*RevMexAA (Serie de Conferencias)*, **24**, 179–183 (2005)

# AN EMPIRICAL CRITERION TO CLASSIFY T TAURI STARS AND SUBSTELLAR ANALOGS USING LOW-RESOLUTION SPECTROSCOPY

D. Barrado y Navascués[1] and E. L. Martín[2]

RESUMEN

Hemos estudiado anchuras y flujos equivalentes en H$\alpha$ de miembros de tipos tardíos en tres cúmulos abiertos jóvenes y utilizamos esos datos para definir un criterio empírico que permita, desde el punto de vista estadístico, distinguir entre las estrellas T Tauri de líneas débiles y las clásicas. Este criterio se basa en la saturación de la actividad cromosférica y se puede utilizar en combinación con espectroscopía de baja resolución. Hemos extendido este criterio al dominio subestelar y lo hemos aplicado a varias regiones de formación estelar de diferentes edades. Nuestra comparación muestra que la fracción del acrecentador desciende rápidamente con la edad, tanto en el dominio estelar como en el subestelar, llegando a ser despreciable en aproximadamente 10 Maños.

ABSTRACT

We have studied the H$\alpha$ (equivalent widths and fluxes) of late-type members of three young open clusters and used these data to define a empirical criterion which allows, from the statistical point of view, to distinguish between Classical and Weak-line T Tauri stars. This criterion is based on the saturation of the chromospherical activity and can be used in combination with low resolution spectroscopy. We have extend this criterion into the substellar domain and apply it several star forming regions of different ages. Our comparison shows that the fraction of accretor decline very fast with age both in the stellar and the substellar domain, becoming negligible at about 10 Myr.

*Key Words:* **STARS: PRE-MAIN SEQUENCE**



## 1. CLASSICAL T TAURI VERSUS WEAK-LINE T TAURI STARS

Low mass stars undergo very distinct phases in their evolution. In fact, the first stages are short-lived, and the stars go from Class I –embedded objects whose spectral energy distribution is dominated by the thermal and far infrared– to Class III, where the IR excesses are small (Adams et al. 1987). This happens in about 10 Myr, and during this time, infall of material onto the central object takes place, a circumstellar disk is formed, accretion from this disk appears and some collimated material might be ejected. All these characteristics have been observationally detected through far-, mid-, near-infrared and UV excesses –this last one produced by the shock of the accreted material–, broad permitted lines such as H$\alpha$ and other Balmer lines, HeI6768, CaII IRT, etc –due to the accretion–, and narrow forbidden lines –arising from the outflow–. In any case, one of the key points in order to understand this evolution is the disk and its properties.

The easiest way to discover the circumstellar, dusty disk is to detect the associated infrared excesses. As stated before, the excess of a Class III (a Weak-line TTauri star, WTT for short) is usually negligible, whereas a less evolved Class II object (Classical TTauri star, CTT) usually shows the excess. However, its detection depends also on the used wavelength range (for instance, they are normally more conspicuous at 5 $\mu$ –$L$ band– than at 2.2 $\mu$ –$K$ band), and there is no one-to-one relationship between accretion and IR excess. Figure 1 shows the H$\alpha$ equivalent width (W) –another accretion indicator, discussed below– versus the excess in the $L$ band for a sample of Taurus CTT –solid circles- and WTT –open circles– stars. Although there is a trend between both quantities, other factors play a role.

The special interest is H$\alpha$. A survey of the specialized literatures shows that there are several criteria do distinguish Classical TTauri from Weak-line TTauri stars, based on the H$\alpha$ equivalent width. Values such as 5 and 20 Å are frequently quoted (see Figure 1). Recently, White & Basri (2003) have updated the available information and defined an empirical criterion which depends on the spectral type.

[1]LAEFF-INTA, Madrid, Spain.
[2]IAC, La Laguna, Spain.

