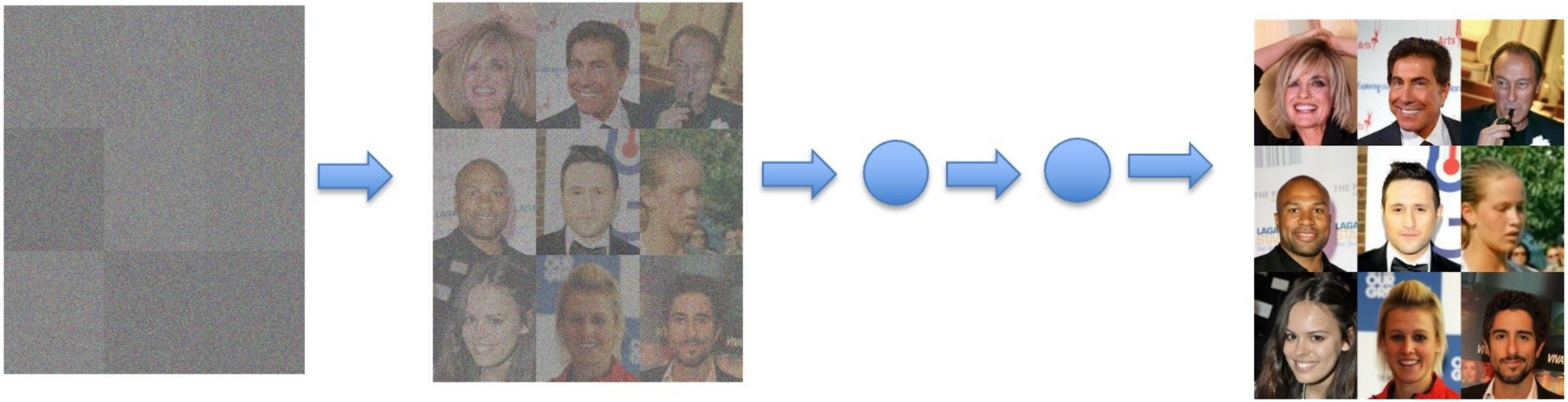
Complex Fluids and Complex Flows Group
Dept. Physics & INFN - University of Rome 'Tor Vergata'
biferale@roma2.infn.it
https://biferale.web.roma2.infn.it/

HOLLYWOOD STARS

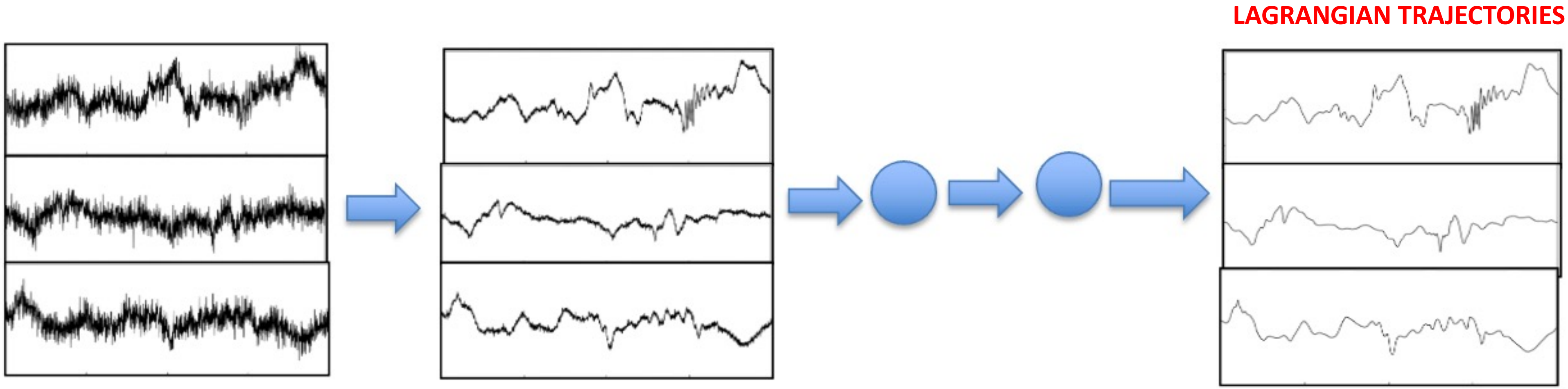


APS DFD23 WASHINGTON
Synthetic Lagrangian Turbulence by Generative Diffusion Models

T. Li, LB, F. Bonaccorso, M. Scarpolini, M. Buzzicotti.
Synthetic Lagrangian Turbulence by Generative Diffusion Models.
arXiv:2307.08529 (2023) – Submittted to Nature Machine Intelligence

CREDITS: T. LI, F. BONACCORSO, M. BUZZICOTTI, M. SCARPOLINI

Complex Fluids and Complex Flows Group
Dept. Physics & INFN - University of Rome 'Tor Vergata'
biferale@roma2.infn.it
https://biferale.web.roma2.infn.it/



APS DFD23 WASHINGTON
Synthetic Lagrangian Turbulence by Generative Diffusion Models

T. Li, LB, F. Bonaccorso, M. Scarpolini, M. Buzzicotti.
Synthetic Lagrangian Turbulence by Generative Diffusion Models.
arXiv:2307.08529 (2023) – Submittted to Nature Machine Intelligence

CREDITS: T. LI, F. BONACCORSO, M. BUZZICOTTI, M. SCARPOLINI

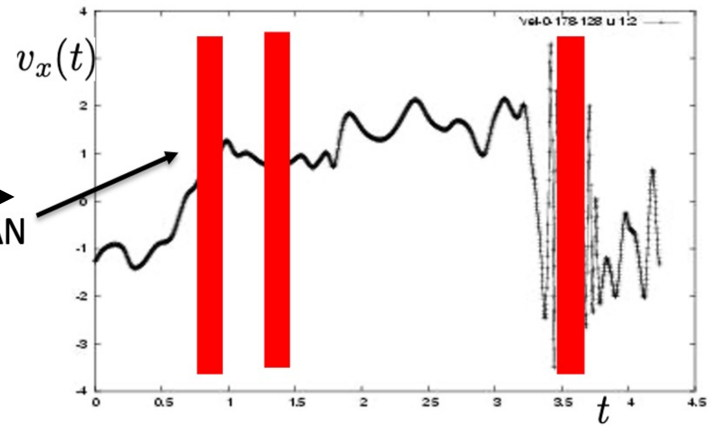
STOCHASTIC MODELS FOR LAGRANGIAN TURBULENCE: WHY?

