

Intermittent onset of turbulence and control of extreme events

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Outline

- 1 Motivation
- 2 Some theoretical results for a simple map
- 3 UDV and on-off intermittency
- 4 The nonlinear Schrödinger equation - NLSE
- 5 Results
 - General dynamics of the NLSE
 - Intermittency
 - Control of extreme events
- 6 Conclusions
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Motivation



Can we develop a general theory of the dynamics of turbulent flows and the motion of granular materials?

So far, such “nonequilibrium systems” defy the tool kit of statistical mechanics, and the failure leaves a gaping hole in physics.

Will mathematicians unleash the power of the Navier-Stokes equations?

First written down in the 1840s, the equations hold the keys to understanding both smooth and turbulent flow. To harness them, though, theorists must find out exactly when they work and under what conditions they break down.

So much more to know... *Science* 309, 5731 (2005), 78–102

Plasma Bursts

PHYSICS OF PLASMAS 18, 066501 (2011)

Convective transport by intermittent blob-filaments: Comparison of theory and experiment

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A blob-filament (or simply "blob") is a magnetic-field-aligned plasma structure which is considerably denser than the surrounding background plasma and highly localized in the directions perpendicular to the equilibrium magnetic field \mathbf{B} . In experiments and simulations, these intermittent structures often form near the magnetic axis between open and closed flux tubes, and seem to arise from any form of saturation process for the diamagnetic effect instabilities and turbulence. Blobs become charge polarized under the action of an external force which causes unequal drifts on ions and electrons; the resulting polarization-induced $E \times B$ drift moves the blobs radially outwards across the scrape-off-layer (SOL). Since confined plasmas generally are subject to radial or outwards expansion forces (e.g., curvature and VB forces in toroidal plasmas), blob transport is a general phenomenon occurring in nearly all plasmas. This paper reviews the relationship between the experimental and theoretical results of blob formation, dynamics and transport and assesses the degree to which blob theory and simulations can be compared and validated against experiments. © 2011 American Institute of Physics. [doi:10.1063/1.3594609]

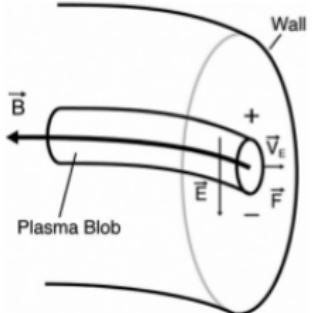
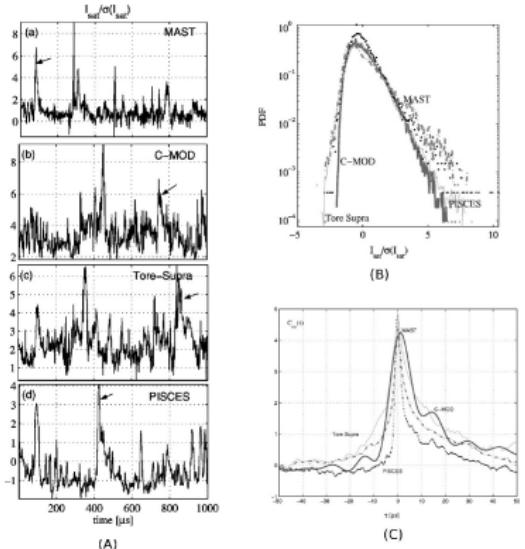


FIG. 1. Sketch of a plasma blob showing the charge polarization mechanism responsible for the radial transport.



Antar, G. Y., Counsell, G., Yu, Y., Labombard, B., Devynck, P. Universality of intermittent convective transport in the scrape-off layer of magnetically confined devices. *Physics of Plasmas* 10, 2 (2003), 419?

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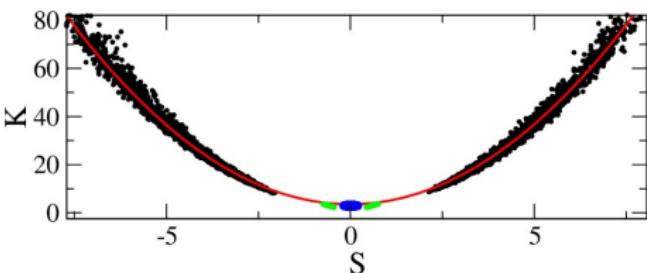
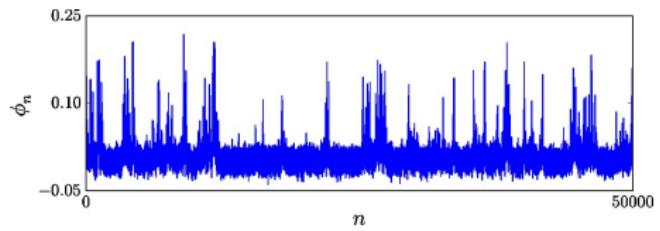
Some theoretical results for a simple map

