X-ray Photoevaporation of Discs

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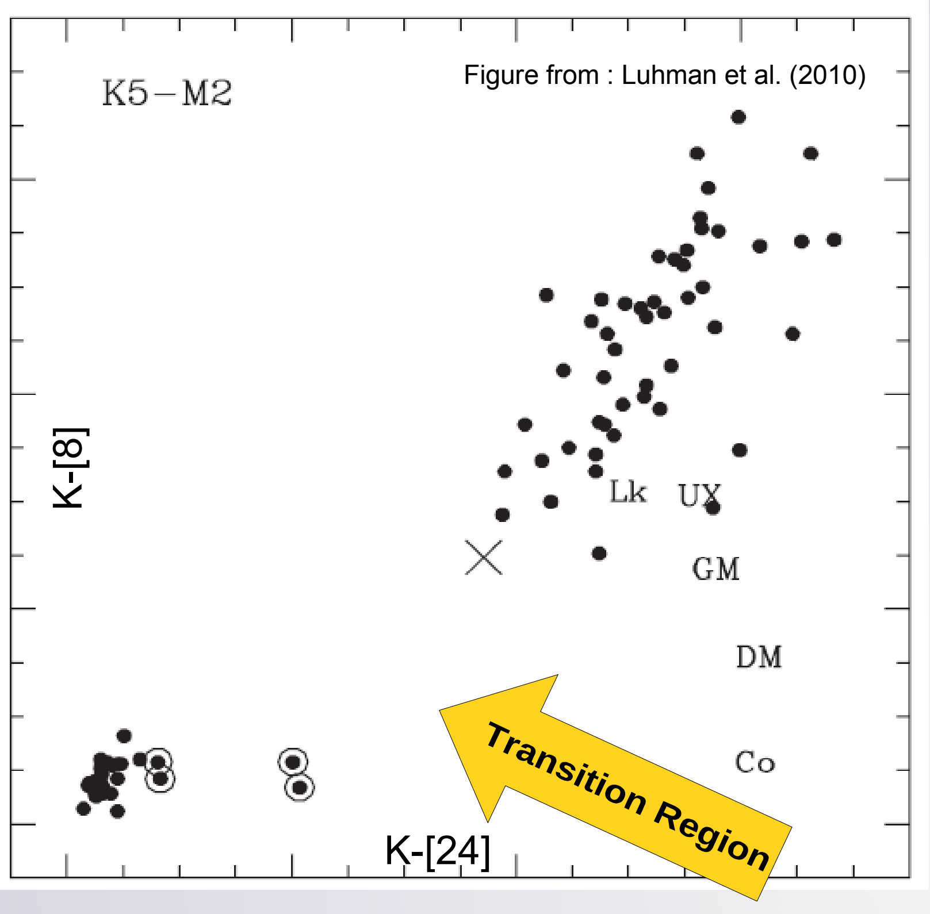
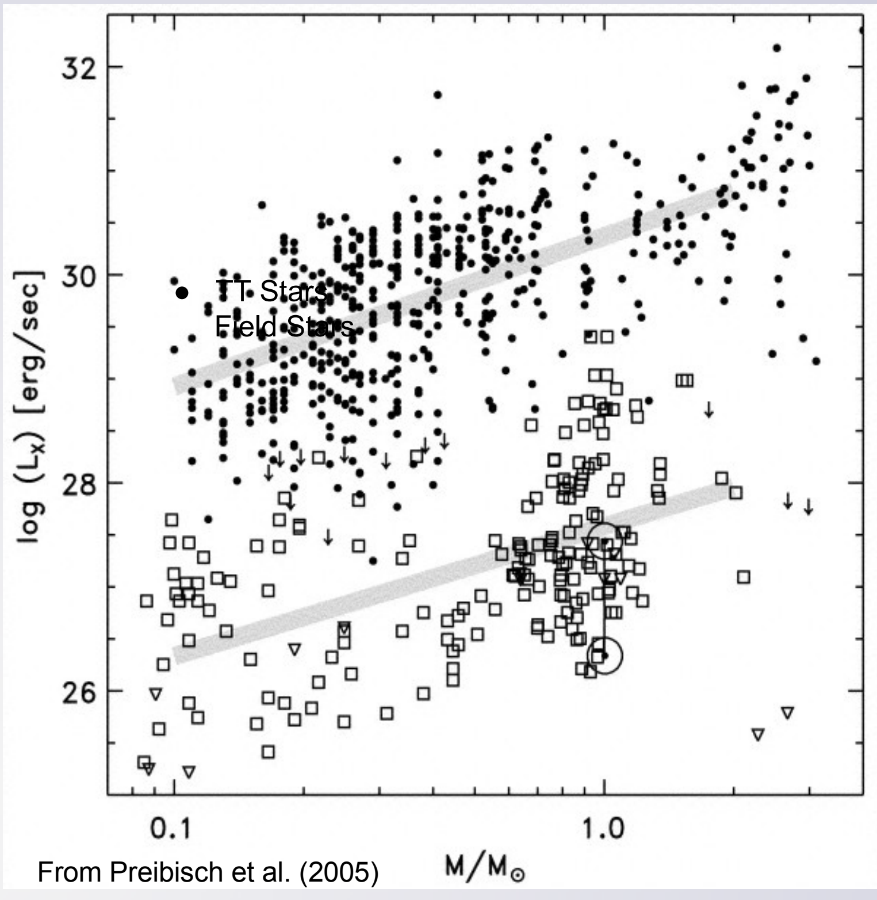
Background



