Cluster Burst Synchronization in A Scale-Free Network of Inhibitory Bursting Neurons

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- **Burst Synchronization**
  - Bursting: Neuronal activity alternates, on a slow timescale, between a silent phase and an active (bursting) phase of fast repetitive spikings
  - Representative bursting neurons: Bursting and chattering neurons in the cortex, thalamic relay neurons and thalamic reticular neurons in the thalamus, hippocampal pyramidal neurons, Purkinje cells in the cerebellum, pancreatic β-cells, and respiratory neurons in pre-Botzinger complex
  - Burst Synchronization: Population synchronization on the slow bursting timescale between the burst onset times
    Associated with the fundamental brain function (e.g., learning, memory, and development) and neural diseases (e.g., Parkinson's disease and epilepsy)

Cluster Burst Synchronization

- **Cluster Synchronization**
  - Cluster Synchronization: The whole population is segregated into synchronous sub-populations (called also as clusters) with phase lag among them.
  - Investigated experimentally, numerically, or theoretically in a variety of contexts in diverse coupled (physical, chemical, biological, and neural) oscillators; Josepson junction arrays, globally-coupled chemical oscillators, synthetic genetic networks, and globally-coupled networks of inhibitory (non-oscillatory) reticular thalamic nucleus neurons and other inhibitory model neurons

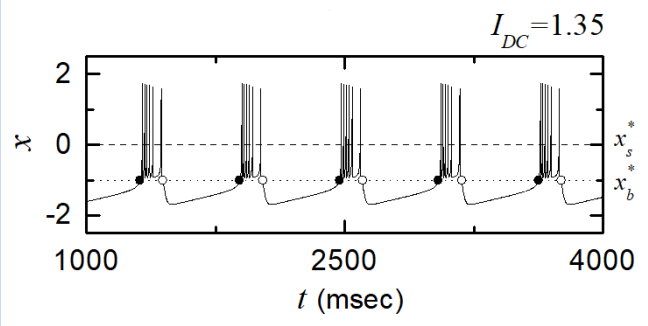
- **Scale-Free Network**
  - Synaptic connectivity in neural networks: Complex topology which is neither regular nor completely random
  - Scale-Free Neural Network: Power-law degree distributions in the rat hippocampal networks and the human cortical functional network

- **Purpose of Our Study**

  Investigation of Occurrence of Cluster Burst Synchronization in Inhibitory Scale-Free Network of Bursting Neurons

Inhibitory Scale-Free Network of Hindmarsh-Rose Bursting Neurons

- **Scale-Free Network of Suprathreshold Hindmarsh-Rose Neurons**
  - Barabási-Albert scale-free network with symmetric attachment degree $l^* = 15$ (Growth and preferential directed attachment with l_{in} incoming edges and l_{out} outgoing edges; $l_{in} = l_{out} = l^*$)
  - Suprathreshold Hindmarsh-Rose Neurons for the DC current $I_{DC,i} \in [1.3, 1.4]$
  - GABA$_A$-mediated inhibitory synaptic currents with $\tau_l = 1$, $\tau_r = 0.5$, $\tau_d = 5$, & $X_{syn} = -2$
  - Deterministic bursting for $I_{DC} = 1.35$

