Intermittency suppresion via forced light particles

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How much can we control turbulence?

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- Can we alter the statistics of small scale turbulence? (Intermittency)

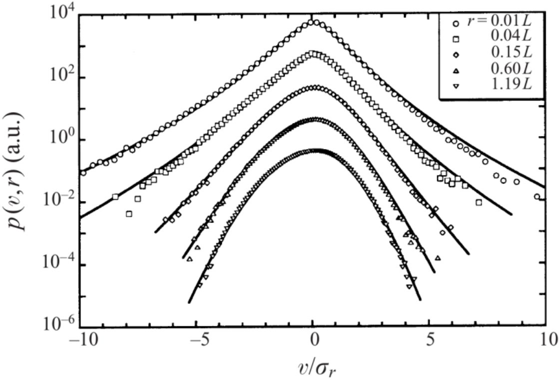

Figure: Renner et al., JFM (2001)

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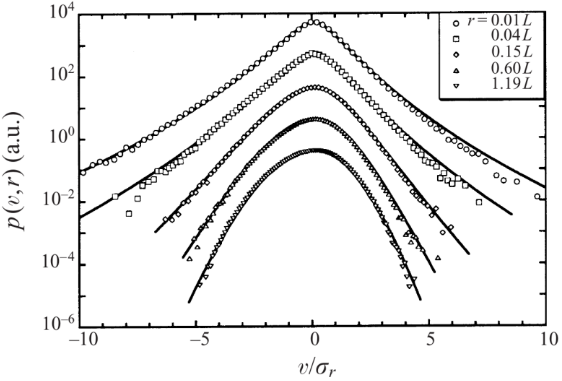

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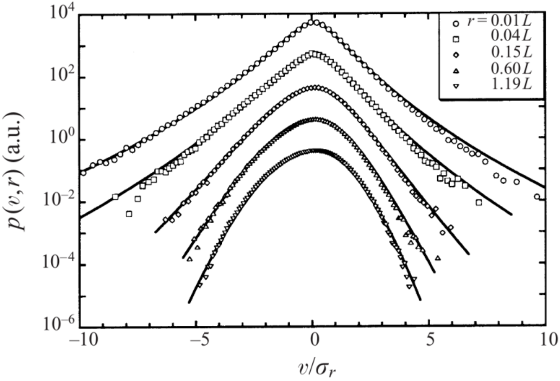
- Small scale universality ... how to avoid this?



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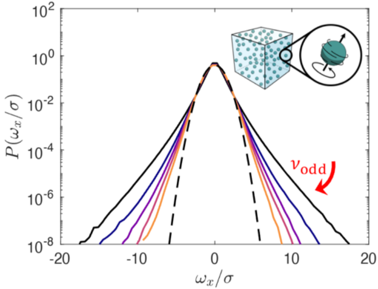
Chen, PRL (2024)



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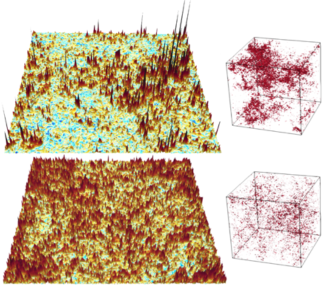
Buzzicotti, PRL (2020)



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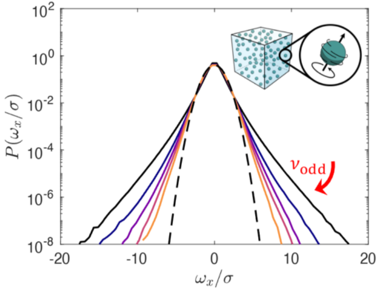

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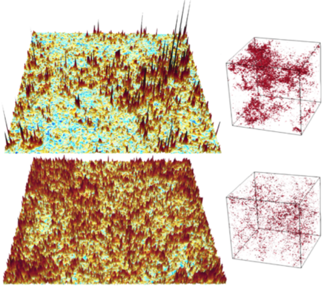

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- Light particles!

