Transition disks in the young cluster NGC 2264

Alana P. Sousa[1] & Silvia H. P. Alencar[1,2]

[1]Universidade Federal de Minas Gerais - UFMG - Brasil

[2]Institut de Planétologie et d'Astrophysique de Grenoble - IPAG - France

alana@fisica.ufmg.br

1 Disk and Transition disk

Young low mass stars (~ 1 Myr and M ≤ 2 M$_\odot$) are surrounded by a circumstellar disk from which they can still accrete. It is known that the disks are planet formation sites. Therefore understanding disk dissipation is essential to study how planets form.

The inner disk gas can be dissipated by accretion to the star through the stellar magnetic field, by photoevaporation through the central star high-energy radiation (Alexander et al., 2014) and the disk material may also be driven out of the system through disk winds and jets (Safier, 1993; Shu et al., 1994). The disk can also still be consumed in the coagulation of grains and planets formation (Papaloizou & Terquem, 1999).

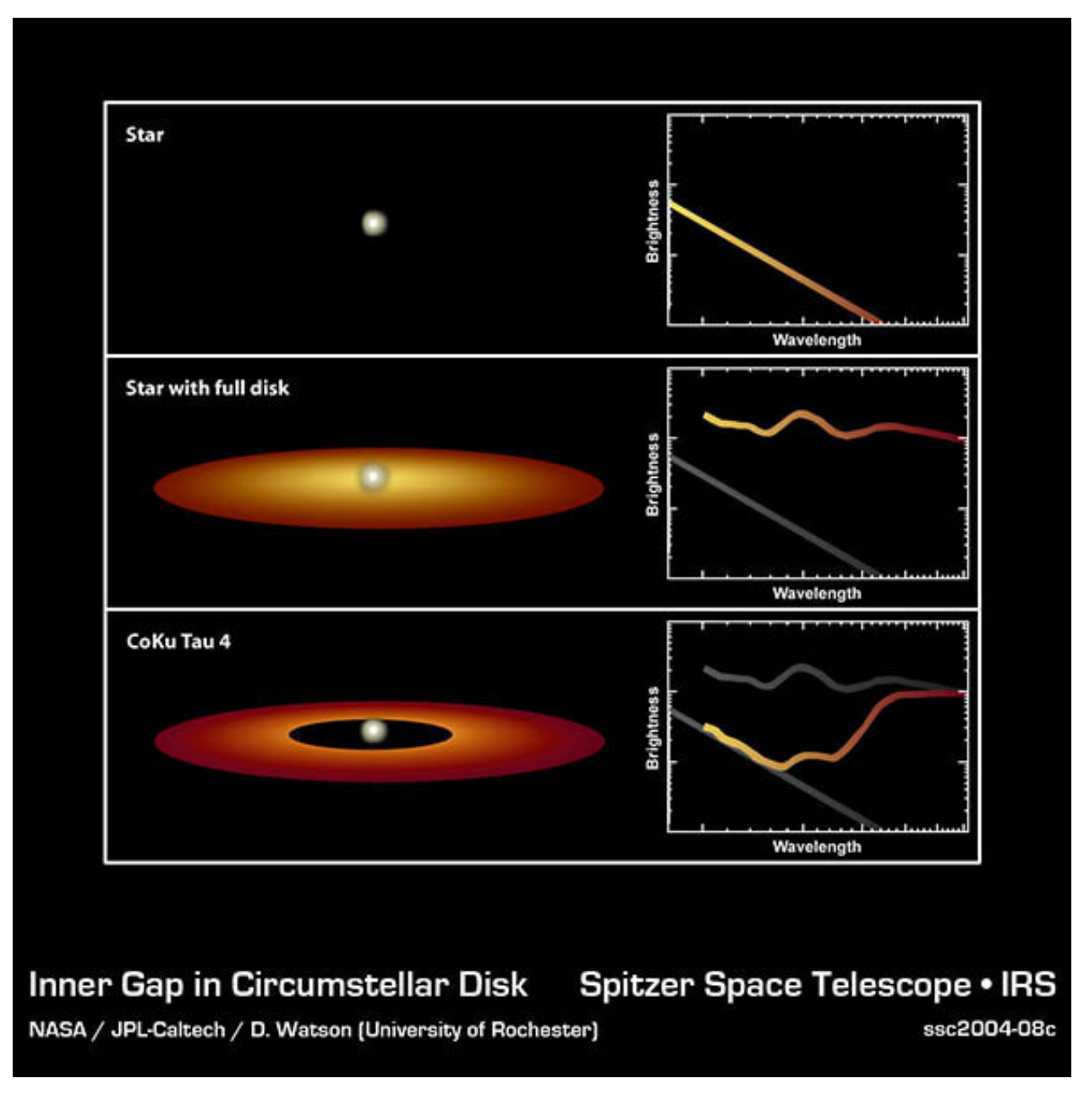

Figure 0. This illustration represents the spectrum and a artistic representation of a star with no circumstellar disk (top), a full disk (middle) and a star with inner hole disk.

