Research Ideas and Outcomes 2: e7869
doi: 10.3897/rio.2.e7869

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Research Idea

Partial synchronization of the colonial diatom *Bacillaria "paradoxa"*

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Reviewable v1

Received: 22 Jan 2016 | Published: 22 Jan 2016

Citation: Gordon R (2016) Partial synchronization of the colonial diatom *Bacillaria "paradoxa"*. Research Ideas and Outcomes 2: e7869. doi: 10.3897/rio.2.e7869

Abstract

Background

The unique gliding motion of the cells in the colonial diatom *Bacillaria "paradoxa"* against one another has intrigued microscopists since 1783. Both the mechanism of movement and of entrainment, which results in partial synchrony, are unsolved.

New information

Experimental and analytical methods that might help solve the synchronization enigma are proposed.

Keywords

colonial diatom, *Bacillaria paradoxa*, gliding motility, synchrony

Overview and background

The worldwide colonial diatom *Bacillaria "paradoxa"* (Ussing et al. 2005) has a unique form of motion in which the cloned cells are stacked in a one dimensional array, with each one sliding back and forth against its two neighbors, as indicated in Fig. 1 (except, of course, the two end cells, which have one neighbor each, although their exposed raphes may be active, as in noncolonial raphid diatoms: Drum and Hopkins 1966).

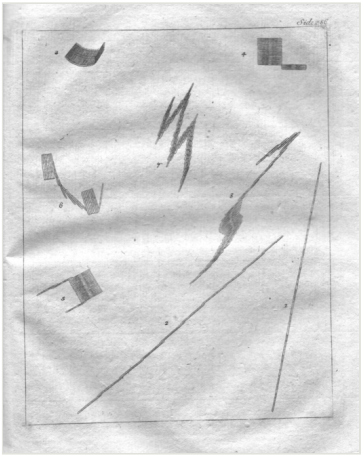

Figure 1.

The first ever description of a diatom was of the colonial diatom *Bacillaria "paradoxa"* (Müller, 1783). Colonies are shown in various configurations between which they can smoothly transition on a time scale of seconds.

From the many movies online (ALMuseum 2009a, ALMuseum 2009b, Basili 2014, BirdWhisperer46 2012, Capilla 2010, Capilla 2012, Capilla 2013, Cimellimay 2011, Do 2012, Gougi 2007, Hsiao 2015, Kersulis 2012, Kiermayer 2001, Laundon 2015, Lobban 2003, Ott 2012, Otyatatemushi 2010, Otyatatemushi 2013, PeacefulProtist 2013, Pierre microscope 2014, Rines 2001, Shilov 2014, Stetson 2015, Tonysharks 2015, uni2さんのチャンネル 2012, WLanier and Communities 2006, Yanase 2015a, Yanase 2015c, Yanase 2015b) and personal observation, it is clear that the motion is partially synchronized. The question is how? Questions that could be addressed experimentally include:

1. The colony is embedded in the elastic, transparent material secreted by the motility apparatus of each cell (its raphes). Does this material provide a mechanical feedback, such as is apparent in the occasional small backwards motion caused by adhesion and nonlinear elastic behavior of the diatom trail in noncolonial raphid diatoms (Sabuncu et al. 2015)?.
2. Is it possible that entrainment occurs via light piping, perhaps when the light sensitive regions at the ends of the cells (Cohn et al. 2004, Cohn et al. 2011, Cohn et al. 2004, Cohn et al. 1999) are aligned (Gordon et al. 2009)?

3. Are there ionic/electric effects and electric polarity, as in some migrating cells (Mousavi et al. 2013), that can be sensed by nearest or further neighbors?
4. The motion stops in the dark, with the cells forming a neat, aligned stack (Kapinga and Gordon 1992), as in the upper left of Fig. 1. In the light the motion, at least often, starts with an end cell and propagates through the colony. Is there some specific cell to neighboring cell communication? If so, how?

The name of this diatom was recently changed to *Bacillaria paxillifer* (O. F. Müll.) Hendy (Kociolek and Kreis Jr. 2015). However, this is out of date, since *Bacillaria paradoxa* (Gmelin 1788) is now recognized as a group of long debated taxonomic status (Schmid 2007) and split into three species with one of them having a variety (Jahn and Schmid 2007). In addition to these, one of the names "currently accepted taxonomically" is still *Bacillaria paradoxa* var. *tumidula* (Grunow) (Guiry 2015). As they all exhibit the same peculiar motions, for the sake of referring to them as a group I use *Bacillaria "paradoxa"* by which they are "better known" (Jahn and Schmid 2007).

