# Learning from Smart Lagrangian particles in turbulent flows: one-way and two-way coupling

## (a journey in Mare Incognitum)


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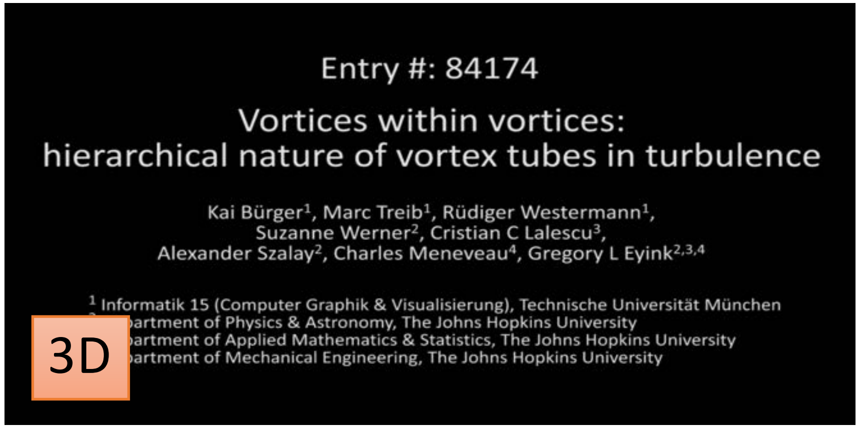
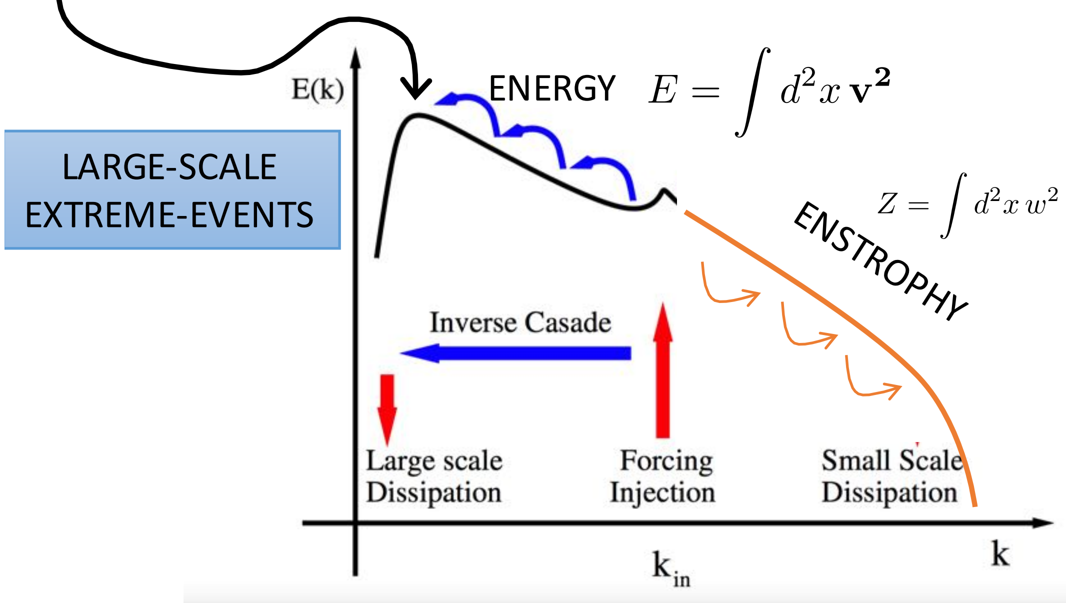
HPC-LEAP
EUROPEAN JOINT DOCTORATES

