# A VLT/X-Shooter study of accretion and photoevaporation in Transitional Disks

C.F. Manara[1], L. Testi[1,2], A. Natta[2,3], L. Ricci[4], M.Benisty[5], G. Rosotti[6], B. Ercolano[6]

cmanara@eso.org - [1]European Southern Observatory, [2]INAF-Arcetri, [3]DIAS, [4]Caltech, [5]Grenoble, [6]USM Munich

## CONTEXT

Transitional Disks (TDs) are considered to be a late evolutionary stage of optically thick massive disks whose inner regions are being evacuated, leaving behind large holes that can be detected both by modeling the infrared spectral energy distribution (SED) or, in some cases, by mm-interferometry. These holes could be produced by processes of photoevaporation, grain growth, or planet formation. Still, none of these processes alone has been shown to be sufficient to explain all observations.

In this context, the combination of inner hole size, mass accretion rate and wind properties is a powerful observational diagnostic of disk evolution models, but the current measurements of mass accretion rates for TDs are mostly based on secondary indicators (such as the 10% H$\alpha$ width), and very few data on the wind properties for these objects are available.

Here we present a detailed study of the accretion and wind properties of TDs carried out with the VLT/X-Shooter spectrograph. Combining new and archival X-Shooter observations, we collected a sample of more than 20 TDs from different nearby star-forming regions. Our sample includes objects with both small (<5-15 AU) and large (>20-30 AU) known inner hole size from the literature (either from mm-observations or infrared SED fitting). We check their stellar parameters ($T_{eff}$, $L_*$, $A_V$, $M_*$) and derive their accretion properties ($L_{acc}$, $M_{acc}$) in a self-consistent way, which makes use of the wide wavelength coverage of X-Shooter, and study their wind properties by mean of different forbidden emission lines analysis. Here we present some preliminary results.

## METHOD

### 1) ACCRETION & SpT FITTER

We fit the observed spectra of our targets with a grid of models that include a range of photospheric template spectra (Class III YSOs from Manara et al. 2013a, augmented with some earlier SpT templates), a range of possible values for the extinction and for the excess spectrum produced by the disk accretion process, modeled as an isothermal hydrogen slab emission (for a detailed description of the method see Manara et al. 2013b).

With the best fitting model we derive self-consistently from the complete X-Shooter spectrum SpT, $A_V$, and $L_{acc}$ for the input target. In general, but with some notable exceptions (see Results section), our findings confirm previous values available in the literature.