Disk holes, corresponding to (almost) dust-free regions, are inferred from infrared observations of T Tauri stars, indicating the existence of a transitional phase between thick disks and debris disks, the so-called transition disks (Fig. 1) e.g., Andrews et al. (2011); Espaillat et al. (2008); Merín et al. (2010); Koepferl et al. (2013).

NGC 2264 is a young stellar cluster ($\sim 3\,\mathrm{Myr}$ and $\mathrm{d} \sim 760\,\mathrm{pc}$), where the star formation process is still happening. We searched for transitional disk candidates belonging to the NGC 2264 cluster to characterize these kind of disk in terms of accretion diagnoses (Hα and excess in the ultraviolet) and disk parameter (excess in the infrared).

2 Observation

We used data from *Coordinated Synoptic Investigation of NGC 2264* (CSI 2264) that was an international campaign which involved simultaneous and high-resolution observations (Cody et al., 2013), that included data from the CoRoT satellite (40 days 2011), VLT FLAMES spectroscopic data during 20 days and u band photometry from Megacam (CFHT). We also used data from catalog surveys, such as near-infrared photometry JHK_s from 2MASS, $UBVR_cI_c$ optical photometry from Rebull et al. (2002), IRAC and MIPs data bands from the Sptizer Telescope and observation from The Wide-field Infrared Survey Explorer (WISE) performed at wavelengths 3.4, 4.6, 12.0 and $22\,\mu m$ (Wright et al., 2010).

3 Sample of stars

We used the α_{IRAC} index (the slope of the spectral energy distribution between $3.6\,\mu m$ and $8\,\mu m$ (Teixeira et al., 2012)) to select 152 T Tauri stars with disk belonging to the NGC 2264 cluster and that have observation available at $22\,\mu m$ or $24\,\mu m$. We constructed SEDs (spectral energy distributions) of all these stars and model them with the Hyperion SED model (Robitaille, 2017, 2011). We found 30 transition disk stars (stars with inner hole according to the SED modeling and that have $24\,\mu m$ flux above photospheric level), 121 stars with a full disk and only a star as diskless (Fig. 2). Additionally, we used 180 stars classified as without inner disk according α_{IRAC} index to complete the sample of stars without disk (adding these stars without disk keeps the fraction of stars with and without disk in NGC 2264, which is about 40% as seen in Sung et al. (2009)). This number of transition disks ($9\,\%$ of the total of 332 stars that we analysed) can indicate that dispersal of disk is rapid compared to disk lifetime.

