Neural encoding of “surprise” in the mouse brain

Lead Group: Hiroki Asari (EMBL Rome)
Partner Group: Giandomenico Iannetti (IIT)

Rationale & Hypothesis: The brain is a predictive machine. It constantly generates a mental model of the outside world to predict future sensory inputs and adjust behavior accordingly. When the prediction differs from actual sensory inputs, the brain then signals the prediction errors – i.e., “surprises” – and use them to update the mental model to better predict future stimuli. Indeed, a “surprise” is a major driving force for learning, and triggers a large brain-wide electrocortical activity (vertex wave) in the human brain and marked changes in behavioral outputs. It remains unclear, though, how this large “surprise” signal is generated in response to afferent input and represented by neuronal ensembles. In this proposal, we will use electrophysiology and functional imaging techniques to characterize the neural representation of a “surprise” in the mouse brain.

Aims: This proposal aims to address the following two questions:

1. *How does the surprise response depend on the stimulus modality?* We will characterize the modality specific and supramodal components of the responses elicited by abrupt and surprising stimuli in different modalities. The neural responses will be measured at single-cell level in the visual pathway by *in vivo* two-photon calcium imaging and/or silicon neural probes in the awake head-fixed mice. Neural activity will also be sampled at population level across multiple cortical areas by wide-field imaging under the head-fixed condition and by micro-electrocorticograph electrodes in freely-behaving animals.
2. *How does the surprise response depend on the stimulus quality and behavioral contexts?* We will assess the responses to surprise stimuli with different features, capitalizing on the rules that have been understood in human experiments. We will explore, for example, ethologically relevant semantic features (e.g., looming stimulus) as well as probabilistic cases (e.g., moving gratings in one direction versus the others). Notably, we will also associate the neuronal responses elicited by such surprising stimuli with behavioral outputs, such as the pupil size, kinematic, locomotion, and facial expression.

Significance & Impact: A transient “surprise” signal can be triggered by different sensory modalities and drastically affect subsequent behavioral responses. Surprising outcomes drive learning, and neural correlates of reward prediction errors have been extensively studied in the dopaminergic system. However, the mechanisms behind the decision that a stimulus is a surprise, as well as the neural and behavioural consequences of such decision remain elusive. Our preliminary data suggest that neurons in the superficial layer of the superior colliculus respond more strongly to a rare stimulus, especially if it is behaviorally relevant, due to modulatory feedback inputs from the visual cortex. The outcome of this proposed research will provide further insights into the neural circuit mechanisms for processing surprise stimuli, and how the brain generalizes the “surprise” elicited by stimuli in different modalities. Comparing data across different species (mouse, humans, and nonhuman primates) will also lead to a better understanding of how the brain has evolved for detecting and responding to surprising environmental stimuli.

Integration of Expertise of Partners: The Iannetti lab at IIT (www.iannettilab.net) has a track record of studying how humans and other animals cope with the world through perception and action, and, in particular, how response to sudden and surprising environmental stimuli affects behaviour. The Asari lab at EMBL Rome (http://www.embl.it/research/unit/asari/index.html) has established methods to label, monitor, and manipulate select types of neurons in mice to study the structure and function of the visual system. This proposal is the natural consequence of the intellectual and empirical advances obtained by the two partners, and will allow the successful applicant to conduct cutting-edge research across species and neural scales, from single-cell recordings in rodents to kinematic analysis of human behavior. The successful applicant will also benefit from the top-quality environment of scientific research in the field of system neuroscience both at IIT (e.g. Panzeri, Fellin, Iurilli groups) and at EMBL Rome (e.g. Rompani, Gross groups).