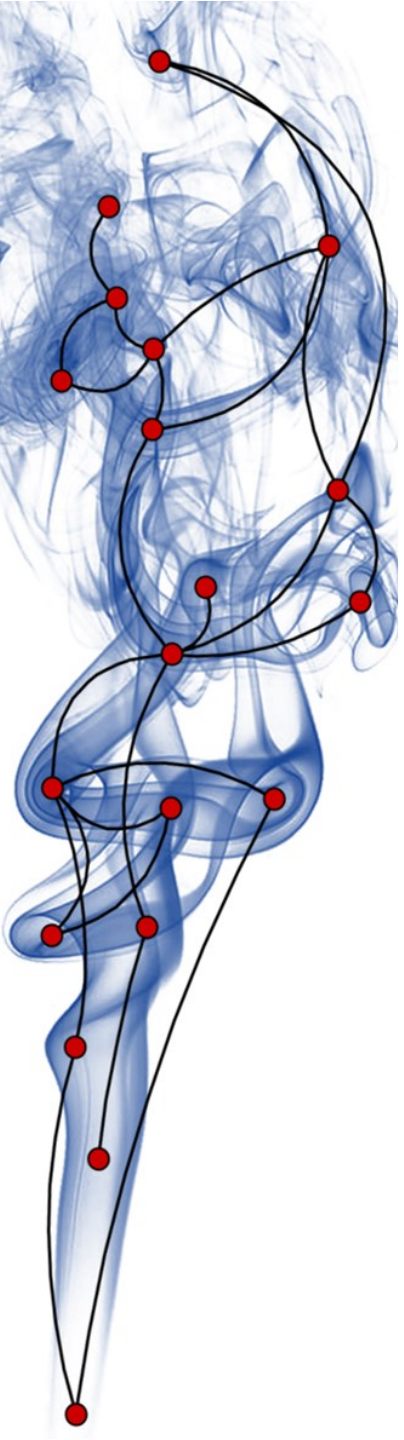


Online Workshop on Network Science for Fluid Dynamics

24-25, June 2020

Complex networks approach to wall-bounded turbulence

Research group @ Politecnico di Torino (Italy)

Group members:

Dr. Giovanni Iacobello (Speaker)

Prof. Stefania Scarsoglio

Prof. Luca Ridolfi

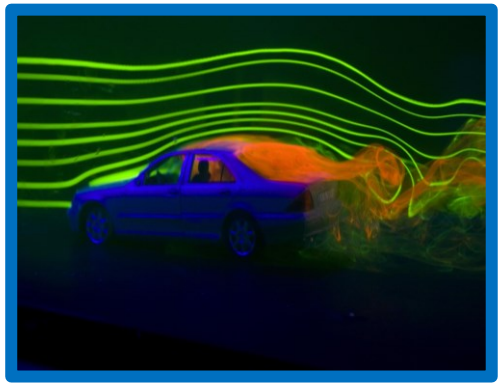
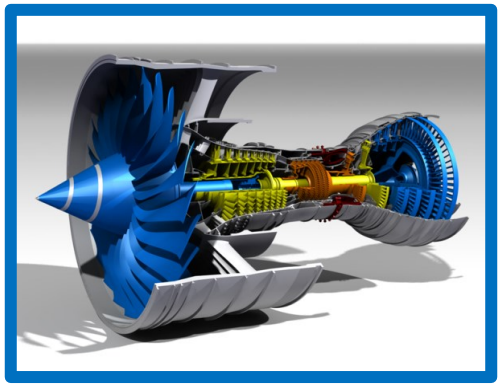
Davide Perrone, PhD student

Collaborations:

Prof. J.G.M. Kuerten (TU Eindhoven)

Prof. Pietro Salizzoni (École Centrale de Lyon)

Prof. Umberto Morbiducci (Politecnico di Torino)

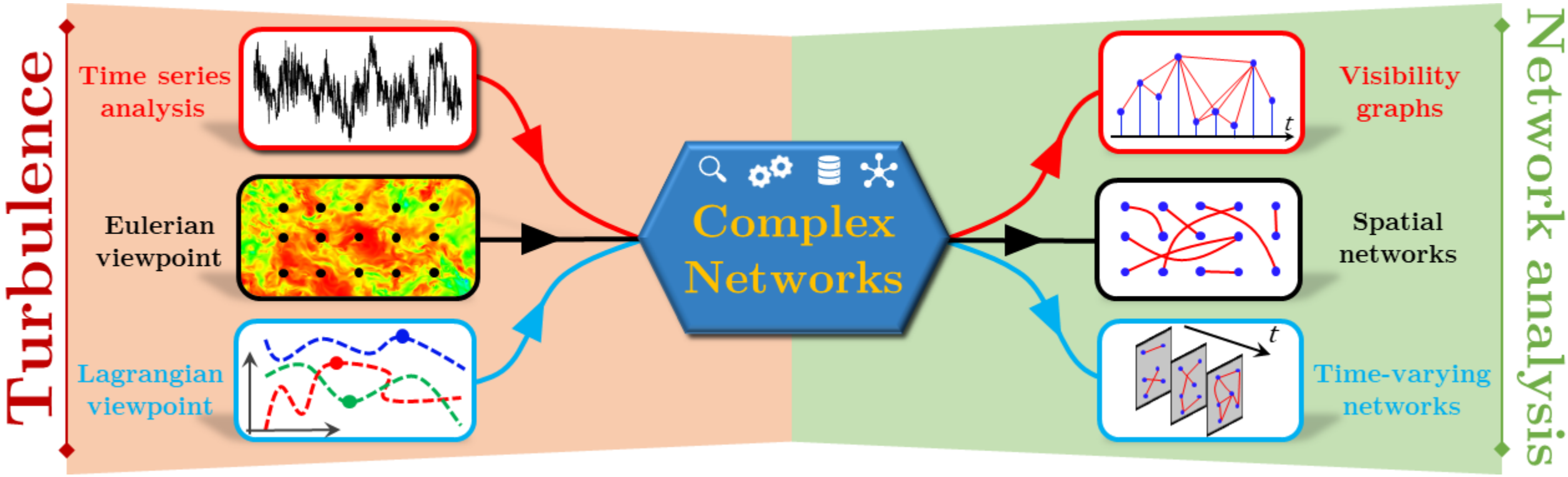




Why wall-turbulence?

- **Technological importance**
- **Energetics – Optimization**
- **Fluid transport**
- **Environmental issues**

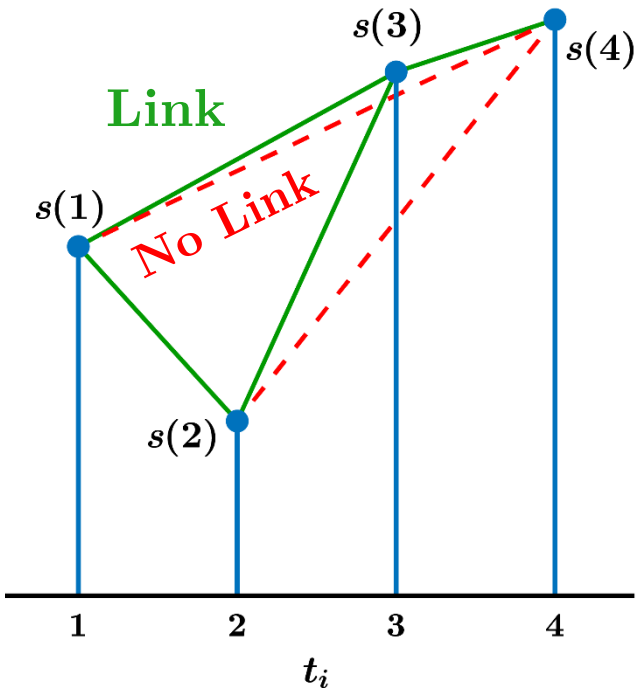
"A 5% reduction of the transportation energy loss in the US would have an environmental impact comparable to a doubling of wind energy production." ⁎

⁎ Smits A. J. and Marusic I.. "Wall-bounded turbulence". In: Physics Today 66.9 (2013), pp. 25–30.



