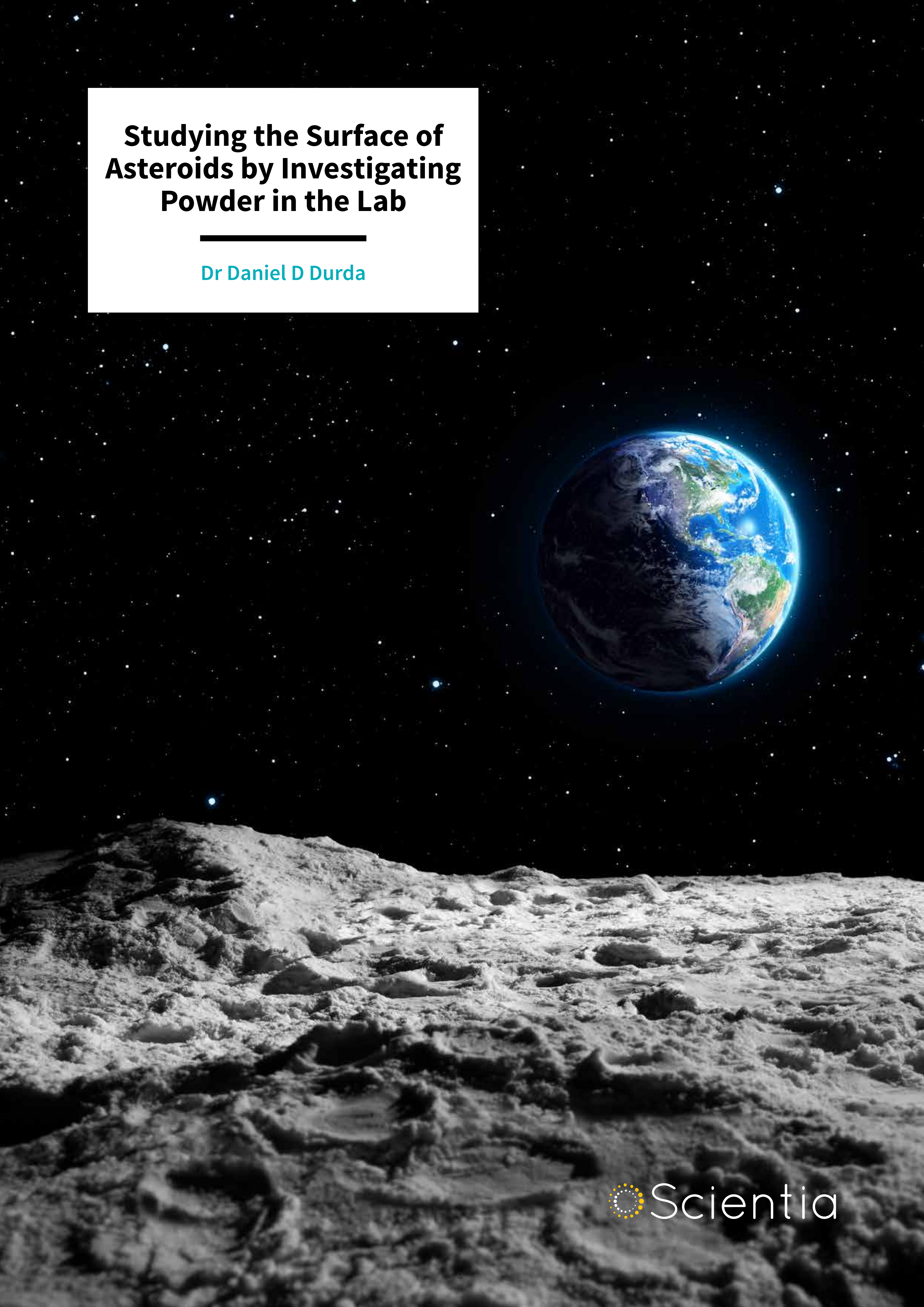
Studying the Surface of Asteroids by Investigating Powder in the Lab