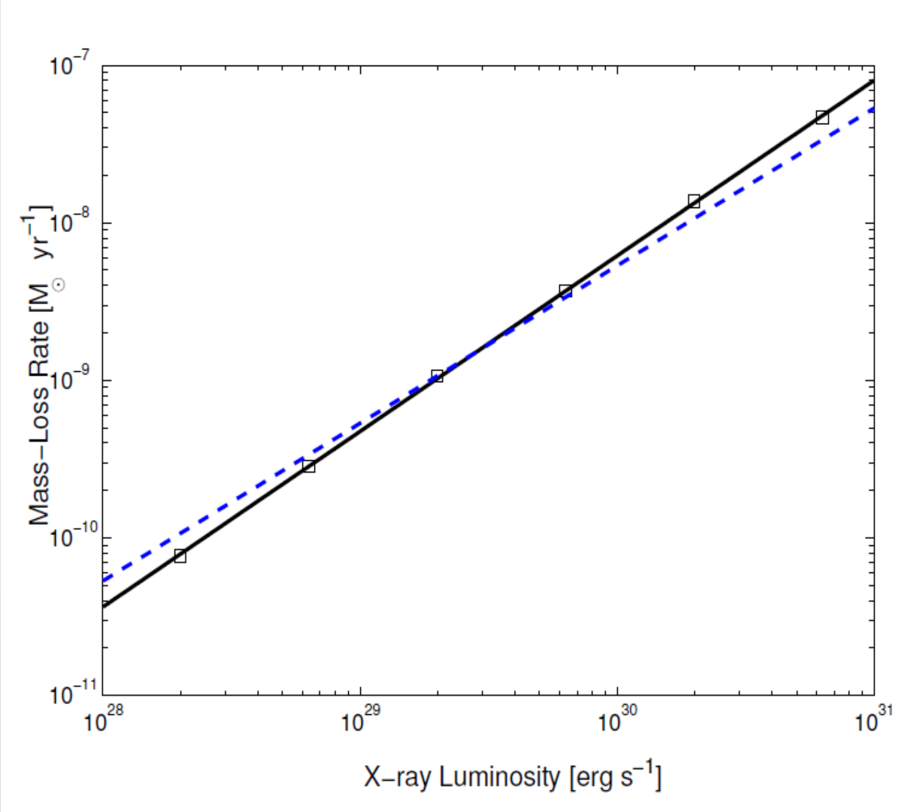
Discs are observed to surround a large percentage of all young stars at an age of ~1Myr and by 10Myr they are mostly gone (Haisch et al. 2001). Very few solar type YSOs have been detected as 'transition' objects at an intermediate evolutionary stage between disc bearing class II sources and discless class III sources. Hence the time for disc destruction occurs on a much shorter timescale than the disc's lifetime. This 'transitional' timescale has been estimated to be ~10^5yr i.e. an order of magnitude shorter than the disc's lifetime (Kenyon & Hartmann 1995; Duvert et al. 2000). These 'transition' objects show inner holes in their (dust) discs with hole radii between 5-50AU. Several mechanisms for the creation of these inner-hole objects have been proposed. Dust trapping by tidal interactions with a formed/forming planet embedded in the disc (Rice et al. 2003). Or inner disc clearing via photoevaporation from high energy radiation (Clarke et al. 2001). Both mechanisms can naturally explain individual objects neither mechanism is able to explain the entire population. Given these two mechanisms compete with each other to remove gas from the disc it is expected both are at work. However, photoevaporation is the only mechanism that can self-consistently produce inner-hole sources while dispersing the disc in the required timescale (Alexander et al. 2006a,b). All previous hydrodynamic photoevaporation models have only included the incident EUV field. In order to investigate recent claim that the EUV field cannot reach the disc (Glassgold et al. 2007) and in-fact it is the X-rays that are driving the photevaporation (Ercolano et al. 2008,2009; Owen et al. 2010a) we have constructed a population synthesis model, based on viscous evolution and X-ray photoevaporation to test the statistical properties of the model against observations.

