# Population spike-synchrony contributes to the spectral exponent of aperiodic neural activity


Michael Preston[1], Teng Fei, Bradley Voytek[1234]

[1]Neurosciences Graduate Program, [2]Department of Cognitive Science, [3]Halıcıoğlu Data Science Institute, [4]Kavli Institute for Brain and Mind, University of California, San Diego, La Jolla, CA, USA.

VOYTEKlab

UC San Diego


## Introduction

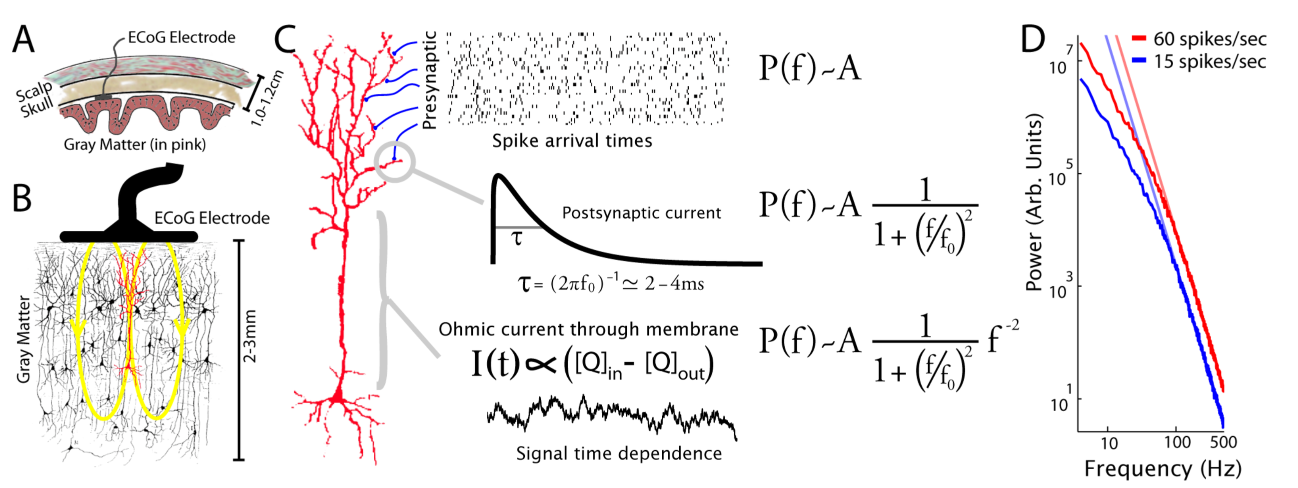
### Background

- Cortical field potentials primarily reflect postsynaptic and transmembrane currents through pyramidal neurons (Buzsaki et al., 2012).
- A simple, physiologically-informed model of cortical field potential generation links broadband activity in the field potential power spectrum to neural firing (Miller et al., 2009).
- Our lab recently extended this model, linking the spectral exponent to the balance of excitation and inhibition (Gao et al., 2017).
- While these models have focused on the high-conductance state during which spiking is asynchronous and irregular, the cortex exhibits highly synchronous activity across a range of states (Poulet & Crochet, 2019).