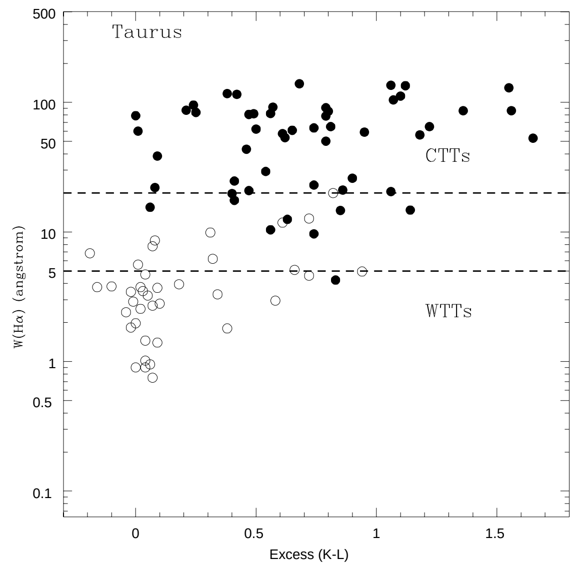


Fig. 1. Equivalent width of Hα –logarithmic scale– against the color excess E($K-L$) for the Taurus population (after Kenyon & Hartmann 1995). Classical and weak-line T Tauri stars are shown as solid and open circles, respectively. The two dashed lines correspond to different criteria proposed to discriminate between these two types of objects.

## 2. A LOW RESOLUTION SPECTROSCOPIC CRITERION

Our aim is to define a criterion based on low-resolution spectroscopy which would easily allow a classification, distinguishing CTT from WTT stars. In addition, we want to extend such a criterion into the substellar domain (i.e., objects unable to burn hydrogen due to its low mass, ∼0.072 M⊙). The properties of the Hα line can provide such criterion, since it has different origin in both types of objects.

It is a well known fact that late spectral type stars present Hα in emission. This feature is associate to the stellar activity, and arises from the chromosphere. Brown dwarfs do show it, and it is assumed that the origin is analogous. Figure 2a displays the ratio between the emitted luminosity in that line and the bolometric luminosity versus the spectral type for three samples belonging to young clusters, IC2391, Alpha Persei and the Pleiades (55, 90 and 125 Myr, respectively). For these association, the substellar boundary appears at about M6-M6.5 spectral type. Clearly, there is a maximum, which appears at around M4 spectral type. This maximum defines the saturation of the chromospheric activity, an also happens for other lines such as Hβ or spectral range like X-rays (see, for instance, Stauffer et al. 1994; Delfosse et al. 1998; Mohanty et al. 2002; and references therein).

