Statistical mechanics of puffs and slugs in the transition to turbulence in pipes

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In recent years, careful experiments in pipes have revealed that the lifetime of transient turbulent regions in a fluid appears to diverge with flow velocity just before the onset of turbulence, faster than any power law or exponential function. I show how this superexponential scaling of the turbulent lifetime in pipe flow is related to extreme value statistics [1], which I show is a manifestation of a mapping between transitional turbulence and the statistical mechanics model of directed percolation [2]. This mapping itself arises from a further surprising and remarkable connection: puffs in a pipe behave as a stochastic predator-prey ecosystem [3,4], building on seminal ideas first proposed by P. Diamond and collaborators in the context of the LH transition in tokomaks. Such ecosystems are governed by individual fluctuations in the population and being naturally quantized, are solvable by path integral techniques from field theory leading to the prediction of directed percolation scaling for the laminar-turbulent transition. I review recent unpublished experiments confirming this prediction, and extend the ecological model to include streamwise shear interactions so that the growth of slugs can also be described [5]. The resulting stochastic theory predicts the emergence of slugs, the weak-strong slug transition, and captures the energy budget of transitional pipe flow that has previously been measured in DNS.

This work was performed in collaboration with Hong-Yan Shih (Academia Sinica Institute of Physics, Taiwan) and Xueying Wang (University of Illinois at Urbana-Champaign).

This work was supported by a grant from the Simons Foundation (Grant number 662985, NG) and from the Ministry of Science and Technology, Taiwan (Grant number MOST 109-2112-M-001-017-MY3).

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