Why X-Rays?

Young stars are extremely strong X-ray emitters, with X-ray luminosities of CTT stars detected up to ~10^{31} erg/s. With an approximately two order of magnitude scatter in luminosity at a given mass. Given that X-rays can penetrate much larger columns than the EUV can, it is extremely likely that the X-rays can reach the surface of the disc even if the EUV cannot. Recent detections of the [NeII] 12.8μm emission line from discs (e.g. Pascucci et al. 2009; Ercolano & Owen, 2010) suggest that high energy radiation must be reaching the discs surface. Detected blue-shifts also indicates the presence of a at least partially ionized flow from the discs surface.



From Preibisch et al. (2005)



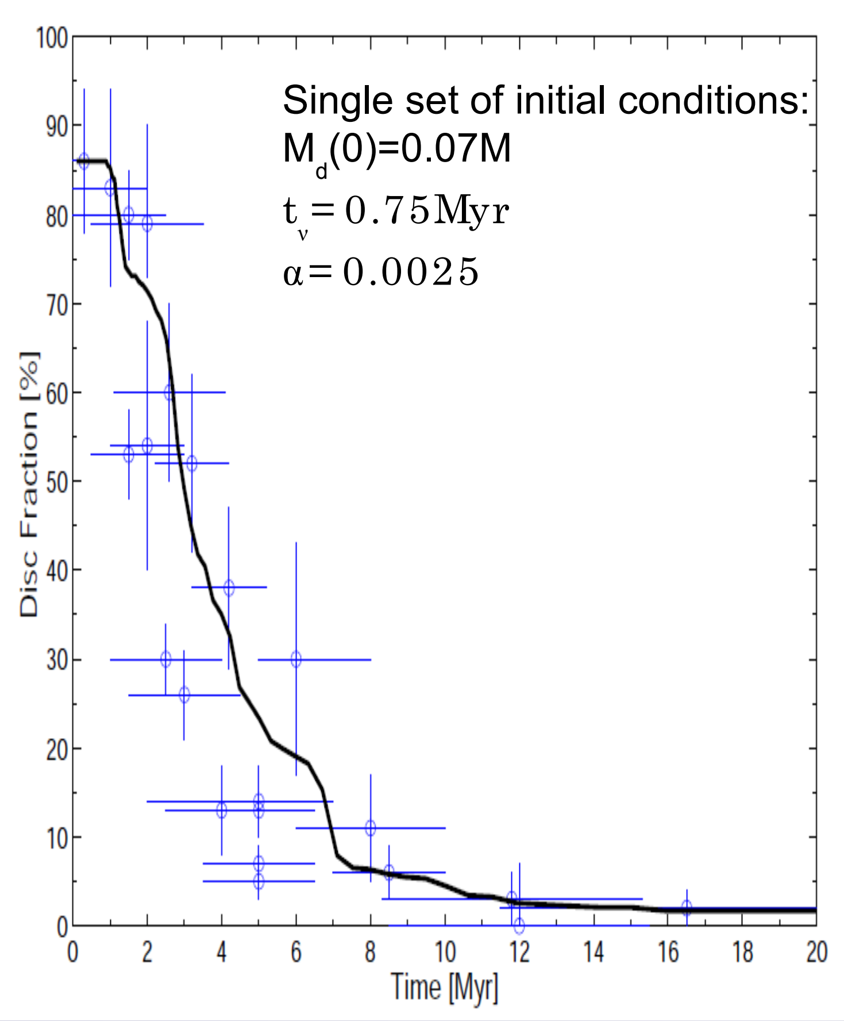
In order to asses the importance X-ray photoevaporation, we have calculated mass-loss rates for the observed X-ray luminosities in T-Tauri stars, using the method presented in Owen et al. (2010a). We find mass-loss rate in the range 10^{-10}-$10^{-7}M_{\odot}$/yr, which are comparable to the observed accretion rates in T-Tauri stars. Thus, it is expected that X-ray photoevaporation will play an dominant role in disc evolution, cutting them off in their prime.