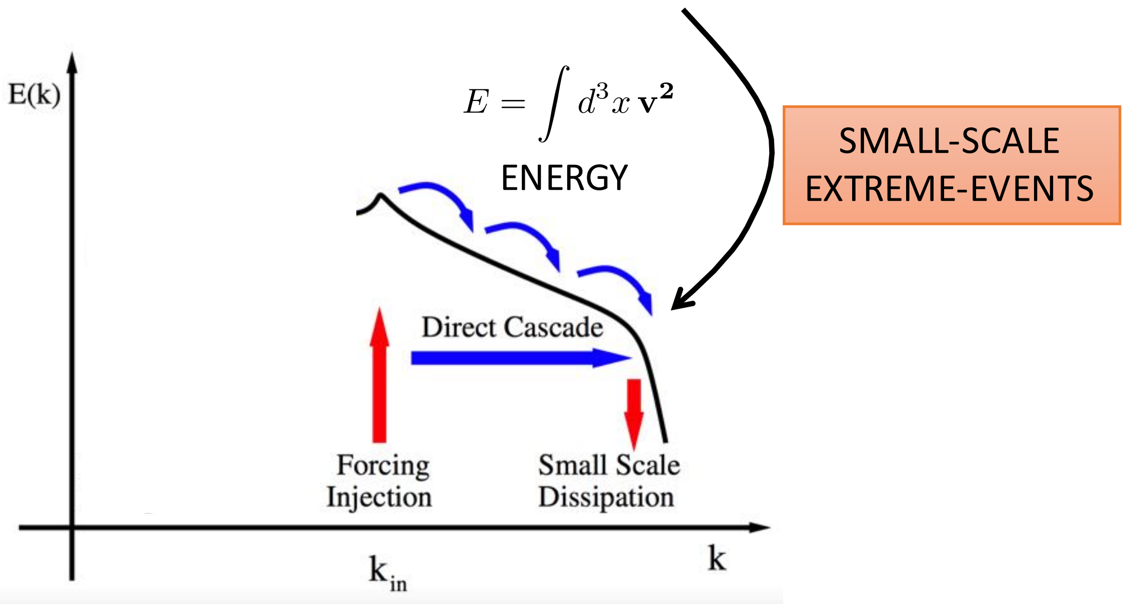
NAVIER-STOKES 3D ←→ 2D

(NASA - Space Flight Center Scientific Visualization Studio)