T. Li, LB, F. Bonaccorso, M. Scarpolini, M. Buzzicotti.
Synthetic Lagrangian Turbulence by Generative Diffusion Models.
arXiv:2307.08529 (2023) – Submittted to Nature Machine Intelligence

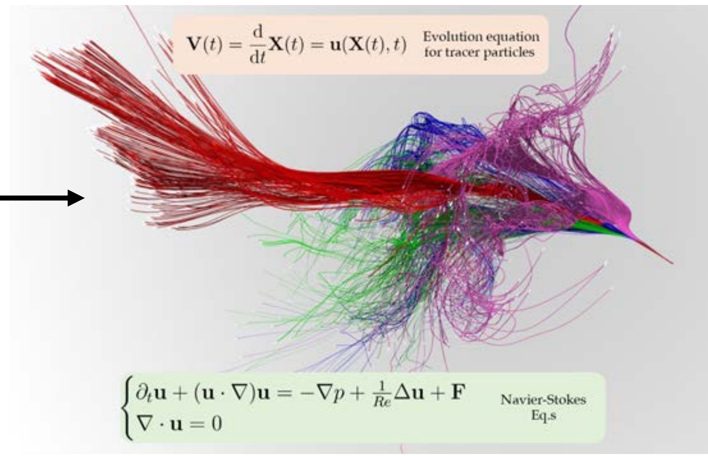
GENERATION OF LARGE SYNTHETIC DATA-BASE FOR
(I) RANKING OF PHYSICS FEATURES
(II) TESTING DOWNSTREAM APPLICATIONS/MODELS

DATA ASSIMILATION/INPAINTING FROM MISSING FIELD/EXPERIMENTAL OBERVATION

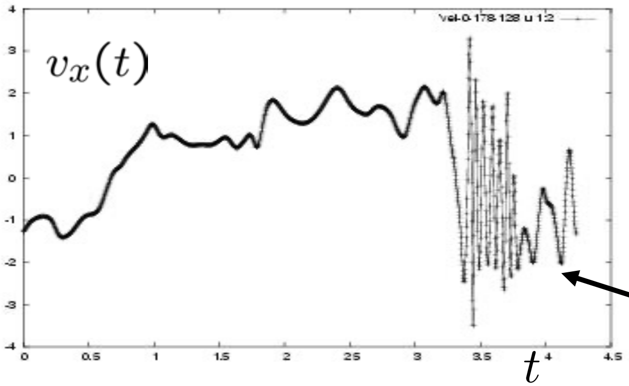
LAGRANGIAN

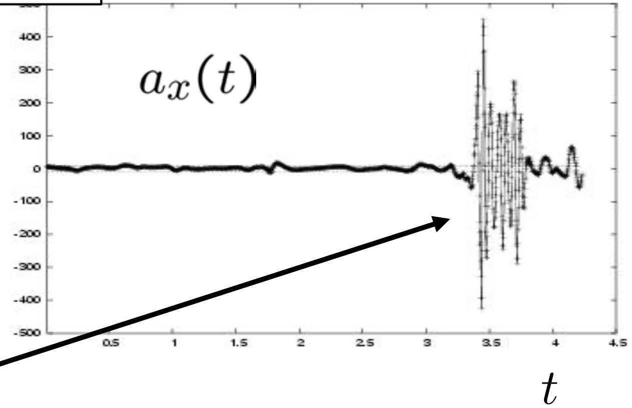


CLASSIFICATION/INFERRAL OF MISSING/INTERNAL PROPERTIES:
(I) INERTIA
(II) SHAPE
(III) ACTIVE DEGREES OF FREEDOM
(IV) ….

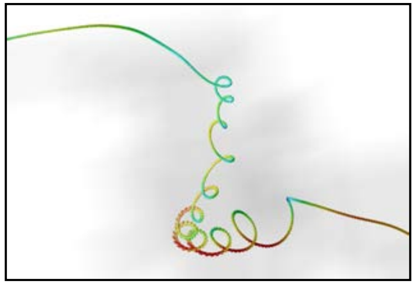


$$\begin{cases} \mathbf{a} = \partial_t \mathbf{u} + (\mathbf{u}\cdot\nabla)\mathbf{u} = -\nabla p + \nu \Delta \mathbf{u} + \mathbf{f} \\ \nabla \cdot \mathbf{u} = 0 \end{cases}$$

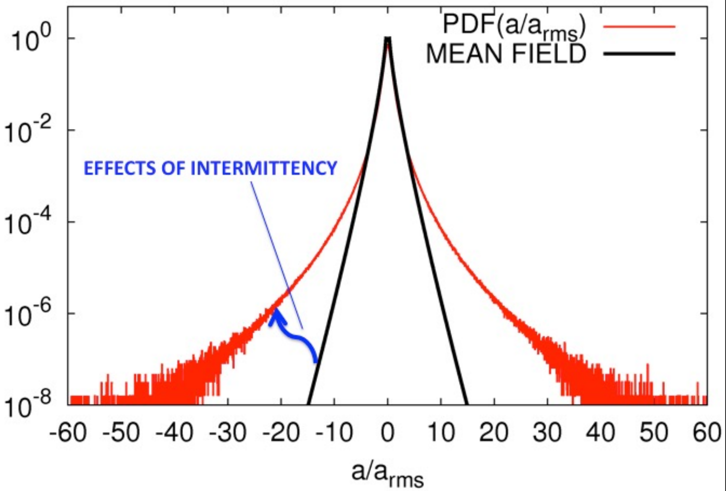




EXTREME EVENTS



$$S_i^{(p)}(\tau) = \langle [v_i(t+\tau) - v_i(t)]^p \rangle$$

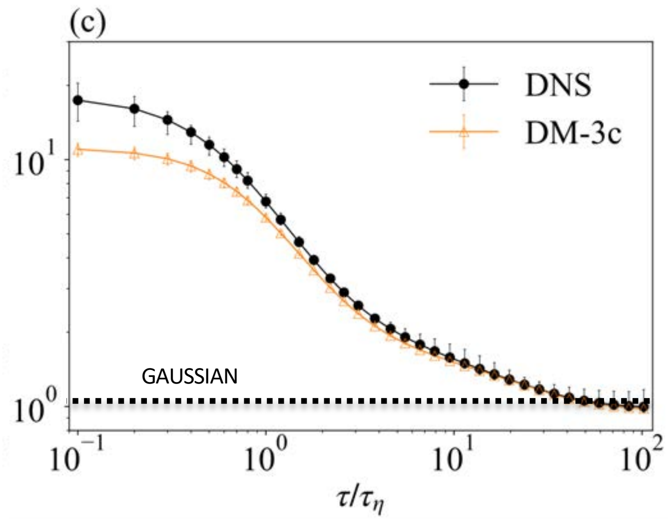


ACCELERATION PROBABILITY DISTRIBUTION FUNCTION (PDF) AT RE ~ 10^5 [Bi04]
COMPARED WITH THE PREDICTION FROM MEAN FIELD (KOLMOGOROV THEORY)

La Porta, G.A. Voth, A.M. Crawford, J. Alexander et al. Fluid particle accelerations in fully developed turbulence. Nature, 409(6823), 1017 (2001)

N. Mordant, P. Metz, O. Michel and J.F. Pinton. Measurement of Lagrangian velocity in fully developed turbulence. Phys. Rev. Lett. 87(21), 214501 (2001)

F. Toschi and E. Bodenschatz. Lagrangian Properties of Particles in Turbulence. Annu. Rev. Fluid Mech. 41, 375 (2009)



$$F(\tau) = \frac{S^{(4)}(\tau)}{[S^{(2)}(\tau)]^2}$$

Sawford, B. L. Reynolds number effects in Lagrangian stochastic models of turbulent dispersion.
Phys. Fluids A: Fluid Dyn. 3, 1577–1586 (1991).

