McGill University, Department of Physics

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Rectified Kuramoto Synchronization in an Embryonic Oscillator Ensemble

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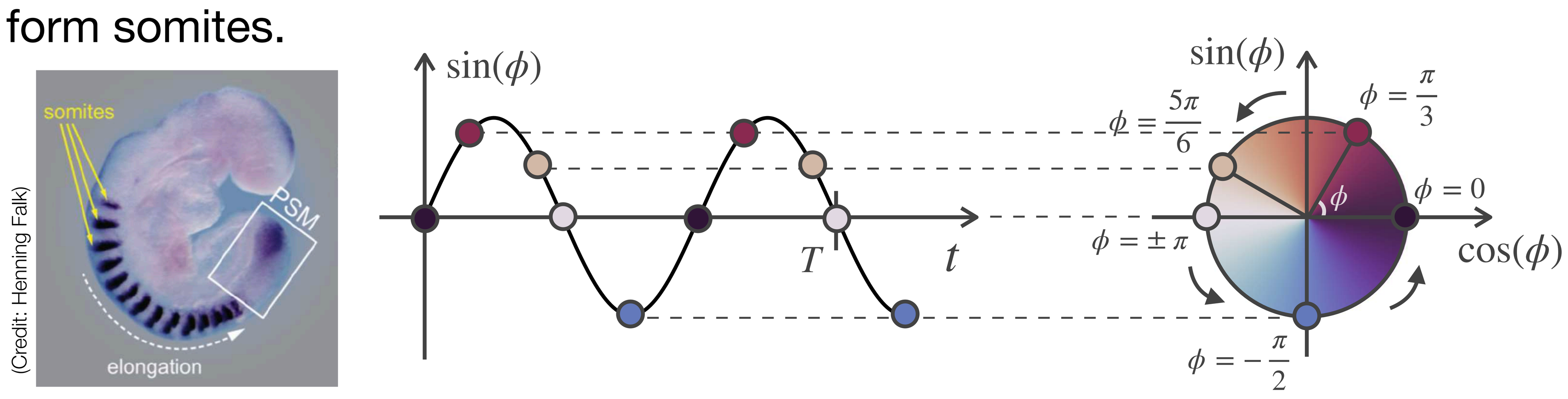
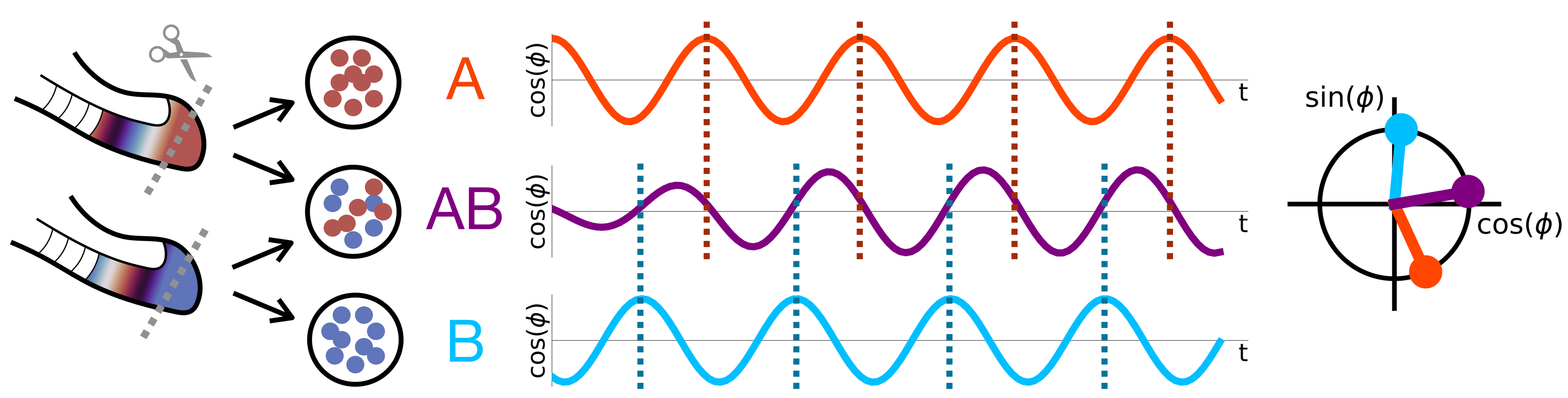
Introduction

During vertebrate embryo development, presomitic mesoderm (PSM) cells tightly synchronize their genetic oscillations in time and space to form somites.