Iacobello G., (**2020**). **PhD Thesis**

Time series → Mapping algorithm → Complex Network

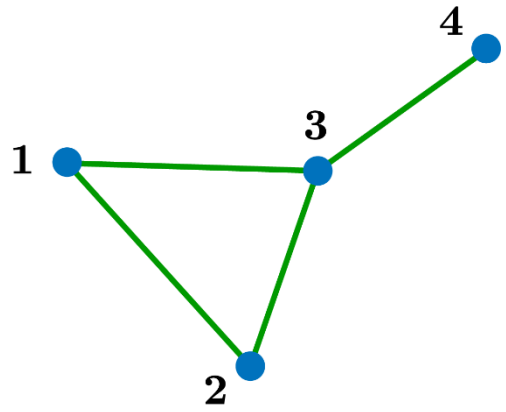


Visibility graph

- Convexity criterion
- Time samples = Nodes
- Invariant under rescaling and translation

$$s(t_k) < s(t_j) + \left(s(t_i) - s(t_j)\right)\frac{t_k - t_j}{t_i - t_j},$$

$$i < k < j$$

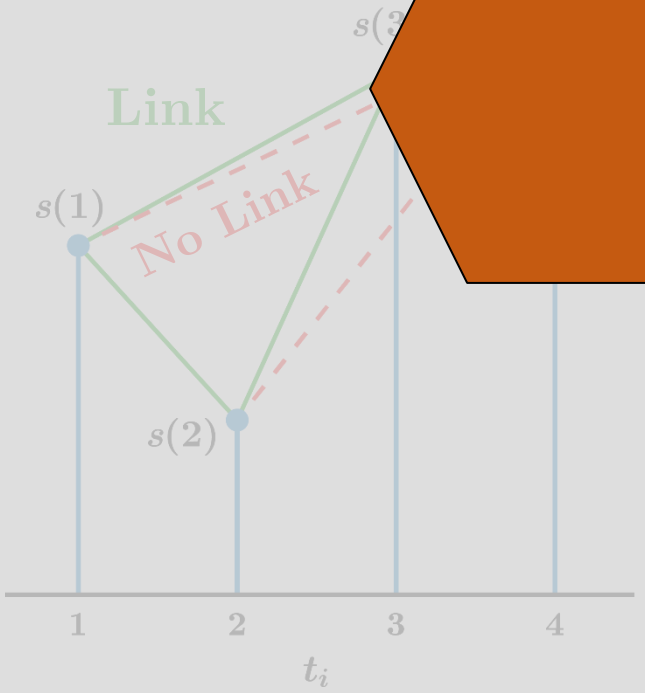


Network hubs ↔ peaks

Lacasa, L., et al. *PNAS* 105.13 (2008): 4972-4975.

Time series → Mapping algorithm → Complex Network

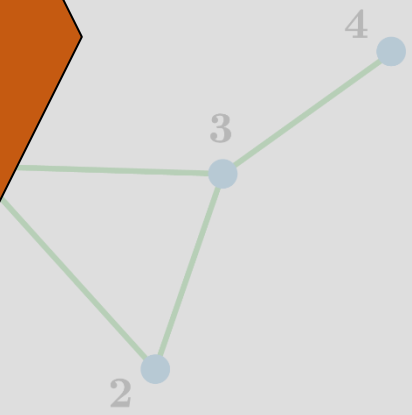
Visibility-networks are sensitive to the temporal structure of the series



and translation

$$s(t_k) < s(t_j) + \left(s(t_i) - s(t_j)\right)\frac{t_k - t_j}{t_i - t_j},$$

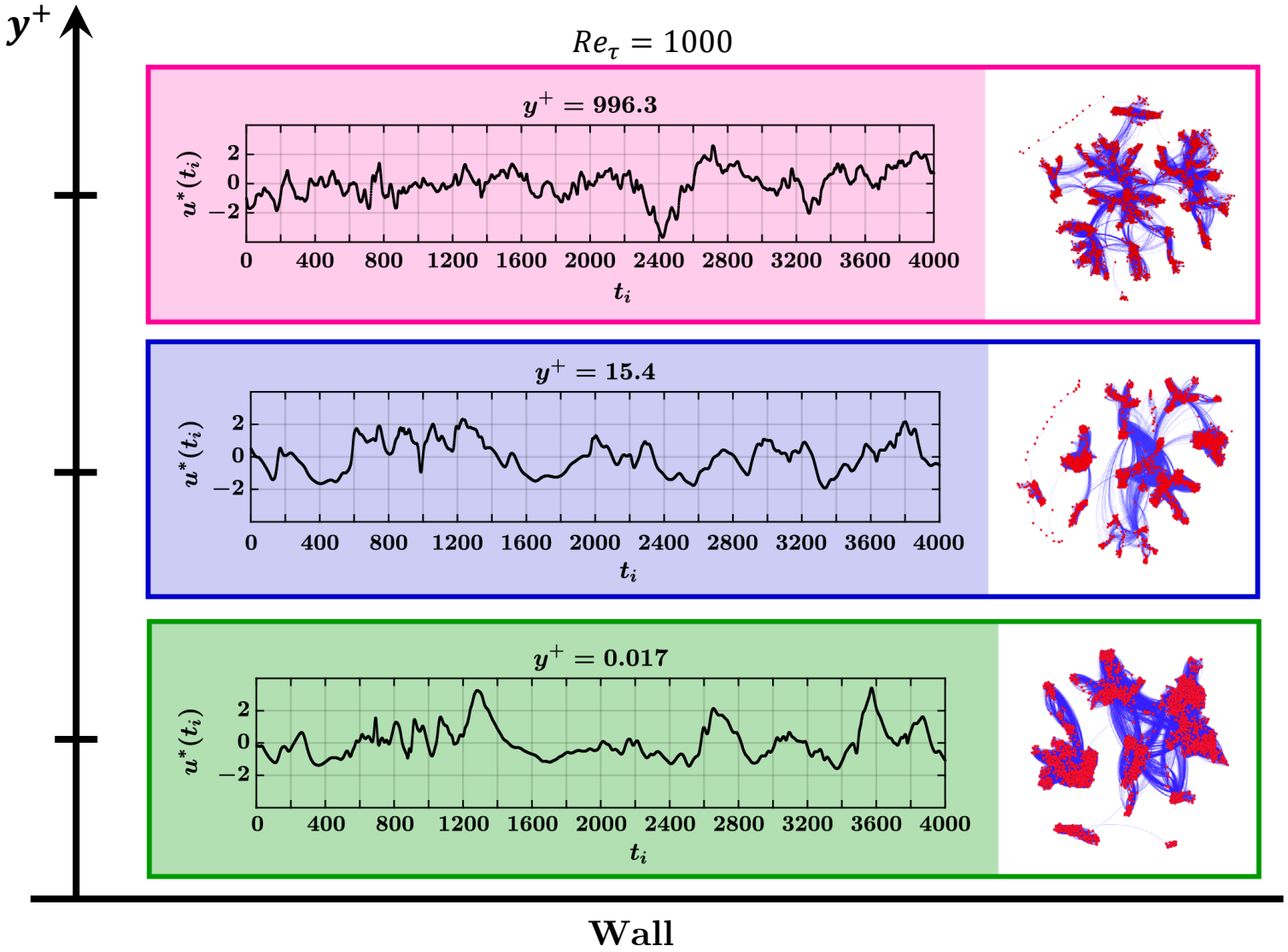
$$i < k < j$$

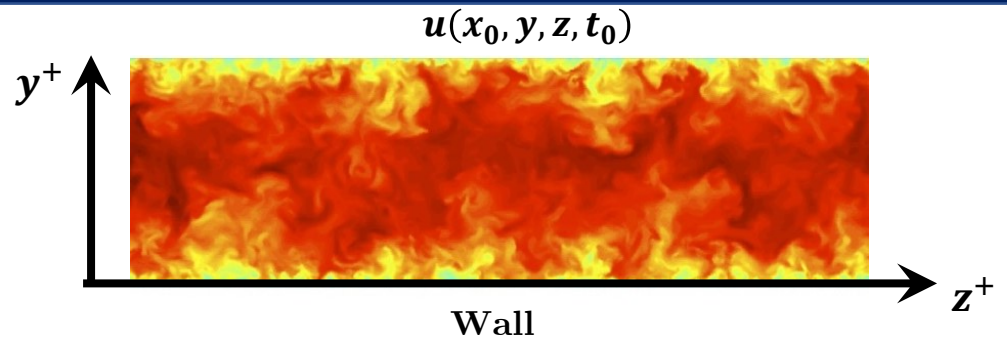


Network hubs ↔ peaks

Lacasa, L., et al. *PNAS* 105.13 (2008): 4972-4975.

Fully-developed turbulent channel flow
(DNS data – Johns Hopkins Turbulence DB)



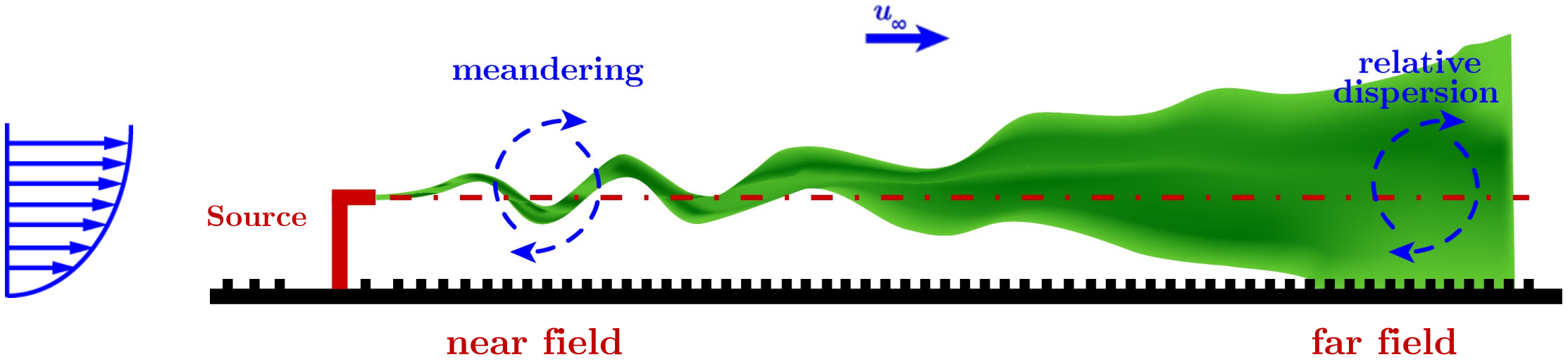


✓ Different temporal structures → different network properties

- Highlight **occurrence** of peaks (extreme events)
- Highlight the presence of **irregularities** (small fluctuations)
- The **metric behaviours** reveal the relative intensity of peaks and irregularities

Iacobello, G., Scarsoglio, S., & Ridolfi, L. (**2018**). **Physics Letters A**, 382(1), 1-11.

