Abstract Submitted
for the DPP19 Meeting of
The American Physical Society

Why a fractal current distribution is a lowest-energy state[1] PAUL BELLAN, Caltech — Because ideal MHD is flux-conserving and has no intrinsic scale, pinching, kinks, and sausage instabilities occur at all scales. However, when the scale shrinks to the ion skin depth, Hall and electron inertia terms come into play, ideal MHD fails, and radically different physics occurs (e.g., fast reconnection). Flux-conserving magnetic energy scales inversely with inductance. Thus, it is energetically favorable for current to be diffuse rather than in a thin layer because a diffuse current has more inductance than a thin current. Since flux conservation precludes current spreading in an axisymmetric plasma, a sequence of non-axisymmetric instabilities of progressively smaller scale must develop to achieve minimum system energy. This sequence causes the current to be distributed like insulated strands of a wire rope where the smallest strand has radius of the order of the ion skin depth. The current distribution is then fractal because a current rope at any specific scale is both (i) an insulated strand of some larger-scale rope and (ii) composed of insulated strands of smaller-scale ropes. This is analogous to Litz wire, a commercial product made of braided insulated fine wires resulting in less inductance than a corresponding solid wire.

[1]Supported by DOE, NSF, and AFOSR

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Date submitted: 29 Jun 2019 Electronic form version 1.4