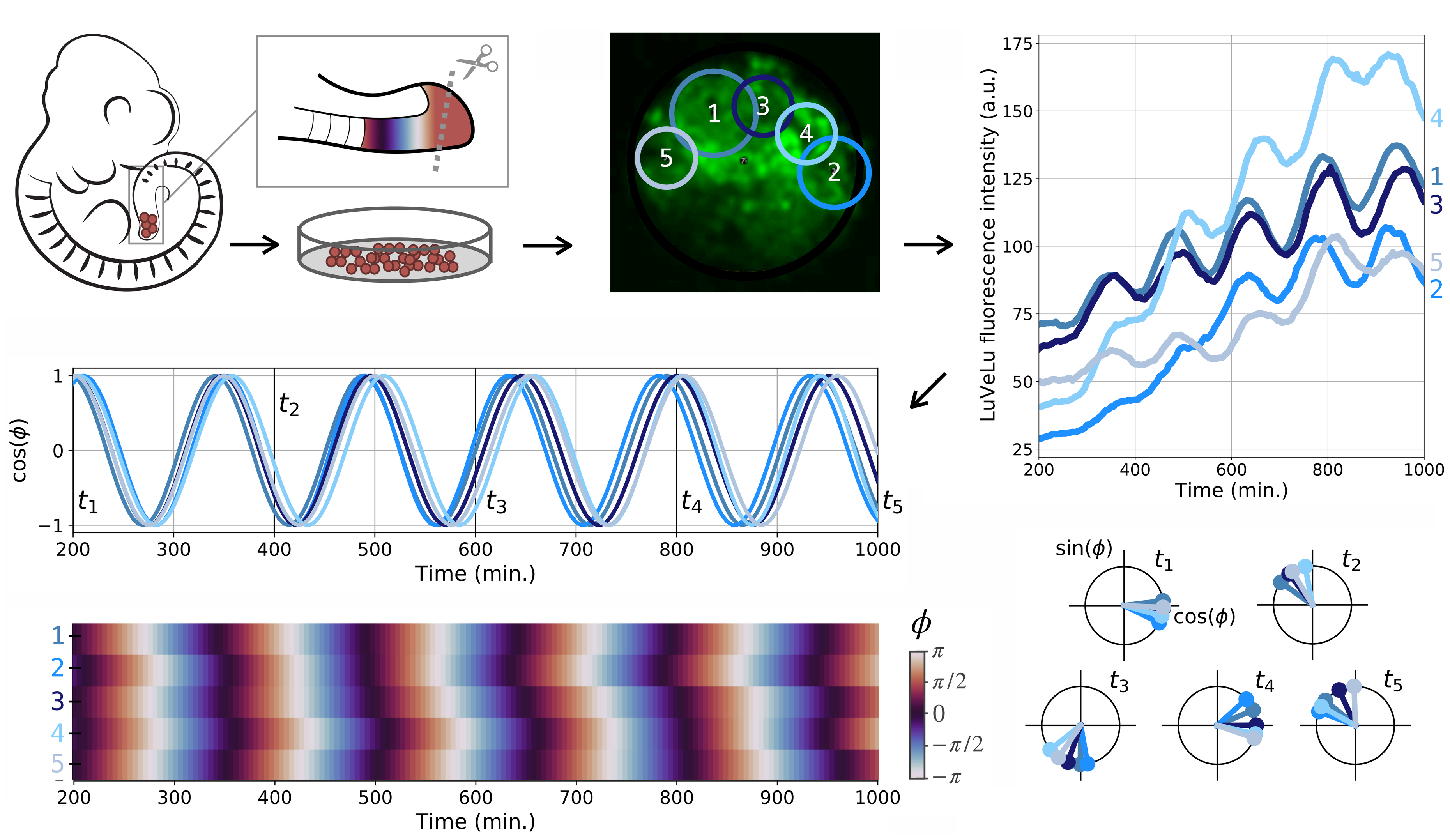


To model this synchronization process, most studies use the Kuramoto model, which predicts that two coupled oscillators will reach the average phase as they synchronize, a phenomenon called phase averaging.