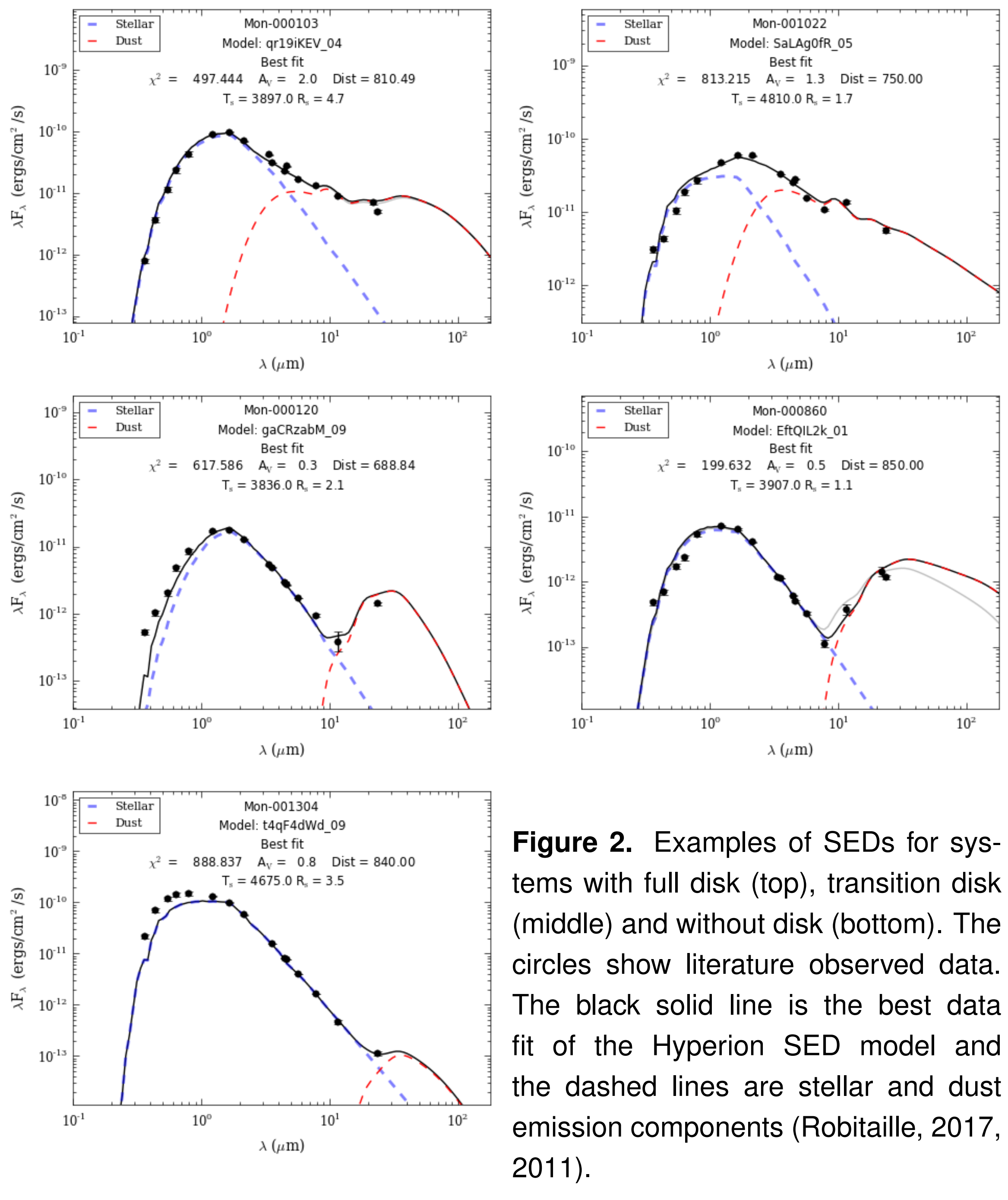

Figure 2. Examples of SEDs for systems with full disk (top), transition disk (middle) and without disk (bottom). The circles show literature observed data. The black solid line is the best data fit of the Hyperion SED model and the dashed lines are stellar and dust emission components (Robitaille, 2017, 2011).

4 Disk diagnostics

A transition disk system has a hole in the inner disk, this hole is characterized by a lower quantity of dust compared to the external part of the disk. Then, we expect that transition disks show little excess in NIR and some excess in MIR (Owen, 2016). In Fig. 2 we show $K_s - [8.0]$ vs. $K_s - [24]$ diagrams.

