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Transition disks: A study of disk holes properties and the connection with planet formation

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Abstract. Over the years, many transition disks have been detected via SED modeling or images. These systems are usually referred to as candidate systems to have newly formed planets. We searched for transition disks belonging to the young (~3 Myr) cluster NGC 2264 and characterized the accretion and disks of these systems. We have modeled 401 T Tauri stars with the Hyperion SED code that allowed us to classify 7% of the systems as transition disk candidates. We estimated the inner hole size of these systems and found sizes from 0.1 to 78AU. We show that 18% of transition disks present hole sizes that can be explained by photoevaporation from stellar radiodontia. The other accreting transition disks are godo candidates to havê planeta in inner disk.

Resumo. Ao longo dos anos, muitos discos de transição foram detectados usando modelos de SED ou imagens. Esses sistemas são usualmente referidos como candidatos a conter planetas recém formados. Procuramos por discos de transição pertencentes ao aglomerado jovem (~3 Manos) NGC 2264 e caracterizamos a acreção e os discos desses sistemas. Modelamos 401 estrelas T Tauri com o código Hyperion SED, que nos permitiu classificar 7% das estrelas como candidatas a disco de transição. Estimamos o tamanho do buraco no disco desses sistemas e encontramos valores de 0,1 a 78 UA. Mostramos que 18% dos discos de transição apresentam tamanho de buraco que podem ser explicados por fotoevaporação devido a radiação estelar. Os outros sistemas com discos de transição, e ainda em processo de acreção, são candidatos a conter planetas na parte interna do disco.

Keywords. Stars: formation – Stars: variables: T Tauri – Accretion disk

1. Introduction

Disks are ubiquitous around T Tauri stars and are sites of planet formation, 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 e.g., Owen (2016).

NGC 2264 is a young stellar cluster (~ 3 Myr and d ~ 760 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 diagnostics and disk parameters.

2. Observation

We used data from the international campaign, *Coordinated Synoptic Investigation of NGC 2264* (CSI 2264) (Cody et al. 2013), that included data from the CoRoT satellite, VLT FLAMES spectroscopic and u band photometry from Megacam (CFHT). We also used data from catalog surveys, such as near-infrared photometry JHK_s from 2MASS, $UBVR_cI_c$ and *ugriz* optical photometry from Rebull et al. (2002) and SLOAN/SDSS (Gunn et al. 1998), respectively, IRAC and MIPs data bands from the *S*ptizer satellite (Fazio et al. 2004; Rieke et al. 2004) and observations from The Wide-field Infrared Survey Explorer (WISE) performed at wavelengths 3.4, 4.6, 12.0 and 22 μm (Wright et al. 2010).

3. Sample of stars

As we intend to analyze the accretion and disk properties of transition disk systems,our sample of stars only contains T Tauri systems that were observed with *Spitzer*/IRAC, which had an α_{IRAC} index (the slope of the SED between 3.6 μm and 8 μm) measured by Teixeira et al. (2012) and were also observed with CFHT/Megacam (Venuti et al. 2014). We constructed SEDs (spectral energy distributions) for a sample of 401 T Tauri stars and modeled them with the Hyperion SED model (Robitaille 2017). We found 7% transition disk candidates (systems with inner hole according to the SED modeling and that have 24 μm flux above photospheric level), 52% systems with a full disk and 41% diskless stars, see Fig. 1. This number of transition disks indicates that disk dispersal is rapid compared to disk lifetime.

4. Disk and inner hole characteristics

Disk parameters were computed by the Hyperion SED model. In Fig 2 we show the distributions of the dust disk mass and the external disk radii. These are however only estimated values, since our data do not cover all the disk extension.

With the output parameters of the SED model we estimated the inner hole size (R_H) and found sizes from 0.1 to 78 AU for the transition disks. Then we compared the inner disk hole size with different characteristics of the star-disk system. In Fig. 4 and 3 we show the accretion and disk parameters, respectively, as a function of the inner hole size.

Transition disk candidates with lower emission in the inner disk tend to have large holes (Fig. 3). Our data do not show a relation between the hole size and the $\alpha_{\rm IRAC}$ index. The sample of transition disk candidates present dust in the inner disk similar to anemic disks, which shows that anemic disk systems can be candidates to have transition disk.

