Mem. S.A.It. Vol. 76, 348

Memorie della

Accretion in brown dwarfs:

a low-resolution criterion

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Abstract. We present evidences of ongoing accretion and outflows in several objects at or below the substellar limit, including the width of the Hα line, the detection of forbidden lines and near-infrared excess. These objects are likely to belong to several SFRs, and have ages in the range 1-8 Myr. In addition, we present an accretion criterion based on low-resolution optical spectroscopy, which can be applied, from the statistical point of view, to large samples.

Key words. Brown dwarfs – Accretion – open clusters

1. Brown Dwarfs, accretion, and high- and medium-resolution spectroscopy

During the last few years, a growing amount of evidences has appeared in the literature concerning the brown dwarfs and accretion: they, indeed, seem to undergo a TTauri phase (Class II objects), which implies the presence of a circun(sub)stelar disk and a flux from it onto the central object, including the associated features such as UV and IR excesses, spectral veiling, a plethora of emission lines and so on. Moreover, outflows seem to be present too. Here, we present the spectra of several very low mass stars and young brown dwarfs, taken at medium- and high-resolution, which do show broad Hα and other permitted lines profiles and, in some cases, intense forbidden lines.

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1.1. The evidences: accreting Brown dwarfs from 1 to 8 Myr

In several observing runs, we have collected medium- and high resolution optical spectra of several young brown dwarfs belonging to several Star Forming Regions, including Chamaeleon II, R CrA, Taurus-Auriga, the Sigma Orionis cluster, and the TW Hydrae Association (hereafter TWA). They have ages from about 1 Myr to up to 8 Myr. Additional information can be found in Barrado y Navascués et al. (2002), Mohanty, Jayawardhana, & Barrado y Navascués (2003), Barrado y Navascués & Jayawardhana (2004), Barrado y Navascués, Mohanty, & Jayawardhana (2004), Barrado y Navascués (2004). In particular, we have observed ChaII-C41 (Vuong et al. 2001), LS-RCrA 1 (Fernández & Comerón 2001), KPNO-Tau-03, 05 & 08 (Briceño et al. 2002), SOri71 (Barrado y Navascués et al. 2002) and 2M1139 & 2M1207 (Gizis 2002). The proper-

Table 1. Summary of the properties of our sample

Object	Width 10% Hα	W(Hα) Å	Forbidden lines	IR excess	Accret. rate	Spectr. Type	Mass $M_{\odot}$	Age Myr	Res.
ChaII-C41	500	106	Yes	Yes	3e-09	M5.5	0.10	1	L,M
KPNO-Tau-03	310	81	No	No	2e-10	M6	0.07	1	M,H
KPNO-Tau-05	125	21	No	No	–	M7	0.06	1	M,H
KPNO-Tau-08	180	12	No	No	–	M6	0.07	1	M,H
KPNO-Tau-12[1]	~280	950	No	No	6e-11	M9	0.02	1	L
SOri71	~600	700	No	No	6e-09	L0	0.02	5	L,M
LS-RCrA 1	460	360	Yes	No	3e-09	M6	0.06	~8	L,M,H
2M1139	111	10	No	No	2e-10	M8	0.04	8	L,M
2M1207	204	300	No	No	1e-09	M8	0.04	8	L.M,H

Accretion rates from H(α) FWHM at 10%, after Natta et al. (2004).
Note that other measurements of the Hα equivalent width can be found in the literature, due to intrinsic secular changes and/or to the different resolution of the spectra.
Resolution: Low (L), medium (M) and high (H).
[1] See Luhman et al. (2003) and Luhman, these proceedings.

ties of these objects are summarized in Table 1.

We note that these objects were discovered using optical and/or infrared photometry and in most cases the subsequent follow-ups –which included low-resolution spectroscopy– indicate that they are good candidate members (i.e., that the likelihood of belonging the association was big). Our medium- and high resolution spectroscopy –although designed mainly to study the properties of those objects– add new evidences regarding the membership, supporting and strengthening the previous classification as members. In any case, all these arguments are, in fact, about probability; they are probable members. From the epistemological point of view, this wealth of data, or any additional information, can not guaranty that they do belong to those associations. After all, Science is about falsification (see Popper 1977).

