Mem. S.A.It. Vol. 76, 295

Memorie della

Accretion disks in the sub-stellar regime

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Abstract. We discuss recent findings on accretion disks around young brown dwarfs and very low mass stars, addressing both infrared and millimeter measurements of dust emission and spectroscopic signatures of gas accretion and outflow. It is now clear that a large fraction of sub-stellar objects harbor near- and mid-infrared excesses consistent with dusty disks, and that these disks exhibit a similar range of geometries and dust properties as their T Tauri counterparts. Similarly, many young brown dwarfs show evidence of on-going accretion and a few also evince possible signatures of mass outflow. On average, the accretion rate decreases steeply with mass, though there is considerable scatter in this relation. Some objects, especially in the 5-10 Myr-old associations, that harbor infrared excess do not show measurable signs of accretion; this may imply that the disks persist beyond the main accretion phase. These strong similarities between brown dwarfs and low-mass stars in their infancy suggest a common formation mechanism.

Key words. stars: low-mass, brown dwarfs – circumstellar matter – stars: formation, pre-main sequence

1. Introduction

There has been much recent interest and activity in investigating the origin and early evolution of sub-stellar objects. Some theorists, most recently Padoan & Nordlund (2004), have suggested that objects all the way from solar-mass stars to brown dwarfs form the same way, via 'turbulent fragmentation'. Others have proposed that brown dwarfs are in fact "stellar embryos", ejected from newborn multiple systems through dynamical gravitational interactions before accreting sufficient mass to become full-fledged stars (Reipurth & Clarke 2001; Bate et al. 2003). A detailed comparison between the properties of brown dwarfs and stars, in their infancy, could help distinguish between these scenarios.

Here we report on our recent findings on accretion disks around sub-stellar objects, both from infrared excess measurements and high-resolution optical spectroscopy.

2. Disk Excess

Using the ESO Very Large Telescope, Keck and the NASA Infrared Telescope Facility, we have carried out a systematic study of infrared L'-band (3.8μm) disk excess in a large sample of spectroscopically confirmed objects near

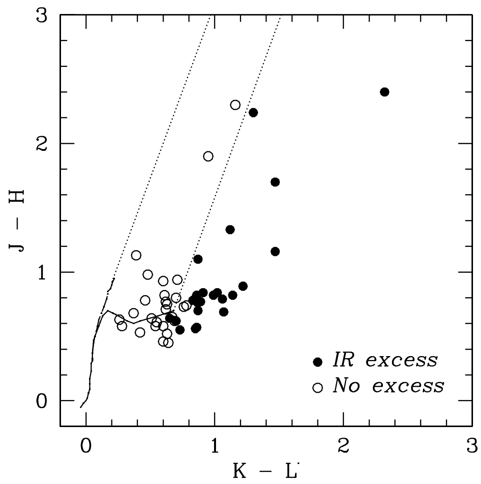

Fig. 1. $J-H/K-L'$ color-color diagram for a sample of young brown dwarfs and very low mass stars from Jayawardhana et al. (2003). Also plotted are the empirical loci of colors for giants (solid) and for main-sequence dwarfs (dashed) from Bessell & Brett (1988) and Leggett et al. (2002) and the reddening vectors (dotted). The filled circles are objects with $E(K-L')>0.2$.

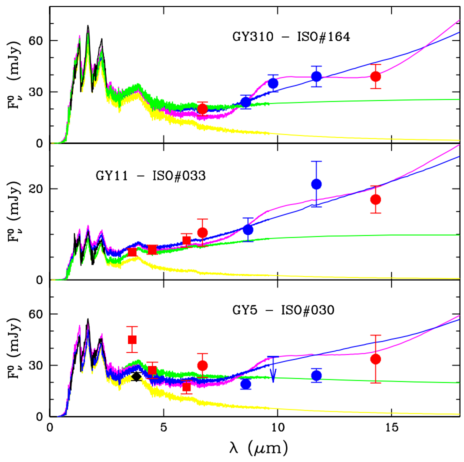

Fig. 2. Observed mid-infrared fluxes and disk model predictions for three objects in ρ Oph from Mohanty et al. (2004). GY 310 and GY 11 exhibit strong evidence of flared disks; flat disks can be ruled out for these two brown dwarfs. The data for GY 5 show large scatter and are marginally consistent with both flared and flat configurations. Inner holes a few sub-stellar radii in size are indicated in all three cases.

