twin around a Sun-like star, we have to devise robust methods for filtering out the star's variability. By providing researchers with a valuable data set for testing their analytical tools, the present study is a step in that direction.

In the coming months, astronomers will certainly be scrutinizing these measurements. Only if other analyses come to the same conclusion can we be sure that this planet exists. Better yet, independent measurements should be made with other facilities and instruments to confirm this candidate planet. ∎

Artie P. Hatzes *is at the Thuringian State Observatory, Tautenburg 07778, Germany.*
e-mail: artie@tls-tautenburg.de

1. Dumusque, X. *et al.* *Nature* **491,** 207–211 (2012).
2. Snellen, I. A. G., de Mooij, E. J. W. & Albrecht, S. *Nature* **459,** 543–545 (2009).
3. Knutson, H. A. *et al.* *Astrophys. J.* **754,** 22 (2012).
4. Latham, D. W. *et al.* *Astrophys. J.* **732,** L24 (2011).
5. Mayor, M. & Queloz, D. *Nature* **378,** 355–359 (1995).
6. Campbell, B., Walker, G. A. H. & Yang, S. *Astrophys. J.* **331,** 902–921 (1988).

MICROBIOLOGY

Bacterial power cords

Geochemical reactions in upper layers of marine sediments are coupled to those in deeper zones. It turns out that centimetre–long bacterial filaments acting as electrical cables are the metabolic link between the layers. SEE ARTICLE P.218

GEMMA REGUERA

A few years ago, any suggestion that microbes could function as power cables to transmit electric currents across centimetre distances would have been met with scepticism. Yet this is exactly what Pfeffer *et al.*[1] report on page 218 of this issue. The authors provide compelling evidence linking the presence of long filaments of a previously unknown group of bacteria to the electric currents that couple spatially separated geochemical reactions in marine sediments*.

In the oceans, atmospheric oxygen diffuses from the water into the upper layers of the underlying sediment. Here, it is rapidly consumed by microorganisms, which use the oxygen as the terminal acceptor of electrons that are generated during the metabolism of organic matter to gain energy for growth. As a result, oxygen concentrations drop sharply in the uppermost layer of the sediment (the oxic zone), leaving the deeper layers oxygen-free (anoxic). Microbes in the anoxic layers therefore rely on other electron-accepting molecules such as sulphate (SO_4^{2-}) to fulfil their energy needs (Fig. 1). The transfer of electrons to sulphate, however, generates hydrogen sulphide (H_2S), a gas that is toxic to oxygen-consuming organisms. Yet hydrogen sulphide levels can be controlled by microbes that convert it into sulphate or into other oxidized sulphur compounds.

Although the oxic and sulphide layers are typically separated by millimetres to centimetres of sediment, reductions in oxygen availability in the upper layer rapidly lead to the accumulation of hydrogen sulphide and the expansion of the sulphide region[2]. As soon as oxygen is available again, hydrogen sulphide

Figure 1 | Electrifying microbial filaments. Microorganisms (purple) in the upper layers of marine sediments use oxygen (O_2) that diffuses from sea water as an acceptor of electrons, which they produce in energy-generating metabolic reactions. As a result, other microbes (orange) in deeper, anoxic layers (where oxygen is scarce or absent) have to use other electron acceptors such as sulphate (SO_4^{2-}) for growth. Transfer of electrons to oxygen results in the formation of water, whereas electron transfer to sulphate produces hydrogen sulphide (H_2S), which is poisonous to many organisms. Pfeffer *et al.*[1] provide evidence that long bacterial filaments could transport electrons generated when hydrogen sulphide is converted into sulphur (S) at the bottom of the sediments and use them to consume oxygen in the upper layers.

consumption resumes and the sulphide layer recedes. The responses are so fast as to exclude mechanisms based on the diffusion of molecules, and they can be explained only by the action of electric currents.

Such electric currents might be mediated by bacterial conductive appendages (microbial nanowires)[3–5], electron-shuttling solid phases (such as humic substances generated during the decomposition of organic matter)[6] and/or conductive minerals[7]. However, evidence so far suggests that these mediators enable the flow of electrons only across nanometre to micrometre distances, whereas the oxic and sulphide sediment layers are typically separated by millimetre to centimetre distances.

Now Pfeffer *et al.* report that sulphidic marine sediments are densely colonized by long, multicellular bacterial filaments — some reaching lengths (up to 1.5 centimetres) that correspond well to the spatial separation of the oxic and sulphide layers. The authors provide experimental evidence that the filaments are required for the electrical coupling between sediment layers. For example, when they cut the filaments or used filters to prevent their passage, oxygen consumption in the upper region was reduced and the sulphide layer expanded.