### Approach

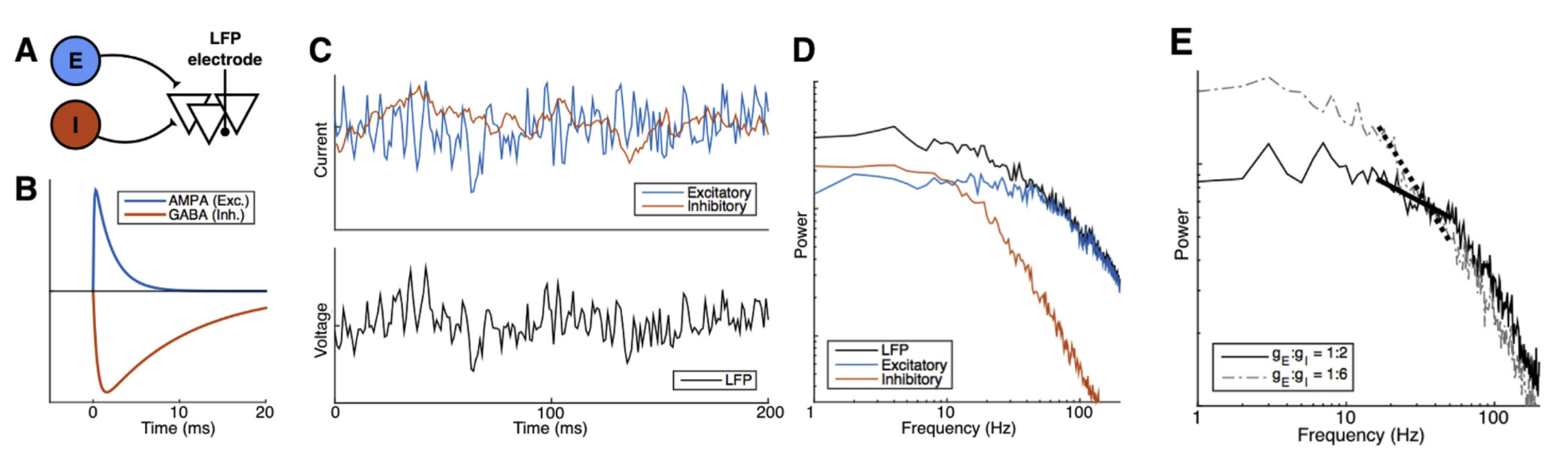
- **We hypothesize** that population spike-synchrony contributes to the shape of neural field potential power spectra.
- In the present study, we extend our field potential model to investigate the relationship between correlated spiking activity and the spectral exponent.
- Converging evidence from multiple simulation approaches suggests that spike-synchrony may be an additional neural mechanism underlying the spectral exponent.