Wilson, J. D. & Sawford, B. L. Review of lagrangian stochastic models for trajectories in the turbulent atmosphere.
Boundary-layer meteorology 78, 191–210 (1996).

Biferale, L., Boffetta, G., Celani, A., Crisanti, A. & Vulpiani, A. Mimicking a turbulent signal: Sequential multiaffine processes.
Physical Review E 57, R6261 (1998).

Arneodo, A., Bacry, E. & Muzy, J.-F. Random cascades on wavelet dyadic trees. Journal of Mathematical Physics 39, 4142–4164 (1998).

Lamorgese, A., Pope, S. B., Yeung, P. & Sawford, B. L. A conditionally cubic-gaussian stochastic
lagrangian model for acceleration in isotropic turbulence. Journal of Fluid Mechanics 582, 423–448 (2007).

Arnéodo, A. et al. Universal intermittent properties of particle trajectories in highly turbulent flows. Physical Review Letters 100, 254504 (2008

Pope, S. B. Simple models of turbulent flows. Physics of Fluids 23, 011301 (2011).

Minier, J.-P., Chibbaro, S. & Pope, S. B. Guidelines for the formulation of lagrangian stochastic models for
particle simulations of single-phase and dispersed two-phase turbulent flows. Physics of Fluids 26, 113303 (2014).

Chevillard, L., Garban, C., Rhodes, R. & Vargas, V. On a skewed and multifractal unidimensional random field, as a
probabilistic representation of kolmogorov's views on turbulence. In Annales Henri Poincaré, vol. 20, 3693–3741 (Springer, 2019).

Viggiano, B. et al. Modelling lagrangian velocity and acceleration in turbulent flows as infinitely
differentiable stochastic processes. Journal of Fluid Mechanics 900, A27 (2020).

Sinhuber, M., Friedrich, J., Grauer, R. & Wilczek, M. Multi-level stochastic refinement for complex
time series and fields: a data-driven approach. New Journal of Physics 23, 063063 (2021).

Zamansky, R. Acceleration scaling and stochastic dynamics of a fluid particle in turbulence. Physical Review Fluids 7, 084608 (2022).

Lubcke, J, Friedrich, J., Grauer, R. Stochastic interpolation of sparsely sampled time series by a superstatistical random process
and its synthesis in Fourier and wavelet space. J. Phys. Complex. 4 015005 (2023)

Diffusion Models

Training set: a set of images $\vec{a}^\mu \in \mathbb{R}^N$ $\quad \mu = 1, ..., P$
N is the dimension of the data, P their number

Langevin equation for an Ornstein-Uhlenbeck process

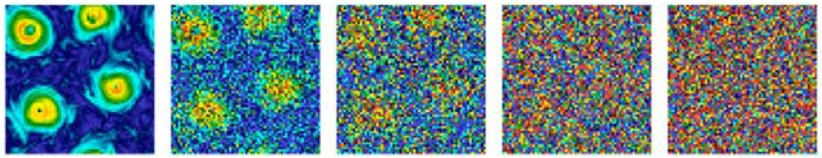
$$\frac{d\vec{x}}{dt} = -\vec{x} + \vec{\eta}(t) \qquad \langle \eta_i(t)\eta_j(t')\rangle = 2T\delta_{ij}\delta(t-t')$$

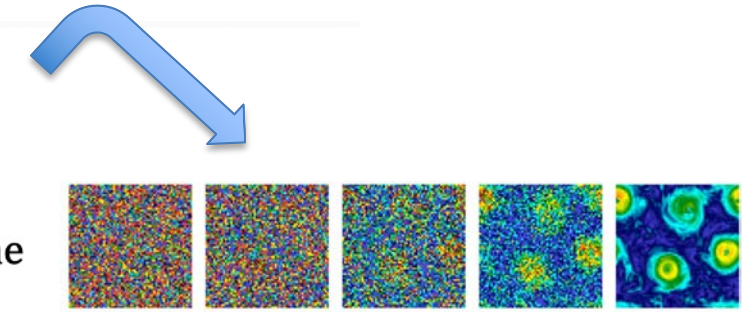
$$\vec{x}^\mu(t=0) = \vec{a}^\mu$$

It transforms the data in iid Gaussian $\mathcal{N}(0,1)$ at t>>1

$$P_t(\vec{x}) = \int d\vec{a}\; P_0(\vec{a}) \frac{1}{\sqrt{2\pi\Delta_t}^N} \exp\left(-\frac{1}{2}\frac{(\vec{x}-\vec{a}e^{-t})^2}{\Delta_t}\right) = \int d\vec{a}\; P_t(\vec{a},\vec{x})$$