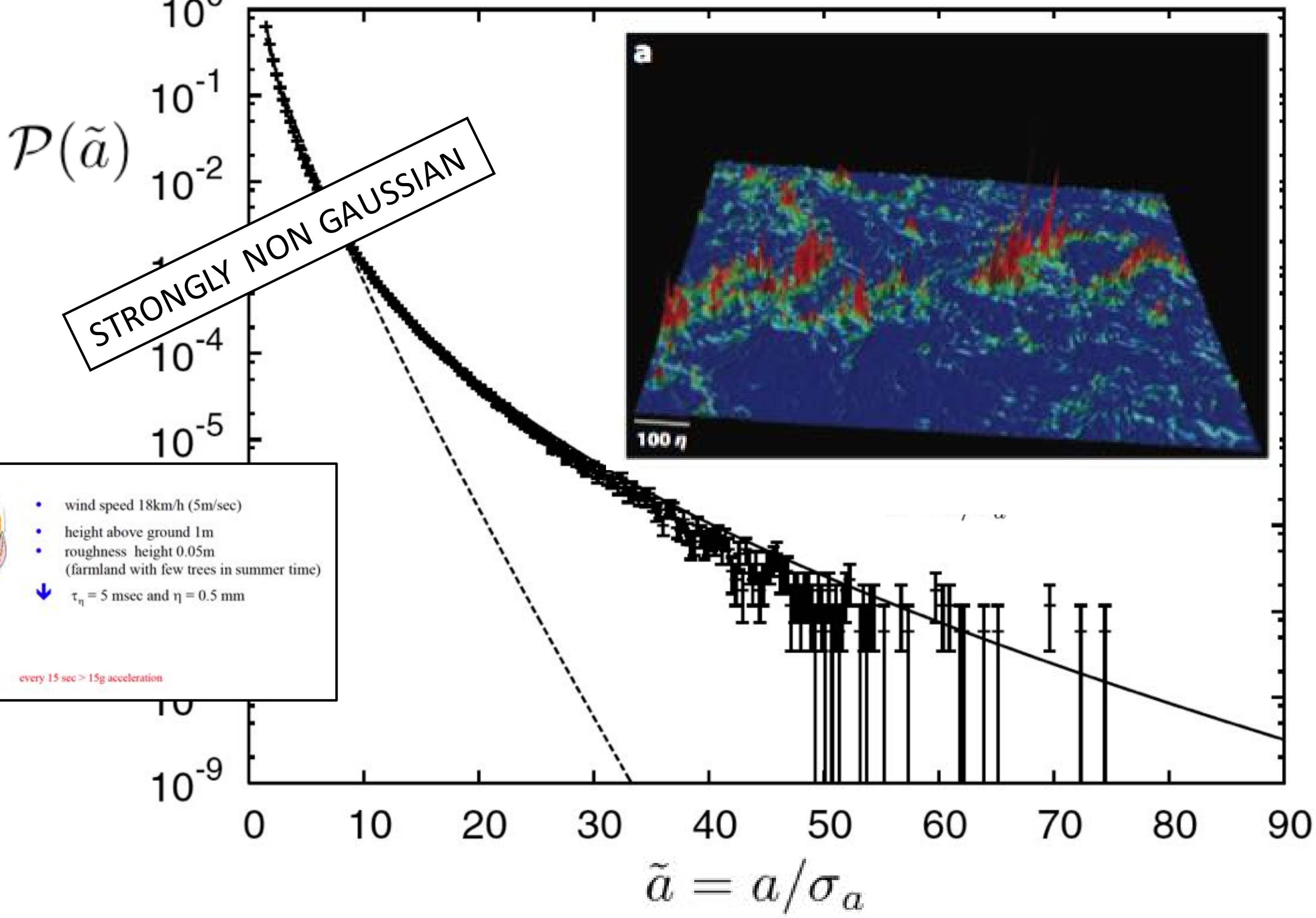

(Vortices within vortices - APS Gallery of Fluid Motions)



$$\mathcal{P}(a) \sim \int_{h\in I} \mathrm{d}h\, a^{\frac{h-5+D(h)}{3}} \nu^{\frac{7-2h-2D(h)}{3}} L_0^{D(h)+h-3} \sigma_v^{-1} \times \quad \exp\left( - \frac{a^{\frac{2(1+h)}{3}} \nu^{\frac{2(1-2h)}{3}} L_0^{2h}}{2\sigma_v^2} \right)$$




- wind speed 18km/h (5m/sec)
- height above ground 1m
- roughness height 0.05m
(farmland with few trees in summer time)

↓ $\tau_\eta$ = 5 msec and $\eta$ = 0.5 mm

every 15 sec > 15g acceleration

L. B., G. Boffetta, A. Celani, B. Devenish, A. Lanotte and F. Toschi *Physical Reviw Letters* **93**, 064502, 2004

LARGE-SCALE
EXTREME-EVENTS

Starry night (V. van Gogh, 1889)

Road with Cypress and Star
(V. van Gogh, 1890)

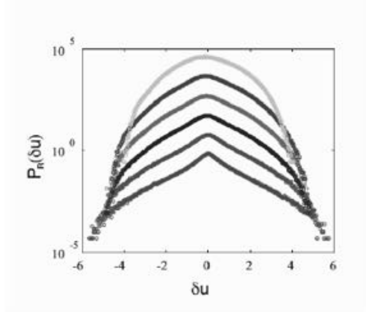
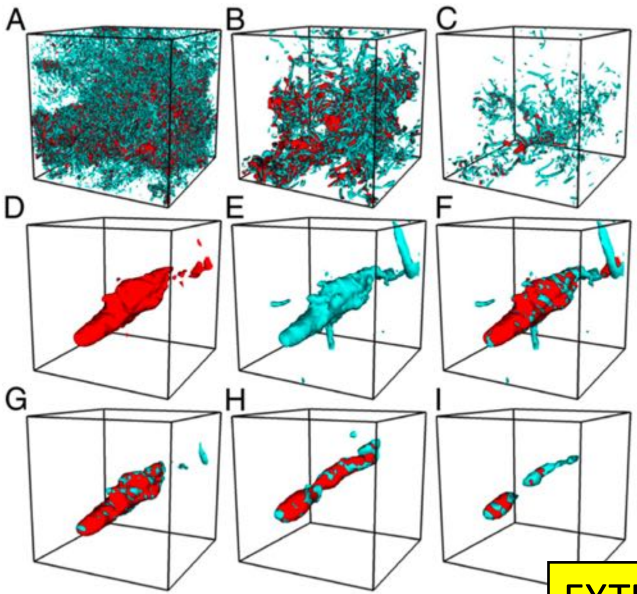



FIG. 5: Left: *Road with Cypress and Star* (Rijksmuseum Kröller-Müller, Otterlo). Right: PDF for pixel separations $R = 2, 5, 15, 20, 30, 60$ (from bottom to top). The studied image was taken from the WebMuseum-Paris, webpage.