## Neural field potential model (Miller et al., 2009)



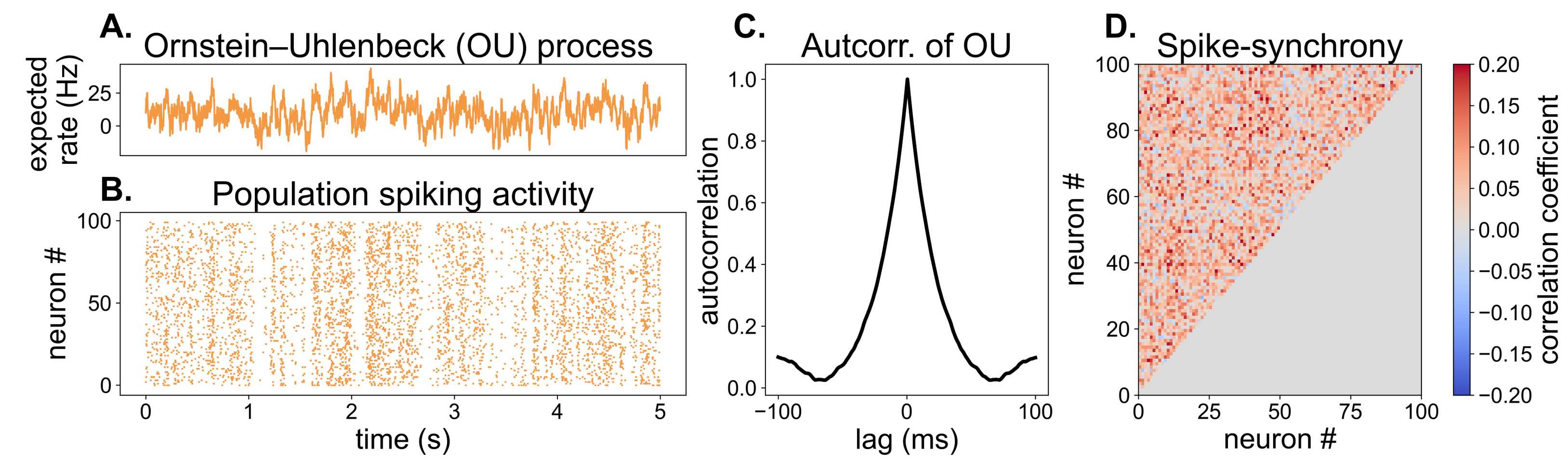

- A simple, physiologically-informed model of cortical field potential generation explains the 1/f-like shape of neural power spectra.
- In this model, Poisson-distributed presynaptic spike trains induce postsynaptic currents, characterized by an exponential rise and decay; the summation of these currents approximates the dipole generating the cortical field potential.
- Here we see that changes in population firing rate recapitulate broadband shifts in spectral power.

## Mechanisms underlying the spectral exponent (Gao et al., 2017)




- Our lab recently published a model linking the spectral exponent of neural field potentials to the balance of excitation and inhibition.
- In this model, local neurons receive inputs from both an excitatory and an inhibitory population; critically, these populations induce postsynaptic currents with characteristic timescales.
- We demonstrate that changes in the ratio of excitatory and inhibitory current recapitulates shifts in the spectral exponent.

## Simulating correlated population spiking




**Ornstein–Uhlenbeck (OU) process**

$$dx_t = -\theta x_t\, dt + \sigma\, dW_t$$

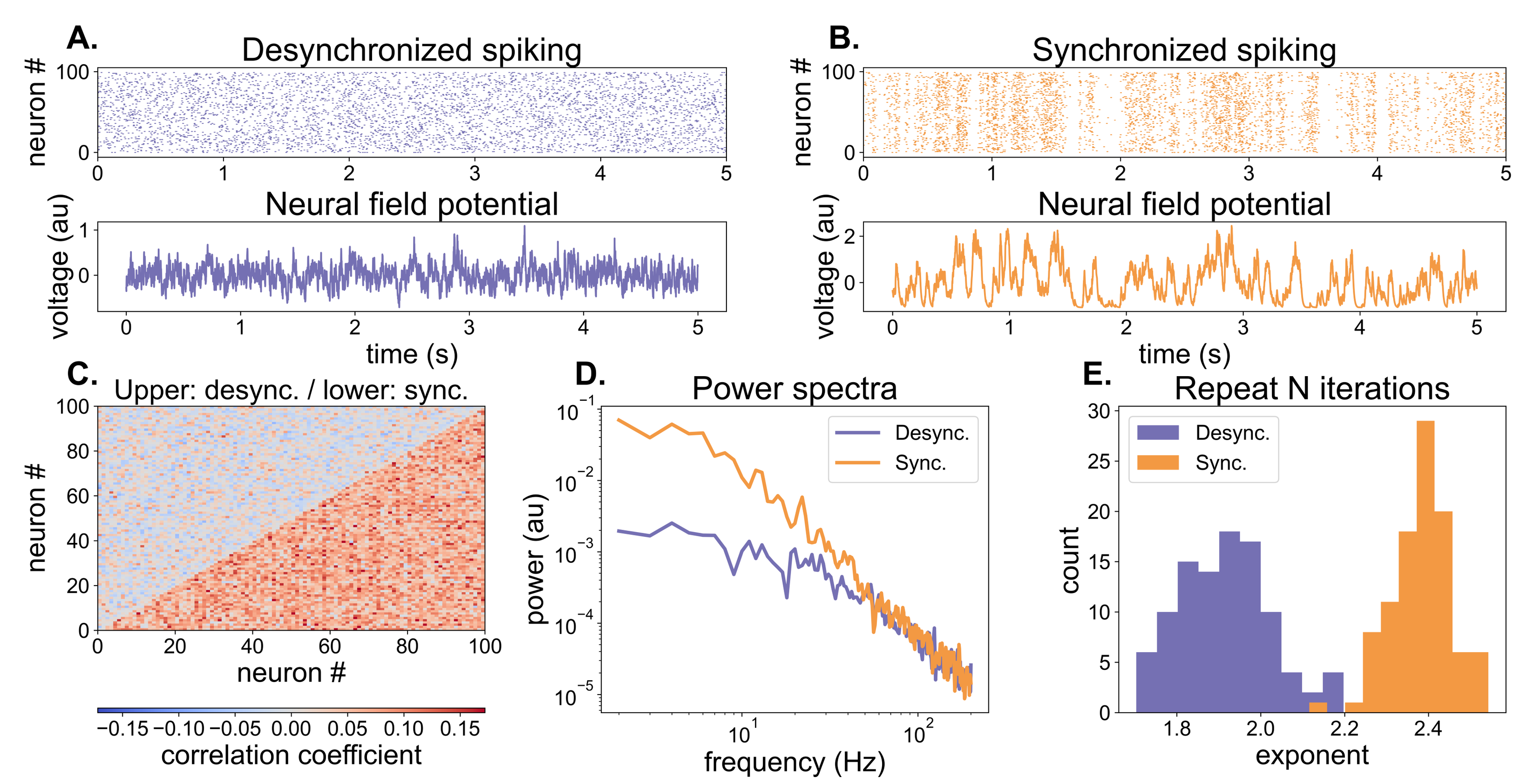
$\theta$ : timescale
$\sigma$ : amplitude of variation (variance = $\sigma^2 / (2\theta)$)
$W_t$ : Wiener process ($dW_t$ = white noise)

