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Reversed-field pinch pursuit of magnetic order exploiting helical states with transport barriers

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Self-organized helical states are a ubiquitous feature in astrophysical and in current carrying hot magnetic-fusion plasmas. In the latter, self-organized helical states are observed *locally* in the core of the tokamak - associated with strong 3D magnetohydrodynamics activity - and *globally* in reversed-field pinch (RFP) plasmas. In the RFP, helical states spontaneously develop from a dominant resistive-kink/tearing mode, creating a hot central region bounded by transport barriers.

In this contribution, we first report a milestone in magnetohydrodynamics modeling of hot RFP plasmas [1, 2] and experimental observation of helical states, namely, we show that experiments in RFX-mod confirm the nonlinear fluid modelling prediction of previously unobserved self-organized helical states. The key element is the use of a small edge magnetic perturbation [3, 4], with a helical periodicity different from the spontaneous dominant one observed in standard discharges, which can impose its helical pitch to the whole plasma column.

As a second result, we find a higher magnetic order in numerical simulations where magnetic perturbations are applied with a non-resonant helical twist. In such new states we observe a broader zone where magnetic field lines lie on conserved magnetic surfaces and a reduction of magnetic field-lines transport with respect to standard regimes. Interestingly and counterintuitively, such new global helical regimes are obtained when exploiting non-resonant Resistive Wall Modes, usually deemed dangerous for plasma discharges. First examples of experimental confirmation of such dynamical and topological results are described.

As a third result, we introduce a novel technique for the computation of Lagrangian Coherent Structures which reveals structures hidden in the stochastic region surrounding the KAM tori [5, 6]. Such structures are interpreted as Cantori sets, which represent a barrier to magnetic field lines transport. We will also introduce preliminary results from the numerical solution of the time-dependent, anisotropic temperature transport equation [7] applied to such new helical regimes coming from the MHD simulation codes.

The novel possibility of changing the global helical twist of the plasma column, and therefore its safety factor, open new opportunities to deepen the theoretical interpretation of transport barrier formation and sustainment in hot-magnetic fusion plasma devices, including tokamaks and stellarators.

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