Mapping terrestrial planets

As a planetary geologist, **Dr James 'Jim' Zimbelman** studies the four rocky planets in the Solar System. His latest work uses high-resolution satellite images to investigate wind flow patterns in the sand dunes of Mars

Credit: NASM photographer Carolyn Russo

As an introduction, could you describe your academic background? What first attracted you to research concerning sand dunes on Mars?

I always knew I wanted to study space and presumed I would be an astronomer. But in graduate school I discovered the questions that most interested me were not related to stars or galaxies, but to the planets. My PhD is in Geology from Arizona State University, USA, where my advisor had me work on sand dunes and lava flows. This is still the main focus of my research, primarily for Mars because we now have so much wonderful data for the planet from a variety of spacecraft.

What are the aims and objectives of your latest project entitled 'Characterization of small sand dunes on Mars'?

My main goal is to use the patterns and orientations of wind ripples on small sand dunes to infer the most recent wind directions that blew over the dunes. Such information might prove useful to people who model wind flow on Mars. My interest is mainly in how various wind patterns may have contributed to the shapes of the small sand dunes. I see this work as extending our knowledge about Martian dunes to sizes that previously were too small to study. The amazing images from the High Resolution Imaging Science Experiment (HiRISE) now allow us to see the ripples on individual sand dunes on another planet. Incredible!

Have your detailed measurements of Martian sand ripples brought any surprises?

So far I would say we have not encountered any major surprises, but I am a little surprised that we are seeing quite consistent wind directional trends for the sites we have studied in detail; I had expected to see a lot more wind complexity. This could easily be due to the fact that we are focusing on small dunes, which themselves do not strongly influence the wind pattern. When dune shape does become important to the wind flow, this is described as form-flow interaction; the structure of the bedform shape actually alters the wind direction. I have seen little evidence of this effect on the dunes that my colleague Molly B Johnson has documented up to now.

How will the creation of 3D digital terrain models (DTMs) of Martian dunes assist in your investigations?

The answer to this refers back to the possible influence of form-flow discussed above. In places where we do see some possible local alteration of wind flow as represented by the ripple patterns, with good 3D information we could assess what surface slopes might be needed for the effect to become important on Mars. To date, Molly and I have observed only two sites where we have both ripple pattern measurements and good HiRISE DTM data, but we hope to get more overlap in future study sites.

Have you come to any conclusions about the benefits and drawbacks of the freeware Java Mission-planning and Analysis for Remote Sensing (JMARS) you have used over commercial software?

One clear advantage of JMARS is that freeware can be readily used by anyone, from students to researchers. JMARS also makes it very easy to access a wide variety of spacecraft images of Mars, and compare them quickly to many digital maps of the planet. The biggest difference we have seen thus far is that JMARS allows us to make ripple measurements, while commercial packages like ArcGIS have more analysis tools that can be brought to bear on the collected data. Both packages do basically the same thing but, not surprisingly, the commercial ones are more capable in terms of analysis.

What do you hope to achieve in the final two years of the project, and what are your plans beyond this?

My main goal for the remainder of the project is to gather as much ripple pattern information as possible from as many places as possible, to see if there is any indication of locational or seasonal influences on the visibility of Martian wind ripples. We are trying to find sites for future work where the HiRISE images show good ripples on the dunes and there is also a stereo image pair so we might eventually be able to get 3D information to merge with the ripple pattern data. I suspect that a future project could potentially rely heavily on working with both HiRISE image mapping and 3D DTM data to tease out more information about when form-flow becomes important on Mars.

Sands of Mars

At the **Smithsonian National Air and Space Museum**, USA, planetary geologists are using images from Mars to study sand movement. Their work will allow improved modelling of wind flow on the surface of the Red Planet

THE SURFACE OF Mars was formed by volcanic activity and contains many iron oxide deposits, hence the planet's distinctive orange or red colour. The first detailed photographs of the Red Planet were beamed back to Earth by Mariner 9 in 1971. A few years later, the Viking orbiters provided relatively high-resolution images of the geographical features of the Martian surface, including volcanoes, canyons, craters and areas of sand dunes that appeared to have been formed by the wind.

NASA's Mars Orbiter Camera (MOC) aboard the Mars Global Surveyor (MGS) spacecraft – launched in 1996 – brought great improvements in image resolution and showed a complex system of gullies, suggesting water had once been present on the planet's surface. The two Mars Exploration Rovers (MERs) – Spirit and Opportunity – were launched in 2003 and have since provided even better photographs of the Martian surface for astrogeologists to analyse. Data beamed back from multiple spacecraft suggest the Martian sands are moving in dunes and ripples at various locations on the planet. Most recently, the Mars Reconnaissance Orbiter (MRO) spacecraft – launched in 2005 – has delivered even higher definition images of the planet's surface features, but the debate continues as to exactly how the Martian sands are being transported.

