NEWS & VIEWS

PLANETARY SCIENCE

Martian sand blowing in the wind

High-resolution spacecraft images show surprisingly large rates of sand transport on Mars. This finding suggests that the planet's surface is a more active environment than previously thought. SEE LETTER P.339

JASPER KOK

The ubiquitous sand dunes on Mars appeared almost motionless when the Viking and subsequent space missions examined them[1]. This made sense. After all, the atmosphere of Mars is about one hundred times less dense than that of Earth, so putting sand into motion on Mars requires rare hurricane-like wind speeds. Consequently, some studies have hypothesized that many Martian dune fields were formed in a previous climate, in which the planet had a thicker atmosphere than it has now[2]. But studies in recent years[3–5] have found surprising signs of activity on the surface of Mars, with movement of sand dunes and ripples detected across the desert planet. On page 339 of this issue, Bridges *et al.*[6] present the first extraterrestrial measurements of sand transport, in a Martian dune field called Nili Patera. Remarkably, the authors report that Mars's thin atmosphere blows sand in this dune field at rates not much lower than Earth's much thicker atmosphere does on terrestrial dunes*.

Bridges and colleagues arrived at this surprising conclusion by combining advances in image analysis with the astounding 25-centimetre resolution of the Martian orbital camera HiRISE (High Resolution Imaging Science Experiment) on NASA's Mars Reconnaissance Orbiter, which exceeds the resolution of any non-military satellite in orbit around Earth. By correlating high-resolution images of Nili Patera taken more than 100 days apart, the authors were able to obtain a map of sand-ripple migration across the dune field. They found that ripple displacement scaled almost perfectly with elevation on the dune, which is a telltale sign of shape-preserving dune migration. The authors then used the measured ripple dimensions to convert ripple-displacement rates to actual sand-transport rates, which correlated well with sand fluxes derived from dune displacements. This procedure resulted in an estimated average sand-transport rate of approximately seven cubic metres per spanwise metre per Earth year, which is only slightly lower than the sand flux in some dune fields on our planet (Fig. 1).

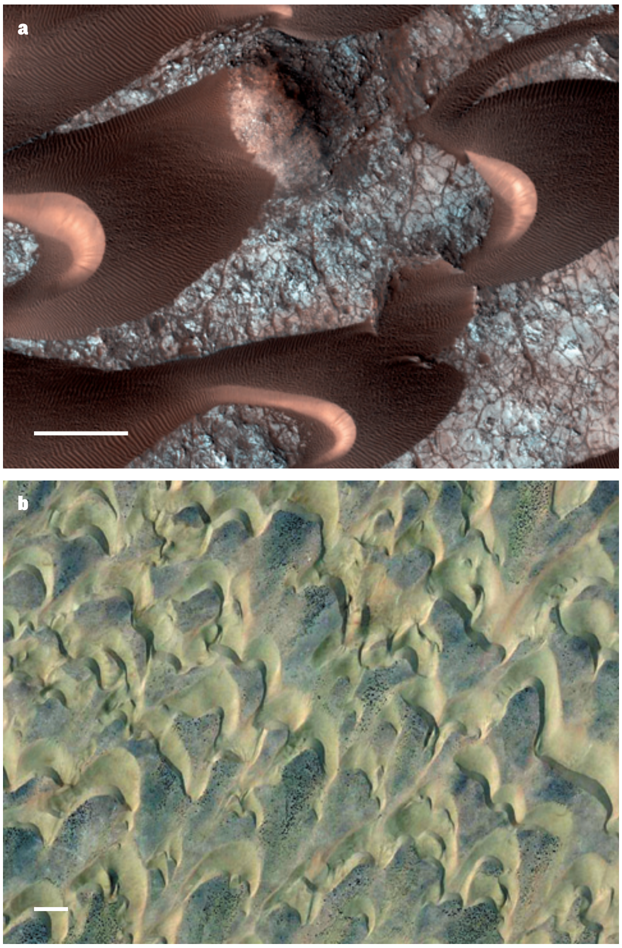

Figure 1 | Sand dunes on Mars and Earth. a, Bridges *et al.*[6] used high-resolution images obtained by the Martian orbital camera HiRISE to quantify movement of sand dunes and ripples over bedrock in the Martian dune field Nili Patera. **b**, The authors find that the rate at which the planet's thin atmosphere moves sand on the dunes is not much smaller than that observed for their terrestrial analogues, an example of which is shown here. Scale bars, 50 metres.

