Patch coalescence as a mechanism for eukaryotic directional sensing

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The cells of multicellular organisms are endowed with a chemical compass of amazing sensitivity, formed as a result of billions of years of evolution [1]. Concentration differences of the order of a few percent in the extracellular soluble attractant chemicals from side to side are sufficient to induce a chemical polarization of the membrane leading to cell migration towards the signal source. This way, a sensible amplifier of slight gradients in the distribution of chemicals in the surrounding environment is realized. Its relevance is easily understood if one recognizes that no multicellular organism could exist without the constituent cells being able to organize themselves following chemical cues. The directional sensing process is initiated by the early chemical polarization of the cell membrane which takes place when a slight anisotropic component in the extracellular chemical signal induces the separation of the membrane into two sharply defined domains, populated by different phospholipid molecules and oriented along the signal anisotropy. It has been realized recently that this early polarization process is the result of a phase-separation instability in a well-characterized network of diffusion-controlled chemical reactions [2,3]. We propose here a universal description of this early simmetry breaking process [4], articulated into subsequent stages of patch nucleation, coarsening and merging into a single domain. Our description implies the existence of two clearly separated polarization regimes depending on the presence or absence of an anisotropic component in the activation pattern produced by the extracellular attractant factor, and the existence of a sensitivity threshold for the anisotropic component. In particular, we find that the polarization time t_ϵ in the presence of an anisotropic extracellular signal depends on the anisotropy degree ϵ through the power law $t_\epsilon \propto \epsilon^{-2}$, and that in a cell of radius R there should exist a threshold value $\epsilon_{\text{th}} \propto R^{-1}$ for the smallest detectable anisotropy. Our results are in agreement with existing experimental data and explain the recent observation of a threshold in the degree of detectable anisotropy.

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