RIPPLES AND DUNES

Dr James 'Jim' Zimbelman is a planetary geologist at the Center for Earth and Planetary Studies at the Smithsonian Institution's National Air and Space Museum (NASM) in Washington, DC, USA. His latest project – Characterization of small sand dunes on Mars – is funded by NASA and forms part of its larger Mars Data Analysis Program (MDAP). As the project enters its third year, Zimbelman and his team are expanding their study of the patterns and orientation of ripples on the Martian surface to uncover how wind patterns have contributed to the formation and shape of the dunes themselves. "This work is rather detail-orientated, but it is certainly filling a gap in our understanding of Martian dunes between what the rovers see on the surface and what has previously been seen from orbit," explains Zimbelman.

Ripples and dunes are both common aeolian features: that is, they are formed by the Martian winds. The mechanisms behind aeolian processes are many, but include creep, which describes the way in which a granule-sized particle is rolled across the surface by impacting sand grains, and saltation, the transportation of sand-sized particles by the wind alone.

The ripples on the surface of Martian sand dunes studied by Zimbelman and his colleagues provide an excellent record of wind flow patterns. Although smaller than dunes, ripples record the latest wind flow on the surface of Mars and show the effect of the wind on sand dune morphology.

TRANSVERSE AEOLIAN RIDGES

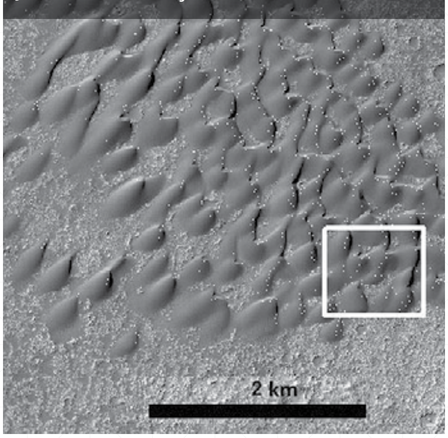
The Smithsonian team's study of Martian dunes relies on images from the University of Arizona's High Resolution Imaging Science Experiment (HiRISE), which has a camera onboard the MRO spacecraft. Capable of a resolution of 25 cm per pixel, HiRISE images record wind ripple patterns on Martian sand dunes from several hundred miles above the planet's surface. "These images show details that are comparable to, or even better than, traditional aerial photographs here on Earth," Zimbelman enthuses. "They are the best yet returned from any orbiting spacecraft, for any planet."

The research findings from Mars are highly relevant to studies back on Earth as they will clarify scientists' existing knowledge about sand motion

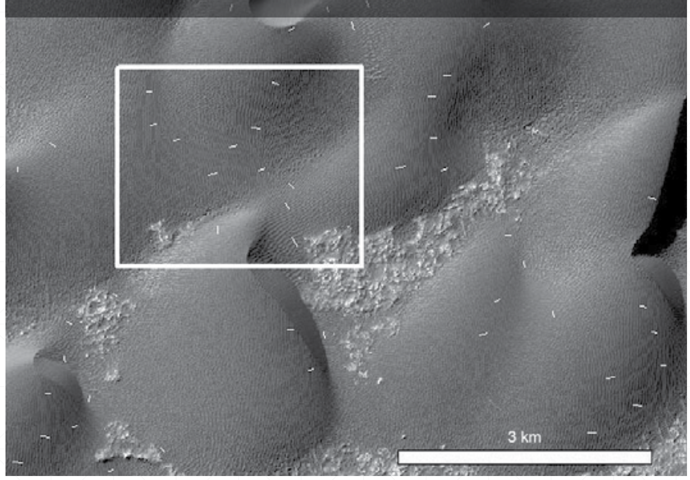
In combination with either the Context Camera (CTX) or Thermal Emission Imaging Spectrometer (THEMIS), the researchers use HiRISE images to identify the distribution, orientation and wavelength of Martian sand ripples. From this information, they intend to put forward hypotheses to explain the formation of small Transverse Aeolian Ridges (TARs), a term coined a decade ago to describe Martian features that are somewhat ambiguous, as they could have originated as either large ripples or small dunes.

Zimbelman's work with the HiRISE images suggests that the size of TARs may provide some clues as to the origin of these Martian features: "Heights smaller than 0.5 m are most likely megaripples, whereas heights greater than 1 m

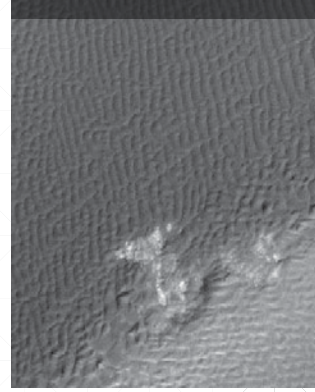
Portion of HiRISE image ESP_025645_1455, showing sand dunes on the floor of an impact crater. The box is the location of the figure to the right. Image: NASA/JPL-Caltech/University of Arizona



Enlarged portion of HiRISE image on the left. White lines are drawn perpendicular to ripple crests. The box is the location of the figure to the right.



Enlarged portion of HiRISE image on the left. White lines are perpendicular to ripple crests, documenting wind flow across the dunes. Areas of complex ripple patterns are not measured.