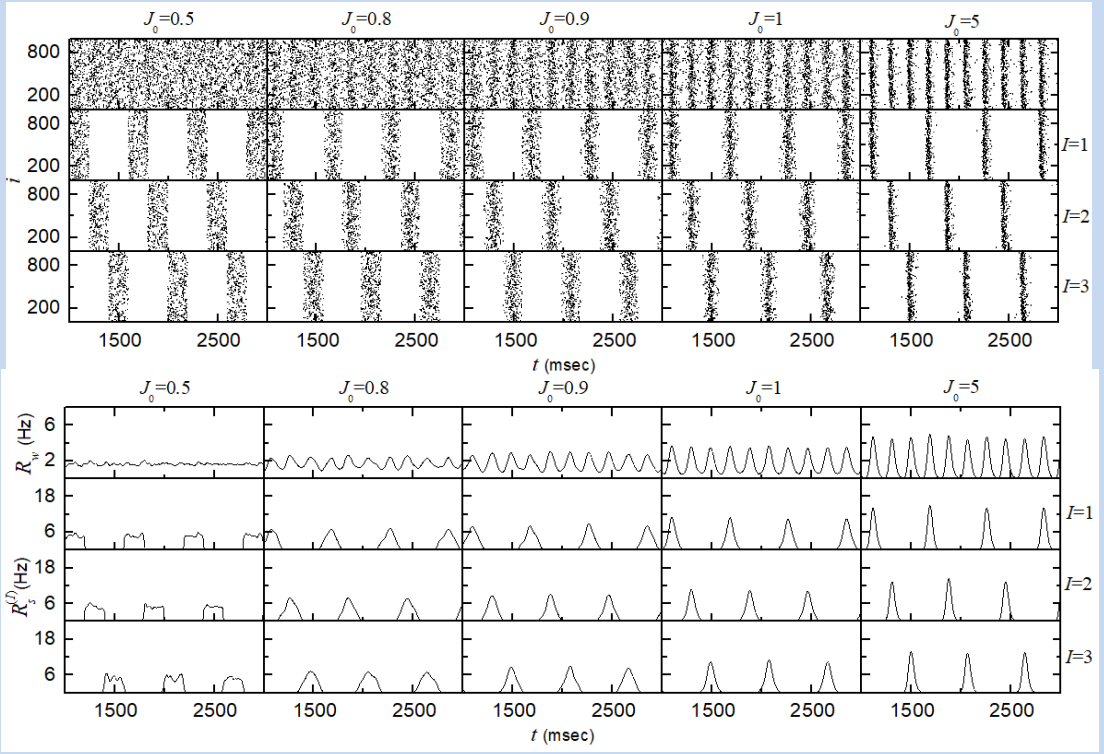


Horizontal dotted line ($x_b^* = -1$): Bursting threshold
Solid circles: Bursting onset times

- **Emergence of Burst Synchronization**
  Occurrence of Burst Synchronization in the range of $J_1^* (\simeq 0.78) < J < J_2^* (\simeq 537)$

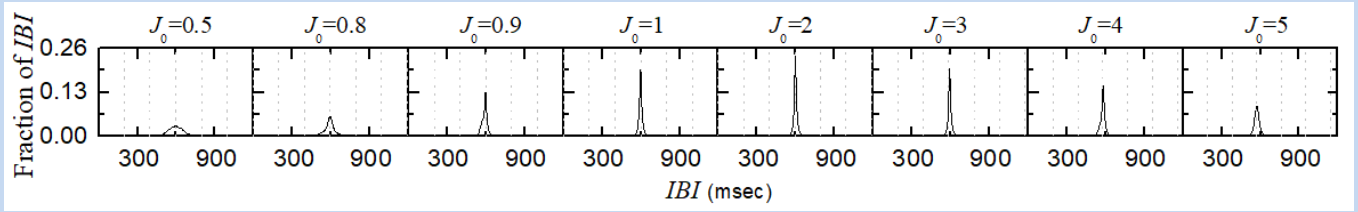
Emergence of 3-Cluster Burst Synchronization

- **Cluster Burst Synchronization**
  - Appearance of bursting stripes in the raster plot of burst onset times in the whole population and small amplitude regular oscillations in instantaneous whole population burst rate $R_w(t)$
  - Appearance of bursting stripes at every 3rd global cycle of $R_w(t)$ and regular oscillation in instantaneous sub-population burst rate $R_s^{(I)}(t)$
  - With increasing J_0, cluster burst synchronization gets better.