and below the sub-stellar boundary in several nearby star-forming regions (Jayawardhana et al. 2003). We find disk fractions of 40%–60% in IC 348, Chamaeleon I, Taurus and Upper Scorpius regions, using a conservative criterion of $K-L'>0.2$ for the presence of optically thick disks. In the somewhat older (~7 Myr) σ Orionis cluster, only about a third of the targets show infrared excess while neither of the two TW Hydrae brown dwarfs (age ~ 10 Myr) in our sample shows a significant $K-L'>$ excess. Interestingly, one of these TW Hydrae objects –2MASS1207-3932– does harbor a mid-infrared excess, implying possible clearing of small grains in the inner disk region (Sterzik et al. 2004).

Our results, and those of Muench et al. (2001), Natta et al. (2002) and Liu, Najita & Tokunaga (2003), show that a large fraction of very young brown dwarfs harbor near- and mid-infrared excesses consistent with dusty disks. Based on the current samples, the timescales for inner disk depletion do not appear to be vastly different between brown dwarfs and T Tauri stars.

Furthermore, disks around very low mass objects exhibit a similar range of disk geometries and dust properties as their T Tauri counterparts. For example, inner holes of a few sub-stellar radii are indicated in several cases (Mohanty et al. 2004; Liu, Najita & Tokunaga 2003); some circum-sub-stellar disks appear flared, with possible silicate emission at 10μm, while others are more consistent with flat disk models (Apai et al. 2002; Mohanty et al. 2004; Sterzik et al. 2004).

So far, much of this work has been carried out in the near- and mid-infrared, so the diagnostics are limited to the innermost portions of the disks. In particular, millimeter observations would be useful for detecting outer, colder, disk material and for deriving dust masses. Klein et al. (2003) have recently detected millimeter emission from two brown dwarfs (CFHT-BD-Tau 4 and IC 348 613), and estimated that each disk contains a few Earth masses of dust. We have initiated a millimeter survey of a large sample of VLM stars and brown dwarfs in order to determine the distribution of disk masses in the sub-stellar regime, and to assess the potential for planet formation in these disks.

3. Accretion Signatures

The shape and width of the Hα emission profile is commonly used to discriminate between accretors and non-accretors among T Tauri stars. Several groups have recently used this and other spectroscopic diagnostics to investigate accretion in the sub-stellar domain (e.g., Jayawardhana, Mohanty & Basri 2002, 2003; White & Basri 2003; Barrado y Navascués & Martín 2003; Muzzerolle et al. 2003; Natta et al. 2004). It has also been noted that irregular high-amplitude photometric variations, seen in some brown dwarfs, may be related to accretion (Scholz & Eislöffel 2004). Furthermore, a number of objects around the hydrogen burning limit exhibit forbidden line emission, usually associated with winds and/or outflows in T Tauri stars and Class I sources (e.g., Fernández & Comerón 2001; Barrado y Navascués, Mohanty & Jayawardhana 2004; Natta et al. 2004; Barrado y Navascués & Jayawardhana 2004).

Using data from Keck and Magellan, we have recently completed a study of disk accretion using the largest high-resolution spectroscopic sample to date of young, very low mass stars and brown dwarfs. Our ~80 targets span spectral types from M5 to M9.5, or masses from 0.15 $M_\odot$ down to ~15 Jupiters. They are confirmed members of the ρ Ophiuchus, Taurus, Chamaeleon I, IC 348, R Coronae Australis, Upper Scorpius and TW Hydrae star-forming regions and young clusters, with ages from <1 to ~10 Myr. This is a close to complete survey of all confirmed brown dwarfs known so far in the regions examined, except in ρ Oph and IC 348 (where we are limited by a combination of extinction and distance).