$$\Delta_t = T(1-e^{-2t})$$



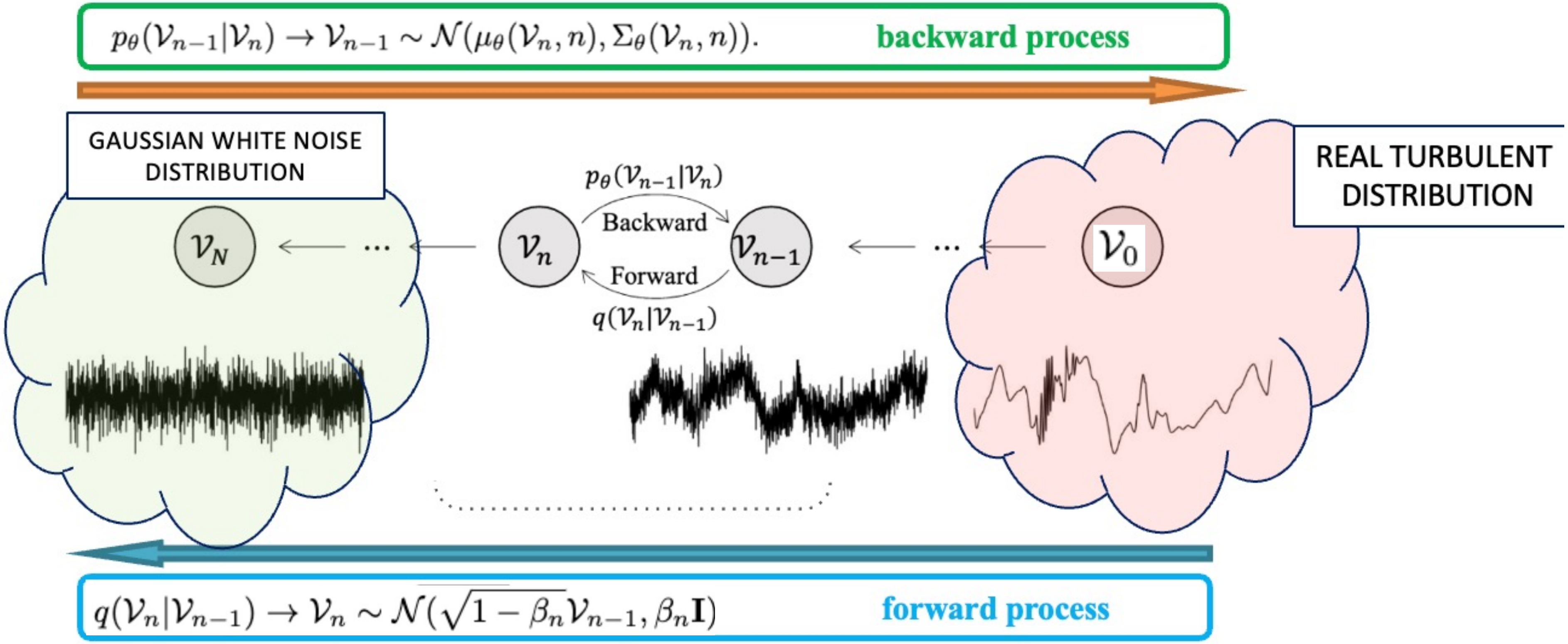


Score function provides the force field to go back in time

$$\mathcal{F}_i(\vec{x},t) = \frac{\partial \log P_t(\vec{x})}{\partial x_i} \qquad -\frac{dy_i}{dt} = y_i + 2T\mathcal{F}_i(y,t) + \eta_i(t)$$

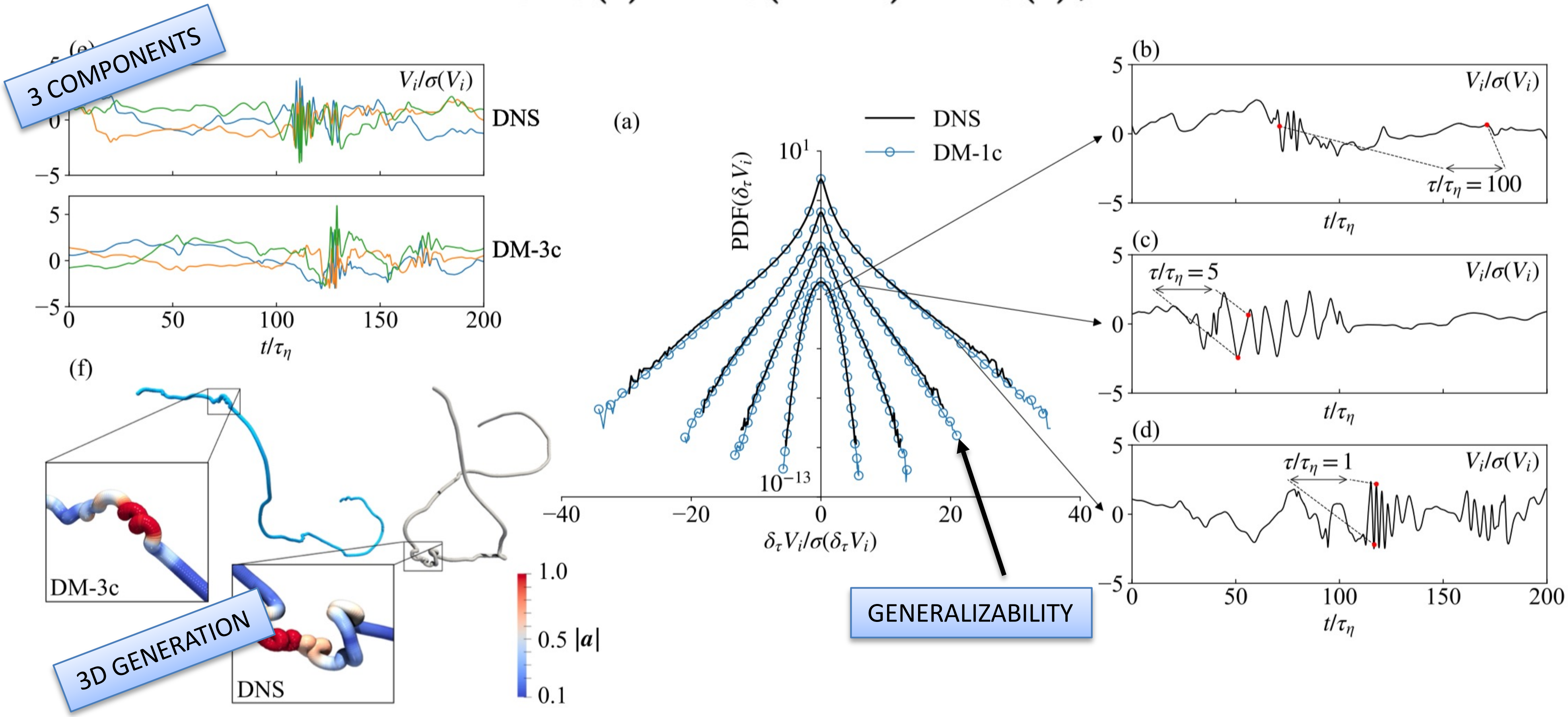
Diffusion Models

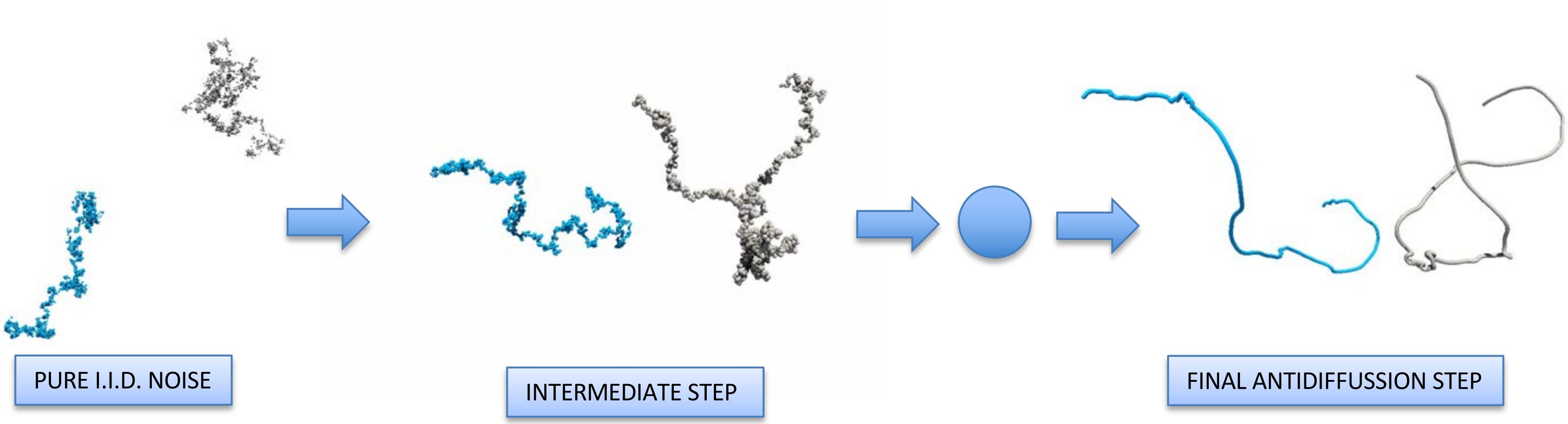
'Synthetica Lagrangian Turbulence: all you need is Diffusion Models' T. Li, L.B, F. Bonaccorso, M. Scarpolini and M. Buzzicotti (arXiv:2307.08529 2023, submitted Nature Machine Intelligence)