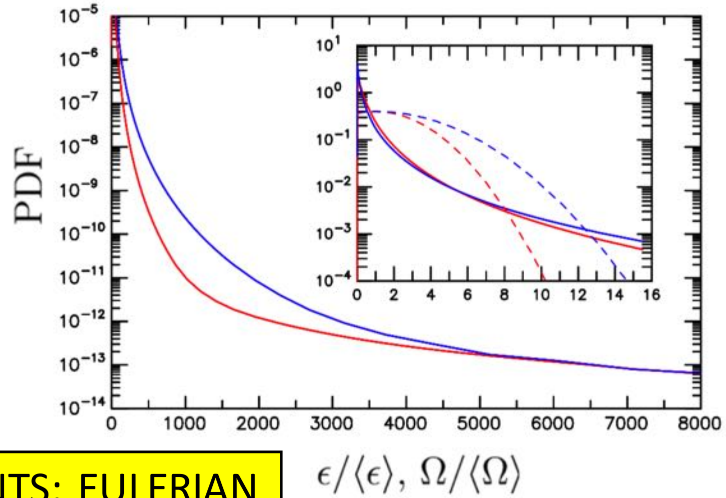
**Turbulent luminance in impassioned van Gogh paintings**
J.L. Aragón, Gerardo G. Naumis, M. Bai, M. Torres, P.K. Maini

**arXiv:physics/0606246 [physics.flu-dyn]**

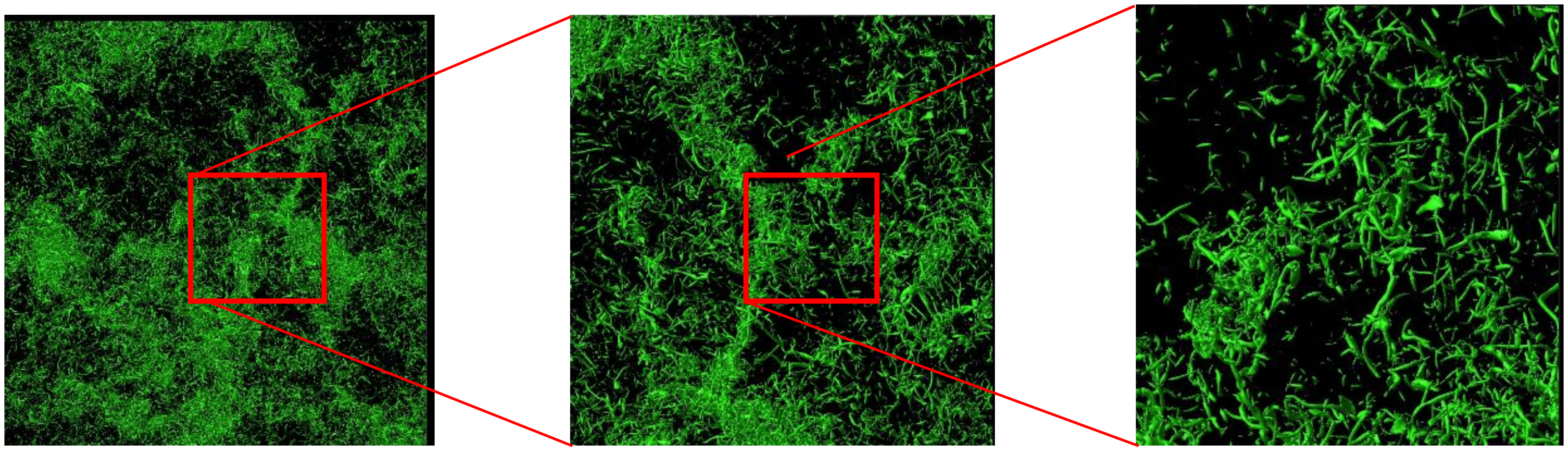
journal of Mathematical Imaging and Vision
March 2008, Volume 30, Issue 3, pp 275–283|
Turbulent Luminance in Impassioned van Gogh Paintings



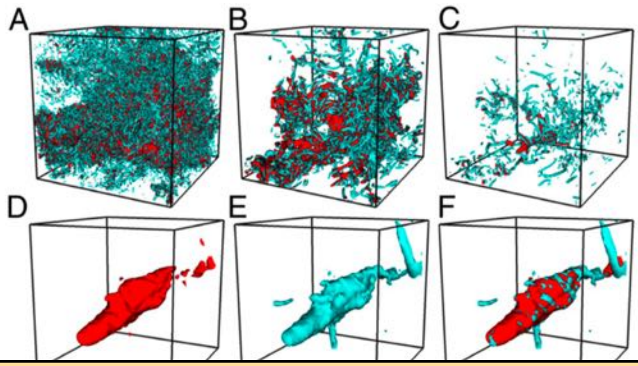

Extreme events in computational turbulence. P. K. Yeung , X. M. Zhai and K.R. Sreenivasan. PNAS 112(41) 12633 (2015)