Passive scalar plume in a turbulent boundary layer (experimental data)



Iacobello, G. et al. (**2019**). **Physical Review Fluids**, 4(10), 104501.

Iacobello, G., et al. (**2018**). **Progress in Turbulence VIII (Springer)**

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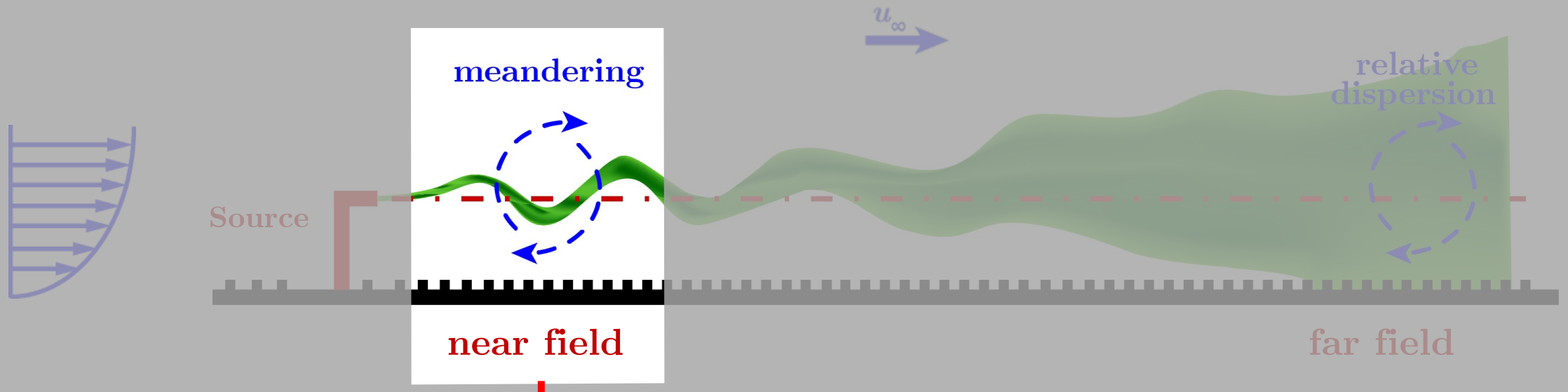
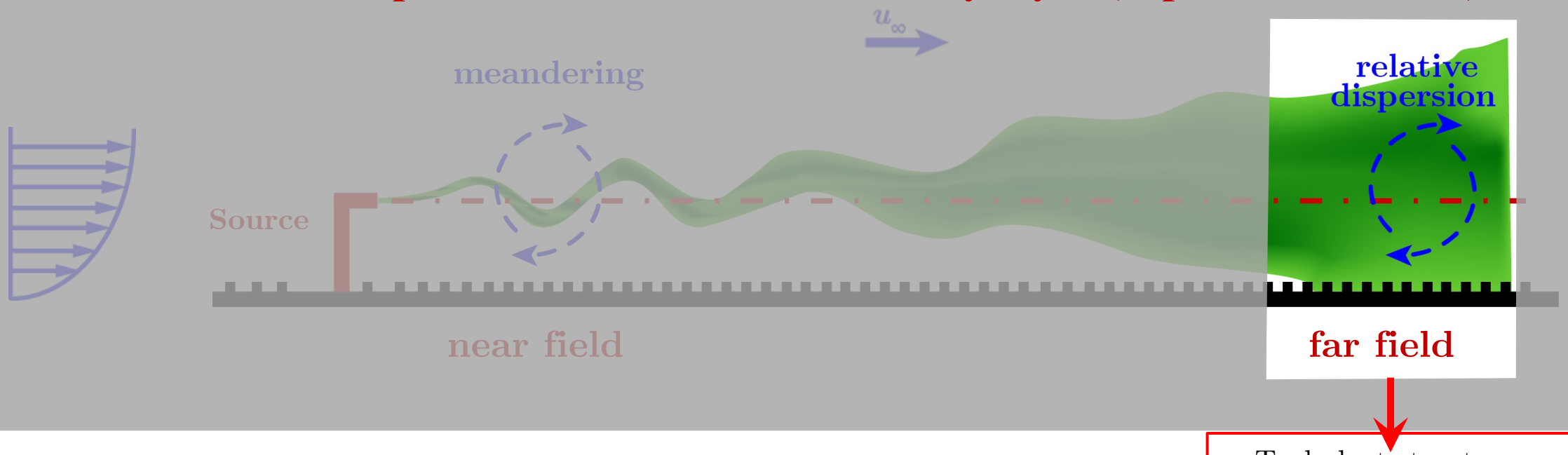


Turbulent structures **larger** than the instantaneous plume size

Iacobello, G. et al. (**2019**). **Physical Review Fluids**, 4(10), 104501.

Iacobello, G., et al. (**2018**). **Progress in Turbulence VIII (Springer)**

Passive scalar plume in a turbulent boundary layer (experimental data)

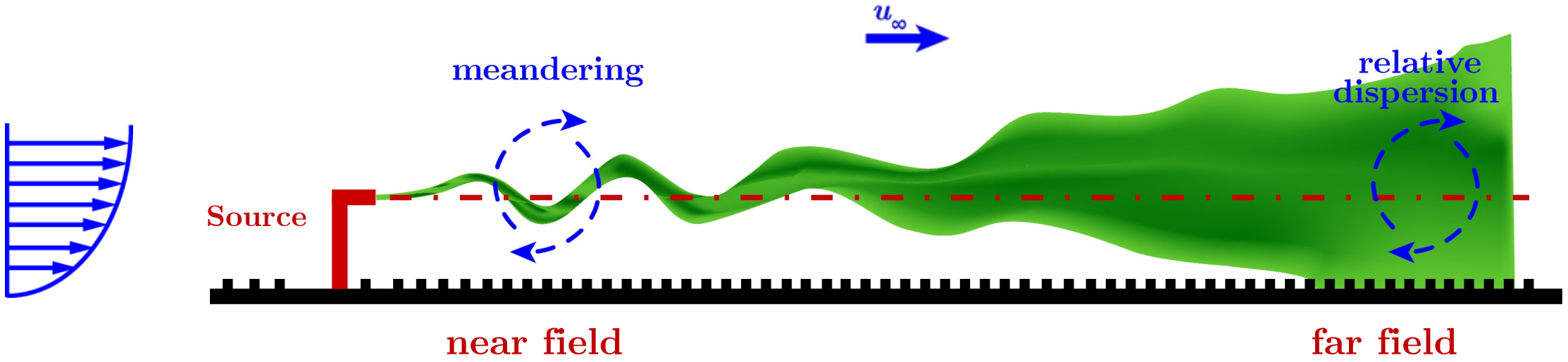


Turbulent structures **smaller** than the instantaneous plume size

Iacobello, G. et al. (**2019**). **Physical Review Fluids**, 4(10), 104501.

Iacobello, G., et al. (**2018**). **Progress in Turbulence VIII (Springer)**

Passive scalar plume in a turbulent boundary layer (experimental data)



Previous findings:

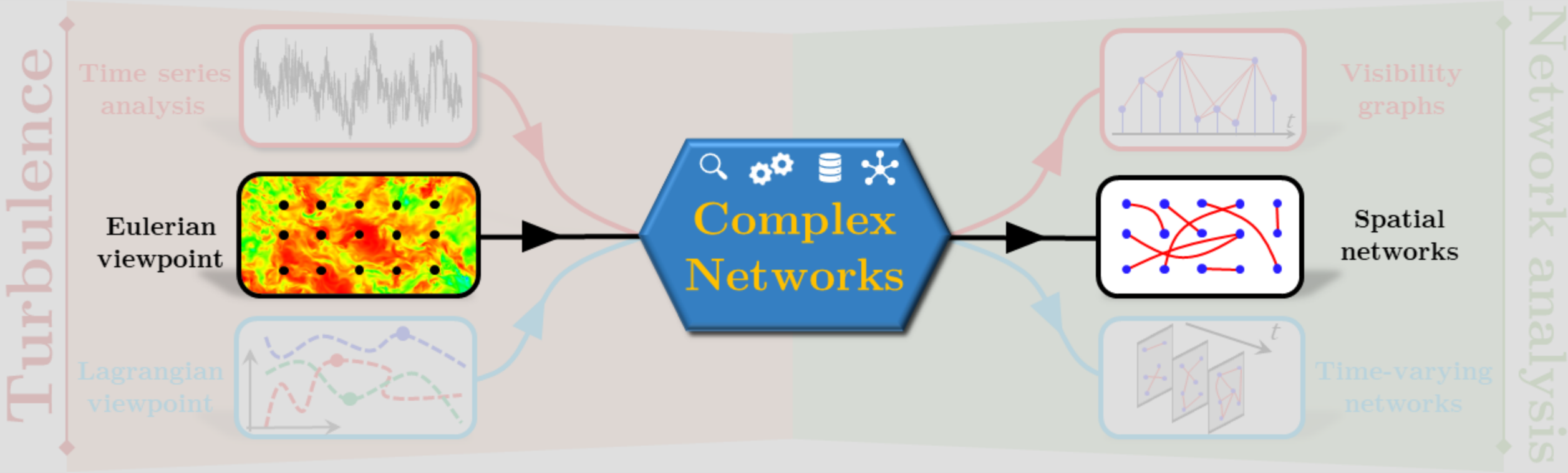
Smaller source size → stronger meandering motion (near field) → higher intermittency.

