



HAL
open science

Motility and aerotaxis in *Sinorhizobium meliloti*, a soil bacterium

Julien Bouvard, Frederic Moisy, Carine Douarche, Nicolas Busset, Peter Mergaert,
Harold Auradou

► To cite this version:

Julien Bouvard, Frederic Moisy, Carine Douarche, Nicolas Busset, Peter Mergaert, et al.. Motility and aerotaxis in *Sinorhizobium meliloti*, a soil bacterium. 25th ICTAM Conference - 25th International Congress of Theoretical and Applied Mechanics, Aug 2020, Milan, Italy. <hal-04398876>

HAL Id: hal-04398876

<https://hal.science/hal-04398876v1>

Submitted on 16 Jan 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization

Motility and aerotaxis in *Sinorhizobium meliloti*, a soil bacterium

Julien Bouvard¹, Frédéric Moisy^{*1}, Carine Douarche¹, Nicolas Busset², Peter Mergaert², and Harold

Auradou¹

¹Université Paris-Saclay, CNRS, FAST, 91405 Orsay, France

²Université Paris-Saclay, CEA, CNRS, Institute for Integrative Biology of the Cell (I2BC), 91198, Gif-sur-Yvette, France

Summary Aerotaxis is the ability of motile cells to move towards oxygen. Bacteria tracking and in-situ oxygen concentration measurements are used to characterize aerotaxis in *Sinorhizobium meliloti*, a motile nitrogen-fixing bacterium naturally present in the soil. Aerotaxis takes place in a sealed glass capillary closed at one end with an oxygen-permeable plug. Our results suggest that the oxygen dependence of the aerotactic velocity, $\propto \nabla c/c^2$, is stronger than the “logarithmic sensing” response ($\propto \nabla c/c$) found in other chemoattractants.

INTRODUCTION

Chemotaxis, the biased migration of a motile cell towards the source of a chemical gradient, is an ubiquitous phenomenon in nature. Yet, our understanding of the basic physical and hydrodynamical mechanisms behind chemotactic swimming in a liquid environment is still limited [1]. Among various chemoattractants, aerobic bacteria are sensitive to the oxygen content of the medium, a specific chemotaxis referred to as aerotaxis [2].

We are interested here in the aerotaxis of a motile nitrogen-fixing bacterium naturally present in the soil, *Sinorhizobium meliloti*, which forms a symbiotic association with some legume plants. Most experiments based on chemotactic/aerotactic assays for *S. meliloti* are qualitative, and do not provide quantitative information on its chemotactic response. A difficulty is to access simultaneously the dynamics of oxygen and bacterial concentrations.

Here oxygen concentration is measured using Ruthenium micelles, an oxygen-sensitive fluorescent dye encapsulated in phospholipid micelles to make it biologically inert [3]. We designed a simple experiment, shown in figure 1: a glass capillary, sealed at one end by a PDMS plug (which is permeable to oxygen) and at the other end by an oxygen-proof plug, is filled by a bacterial suspension mixed with Ruthenium micelles. Simultaneous measurements of oxygen concentration, bacteria concentration and bacteria swimming velocity are carried out to reconstruct the aerotactic response.

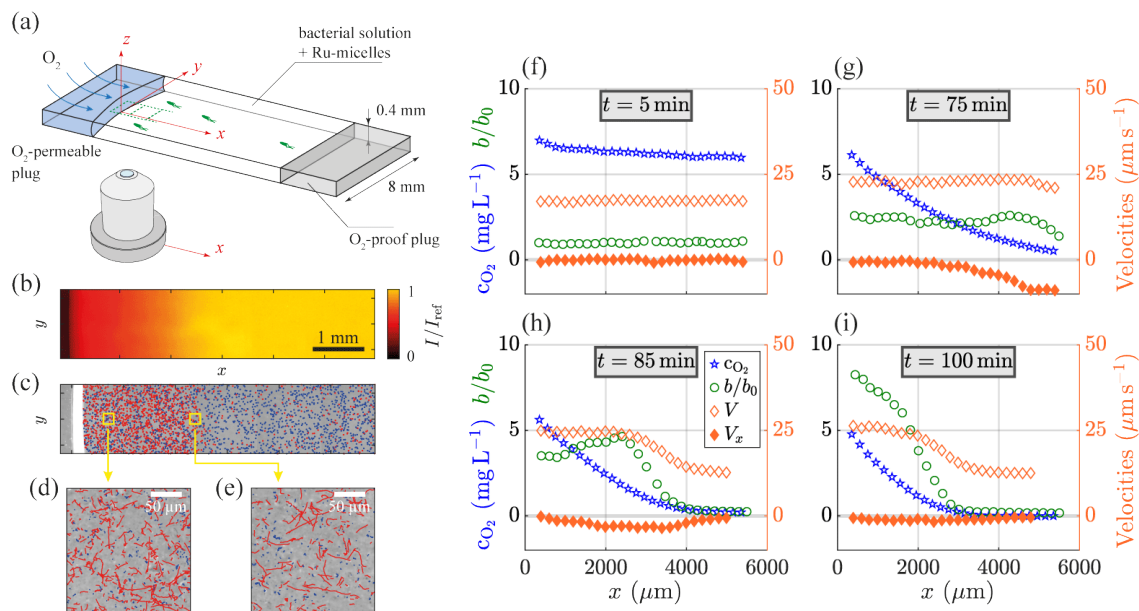


Figure 1: (a) Experimental setup: a glass chamber of rectangular section is filled with the bacterial suspension and Ruthenium micelles. One side of the capillary is sealed by pdms, permeable to oxygen, while the other side is sealed with an O₂-proof grease plug. (b) Fluorescence light intensity, mapping the oxygen concentration field (dark: high [O₂]). (c) Images of bacteria, superimposed to the bacteria tracks (non-motile and motile bacteria are in blue and red, respectively). (d), (e): Magnifications at two locations, showing the random and biased trajectories. (f), (g), (h) and (i): Variation of the local density of bacteria, oxygen concentration, magnitude of the swimming velocity of the bacteria and aerotactic velocity as function of the distance from the PDMS for four different times. The capillary is initially filled with an homogeneous suspension of bacteria at OD = 0.05.