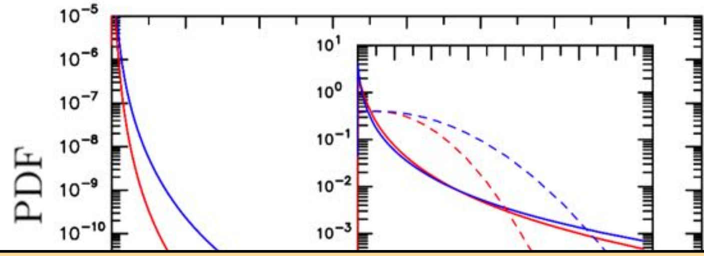

EXTREME EVENTS: EULERIAN



Watanabe and Gotoh, Phys. Fluids 19, 121701 (2007)




Extreme events in computational turbulence. P. K. Yeung , X. M. Zhai and K.R. Sreenivasan. PNAS 112(41) 12633 (2015)

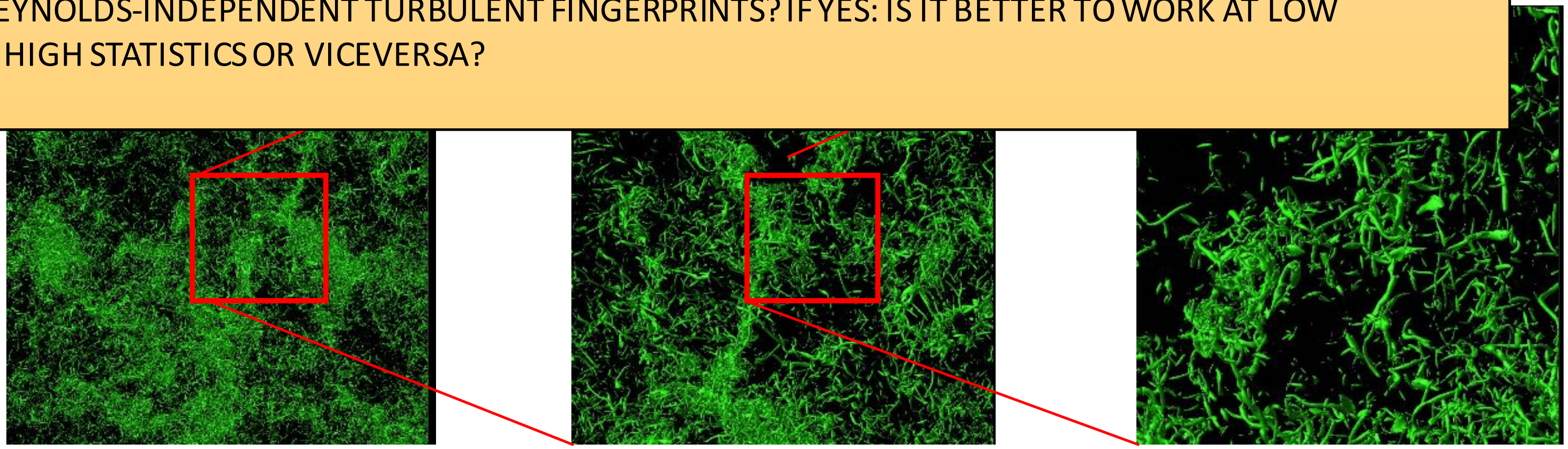



1. IS IT POSSIBILE TO PREFERENTIALLY TRACK INTENSE (LARGE- OR SMALL-SCALE) STRUCTURES?

2. CAN WE INVENT IN-SILICO EXPERIMENTS TO ENGINEER A (LAGRANGIAN) WAY TO CONTROL/STUDY TURBULENCE?

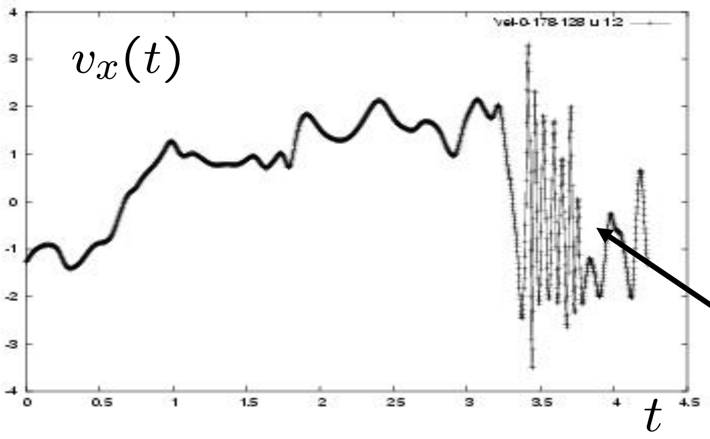
3. CAN WE IDENTIFY THE KEY DEGREES-OF-FREEDOM TO RECONSTRUCT THE FLOW (KEY FLOW STRUCTURES)?