We find that classical T Tauri-like disk-accretion persists in the sub-stellar domain down to nearly the deuterium-burning limit. While an Hα 10% width $\gtrsim$ 200 km s^{-1} is our prime accretion diagnostic (following JMB03), permitted emission lines of CaII, OI, and HeI are also good accretion indicators, just as in CTTS. (We caution against a blind use of Hα width alone, since inclination and rotation effects on the line are especially important at the low accretion rates in these objects.) The CaII 8662Å line flux is an excellent quantitative measure of the accretion rate in brown dwarfs (as in higher-mass CTTS), correlating remarkably well with the $\dot{M}$ obtained from veiling and Hα profile fitting (see Mohanty et al. contribution in these proceedings). The accretion rate diminishes rapidly with mass – our measurements support previous suggestions that $\dot{M} \propto \mathcal{M}_*^2$ (albeit with considerable scatter), and extend this correlation to the entire range of sub-stellar masses (see Mohanty et al. for further discussion).

Our results show that the fraction of very low-mass stellar and brown dwarf accretors decreases substantially with age, as in higher-mass stars; at a given age, the fraction of very low-mass accretors is comparable to the accretor fraction in higher-mass stars. A number of targets with infrared excesses, presumably from dusty disks, do not show measurable accretion signatures, with the incidence of such a mismatch increasing with age: this implies that disks in the ultra-low mass regime can persist beyond the main accretion phase, and parallels the transition from the classical to post-T Tauri stage in more massive stars.

Interestingly, 2MASS 1207-3932 in the TW Hydrae association appears to be a (weak) accretor even at an age of 8-10 Myrs (Mohanty, Jayawardhana & Barrado y Navascués 2003). While we cannot rule out activity, comparison with a flaring field dwarf implies that such activity would have to be quite anomalous. What's more, we have now found forbidden [OI] 6300 Å emission in its spectrum, possibly indicating a wind/outflow. The verification of these findings would make it the oldest actively accreting brown dwarf known to date as