We show the spectra in Figure 1. The left panel includes the medium-resolution spectra of LS-RCrA 1, ChaII-C41, SOri71, 2M1139 and 2M1207. They were taken with Magellan telescope and the B&C spectrograph, except in the case of SOri71, where we used Keck and LRIS. The right panel displays spectra of three objects belonging to Taurus (KPNO-Tau-03, 05 & 08), and they were obtained with Magellan and the MIKE echelle spectrograph. In this case, we only show the order containing the Hα line. From this last diagram, it is clear that KPNO-Tau-03 satisfies the accretion criteria by White & Basri (2003) and Jayawardhana et al. (2003), since the width at 10% of the maximum is larger than 200 km/s. The other two cases are not so clear, since their widths are much smaller than in the first case, but some asymmetries might be present. The same kind of analysis can be done with the objects whose spectrum is displayed in Figure 1a. The measurements are listed in Table 1, and they indicate that most of them are accreting. In some cases, they also show secondary accretion indicators, such as HeI6678 Å (although this feature might be due to the presence of flares too). Moreover, there is a trend between the Hα width and the equivalent widths. We will use this characteristic to define an accretion criterion in Section 2.

Based on the Hα width at 10% and in Natta et al. (2004), we have tentatively estimated the accretion rates in our objects. They range from $6{\times}10^{-9}$ to $6{\times}10^{-11}$ $M_{\odot}$/yr (i.e., two orders of magnitude of difference), in the same approximate range as those rates derived by Muzerolle et al. (2003) for this mass range.

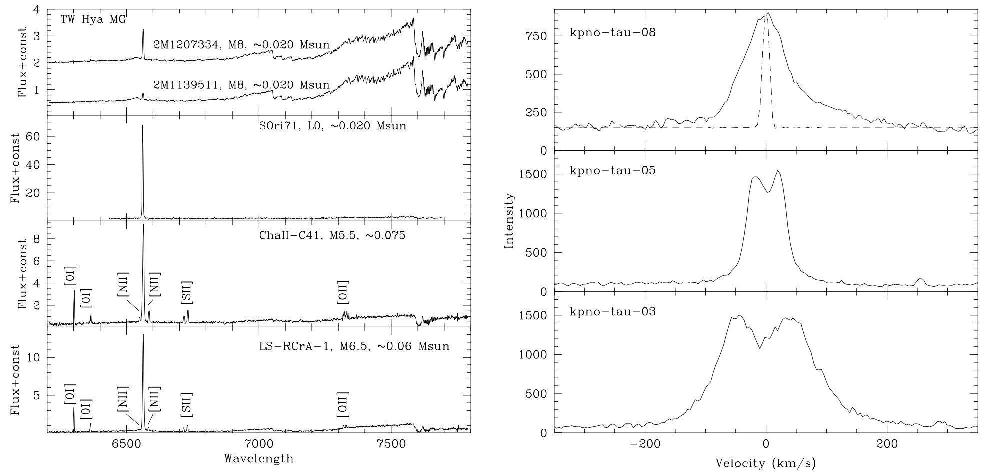

Fig. 1. Left panel: Medium resolution spectra for objects at or below the substellar limit: We display two brown dwarfs belonging to the 10 Myr TW Hydrae Association (Mohanty et al. 2003); a L0 brown dwarf belonging to the Sigma Orionis Cluster (SOri71, Barrado y Navascués et al. 2002); ChaII-C41, a member of Chamaeleon II (Barrado y Navascués & Jayawardhana 2004); and LS-RCrA 1, which is a member of RCrA cloud (Barrado y Navascués et al. 2004). Note the strong forbidden lines in the last two cases. Right panel: Hα profiles of three Taurus members. Tau-KPNO-3 is clearly accreting, since the width at 10% of the maximum intensity is larger than 200 km/s (Jayawardhana et al. 2003). The spectral resolution is shown as a dashed line (see Barrado y Navascués 2004)