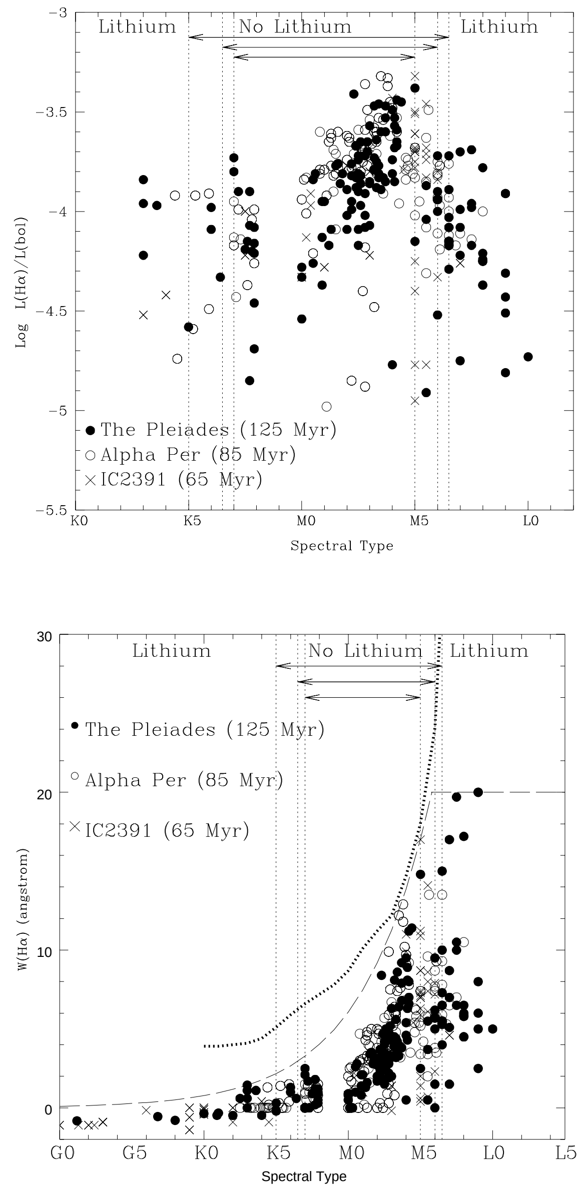


Fig. 2. **a** Ratio between the Hα and the bolometric luminosities versus the spectral type for several young open clusters: the Pleiades (80-120 Myr), Alpha Per (50-90 Myr), and IC2391 (30-55 Myr). The vertical, dotted lines delimit the location of of the spectral type ranges where the lithium has been preserved or depleted. **b** Same as panel a, Hα equivalent widths are plotted in the y-axis. The dashed segments correspond to the upper envelope of the W(Hα) for these three clusters (i.e., the maximum emission due to chromospheric activity). The bold, dotted curve is the saturation limit at log {L(Hα)/L(bol)}=-3.3. Note the linear scale in the y-axis.

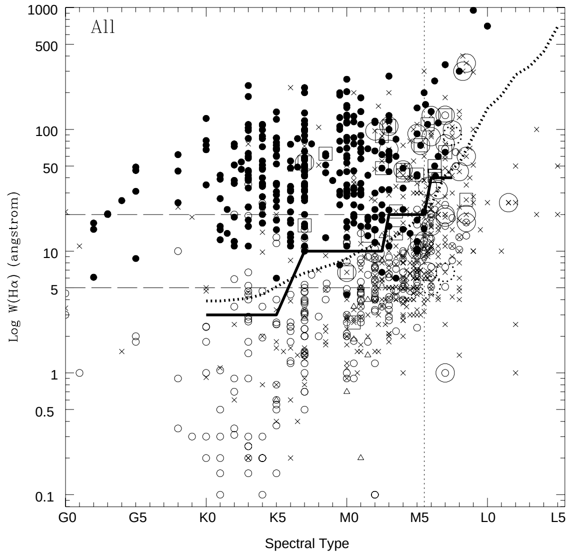


Fig. 3. All data corresponding to the previous eight very young stellar associations. Labels as in Figure 4. We have also added the criterion defined by White & Basri (2003) as a solid line.

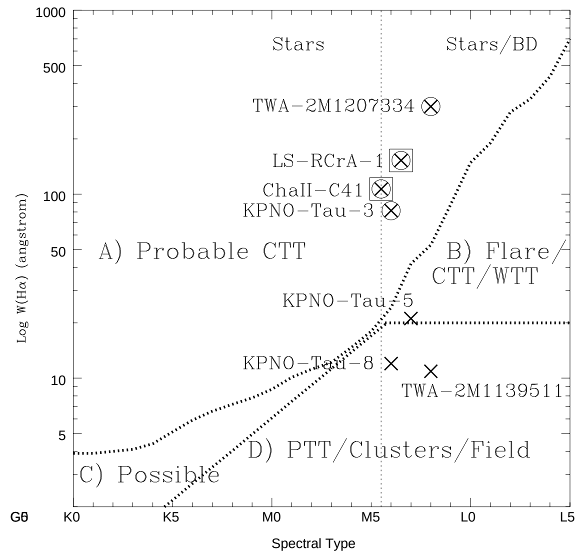


Fig. 4. A schematic diagram with our empirical Hα criterion. The saturation limit –upper curve– and the maximum limit –lower curve– found in open clusters discriminate four regimes. Low mass objects with forbidden emission lines and broad Hα profiles –from high resolution spectra– are indicated with large squares and circles, respectively. The dashed, vertical segment corresponds to the substellar borderline for young objects.

We propose this saturation limit, located at Log L(Hα)/L(bol)=−3.3, as the accretion criterion. Since it is not easy to obtain flux-calibrated spectra and, in any case, the distance –needed for the luminosity– is not very well known to most of the star formation region, where most of the CTT and WTT are located, we have transformed the Hα luminosities into equivalent widths (see details in Mohanty & Basri 2003 and Barrado y Navascués & Martín 2003), and redefined in the W(Hα)–Sp.Type plane the criterion. Figure 2b displays this comparison for the three clusters mentioned before, as well as the upper envelope of the emission (dashed line) and the saturation or accretion criterion (dotted line). In principal, any low mass star or brown dwarf whose W(Hα) is above this criterion should have a energy source different to pure chromospheric activity. Note that flare stars, such as UV Cet type, normally do not surpass this limit. The easiest explanation is, for young objects, accretion.

