PHOTOEVAPORATION OF PROTOPLANETARY DISCS. Richard Alexander, Cathie Clarke, Jim Pringle, *Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge, CB3 0HA, UK, (rda@ast.cam.ac.uk)*.

We present a new model of protoplanetary disc evolution which combines photoevaporation with viscous evolution of the disc. Our model takes account of direct photoevaporation of the outer disc at late times and successfully reproduces observations across a wide range of wavelengths, from the near-infrared to the millimetre. The model provides a natural mechanism for producing "inner holes" in discs, and we predict that future observations, especially with *Spitzer*, will detect many more such objects.

It is now well established that at an age of $\sim 10^6$yr most stars are surrounded by discs which are optically thick at optical and near-infrared wavelengths (eg. Haisch et al. 2001). Studies at millimetre wavelengths imply that these discs are relatively massive, typically a few percent of a solar mass (eg. Beckwith et al. 1990), and are therefore widely held to be potential sites of planet formation. However by an age of $\sim 10^7$yr most stars no longer possess such massive discs, although low-mass "debris discs" may remain. By which process(es) stars lose their discs remains an open question.

Studies in the infrared and at millimetre wavelengths show a striking lack of objects in states between the disc-bearing (classical T Tauri, henceforth CTT) and disc-less (weak-lined T Tauri, henceforth WTT) states (eg. Kenyon & Hartmann 1995; Hartmann et al. 2005; Andrews & Williams 2005). This suggests that discs are dispersed on a timescale much shorter than the time spent in either the CTT or WTT states, with typical estimates putting the dispersal timescale in the range 10^4–10^5yr (eg. Simon & Prato 1995). Additionally, observations across a wide range of wavelengths demonstrate that the dispersal is essentially simultaneous across the entire disc, covering a radial range of $\sim$ 0.1–100AU (eg. Duvert et al. 2000). Such behaviour, showing two distinct timescales, is inconsistent with conventional models of disc evolution (Hartmann et al. 1998; Armitage et al. 1999), which invariably predict dispersal timescales comparable to the disc lifetime.

Our model is based on the so-called "UV-switch" model of Clarke et al. (2001), which is the only model to date which has successfully reproduced the "two-timescale" behaviour seen in observations of protoplanetary discs. In the UV-switch model photoevaporation by ionizing photons from the central star creates a layer akin to an H II region on the surface of the disc, and at radii beyond a few AU this ionized material is unbound and flows away from the surface of the disc as a wind. Initially this is negligible compared to the disc accretion rate, but at late times the accretion rate becomes comparable to the photoevaporation rate and the inner disc is deprived of resupply. Consequently the inner disc is drained on its viscous timescale, which is much shorter than the disc lifetime, thus satisfying the two-timescale constraint. We have previously demonstrated that it is reasonable to treat the ionizing flux produced by T Tauri stars (TTs) as approximately constant, and in the range $\sim 10^{41}$–10^{43}photon s^{-1} (Alexander et al. 2005). However our new model exploits a flaw in the UV-switch model. Clarke et al. (2001) use the wind prescription of Hollenbach et al. (1994), in which the diffuse (recombination) radiation field dominates the photoevaporation. Consequently their model fails to account for the direct radiation field, and we show that photoevaporation by the direct field dominates once the inner disc has drained.

In order to investigate this process in detail we have constructed hydrodynamic models of this process. We use the model of Clarke et al. (2001) in conjunction with the updated photoevaporation model of Font et al. (2004) to generate initial conditions. Our models evaluate the effects of direct photoevaporation of a disc with an inner hole, by incorporating a simplified radiative transfer scheme into the ZEUS2D hydrodynamics code (Stone & Norman 1992). A snapshot of one of our simulations is shown in Fig.1. We find that the wind due to direct photoevaporation is much more efficient than that due to the diffuse field. Additionally we are able to fit the wind profile well with a simple functional form, which enables us to study the effects of the wind over the entire lifetime of the disc.

Subsequently we have incorporated the wind profile derived from our hydrodynamic simulations into a disc evolution model. Our model shows that direct photoevaporation disperses the outer disc much more rapidly than in the model of Clarke et al. (2001), and is consistent with the entire disc being cleared on a timescale of $\sim 10^5$yr after a disc lifetime of 1–10Myr. We use a simple prescription to model the spectral energy distribution of the evolving disc, and demonstrate that our model is consistent with current observational data (see Fig.2). The disc is cleared "inside-out", and consequently while the disc is being cleared objects show "holes" in the inner parts of their discs. We suggest that our model provides an alternative explanation for objects such as CoKu Tau/4 (Forrest et al. 2004), and predict that such objects should represent approximately 1–10% of the total population of TTs. We suggest that future observations in the mid-infrared and sub-millimetre will provide valuable tests of the model. Mid-infrared observations such as those being made by *Spitzer* should provide a means of detecting many more inner-hole sources than are currently known.