Objectives

Here are some experimental, simulation and mathematical approaches that may be worth considering to answer these questions:

1. Break up colonies, so we could observe colonies of sizes n = 1,2,3, etc. We already know that a single cell oscillates against the shard of its laser-killed neighbor (Drum et al. 1971), so that the oscillations are intrinsic to the cells, and not an emergent phenomenon.
2. Do computer simulations of the cells' motion, using various rules of interaction, to find a best match to the observed motion.
3. Analyze movies using image processing, especially to translate the coordinate system to each cell, one at a time, to get details of its motion relative to its neighbors, and correlations versus neighbor distance.
4. Regard the problem as an inverse synchronization problem, to derive coupling parameters from the observed motion. For the forward problem, see (Pikovsky et al. 2001).
5. Try to entrain the motion optically, with focused light pulses, or mechanically, with any form of micromanipulation.
6. Visualize the cloud of raphe material around the colony using colloidal particles, and analyze its motion as the cells move, perhaps using PIV (particle image velocimetry).
7. Measure the electric field around *Bacillaria* or other motile diatoms, and see if its polarity alters when they reverse direction.
8. Bend a colony under a known force until it breaks, to measure the strength of adhesion of the cells to one another, despite their relative motion.

9. Observe the motility of dividing cells within a colony, to see if they behave the same as cells that are not dividing, and how the daughter pair initiates relative motion between them.
10. Analyze the motion of colonial diatoms that slide just once (Ussing et al. 2005).
11. Observe how the motion changes with light intensity and its color.

Acknowledgements

Collaborations are welcome on any or all aspects.

Hosting institution

Gulf Specimen Aquarium & Marine Laboratory, Panacea, Florida USA

References

- ALMuseum (2009a) クサリケイソウの不思議Mysterious behavior of Bacillaria [movie]. https://www.youtube.com/watch?v=BDvCkttQPMk
- ALMuseum (2009b) クサリケイソウの舞; Dancing Bacillaria [movie]. https://www.youtube.com/watch?v=PUCSTiwZZ18
- Basili D (2014) Bacillaria paxillifer [movie]. https://www.youtube.com/watch?v=SPfhjazILYA
- BirdWhisperer46 (2012) Bacillaria paxillifer - Is Not a Caterpilififer [movie]. https://www.youtube.com/watch?v=klMGTnqMwfg
- Capilla FP (2010) Bacillaria Diatomea [movie]. https://www.youtube.com/watch?v=o9zNtXw2JMI
- Capilla FP (2012) Bacillaria paxillifer diatomea - diatom [movie]. https://www.youtube.com/watch?v=lVg0lSKziys
- Capilla FP (2013) Bacillaria paxillifer Diatomea [movie]. https://www.youtube.com/watch?v=xFfQ9piAzDo
- Cimellimay (2011) Bacillaria [movie]. https://www.youtube.com/watch?v=M2f6y4aiU8s
- Cohn S, Bahena M, Davis J, Ragland R, Rauschenberg C, Smith B (2004) Characterisation of the diatom photophobic response to high irradiance. Diatom Research 19 (2): 167-179. DOI: 10.1080/0269249x.2004.9705869
- Cohn SA, Zapata Y, McLaughlin MJ (2011) Comparative analysis of light- stimulated motility responses in diatoms. Molecular Biology of the Cell 22: 15-48.
- Cohn SA, Green T, Payne KJ, Saini VS (2004) Comparative analysis of irradiation-induced direction change in diatoms. Molecular Biology of the Cell 15: 163.
- Cohn SA, Zelner D, Crea J, Wibisono B, Silverman M (1999) Analysis of diatom motility using light avoidance and fluorescent bend assays. Molecular Biology of the Cell 10: 15-27.