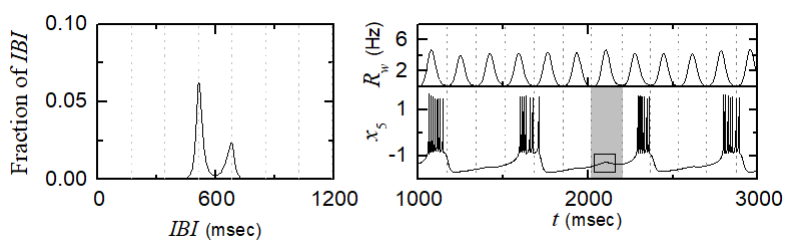
- **Localized Interburst Interval**

  Single peak at $3T_C$(T_C: cluster period & same with global period T_G of R_w) in histogram
  Interburst interval: Localized in $2T_C < IBI < 4T_C$
  Maximum height for $J_0 = 2$. Decrease and broader with increasing J_0



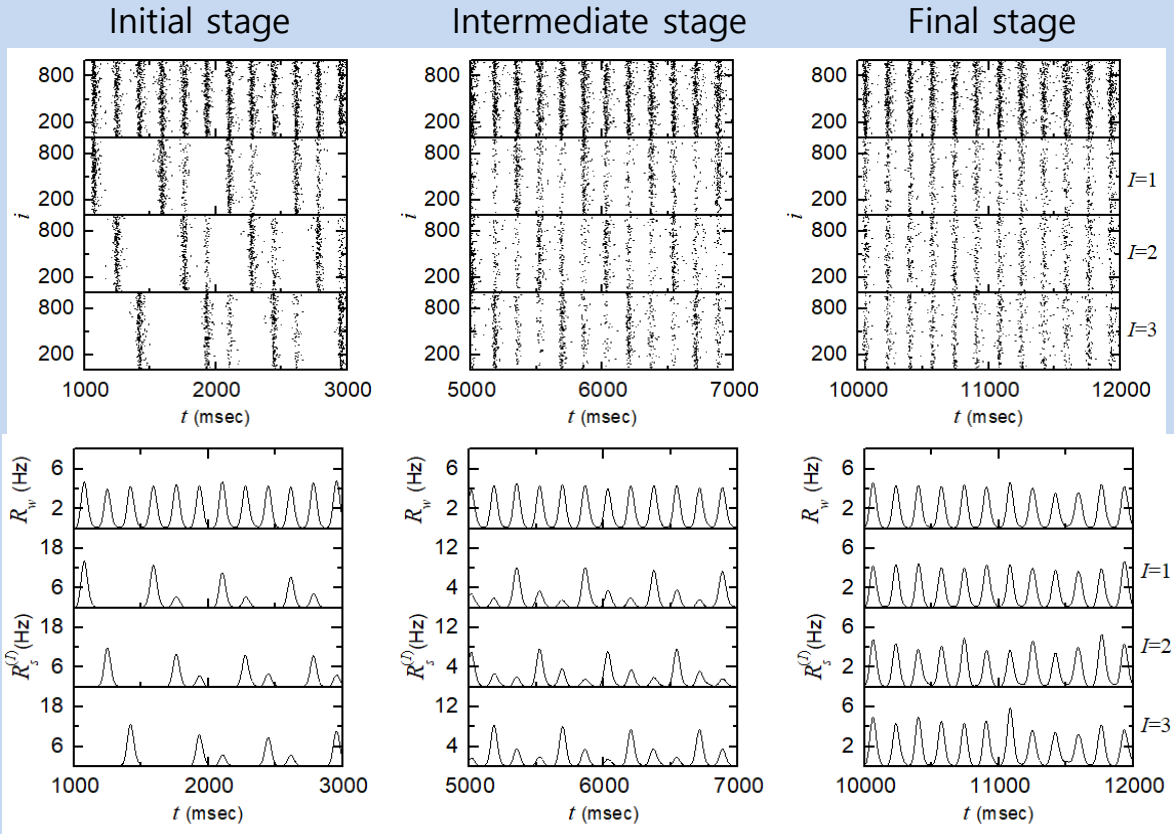
Break-up of 3 Clusters via Intercluster Hopping for $J_0 = 10$

- **Break-up of Cluster Burst Synchronization**
  - Delocalized interburst interval:
    Two peaks at $3T_G$ & $4T_G$
    → Occurrence of burst skipping
    → Break-up of cluster bursting synchronization



