Turbulence control by time-symmetry breaking

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abstract

We propose and prove the control of turbulence by time-symmetry breaking. The effect is based on the modification of the energy cascade through wavenumbers by the introduction of a spatiotemporal non-Hermitian potential. Turbulence may be reduced by effecting a condensing energy at the lowest order mode (homogeneous state). On the contrary, turbulence is enhanced just by changing the unidirectional mode coupling of the energy cascade (by setting the phase shift between the real and imaginary part of the potential). The method is proven for the universal Complex Ginzburg Landau equation and its fractional counterpart with conical dispersion.

motivation and model

general scheme of excitation energy cascade of turbulence

energy injection large spatial scale
small wavenumber scale

energy dissipation large spatial scale
small wavenumber scale

turbulence

spatiotemporal potential

$V(x, t) = \cos(q x) \cos(\Omega t)$
symmetrically couples
$k$ with modes $k+q$ and $k-q$
couples $\omega$ to $\omega+\Omega$
(arrows 1 and 2)
couples $\omega$ to $\omega-\Omega$
(arrows 3 and 4)

CGLE

$$\frac{dA}{dt} = (1 + ia) A \left( 1 - |A|^2 \right) + (d - i) \frac{\partial^2 A}{\partial |x|^2} + iV(x, t) A$$

turbulent field

$A(x, t) = \left( 1 - dk^2 \right)^{1/2} e^{ikx+ir}$

conical dispersion $\beta=1$

results

the general potential:

$V(x, t) = \cos(q x) \left[ m_1 \cos(\Omega t) + m_2 \cos(\Omega t + \phi) \right]$  

Analytical analysis conclude that for parabolic dispersion
the desired unidirectional coupling happens for:

$m_1 = \alpha \sqrt{\Omega^2 + 1} m_2$ 
$\phi = \pi/2 - \arctan(1/\Omega)$

taming of the turbulent spectrum

charts of second order momentum of the 2D FT for $\beta=2$

generalisation to 2D for $\beta=2$

2D turbulent spectrum

conclusions

Non-Hermitian potentials periodically modulated in space and time can influence the excitation cascade mechanism in turbulence.

We are able to regularise the spectrum and oppositely, enhance turbulence by shifting the real and imaginary part of the temporal modulation.

We prove this idea on the Ginzburg-Landau equation for 1D and 2D systems and its fractional counterpart with conical dispersion.

The proposed turbulence control method could be implemented in different systems for being proved in a universal model.