$$x_{n+1} = (1 - \epsilon)rx_n(1 - x_n) + \epsilon\mathcal{W}$$

$$\phi_{n+1} = \frac{1}{2\pi}px_n \sin(2\pi\phi_n)$$

$$S(x) = \langle x^3 \rangle / \langle x^2 \rangle^{3/2}$$

$$K(x) = \langle x^4 \rangle / \langle x^2 \rangle^2$$

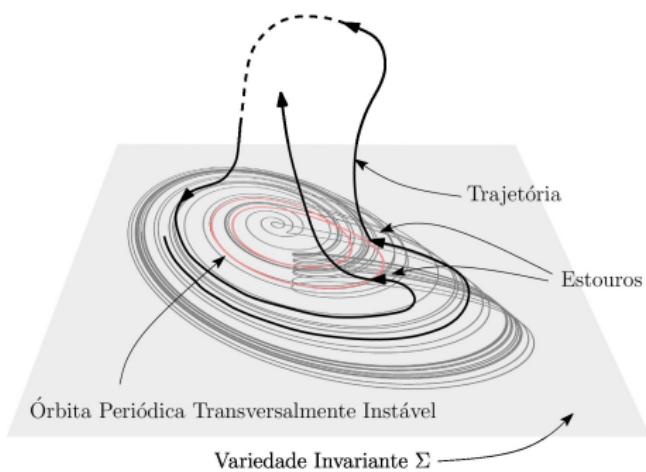


Galuzio, P., Lopes, S., dos Santos Lima, G., Viana, R., Benkadda, M. Evidence of determinism for intermittent convective transport in turbulence processes.
Physica A: Statistical Mechanics and its Applications 402, 0 (2014), 8 – 13.?

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UDV and *on-off* intermittency



Time distribution of the laminar states (the time between two ejection events):

$$P(\tau) \sim \begin{cases} \tau^\nu & \tau \text{ pequeno;} \\ e^{\gamma\tau} & \tau \text{ grande.} \end{cases} \quad (1)$$

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The nonlinear Schrödinger equation

$$i\Psi_t - \Psi_{xx} - g|\Psi|^2\Psi = 0 \quad (2)$$

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- Periodic boundary conditions: $\Psi(x, t) = \Psi(x + L, t)$
- External energy source \rightarrow periodic forcing $\epsilon e^{-i\Omega^2 t}$;
- linear damping term γ .

$$i\Psi_t - \Psi_{xx} - g|\Psi|^2\Psi = \epsilon e^{-i\Omega^2 t} - i\gamma\Psi. \quad (3)$$

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$$i\Psi_t - \Psi_{xx} - g|\Psi|^2\Psi = \epsilon e^{-i\Omega^2 t} - i\gamma\Psi. \quad (3)$$

Variable changing : $\psi(x, t) = \Psi(x, t)e^{i\Omega^2 t}$

$$i\psi_t - \psi_{xx} - (g|\psi|^2 - \Omega^2)\psi = \epsilon - i\gamma\psi. \quad (4)$$

The Schrödinger nonlinear equation

Mass

$$M = \frac{1}{L} \int_{-\frac{L}{2}}^{\frac{L}{2}} |\psi|^2 dx, \quad (5)$$

Energy

$$E = \frac{1}{L} \int_{-\frac{L}{2}}^{\frac{L}{2}} \left(-\left| \frac{\partial \psi}{\partial x} \right|^2 + \frac{g}{2} |\psi|^4 - \Omega^2 |\psi|^2 \right) dx, \quad (6)$$

Hamiltonian

$$H = \frac{1}{L} \int_{-\frac{L}{2}}^{\frac{L}{2}} \left(\left| \frac{\partial \psi}{\partial x} \right|^2 - \frac{g}{2} |\psi|^4 + \Omega^2 |\psi|^2 - \epsilon(\psi + \psi^*) \right) dx, \quad (7)$$

The Schrödinger nonlinear equation

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Energy

Integral of the motion when $\epsilon = \gamma = 0$

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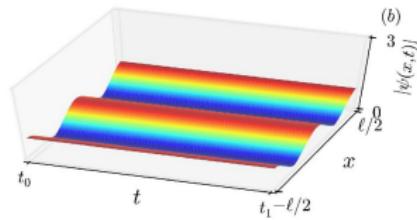
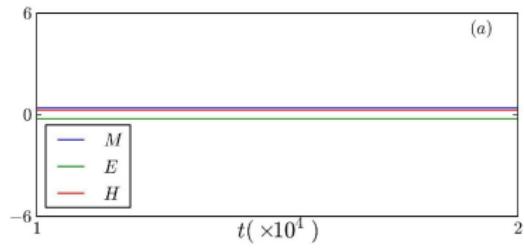
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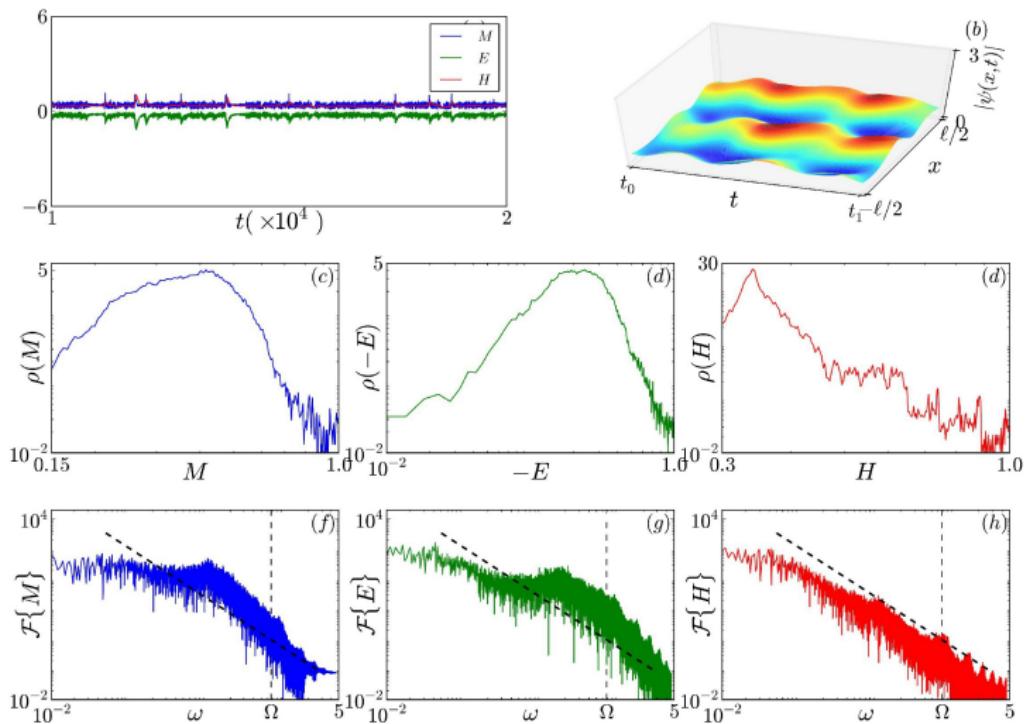
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General dynamics



