WHY THE WINDS FROM LATE-TYPE GIANTS AND SUPERGIANTS ARE COOL

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ABSTRACT We present a model for the coronae of late-type evolved stars where the coronal temperature is regulated by heating from Alfvén waves present in stellar coronal holes. Temperatures predicted from this model are in reasonable agreement with observations.

Keywords: Winds; Coronae; Evolved Stars; Alfvén Waves

INTRODUCTION

Rosner et al. (1991) have proposed that the massive cool \(10^4 \, K < T < 10^5 \, K\) winds from late-type giants and supergiants are driven by the reflection of Alfvén waves in open magnetic fields analogous to those in the solar wind that are rooted in coronal holes. They point out that the reflection can be strong because the “corona” in the open-field regions on these stars is cool \(T < 10^5 \, K\), which makes the Alfvén velocity gradient steep enough for strong reflection. They also note that why these stellar coronae are so cool, i.e., what determines the temperature, remains an open question. Moore et al. (1991) present evidence that the temperature in solar coronal holes is regulated by heating by reflected Alfvén waves. Here we point out that if in the open-field “coronal” holes (from which flow the winds) on giants and supergiants the temperature is regulated by heating by reflected Alfvén waves as in solar coronal holes, then the expected temperature of their winds is of the order of that observed.

THE MODEL AND RESULTS

In the model that we have used to compute the variation of Alfvén velocity with radius in open-field regions of stellar atmospheres, we assume: (1) that, like the solar wind, other stellar winds come from open-field regions, (2) that, like the corona in coronal holes (which are the open-field regions on the Sun), the base of
the wind within a few stellar radii of a star’s surface is roughly both hydrostatic and isothermal, and (3) that, on other stars, as in the first few solar radii in a coronal hole, in most of the volume of the wind base the magnetic field is predominantly radial. We denote the stellar radius and gravity by $R_*$ and $g_*$, respectively, with the subscript * indicating the surface of the star. Alfvén waves of any given wavelength that are emitted up into the wind base (approximately one stellar radius above the surface) from below will be reflected back down by the wind base if the Alfvén velocity profile through the wind base is steep enough; if the profile is not steep enough, the waves will not be appreciably reflected and will pass on up through the wind base and out into the stellar wind.

Variation of Alfvén velocity with radius in our model stellar wind base is plotted in Figure 1. The parameter $\alpha$ is the ratio of the radius to the hydrostatic scale height at the bottom of the wind base: $\alpha = R_*/H_*$, $H_* = kT/mg_*$, $g_* = GM_*/R_*^2$. For any one star, because the mass $M_*$ and radius $R_*$ of the star are fixed, $\alpha$ is inversely proportional to the temperature of the wind base. Because the plasma density varies exponentially with temperature, a small change in temperature (or $\alpha$) makes a big change in the Alfvén-velocity profile, as is seen in Figure 1. Alfvén waves with wavelengths of the order of $R_*$ are strongly reflected by the wind base if $\alpha > 10$, but suffer little reflection and escape out into the wind if $\alpha < 10$ (Rosner et al. 1991). Hence, $\alpha \approx 10$ is the critical range of $\alpha$ in which strong reflection of these Alfvén waves sets in as $\alpha$ increases (as
Figure 2. Predicted wind-base temperatures on giants and supergiants across the X-ray/mass-loss dividing line.

temperature decreases). Because of this effect, it appears that in solar coronal holes, the temperature is regulated by heating by the reflected Alfvén waves so that $\alpha_\odot \approx 10$: $\alpha_\odot = R_\odot / H_{\text{coronal hole}} \approx 10^{10.8}$ cm / $10^{9.8}$ cm = 10 (Moore et al. 1991). On the basis of these results, we adopt as a working hypothesis that, as in solar coronal holes, heating by reflected Alfvén waves regulates the temperature of the base of other stellar winds, including in particular the massive cool winds from late-type giants and supergiants, so that $\alpha = 10$.

In Figure 3, we present the predicted wind-base temperatures on giants and supergiants across the X-ray/mass-loss dividing line. These temperatures were computed from the known values of mass and radius for these stars and our assumption that $\alpha = 10$. The predicted wind-base temperatures are in the range $10^4 - 10^8$ K, of the same order as the observed temperatures of the cool winds. This agreement suggests that the winds from late-type giants and supergiants are cool because the wind-base temperature is regulated by heating by reflected Alfvén waves so that $\alpha = 10$ as in solar coronal holes. That the predicted wind-base temperatures are of the same order on both sides of the dividing line suggests that any (yet to be observed) winds from coronal giants are also cool ($T < 10^8$ K). In Rosner et al. (1991), we proposed that the transition across the dividing line from coronal stars to cool-wind stars results from a transition from predominantly closed to predominantly open magnetic fields on the stars. On the coronal side, most of the star is covered by magnetically closed, hot active
regions, whereas on the cool-wind side most of the star is covered by open-field cool-wind-base regions. Hence, the X-ray emission dies out and the cool winds become dominant from left to right across the dividing line. The dependence of Alfvén-wave reflection on the temperature of the wind-base region as outlined in this present paper and the resulting expected wind-base temperatures shown in Figure 2 offer an explanation for why the winds from the open-field regions on giants and supergiants are so cool. From our previous paper and the present paper together, it appears that both the acceleration of the massive cool stellar winds and the temperature of these winds result from the reflection of Alfvén waves.

REFERENCE