The filamentous microbes belong to the family Desulfobulbaceae, a morphologically diverse group of bacteria with members previously shown[8] to both generate and consume hydrogen sulphide; these reactions are localized to the space (periplasm) contained between the cytoplasmic (or inner) membrane and the outer membrane. Interestingly, the outer membrane of the filamentous microbes is structured as ridges, which define tubular channels of periplasm running along the cells, and continue as junctions between neighbouring cells. Furthermore, although the outer membrane of the ridges and junctions acts as an insulator, their internal content is highly charged. These unique structural and electrical
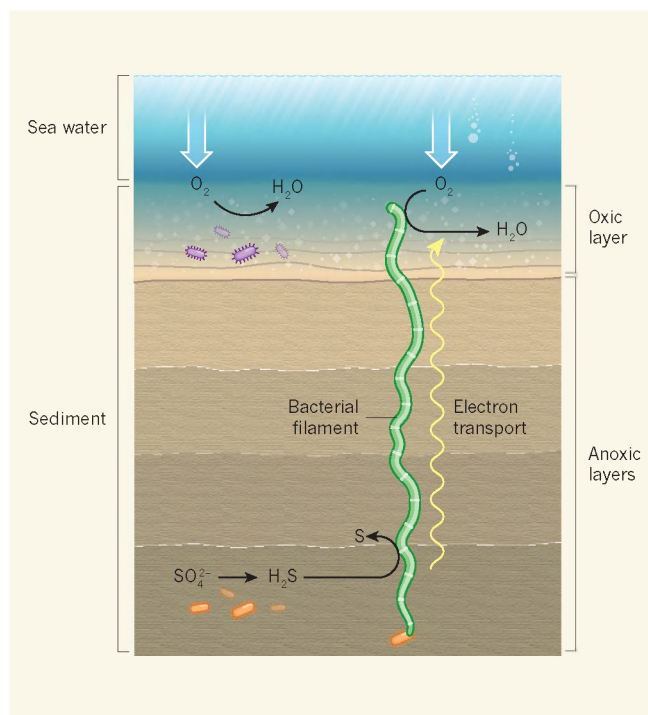
*This article and the paper under discussion[1] were published online on 24 October 2012.

properties hint at a potential mechanism for electron transfer involving the periplasmic conduits.

The authors propose a plausible model in which cells at one end of the filament oxidize hydrogen sulphide to supply electrons to the oxygen-consuming cells located at the opposite end (Fig. 1). However, the idea that the microbial filaments behave as living, centimetre-long power cords, presumably transporting electrons through continuous tubular channels, defies our understanding of biological electron transfer. Nevertheless, it is known that the periplasm of some bacteria that use metals as electron acceptors houses abundant metal-containing proteins, mostly of the cytochrome class, that allow electrons to flow from the inner to the outer membrane[9]. Cytochromes and microbial nanowires can transmit electric currents across micrometre-thick films formed by these bacteria. Therefore, similar mechanisms — but contained within tubular periplasmic ridges — might mediate long-range electron transfer in the Desulfobulbaceae filaments.

Pfeffer and colleagues' report raises questions about the ecological role of these bacteria as well. If widespread, the bacterial cables could constitute the main mechanism for the transport of electric currents in marine sulphidic sediments. However, it is unclear whether they act alone or in concert with other microbes. When the authors cut the filaments or prevented their permeation through the sediments with filters, they might have also disrupted other microbial electrical networks. Hence, to assess the exact contribution of the filaments to the electric currents of the sediments, it will be crucial to confirm that electrons can travel along the filaments and to measure the transport rates. Furthermore, the ability to consume the toxic hydrogen sulphide, if demonstrated, might allow the bacteria to outcompete other microbes, and promote metabolic interactions with others.

Finally, it should be noted that the bacterial cables might not simply provide a mechanism to cope with toxic hydrogen sulphide in sediments. Rather, they could enable a more widespread biological process for energy transfer and the coupling of spatially separated biogeochemical reactions. As noted in an earlier report[2], hydrogen sulphide consumption in some subsurface sediments is not high enough to sustain the levels of oxygen consumption measured in the sediment's top layer. Thus, other biogeochemical reactions could be electrically coupled to the reduction of oxygen in sediments as well.