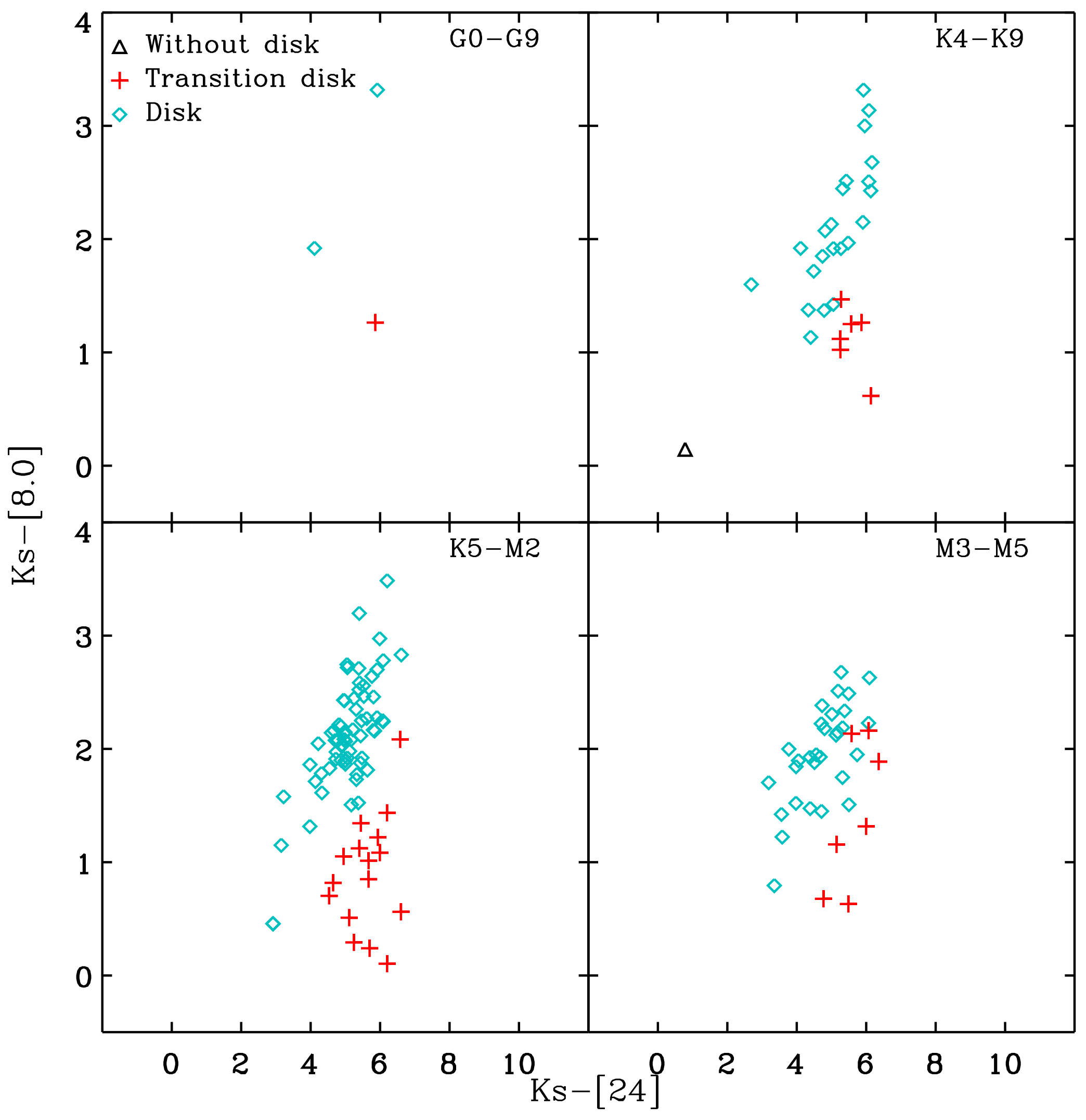

Figure 2. NIR and MIR color diagram for stars belonging to the NGC 2264 cluster. We can see two different populations: Stars with disk have excess, above the photospheric emission, in the inner and external parts of the disk, transition disks systems present weak dust emission in the inner disk, and present dust emission in the external disk like a star with disk.

The α_{IRAC} index allows a classification of inner disk evolution, as shown in Fig. 3.