A, NASA/JPL/UNIV. ARIZONA; B, GEOEYE/GOOGLE

Together with the other recent studies[3–5] reporting active Martian sand transport, the surprisingly large sand fluxes estimated by Bridges *et al.* force us to view the Martian surface as a more active environment than expected. For instance, this small army of bouncing sand grains grinds away at the bedrock between the dunes much more quickly than previously thought. Moreover, the large sand flux in Nili Patera implies that this dune field could have formed in fewer than 10,000 years[6]. Because climate-altering fluctuations in Mars's orbit occur on timescales about ten times longer than that[2,7], this implies that Nili Patera, and probably other Martian dune fields, are not relicts from a previous climate with a thicker atmosphere, but could have formed in the present climate.

However, the finding that the thin Martian atmosphere transports copious amounts of sand poses more questions than it answers. In particular, atmospheric circulation models predict wind stresses that generally remain well below the threshold for sand lifting[7], even in areas where active sand transport is observed[4]. In addition, sporadic measurements by Mars landers have found that wind speeds surpass the sand-transport threshold only exceedingly rarely[1]. So the million-dollar question is: how is all this sand being moved?

Part of the answer might be that small-scale topography and convection generate strong localized winds on Mars, which cannot be accurately simulated by the coarse resolution of Martian atmospheric circulation models[8]. The transport of sand by these localized winds would also help to explain the poor correlation between areas where sand transport is observed and areas where models predict strong large-scale winds[5]. Another piece of the puzzle might be that, once a strong gust of wind starts blowing sand on Mars, the sand may well be kept adrift by moderate winds of velocities up to a factor of ten lower than that needed to initiate transport[9]. This occurs because the low Martian gravity and vertical air drag combine to make bouncing sand on Mars akin to playing golf on the Moon:

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particles travel much higher trajectories than on Earth, allowing them to gain substantial momentum even in light winds, so that on landing they splash up enough new particles to keep transport going at low wind speeds[9].

In addition to this question of exactly how sand is moved by the thin Martian atmosphere, Bridges *et al.* leave plenty of other exciting questions to be answered by future studies. For instance, are these high sand-transport rates typical for Mars, or does the Nili Patera dune field represent an outlier — a hotbed of aeolian activity much like the Saharan Bodélé depression on Earth[10]? And, given that many other Martian dune fields are probably inactive[1,2], which processes determine whether a dune field is active? Furthermore, on Earth, the suspended dust in dust storms is generated by the mechanical impact of blowing sand onto soils. Does the sandblasting of Martian soils similarly provide dust to Mars's many, and occasionally planet-encircling, dust storms? Or is Martian dust-lifting dominated by other processes, such as the aerodynamic lifting of low-density dust aggregates[3]? In the coming years, a widespread application of Bridges and colleagues' technique of using high-resolution satellite imagery to map Martian sand fluxes might help to provide answers to these fundamental questions. Combined with continued advances in our knowledge of the mechanics of Martian sand transport[3,9], this approach could facilitate improvements in Martian atmospheric circulation models, and drive further leaps forward in understanding our planetary neighbour. ■

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1. Zimbelman, J. R. *Geophys. Res. Lett.* **27,** 1069–1072 (2000).
2. Gardin, E. *et al. Planet. Space Sci.* **60,** 314–321 (2012).
3. Sullivan, R. *et al. J. Geophys. Res.* **113,** E06S07 (2008).
4. Chojnacki, M., Burr, D. M., Moersch, J. E. & Michaels, T. I. *J. Geophys. Res.* **116,** E00F19 (2011).
5. Bridges, N. T. *et al. Geology* **40,** 31–34 (2012).
6. Bridges, N. T. *et al. Nature* **485,** 339–342 (2012).
7. Haberle, R. M., Murphy, J. R. & Schaeffer, J. *Icarus* **161,** 66–89 (2003).
8. Fenton, L. K. & Michaels, T. I. *Mars* **5,** 159–171 (2010).
9. Kok, J. F. *Phys. Rev. Lett.* **104,** 074502 (2010).
10. Vermeesch, P. & Drake, N. *Geophys. Res. Lett.* **35,** L24404 (2008).