Network metrics – Near field:

- Decreasing occurrence of extreme events for smaller source sizes;
- Increasing relative intensity of extreme events (outliers) for smaller source sizes.

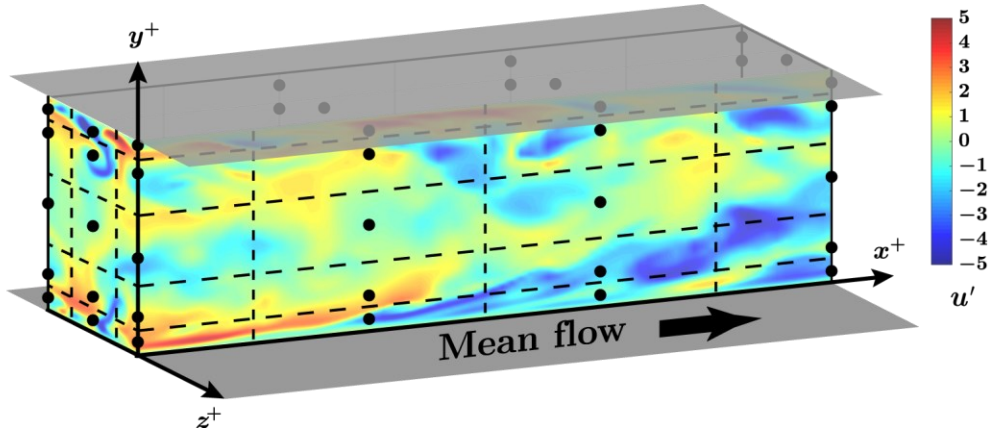
Iacobello, G. et al. (**2019**). **Physical Review Fluids**, 4(10), 104501.

Iacobello, G., et al. (**2018**). **Progress in Turbulence VIII (Springer)**



Iacobello G., (**2020**). **PhD Thesis**

- DNS of a fully developed turbulent channel flow
- $Re_\tau = 180$
- Streamwise velocity, u

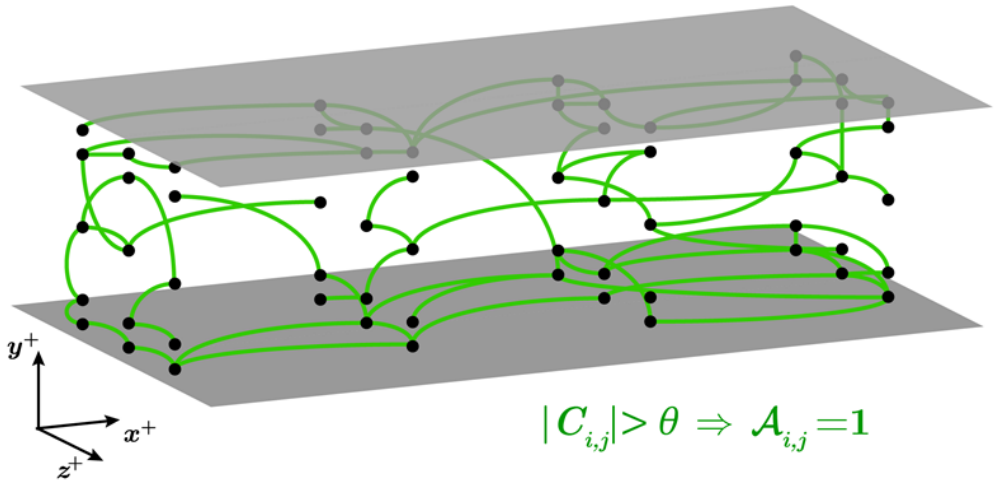


» What is the spatial organization of high correlation values? «

Spatial correlation-network:

- **Nodes:** fixed spatial positions ($\sim 10^6$)
- **Links:** high u-based correlation coefficients,

$$|C_{i,j}| > threshold$$



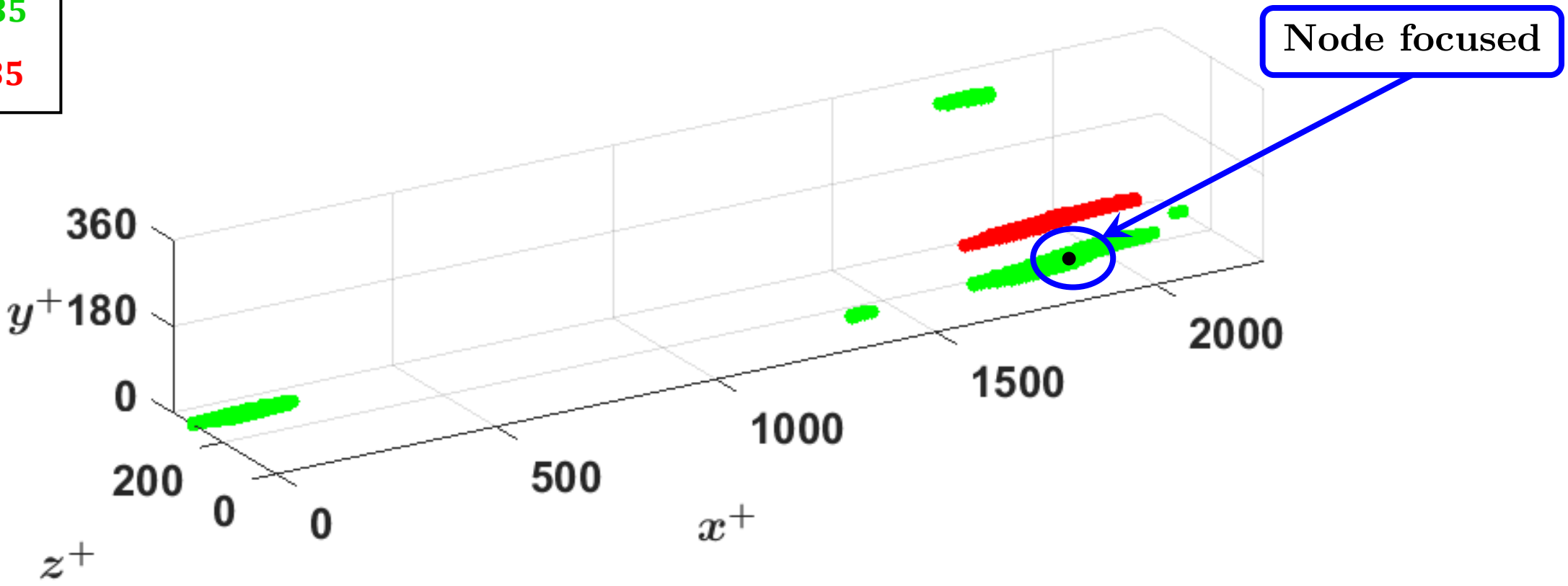
Iacobello G., Scarsoglio, S., Kuerten, J. G. M., & Ridolfi, L. (**2018**). **Physical Review E**, 98(1), 013107.

