# RADIATION-ACCELLERATED IONS IN HOT STAR WINDS: HEATING AND "TURBULENCE" EFFECTS

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In the papers by Vilkoviskij (1981), Vilkoviskij and Tambovtzeva (1988) and Springmann and Pauldrach (1992) it was shown that ions can reach velocities $v_i \geq \overline{v}_{Tp}$ ($\overline{v}_{Tp} = (2kT/m_p)^{1/2}$) relative to the wind plasma when the radiation pressure force exceeds the protons frictional force. The condition for this transition can be estimated as

$$v_7 \geq 0.7\dot{M}_6 z_i^2/(R_1^2 T_4 \phi(\lambda_i T_*)) \quad , \tag{1}$$

where $v_7$ is the wind velocity in units of $10^7$ cm/s, $\dot{M}_6 = dM/dt$ the stellar mass-loss rate in units of $10^{-6} M_\odot/\mathrm{yr}$, $z_i$ the ion charge, $R_1 = R_*/(10R_\odot)$, $\phi(\lambda_i T_*) = f_i \lambda_5^{-3}/e^{14.4/(\lambda_5 T_4)-1}$, $\lambda_5 = \lambda_i /10^3$Å and $T_4 = T_e/10^4$K. The ion distribution function consists of two parts: the part $DF_1$ approximates the "shifted Maxwell" distribution, and the non-Maxwellian part $DF_2$ is for "runaway" particles:

$$DF(v_i) = (1 - q_2)DF_{1i} + q_2 DF_{2i} \quad , \tag{2}$$

where $q_2 > 0$ when condition (1) is fulfilled. The specific heat power, divided by $N_p^2$ is

$$H = N_i/N_p^2 \int_0^\infty v_i DF(v_i) F_{ip} dv_i \quad , \tag{3}$$

where $N_i$ and $N_p$ are the ion and proton densities and $F_{ip}$ is the frictional force. If the "runaway condition" (1) is not fulfilled, the mean velocity of ions relative to the wind plasma $\overline{v}_i$ is less then $\overline{v}_{Tp}$, but it rises to about the electron thermal velocity $\overline{v}_{ep} \sim 43\overline{v}_{Tp}$ in the opposite case.
So we can estimate

$$H = H^m(\overline{v}_i/v_{Tp}(1 - q_2) + 43q_2) \quad , \tag{4}$$

where $H^m \cong \pi e^4 z_i^2 N_i (N_p k T_p)^{-1} \ln \Lambda \; v_{Tp} = (N_i)$
which is $\sim 2 \cdot 10^{-22} z_i^2 T_{p4}^{-1/2} (n_i/10^{-4})$ erg cm$^3$/s, where $n_i = N_i/N_p$.
Model calculations show that for the O- and early B-type stars this "kinetic heat" is sufficient for heating of the wind to a temperature $T_e \sim 10^5$ K at $R \geq 2R_*$ and to $T_e \geq 10^6$ K at $R \geq 100R_*$, and the ion's velocity distribution can manifest itself as "turbulence" in spectral lines.

*L. A. Balona et al. (eds.), Pulsation, Rotation and Mass Loss in Early-Type Stars*, 490–491.

So the physical picture including kinetic heat resembles the empirical "warm wind" model, and moreover, it predicts an outer hot corona at $R \geq R_k \sim 100 R_*$. The X-ray luminosity of the corona is $L_x = 4\pi \int_{Rk}^{\infty} \epsilon_X R^2 dR$. With $\dot{M} = 4\pi\rho v r^2$, $\epsilon_X \cong 2 \cdot 10^{-27} N_e^2 T_e^{1/2}$ erg/cm$^3$s, we have

$$L_x \cong 5 \cdot 10^{32} T_{e7}^{1/2} \dot{M}_6^2 / (R_1 v_8^2 (r_k/100)) \ \text{erg/s} \ , \qquad (5)$$

where $R_1$ is the stellar radius in units of $10\, R_\odot$, $r_k = R_k/R_*$, $T_{e7} = T_e/10^7$K and $v_8$ is the wind velocity in units of $10^3$km/s at $R_k$.

We can predict the wide dispersion of X-ray luminosities as due to the dispersion in stellar parameters, and the X-ray variability (with a characteristic time scale of several hours to days) as due to stellar wind variability.

## References

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