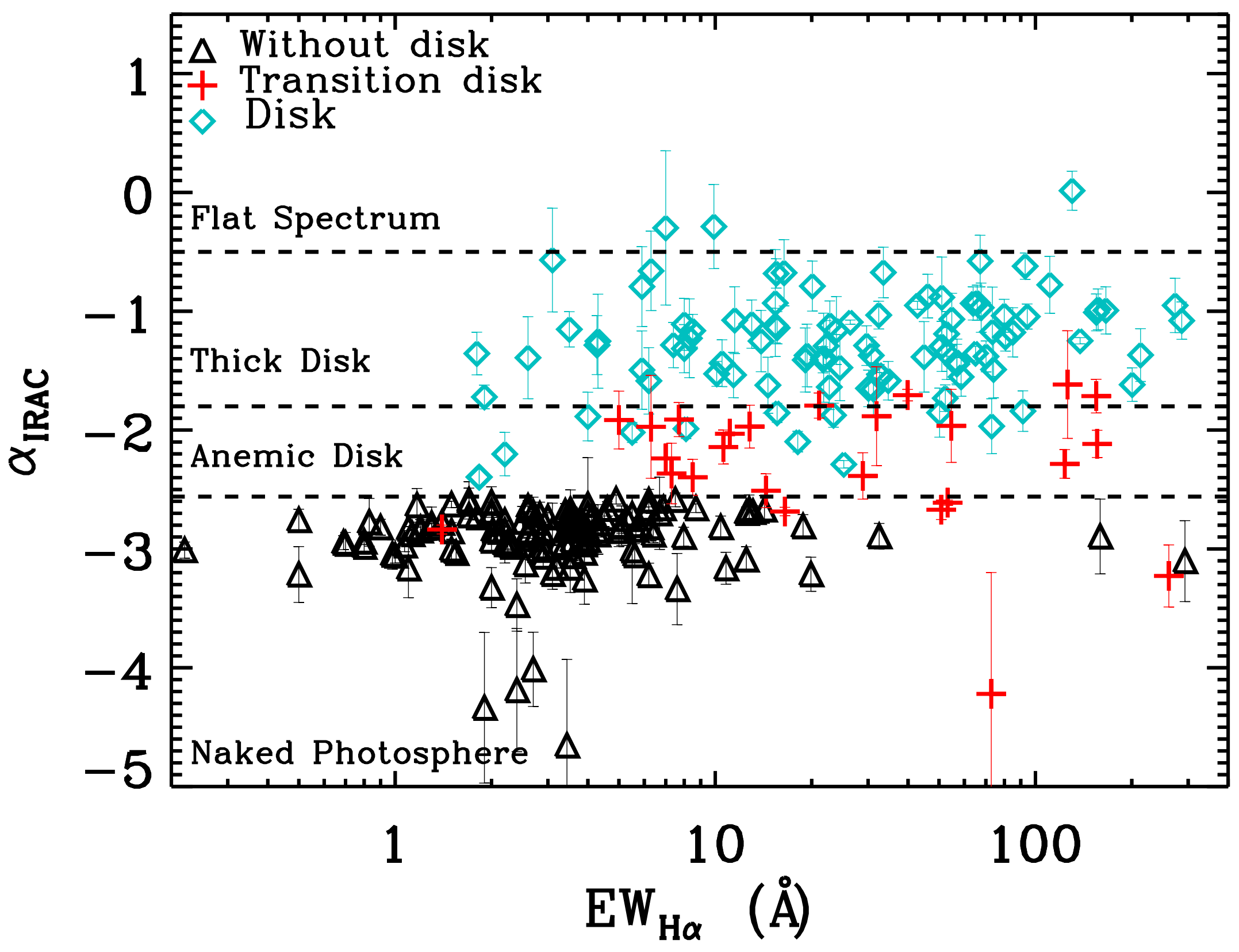

Figure 3. Slope of the spectral energy distribution from $3.6\,\mu m$ to $8\,\mu m$ (Teixeira et al., 2012) as a function of Hα equivalent width obtained by Sousa et al. (2016) & Dahm & Simon (2005). Almost all transition disk stars are located at the anemic disk region of the plot, that corroborates with the depletion of the dust in the inner disk.

5 Accretion diagnostics

Low mass accreting stars are known as classical T Tauri stars (CTTSs) and are characterized by emission lines (e.g. Hα, Hβ, He) that vary in intensity and morphology as the star-disk system rotates, and UV excess above the photospheric emission (Fig. 4). When the accretion process ceases the stars are called weak line T Tauri stars (WTTSs).

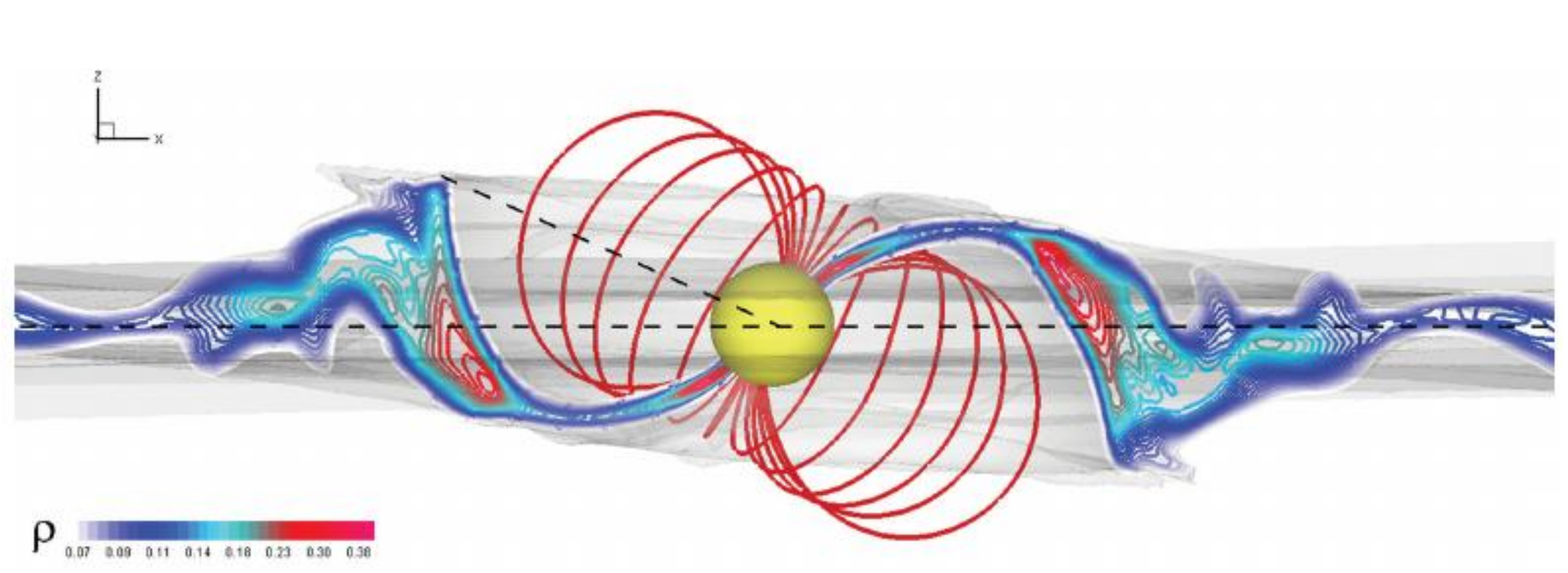

Figure 4. MHD simulation of accretion onto a CTTS. This simulation shows the accreting funnel (Romanova et al., 2013). Red lines show selected magnetic field lines.