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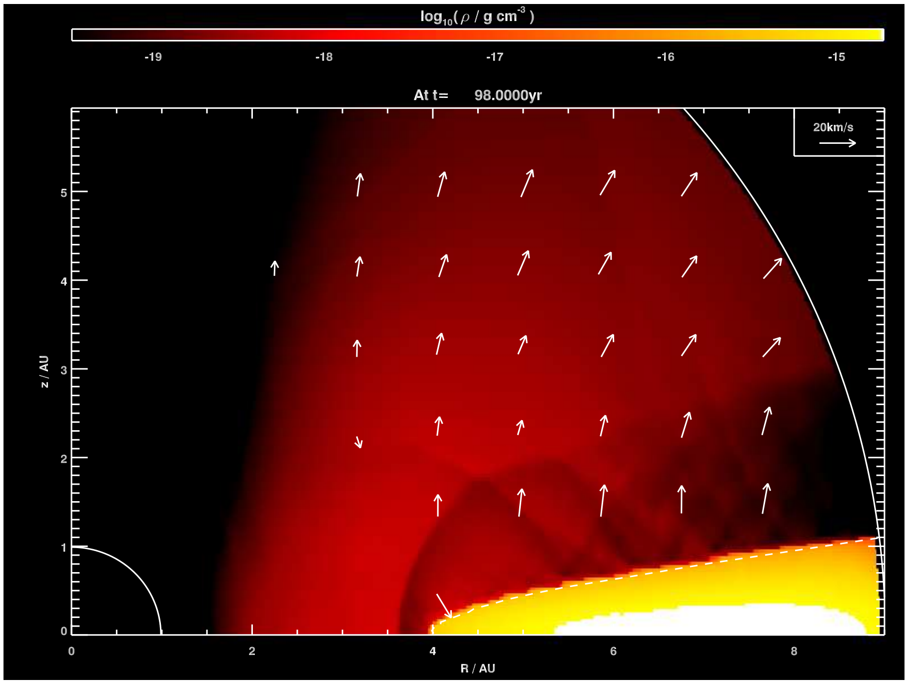

Figure 1: Snapshot of one of our hydrodynamic simulations, showing a photoevaporative wind flowing away from the cold disc. Density is plotted as a colour scale, with the ionization front denoted by a dashed line and the computational boundaries denoted by solid lines. Velocity vectors are plotted at regular intervals, but are omitted when they are either smaller than 0.2 times the length of the reference vector, or when the density is below the minimum of the colour-scale.

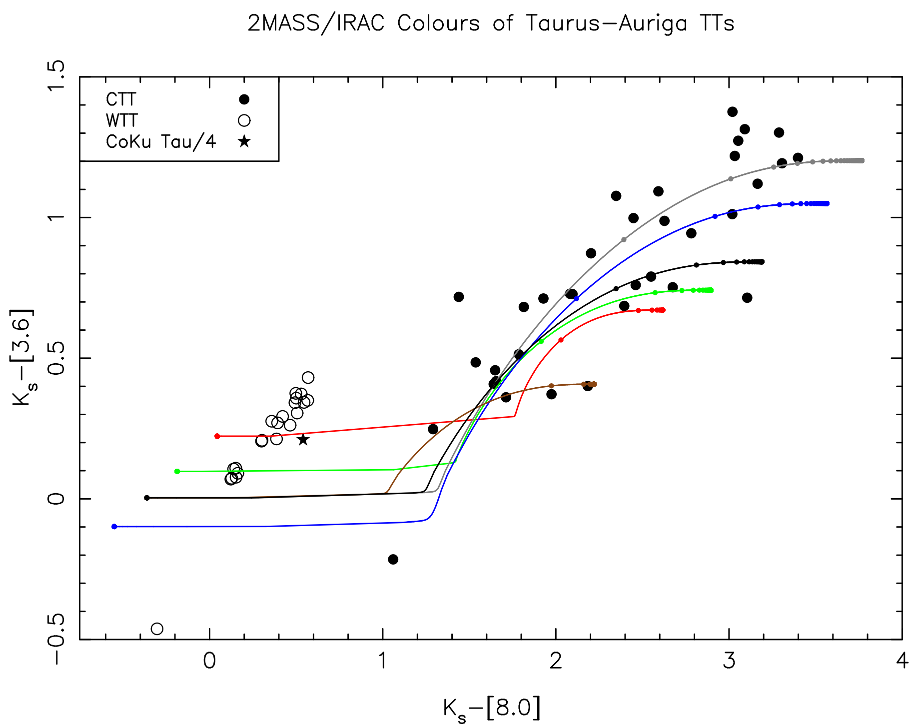

Figure 2: 2MASS/IRAC $K_s - [3.6]$ / $K_s - [8.0]$ plot, with data points from Hartmann et al. (2005). Solid circles represent CTTs and open circles WTTs, with the possible transition object CoKu Tau/4 represented by a star. Evolutionary tracks are plotted for different stellar masses with inclination angle $i = 60°$: $M_* = 0.2$ (red), 0.5 (green), 1.0 (black) and 2.0$M_\odot$ (blue). The grey track is for $M_* = 1.0M_\odot$ with $i = 0$, and the brown track $i = 80°$. Points are added to the tracks every 10^5yr to illustrate the evolution: note the rapid transition between the CTT and WTT states.