Rotating turbulence: 2D or not 2D?

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Résumé

Rotation, a primary driver of geophysical or astrophysical systems, profoundly alters a three-dimensional fluid: rotation produces 3D inertial waves, while also sustaining emergent two-dimensional structures and favoring domain-scale flows.
This interplay raises a fundamental question: why and when are 2D flows sustained even when only 3D waves are excited?
Using extensive numerical simulations of the rotating 3D Navier–Stokes equations together with a quasi-linear wave–kinetic theory, I will show that near-resonant interactions between 3D waves and a large-scale 2D flow impose an additional conservation law:
inertial waves must conserve their helicity separately for each helicity sign. This hidden sign-definite invariant constrains the waves to transfer their energy to large-scale 2D motions.
However, as rotation increases, resonance conditions become more restrictive and the energy transfer from 3D to 2D progressively vanishes, leading to a transition from 2D-dominated turbulence to 3D wave turbulence.
I will present an analytical framework capturing the 3D–2D energy transfer as a function of rotation, Reynolds number and domain geometry, which agrees well with numerical simulations.
Together, these results suggest a nonlinear mechanism underlying spontaneous two-dimensionalization in rotating turbulence, and, more broadly, illustrate how non-linear systems sustaining waves can self-organize into anisotropic, zero-frequency structures – a phenomenon present in planetary flows, stratified turbulence or chiral fluids.

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