Fig. 5 shows that $90\,\%$ of the transition disk stars are accreting, which shows the presence of a hole in a disk does not stop the accretion process.

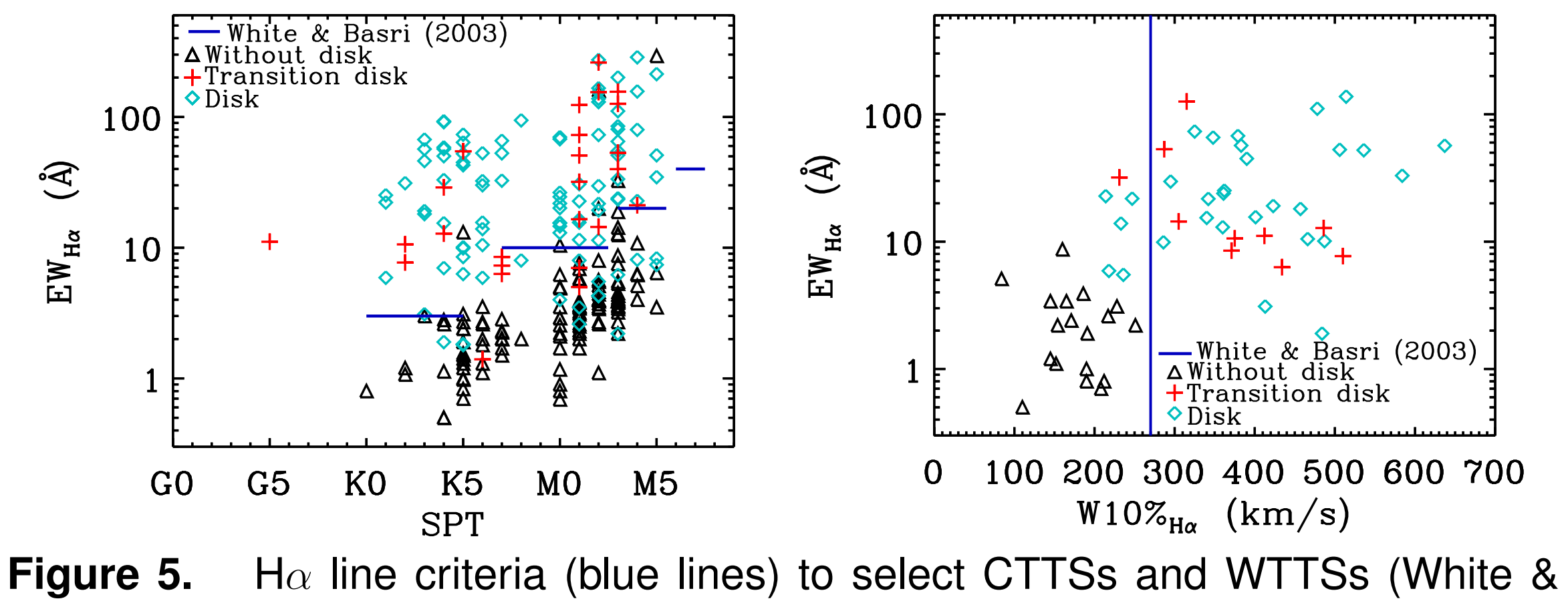

Figure 5. Hα line criteria (blue lines) to select CTTSs and WTTSs (White & Basri, 2003). Left: Hα equivalent width vs. spectral type. Right: Hα equivalent width vs. Hα width at 10% of maximum intensity.

In Fig. 6 we show distributions of $\mathrm{EW}_{\mathrm{H}\alpha}$ and $\mathrm{W10\%}_{\mathrm{H}\alpha}$ for the sample of stars. The $\mathrm{EW}_{\mathrm{H}\alpha}$ mean value for the three groups of stars are $(8 \pm 3)\,\mathrm{\AA}$ for stars without disk, $(49 \pm 13)\,\mathrm{\AA}$ for transition disk and $(46 \pm 6)\,\mathrm{\AA}$ for thick disk star. The distribution of transition disk sample looks more similar to the distribution for stars with disks than the distribution of stars without disk. Similar result was found using Hα width at 10% of maximum intensity.