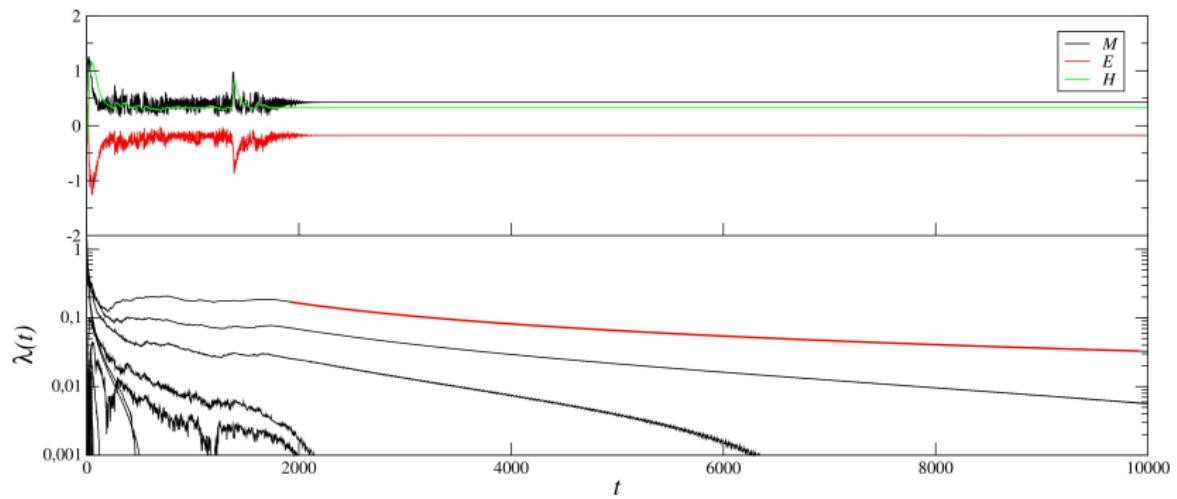
$$\epsilon = 0.10$$

General dynamics



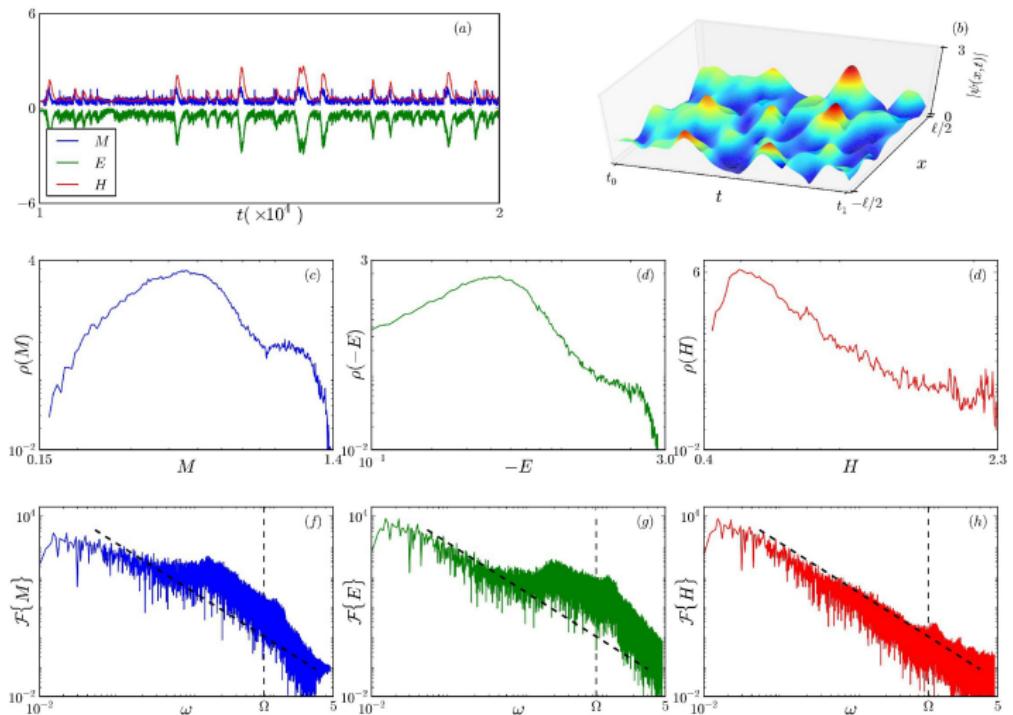
$$\epsilon = 0.21$$

General dynamics



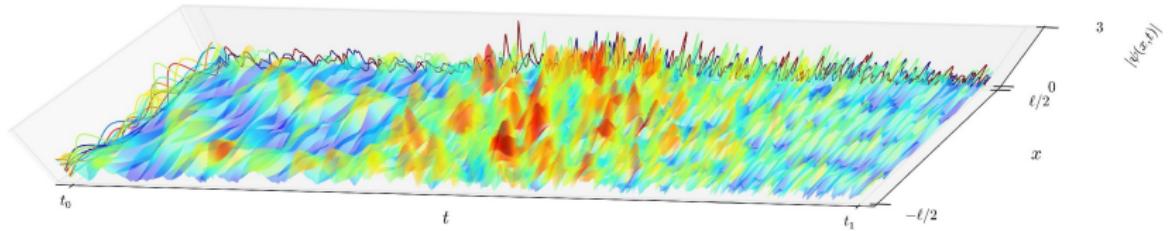
$$\epsilon = 0.20$$