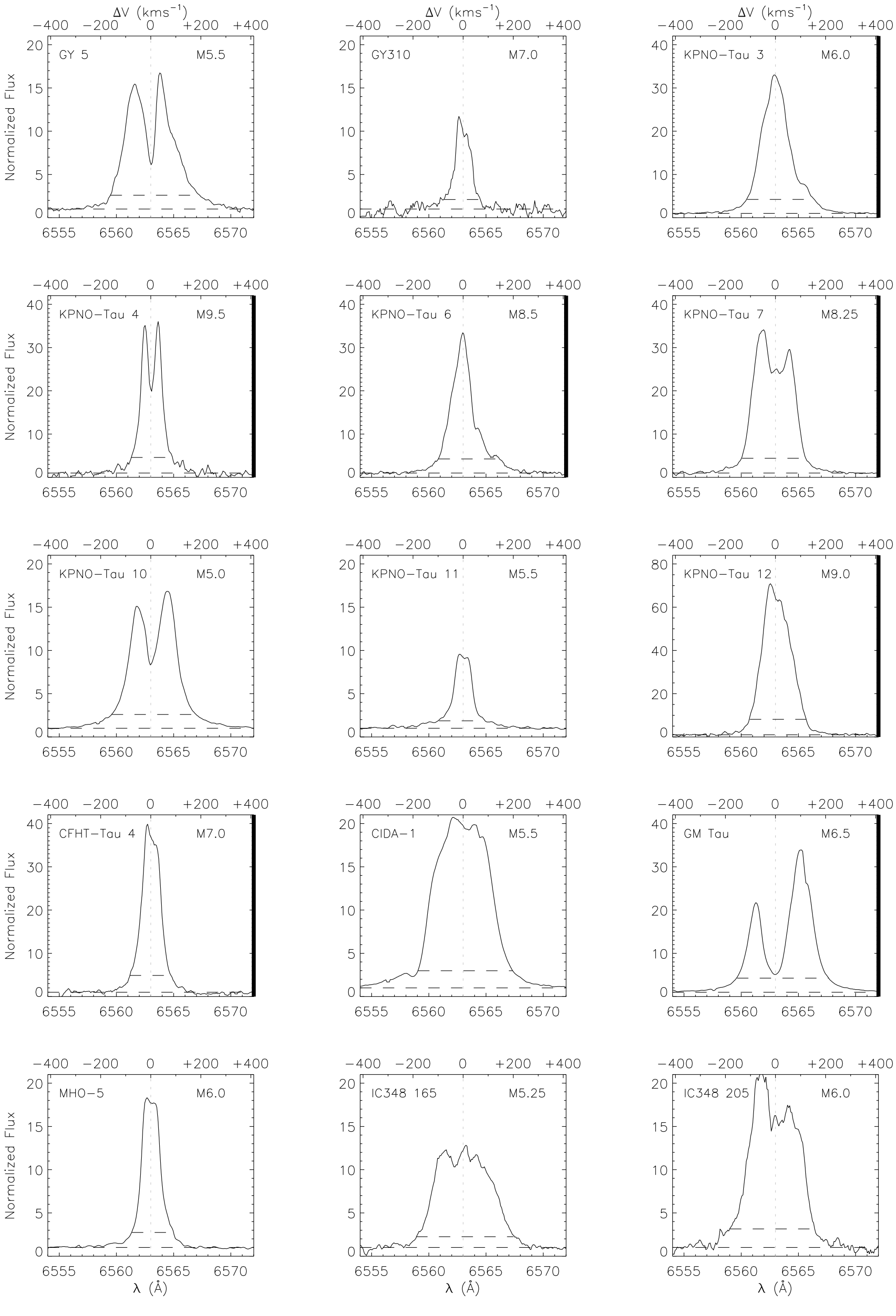

Fig. 3. Hα profiles for the accretors (including 5 objects designated "probable" or "possible" accretors) from Mohanty, Jayawardhana & Basri (2005). Dashed horizontal lines indicate the continuum and the 10% line width.