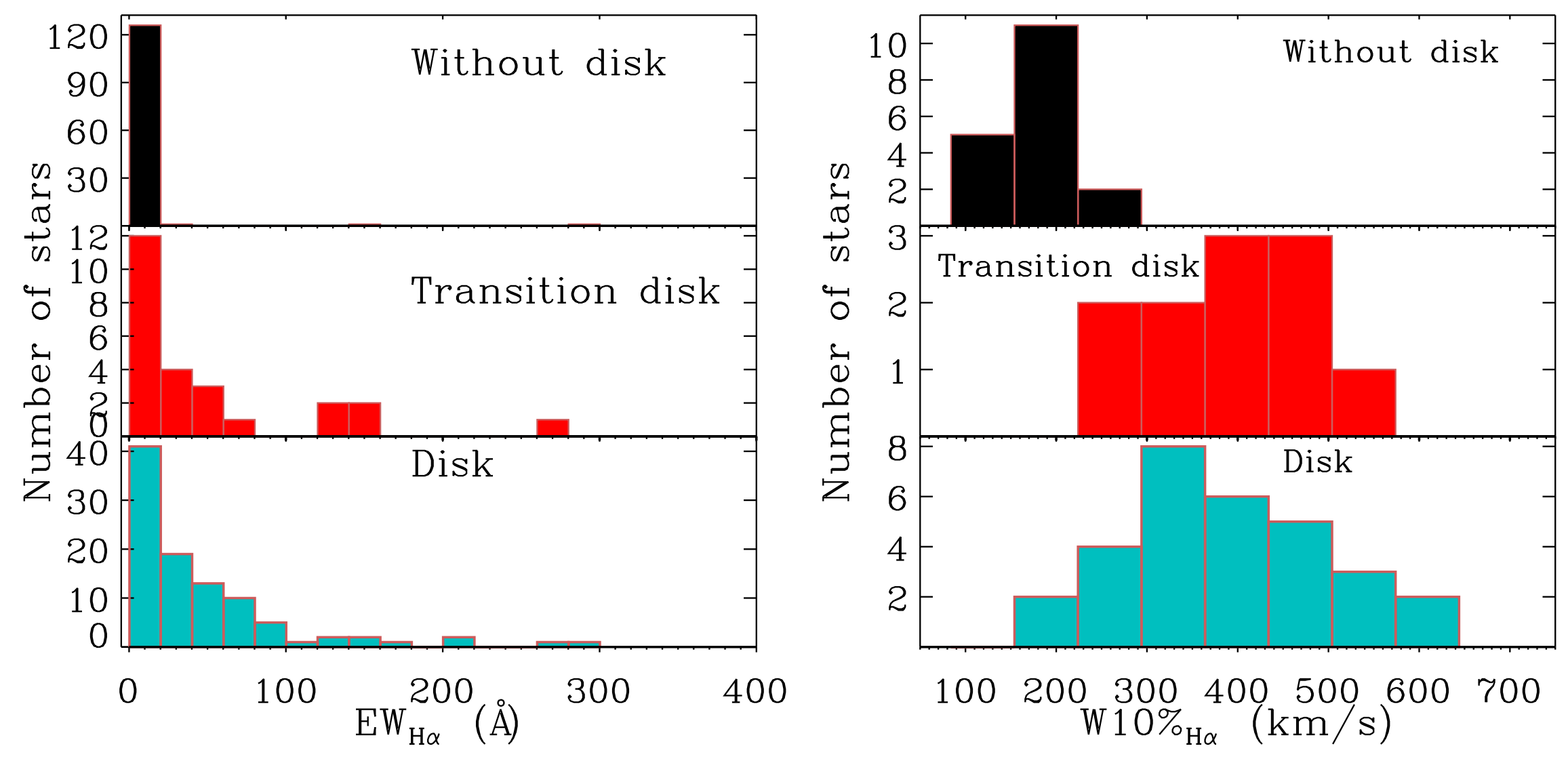

Figure 6. Distribution of Hα equivalent width (left) and Hα width at 10% of maximum intensity (right) of NGC 2264 sample of stars.

In accreting star-disk systems the stellar magnetic field interrupts the disk at a few radii from the star, and at this point the gas from the disk follows the magnetic field and hits the star at high latitude (Fig. 4) forming hot spots. The UV excess above the photospheric level, in a CTTSs, comes from hot spots, consequently the UV excess is also used as a diagnostic of accretion (Venuti et al., 2015, 2014).

We show in Fig. 7 the UV excess versus $\mathrm{EW}_{\mathrm{H}\alpha}$. Stars without disks do not present UV excess. Stars with a full disk are expected to show accretion, and they present UV excess (Venuti et al., 2014). Transition disk candidates, in general, present UV excess like stars with disk, and this is consistent with active accretion.