Sohl-Dickstein et al., Deep Unsupervised Learning using Nonequilibrium Thermodynamics, ICML 2015
Ho et al., Denoising Diffusion Probabilistic Models, NeurIPS 2020
Song et al., Score-Based Generative Modeling through Stochastic Differential Equations, ICLR 2021

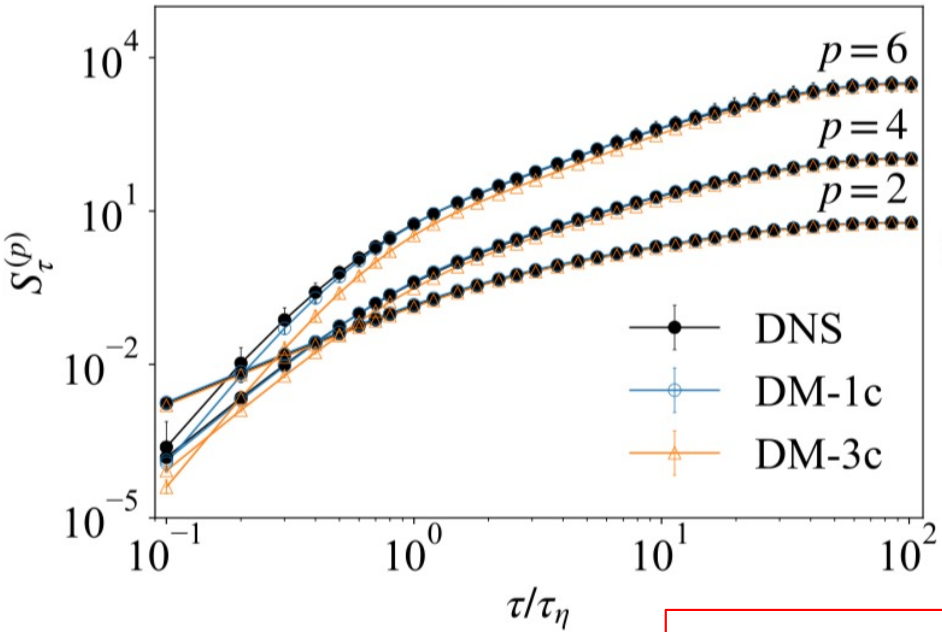
$$\delta_\tau V_i(t) = V_i(t+\tau) - V_i(t),$$