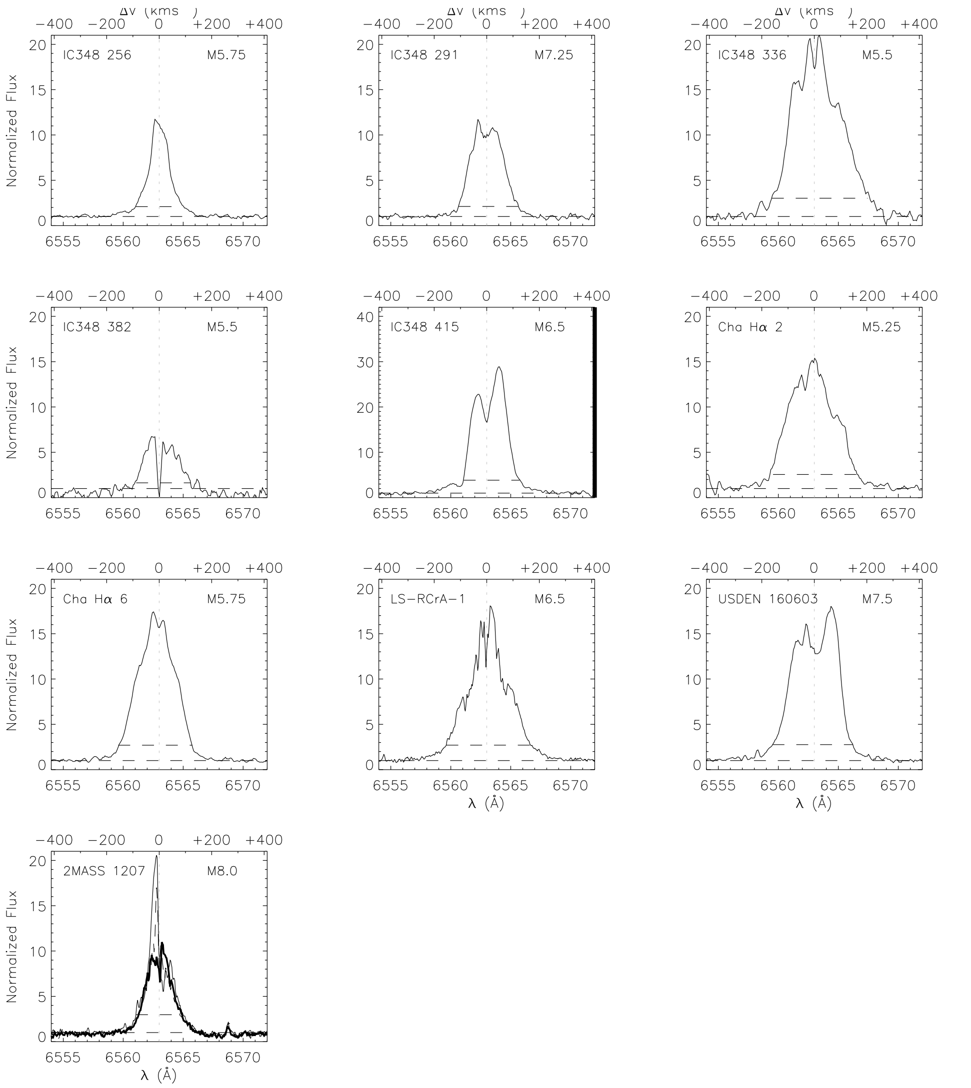

Fig. 3. (continued) Hα profiles for the accretors (including 5 objects designated "probable" or "possible" accretors) from Mohanty, Jayawardhana & Basri (2005). Dashed horizontal lines indicate the continuum and the 10% line width.

well as one of the lowest mass objects with evidence of mass outflow.

4. Conclusions

There is now a wealth of compelling evidence, in the form of disk excesses and spectroscopic signatures of accretion and outflow, that young brown dwarfs undergo a T Tauri phase similar to that of solar-mass stars. The analogy appears to hold for the entire range of masses from near the hydrogen-burning limit to nearly planetary masses, likely implying that these ultra-low mass objects share a common formation mechanism with Sun-like stars.

