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Spontaneous large scale momentum exchange by microinstabilities: an analogy between tokamaks and space plasmas

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Based on a recent theory (Coppi, Nuclear Fusion, 42, 1, 2002) of spontaneous toroidal rotation in tokamaks (Lee et al, Phys Rev Lett, 91, 205003, 2003) and in astrophysical accretion disks, we propose that an analogous process could be at play also in the Earth space environment.

The understanding of the interplay between microinstabilities and macroscopic system- scale processes poses a formidable challenge to current plasma physics research. The present paper attempts to attract the attention of the plasma physics research community to a possi- ble analogy between space plasmas and tokamaks in the hope that a fruitful interdisciplinary exchange can lead to a new a deeper understanding. Among the small scale kinetic processes, the drift instabilities driven by density gradients have attracted considerable attention [1]. It has long been known that the small scale electric field and magnetic field fluctuations induced by such waves can act as an effective collision

by altering the momentum of plasma particles in a manner analogous to regular classical collisions [2]. Such processes have been termed anomalous in the sense that when modeled within the framework of classical transport or fluid frameworks appear to lead to a much higher collisionality than is actually present [3]. But such an approach focuses on the small scale momentum exchanges and sees the microinstabilities as acting in a localized fashion akin to collisions. Instead, a number of recent findings suggest that drift instabilities can act to alter momentum on a global macroscopic scale. Recent tokamak research has incurred in a new crucial experimental finding: the sponta- neous creation of toroidal rotation. In a number of experiments (including Alcator C-Mod, DIII-D, TCV, Tore-Supra, JET, TFTR, COMPASS) the plasma has been observed to ac- quire a toroidal rotation profile spontaneously in shots where no external input of toroidal momentum was imposed (see ref. [4-6] and references therein). Researchers at Alcator C- Mod have investigated the issue in depth [4, 7, 8]. We refer the reader to their work for details and we limit the present discussion to highlight the findings most relevant to the present work. First, the generation of toroidal rotation is spontaneous and no external in- jection of angular momentum could be identified. Second, the source of angular momentum appears to be located in the edge zone where angular momentum is observed to form first. Later during the shot, toroidal angular momentum is transported inward at a pace faster than predicted by neoclassical diffusivity. To explain the observed spontaneous angular rotation in tokamaks, a number of possi- bilities have been proposed. We refer the reader again to the existing literature from the Alcator C-Mod team for a discussion of all possibilities [8] and we limit the scope here to the particularly promising theoretical model proposed by Coppi [9]. Coppi noted an intriguing analogy between the spontaneous rotation observed in tokamak experiments and angular momentum exchange in accretion disks in astrophysical systems (such as forming stars or accreting black holes). The same core mechanism is at play in both systems: the exchange of angular momentum from the action of microscopic drift instabilities caused by the pres- ence of pressure gradients. When applied to tokamak plasmas, Coppi's model identifies the source of angular momentum at the edge of the plasma column where fluctuations due to edge-localized pressure-driven modes scatter particles out of confinement and transfer angu- lar momentum to the wall, thereby producing a net momentum in the plasma by reaction. The momentum created at the plasma edge is then transported inward and leads to the observed profiles of toroidal angular velocity measured in Alcator C-Mod. In the present work we revisit the model proposed by Coppi and extend the analogy to a different class of plasmas: the space plasmas present in the near Earth environment. The usefulness of this analogy is that space plasmas are amenable to direct satellite observation of small scale processes and a wealth of data is available from past, current and planned missions.

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