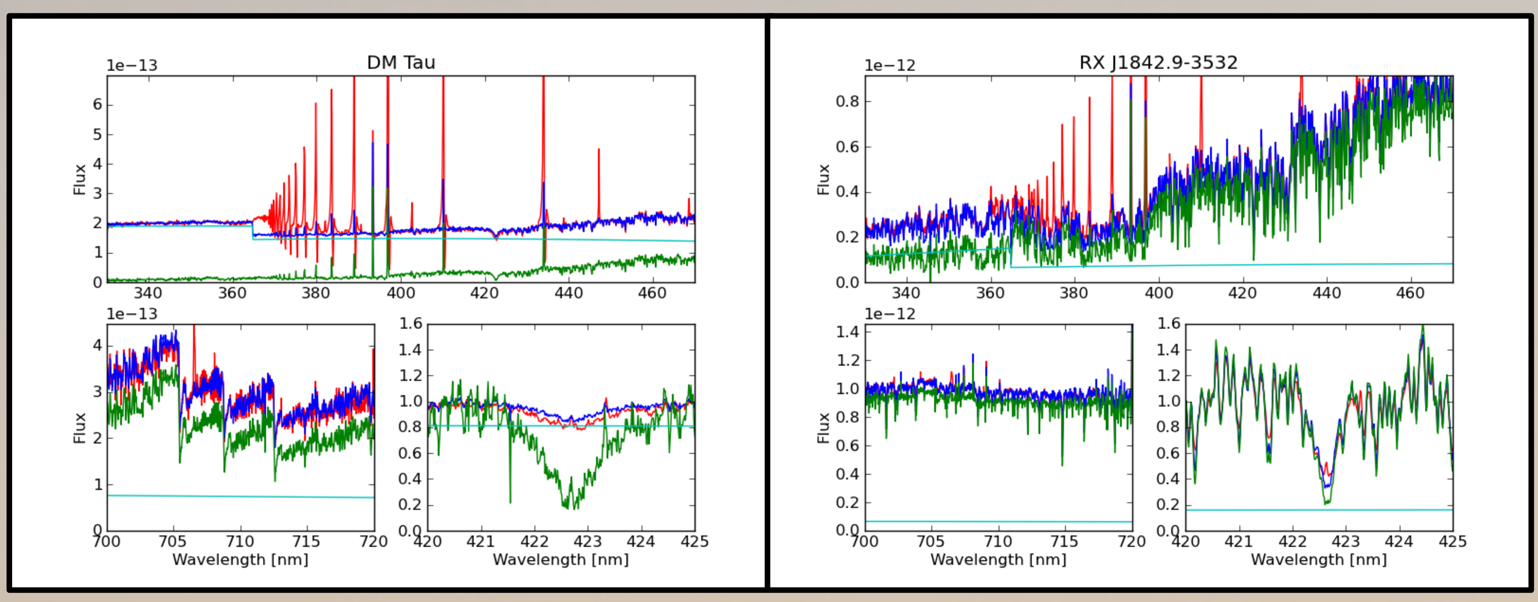


**Fig.1:** Examples of the fitting procedure.

### 2) FORBIDDEN LINES

We search for emission in various forbidden lines to check for the presence of winds and disk photoevaporation in each source. In particular, we check various [OI] lines ($\lambda\lambda$=630, 636.4, 557.7 nm), the [NI] lines ($\lambda\lambda$=519.8, 346.6 nm), and the [SII] line at $\lambda$=673.1 nm.

A clear detection of all these lines is usually evidence of outflows, possibly caused by disk photoevaporation. In order to asses that, we have to study in detail the kinematics and intensity of these lines. In particular, we need to detect blueshifted components in the lines.

