Up-down symmetry breaking and the density pinch in global tokamak edge simulations

Ben Zhu, Manaure Francisquez, Barrett Rogers

Department of Physics and Astronomy, Dartmouth College
Hanover, NH 03755

March 28, 2018

In global tokamak edge simulations of a shifted-circle magnetic geometry with an in-board limiter [1], the plasma density and temperatures are consistently poloidally asymmetric despite the (nearly) symmetric magnetic geometry and boundary conditions. In particular, in the closed flux region, the ion temperature profile tends to be *up-down* asymmetric (hotter at bottom) while the density exhibits similar asymmetric pattern but with opposite polarity (denser at top). We show that the compressibility (or, curvature) contribution of the ion transverse heat flux breaks the up-down symmetry of the ion temperature profile as predicted by neoclassical theory. The up-down asymmetric ion temperature further impacts other plasma quantities, $E\times B$ flow and turbulence via different physical mechanisms. For instance, the density is driven to be up-down asymmetric in order to satisfy the force balance. Analytical estimates suggest this up-down asymmetry $f_1/f_0 \propto nq^2/(T_i^{3/2}L_{T_i})$; therefore it is profound at the edge region where q is large, ion temperature is relatively low and its gradient is strong [2]. This up-down symmetry breaking mechanism might also provide an explanation of the strongly asymmetric inboard up-shifted edge density observed in recent J-TEXT near density-limit experiment [3] as our prediction indicates the up-down asymmetry is proportional to the local density n.

More strikingly, we find this up-down symmetry breaking introduces a *new* particle pinch mechanism other than the Ware effect [4], thermal-diffusion [5] and turbulence equipartition theory [6]: in our numerical studies a peaked radial equilibrium density profile is formed in the closed field line region even though the particles are sourced only locally near the last-closed flux surface. Once the transverse heat flux term is turned off, the radial density profile flattens in the closed flux region as the plasma density and temperature, as well as the spontaneous $E\times B$ flow and turbulence become up-down symmetric. These very new results suggest that a robust density pinch is produced in our 3D global edge model and is most likely caused by physics associated with the poloidal up-down symmetry breaking [7].

[1] B. Zhu, M. Francisquez and B. Rogers, *Phys. Plasmas* **24**, 055903 (2017)
[2] B. Zhu, M. Francisquez and B. Rogers, submitted to *Nuclear Fusion*
[3] P. Shi et.al., *Nucl. Fusion* **57**, 116052 (2017)
[4] A. Ware, *Phys. Rev. Lett.* **25**, 15 (1970)
[5] B. Coppi and C. Spight, *Phys. Rev. Lett.* **41**, 551 (1978)
[6] M. B. Isichenko, A. V. Gruzinov and P. H. Diamond, *Phys. Rev. Lett.* **74**, 4436 (1995)
[7] B. Zhu, M. Francisquez and B. Rogers, in preparation