Line-Driven Ablation of Star Forming Disks

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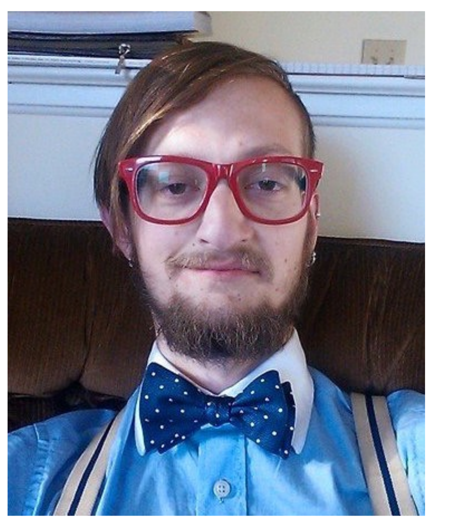


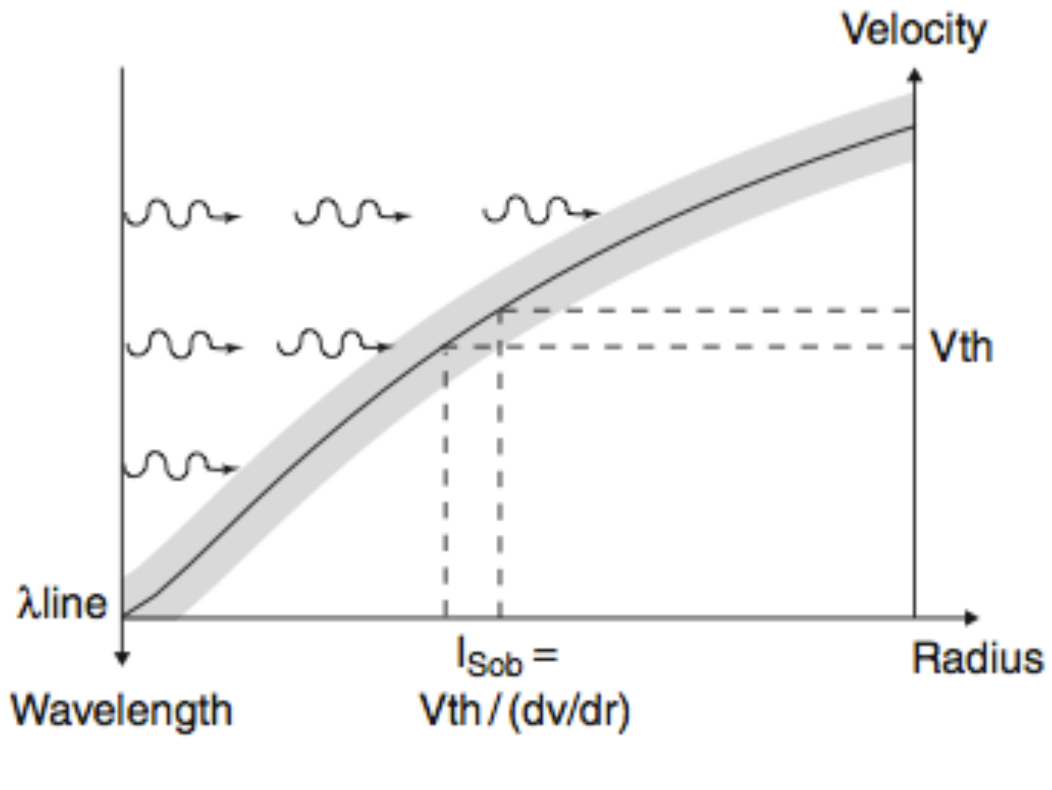
Background

Abstract

Evolved hot, luminous stars are known to drive strong mass loss (10^{-10} - 10^{-4} M⊙/yr) from their surfaces through UV-scattering forces. High-mass stars already drive strong winds while still in their accretion epoch. Therefore, stellar UV-scattering forces will efficiently ablate material off the surface of their circumstellar disks, and perhaps even shut off, the final accretion through the last several stellar radii and onto a massive protostar. By using a fully three-dimensional UV-scattering prescription (Castor, Abbott, and Klein 1975; Cranmer and Owocki 1995), we here quantify the role of radiative ablation in controlling the disk's accretion rate onto a forming massive star.