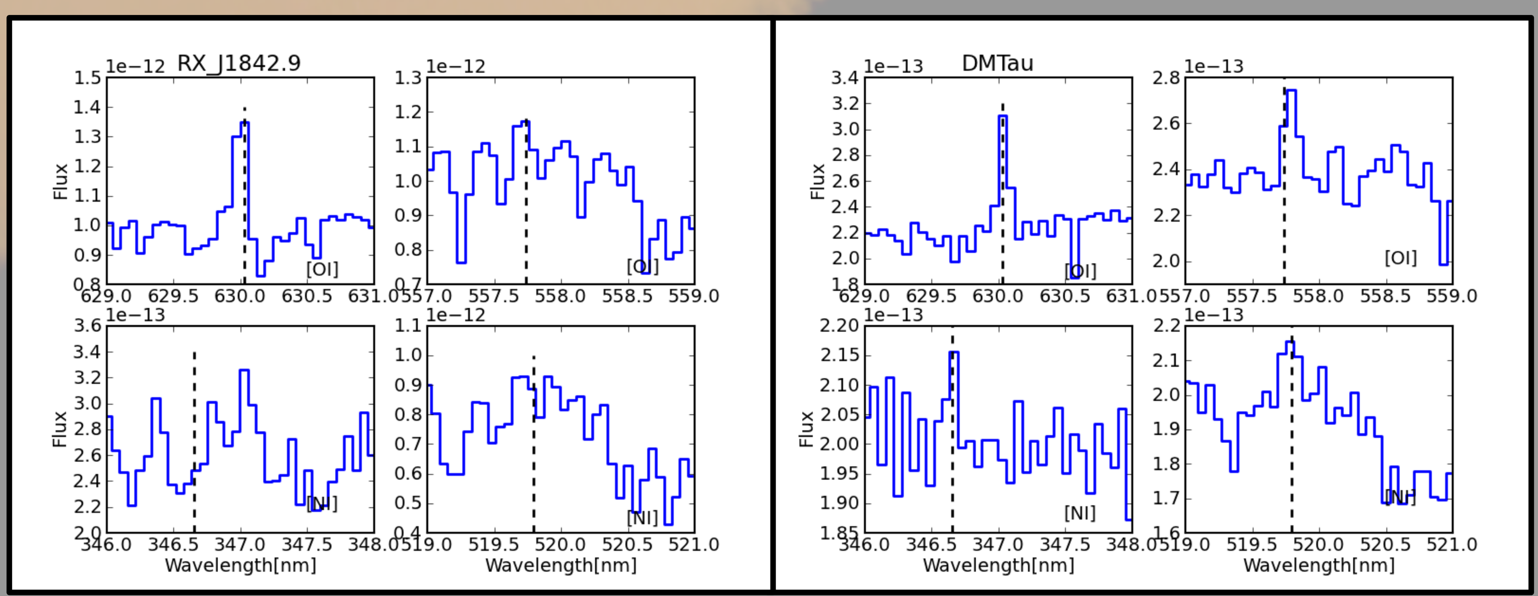


**Fig.2:** Examples of forbidden emission lines.

### REFERENCES:

Andrews et al. 2009, ApJ, 700, 1502; Andrews et al. 2011, ApJ, 732, 42; Brown et al. 2008, ApJ, 675, L109; Brown et al. 2009, ApJ, 704, 496; Espaillat et al. 2010, ApJ, 717, 441; Hughes et al. 2007, ApJ, 664, 536; Hughes et al. 2008, ApJ, 678, 1119; Hughes et al. 2010, AJ, 140, 887; Kim et al. 2009, ApJ, 700, 1017; Manara et al. 2013a, A&A, 551, A107; Manara et al. 2013b, A&A, submitted; Merin et al. 2010, ApJ, 718, 1200; Owen et al. 2011, MNRAS, 412, 13; Owen et al. 2012, MNRAS, 422, 1880; Rosotti et al. 2013, MNRAS, 430, 1392; Zhu et al. 2011, ApJ, 729, 47.

## RESULTS

### MASS ACCRETION RATES

- We confirm that SR21 ($R_{in}$=36 AU) is not accreting. The X-Shooter spectrum of this object does not show any signature of accretion.
- For Ser29, (SSTc2d J182911.5+002039, Rin = 8 AU) we find a value of $M_{acc}$= 1.6·10$^{-9}$$M_\odot$/yr instead of the one reported in the literature, which is $M_{acc}$=10$^{-7}$$M_\odot$/yr (Merin et al. 2010).

### PHOTOEVAPORATION WIND SIGNATURES

Most of the objects with large inner holes and low accretion rates (e.g. SR21, RX J1615) do not show the signatures expected from photoevaporating winds (forbidden line emission). On the contrary,most of the objects with $R_{in}$<25AU show forbidden line emission.

| Name | SpT | $R_{in,SED}$ [AU] | $R_{in,mm}$ [AU] | $\dot{M}_{acc}$ [$M_\odot$/yr] | Ref ($R_{in}$) |
|---|---|---|---|---|---|
| RX J1615 | K5 | ... | 30 | | 1 |
| SR21 | G4 | ... | 36 | | 2,3 |
| RX J1842.9 | K2 | ... | 5 | | 4 |
| RX J1852.3 | K2 | ... | 16 | | 4 |
| Oph22 | M3 | 1 | ... | | 5 |
| Oph24 | M3 | 3 | ... | | 5 |
| Ser29 | M3 | 8 | ... | | 5 |
| Ser32 | K7 | 7 | ... | | 5 |
| Ser34 | M2 | 25 | ... | | 5 |
| GMAur | K5 | ... | 28 | | 4,6 |
| DMTau | M3 | ... | 19 | | 1 |
| UXTauA | G8 | ... | 25 | | 1 |
| LkH$\alpha$330 | G4 | ... | 68 | | 1,7 |
| ISO-Oph196 | M5.5 | ... | 15 | | 3 |
| DoAr44 | K2 | ... | 30 | | 3 |
| Sz 84 | M5 | 55 | ... | | 5 |
| TW-Hya | K7 | ... | 4 | | 8 |
| LkCa15 | K2 | ... | 50 | | 1 |
| CS Cha | K2 | 43 | ... | | 9 |
| CHX22 | G8 | 37 | ... | | 9 |
| Sz Cha | K2 | 29 | ... | | 9 |

**References.** (1) Andrews et al. (2011), (2) Brown et al. (2009), (3) Andrews et al. (2009), (4) Hughes et al. (2010), (5) Merín et al. (2010), (6) Hughes et al. (2008), (7) Brown et al. (2008), (8) Hughes et al. (2007), (9) Kim et al. (2009)