A Population of Photoevaporating Discs

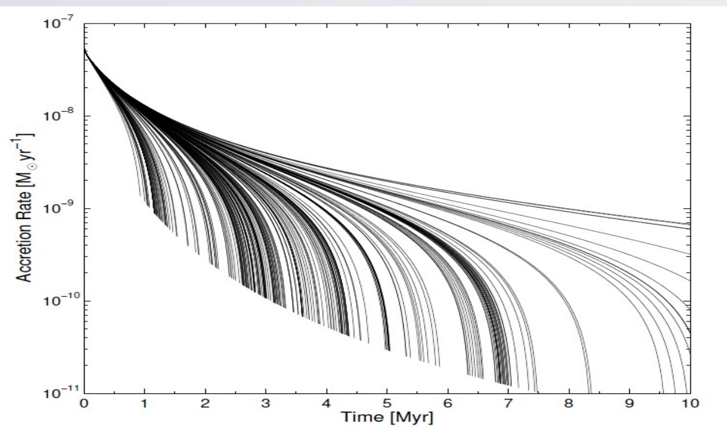
We allow the disc to evolve viscously using a simple linear power law prescription of viscosity, with photevaporation included as a source term. We switch between the primordial mass-loss profile and the inner hole profiles when the inner edge is exposed to X-ray irradiation. We use a *single* set of initial conditions, and stochastically sample the X-ray luminosity function to obtain a synthetic population of viscously evolving, X-ray photoevaporating