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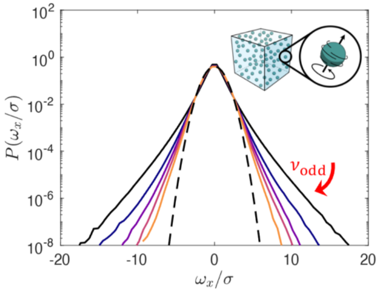

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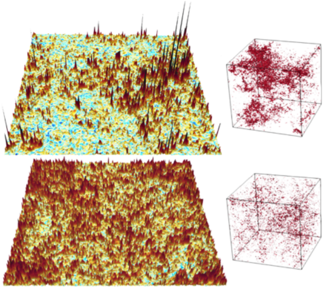

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Governing equations

NSE:

$$\frac{D\mathbf{u}}{Dt} = -\nabla p + \nu\nabla^2\mathbf{u} + \mathbf{f} + \mathbf{f}_p\,, \qquad \nabla\cdot\mathbf{u} = 0\,, \tag{1}$$

Particle phase (Maxey-Riley):

$$\frac{d\mathbf{X}}{dt} = \mathbf{V} + \text{(collisions)}, \tag{2}$$

$$\frac{d\mathbf{V}}{dt} = \beta\frac{D\mathbf{u}}{Dt} - \frac{1}{\tau_p}(\mathbf{V}-\mathbf{u}) + \boldsymbol{f}_E, \tag{3}$$

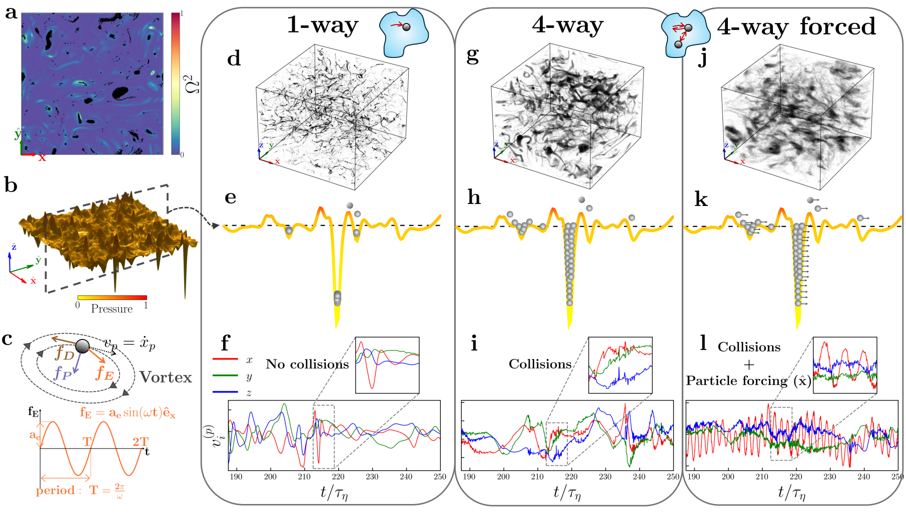
where $\beta = 3/(1+2\rho_p/\rho_f)$ (we take $\beta = 3$).
Particle feedback on the fluid:

$$\mathbf{f}_p(\mathbf{x},t) = \sum_i \left[\frac{D\mathbf{u}}{Dt} - \frac{\rho_p}{\rho_f}\frac{d\mathbf{V}_i}{dt} + \frac{3}{2\beta}f_E\right]\mathscr{V}_p\delta(\mathbf{x}-\mathbf{X}_i(t)), \tag{4}$$

External forcing acting on the particle:

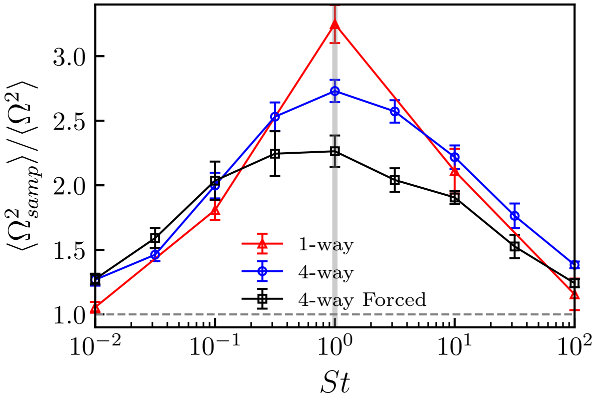
$$f_E = a_e\sin(\omega t)\hat{\mathbf{e}}_x\,. \tag{5}$$