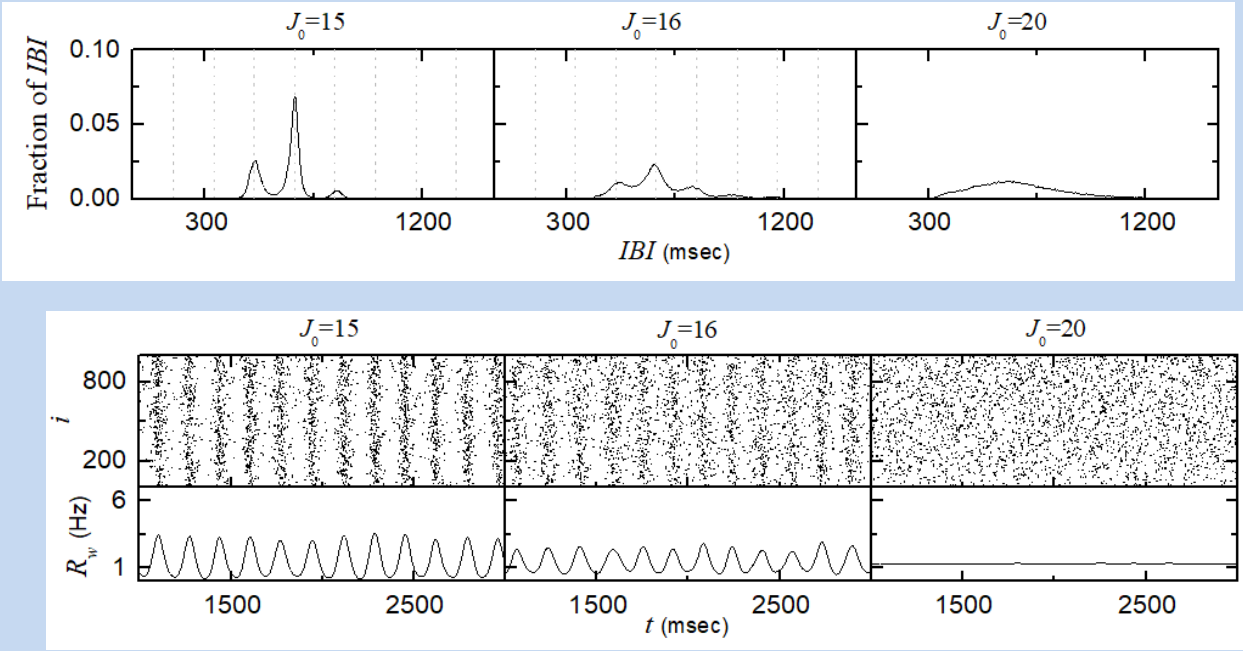
- **Intercluster Hopping**
  - Occurrence of intermittent intercluster hoppings from Ith cluster to the nearest neighboring $(I+1)$th cluster in cyclic way due to burst skippings

  - Break-up of clusters
    Persistent of burst synchronization in the whole population
    → Non-cluster burst synchronization



Transition to Burst Synchronization to Desynchronization

- **Intensified Burst Skipping**



Distribution of interburst interval: Broaden with increasing J_0

Bursting stripes in the raster plot: more smeared

Amplitude of instantaneous whole population burst rate: Decreased

$\rightarrow$ With increasing J_0, burst synchronization becomes more and more worse.

Desynchronization: Broad single peak in the interburst interval histogram

Completely scattered raster plot without forming any bursting stripes

& nearly stationary instantaneous whole population burst rate

Summary

- **Cluster Burst Synchronization in Scale-Free Network of Burst Neurons**
  - Occurrence of dynamical clustering in the scale-free network with no internal symmetry
  - Localization of interburst intervals in the region of $2T_C < IBI < 4T_C$ (T_C: cluster period)
    $\rightarrow$ Occurrence of 3 cluster burst synchronization

- **Break-up of Cluster Burst Synchronization**
  - Occurrence of burst skipping and delocalization of interburst intervals
  - Intercluster hoppings from the Ith cluster to the $(I+1)$th cluster due to burst skipping
    $\rightarrow$ Break-up of clusters