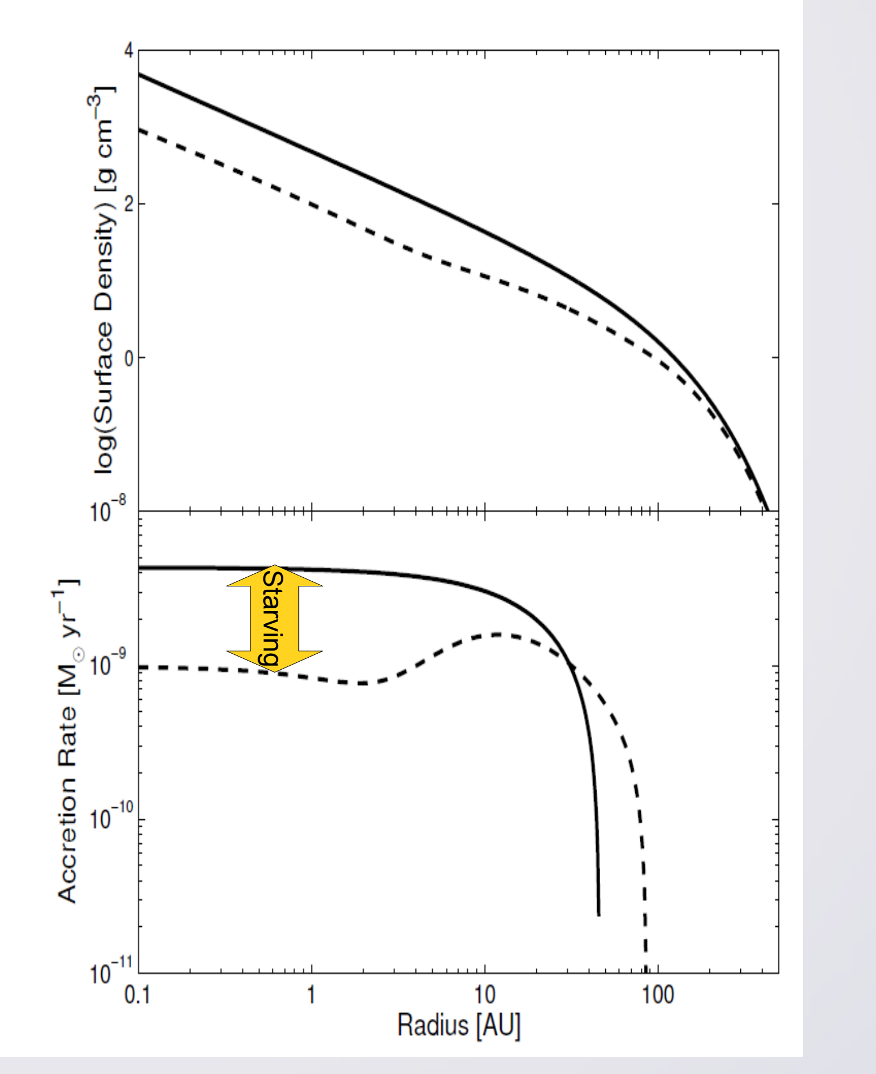
$$\frac{\partial\Sigma}{\partial t}=\frac{3}{R}\frac{\partial}{\partial R}\left[R^{1/2}\frac{\partial}{\partial R}\left(\nu(R)\Sigma R^{1/2}\right)\right]-\dot{\Sigma}_w(R,t)$$

Photoevaporation



We can reproduce the observed disc fractions as a function of time, using the spread in photoevaporation rate alone. Contrary to previous models, that have suggested a spread in initial conditions (Armitage et al. 2003; Alexander & Armitage, 2009). We can also reproduce the observed spread in accretion rates at time >1Myr.





Photoevaporation starves the inner disc of material compared to a disc that is not under going photoevpoartion. Therefore, discs with higher mass-loss rates should have lower accretion rates at any given time. Prediction: Stars with higher X-ray luminosities should have systematically lower accretion rates ('Photoevaporation starved accretion', Drake et al. 2009).

This predicted negative correlation has been observed in the Orion data (Drake et al. 2009). It also appears in the X-ray luminosities of WTTs, which are systematically more luminous than CTTs, since X-ray bright objects lose their discs first.