With co-author Dr Ralph D Lorenz, Zimbelman's new book *Dune Worlds: How windblown sand shapes planetary landscapes*, was published in May 2014 by Springer-Praxis.

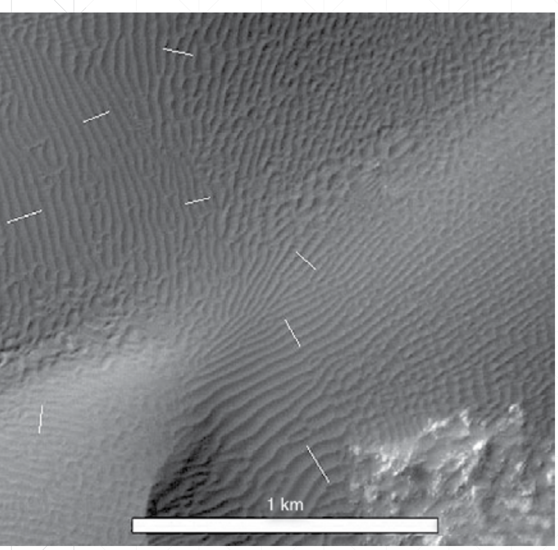
are similar to reversing sand dunes," he notes. "We have been focusing mostly on collecting ripple information, but I hope to increase our TAR studies in the coming year."

FUTURE FOUNDATIONS

In leading the current project, Zimbelman wants to ensure he is laying the foundations for future research into our Solar System's planetary geology. "It is very important to me to work with young scientists, both to help with data collection and interpretation, but also to help train the next generation of planetary scientists," he emphasises.

Reflecting this priority, Molly B Johnson currently works as a full-time assistant on the project. Although she has yet to complete her PhD, Johnson has already accumulated a great deal of experience in studying sand dunes on both Earth and Mars. The two researchers work together to build digital terrain models (DTMs) of the Martian surface using stereo HiRISE images and height data from the Mars Orbit Laser Altimeter (MOLA) aboard the MGS spacecraft. To create the DTMs, the researchers employ the SOft Copy Exploitation Toolkit (SOCET SET) located at the US Geological Survey's facilities at Flagstaff, Arizona. DTMs provide a relief representation of Martian dunes that help the scientists to understand the planet's surface wind patterns.

Another of Zimbelman's protégés is Zac Y C Liu, who worked on the project as an intern at NASM in summer 2013. Liu and Zimbelman used HiRISE images to record the patterns made by surface winds on small sand dunes located to the west of Mars' Hellas Basin. The researchers developed a new technique to illustrate how multiple ripple orientations can be connected across a single dune. This enhanced their ability to recognise form-flow – or the way the dune surface affects the flow of wind across it – in the ripple patterns.



RIPPLES, DUNES AND DRAAS

The distinction between the formation processes of ripples and dunes was first described by Ralph A Bagnold in *The Physics of Blown Sand and Desert Dunes* (1941). Bagnold's work was based on his experience of the Libyan Desert before and during World War II, but his basic theories are still applicable today to sand formations on Mars and other planetary surfaces.

Subsequent researchers defined three ranges of wavelengths for aeolian landforms (although the boundary between the categories is not firmly fixed):

- **Ripples**, ranging from 1 cm-10 m
- **Dunes**, ranging from 10-500 m
- **Draas**, ranging from 700 m-5.5 km

BACK TO EARTH

The work of Zimbelman and his colleagues is expanding our understanding of the surface conditions on Mars and will facilitate wind and atmosphere modelling by fellow scientists. Findings from Mars are also highly relevant to studies back on Earth, as they will clarify scientists' existing knowledge about sand motion: "The basic physics of sand movement should be independent of the planetary environment in which the sand is found," emphasises Zimbelman, who believes that once this motion has been expressed correctly, scientists should be able to calculate the behaviour of sand under any of the various conditions found on other terrestrial planets or moons with atmospheres within the Solar System.

Ripples might be relatively small-scale features of the Martian landscape, but understanding how they form is advancing our knowledge of Martian sand deposits, maximising the amount of scientific information that can be gained from NASA's Mars missions, and improving our understanding of the geological forces at work on our home planet.

INTELLIGENCE

CHARACTERIZATION OF SMALL SAND DUNES ON MARS

OBJECTIVES

Through analysis of detailed images from the High Resolution Imaging Science Experiment (HiRISE):

- To document the distribution, orientation and wavelength of sand ripples on small sand dunes on Mars
- To assess hypothesised modes of formation for small Transverse Aeolian Ridges (TARs) on Mars

KEY COLLABORATORS

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FUNDING

Mars Data Analysis Program, grant NNX12AJ38G, NASA

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JAMES 'JIM' ZIMBELMAN completed his PhD in Geology at Arizona State University, before becoming a research scientist at the Lunar and Planetary Institute (Houston) for four years. He has been a staff scientist (planetary geologist) at NASM for more than 25 years.

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