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Collisionless cooling of perpendicular electron temperature in the thermal quench of a magnetized plasma

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A magnetized plasma can undergo a rapid thermal collapse when an energy (and particle) sink is suddenly introduced in the system. In a tokamak, this is known as a thermal quench (TQ) of a major disruption, which releases substantial plasma thermal energy to the wall within one or a few milliseconds and thus represents one of the most critical issues for achieving an economically viable tokamak fusion reactor. One subtlety in a fusion-grade plasma TQ is that the plasma is nearly collisionless with the electron mean-free-path much longer than the magnetic connection length so that the parallel transport can dominate over the perpendicular transport. Such parallel transport leads to the rapid cooling of the parallel electron temperature, which, for a nearly collisionless plasma, is mainly due to the free-streaming loss of the high-energy electrons along the magnetic field [1]. However, due to the lack of collisions, the fast cooling of the perpendicular electron temperature $T_{e\perp}$, is somewhat a mystery. Here, we use the first-principles kinetic simulations and theory to unveil the critical role of self-excited whistler modes in collisionless cooling of $T_{e\perp}$. Here the whistler instability is mainly driven by the trapped electrons with damping effect induced by the cold recycled electrons. We found that the saturation of the whistler modes and the associated temperature isotropization depend strongly on the trapped-passing boundary v_c in the electron distribution, where appreciable $T_{e\perp}$ cooling occurs at $v_c \lesssim v_{th,e}$ with $v_{th,e}$ the electron thermal speed. The residual temperature anisotropy is at nearly the marginality of the whistler instability that is driven by the temperature anisotropy.

[1] Y. Zhang, J. Li and X-Z Tang, cooling flow regime of plasma thermal quench, Europhysics Letters **141**, 54002

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