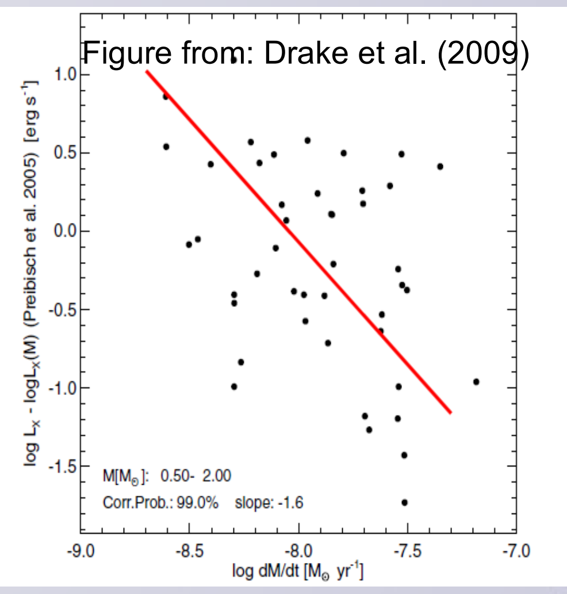
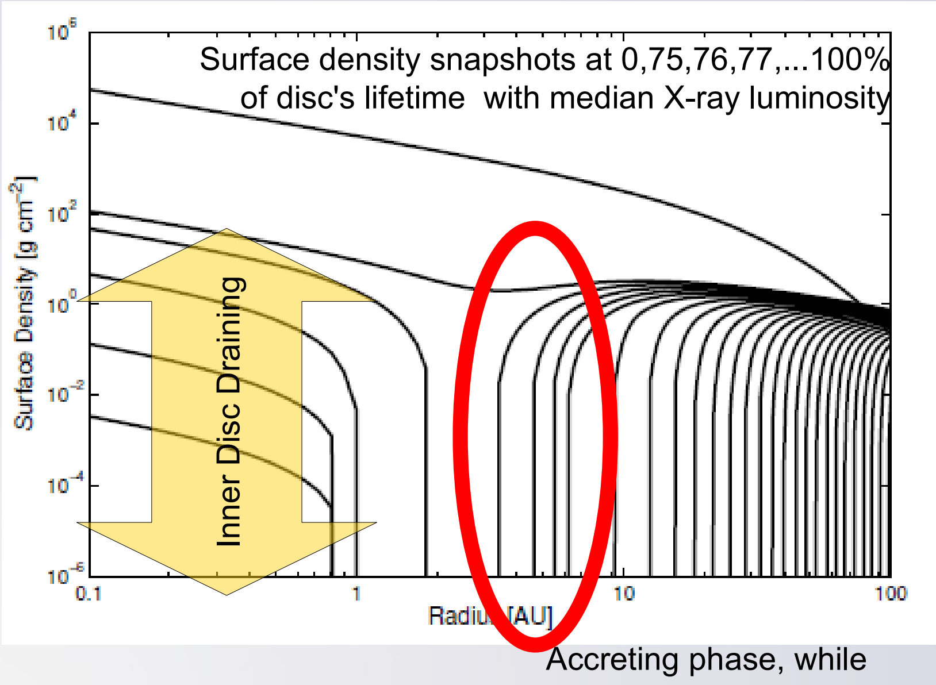


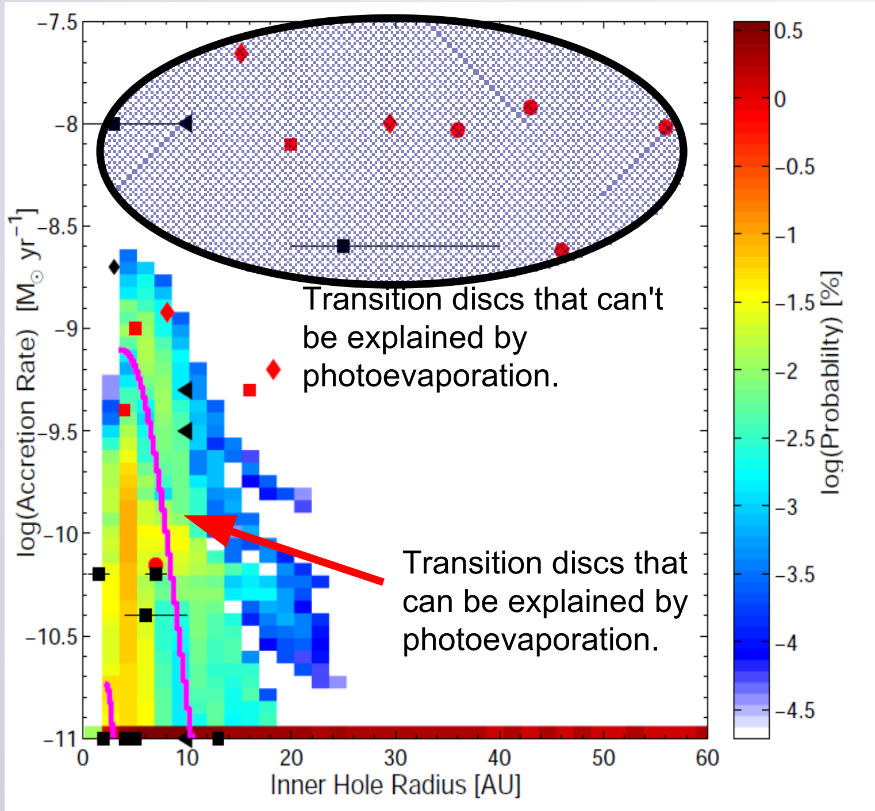
Figure from: Drake et al. (2009)