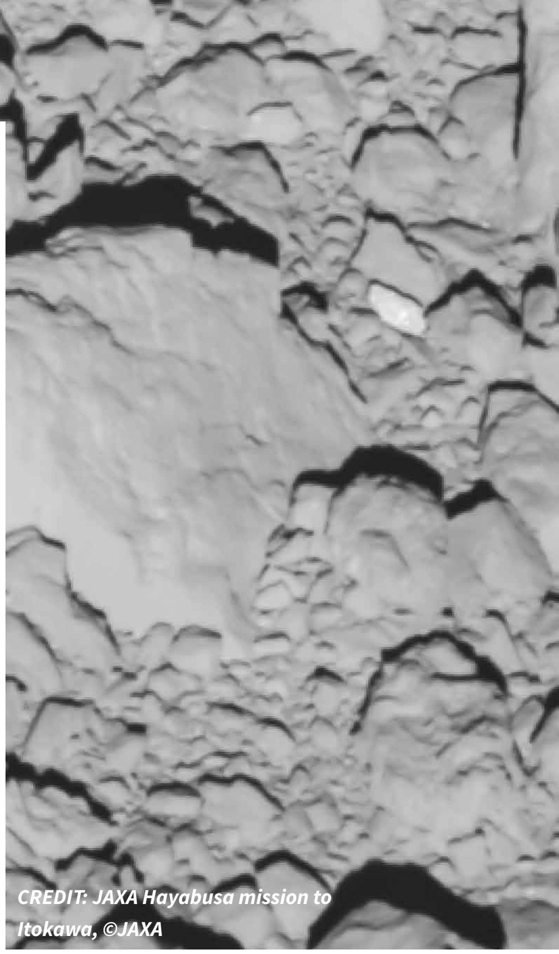
Dr Daniel D Durda



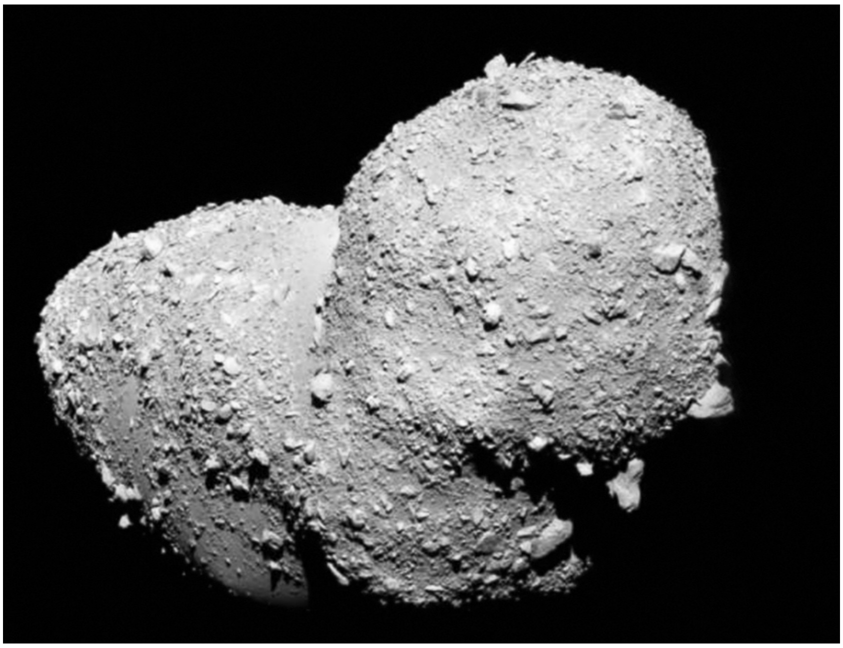
Scientia

STUDYING THE SURFACE OF ASTEROIDS BY INVESTIGATING POWDER IN THE LAB

Space scientist **Dr Dan Durda** and his team at the Southwest Research Institute in Boulder, Colorado, are working to understand how the planets in our Solar System evolved. The team is searching for practical ways to exploit nearby asteroids, through investigating how materials on their surfaces act in microgravity.



CREDIT: JAXA Hayabusa mission to Itokawa, ©JAXA



Itokawa, CREDIT: ISAS, JAXA ©JAXA

We are not alone in our planetary neighbourhood. Scientists currently estimate that there are almost 17 thousand *near-Earth objects* – astronomical bodies whose orbits bring them to less than 1.3 astronomical units from the Sun. One astronomical unit, or 1 AU, is the distance between the Earth and the Sun (about 150 million kilometres), meaning that objects within 1.3 AU from the Sun are pretty close to Earth's orbit. Of these thousands of near-Earth objects, about 16,600 of them are asteroids – the rest being comets, meteoroids or miscellaneous spacecraft.

