Quasi-two dimensionality and the Magnetic Taylor-Proudman constraint in Rotating Magneto-Convection

A. Pothérat*, R. Agrawal† and K. Aujogue*

Convection is the beating heart of planets such as the Earth: the rate at which the planet cools, spins-down and the dynamics of its magnetic field are all controlled by the complex interplay between buoyancy, the Coriolis force due to planetary rotation and the Lorentz force in the liquid region of the planet. Yet the combination of these three forces and the extreme regimes in which they operate makes the resulting rotating turbulent magneto-convection particularly arduous to elucidate. The main effect of rotation is to oppose fluid motion across an imaginary surface in the shape of a so-called *Tangent Cylinder* (TC) extruded from the equatorial perimeter of the solid inner core along the rotation direction, and up to the boundary between the liquid core and the mantle[1]. Magnetic fields on their own are expected to have a similar effect [2]. Recent work suggests that intense flow within this region may participate in the planetary dynamo that sustains the Earth's magnetic field[3]. Yet, the mechanisms driving the flow within this region, especially how convection develops under the combined action of rotation and magnetic field, are yet to be understood.

We show that under the simplified assumption of quasi-static magnetohydrodynamics, where the magnetic field is imposed, the classical Taylor-Proudman theory can be extended into a new constraint that applies to the combined current density of both mass and charge. The new *Magnetic Taylor-Proudman constraint* appears as a particular case of a much more general property applicable to the wider class of quasi-2D flows. In the case of magneto-rotating convection, this constraint translates into a kinematic equation linking the radial and the azimuthal components of the flow at the TC boundaries. This adds to the previous suggestion that a radial flow may exist across the Earth's TC [4]

The theory is tested on the *Little Earth Experiment*(LEE[5,6]), an original device where rotation, magnetic field and buoyancy can be controlled, and where rotating magnetoconvective patterns are visualised for the first time. The principle of the experiment is to model the liquid core with a vessel representing the core-mantle boundary, with a cylindrical heating element placed at its centre modelling the solid inner core and the buoyancy it creates. The vessel is filled with a transparent electrolyte, driven in rotation and placed inside a large magnet imitating the feedback of the Earth's magnetic field on the flow. Particle Image Velocimetry and thermistors provide us with velocity maps and local temperature measurements. We operate LEE in regimes where the flow inside the TC is either 3D or quasi-2D, and show that the time- and azimuthally- averaged radial flow near the TC boundary indeed follows the prediction

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*Centre for Fluid and Complex Systems, Coventry University, Mile lane Coventry, CV1 2NL, UK
†University of Liverpool

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