General dynamics



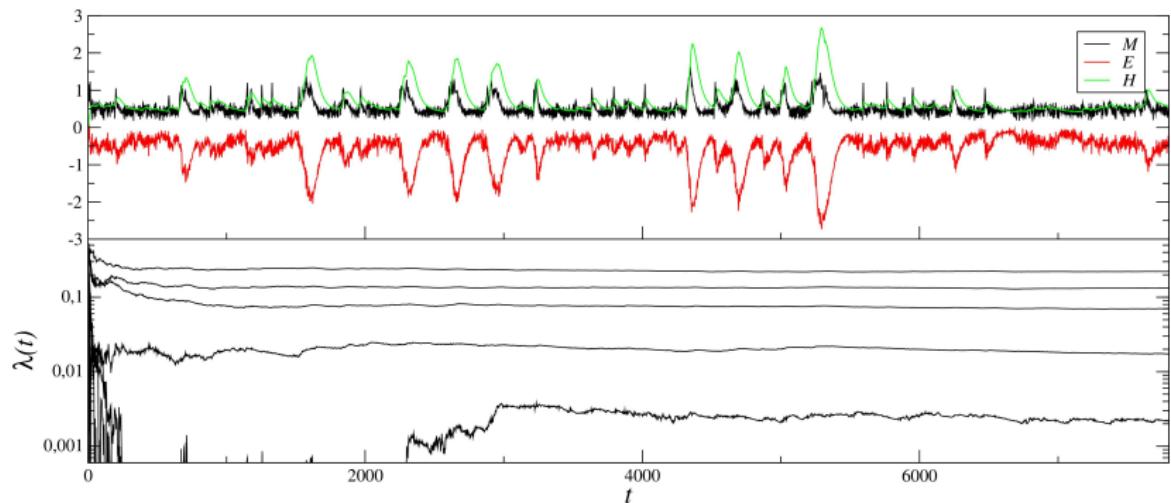
$$\epsilon = 0.30$$

General dynamics



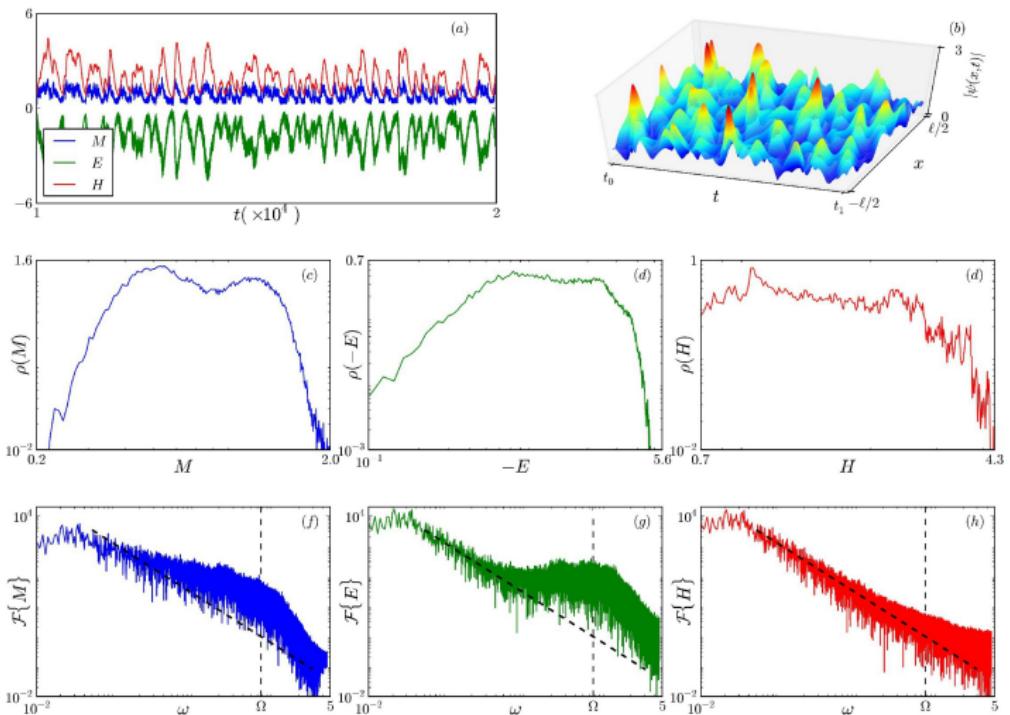
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General dynamics