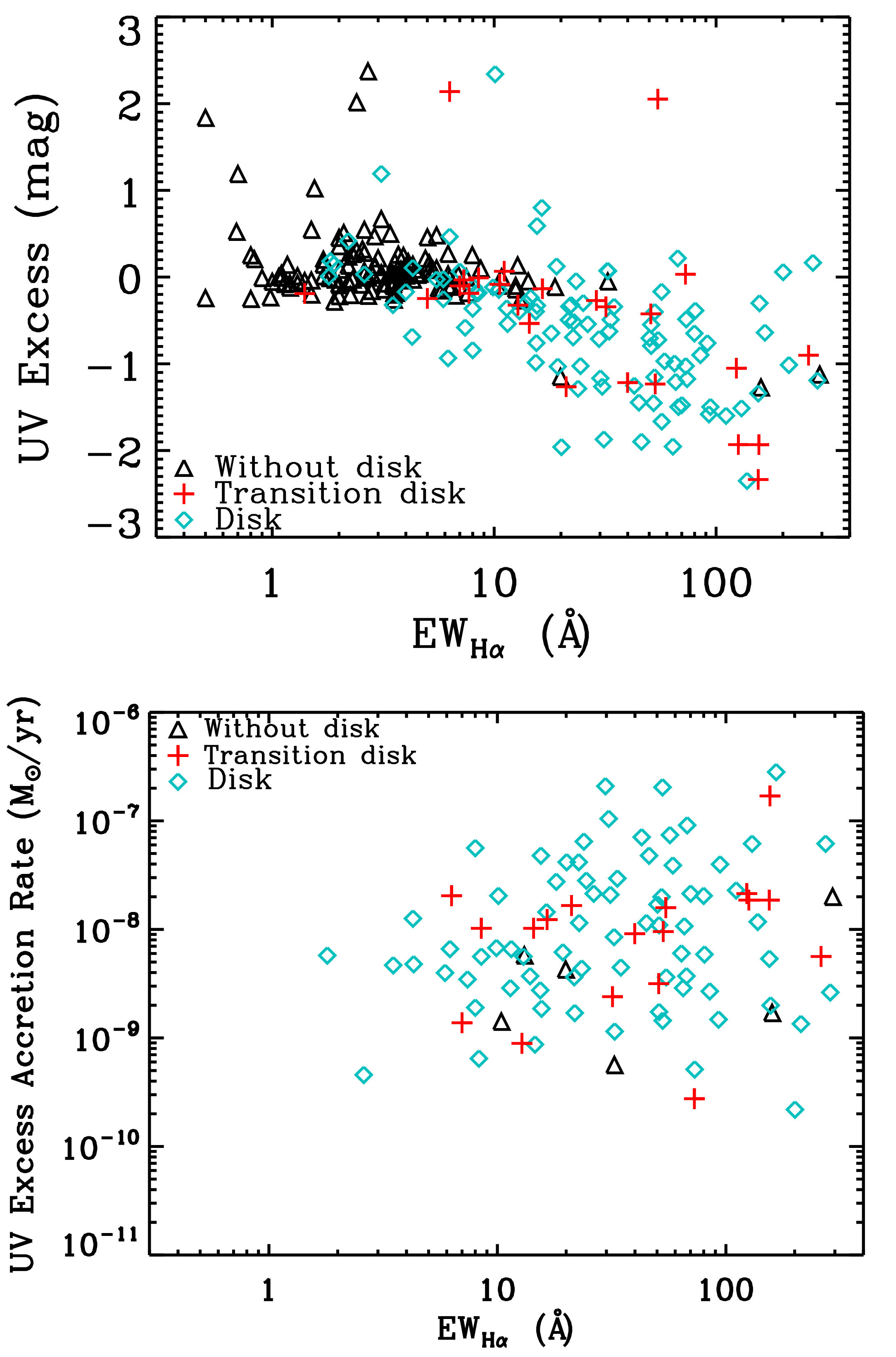

Figure 7. UV excess (top) and mass accretion rates (bottom) calculated by Venuti et al. (2014) as a function of Hα equivalent width. In the top plot, more negative values indicate higher UV excess.

With the UV excess, Venuti et al. (2014) calculated mass accretion rates for the CTTSs in NGC 2264. We show in Fig. 7 that mass accretion rates for stars with transition disk and with thick disk are of the same level (the mean values are $(1.74 \pm 0.78) \times 10^{-8}\,\mathrm{M}_\odot/\mathrm{yr}$ and $(2.34 \pm 0.47) \times 10^{-8}\,\mathrm{M}_\odot/\mathrm{yr}$ for stars with transition disk and thick disk, respectively).

6 Conclusions

- SED modelling shows that $9\,\%$ stars of the 332 stars of the NGC 2264 that we analysed presented inner disk holes. Then, transition disks are a rapid phase of disk evolution, as also reported in the literature.
- The presence of a hole in the inner disk does not stop the accretion process, since $90\,\%$ of transition disk stars belonging to the NGC 2264 cluster are still accreting, suggesting that gas is flowing through the hole.
- Transition disk systems show Hα, UV excess and mass accretion rates at the same level as accreting systems.

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