Survival of the chiral

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***Short Abstract* — The origin of chirality has intrigued generations of scientists. The role of natural selection, however, has been largely overlooked. Yet, chirality in shape and motility readily evolve in bacteria and cancer cells. We find that cells gain a substantial fitness advantage by increasing their chirality, or switching handedness. Selection occurs via bulges along the colony edge in regions where cells with different chiralities meet. We developed an analytical framework that explains these bulges and their effect on selection. Overall, our work suggests that chirality could be an important ecological trait that mediates competition, invasion, and spatial structure in cellular populations.**

***Keywords* — evolution, chirality, population dynamics, cancer, range expansions, pattern formation, KPZ equation.**

I. Introduction

CHIRALITY exists at all scales: from DNA and flagellar motion to embryogenesis and bacterial swarms. The classic explanation for molecular chirality is a fluctuation that slightly breaks the left-right symmetry, magnified by a self-amplifying process [1]. The many chiral components in the cell then serves as a natural explanation for macroscopic chirality. This existing theory explains how, but not why, chirality emerges. Several lines of evidence suggest that a change in chirality could be advantageous. Experiments with *Arthrospira* observed switching from a right-handed to left-handed helix following exposure to grazing by a ciliate [2]. Extensive work with *Paenibacillus* demonstrated that this microbe switches between chiral and non-chiral forms to optimize its fitness in different environments [3]. A study of spatial patterns made by human and mouse cells across tissue types found that all cells tested produced chiral patterns [4]. Additionally, skin cancer cells displayed a chirality opposite to that of human cells, including skin cells derived from the same patient.

II. Results

Motivated by these experimental observations, we asked whether chirality could be related to natural selection in the context of growing cellular populations. We developed a minimal reaction-diffusion model of chiral growth in compact colonies. For strains with equal chiralities, our model quantitatively reproduced logarithmic twisting of boundaries between the strains and other spatial patterns observed in experiments [5]. Colonies of a chiral strain and a non-chiral strain expanded at the same rate when grown separately. However, the chiral strain was more fit when grown together. We found that competition always favored the more chiral strain when two strains with the same handedness, but different magnitude of chirality were competed. In contrast, the competition between two strains with different handedness often resulted in stable coexistence. To understand our observations, we developed an effective theory of chiral growth. For chiral strains, the population dynamics is described by the chiral KPZ equation coupled to the Burger's equation with multiplicative noise. The theory shows that selection for a specific chirality is mediated by bulges along the colony edge that appear in regions where the strains with different chiralities meet. Additionally, we observe that strains of opposing chiralities can overcome the effects of genetic drift which causes sharp boundaries between strains in growing colonies [6]. For sufficiently strong chirality, we observe a transition to a completely intermixed state.

III. Conclusion

Using a minimal reaction-diffusion model, we captured experimental observations of logarithmic boundaries formed by chiral bacteria. Extending this, we have shown that selection for chirality is mediated by the formation of bulges. We have also shown that chirality can significantly alter the spatial structure within a colony. The intermixed phase can facilitate and stabilize interactions such as nutrient exchange. We developed an analytical framework to study the two-way coupling between selection and colony front. The theory could also be valuable for studies of competition in microbial colonies accounting for the effect of front undulations, which are known to fundamentally change the nature of competition. Our work suggests that some changes in cellular chirality could mediate invasion, coexistence and spatial structure and, therefore, deserve further study.

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