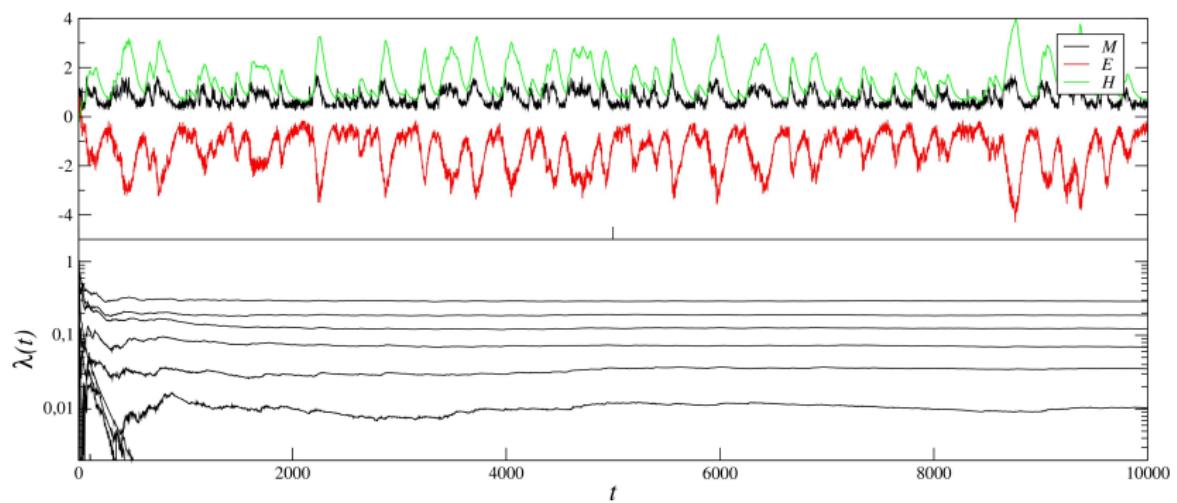
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General dynamics