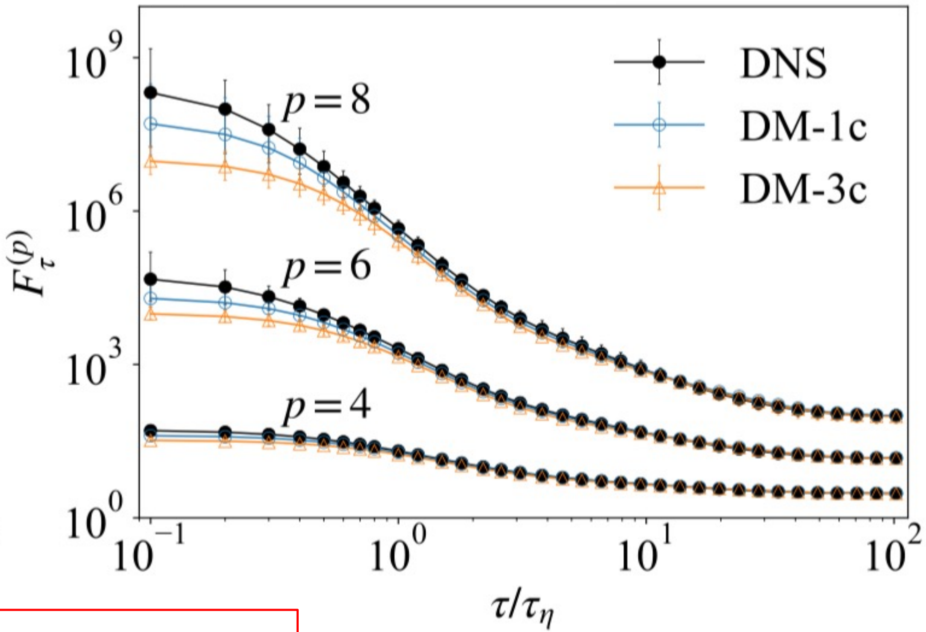
LAGRANGIAN STRUCTURE FUNCTIONS

$$S_\tau^{(p)} = \langle (\delta_\tau V_i)^p \rangle$$

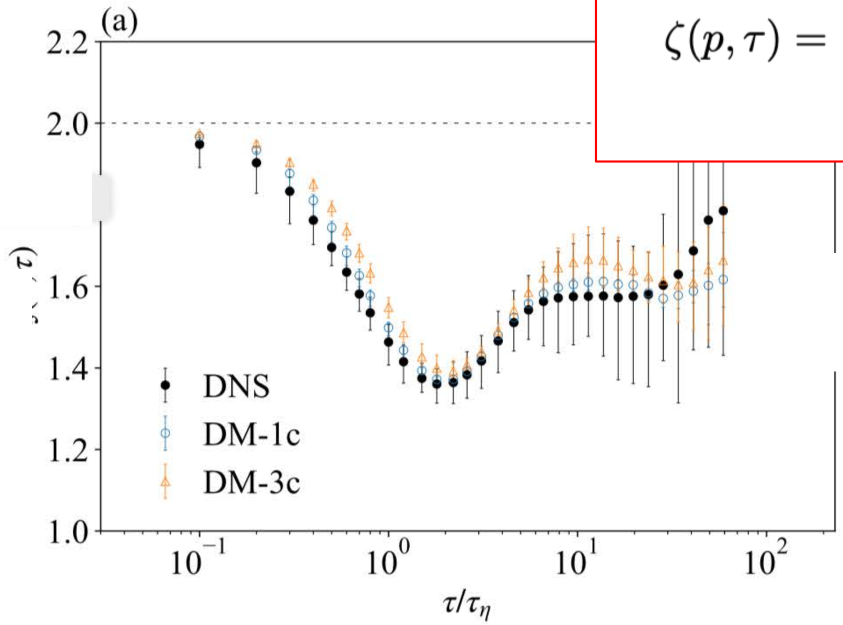


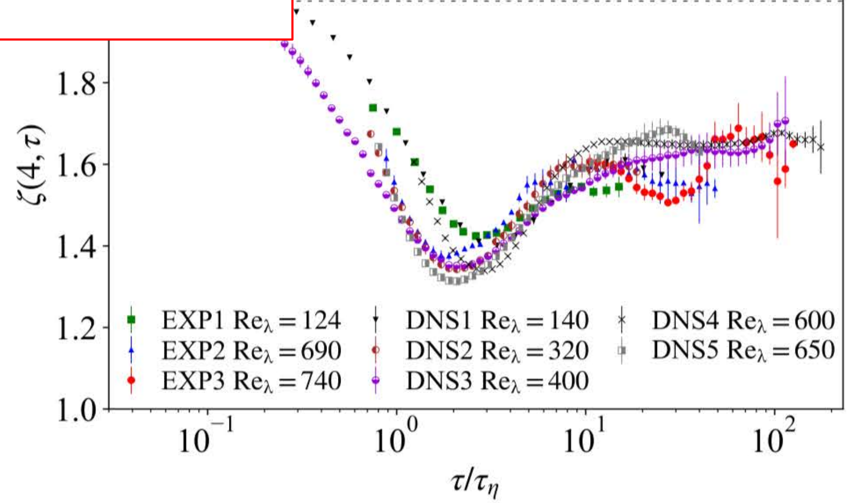
GENERALIZED FLATNESS

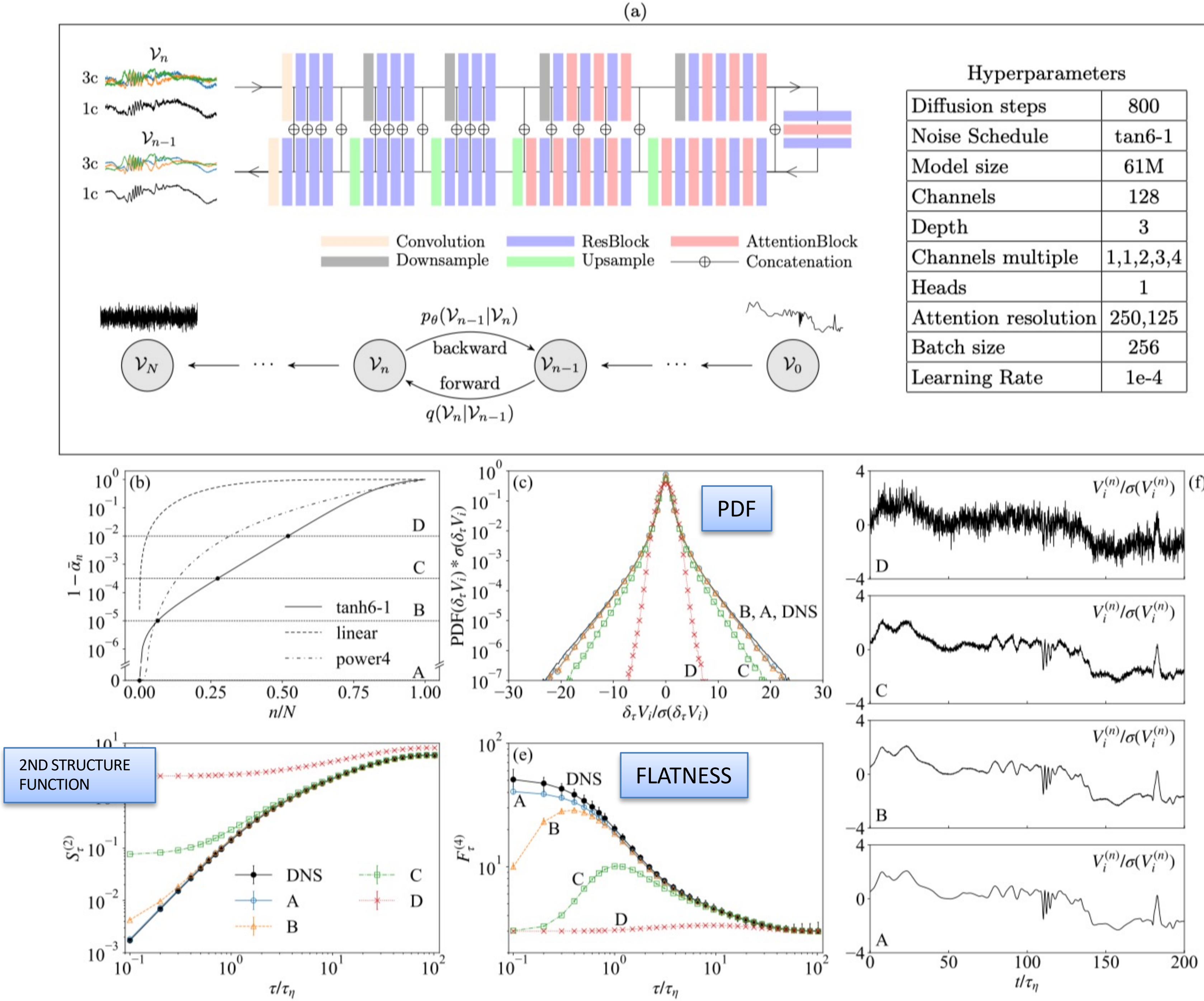
$$F_\tau^{(p)} = S_\tau^{(p)}/[S_\tau^{(2)}]^{p/2}.$$



$$\zeta(p,\tau) = \frac{d\,\log S_\tau^{(p)}}{d\,\log S_\tau^{(2)}}.$$







Hyperparameters	
Diffusion steps	800
Noise Schedule	tan6-1
Model size	61M
Channels	128
Depth	3
Channels multiple	1,1,2,3,4
Heads	1
Attention resolution	250,125
Batch size	256
Learning Rate	1e-4

WHAT WE HAVE:

- QUICK STOCHASTIC TOOL TO GENERATE REALISTIC 3D TRAJECTORIES OF TRACERS IN HOMOGENEOUS AND ISOTROPIC TURBULENCE, EASY TO GENERALISE FOR DIFFERENT APPLICATIONS

- IMPRESSIVE QUANTITATIVE AGREEMENT WITH MULTI-SCALE STATISTICAL PROPERTIES

WHAT WE MISS:

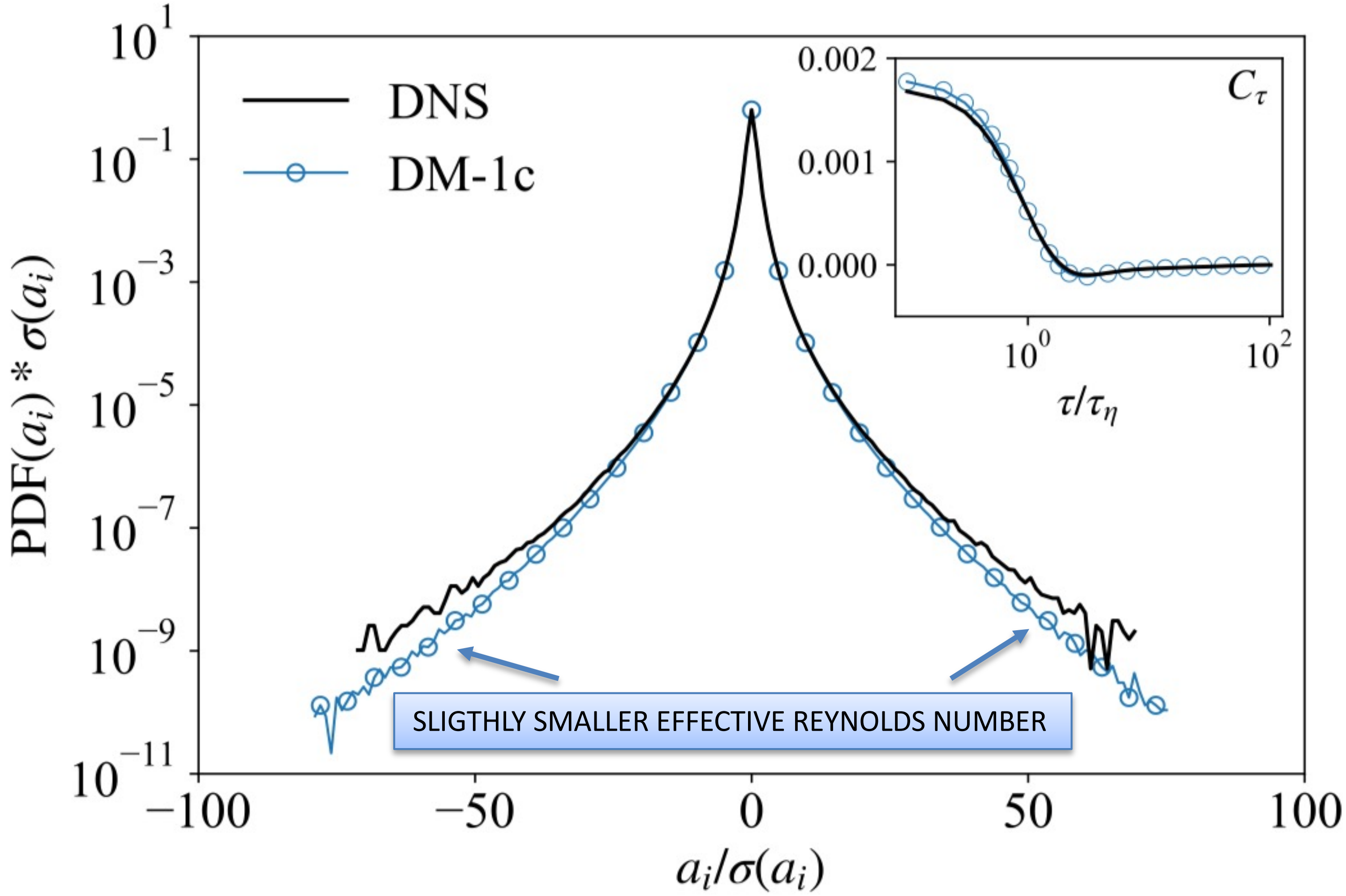
- UNDERSTADING OF ROBUSTNESS IN GENERALISING OUT-OF-SAMPLE:
EXTREME EVENTS, DIFFERENT REYNOLDS NUMBERS, DIFFERENT PARTICLES' PROPERTIES

- UNDERSTANDING SCALING PROPERTIES FOR TIME-TO-SOLUTION AT CHANGING IN-SAMPLE PROPERTIES, I.E. AT CHANGING DIMENSION OF THE TRAINING DATASET,
SETS OF HYPER-PARAMETERS, CNN ARCHITECTURES: GAN, DM, TRANSFORMERS

-WHAT-IF QUESTIONS: EXPLICABILITY OF THE GENERATED DATA, FEATURES RANKINGS, PHYSICS DISCOVERY

T. Li, LB, F. Bonaccorso, M. Scarpolini, M. Buzzicotti.
Synthetic Lagrangian Turbulence by Generative Diffusion Models.
arXiv:2307.08529 (2023) – Submittted to Nature Machine Intelligence

ACCELERATION PDF



$$S_i^{(p)}(\tau) = \langle [v_i(t+\tau) - v_i(t)]^p \rangle$$

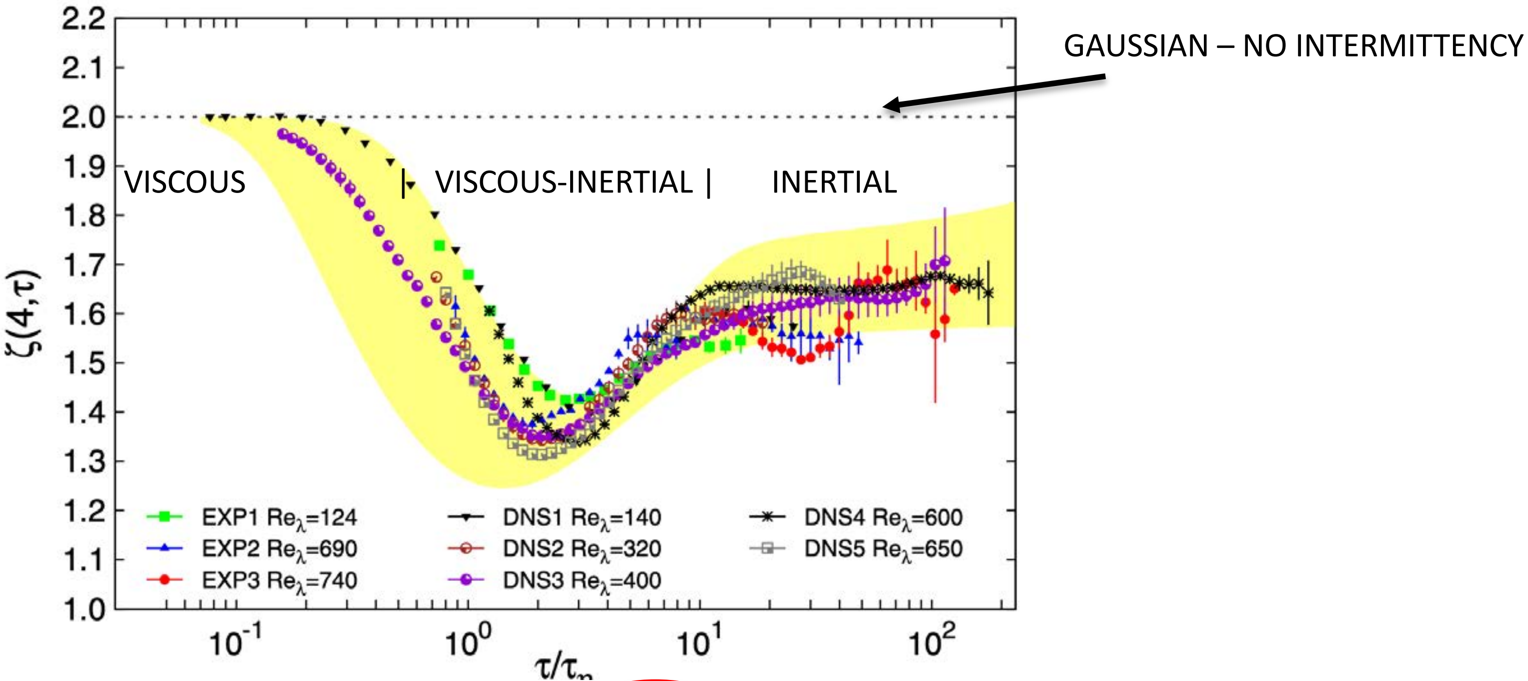
$$\zeta(4,\tau) = \frac{d \log S^{(4)}(\tau)}{d \log S^{(2)}(\tau)}$$