Asteroids are practically a fossil record of the solar system, containing material that was around at the very beginning of our Solar System's formation. Therefore, studying asteroids can give us invaluable insights into how our own planet evolved. According to Dr Dan Durda of the Southwest Research Institute in Boulder, Colorado, near-Earth asteroids are 'the most accessible and best-preserved fossil building blocks of the terrestrial planets.'

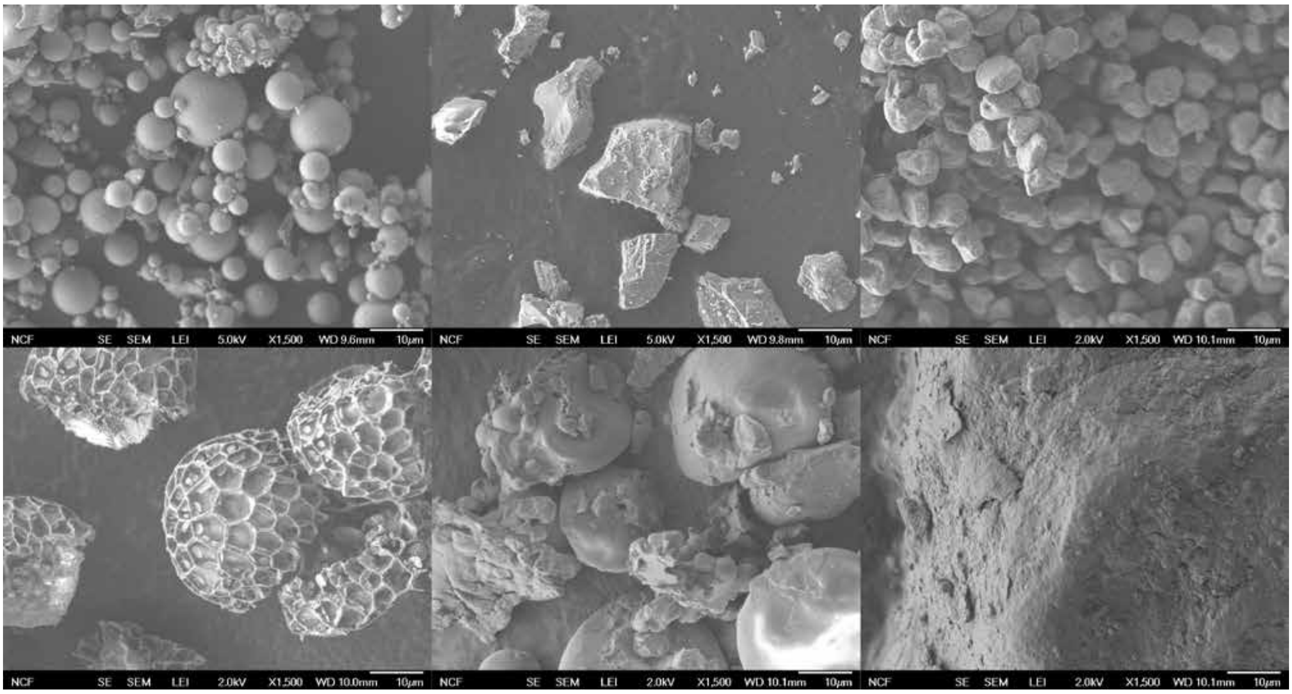
In addition, near-Earth asteroids are close enough that we could potentially mine them for valuable minerals. In Dan's words, they are 'literal gold mines in the sky'. Of course, due to their close proximity, these asteroids also pose the alarming threat of colliding with Earth. Therefore, having a better understanding of these objects might help us in designing strategies to mitigate potential impacts in the future.

But what about that cold, dark rock image that we often see in disaster movies – is this what asteroids really look like? Actually, no. Information provided by spacecraft launched in the last few decades has told us that asteroids are not simply naked masses of rock. For example, the spacecraft *Near Earth Asteroid Rendezvous-Shoemaker* (NEAR-Shoemaker) was launched in 1996 from Cape Canaveral, Florida, the first such mission intended to study an asteroid close up. After a flyby of the main-belt asteroid 253 Mathilde, in 2001, NEAR-Shoemaker orbited and actually landed on an asteroid called 433 Eros – the second largest near-Earth asteroid with a diameter of almost 17 km. Images of Eros show that it is not simply a mass of bare rock – it is covered at least partially with loose layers of gravel and dust, formed as a result of meteor impacts and other space weathering effects.