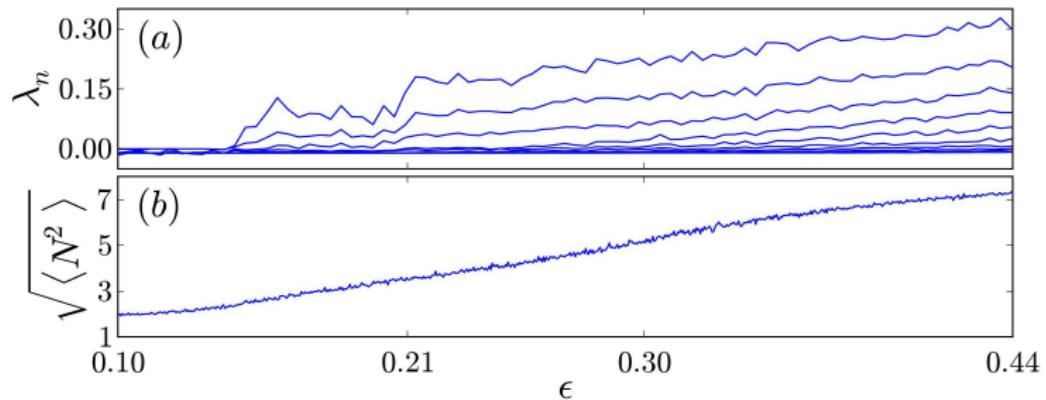
$$\epsilon = 0.44$$

General dynamics



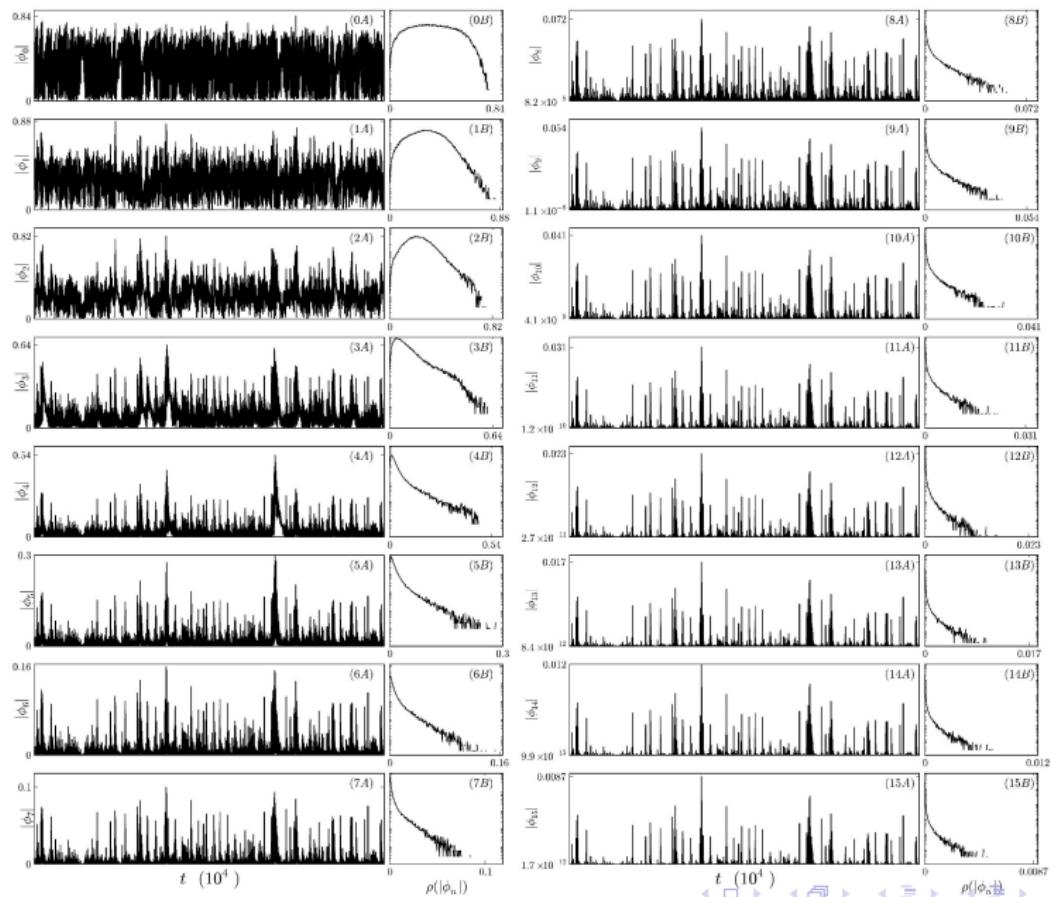
$$\epsilon = 0.40$$

Lyapunov exponents

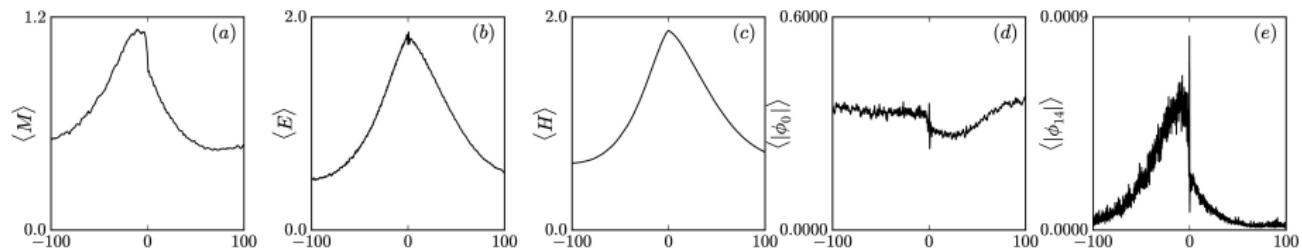


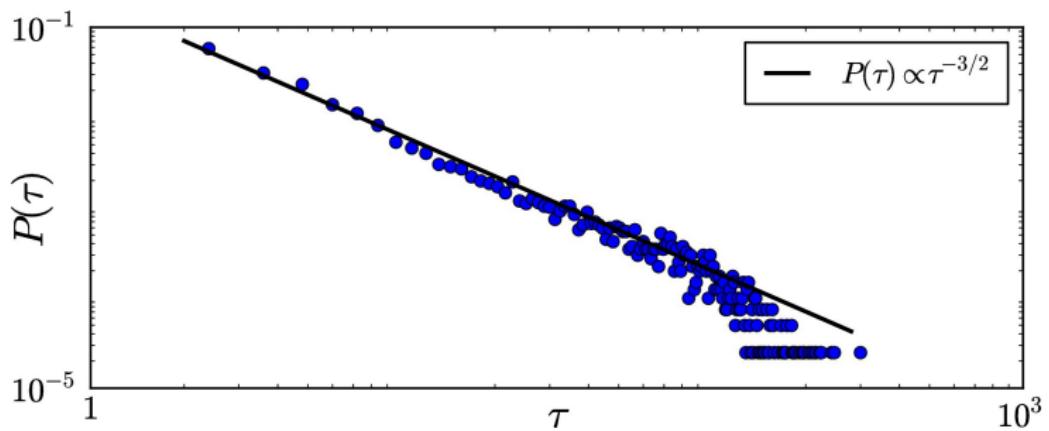
$$\sqrt{\langle N^2 \rangle} = \sqrt{\frac{\sum_{n=0}^{N/2} (n+1)^2 |\phi_n|^2}{\sum_{n=0}^{N/2} |\phi_n|^2}} \quad (8)$$