- Do R (2012) Bacillaria paradoxa [movie]. https://www.youtube.com/watch?v=7ddWMC1KjPc
- Drum R, Hopkins JT (1966) Diatom locomotion: An explanation. Protoplasma 62 (1): 1-33. DOI: 10.1007/bf01254629
- Drum RW, Gordon R, .Bender R, Goel NS (1971) 'On weakly coupled diatomic oscillators: *Bacillaria*'s paradox resolved. Journal of Phycology 7: 13-14.
- Gmelin JF (1788) *Bacillaria paradoxa*. Caroli à Linné Systema naturae. 6, 1. Beer, Leipzig, Germany, 3903 pp.
- Gordon R, Losic D, Tiffany MA, Nagy S, Sterrenburg FS (2009) The Glass Menagerie: diatoms for novel applications in nanotechnology. Trends in Biotechnology 27 (2): 116-127. DOI: 10.1016/j.tibtech.2008.11.003
- Gougi S (2007) クサリケイソウ (バキラリア) 属の一if - Bacillaria sp. [movie]. https://www.youtube.com/watch?v=sQU1nWZk_cE
- Guiry MD (2015) *Bacillaria* J.F.Gmelin, 1791. In: Guiry MD, Guiry GM (Eds) AlgaeBase. National University of Ireland, Galway. URL: http://www.algaebase.org/search/genus/detail/?genus_id=s2335e6205d52bee2&-session=abv4:43E996C81db731E398Rh3AF9EDC0
- Hsiao A (2015) 奇異棍形藻 Bacillaria paxillifera (偏光、穿透光) [movie]. https://www.youtube.com/watch?v=PD7FKihgAjY
- Jahn R, Schmid A (2007) Revision of the brackish-freshwater diatom genus Bacillaria Gmelin (Bacillariophyta) with the description of a new variety and two new species. European Journal of Phycology 42 (3): 295-312. DOI: 10.1080/09670260701428864
- Kapinga MM, Gordon R (1992) Cell motility rhythms in *Bacillaria paxillifer* . Diatom Research 7 (2): 221-225. DOI: 10.1080/0269249x.1992.9705215
- Kersulis D (2012) Bacillaria paxillifer [movie]. https://www.youtube.com/watch?v=2np5EhefZKo
- Kiermayer O (2001) Gliding Movement - Diatom (Bacillaria paradoxa, Pennales)/ Gleitbewegung - Kieselalge (Bacillaria paradoxa, Pennales) [movie]. http://www.cells.de/cellseng/medienarchiv/archiv/bp1c1562d/1562_b58.html
- Kociolek JP, Kreis Jr. R (2015) Bacillaria paradoxa Gmelin: Taxonomic Serial No.: 5302. http://www.itis.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=5302. Accession date: 2015 12 17.
- Laundon D (2015) 11/07/15 Diatom Colony (Bacillaria paxillifer?) [movie]. https://www.youtube.com/watch?v=cWiDIMY_QgM
- Lobban C (2003)) Bacillaria: The "carpenter's rule" diatom, easily recognized by the sliding of the cells against one another in the colony. [QuickTime movie]. http://www.uog.edu/classes/botany/474/diatoms/bacillaria.html
- Mousavi SJ, Doweidar MH, Doblaré M (2013) 3D computational modelling of cell migration: A mechano-chemo-thermo-electrotaxis approach. Journal of Theoretical Biology 329: 64-73. DOI: 10.1016/j.jtbi.2013.03.021
- Ott D (2012) Bacillaria paxillifer - a diatom with a spectacular gliding movement [movie]. https://www.youtube.com/watch?v=NvHF-YjDZBo
- Otyatatemushi (2010) イカダケイソウのii'ti / Bacillaria sp. [movie]. https://www.youtube.com/watch?v=GUdDI_QhaoI
- Otyatatemushi (2013) イカダケイソウBacillaria paradoxaのii'ti [movie]. https://www.youtube.com/watch?v=SyYjuMhKU3Y

- PeacefulProtist (2013) The Amazing Sliding Diatom (Bacillaria paxillifer) [movie]. https://www.youtube.com/watch?v=s5LQbh4dVoM
- Pierre microscope (2014) Bacillaria paradoxa [movie]. https://www.youtube.com/watch?v=3Mk1xi6FMXE
- Pikovsky A, Rosenblum M, Kurths J (2001) Synchronization: A Universal Concept In Nonlinear Sciences. Cambridge University Press, 432 pp. URL: http://dx.doi.org/10.1017/cbo9780511755743 DOI: 10.1017/cbo9780511755743
- Rines J (2001) Plankton Theater, Bacillaria paxillifera, a motile, colonial pennate diatom, Narragansett Bay, Rhode Island, Fall [movie]. http://thalassa.gso.uri.edu/plankton/theater/alphabetical.html
- Sabuncu AC, Gordon R, Manoylov K, Beskok A (2015) The acceleration noise of motile diatoms. To be submitted in preparation.
- Schmid A (2007) The "paradox'' diatom *Bacillaria paxillifer* (Bacillariophyta) revisited. Journal of Phycology 43 (1): 139-155. DOI: 10.1111/j.1529-8817.2006.00299.x
- Shilov P (2014) Carpenters Rule Diatoms (Bacillaria paxillifer) [movie]. https://www.youtube.com/watch?v=DxK7QgD9Oic
- Stetson J (2015) microlife casco bay unfolding diatoms Bacillaria paxillifer 092914 plant locomotion [movie]. https://www.youtube.com/watch?v=FF9JKX48_fw
- Tonysharks (2015) https://www.youtube.com/watch?v=N6XV849ZAmQ
- uni2さんのチャンネル (2012) Bacillaria paradoxa.AVI [movie]. https://www.youtube.com/watch?v=a864NCFBsDs
- Ussing AP, Buczko K, Desnitskiy AG, Ector L, Gordon R, VanLandingham SL, Witkowski A (2005) The colonial diatom "Bacillaria paradoxa": chaotic gliding motility, Lindenmeyer Model of colonial morphogenesis, and bibliography, with translation of O. F. Müller (1783). 'About a peculiar being in the beach-water. Gantner, 139 pp.
- WLanier, Communities H (2006) Bacillaria paxillifera Just Slides Along [movie]. https://www.youtube.com/watch?v=Ol6hbX5mhPc
- Yanase R (2015a) The ground swell produced by gliding motion of diatom, Bacillaria paradoxa (うごめくイカダケイソウ) [movie]. https://www.youtube.com/watch?v=HyGoK7WfoS8
- Yanase R (2015b) The gliding motion of diatom, Bacillaria paradoxa Part 2 [movie]. https://www.youtube.com/watch?v=4cJb9jCN2oI
- Yanase R (2015c) The gliding motion of diatom, Bacillaria paradoxa Part 1 [movie]. https://www.youtube.com/watch?v=j1lCCpZPNH8