Simulations of radiatively driven disc winds around MYSOs

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Abstract

A radiation-driven disc wind model is presented in order to explain the mass loss signatures of MYSOs and make predictions for high resolution observations of them. Using 2.5D AMR hydrodynamics, we model the flow of mass from the star and off the surface of an optically and geometrically thick hydrostatic accretion disc. The wind is driven by the radiation pressure from the protostar and a thin disc with a luminosity profile corresponding to an accretion rate of $10^{-3} M_\odot$yr on to a 10 $M_\odot$ star.

The wind is driven from the inner regions of the disc, which are modelled to high resolution ($\leq 1$ AU), with the line driving force taking into account the velocity gradients along sightlines integrated over the surface of the star and the disk. The resultant time averaged flow from the inner disc in these simulations are used as inner boundary conditions for larger hydrodynamical simulations which includes only gravity and radial radiation forces.

We present a range of models, varying the radius and effective temperature of the central massive young stellar object (MYSO) and intend to compare our model results to high resolution radio data on S140 IR5.

Introduction

The long standing question is whether MYSOs form in a similar manner to their lower mass counterparts that are known to form via dusty accretion discs. (Shu et al. 1987, ARA&A 25, 23)

If MYSOs do behave as “scaled up” low mass YSOs then their high luminosities and temperatures, together with the fact that they ionise their surroundings, should lead to a wind being blown off the surface of the accretion disc.

Initial and Boundary Conditions

The initial conditions for the models simulated were of a constant $\alpha$, hydrostatic disc with density and temperature structure determined by irradiation and a mid-plane density of $10^{-5} \, \rho_0$. Angular momentum is represented as an advected scalar. Outside the disc the ambient medium is set up as the steady state solution from a 1D spherical model with the same stellar parameters. We use two sets of simulations to simulate the inner and outer discs of a 10 $M_\odot$ protostar.

Effects of Stellar Size

Figure 3 shows the density and velocities of the model as a function of latitude. We can see that the bulk of the emission (cyan) comes from the region where the rotational and linear velocities are comparable and the density is fairly high, i.e. the disc wind. In the model with a smaller stellar radius this region is much larger than in the larger stellar model.

![Fig 3. The distribution of density (blue), rotational and linear velocity (green-red) and ionised density squared (cyan) as a function of the the polar angle $\theta$ at a radius of 25AU for two models with protostellar radii of 5.5 $R_\odot$ (left) and 16.2 $R_\odot$ (right). The dashed lines indicate regions of the model which are gravitationally bound.](image)

As the protostar moves towards the main sequence it both contracts and heats up whilst maintaining near constant luminosity. There are a number of effects from this on the driving of a wind from the disc. Namely the increase in the star’s $T_{\text{eff}}$ changes the $k$ and $\alpha$ parameters; the effective gravity increases for smaller radii and there is more accretion luminosity for smaller protostars.

Figure 4 shows the mass loss rate of the disc and the mean of the disc radiation flux (within the inner 10R). This shows that the total disc flux and mass loss rate follow similar power law profiles. The mean disc radiation flux goes as $1/R_2^{3.1}$ and the mass loss goes as $1/R_2^{4.6}$. The remaining discrepancy between these two power laws is likely a mixture of the decreasing $k$ and $\alpha$ for the higher temperatures and the fact that for larger radii protostars the mass is being driven from higher up in the stars gravitational well. On the right of the figure the average rotational velocity of the disc wind is shown for various weightings, in general there is little dependence of the rotational velocity as a function of protostellar radius showing that the mass is being driven from similar radii in each of the models.

![Fig 4. Left: The mass flux from the disc (green points blue line) and the average flux from the accretion disc (black points red line). Right: The average rotational velocities of the disc winds for each of the models under different weightings.](image)

The mass fluxes from all the models are $10^5$ higher than would be the case for a spherical wind from these protostars, showing that the presence of a disc can significantly boost the mass loss rate of a young massive protostar.

Further Work

Radiative transfer simulations of free-free radio emission and hydrogen recombination lines of these models will allow us to make predictions for how such a protostar-disc system would be observed using instruments such as the JVLA and e-MERLIN. These can then be compared to observations of candidate disc wind systems such as S140 in order to see if such a model would explain the observations.