Novel experimental assay

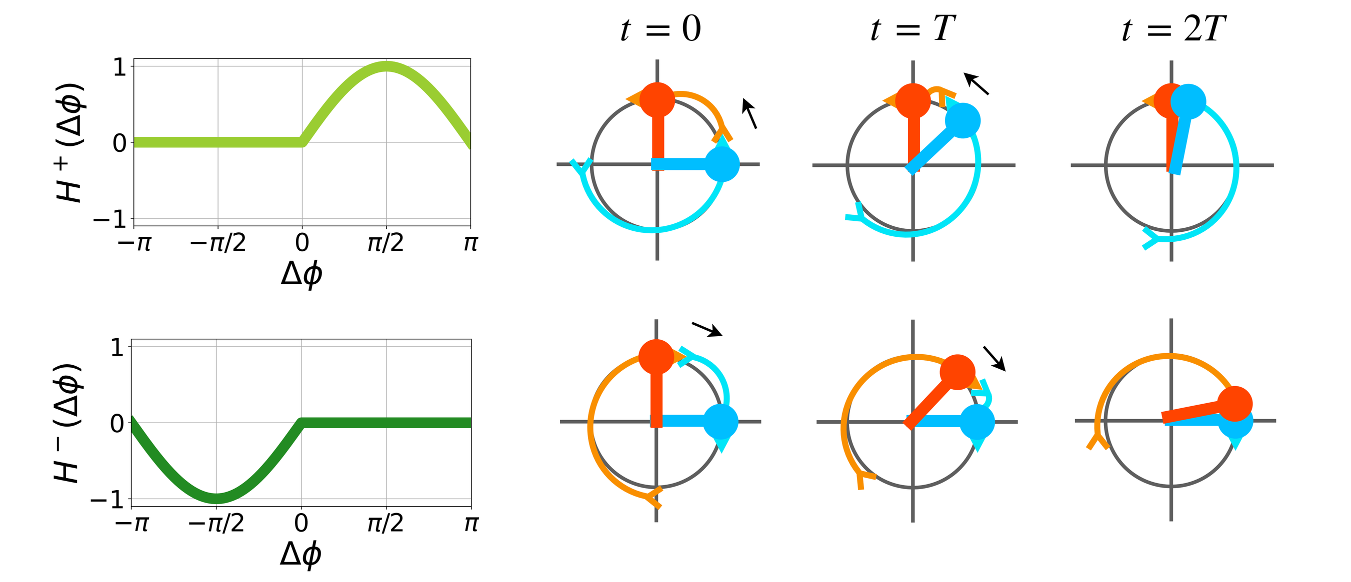
To test this prediction, we develop a novel experimental assay to culture mouse PSM cells that are stably oscillating for a long period of time.



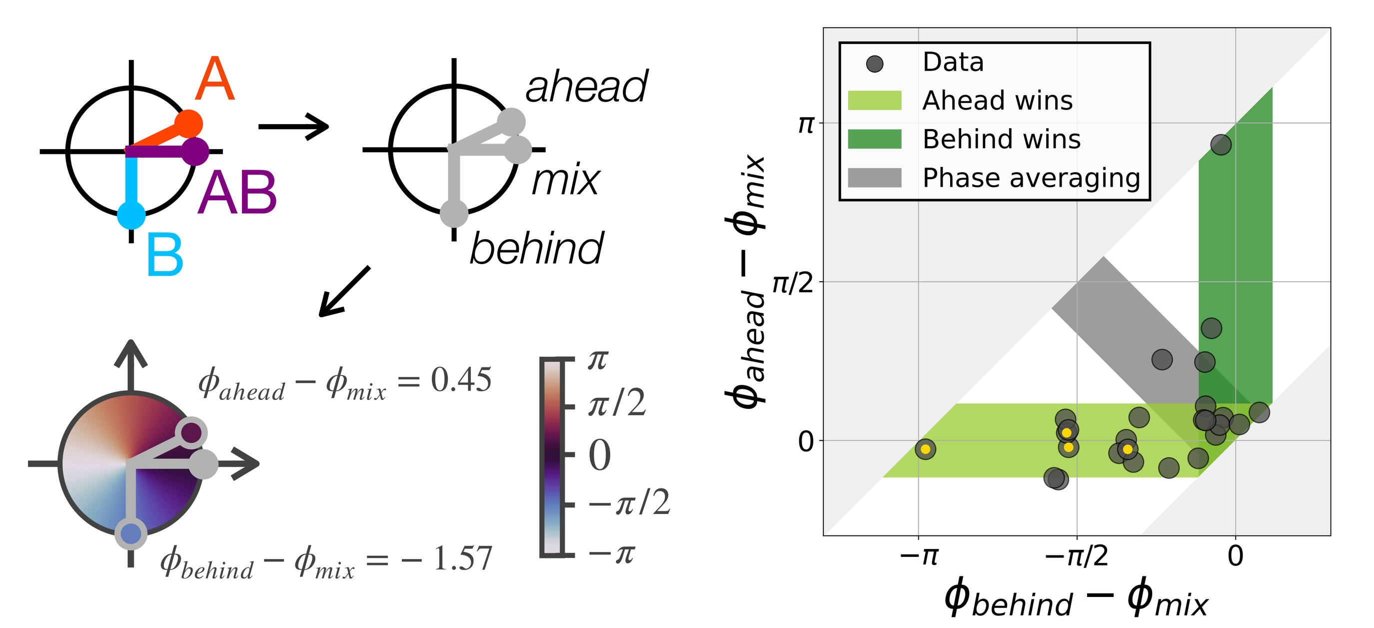
We also 1) quantified the high degree of synchronization within our cell cultures, 2) computed the narrow period distribution and the wide phase distribution across our cell cultures, and 3) verified phase consistency for cell cultures obtained from the same embryo.