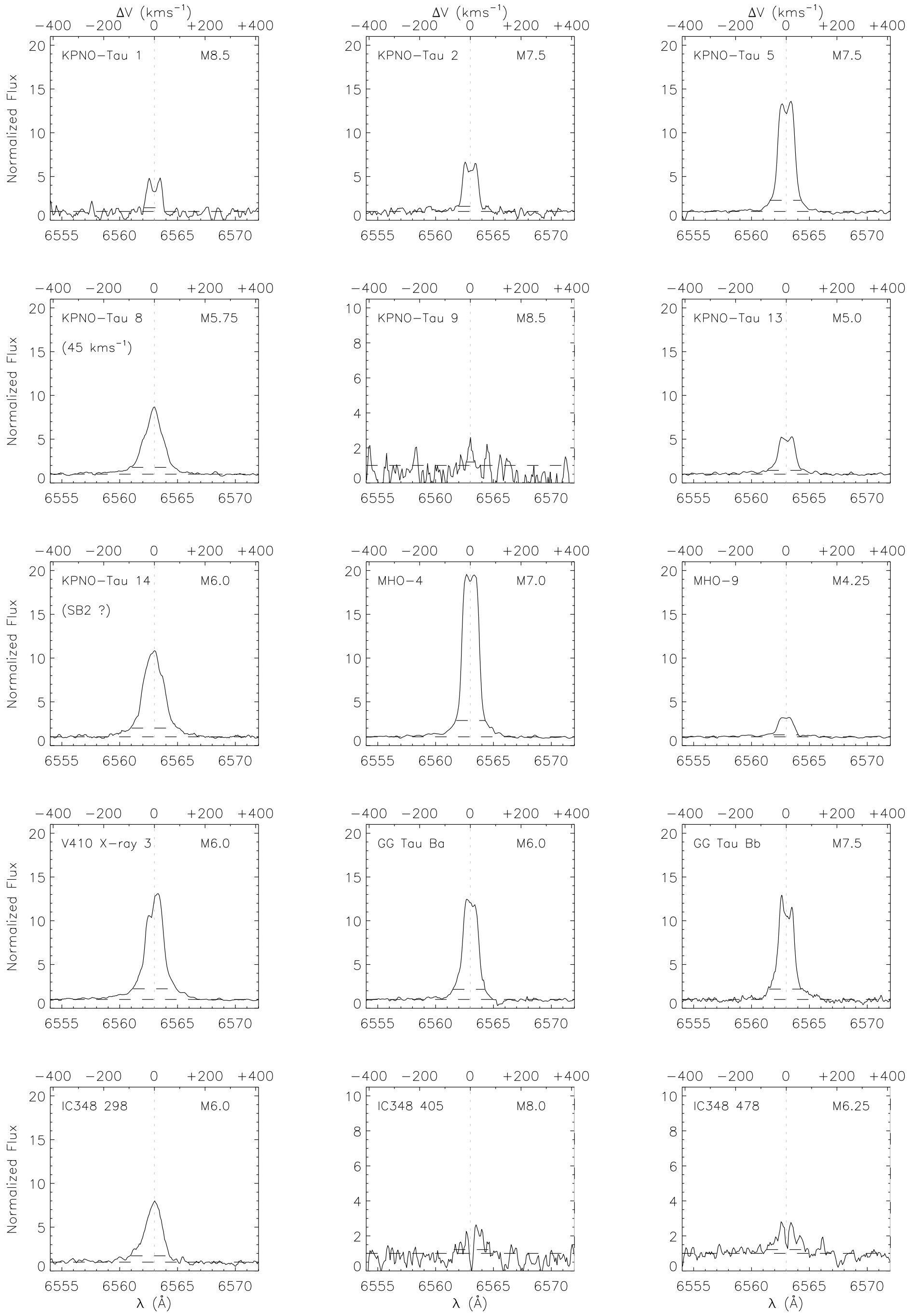

Fig. 4. Hα profiles for the non-accretors from Mohanty, Jayawardhana & Basri (2005). Dashed horizontal lines indicate the continuum and the 10% line width.