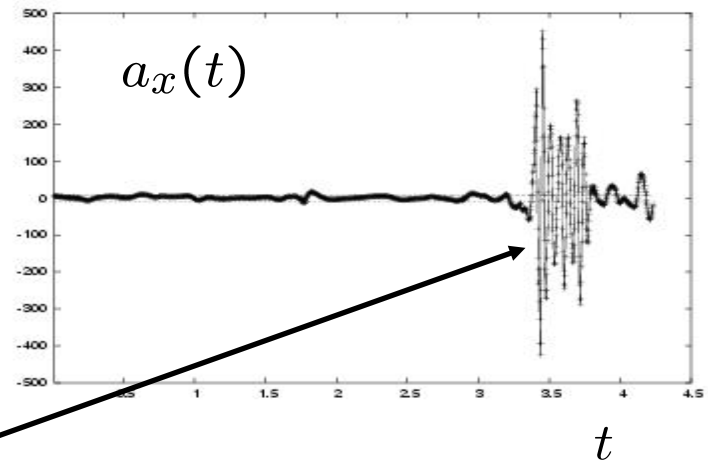
4. ARE THERE REYNOLDS-INDEPENDENT TURBULENT FINGERPRINTS? IF YES: IS IT BETTER TO WORK AT LOW REYNOLDS AND HIGH STATISTICS OR VICEVERSA?

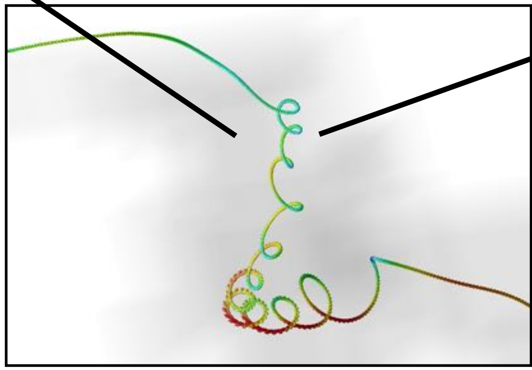


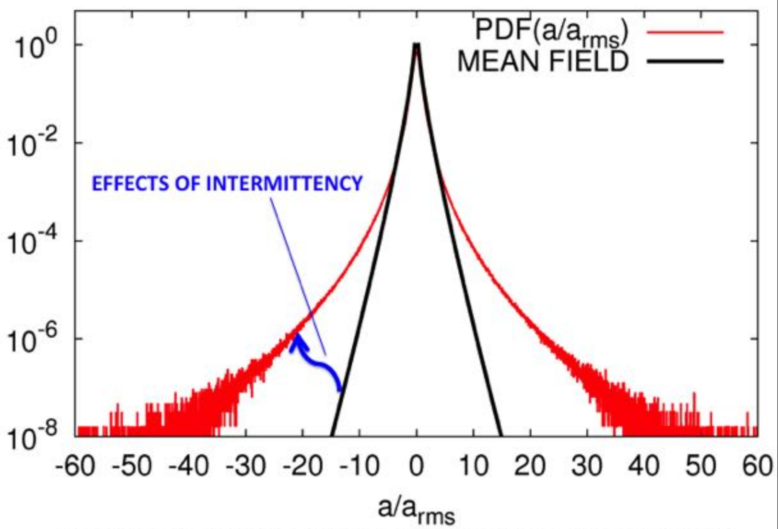
Watanabe and Gotoh, Phys. Fluids 19, 121701 (2007)

