Critical role of plasma heat flux on Bohm criterion

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The competition between parallel and perpendicular transport sets the width of the scrape-off layer for plasma particle and energy exhaust. Transport along the magnetic field is dominated by parallel streaming, which is a fast process constrained by ambipolarity. This becomes most transparent at the divertor surface, where the non-neutral sheath regulates the exhaust flux in terms of the boundary plasma density, temperature, and flow. The exit flow speed is constrained by the Bohm criterion to a local sound speed, which is set by the plasma temperature. For a warm ion plasma, the highest local parallel sound speed in the literature for Bohm criterion analysis is $c_{s\parallel} \equiv \sqrt{k_B \left(T_{e\parallel} + 3T_{i\parallel}\right)/m_i}$, with $T_{e\parallel}$ and $T_{i\parallel}$ the electron and ion parallel temperature.

Direct kinetic-Maxwell simulations [1] reveal that the plasma exit flow robustly exceeds $c_{s\parallel}$ at the sheath entrance, contradicting a foundational plasma theory prediction. Based on the extended CGL formulation [2], we have performed a new analysis that yields

$$u_{Bohm} \equiv \sqrt{\frac{3k_B \left(T_{i\parallel} + Z\beta T_{e\parallel}\right)}{m_i} - Z\beta \frac{m_e}{m_i} \frac{j^2}{\left(en_e\right)^2}} \tag{1}$$

where j is the net current density to the wall and Z the ion change number. The most important and interesting quantity is the heat flux factor β, which depends on the parallel heat flux [3].

With this new formulation, we are able to explain a wide range of plasma exit flow speeds as functions of plasma collisionality and current into the wall, and resolve a number of observed contradictions between simulations and traditional theory.

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[1] X.Z. Tang & Z. Guo, PoP **22**, 100703 (2015); [2] Z. Guo, X.Z. Tang, & C. McDevitt, PoP **21**, 102512 (2014); [3] X.Z. Tang & Z. Guo, Phys. Plasmas **23**, 120701 (2016);