General theory of wind/globule flow interaction

Compare the wind pressure with the PE flow pressure, based on general properties of star and size of globule

Wind momentum rate : $\dot{M} V_w = \eta_w L_* / c$

Ionizing Luminosity : Q_0

We can define a characteristic energy $E_* = \dfrac{L_*}{Q_0}$

E.g. with $\left. \begin{array}{l} L = 10^5 L_\odot \\ Q = 10^{49} s^{-1} \end{array} \right\}$ $E_* = 23.8\ eV = 1.75\ Ryd.$

$$\Rightarrow \quad E_* = 1.75\ Ryd \ \frac{L_5}{Q_{49}}$$

Examples from Table 1 of Henney & Arthur 2019 a

	L_5/Q_{49}	η_w	L_5	Q_{49}	$\eta_w L_5 Q_{49}^{-1/2}$
MS B1.5V	485	0.0066	0.063	0.00013	0.036
MS O9V	3.4	0.1199	0.545	0.16	0.16
MS O5V	1.6	0.4468	2.22	1.41	0.83
BSG B0.7Ia	200	0.3079	3.02	0.016	7.35
WNL WR124	8.1	3.0	5.75	0.71	20.5

So, we have ionization balance in PE flow

$$\alpha_B \, \omega \, r_0 \, n_0^2 = Q_0 / 4\pi R^2$$

$$P_0 \simeq 2 n_0 k T_0 = \frac{2kT}{R} \left[\frac{Q_0}{\alpha_B \, \omega \, r_0 \, 4\pi} \right]^{1/2}$$

Take fiducial values of $Q_0 = 10^{49}\ s^{-1}$

$R = 1\,pc$, $T = 10^4 K$ and put $r_0 = \delta . R$ $\quad \omega = 0.125$

$$n_0 = 932\, Q_{49}^{1/2} R_{pc}^{-3/2} \delta^{-1/2}\ cm^{-3}$$

For M1-67 we have $R_{pc} = 0.25 - 0.75$ and $\delta \simeq 0.01$
so, this would give $n_0 \simeq 3 \times 10^4 Q_{49}^{1/2}$

So, the total pressure (thermal + ram) at base of photoevaporation flow is $\frac{P}{k} \approx 2 \times 2 n T$

$$\frac{P_0}{k} \simeq 4 \times 10^6\ Q_{49}^{1/2} R_{pc}^{-3/2} \delta^{-1/2}\ K\,cm^{-3}$$

Compare with wind ram pressure

$$\frac{P_w}{k} = \frac{\eta_w L_*/c}{4\pi R^2 k} = 7.7 \times 10^5\, \eta_w L_5 R_{pc}^{-2}\ K\,cm^{-3}$$

Taking ratio: $\boxed{\frac{P_w}{P_0} \approx 0.2\, \eta_w L_5 Q_{49}^{-1/2} R_{pc}^{-1/2} \delta^{1/2}}$

So for M1-67 with $R_{pc} \sim 0.25$, $L_5 \sim 6$, $Q_{49} \sim 1$, $\delta \sim 0.01$
we have $\frac{P_w}{P_0} \simeq 0.25\, \eta_w$

So we see that P_w / P_0 is generally < 1, unless $R \ll 1\,pc$ and δ is not too small.

We can also work out β: the wind momentum ratio.

Momentum of PF $= \dot{M}_{PF} V_{PF} = 4\pi r_0^2 n_0 \bar{m} c_s \times M_1 c_s$

$= 4\pi r_0^2 P_0 \left(\frac{3}{2}\right)$

Momentum of SW $= \dot{M}_w V_w = \eta_w L_* / c = 4\pi R^2 P_w$

Therefore $\beta = \frac{\dot{M}_w V_w}{\dot{M}_{PF} V_{PF}} = \frac{2 R^2}{3 r_0^2} \frac{P_w}{P_0} = \frac{2}{3\delta^2} \frac{P_w}{P_0}$

So $\beta = 0.13 \left(\eta_w L_5 Q_{49}^{-1/2}\right) R_{pc}^{-1/2} \delta^{-3/2}$

So this is very similar to $\frac{P_w}{P_0}$ in the case of large globules $(\delta \sim 1)$ but is bigger by a factor of $1/\delta^2$ in the case of small globules $(\delta \ll 1)$.

Observationally, we have a variety of β values, from $\beta < 1$ such as in the California Nebula and in σ Orionis. In both cases, we have $\delta \sim 1$.

Then $\beta \simeq 1$ in Pismis 24, which has $\delta \sim 0.1$.

And $\beta \gg 1$ in Orion proplyds, in M1-67, and in Helix knots, In all these cases we have $\delta \ll 1$.

For cases with $\beta > 1$ it would be best to turn it over and use $\beta_\bullet = \beta^{-1}$ (where $\beta_\bullet$ is pronounced "beta glob")