# EXTREME EVENTS: LAGRANGIAN






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

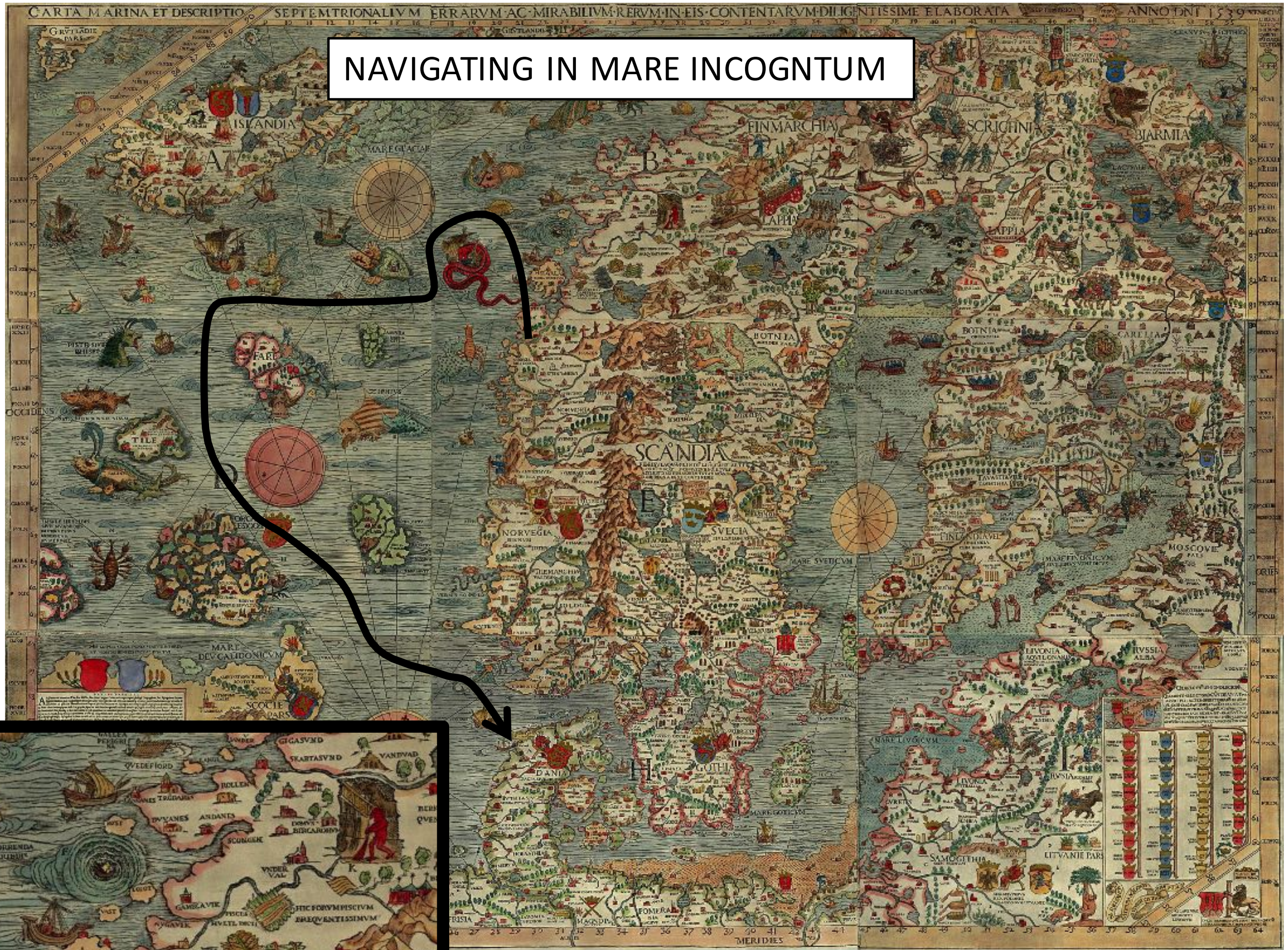

L.B., G Boffetta, A Celani, A Lanotte, F Toschi. Particle trapping in three-dimensional fully developed turbulence Physics of Fluids 17 (2), 021701 (2005)

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)