*Corresponding author. E-mail: frederic.moisy@universite-paris-saclay.fr

RESULTS

Under usual conditions, a suspension of *S. meliloti* is composed of both non-motile and motile bacteria. Non-motile bacteria may be either attached to the substrate (on which they may form biofilms) or freely suspended in the liquid medium. We focus here on the motile population, swimming at a mean velocity of $20\text{-}25\ \mu\text{m s}^{-1}$ and performing aerotaxis. Bacterial motion is observed using high-speed imaging under phase-contrast microscopy, and their trajectories are analysed by standard tracking methods using *ImageJ*.

Starting from an initial homogeneous concentration of bacteria and oxygen, oxygen consumption by the bacteria gradually produces an oxygen gradient near the oxygen-permeable PDMS plug, at $x = 0$. This oxygen gradient triggers the bacterial aerotaxis: Fig. 1 shows the propagation of a bacterial band escaping the low-oxygen region towards the oxygen source by swimming up the gradient. Reproducing this experiment with different initial concentrations yields the same qualitative result, on a time scale that depends on the initial bacterial concentration.

To infer the aerotactic response, we describe the bacterial concentration $b(x, t)$ using the standard one-dimensional Keller-Segel equation [4,5]:

$$\frac{\partial b}{\partial t} + \frac{\partial J_x}{\partial x} = 0, \quad J_x = \chi(c)b \frac{\partial c}{\partial x} - \mu(c) \frac{\partial b}{\partial x}, \quad (1)$$

where c is the oxygen concentration, μ is the motility coefficient and χ the aerotactic sensitivity coefficient. The averaged bacterial flux J_x has two contributions, aerotactic and diffusive. This equation assumes that the bacterial time response to changes in oxygen level is much faster than the dynamics of the propagating front, and that the mean run length is much smaller than the typical front width.

The flux in Eq. (1) is directly related to the averaged bacterial velocity V_x computed from the bacteria tracking through $J_x = bV_x$. This shows that the measured bacterial velocity V_x gives the aerotactic velocity $\chi(c)\partial c/\partial x$ only where b is uniform, *i.e.* at the location of the front or far from oxygen source, which severely limits the range of oxygen where $\chi(c)$ can be measured. Because of the large motility of *S. meliloti*, $\mu \simeq (8 \pm 2) \times 10^3\ \mu\text{m}^2\ \text{s}^{-1}$, the diffusive flux represents a strong contribution to the total flux. Taking into account the diffusive flux term allows us to extend the range of oxygen concentration where the aerotactic sensitivity coefficient $\chi(c)$ can be measured.

Our measurements show that the quantity $[V_x + (\mu/b)\partial b/\partial x]/(\partial c/\partial x)$ is indeed independent of x, t , and the initial bacterial concentration over a significant range of oxygen concentration, indicating that Equation (1) holds in the explored range of parameters. A power-law is found for the aerotactic sensitivity, $\chi(c) \propto 1/c^2$, over the whole range of oxygen concentration for which the cells are motile: between $0.3\ \text{mg L}^{-1}$ (below which motility stops) and $5\ \text{mg L}^{-1}$ (close to the saturation concentration). This scaling is compatible with the general form proposed by Lapidus and Schiller [6] and Rivero *et al.* [7], which applies when the dissociation constant of the considered chemoattractant (here oxygen) is much smaller than the ambient attractant concentration.

Our results suggest that aerotaxis in *S. meliloti* is a very efficient process: the biased swimming towards oxygen is strongly enhanced in low-oxygen regions, with an oxygen dependence that exceeds the ‘‘logarithmic sensing’’ aerotactic response ($\chi \propto 1/c$) found in other species.

References

- [1] J. B. Raina, V. Fernandez, B. Lambert, R. Stocker and J. R. Seymour. *Nat. Rev. Microbiol.* **17**, 284-294 (2019).
- [2] R. Götz, N. Limmer, K. Ober and R. Schmitt. *Microbiology*, **128**(4), 789-798 (1982).
- [3] C. Douarache, A. Buguin, H. Salman and A. Libchaber. *Physical Review Letters* **102**, 198101 (2009).
- [4] E. F. Keller and L. A. Segel. *Journal of theoretical biology* **30**(2), 225-234 (1971).
- [5] E. F. Keller and L. A. Segel. *Journal of theoretical biology* **30**(2), 235-248 (1971).
- [6] I. R. Lapidus and R. Schiller. *Biophysical journal* **16**(7), 779-789 (1976).
- [7] M. A. Rivero, R. T. Tranquillo, H. M. Buettner and D. A. Lauffenburger. *Chemical engineering science* **44**(12), 2881-2897 (1989).