# Interactions between large-scale coherent and small-scale incoherent structures in turbulent pipe flow

A. Shahirpour [a] and J. Sesterhenn [a]

Energy transfer between different length-scales in turbulent pipe flow are studied in order to establish a measure for how sustainable large-scale coherent structures are and on which length-scales they feed on. The flow field is decomposed to identify each group of structures based on their energy content and length-scales. Since the structures in wall-bounded flows are transport dominated, traditional data-driven methods such as Proper Orthogonal Decomposition (POD) and Dynamic Mode Decomposition (DMD) will fail to describe the structures with minimal number of modes. Therefore, a Characteristic DMD is used to identify the subspaces and to capture transport-dominated structures (Sesterhenn & Shahirpour 2019[1]).

A temporal sequence of state vectors from DNS or time-resolved measurements, are transformed such that persistent dynamical modes are found on a hypersurface traveling along its normal in space and time with the normal being aligned with the characteristics of the flow. A subset of the spatio-temporal modes is selected so that their reconstruction optimally represents the spectral peak in premultiplied energy spectra in physical space. The latter modes form a subspace which accommodates large-scale features of the flow. DMD spectrum, mode coefficients and kinetic energy of the modes are then used to detect further subspaces interacting with each other and with the coherent structures.

Through a resolvent analysis using the DMD modes and eigen values describing the underlying dynamics of the flow, we look for the most responsive forcings and the most receptive responses along the characteristics. Hereby we search for the largest input output gain, optimized for all possible forcing vectors. It is observed that while many large-scale forcings excite smaller scale responses, there are also small-scale forcings feeding large-scale responses (Fig 1). Resolvent modes defined in DMD space, are transformed back to physical space as shown in Figure 1 with forcing shown in red and green, and the response in yellow and blue.

---

[a] Chair of Technical Mechanics and Fluid Mechanics, University of Bayreuth, Bavaria, Germany

[1] Sesterhenn and Shahirpour, *J. Theoretical and Computational Fluid Dynamics.* **33**, 281 (2019).

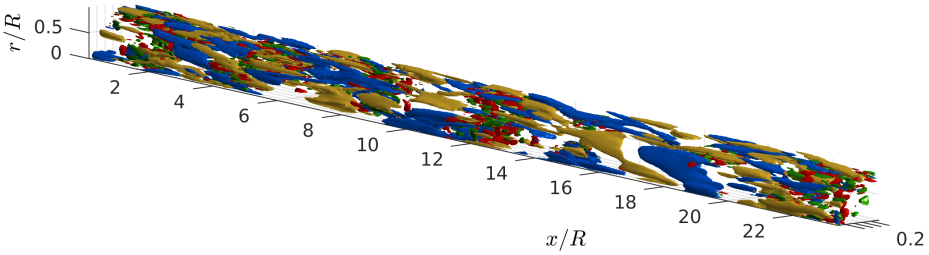


Figure 1: Small scale structures plotted in (red and green), feeding the larger scale structures (yellow and blue). DNS at $Re_b$ =5300 using a hybrid parallel DNS code (Lopez et al. 2019).