Transition Discs

Transition discs are discs that show a deficit of emission at NIR wavelengths, i.e. an opacity drop at small radii, which has been interpreted as evidence for an inner hole in the disc. In the X-ray photoevaporation model, transition discs occur when photoevaporation opens a gap in the disc. Once the gap opens, the inner disc begins to drain onto the central star, while the inner edge of the outer disc is eroded to larger and larger radius by photoevaporation. During this draining phase, dust drag clears the inner disc of dust on a time-scale of ~10^3 yr, much shorter that the draining time-scale (Alexander & Armitage, 2007).


Surface density snapshots at 0,75,76,77,...100% of disc's lifetime with median X-ray luminosity

Accreting phase, while inner edge is eroded



Transition discs that can't be explained by photoevaporation.

Transition discs that can be explained by photoevaporation.

Figure showing probability map of transition discs arising from the disc population, lines show tracks of individual models and points show observed T-Tauri 'transistion' discs.

Thus, while the inner disc drains onto the star, producing an accretion signature, the inner disc is optically thin at NIR wavelengths. This gives rise to the deficit in emission that defines a transition disc. Once the inner disc has completely drained on to the star, a centrifugal barrier prevents material from being further accreted from the inner edge of the disc onto the star. Therefore, photoevaporation can account for transition discs with low accretion rates and small inner holes, or large holes and no accretion.

Conclusions

In this work we have used the radiation-hydrodynamic models of X-ray photoevaporating T-Tauri discs by Owen et al. (2010ab) to study the statistical properties of an evolving disc population. We find that using a single set of initial conditions, viscous evolution and X-ray photoevaporation is enough to match the observed disc fractions as a function of time. Furthermore, such a model naturally reproduces the observed spread in accretion rates at late time (i.e. >1 Myr).

We have confirmed the conjecture of Drake et al. (2009) that X-ray photoevaporation can give rise to 'photoevaporation starved accretion' resulting in an observed negative correlation between accretion rate and X-ray luminosity. The model also recovers the well known systematic discrepancy in the X-ray luminosities of WTTs and CTTs, i.e. WTTs are more X-ray luminous than CTTs, simply because stars with higher X-ray luminosities lose their discs first.

Finally, the model is able to account for a large fraction of the observed transition discs with small holes (<20AU) and low accretion rates (<$10^{-8}M_{\odot}$/yr), both with low and high mass discs. These transition disc arise when photoevaporation opens a gap in the disc at high accretion rates and dust drag clears the inner disc of dust on a time-scale much shorter than the draining timescale. However, the model is unable to account for transition discs with very large inner holes (>20AU) and high accretion rate (>$10^{-8}M_{\odot}$/yr), such objects require a different formation mechanism, i.e. planet formation (e.g. Rice et al. 2003)

Further Reading
Owen J, Ercolano B, Clarke, C: 2010 MNRAS (in press) – arXiv: 1010.0826
Ercolano B & Owen J: 2010 MNRAS 406, 1553
Owen J, Ercolano B, Clarke C, Alexander R: 2010 MNRAS 401, 1415
Ercolano B, Clarke C, Drake J: 2009 ApJ 699, 1639
Alexander R: 2008 New Astronomy Reviews