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Observational evidence of proton heating by kinetic Alfvén waves in the solar wind

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The solar wind is a magnetized plasma streaming outward from the Sun. It undergoes nonadiabatic expansion and therefore heating process, with its temperature decreasing more slowly than the adiabatic radial profile.[1,2] The heating has been extensively discussed in past decades, but still not well understood. Two key questions are perhaps what heats the solar wind, and how it heats the solar wind.

We conducted several studies on the solar wind heating problem in the most recent years. The studies were based on more than ten years of in situ measurements by *Wind* spacecraft, and some interesting results were obtained.[3-5] It was found that solar wind proton temperatures are clearly associated with the proton-scale turbulence.[4] A positive power-law correlation arises between proton perpendicular temperature and turbulent magnetic energy density (P_k) at proton scales. Figure 1 shows the correlation at two specific scales, where k being the wavenumber and *rho_p* being the proton gyroradius. This result should support that the proton-scale turbulence is relevant to the proton heating in the solar wind.

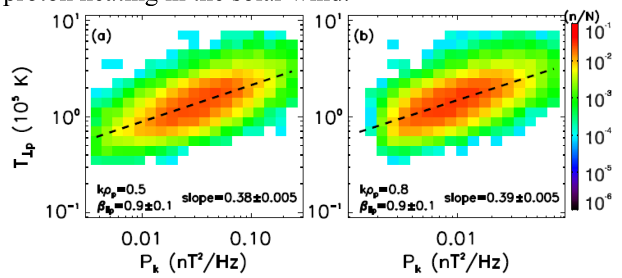

Figure 1. Probability density distributions of magnetic energy density (P_k) and proton perpendicular temperature. The black dashed lines are the linear fitting of the data in logarithmic space.[4]

On the other hand, the presence of the magnetic helicity signature is shown to be very common in solar wind turbulence at proton scales.[5] Magnetic helicity signature appears to be an important indicator in the association; a high magnetic helicity favors the positive correlation between the proton perpendicular temperature and the magnetic energy density. Moreover, the magnetic helicity tends to play roles in regulating magnetic energy spectra and proton temperatures in the solar wind. As helicity magnitude increases, the power index of the energy spectrum becomes more negative, and the proton temperatures (perpendicular and parallel with respect to the background magnetic field) rise significantly, as shown in Figures 2 and 3, respectively.

According to Figure 3, the rise of the perpendicular temperature is faster than the parallel temperature, especially when the plasma beta value is less than 0.3.

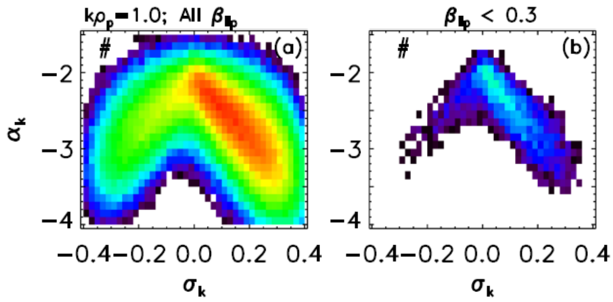

Figure 2. Probability density distributions of magnetic helicity (sigma_k) and power index (alpha_k). It shows that the magnetic energy spectrum steepens as helicity magnitude increases.[5]

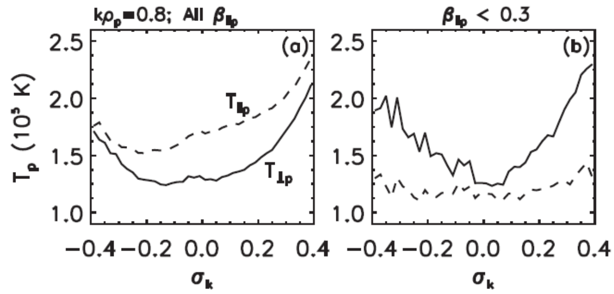

Figure 3. Proton temperatures against magnetic helicity (sigma_k). It shows that proton temperatures rise with helicity magnitude, and the rise of perpendicular temperature is faster than parallel temperature.[5]

Our examination on the nature of the solar wind turbulence at proton scales supports the kinetic Alfvén wave (KAW) model, consistent with previous results. We interpret our findings as evidence of proton heating by the proton-scale KAWs in the solar wind. The heating mechanism could be cyclotron resonance and/or stochastic heating process, which favor the perpendicular heating.

References

[1] P. R. Gazis et al, Geophys. Res. Lett., **9**, 431 (1982)
[2] E. Marsch et al, J. Geophys. Res., **87**, 52 (1982)
[3] G. Q. Zhao et al., Astrophys. J. Lett., **889**, 14 (2020)
[4] G. Q. Zhao et al, Geophys. Res. Lett., **47**, e2020GL089720 (2020)
[5] G. Q. Zhao et al., Astrophys. J., **906**, 123 (2021)