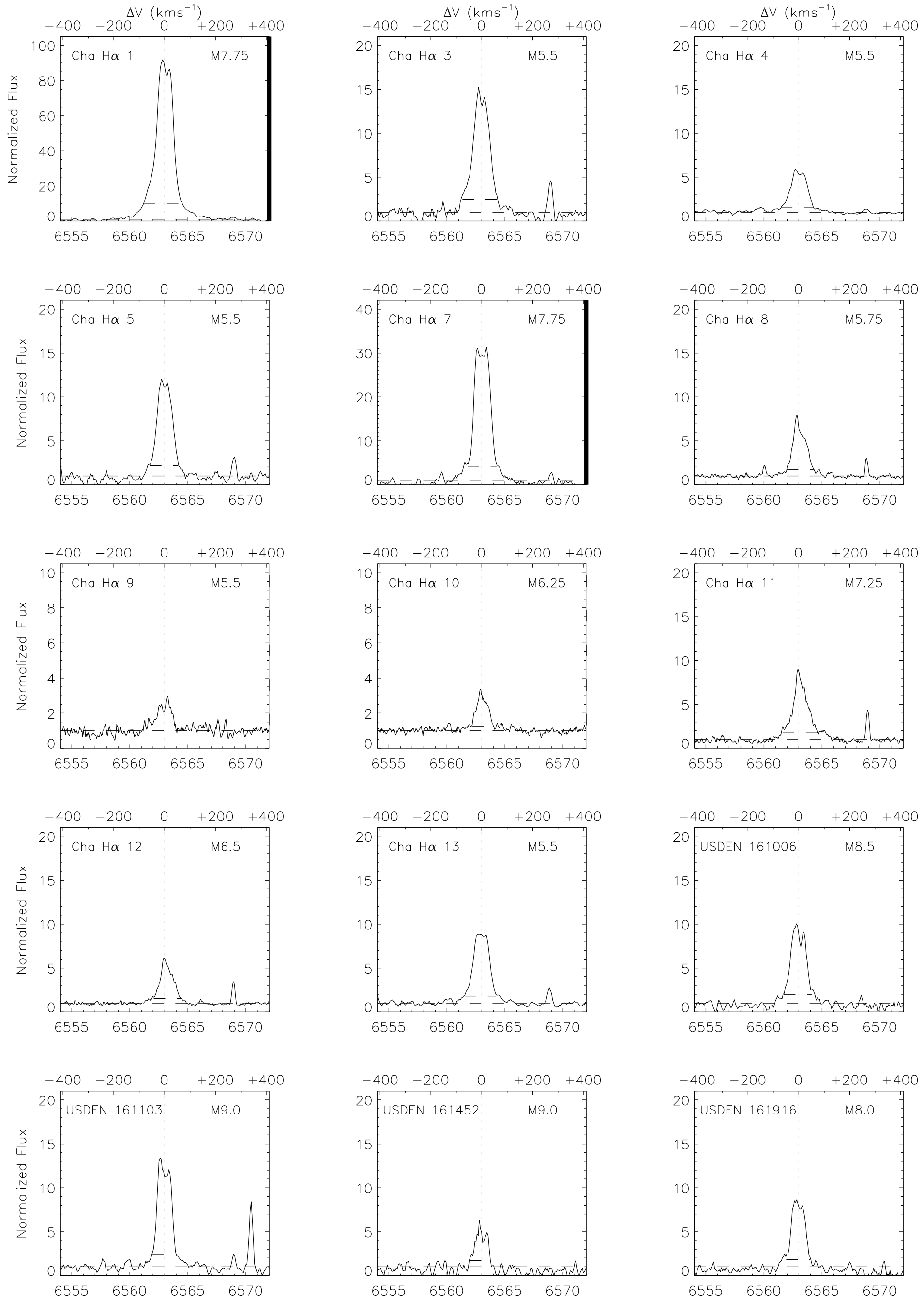

Fig. 4. (continued) Hα profiles for the non-accretors from Mohanty, Jayawardhana & Basri (2005). Dashed horizontal lines indicate the continuum and the 10% line width.

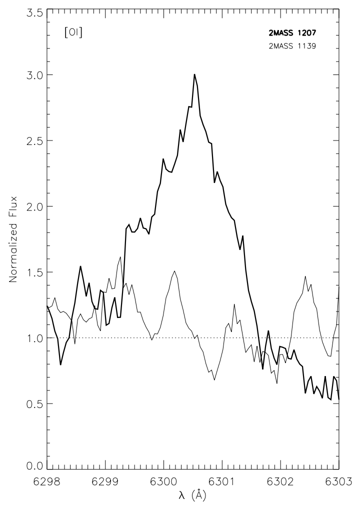

Fig. 5. Forbidden [OI] 6300 Å emission in the accreting brown dwarf 2MASS 1207-3932 (M8) in the TW Hydrae association. For comparison, we overplot (as a thin line) the spectrum of 2MASS 1139-3159 which is a non-accretor of the same spectral type in the same association.

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