In this talk, I shall describe the broad goal my research which is to develop novel tools for analyzing complex high-dimensional signals using spectral and functional data analytic methods. This research is primarily motivated by open problems in analyzing brain signals. The key challenges are the high dimensionality of brain data, its massive size and the complex nature of the underlying physiological process – in particular, non-stationary. In this presentation, I will highlight some of the current projects.

In the first and second projects, we develop a practical tool that identifies changes in brain activity during seizure when a population of neurons in a localized area exhibits abnormal firing behavior which then spreads to other subpopulations of neurons. This abnormal firing behavior is captured by increases in signal amplitudes, changes in the decomposition of the waveforms and in the strength of dependence between different regions (or groups of channels). In the first project, we develop a frequency-specific change-point detection method (FreSpeD) that uses a cumulative sum-type test statistic within a binary segmentation algorithm. Theoretical optimal properties of FreSpeD will be discussed. Moreover, when applied to an epileptic seizure EEG data, FreSpeD identifies the correct brain region as the focal point of seizure, the time of seizure onset and the very subtle changes in cross-coherence immediately preceding seizure onset. In the second project, we develop a spectral clustering procedure to determine changes in spatial boundaries (or more generally spatial sets) as the seizure process unfolds.

The third project is motivated by a problem of modeling changes in neuronal activity during learning. While many approaches take into account non-stationarity within a single trial of the experiment, the evolution of brain dynamics across the entire learning experiment is often ignored. We recently developed the evolving locally stationary process (Ev-LSP) which is a novel time series model that captures both sources of non-stationarity. The proposed model provides a framework under which the “evolving” evolutionary spectral quantities can be both rigorously defined and estimated. I will show that the proposed method can be utilized to study how the spectral properties of the hippocampus and the nucleus accumbens of a macaque monkey evolves over the course of an associative learning experiment.

The first project is in collaboration with Anna Schroeder (London School of Economics); the second is with Carolina Euan (CIMAT, Mexico) and Ying Sun (KAUST); the third project is with Mark Fiecas (University of Warwick, UK).