Criticality in the brain

It is nowadays recognized that brain dynamics and, in particular, the information flow in the brain neuronal network involve universal mechanisms of emergent complex phenomena [1], thus involving neuronal avalanches, power-law behavior and scale-free behavior. Neuronal avalanches are found in neuronal networks, both experimentally and theoretically [2], and are typically observed in dynamical systems posed near a critical point, where long-range correlations and collective behavior emerge. Further, critical dynamics was also found to be consistent with Type-I intermittency [3], associated with a sequence of critical events with power-law distributed inter-event times. The existence of brain critical events is well-established, as spontaneous neuronal activity can exhibit relatively quiet periods in alternance with chaotic or bursty periods. Such brain events can be estimated from EEG (ElectroEncephaloGram) data with detection algorithms. In this case, events are defined as abrupt transitions (RTPs, or Rapid Transition Processes [4]) to and from metastable states, via multichannel EEGs [5]. Depending on the temporal scale, brain events can display a complex structure in terms of neuronal avalanches. Following the approach of Type-I intermittency, involving the idea of brain critical events, criticality has been established in human brain dynamics in basal conditions, by studying the scaling of event-driven random walks, which allows to get a robust estimation of the intermittency exponent, i.e., of the power-law decay of the inter-event time distribution [5-6]. Similar approaches based on brain events and point processes have been recently applied, confirming the robust and universal critical behavior of brain dynamics and neuronal networks [7-8]. Some authors argue that the robust behavior and the great plasticity of the brain dynamics are strictly related with this critical condition [9].
Intermittency and consciousness

Consciousness is sustained by a serial process of global integration emerging from the dynamics of the brain neuronal network, insofar as a single scene at a time takes place [10]. In recent papers, we found that a serial point process of global integration exists in the human brain during a resting state wake condition and we found well-defined scaling exponents in both distributions of avalanche sizes and inter-event times [5-6], thus confirming the brain critical condition [9]. However, it remained unsolved whether this serial process displaying Type-I intermittency correlates with consciousness or, alternatively, with a non-task-driven default mode activity of the brain [11], also present in non-conscious states, such as NREM sleep. Here we show that in NREM sleep this serial dynamical behavior breaks down, insofar as the inverse-power-law distributions of the inter-event times are replaced, in the long-time regime, by exponential cutoffs that are particularly evident in the Slow Wave Sleep (SWS) stage. During REM sleep the dynamics turns back to the Type-I intermittency behavior observed during wakefulness. This demonstrates that the metastable-state dynamics of NREM sleep, with a strong discrepancy with respect to the serial behavior of wakefulness and REM sleep, is not dynamically compatible with a serial (single time) scenario, where consciousness takes place. Surprisingly, the distribution of avalanche sizes does not change when comparing wakefulness, NREM and REM sleep. This means that, at variance with the intermittent behavior, the global topological features of the brain neuronal network are independent from the particular brain condition (wakefulness, REM, NREM).