Pfeffer and colleagues' report adds to the growing body of evidence highlighting the crucial role that microbial electron transfer has in global geochemical processes and in the functioning of ecosystems. These are indeed exciting times for microbiologists, and the present work reminds us — one

more time — just how much more awaits discovery. ∎

Gemma Reguera *is in the Department of Microbiology and Molecular Genetics, Michigan State University, East Lansing, Michigan 48824, USA.*
e-mail: reguera@msu.edu

1. Pfeffer, C. *et al. Nature* **491**, 218–221 (2012).
2. Nielsen, L. P., Risgaard-Petersen, N., Fossing, H., Christensen, P. B. & Sayama, M. *Nature*
  463, 1071–1074 (2010).
3. El-Naggar, M. Y. *et al. Proc. Natl Acad. Sci. USA* **107**, 18127–18131 (2010).
4. Gorby, Y. A. *et al. Proc. Natl Acad. Sci. USA* **103**, 11358–11363 (2006).
5. Reguera, G. *et al. Nature* **435**, 1098–1101 (2005).
6. Roden, E. E. *et al. Nature Geosci.* **3**, 417–421 (2010).
7. Kato, S., Hashimoto, K. & Watanabe, K. *Proc. Natl Acad. Sci. USA* **109**, 10042–10046 (2012).
8. Fuseler, K., Krekeler, D., Sydow, U. & Cypionka, H. *FEMS Microbiol. Lett.* **144**, 129–134 (1996).
9. Shi, L., Squier, T. C., Zachara, J. M. & Fredrickson, J. K. *Mol. Microbiol.* **65**, 12–20 (2007).

APPLIED PHYSICS

Brighter images with no added noise

A special type of optical amplifier based on a vapour of rubidium has been demonstrated that makes faint images brighter without adding noise. This concept could find use in biological imaging and image processing.

STÉPHANE CLEMMEN & ALEXANDER GAETA

Anyone who has adjusted the sensitivity settings of a camera in weak light will have noticed that increasing the electronic gain of the camera's light sensor yields images of poor quality. This observation reveals a general property of amplification of signals: it is accompanied by noise. However, there are special conditions in which such noise can be circumvented. Writing in *Physical Review Letters*, Corzo *et al.*[1] describe how they have achieved this in the amplification of faint images.

In the quest to improve the accuracy of measurement and observation of a system, certain fundamental bounds exist that limit the precision with which a physical quantity can be determined. Specifically, according to Heisenberg's uncertainty principle, it is not possible to attain perfect precision in simultaneously determining a system's observable quantity and its conjugate variable; two variables, X and Y, are conjugate variables if they are related to one another through a mathematical operation known as a Fourier transform. Examples of pairs of conjugate variables include time and frequency, and position and momentum. The case in which the uncertainties ΔX and ΔY in X and Y, respectively, are equal and minimal is known as the standard quantum limit for X and Y, and a system in such a state of minimum uncertainty is said to be in a coherent state. However, because the uncertainties are not necessarily equal, measurements can be performed that have a precision beyond the standard quantum limit. Such precision can be achieved using 'squeezed' states[2], in which one of the two

conjugate variables has a smaller (squeezed) uncertainty than that associated with coherent states.

For light, the conjugate variables X and Y are typically taken to be the quadratures that define the light's time-varying electromagnetic field: $E(t) = X\cos(2\pi v t) + Y\sin(2\pi v t)$, where t denotes time and v is frequency. Figure 1 shows a comparison between the electromagnetic field in a coherent state, typically that of a laser beam, and one in a squeezed state[2,3]. Squeezing can be produced by a nonlinear optical process called four-wave mixing, in which two photons at frequencies v_1 and v_2 are annihilated and two new photons at frequencies v_3 and v_4 are created while satisfying conservation of energy, and therefore frequency: $v_1 + v_2 = v_3 + v_4$. For this process to occur efficiently, another rule, known as phase matching, must apply. This states that the sum of the momenta of the interacting photons at these frequencies is conserved (that is, the sum of the propagation constants $k_1 + k_2 = k_3 + k_4$). The result of this interaction is that the uncertainties in the quadratures of the generated photon field become unequal, such that one is less than (squeezed) that of a coherent state and the other is greater.

The interaction that produces squeezing represents a special type of linear amplifier. The most common form of amplifier produces phase-insensitive amplification (PIA), in which both quadratures of the field are amplified equally. But phase-sensitive amplification (PSA), in which one quadrature is amplified while the other is de-amplified, can also be realized. In PIA, the quotient between the signal-to-noise ratio of the input field and that of the output, amplified field — the noise figure