Disc Photoevaporation and Dispersal

Richard Alexander, Cathie Clarke & Jim Pringle
IoA, Cambridge, UK

Introduction

Disc evolution is an important area of study as it provides important constraints on theories of both star and planet formation. For low-mass, T Tauri-type stars, disc lifetimes are observed to be in the range $10^6$-$10^7$ years (eg. Haisch et al. 2001). However disc dispersal timescales - the time taken to evolve from a disc-bearing to a disc-less state - are observed to be 1-2 orders of magnitude shorter than the lifetime (eg. Armitage et al. 1999; Duvert et al. 2000). Most models of disc evolution predict dispersal timescales comparable to disc lifetimes, and the observed two-timescale behaviour is difficult to reproduce. Further, this two-timescale behaviour is most clearly observed in low-mass star-forming regions (such as Taurus-Auriga or Chamaeleon) implying that the mechanism responsible is intrinsic to individual sources, rather than an environmental effect.

Disc Photoevaporation

Disc photoevaporation models provide a possible solution. In these models, ionizing photons from the central source create a hot, ionized layer on the surface of the disc. This layer can subsequently photoevaporate the disc. There have been a number of theoretical models proposed for disc photoevaporation, with snapshot models every $2\times10^6$ years. However at late times the accretion rate through the disc falls to a level comparable to the wind mass-loss rate. However at late times the accretion rate through the disc falls to a level comparable to the wind mass-loss rate. At this point the inner disc cannot be resupplied and the disc drains rapidly on a viscous timescale, satisfying the two-timescale constraint.

Driving Photoevaporation

A key requirement of the photoevaporation model is that the central star produce a strong ionizing flux, of order $10^{45}$ photon/s. We have previously considered both the accretion shock and coronal X-rays as potential sources of ionizing photons, but have found that neither can drive the required wind (Alexander et al. 2004a, 2004b). Here we turn our attention to the chromospheres of T Tauri stars (Alexander et al. 2005). In order to estimate the ionizing flux emitted by the chromosphere we have first made use of an emission measure (EM) analysis. We model the chromosphere as an optically thin plasma, using EMs taken from the literature (Brooks & Costa 2003). Using these data and the CHIANTI spectral synthesis code we have estimated ionizing fluxes for 5 T Tauri stars to be in the range $10^{44}$-$10^{45}$ photon/s (see Table 1). These values are somewhat uncertain, due to reddening uncertainties, but are ample to drive the photoevaporation model. However, the model also requires that the ionizing flux persist to late times in the disc evolution. We note that the synthetic spectra from our plasma model reproduce the observed lines well (1200-1900Å), with the exception of the He II 1640Å line.

![Figure 1: Snapshots of the disc surface density distribution from a combined photoevaporation/viscous evolution model, with snapshots plotted every $2\times10^6$ years. Once the accretion rate falls to a level comparable to the disc wind the inner disc is rapidly cleared, satisfying the two-timescale constraint. (Figure adapted from Clarke et al. 2001.)](image1)

![Figure 2: Observed Her II/CIV line ratio plotted against stellar age (ages from Palla & Stahler 2002). The line ratio shows no evidence for decline with time against any evolutionary indicators, implying that the ionizing flux produced does not decrease as the objects evolve. (Figure from Alexander et al. 2005.)](image2)

![Figure 3: As Fig.2, but with the line ratio now plotted against accretion rate (accretion rates from Guibbing et al 1998, plotted so that objects “evolve” to the right). Again, there is no evidence for any decline in the ionizing flux with evolution. (Figure from Alexander et al. 2005.)](image3)

Summary

Photoevaporation of discs, when combined with viscous evolution, can explain the rapid inner disc clearing observed in T Tauri stars. We have shown that the stellar chromosphere can provide the ionizing flux required to drive such models. We are now incorporating this result into disc evolution models.

Table 1: Derived ionizing fluxes from EM analysis of 5 T Tauri stars. The fluxes obtained from our models in two other UV wavebands are included for comparison. (Table from Alexander et al. 2005.)

<table>
<thead>
<tr>
<th>Star</th>
<th>Photon flux in waveband ($10^{45}$ photon/s)</th>
<th>$A_v$</th>
</tr>
</thead>
<tbody>
<tr>
<td>BP Tau</td>
<td>0.68</td>
<td>1.5</td>
</tr>
<tr>
<td>RY Tau</td>
<td>2.1</td>
<td>14</td>
</tr>
<tr>
<td>RU Lup</td>
<td>2.3</td>
<td>16</td>
</tr>
<tr>
<td>GW Ori</td>
<td>13</td>
<td>56</td>
</tr>
<tr>
<td>CV Cha</td>
<td>78</td>
<td>440</td>
</tr>
</tbody>
</table>

References