1.2. Brown dwarfs, forbidden line emission and outflows

In two cases (ChaII-C41 and LS-RCrA 1), strong forbidden lines from sulfur, nitrogen and oxygen can be distinguished. These lines are associated to outflows in Classical TTauri stars, and it seems that this phenomenon is taking place in the case of LS-RCrA 1 (see Mohanty et al. 2005, in prep). Figure 2 contains the profiles of both permitted lines (left panel) and forbidden lines (right panel) for this last object. The data correspond to high resolution, echelle spectroscopy obtained with Magellan/MIKE. A more detailed analysis and discussion can be found in Barrado y Navascués, Mohanty, & Jayawardhana (2004). In any case, the first set of lines are much wider than the second set, indicating that they have different source, and in agreement with origin from accretion in those and from an outflow in these ones. Recently, Masciadri & Raga (2004) have found that while the mass loss rates associated with jets from BDs are about two orders of magnitude lower than the mass loss rates associated with jets in TTauri stars, their velocities are likely to be similar.

1.3. The IR Color-Color diagram as a tool for accretion diagnostics

We have also examined the optical and infrared colors of our sample, trying to discern whether any of them have infrared excess in the K band due to a circun(sub)stellar disk. Figure 3 corresponds to Color-Color Diagram using IR data, where only ChaII-C41 shows a clear excess. In the diagram, objects with large open circle and squares have either large Hα emissions and/or forbidden lines. Clearly, there is no one-to-one relationship between these three properties (intense Hα emission, forbidden lines and IR excesses). Some objects lacks K ex-

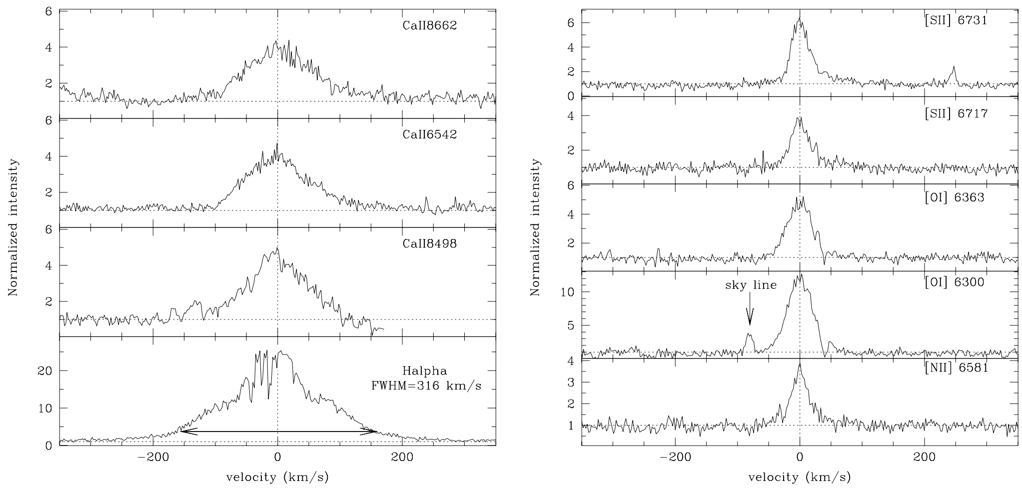

Fig. 2. Profiles of permitted (left panel) and forbidden (right panel) for LS-RCrA 1.

cess from a hot disk, although they are accreting and, in some cases can have outflows. So far, the easiest way to detect accretion in a population of young objects was the diagnostic with a Color-Color Diagram. However, it can fail even for BDs with outflows. Obviously, the near-IR Color-Color Diagram is not an optimal tool to detect and study, from the statistical point of view, the accretion. We suggest a criterion, based on low-resolution optical spectroscopy, in the next section.

2. Accretion from low-resolution spectroscopy

Several works (see, for instance, Stauffer et al. 1994) have determined that the chromospheric activity of late-type stars saturates, that they have a maximum value. Based on data compiled from three young open clusters (IC2391, Alpha per and the Pleiades, with ages of 50, 85 and 120 Myr), Barrado y Navascués & Martín (2003) have determined that this value is, in the case of Hα, Log {Lum(Halpha)/Lum(bol)}=−3.3 dex. This phenomenon has been used by them to propose an accretion criterion, which only requires low-resolution spectroscopy. When translated into equivalent width, the saturation/accretion criteria correspond to increasing W(Hα) as we move toward cooler objects. The criteria can be found in Figure 4a, where they appear as dotted lines and discriminates four distinct areas. These criteria have been checked against a