Similarly, in 2005, the Japanese spacecraft Hayabusa touched the surface of 25143 Itokawa, a small near-Earth asteroid less than 350 metres in diameter. Far from being a solid mass of rock, Itokawa was found to be mostly a loose aggregate of variable sized boulders – what scientists call a 'rubble pile' – that had accumulated over time through collisions of smaller pieces of space debris, perhaps from the break-up of larger asteroids. Hayabusa actually collected samples of dust from the surface of Itokawa and returned it to Earth in 2010. These samples showed that Itokawa was a non-metallic asteroid, having low levels of iron and nickel and being primarily made up of

CREDIT: JAXA Hayabusa mission to Itokawa, ©JAXA

‘I’ve been fascinated with understanding the surface environments of small asteroids from the perspective of human and robotic exploration for many years.’



Scanning electron microscope views of the various powders used in laboratory experiments to explore the cohesive behaviour of granular regoliths on the surfaces of small asteroids.

material consistent with the most common type of rocky meteorites that fall to Earth – minerals present very early in the formation of the solar system.

Standing on Eros or Itokawa would feel somewhat like standing on a layer of sand or gravel – something scientists call ‘regolith’. Regolith is a layer of heterogeneous, loose material that covers bedrock. Sand dunes and gravel beds are what we think of when we speak of regolith here on Earth, but now we know that regolith is present on extra-terrestrial bodies, including asteroids. However, regolith on Earth and other planets with atmospheres is quite different from that found on airless bodies such as asteroids, as the latter is almost entirely generated by impacts. Itokawa can be thought of as being entirely composed of regolith, since it apparently has no rocky core.

It is this characteristic of asteroids that Dan and his colleagues try to understand. They study how regolith on asteroid surfaces behaves, so that we might be able to land on and mine asteroids for materials we need to build space stations, or even habitable colonies on other planets.

What Goes Up Must Come Down – to Some Degree

‘I’ve been fascinated with understanding the surface environments of small asteroids from the perspective of human and robotic exploration for many years,’ says Dan. ‘I think it’s a good idea to gain a better understanding of what it’s going to be like to work on and near their surfaces.’ As mentioned earlier, Dan believes that asteroids are key to learning how the solar system formed and evolved, and they ‘will be important in-situ resources for us when we’re routinely exploring and navigating the inner solar system.’ But there’s a problem studying asteroids – compared to the Earth, or even the Moon – they’re small.

Here on Earth, we are used to working in Earth’s gravity. The acceleration due to gravity here on Earth – denoted as ‘1 g’ – is around 9.8 m/s^2. This means that the speed of an object falling towards the Earth increases by about 9.8 metres per second every second – if we ignore the effects of air resistance. By contrast, gravity on the Moon is 1.6 m/s^2, or 0.16 g. So, a person on the Moon weighs only about 16% of what they weigh on Earth. Recall the images of the lunar astronauts bounding along the lunar surface, seemingly in slow motion, due to the low gravity.

The gravity on Earth dictates how regolith behaves here. Consider sand falling through an hourglass – it forms a roughly pyramidal mound due to the interaction between the pull of gravity and the cohesion of the sand’s granules and friction as they rub together. The same can be expected of gravel falling from a conveyor – gravity dictates the shape of the pile because it is stronger than the forces between the particles themselves. But what happens to regolith on an asteroid that is only a fraction of the Earth’s size? How do the forces of friction and the adhesion and cohesion of the regolith particles compare to the fairly minimal gravitational force, or ‘microgravity’, of an asteroid?

The flow and migration of regolith on an asteroid may not necessarily be the same as the flow of gravel or sand on Earth, since the gravity is minimal compared to the forces between the particles themselves. Take the asteroid Eros, for example. With a mass of roughly $7x10^{15}$ kg compared to Earth’s $6x10^{24}$ kg, Eros’ gravity is many orders of magnitude smaller than Earth’s. The forces between particles of regolith on Eros can be vastly more important than the force of gravity that acts on those particles, unlike the situation on Earth. Itokawa is even smaller, with a mass of about $4x10^{10}$ kg, much smaller than Eros.

A collapsed pile of ordinary baking flour shows many features characteristic of self-cohesion between the small constituent grains, such as large clumps and clods, that closely resemble the rubbly surfaces of asteroids. In the microgravity environments of those little worlds such self-cohesive forces might be at play among mm- to cm-scale rocky debris.