ATOMIC PHYSICS

Electrons get real

Strong laser fields allow electrons to tunnel out of atoms. The response of such electrons to a second laser field supports the idea that they start tunnelling at a time defined by a complex number, but exit atoms at a 'real' time. **See Letter p.343**

MANFRED LEIN

Physicists are perfectly aware that the microscopic behaviour of electrons cannot be understood without the laws of quantum theory. Nevertheless, when scientists trace the dynamics of subatomic phenomena, they like to ask questions that are motivated by a classical, non-quantum perspective. In this spirit, Shafir *et al.*[1] report on page 343 the exact times at which electrons 'exit' atoms that are irradiated by a short flash of laser light. The existence of such an exit time is seemingly counter-intuitive, given that electrons are described by wavefunctions that extend smoothly from the inside to the outside of atoms — part of the electron is always outside the atom. In the presence of a laser field, however, there is a continuous outward flow of electron density, which Shafir and colleagues have decomposed into different electron trajectories, assigning each trajectory an experimentally determined starting time.

The emission of electrons from atoms in Shafir and colleagues' experiments is a consequence of quantum tunnelling. The applied laser field changes the potential-energy profile experienced by the electron, forming a finite barrier that is impenetrable to classical Newtonian particles, but which can be tunnelled across by electrons. A similar process forms the basis of scanning tunnelling microscopy: electrons tunnel between the surface of the object under study and the tip of the microscope. Tunnelling occurs because electron wavefunctions encompass both sides of a potential barrier (Fig. 1a); so what is the meaning of an exit time?

Before answering that question, one must realize that the authors did not detect electrons in their experiments. Instead, they recorded the light released on the return of an emitted electron to its parent ion. Light release occurs because the electric field in a laser pulse reverses direction periodically. This means that, about 1 femtosecond (10^{-15} seconds) after an electron has tunnelled out of an atom, the laser's force pushes it back towards the resulting ion (Fig. 1b). If the electron and ion recombine to form the same bound state that existed before ionization, then a photon is emitted[2]. Because the photon's frequency (and therefore its energy) is much higher than that of the incident laser light, the photon-forming process is called high-harmonic generation.

To resolve the electron emission in time, Shafir *et al.* perturbed electrons emitted from helium atoms with a second, weak probe field acting perpendicular to the main laser field. To picture the experiment, imagine a game

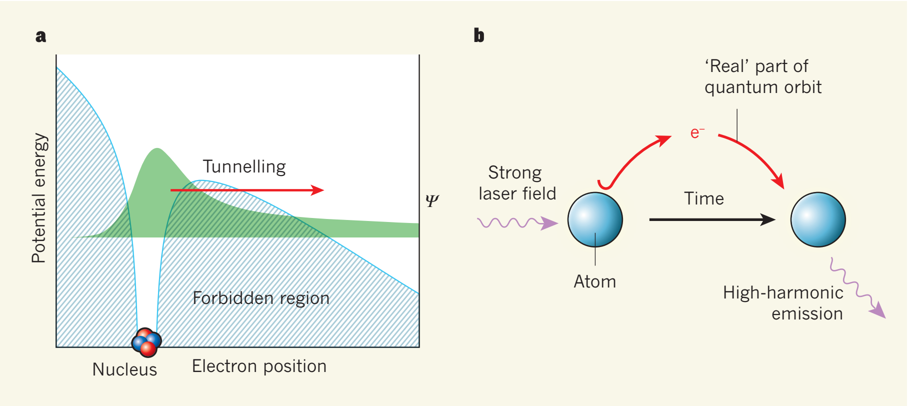

Figure 1 | Quantum tunnelling and high-harmonic generation. **a,** The blue line depicts the potential-energy profile that binds an electron in a laser-irradiated atom. The atom's nucleus is at the profile's minimum. If the electron were a classical Newtonian particle, it could not enter the shaded 'forbidden' regions and would be trapped in the atom. But electrons are quantum-mechanical objects whose probability distributions in space are described by wavefunctions (Ψ, such as the one shown in green). Because wavefunctions extend through the right-hand forbidden area, electrons may tunnel out of the atom. **b,** In the phenomenon of high-harmonic generation, a laser field accelerates an electron (e^-) that has tunnelled out of an atom away from the resulting ion, then directs it back again. Recombination of the electron with the parent ion generates a high-energy photon (a high-harmonic emission). Shafir and colleagues' report[1] suggests that high-harmonic emissions from helium atoms are described by 'quantum orbits'. This means that tunnelling proceeds in imaginary time (the imaginary part of time as defined by a complex number), but the electron moves as a classical particle in 'real' time once it has exited the atom. At the start of its real-time journey, the electron counter-intuitively moves towards the parent ion.

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