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Line-driven ablation of circumstellar disks

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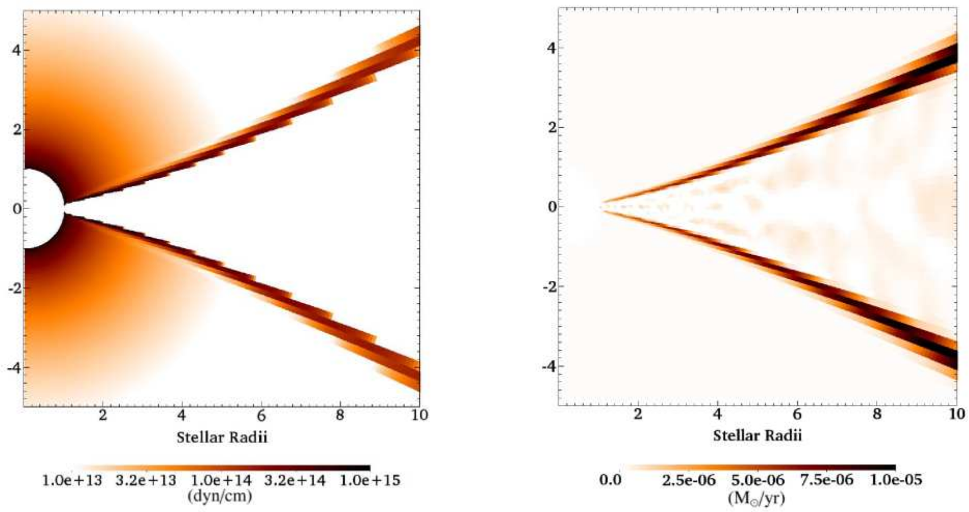
Abstract. Evolved hot, luminous stars are known to drive strong mass loss (10^{-10} to 10^{-5} $M_{\odot}$/yr) through UV line-scattering. High-mass stars already drive such strong winds while still in their accretion epoch. This means stellar line-scattering forces can efficiently ablate material off the surface of a massive protostars disk, and perhaps even shut off the final accretion onto the protostar. By using a fully three-dimensional line-scattering prescription, we quantify this effect, and its potential role in setting the stellar upper mass limit.

Simulations of the formation of individual stars fall into two categories. The first of these is most concerned with how material from the parsec-scale giant molecular clouds proceeds toward the forming star. Due to computational costs, it is currently not feasible to trace the material all the way to the surface of the forming star. This is where the second category takes over, using what has been found on large scales to simulate the final accretion of material from AU length scales onto the star. In turn, such small scale simulations provide information about feedback which may affect large scale dynamics, allowing an iterative process of corrections to be made to both the large and small scale simulations.

Unfortunately, for simulations of high-mass ($M_* \gtrsim 8M_{\odot}$), the latter category of small scale simulations is substantially underdeveloped. In general, the approximation is made that what is known from low-mass star formation will scale to high-mass star formation fairly reliably. While for many types of stellar feedback this may be true, it is not universally true. For instance, the high effective temperature and luminosity of a massive star introduces feedback from the interaction of a UV-photon flux with spectral lines of ionized metal species, a process which simply does not exist in low-mass star formation.

To determine the effect of such a line-driven acceleration on protostellar accretion, we undertake simulations of the circumstellar environment on length scales comparable to the stellar radius. To do so, we use the hydrodynamics code, PLUTO (Mignone et al. 2007, 2012), modified to account for the acceleration from spectral lines by adding a three-dimensional UV line-driving prescription following the Cranmer & Owocki (1995) extension to Castor et al. (1975). This fully three-dimensional line-acceleration is necessary because, as shown by Kee (2015), the interaction of photons with the non-radial Keplerian shear is important in driving material away from the disk.

Consistent with Kee et al. (2016), material in the top and bottom layers of the circumstellar disk is accelerated through the full radius of the simulation, as shown by the time



(a) $\rho g_r r^2$ (b) $d\dot{M}/d\cos(\theta)$

Fig. 1: The radial component of the force per unit length (left) and the mass flux per unit solid angle (right), both averaged over 100 days. The central star in this model has luminosity $L_* = 10^5 L_\odot$, comparable to an O7 main-sequence star.

averaged force-per-unit-length, $\rho g_r r^2$, plotted in panel (a) of figure 1. Panel (b) of figure 1 shows the mass flux distribution per unit solid angle, for an axially symmetric model given by $d\dot{M}/d\cos(\theta) = 2\pi\rho v_r r^2$, showing that the mass flux is dominated by these ablation layers. The combination of the high value of $d\dot{M}/d\cos(\theta)$ in the ablation layers combines with the thinness of these layers to drive a comparable or, in some cases, as much as ten times more mass per year away from the star than is expected from a spherically symmetric wind of a main-sequence star with the same stellar properties. For an accreting star with mass ~ 100 M$_\odot$, this mass loss rate is on the order of several times 10^{-5} M$_\odot$/yr, suggesting that such a star may have its accretion shut off, or at least severely hampered, by line-driven ablation.

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