10 Myr. The mass accretion rates in the 10 Myr-old disks are significantly lower than in typical 1 Myr-old objects, which indicates that the gas disk surface densities have decreased substantially over 10 Myr. Such a decrease is in fact predicted by models of viscous disk evolution (Hartmann et al. 1998).

Moreover, the fraction of TWA members which are still accreting, and hence possess optically thick gas disks, is only 13%. This is significantly lower than

[2]Batalha and Alencar, this volume, present extensive observations of the blue excess and line profile variations, deriving larger accretion rates for TW Hya. The reason for the discrepancy is unclear, but possibly due in part to intrinsic variability.

that found in the 1 Myr-old star forming regions such as Taurus and Orion, where disk fractions as determined from near-infrared excesses range from 60-80% (Kenyon & Hartmann 1995; Lada et al. 2000). Both the decreased accretion disk fraction and the very small mass accretion rates in the three TWA accretors lend substantial evidence for significant disk evolution occurring over 10 Myr. Recent results using near- and mid-infrared excesses as signatures of optically thick inner and outer disk regions also point to similar disk dissipation timescales (e.g., Jayawardhana, this volume).

The presence of the three accreting 10 Myr-old T Tauri stars further begs the question of why their disks have survived for so long when optically thick gas disks in the remaining TWA members have since dissipated. The presence of close companions does not seem to preclude long-lived accretion disks, since Hen 3-600A is a spectroscopic binary with accretion signatures, and also has a third companion (Hen 3-600B, not accreting) ~ 50 AU distant. As noted by Muzerolle et al. (2000), a circumbinary disk around the two components of Hen 3-600A should be truncated to ~ 20 AU; for the gas to have lasted for 10 Myr, the initial mass of the circumbinary disk must have been more massive than typical ($\gtrsim 0.1\ M_\odot$). It is possible that planet formation has led to the dissipation of gas disks in the other TWA stars, some of which do exhibit mid-infrared emission from debris disks (Jaywardhana et al. 1999b), which may represent the detritus of the planet formation process. Planet formation may be ongoing in the disks of the three accretors; the spectral energy distribution of TW Hya indicates that dust coagulation or clearing has occurred within the innermost ~ 1 AU of its disk (see D'Alessio, this volume).

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