Iacobello G., (**2020**). **PhD Thesis**

$C_{i,j} > +0.85$

$C_{i,j} < -0.85$

$y^+ = 3.5, \quad T^+ = 225$



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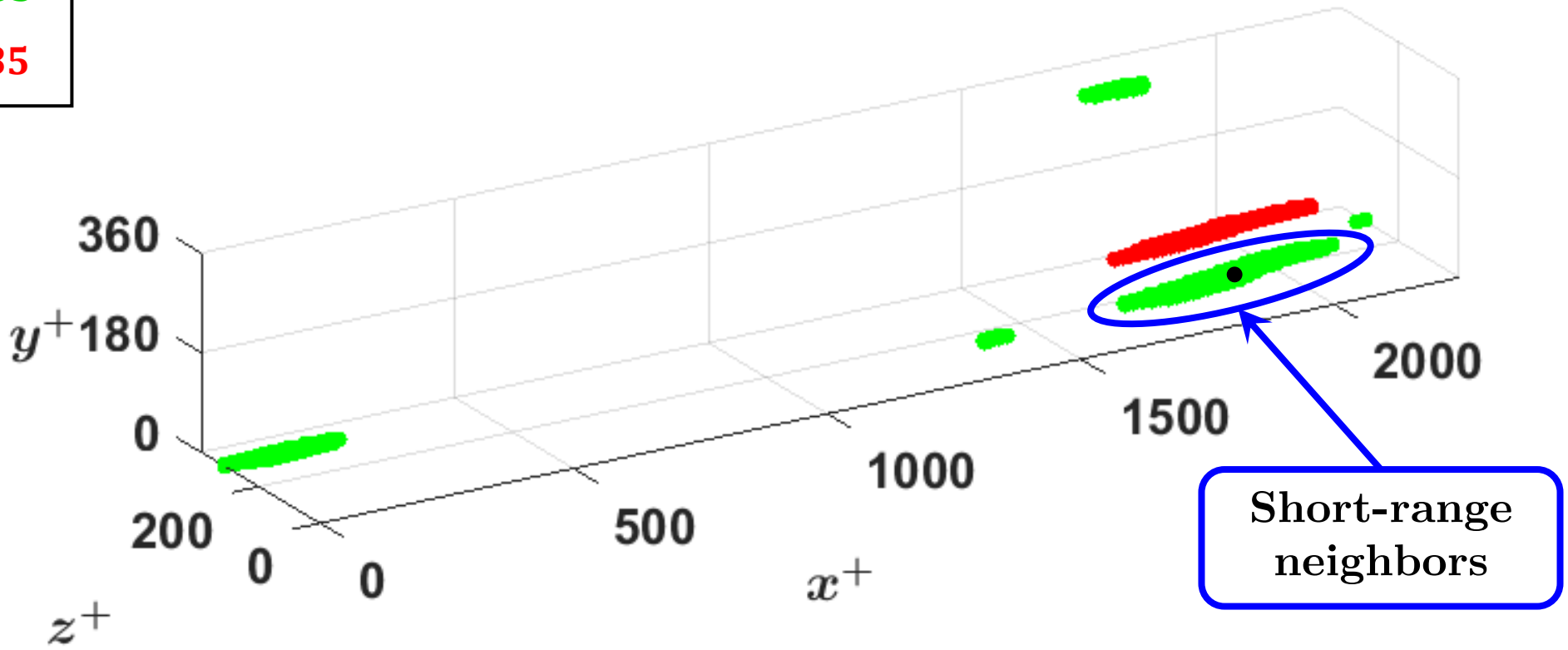

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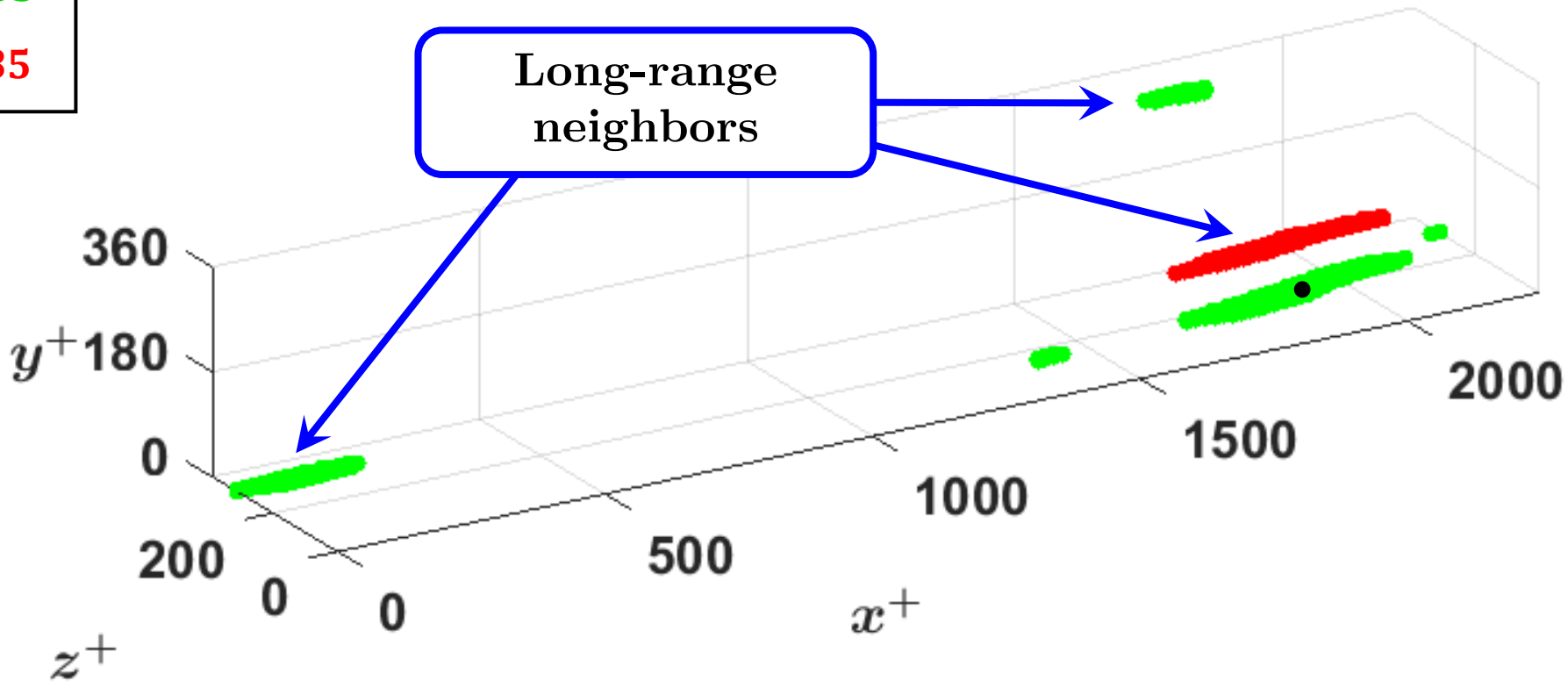


Teleconnections:

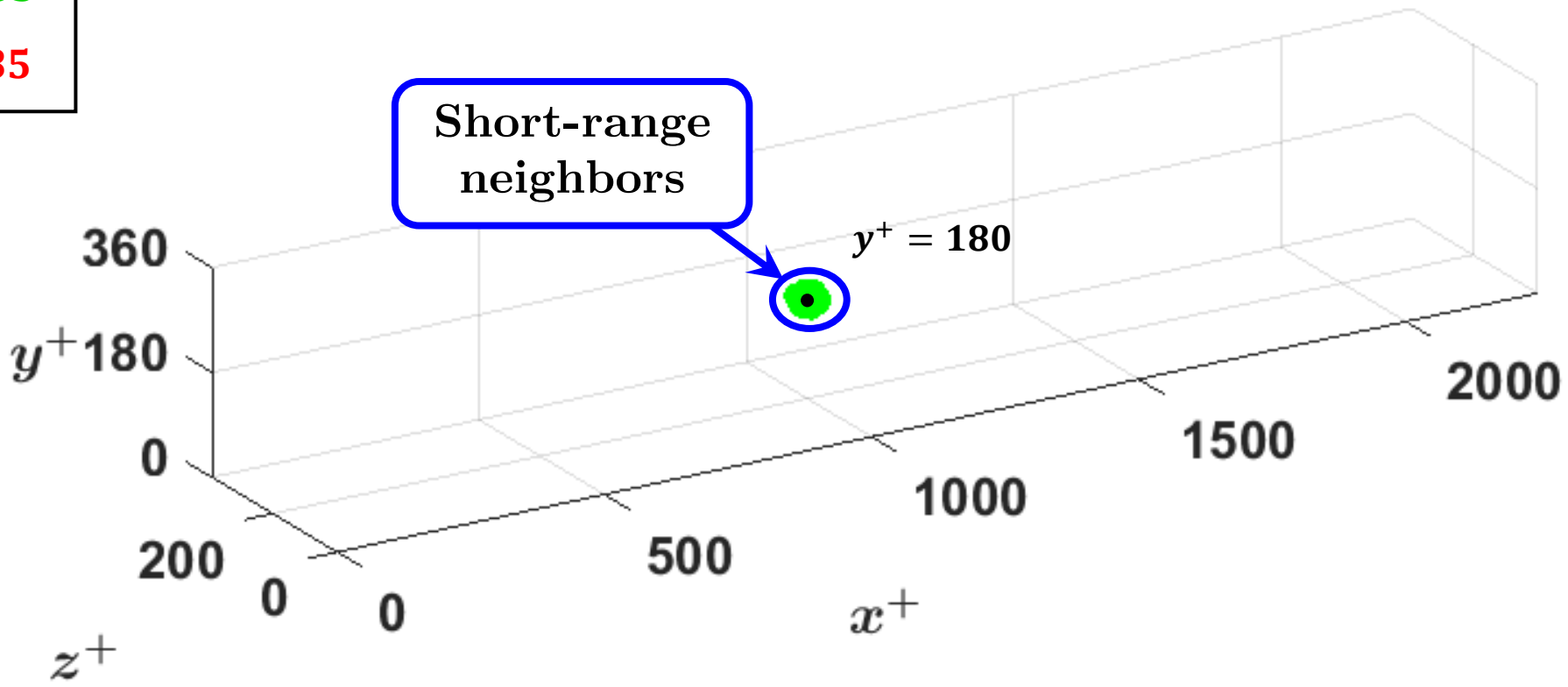
long-distance high-correlation links →
Imprint of coherent high- and low-speed streaks

Iacobello G., Scarsoglio, S., Kuerten, J. G. M., & Ridolfi, L. (**2018**). **Physical Review E**, 98(1), 013107.