Different mechanisms can be responsible for creating a hole in the inner disk. Photoevaporation of the inner disk by the central star radiation can open holes, but, in general, with small radii (R_H < 10 AU) and for small mass accretion rates (< $10^{-9}\ M_\odot yr^{-1}$) (Owen et al. 2011; Owen 2016). We indicated the five systems that fall in the photoevaporation region in Fig. 4. We can see that almost all our transition disk candidates are outside

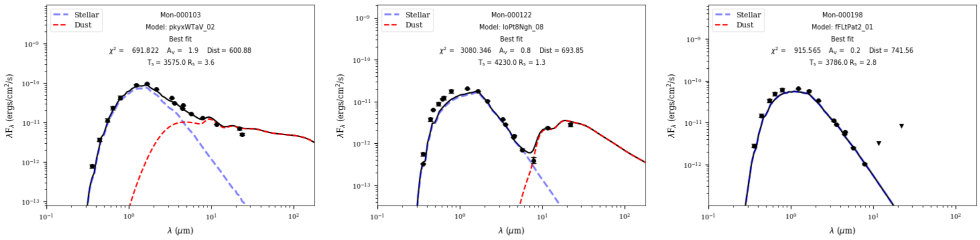

Figure 1. Examples of SEDs for systems with full disk (left), transition disk candidate (middle) and diskless (right). Circles show literature observed data. The black solid line is the best data fit of the Hyperion SED model and the dashed lines are stellar (blue) and dust emission (red) components (Robitaille 2017).

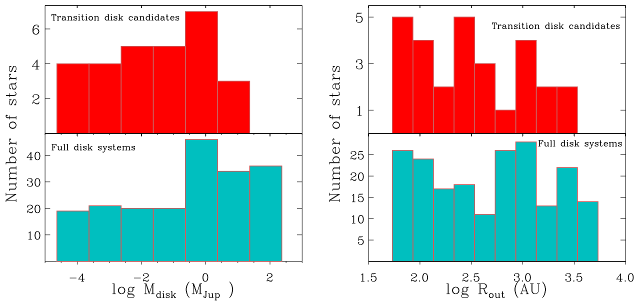

Figure 2. Disk parameters obtained by the SED model fitting of transition disk and full disk systems. Left: Disk dust mass. Right: Disk outer radius.

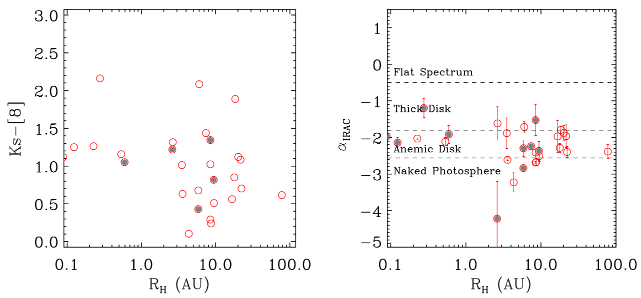

Figure 3. Disk diagnostics as a function of disk hole size for our sample of transition disk candidates. Left: Near-infrared color. Right: α_{IRAC} index, that is the slope of the spectral energy distribution from 3.6 μm to 8 μm measured by Teixeira et al. (2012) . Gray filled symbols identify systems that fall in the region where the inner disk hole can be explained by X-ray photoevaporation.

of the region where photoevaporation can explain the inner disk hole.

Planet formation in the disk is one of the most plausible mechanisms to explain transition disk systems that present signs of accretion, despite the fact that the models do not explain all the observational characteristics of transition disks (Owen 2016). Accreting transition disks with large or small holes (depending of the evolution stage of the planet in the disk) can be explained by planet formation and its evolution in the inner disk. The systems that fall out of the region limited by the dashed lines in Figure 4 (left) can be candidates to have planets in different stages.

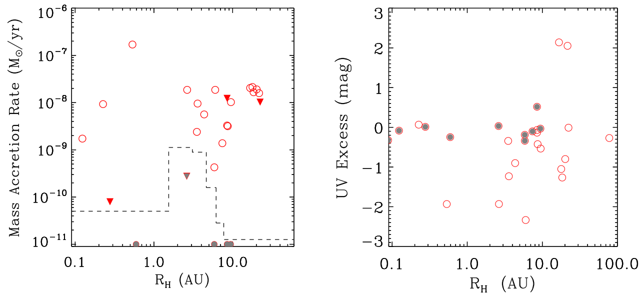

Figure 4. Accretion diagnostic as a function of disk hole size for transition disk candidates. Left: Mass accretion rates are from UV excess (preferentially) (Venuti et al. 2014) and from Hα equivalent width (Sousa et al. 2016). The upside down triangles correspond to the upper limits of the mass accretion rate. The dashed line represents the region where the inner hole can be explained by X-ray photoevaporation (Owen et al. 2011). Right: UV emission excess (Venuti et al. 2014). Gray filled symbols identify systems that fall in the region where the inner disk hole can be explained by X-ray photoevaporation.

5. Conclusions

- SED modelling shows that only 7 % of the 409 stars of NGC 2264 that we analyzed presented inner disk holes. This indicates that transition disks represent a rapid phase of disk evolution, as also reported in the literature.
- Among our sample of transition disk candidates, only 18 % have small mass accreting rate ($< 10^{-8}$ $M_\odot yr^{-1}$), that can be explained by X-ray photoevaporation of the inner disk by stellar radiation.
- We show that $\sim$ 82% could be explained by planet formation in different evolutionary stages.

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