## 3. THE LITMUS TEST (I): SFR DATA

We have confronted our proposed accretion criterion with real data. We have selected several samples composed of CTT and WTT stars belonging to the several Star Forming Regions (SFR) and very young clusters, namely, Orion population, IC348, Taurus-Auriga Complex, Sco-Cen-Lupus-Crux Complex, including the $\rho$ Oph molecular cloud, Chamaeleon, and Sigma Orionis cluster In these figures, solid circles, small open circles and open triangles correspond to CTT, WTT and post TT stars (PTT), respectively. Small crosses denote the data with no available classification. Stars and BDs with near- or mid-infrared excesses (signpost of circumstellar disks) are indicated as large open circles. Large open squares correspond to objects with forbidden lines, which characterize outflows. The vertical dotted segment is located at the spectral type which divides the stellar from the substellar domain. The bold, dotted curve corresponds to our proposed empirical criterion to classify classical TTauri stars and substellar analogs (see next section). The 5 or 20 Å limits (long-dashed horizontal lines) are also included, as well as the White & Basri (2003) criterion.

Clearly, the large majority of WTT and CTT stars conform to our classification criterion, at least from the statistically point of view. Few late spectral type objects, which shows infrared excesses and/or forbidden lines, do not follow the saturation criterion. This fact might be due to the presence of veiling, which has not taken into account to correct the measured W(Hα).

## 4. THE LITMUS TEST (II): BROWN DWARFS

As we have said, one of the goals is to extend the accretion criteria into the substellar domain. Brown dwarfs are intrinsically faint, and to collect a high-resolution, high signal-to-noise spectrum requires an 8 meter class telescope. Such a spectrum can be used to detect faint forbidden, narrow lines and/or permitted, broad lines. Barrado y Navascués (2004, this volume) provides several examples of accreting brown dwarfs, which have been observed recently in such conditions. They have spectral types, ages and masses in in the ranges M5.5-M8, 1-10 Myr and 0.07-0.02 $M_\odot$; and belong to Taurus complex, the RCrA dark cloud, Chamaeleon II and the TW Hydra association.

Figure 4 is analogous to Figure 3, but in this case we display the sample of brown dwarfs, together with the accretion criteria and the maximum envelope for the chromospheric activity as defined by open cluster members (see Section 2 and Figure 2b). Note that these H$\alpha$ equivalent widths were measured in high-resolution spectra, whereas the data displayed in Figure 3 comes essentially from low-resolution spectroscopy, which tends to produce larger values (i.e., the location of brown dwarfs would be higher if we would have collected low resolution spectroscopy). This test clearly shows that our criterion is very useful to select potential candidates for further high-resolution follow-up when dealing with a sample of young members of a stellar association, looking for CTT stars and substellar analogs.

## 5. THE H$\alpha$ EQUIVALENT WIDTH – SPECTRAL TYPE PLANE

Figure 4 provides a powerful tool to classify the status of a late spectral type, young object, based solely in the spectral type and the H$\alpha$ equivalent width. These both quantities can be obtained from a moderate signal-to-noise, low-resolution spectrum. We note that this criterion is statistics, and it works better when applied to a sample of coeval objects:

i) Any object whose H$\alpha$ equivalent width is located below the upper envelope of the star clusters can be defined, in principle, as a non-accreting objects. They can be Weak-line and Post T Tauri stars or substellar analogs.

ii) Region C is saddled by the upper envelope, the saturation criteria and $\sim$M4 spectral type. The status on an object located within its boundaries is ambiguous, since it might be either a CTT, a WTT or PTT stars.

iii) Region B is similar to region C, but located at the cooler side of the diagram, where the spectral types are later than about M4. Both CTT and WTT stars and substellar analogs populate this area, as well as older flare stars and brown dwarfs.

iv) Finally, an object located above the saturation criterion have to be a probable accretor.

Finally, flaring has an important role in the normal life of late spectral type stars. However, due to the typical evolution of this phenomena (a rapid increase and a smoother decay), two or three consecutive spectra can easily establish whether a flare is taking place, and thus avoiding a misclassification. Additional data, coming from medium- and high resolution spectra (age-dependent features such as lithium or gravity-dependent ones, such as sodium and potassium at 7700 and 8200 Å, respectively, are very helpful to further advance the knowledge of the nature of these objects.