$y^+ = 180, \;\; T^+ = 225$

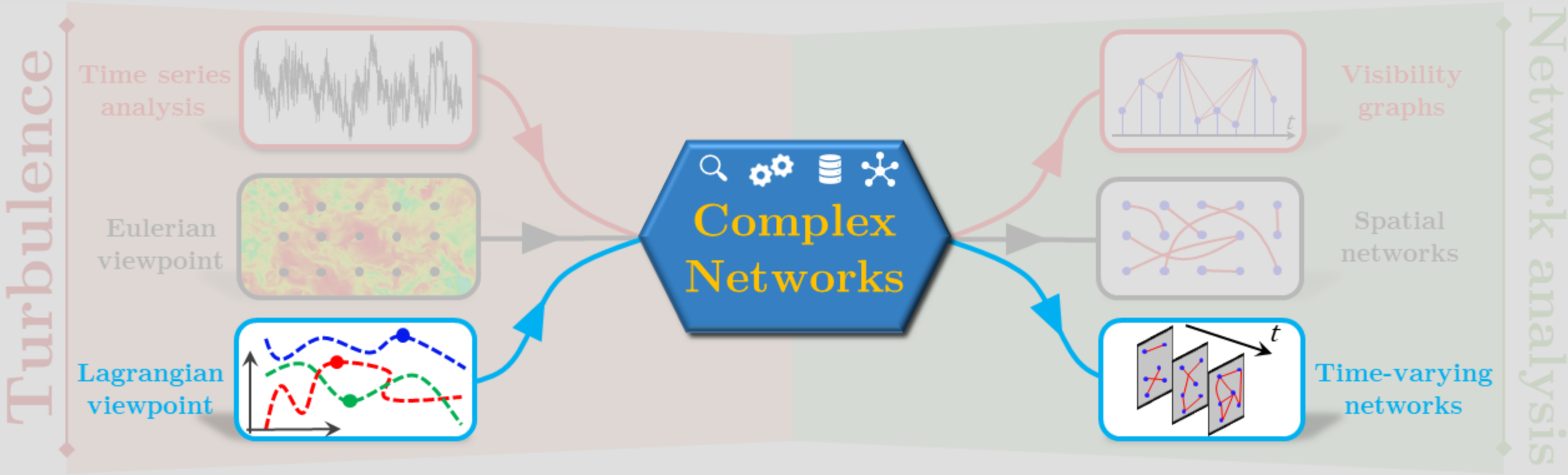
$C_{i,j} > +0.85$

$C_{i,j} < -0.85$



No teleconnections
for nodes far from the walls

Iacobello G., Scarsoglio, S., Kuerten, J. G. M., & Ridolfi, L. (**2018**). **Physical Review E**, 98(1), 013107.



Iacobello G., (**2020**). **PhD Thesis**

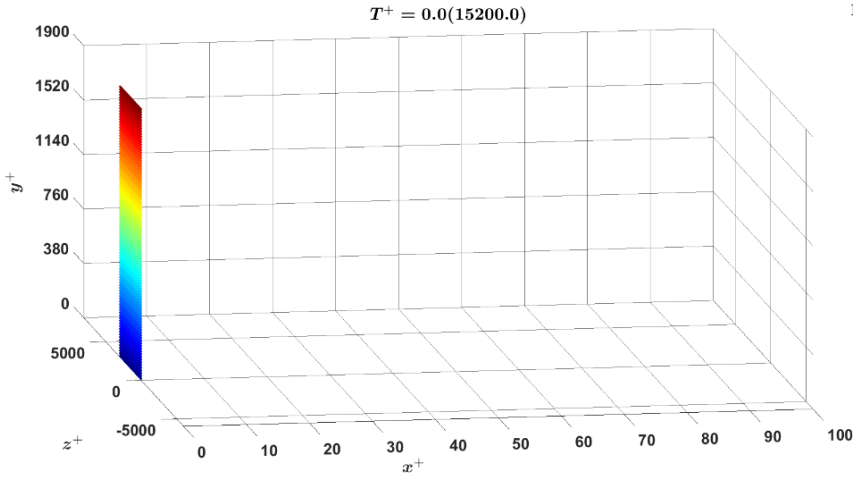
Dispersion of fluid particles in a turbulent channel flow:

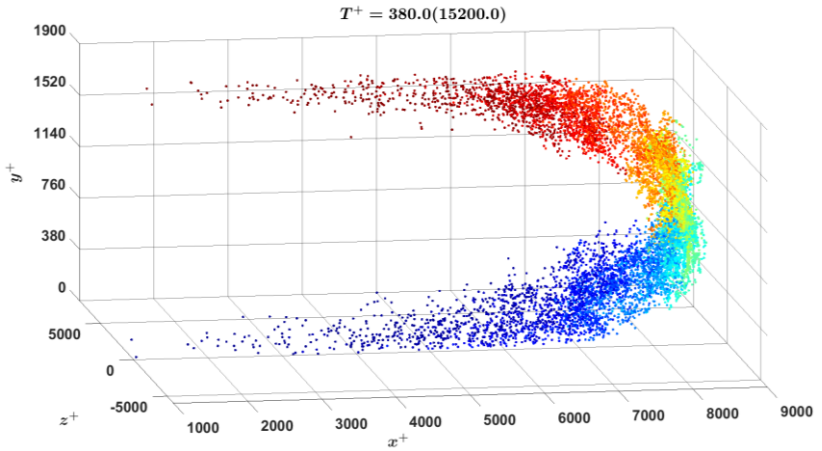
DNS:

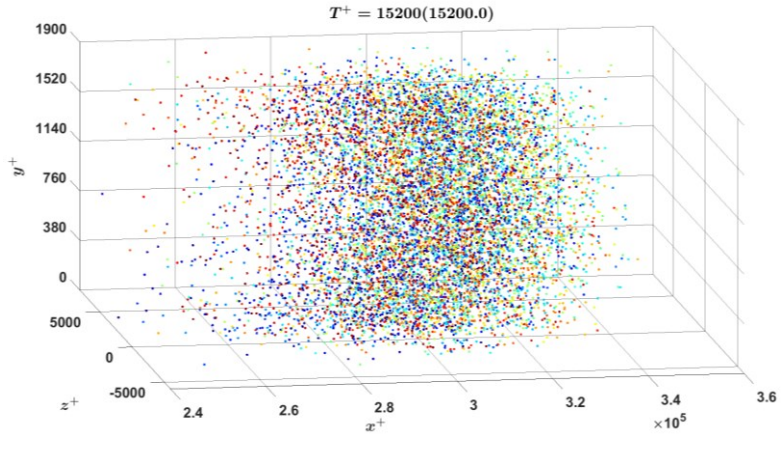
- $Re_\tau = 950$
- $T^+ = 15200$ $(\Delta t^+ = 4.75)$

Fluid particles ($t = 0$):

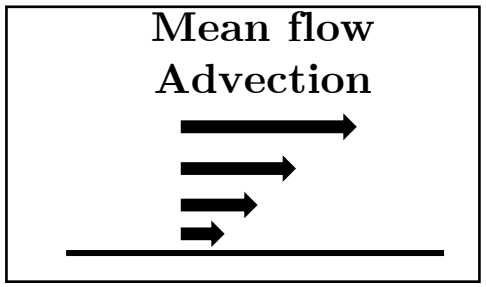
$N_y \times N_z = 100 \times 100$





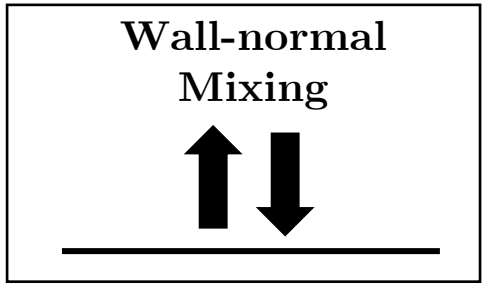


t



Short time

+



Long time

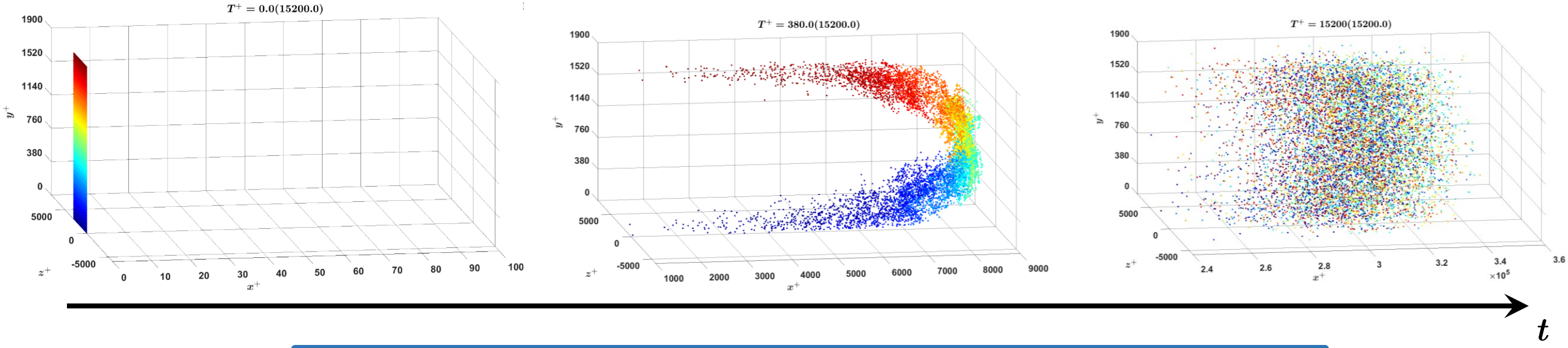
Dispersion of fluid particles in a turbulent channel flow:

DNS:

- $Re_\tau = 950$
- $T^+ = 15200$ $(\Delta t^+ = 4.75)$

Fluid particles ($t = 0$):

$N_y \times N_z = 100 \times 100$

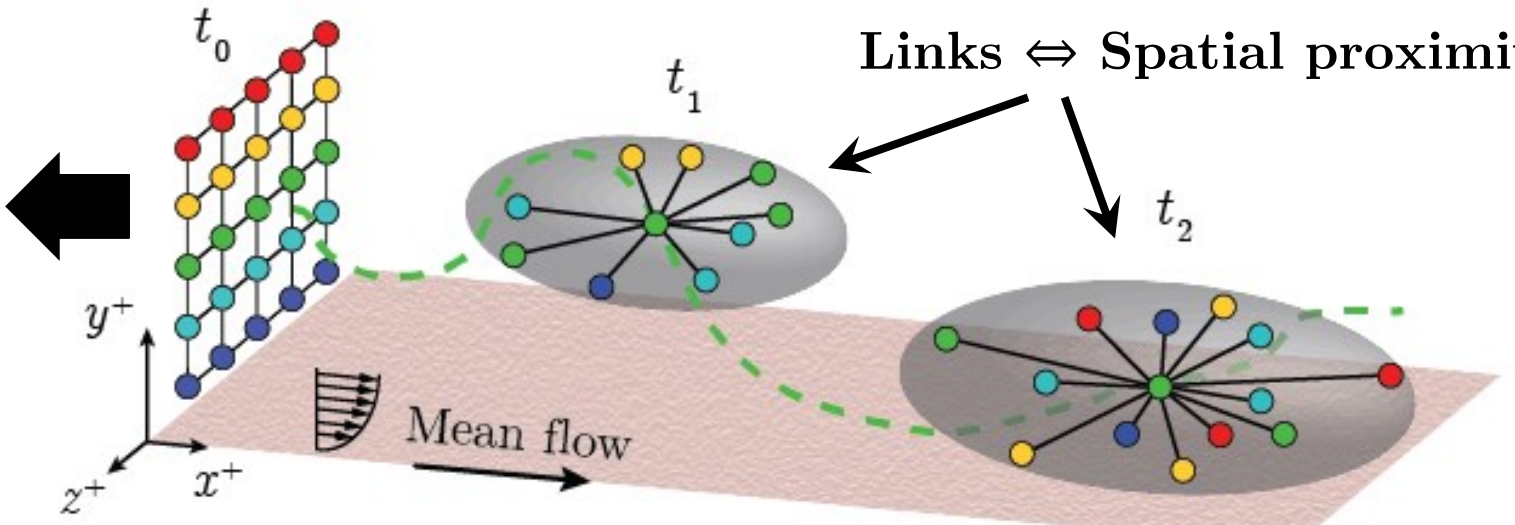


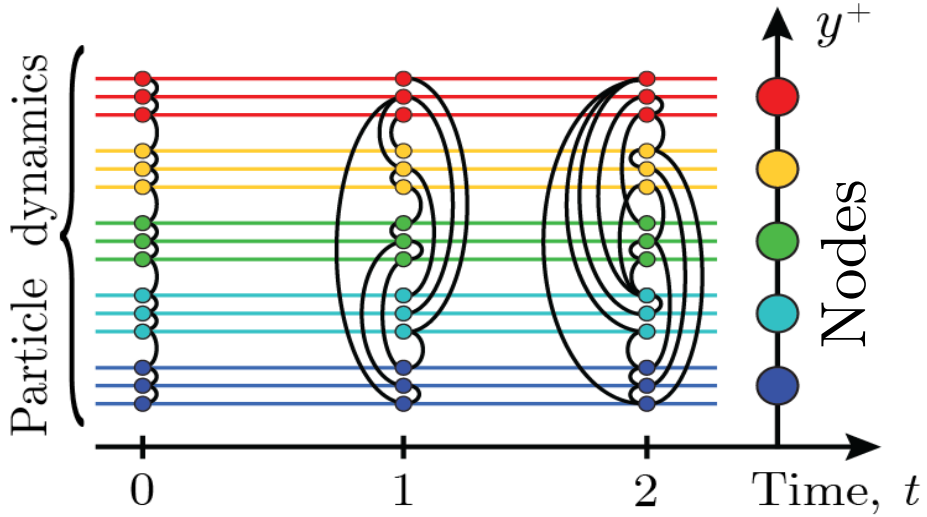
Geometrical representation of <u>turbulence mixing</u> via complex networks

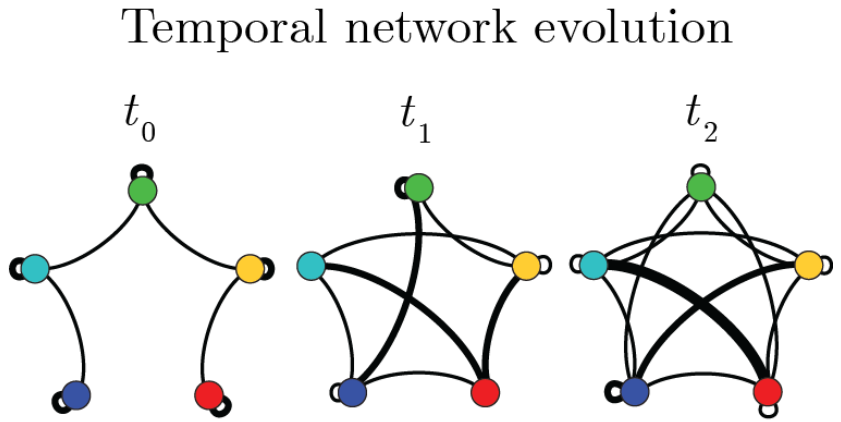
Iacobello G., Scarsoglio S., Kuerten J.G.M., & Ridolfi L., **Journal of Fluid Mechanics**, 865 (**2019**), 546-562.