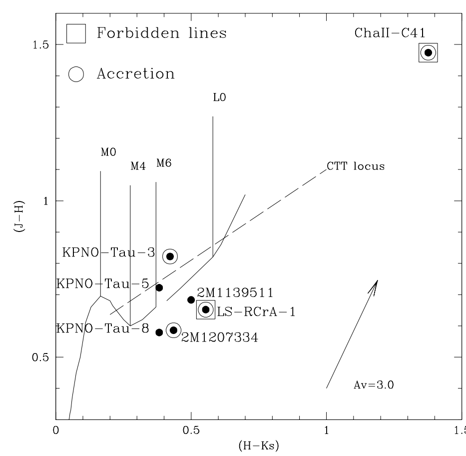

Fig. 3. Infrared Color-Color diagram displaying data corresponding to several brown dwarfs with broad Hα profiles (big circles) and the presence of forbidden lines (big squares) in their spectrum.

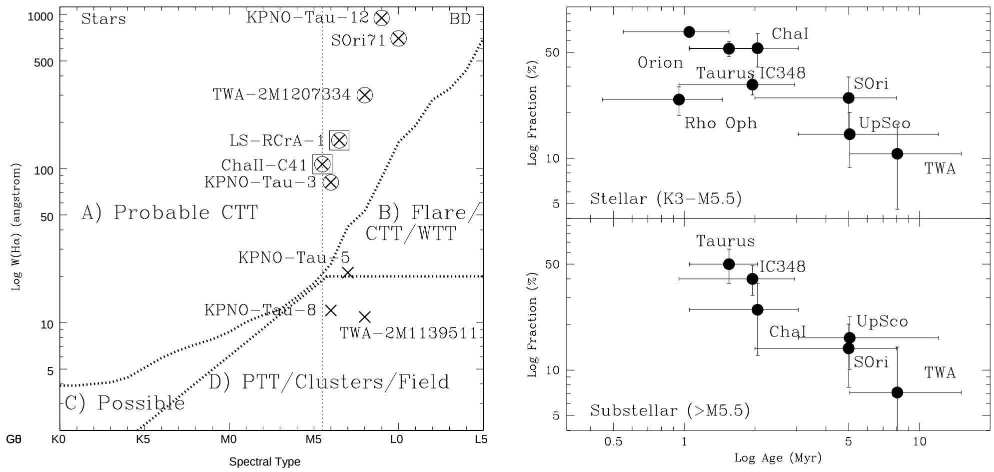

Fig. 4. Left panel: Hα equivalent width versus the Spectral type. The dotted lines represent the accretion criterion (from the saturation) and the maximum envelope for cluster members (From Barrado y Navascués & Martín 2003). Right panel: Fraction of objects classified as CTT stars or substellar analogs. The top panel represents the stellar members, whereas the bottom panel corresponds to the substellar domain (spectral type coller than M5.5). Note the logarithmic scale.

number of Star Forming Regions such as the Orion population, the Taurus-Auriga, IC348, Sco-Cen-Lupus-Crux Complex (including the ρ Oph molecular cloud) Chamaeleon I, σ Orionis cluster, and TW Hydra association –TWA–. From the statistical point of view, low mass stars and brown dwarfs do comply with the criteria.

We have carried out an additional verification with the present sample of BDs. They have been overplotted in Figure 4a as crosses. As in Figure 3, overlapping large circles and squares denote the detection of accretion –based on the width of Hα at 10%– and forbidden lines. All our accreting very low mass objects do follow the criteria, they have a Hα equivalent width well above the accretion criterion. Moreover, the other objects, those with dubious or no accretion, are below the saturation criterion.

We have used this property to try to understand how the disk population evolves. Using the SFRs quoted above, we have derived the fraction of stars and brown dwarfs above and below the accretion criterion and represented this value versus the age of the association (Figure 4b). Clearly, this is an exercise which is only meaningful from the statistically point of view. In any case, the fraction has a strong dependency with age, falling to values close to zero after 10 Myr. This might indicate that accretion, both in stars and in brown dwarfs, is not efficient any longer after this age.

Acknowledgements. Part of this work was supported by Spanish *Programa Ramón y Cajal* and the PNAyA AYA2003-05355.

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