PRL 100, 254504 (2008) PHYSICAL REVIEW LETTERS week ending 27 JUNE 2008

Universal Intermittent Properties of Particle Trajectories in Highly Turbulent Flows

A. Arnèodo,[1] R. Benzi,[2] J. Berg,[3] L. Biferale,[4,*] E. Bodenschatz,[5] A. Busse,[6] E. Calzavarini,[7] B. Castaing,[1] M. Cencini,[8,*] L. Chevillard,[1] R. T. Fisher,[9] R. Grauer,[10] H. Homann,[10] D. Lamb,[9] A. S. Lanotte,[11,*] E. Lévèque,[1] B. Lüthi,[12] J. Mann,[3] N. Mordant,[13] W.-C. Müller,[6] S. Ott,[3] N. T. Ouellette,[14] J.-F. Pinton,[1] S. B. Pope,[15] S. G. Roux,[1] F. Toschi,[16,17,*] H. Xu,[5] and P. K. Yeung[18]

(International Collaboration for Turbulence Research)



$$\delta_\tau v(h) = V_0 \frac{\tau}{T_L}\left[\left(\frac{\tau}{T_L}\right)^{\beta} + \left(\frac{\tau_\eta}{T_L}\right)^{\beta}\right]^{(2h-1)/\beta(1-h)}, \qquad \tau_\eta(h)/T_L \sim R_\lambda^{2(h-1)/(1+h)}$$

G. K. Batchelor. “Pressure fluctuations in isotropic turbulence” Proc. Camb. Philos. Soc. 47, 359 (1951)
G. Paladin and A. Vulpiani, “Degrees of freedom of turbulence,” Phys. Rev. A 35, 1971 (1987)
C. Meneveau, “Transition between viscous and inertial-range scaling of turbulence structure functions“ Phys. Rev. E 54, 3657 (1996)

Smart-Turb

Datasets | Organizations | Help | About | Us

Guide for users

What is Smart-TURB*? It is a brand new software infrastructure (born June 2020) for the research community working on turbulence and complex flows with particular emphasis to collect/standardize and preserve huge datase ... ig-data and Machine Learning approaches to fluid mechanics in genera ... nce, in particular. It is an easily accessible web platform for high qua ... is to host, standardize and manage a large collecti ... rimental and numerical data sets from high-end fluid dyn ... ies and High Performance Computational centers. Smart- ... ble performances when accessing/uploading/searching data. The ... munity is asked to contribute, by deploying freely downloadable, accurate an ... mented dataset for the sake of "reproducibility": The process of documenting ... edures and archiving data so that others can fully reproduce scientific results. ... se contact the administrator for infos about how to upload your dataset. We ... by deploying a first dataset made of 2d and 3d turbulent configurations under ... on TURB-Rot. More will come.*

https://smart-turb.roma2.infn.it/

TURB-Rot. A large database of 3D and 2D snapshots from turbulent rotating flows

A Preprint

L. Biferale
Dept. Physics and INFN
University of Rome Tor Vergata, Italy, and IIC-Paris, France
biferale@roma2.infn.it

F. Bonaccorso
Center for Life Nano Science@La Sapienza
Istituto Italiano di Tecnologia and INFN
University of Rome Tor Vergata, Italy.
fabio.bonaccorso@roma2.infn.it

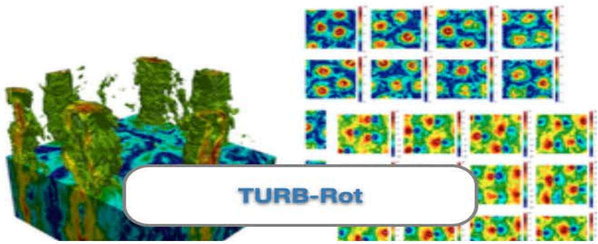
M. Buzzicotti
Dept. Physics and INFN
University of Rome Tor Vergata, Italy.
michele.buzzicotti@roma2.infn.it

P. Clark Di Leoni
Department of Mechanical Engineering,
Johns Hopkins University, Baltimore, USA.
pato@jhu.edu

Search for datasets

1 Datasets

TURB-Rot
A large database of 3d and 2d snapshots from turbulent rotating



2 Organizations

web_admin web_admin group	1 member

DEAR CHALRES, THE INFLUENCE OF YOUR WORK ON MY SCIENTIFIC CAREER WENT WELL BEYOND THE FEW INTERMITTENT SCIENTIFIC COLLABORATION WE HAD TOGETHER.

MY SCIENTIFIC TRAJECTORY WOULD HAVE NOT BEEN THE SAME WITHOUT YOUR SCIENCE, YOUR WORK FOR THE COMMUNITY, YOUR SCIENTIFIC VISION AND YOUR CONTINUOS SUPPORT.

I AM PROUD CONSIDER MYSELF A GOOD FRIEND OF YOU AND OF YOUR WONDERFUL FAMILY, HAPPY BIRTHDAY AND AD MAIORA!

PS: I AM LOOKING FORWARD FOR THE NEXT BIRTHDAYS,

Level Set Methods for Fluid Interfaces
J. A. Sethian and Peter Smereka
Vol. 35, 2003, pp. 341–372
Preview Abstract - Figures

Small-Scale Hydrodynamics in Lakes
Alfred Wüest and and Andreas Lorke
Vol. 35, 2003, pp. 373–412
Preview Abstract - Figures

Stability and Transition of Three-Dimensional Boundary Layers
William S. Saric, Helen L. Reed, Edward B. White
Vol. 35, 2003, pp. 413–440
Preview Abstract - Figures

Shell Models of Energy Cascade in Turbulence
Luca Biferale
Vol. 35, 2003, pp. 441–468
Preview Abstract - Figures

Flow and Dispersion in Urban Areas
R. E. Britter S. R. Hanna
Vol. 35, 2003, pp. 469–496
Preview Abstract - Figures

Annual Review of Fluid Mechanics