Lagrangian network approach

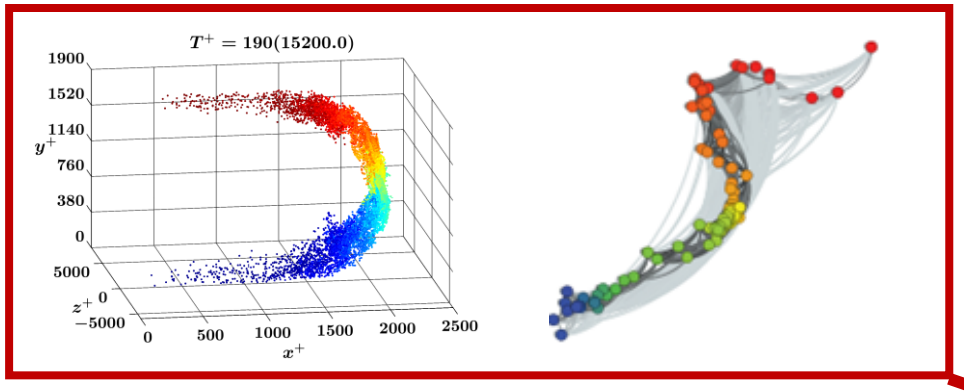
Nodes = y^+- rows of particles

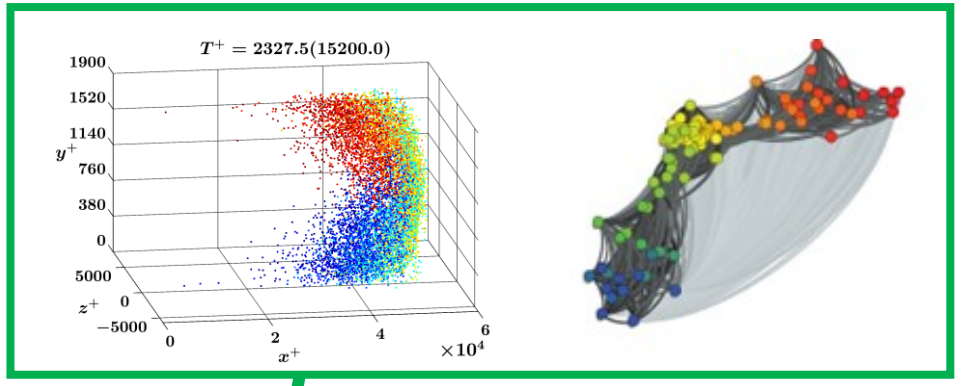




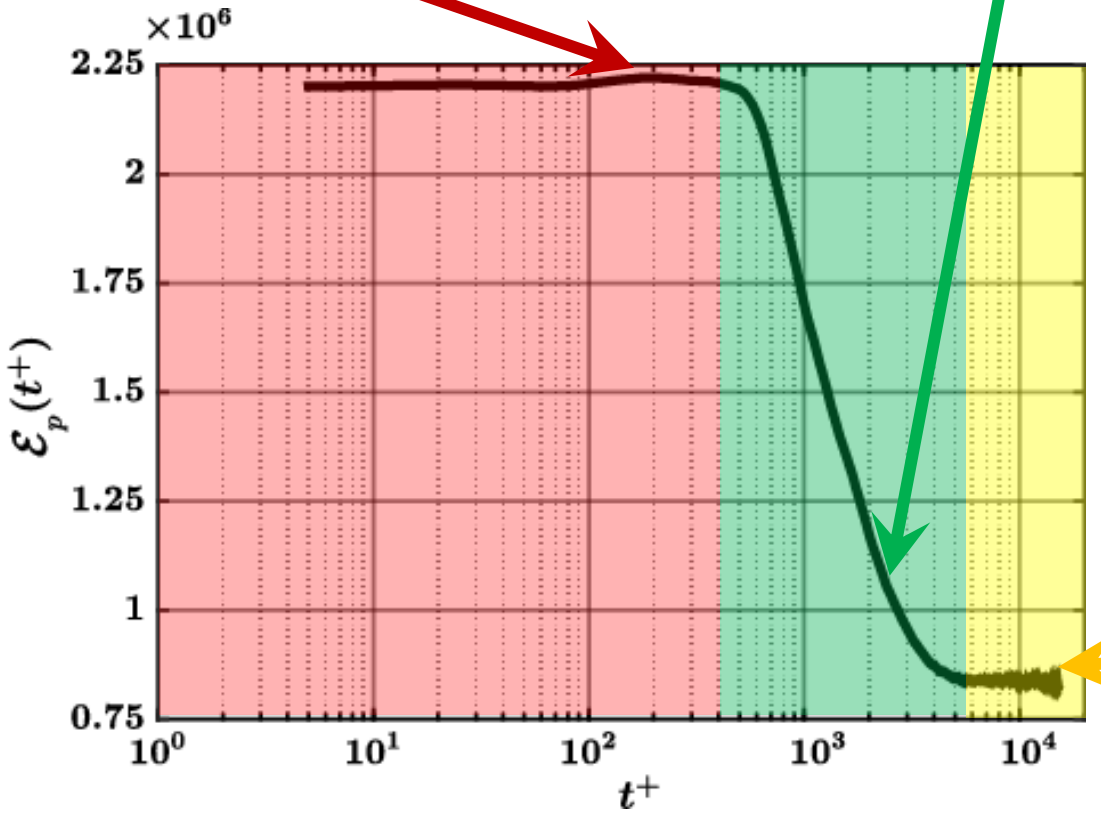


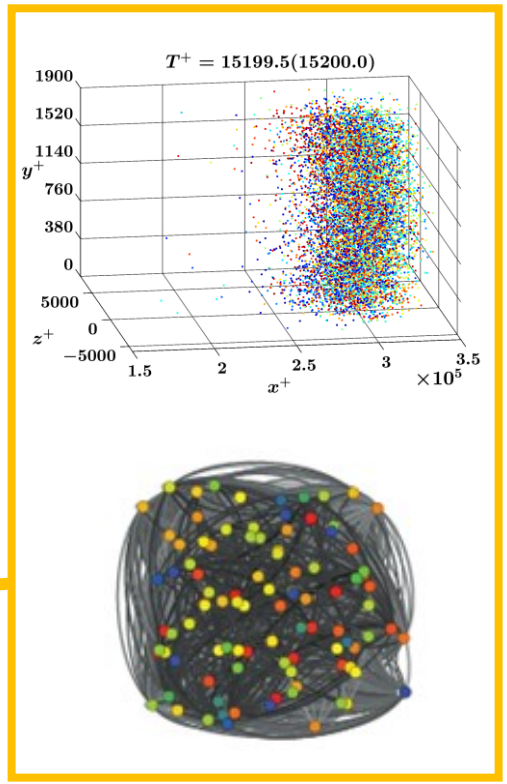
Link weight: number of connections between particles





Total number of connections





Iacobello G., Scarsoglio S., Kuerten J.G.M., & Ridolfi L., **Journal of Fluid Mechanics**, 865 (**2019**), 546-562.

✓ Highlight spatio-temporal features of the flow that would be difficult to capture by means of other techniques

- **Time-series:**
  - ❑ Highlight occurrence and (relative) intensity of **extreme events**.
  - ❑ Sensitiveness to the **temporal structure** of the signal → Different from kurtosis & higher-order moments

- **Spatial networks:**
  - ❖ Appearance of **teleconnections** between near wall regions along all directions.
  - ❖ High-correlation **spatial information** is retained → lost in two-point average correlation.

- **Particle trajectory-based networks:**
  - ➢ Identify characteristic regimes of **particle dynamics**: Advection → transition → mixing.
  - ➢ Lagrangian **transport and mixing** in wall-turbulence.

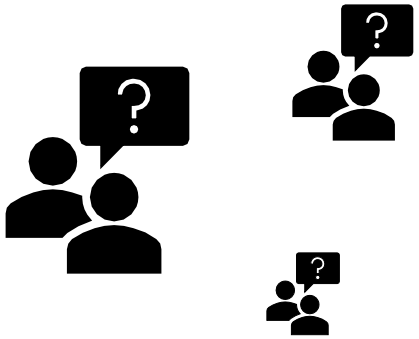
✓ Future outlooks

- **Versatile framework for fluid applications:** inhomogeneous, multiphase flows, biomedical applications

  E.g.: **hemodynamics** → see group **{**L. Ridolfi, S. Scarsoglio, U. Morbiducci**}** @ Politecnico di Torino

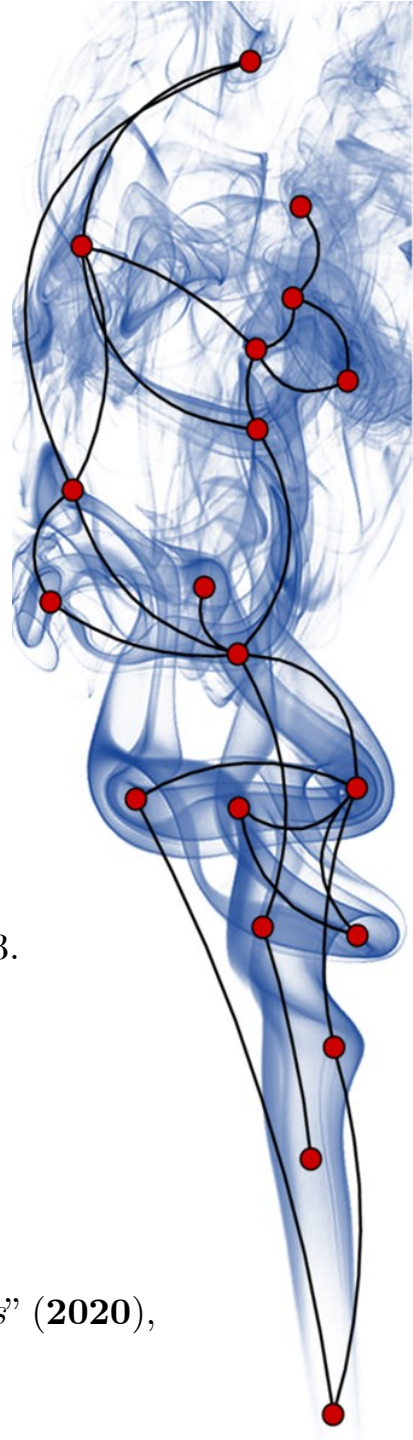
- **Investigate different flow quantities:** velocity, energy, vorticity, ...

- **Higher-order network formulations:** multilayer, simplicial complexes, ...



Thank you for your attention!

Questions?



Contact:

stefania.scarsoglio@polito.it

www.polito.it/fluidlab/

References:

1. Scarsoglio, S., Iacobello, G., & Ridolfi, L. (**2016**). **International Journal of Bifurcation and Chaos**, 26(13), 1650223.
2. Iacobello, G., Scarsoglio, S., & Ridolfi, L. (**2018**). **Physics Letters A**, 382(1), 1-11.
3. Iacobello, G., Scarsoglio, S., Kuerten, J. G. M., & Ridolfi, L. (**2018**). **Physical Review E**, 98(1), 013107.
4. Iacobello, G., Ridolfi, L., Marro, M., Salizzoni, P., & Scarsoglio, S. (**2018**). **Progress in Turbulence VIII** (Springer)
5. Iacobello, G., Scarsoglio, S., Kuerten, J. G. M., & Ridolfi, L. (**2019**). **Journal of Fluid Mechanics**, 865, 546-562.
6. Iacobello, G., Marro, M., Ridolfi, L., Salizzoni, P., & Scarsoglio, S. (**2019**). **Physical Review Fluids**, 4(10), 104501.
7. Iacobello, G., "*Spatio-temporal analysis of wall-bounded turbulence: A multidisciplinary perspective via complex networks*" (**2020**), **Doctoral dissertation**, Politecnico di Torino. EMAIL: giovanni.iacobello@polito.it