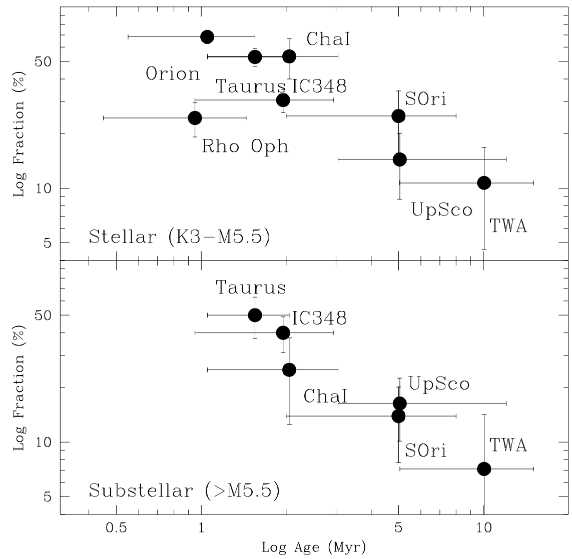


Fig. 5. Fraction of objects classified as CTT stars or substellar analogs. The two panels differentiate between stars and brown dwarfs. Note the logarithmic scale.

## 6. THE ROLE OF GTC AND GTM

Only a handful of SFR have been studied in depth. This is particularly true when the substellar domain is involved. So far, the influence of the environment has not been determined either in the formation mechanism per se or in the evolution of the circum(sub)stellar disks. Both GTC and GTM can be applied for these goal, by collection low resolution spectra of several samples of different ages of coeval objects. This can be done with ELMER and OSIRIS in an efficient manner. Once the probable accreting stars and brown dwarfs have been identified, the role of GTM can be essential to study the morphology, properties and dynamics of the disks. These studies can be complementary to those carried out with CanaryCam.

## 7. AN APPLICATION: THE EVOLUTION OF THE DISK FRACTION

We have applied our accretion criterion to the samples of low mass stars and brown dwarfs belonging to star forming regions and young stellar associations (shown in Figure 3). Figure 5 illustrates the fraction of CTT to WTT stars and substellar analogs, differentiating in the upper and bottom panels the stellar and substellar populations. As expected, the decline in the stellar domain is sharp, leaving almost no star with disk after 10 Myr. Similar result is reached for brown dwarfs. Therefore, the diagram suggests that the timescale for disk evolution is similar in low mass stars and brown dwarfs.

Recent works (Muench et al. 2001, Haisch et al. 2001, Liu et al. 2003, Jayawardhana et al. 2003b.) have derived the fraction of objects with disks using different techniques for these and other SFR. Although the ratios are systematically larger in those studies, the trend is similar and it seems to be clear that there is not observable circum-stellar or substellar disk accretion beyond ∼10 Myr.

## REFERENCES

Adams F. C., Lada C. J., Shu F. H., 1987, ApJ, 312, 788
Barrado y Navascués D. & Martín E. L. 2003, AJ, 126, 2997
Barrado y Navascués D., 2005, RevMexAA Ser. Conf., this issue
Delfosse X., Forveille T., Perrier C., Mayor, M., 1998, A&A, 331, 581
Haisch K .E., Lada E. A., Lada C. J., 2001, ApJ, 553, L153
Jayawardhana R., Ardila D. R., Stelzer B., Haisch K. E., 2003, AJ, 126, 1515
Liu M. C., Najita J., Tokunaga A. T., 2003, ApJ, 585, 372
Mohanty S., Basri G., Shu F., et al. 2002, ApJ, 571, 469
Mohanty S., Basri G., 2003, ApJ, 583, 451
Muench A. A., Alves J., Lada C. J., Lada E. A., 2001, ApJ, 558, L51
Stauffer J. R., Caillault J. P., Gagne M., Prosser C. F., Hartmann L.W., 1994, ApJSS, 91, 625
White R. J., & Basri G., 2003, ApJ, 582, 2109

David Barrado y Navascués: Laboratorio de Astrofísica Espacial y Física Fundamental, INTA, Apartado Postal 50727, 28080 Madrid, Spain (barrado@laeff.esa.es).
Eduardo L. Martín: Instituto de Astrofísica de Canarias, C/ Vía Láctea, s/n, E38200 La Laguna (Tenerife), Spain (ege@ll.iac.es).