**Neural firing rate**

$$r_i(t) = x_i(t) + \beta_i * g(t)$$

x : task-evoked firing rate
$\beta_i$ : coupling strength
g : spontaneous rate fluctuations (OU process)

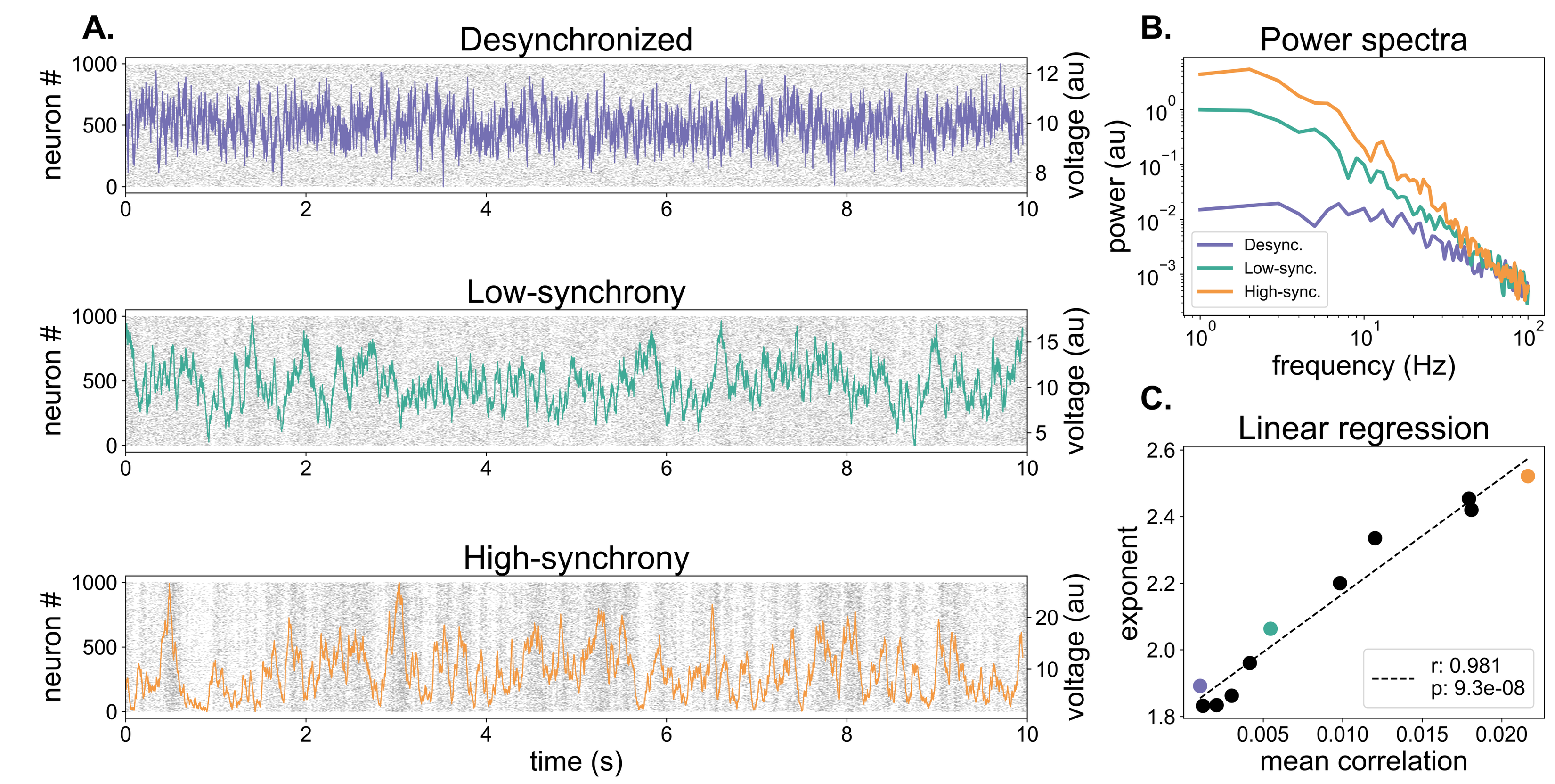
## Correlated spiking activity is associated with steeper field potential power spectra