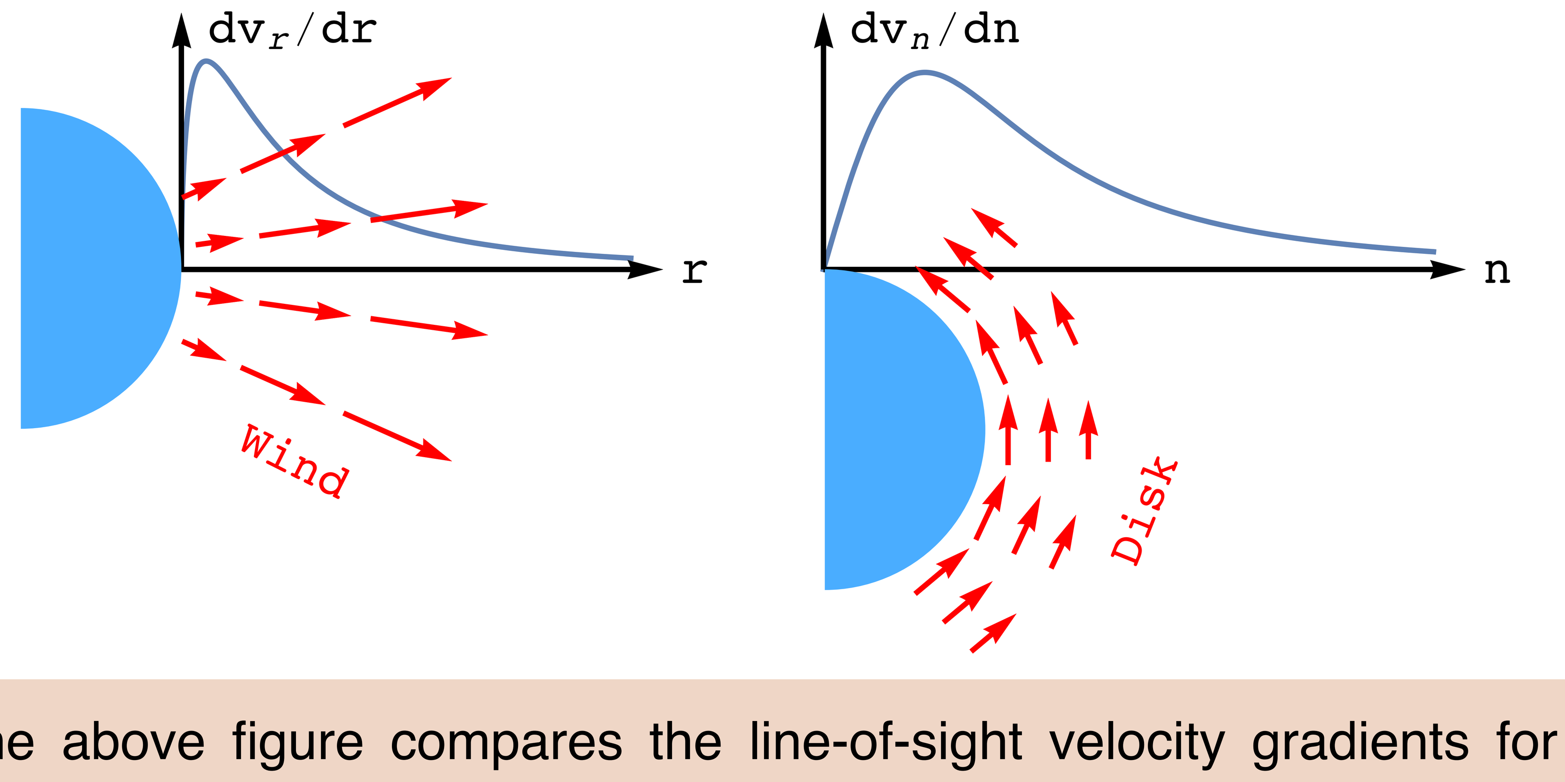
UV Line-Driving

- UV scattering lines have opacities order 1000x continuum electron scattering, but confined to a narrow spectral range.
- To access this high opacity for the force, the line must be Doppler shifted out of its own shadow.
- As shown below, the combination of thermal broadening (grey shading) with a velocity gradient restricts scattering to spatially confined regions.
- Force is proportional to the local value of $\frac{|dv_n/dn|}{\rho}$ for n the line of sight direction