Problem setup



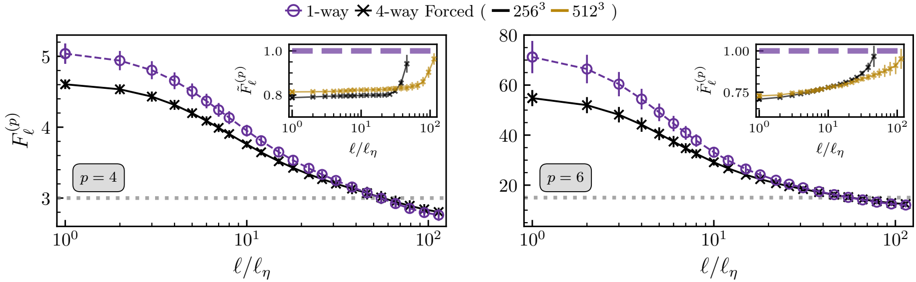
Problem setup

$$St = \tau_p / \tau_\eta \tag{6}$$



$$S_\ell^{(p)} \equiv \langle (\delta_\ell u)^p \rangle \qquad (7)$$

$$F_\ell^{(p)} = \frac{S_\ell^{(p)}}{\left(S_\ell^{(2)}\right)^{p/2}} \qquad (8)$$



$Re_\lambda = 87$ and $Re_\lambda = 168$, $\phi = 1\%$.

Amplitude and Resonance Effect

$$\mathbf{f}_E(t) = a_e \sin(\omega t)\,\hat{\mathbf{e}}_x$$

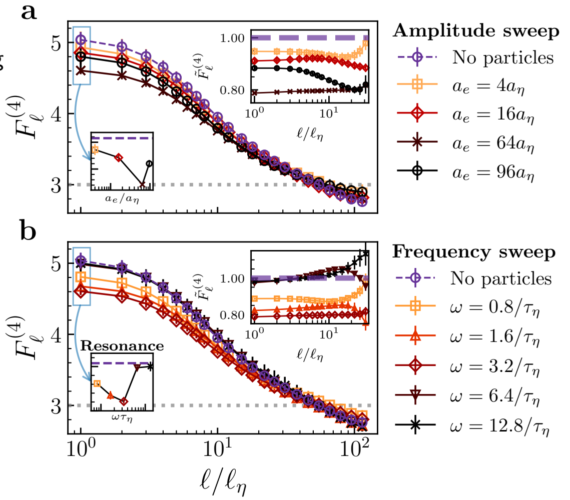
introduces a characteristic forcing length scale

$$\ell_F = \frac{a_e}{\omega^2}.$$

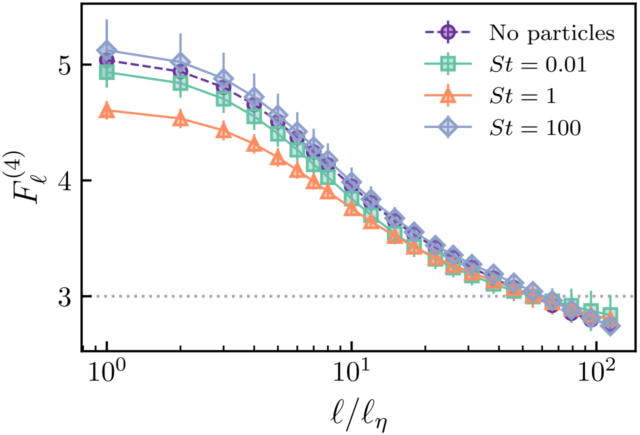
For the optimal forcing parameters, we obtain

$$\ell_F/\ell_\eta \simeq 6,$$

which is consistent with the characteristic width of intense vortex filaments, $\mathcal{O}(\ell_\eta)$ (Ghira (2022), da Silva (2011)).