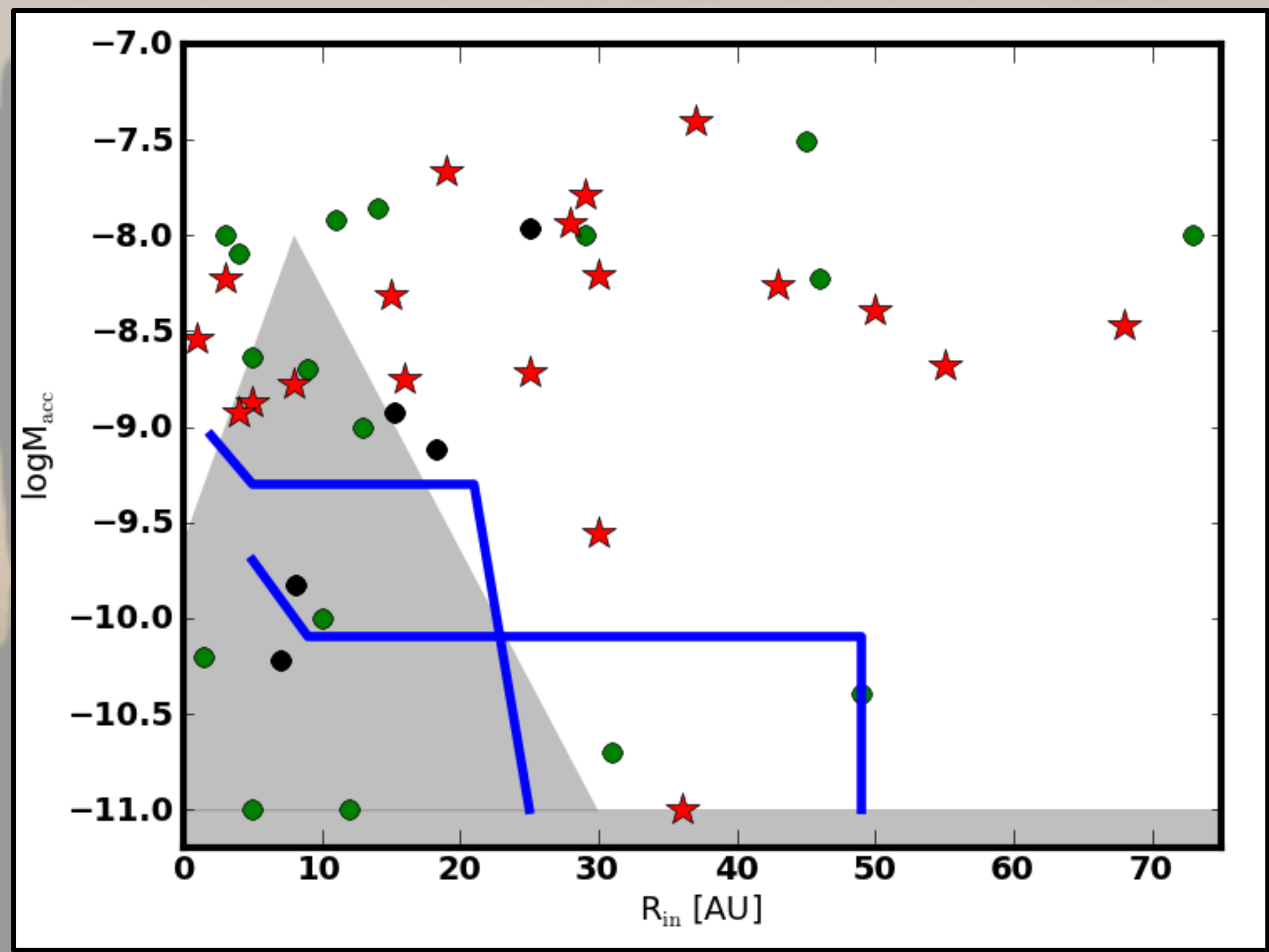


**Fig.3:** Plot of mass accretion rates as a function of the inner disk radius. The grey shaded area represents the region of this parameter space where the objects are consistent with gaps created by photoevaporation (Owen et al. 2012). The blue lines represent the tracks predicted by models where planet formation and photovaporation occur at the same time (Rosotti et al. 2013). Objects in our sample presented here are shown with red stars. For these objects, mass accretion rates reported are those measured by us. Data taken from the literature for both $R_{in}$ and $M_{acc}$ are reported with circles.

## DISCUSSION

Disk accretion signatures have been used to exclude the possibility that photoevaporation plays a dominant role in the disk clearing process (e.g. Espaillat et al. 2010), because gas should not be anymore present in the inner-hole if photoevaporation is occuring. As opposite to that, planet induced gaps may still allow for large values of the mass accretion rate (e.g. Zhu et al. 2011). On the other hand, photoevaporation models predict ongoing accretion if the dimension of the inner hole is small (Owen et al. 2011, 2012). Models including both planet formation and photoevaporation are now being developed, but they still cannot explain TDs with large inner holes and large accretion rates (Rosotti et al. 2013)

In our sample we see that some objects with very large inner holes, i.e. $R_{in}$>30 AU, in particular SR21, have low or negligible accretion, and their inner holes could be possibly originated by photoevaporation. At the same time, there are some TDs with large inner holes and not negligible accretion rates ($M_{acc}$ >10$^{-9}$ Msun/yr) that, within the current theoretical framework, are difficult to explain with current photoevaporation models. More analysis on their wind and stellar properties will help to understand their real origin and whether they are a different class of TDs.