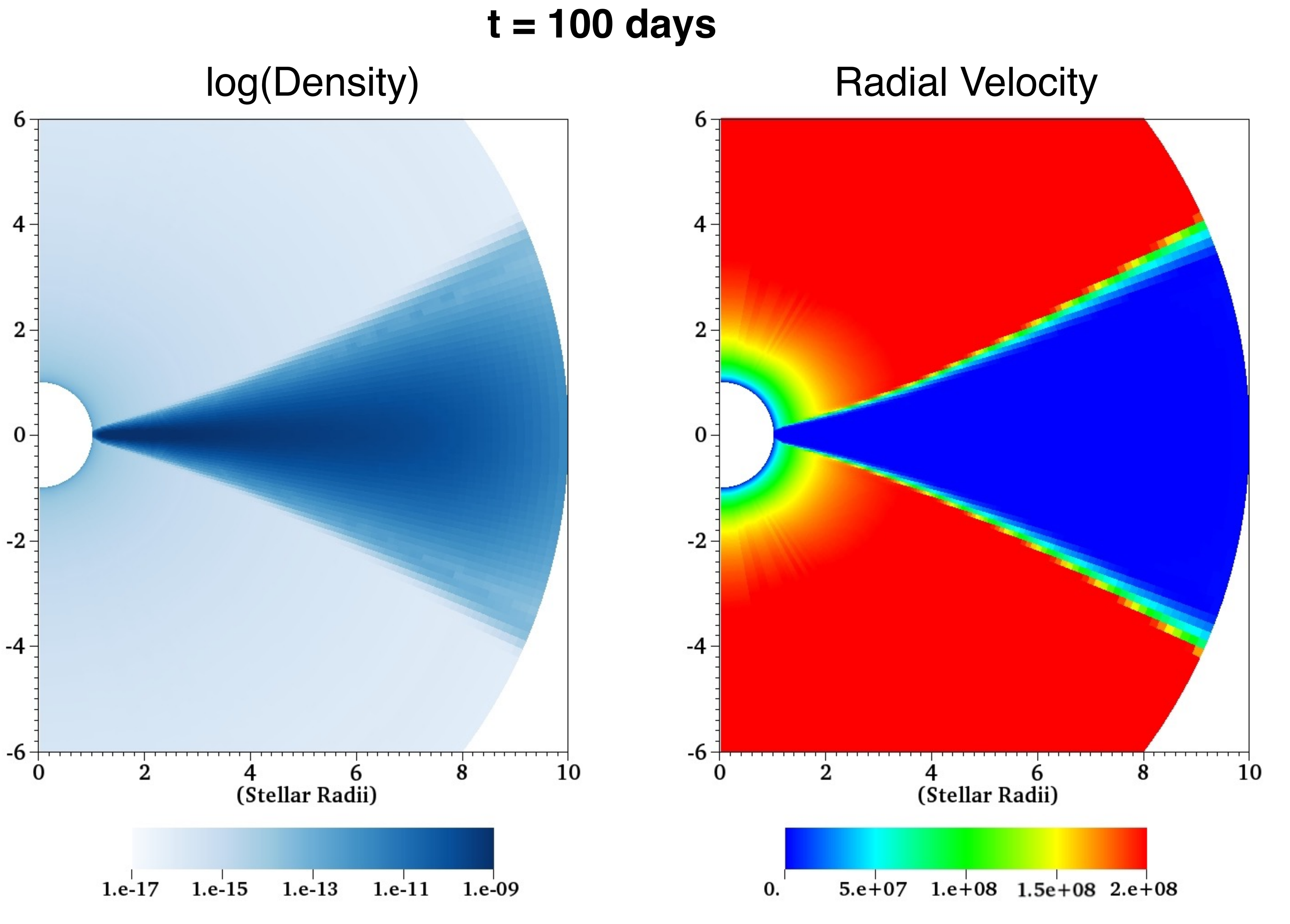
Radial Wind vs Keplerian Disk

- Winds naturally generate a line-force with velocity gradient dv_r/dr in the direction of the wind.
- Keplerian disks also generate a force along non-radial rays where Keplerian shear generates dv_n/dn



The above figure compares the line-of-sight velocity gradients for a slice through the equatorial plane of a wind and a disk. Note that, while the gradients arise along different rays, both their magnitudes and spatial variations are quite similar. Therefore, material within a factor of a few of wind density is expected to be blown outwards by UV line-scattering forces.

Characteristic Hydrodynamic Structure



2D Axisymmetric, Isothermal, Simulation Parameters

Shown above, O7 star: $M_* = 26.5$ M⊙, $R_* = 9.4$ R⊙, $T_{eff} = 36$ kK,

$\dot{M}_{wind} = 1.3 \times 10^{-7}$ M⊙/yr

For each simulation the disk is put into Keplerian orbit and vertical hydrostatic equilibrium with a power-law in density in the equatorial plane. The disk is then superimposed onto a spherically symmetric, line-driven stellar wind. The disk density in the equatorial plane is everywhere at least 10^4 times the wind density at the same radius.

- The asymptotic state (shown above) includes both a narrowing of the contact between disk and star and the removal of material along the disk surfaces in high density, thin sheets with radial velocity approximately half of the wind velocity.
- The disk tends to be removed from near the star first.
- Material is ablated at some enhancement factor, f, times the spherically symmetric mass loss rate. From the simulations, $f \sim 10$.

Analytic Scaling of Line-Driven Ablation

$$\dot{M}_{ablation} = 3.7 \times 10^{-6} \, f \sqrt{\frac{L_6^3}{M_{100}}} \; M_\odot/yr$$

Line-driven wind theory allows us to predict wind mass loss rate as a function of mass, here $M_{100} \equiv M_*/(100 M_\odot)$, and luminosity, here $L_6 \equiv L_*/(10^6 L_\odot)$. By multiplying wind mass loss rate by f determined from simulations, we get the disk ablation rate.

Conclusions

- For an enhancement factor, f, between 10 and 100, the line-driven disk ablation rate for a 100 M⊙ star becomes competitive with, or exceeds, the mass accretion rate.
- This corresponds quite closely to the observed stellar upper mass limit, suggesting ablation may help explain this limit.
- For lower enhancement factors, the tendency of material to be removed from the stellar surface outwards is likely to still impede the accretion of material on to the stellar surface.
- For more information, see Kee et al. 2016 in MNRAS

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