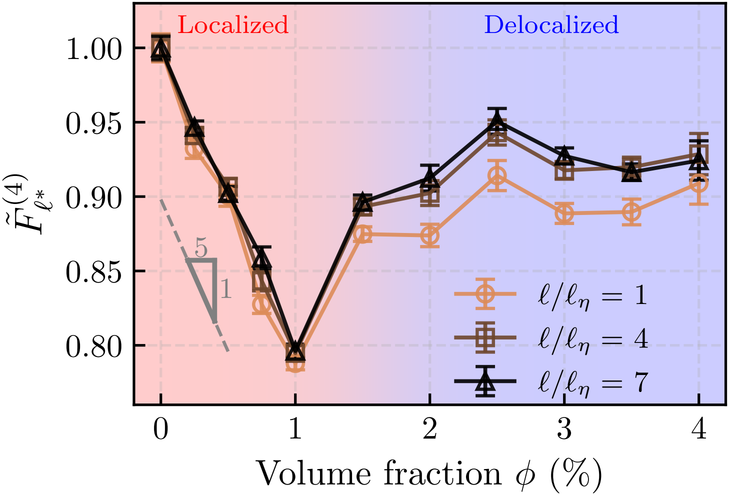


Modulation only happens when acting on important DoFs



Volume fraction effect

$$\tilde{F}^{(4)} = (F^{(4)} - 3)/(F^{(4)}_{\text{no particles}} - 3) \quad (9)$$



Summary

- Externally forced light particles act as **smart Lagrangian agents** that interact non-trivially with turbulence.
- When particles cluster in **vortex filaments**, oscillatory forcing strongly **reduces intermittency**.
- Modulation is effective only near **St** ≈ 1, when forcing frequency resonates with the Kolmogorov timescale, and when the forcing length scale match the characteristic width of vortex filaments.
- Volume fraction matters: filling vortex filaments enhances suppression, up until saturation of the filaments.
- Opens a path to **active turbulence control** using embedded particles.

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AQTIVATE

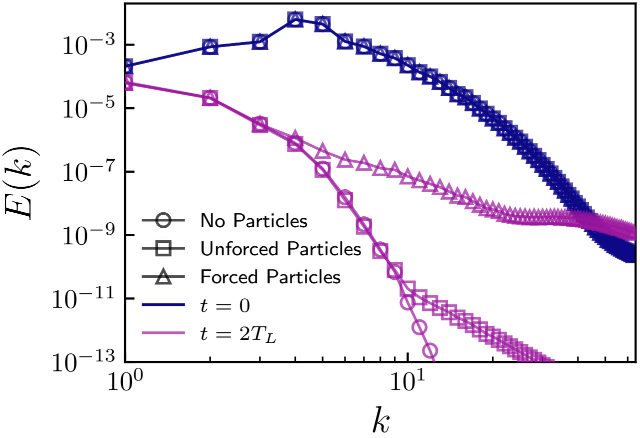
Thanks!



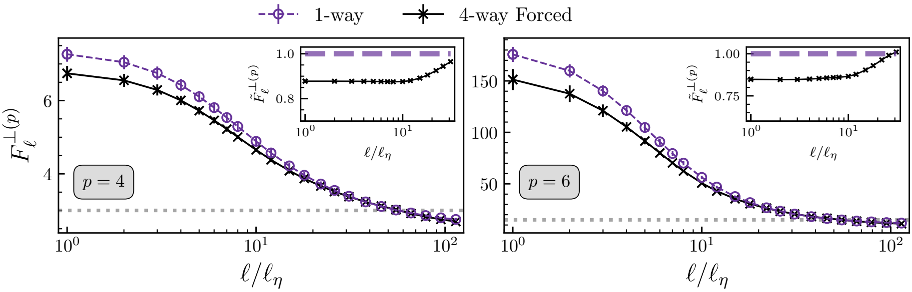


- A. Freitas, X. de Wit, Z. Wang, L. Biferale, F. Toschi. *Statistical properties of turbulence under a smart Lagrangian forcing*, **arXiv** (2025).

Decaying turbulence



Tranverse velocity increments



Directional response