We introduce temporally correlated spike trains into our field potential model and compare spectral signatures to those of the desynchronized population. Correlated population spiking is consistently associated with increased spectral exponents.

A. Desynchronized population spiking (100 neurons) and associated neural field potential.
B. Synchronized population spiking and associated neural field potential.
C. Pairwise Pearson's correlation coefficient between all neurons in the population. Results for the desynchronized population are plotted in the upper triangle and results for the synchronized population are plotted in the lower triangle.

## The spectral exponent is correlated with spike-synchrony




Population spiking is modeled as a combination of spontaneous and task-evoked activity. The expected firing rate of each neuron is modeled as the sum of an independent (task-evoked) rate and a shared (spontaneous) rate, analogous to global fluctuations in network state (Kelly et al., 2010). Populations in which neurons are tightly coupled to global rate fluctuations exhibit greater spike-synchrony and increased field potential spectral exponents.

A. Simulated field potentials are plotted atop underlying population spiking activity. Here, three example populations are shown with contrasting levels of spike-synchrony.
B. Field potential power spectra for the example populations plotted in A.
C. Linear regression results. The spectral exponent was regressed on the mean Pearson correlation coefficient across all pairs of neurons in the population.

## Discussion

### Conclusions

- Correlated population spiking activity can be simulated by sampling multiple spike trains from an autocorrelated rate process, such as the Ornstein-Uhlenbeck process.
- Alternatively, independent spike trains can be coupled to global rate fluctuations, analogous to dynamic shifts in network state.
- Local field potential (LFP) simulations incorporating correlated spiking activity exhibited steeper LFP power spectra (increased aperiodic exponent).
- The LFP spectral exponent is linearly correlated with population spike-synchrony.

### Future Directions

- We will investigate the relationship between population spike-synchrony and the LFP aperiodic exponent in simultaneous, high-density recordings.
- We will model our spectral signatures as a function of spiking statistics during spontaneous activity and between behavioral states.


mpreston@ucsd.edu
mwprestonjr
mwprestonjr