Rectified Kuramoto model

To explain the observed coupling dynamics, we devise a new synchronization model, which predicts that the "winning" cell population is either always ahead of the "losing" cell population, or always behind.

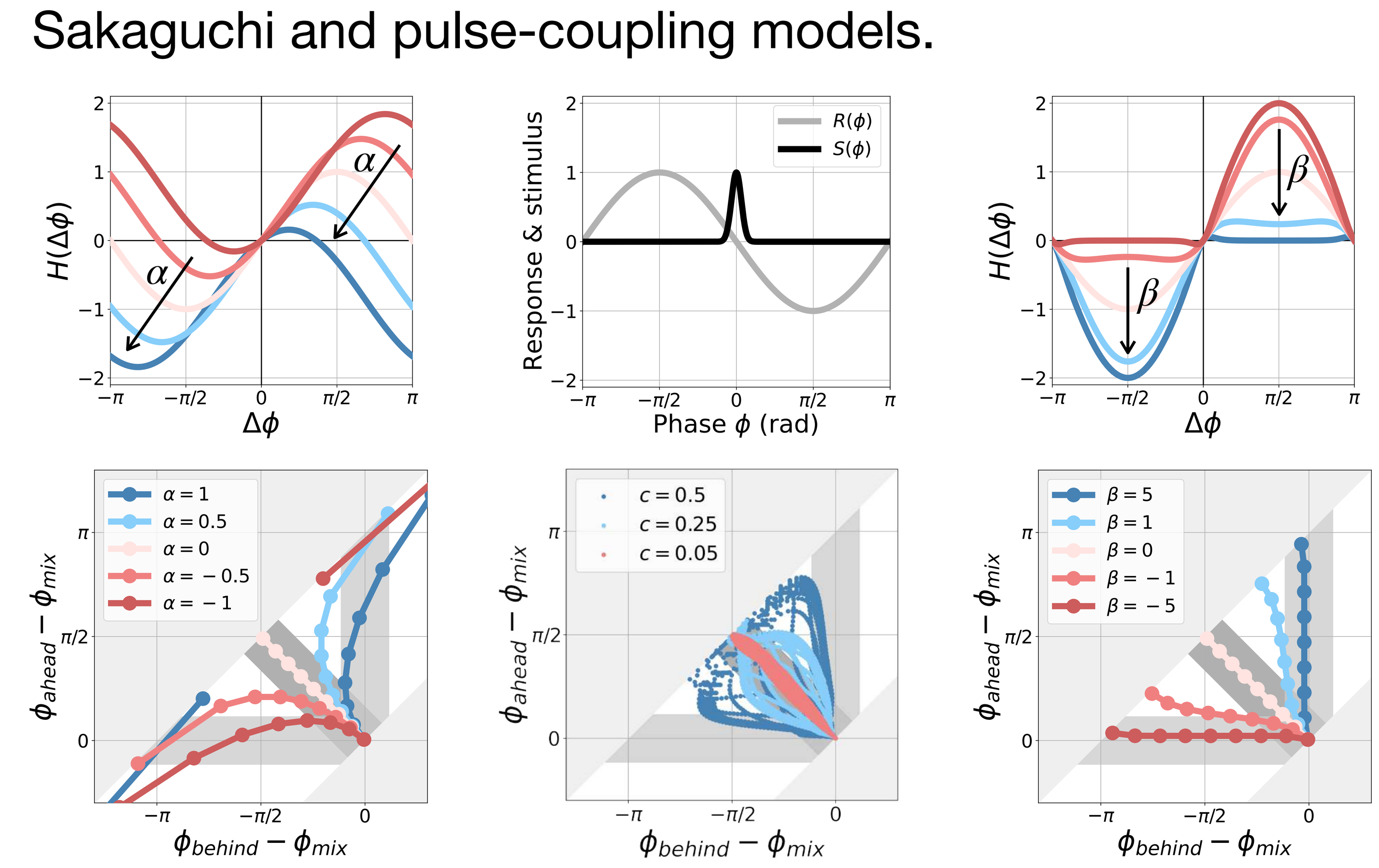


Our experimental data shows that "ahead wins."



Alternative models

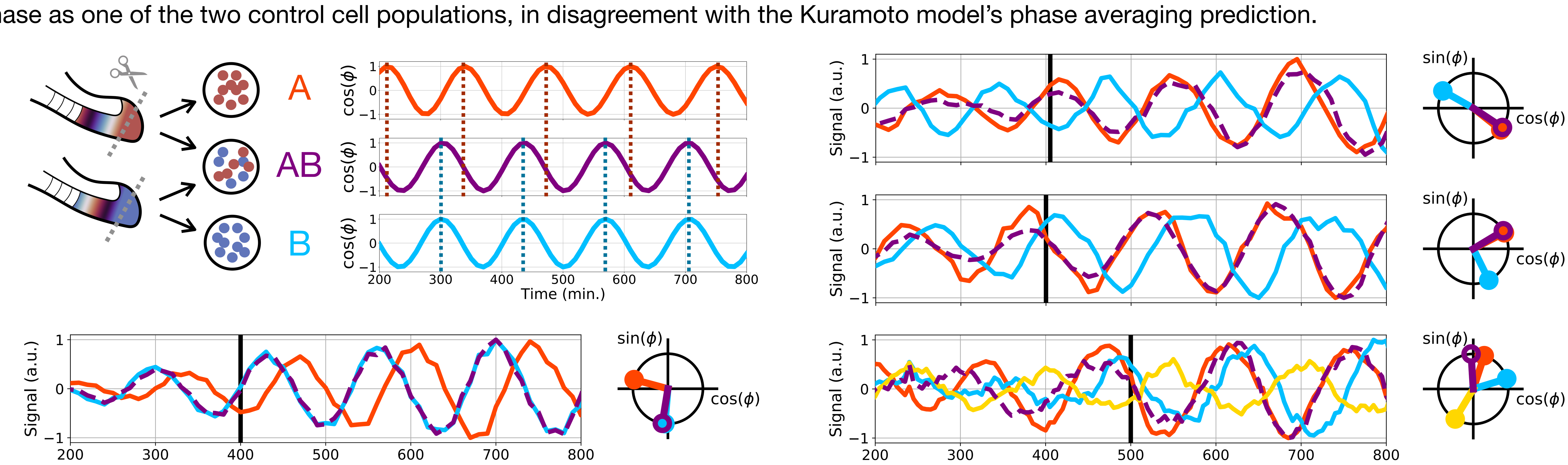
We also tested alternative models, including the Kuramoto-Sakaguchi and pulse-coupling models.



We further showed that 1) the detailed shape of the coupling function is irrelevant, and 2) cell cultures close to anti-phase prior to synchronization are the most informative to discriminate between models.

Results

Our embryonic oscillator ensembles undergo "winner-takes-it-all" synchronization, i.e. the mixed cell population synchronizes to the same phase as one of the two control cell populations, in disagreement with the Kuramoto model's phase averaging prediction.



We also verified that 1) in the mixed cell population, the "losing" cells oscillate in synchrony with the "winning" cells, and 2) cells can "win" even if they are a minority in the mixed cell population.