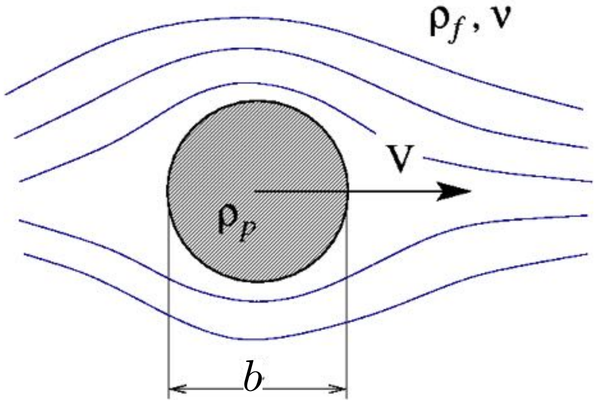
NAVIGATING IN MARE INCOGNTUM



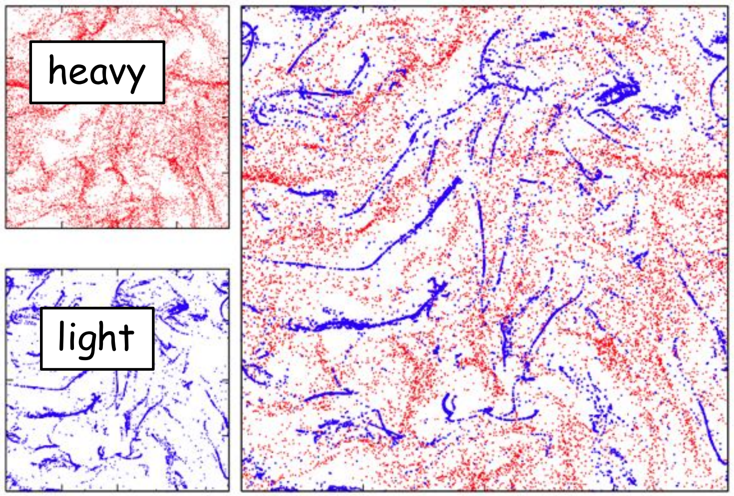


***Carta Marina*** *et descriptio septemtrionalium terrarum ac mirabilium rerum in eis contentarum, diligentissime elaborata anno* ***1539*** *Veneciis.* **Olao Magno**

## INERTIAL PARTICLES IN COMPLEX FLOWS




$$\begin{cases} \partial_t \mathbf{v} + \mathbf{v} \cdot \partial_{\mathbf{x}} \mathbf{v} + \partial_{\mathbf{x}} P = \nu \Delta \mathbf{v} \\ \dot{\mathbf{X}}_i = \mathbf{U}_i \\ \dot{\mathbf{U}}_i = -\frac{\mathbf{U}_i - \mathbf{v}}{\tau} + \beta D_t \mathbf{v} - g(1-\beta)\hat{\mathbf{z}} \end{cases}$$




$$\beta = \frac{3\rho_f}{\rho_f + 2\rho_p}$$

$\beta<1$ heavy particles

$\beta>1$ light particles

$$\tau = \frac{b^2}{3\nu\beta}$$

Drag: **Stokes Time**

**Preferential concentration**

Naive light(heavy) particles accumulate inside(outside) highly vortical regions

M.R. Maxey, J. Fluid Mech. **174**, 441 (1987); G. Falkovich et al, Phys. Rev. Lett. **86**, 2790 (2001)

**OLD QUESTIONS:**

1. IS IT POSSIBILE TO PREFERENTIALLY TRACK INTENSE (LARGE- OR SMALL-SCALE) STRUCTURES?
2. CAN WE INVENT IN-SILICO EXPERIMENTS TO ENGINEER A (LAGRANGIAN) WAY TO CONTROL/STUDY TURBULENCE?
3. CAN WE IDENTIFY THE KEY DEGREES-OF-FREEDOM TO RECONSTRUCT THE FLOW (KEY FLOW STRUCTURES)?
4. ARE THERE REYNOLDS-INDEPENDENT TURBULENT FINGERPRINTS? IF YES: IS IT BETTER TO WORK AT LOW REYNOLDS AND HIGH STATISTICS OR VICEVERSA?

**NEW TOOLS:**

**1. SMART LAGRANGIAN PROBES (ONE-WAY COUPLING):** REINFORCEMENT LEARNING TO TRACK PREFERENTIAL VORTICITY STRUCTURES (OR STRAIN, QUADRANTS, HAIRPINS, THERMAL PLUMES…)

**2. SMART LAGRANGIAN PROBES (TWO-WAY COUPLING):** AD-HOC FEEDBACK ON THE FLOW STRUCTURES TO CONTROL TURBULENCE

**3. NUDGING**: AN EQUATION-INFORMED TOOL TO ASSIMILATE AND RECONSTRUCT TURBULENCE DATA

**4. HYBRID-MONTE-CARLO** FOR MARTIN-SIGGIA-ROSE STOCHASTIC PDES: A TOOL TO PREFERENTIALLY FOCUS ON INTENSE-AND-RARE FLUCTUATIONS (INSTANTONS) AT SMALL REYNOLDS