Intermittency $\epsilon = 0.3$

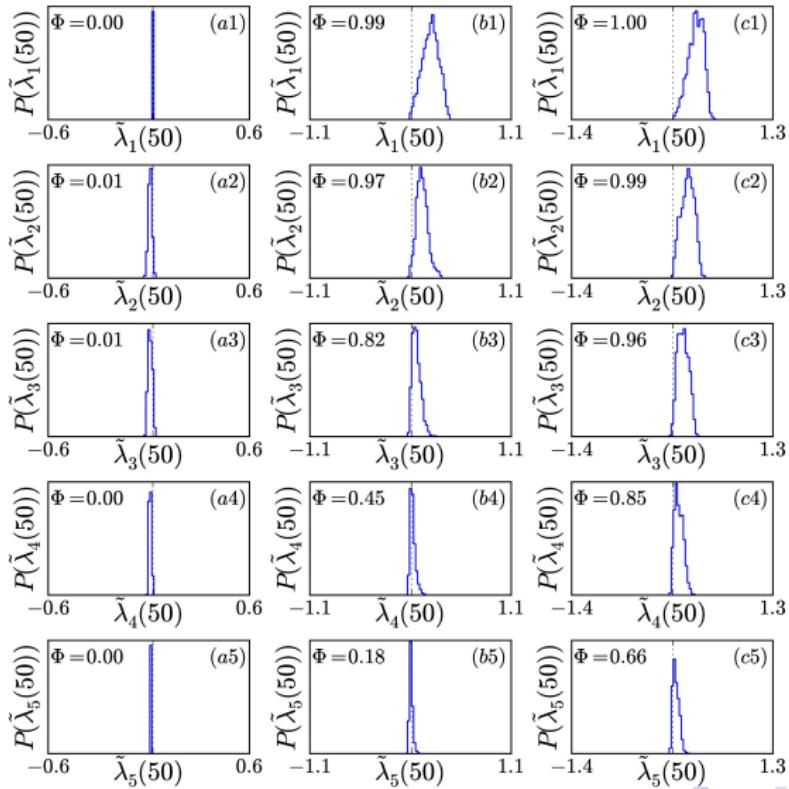


Conditional average – $\epsilon = 0.3$

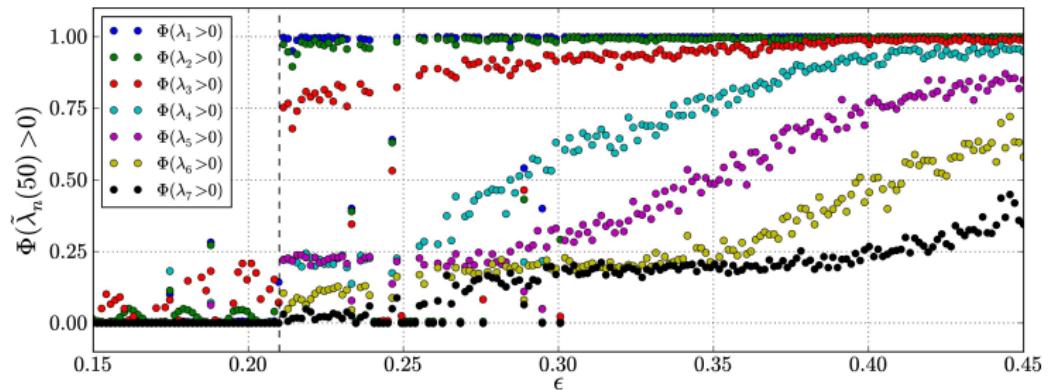


Inter-Bursts distributions – $\epsilon = 0.3$ 

Positive fraction of finite time Lyapunov exponents FTLE for $\epsilon = 0.10(a_n)$ $\epsilon = 0.30(b_n)$ $\epsilon = 0.45(c_n)$

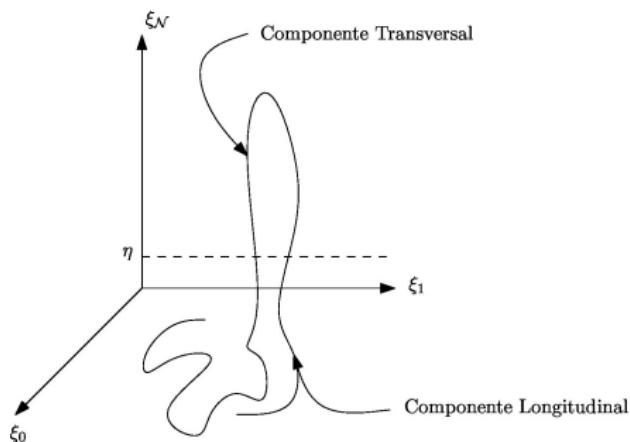


Positive fraction of finite time Lyapunov exponents FTLE for $\epsilon = 0.10(a_n)$ $\epsilon = 0.30(b_n)$ $\epsilon = 0.45(c_n)$



Low dimension chaotic attractor

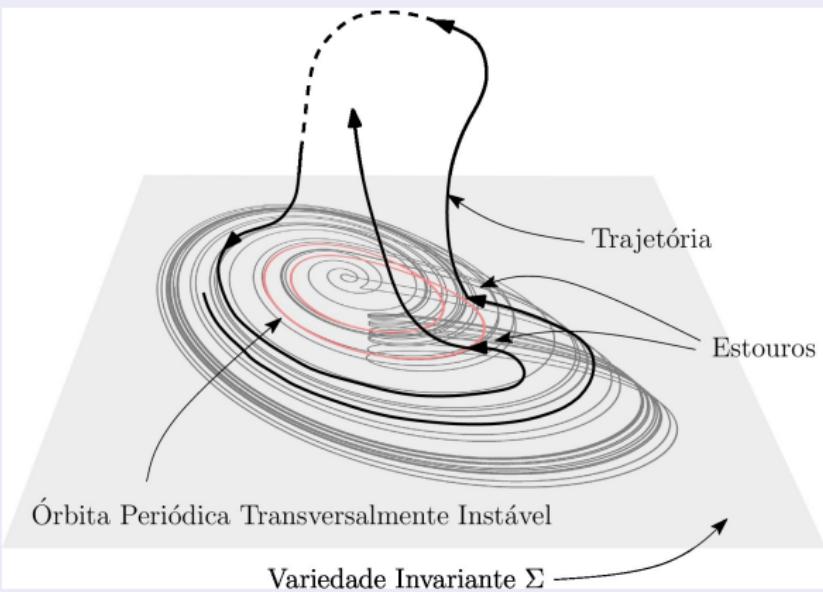
Notation: $|\phi_n(t)| \equiv \xi_n$



- Longitudinal components:
 $\xi_0, \xi_1, \dots, \xi_{N-1}$
- Transversal components:
 $\xi_N, \xi_{N+1}, \dots, \xi_N$

Burst: condition $\xi_N > \eta$

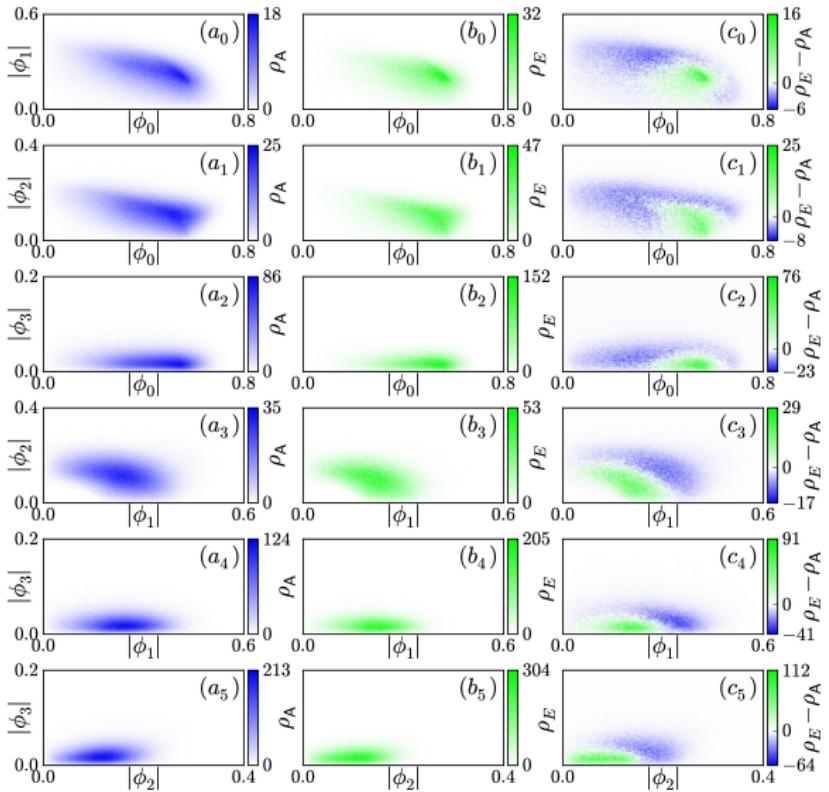
Low dimension chaotic attractor



2D PDFs of the projections the phase space

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Control of extreme events

Perturbation: $(\xi_0, \xi_1)_{\max(\rho_E, \rho_A)} = (0.60, 0.20) - d \leq 0.005;$

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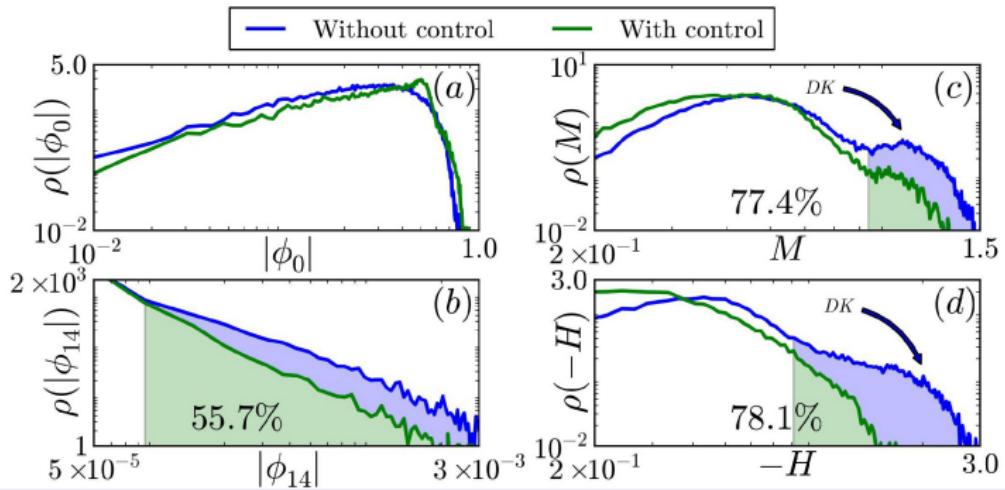
Amplitude: $\mathcal{G}(\mu = 0, \sigma = 2 \times 10^{-2})$;

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Interval of time for the perturbation: 3.7% of the integration time.

Control of extreme events

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Conclusions

- Intermittent transition temporal chaos → Turbulence;
- Fourier spectrum of the system in the high level energy state is consistent with a turbulent flux;
- time distribution of laminar states is a signature of *on-off* intermittency;
- Due to UDV the problem has localized unstable regions;
- **The control makes possible to prevent a great number of extreme events in the system.**