This is the problem that Dan and his colleagues face. We need to know how the surfaces and interiors of asteroids move and shift in microgravity in order to fully interpret spacecraft images and to understand how asteroids evolve over time. We also need to be able to either collect smaller asteroids or land on larger ones to use the minerals to support our efforts in exploring space. But studying these unfamiliar microgravity phenomena while burdened with Earth's gravity presents a number of challenges and limitations.

If You Want to Cook Something Up, Get to the Kitchen

The problem of looking at regolith on Earth – in Earth's 1 g gravity – is that the weight of the material is much larger than any forces acting between the particles of the material. One way that Dan's team gets around this problem is to use particles so small – fine powders – that the force of Earth's gravity is less that the forces between the particles of the powders. Cohesive forces such as 'van der Waals attractions' can exceed the gravitational force on very fine particles, thus mimicking the situation of larger particles in microgravity on an asteroid.

Dan's group has considered a number of fine powders for their asteroid regolith simulations, from common kitchen ingredients to high-tech materials. To investigate particles of various shapes and sizes, the group has studied the characteristics of common white and whole-wheat flour, which can be found in any kitchen. They studied these particles in a vacuum chamber at Ball Aerospace under varying degrees of dryness and wetness, heat and cold, all in an attempt to duplicate the structures and features imaged on Eros, Itokawa and other asteroids by NEAR-Shoemaker and other spacecraft.

The team also looked at glass microspheres, simulated lunar regolith material, Colorado desert sand, toner particles used in copy machines, and even pollen from a species of moss. They basically wanted to know what forces make these particles move, shift, and slide under various stresses. What they've found so far is illuminating – and they may have a model for asteroid regolith.

Failure is Not an Option – It's the Whole Point

In an article submitted for publication to the journal *Planetary and Space Science*, Dan and his group report their preliminary work with fine powders, which sheds light on the behaviour of asteroids. They performed a series of experiments looking at the failure behaviour of columns and piles of cohesive fine powders – in Earth's 1 g – as a proxy for regolith on asteroids composed of even millimetre- and centimetre-sized pebbles and cobbles moving in an asteroid's microgravity environment. Starting with symmetrical piles of fine powders and subjecting them to tilt or rotation, the team showed that the piles develop features similar to those observed on asteroids. They demonstrated features such as 'slide planes', finer cohesive structures, and 'fracture planes'. They also observed the formation of steep cliffs that looked like features often seen on asteroids.

The team's preliminary experimental results showed a good correlation with the numerical simulations they devised to describe them. It looks like the microstructure and particle size distribution of the regolith in large part determines the extent of cohesiveness between the particles. The team found better cohesion when they experimented with certain ratios of coarser particles and fine powders.

Dan believes that the wide range of qualitative features and behaviours in his team's fine powder models can reasonably approximate what is seen on the surface of an asteroid as it ages. This work has important implications for understanding the early evolution of our planet, preparing for future missions to asteroids, and even in helping to mitigate a potential asteroid collision with Earth. In any event, it's work that Dan and his group are seeking to expand upon with the help of grant funding for a three-year study of fine powder models of asteroid regolith.

The Ultimate Goal of Asteroid Research

'The problem here generally is that having grown up as a species and as individuals on a large planet with a substantial surface gravity we have no intuitive feel for what it's going to be like to interact with the geology of these things – other planets and asteroids – in microgravity,' says Dan. Of course, we know how to work in spacesuits and with tools in microgravity. We have all seen videos of astronauts in low-Earth orbit fixing the Hubble Space Telescope, for example, or assembling and maintaining the International Space Station. Humans have done geologic fieldwork on the dusty, rocky surface of the Moon. But, according to Dan, 'we've never had hands-on experience with both at the same time.' That's what we have to think about when we finally visit near-Earth asteroids like Eros or Itokawa. The experiments Dan and his group are doing are, in his words, 'a step toward helping to wrap our heads around some of the sometimes-counterintuitive properties and processes of the materials we're going to encounter on the surfaces of these little worlds.'

Meet the researcher

Dr Daniel D Durda
Department of Space Studies
Southwest Research Institute
Boulder, CO
USA

Dr Dan Durda received his BS from the University of Michigan in 1987, an MS from the University of Florida in 1989, and a PhD from the University of Florida in 1993. Subsequently, he served as a Research Associate in the Lunar and Planetary Laboratory of the University of Arizona and then joined the Department of Space Studies at the Southwest Research Institute in Boulder, Colorado, as a postdoctoral fellow. Since 2001, Dr Durda has been a research scientist at the Southwest Research Institute, although he has also done a stint as Special Assistant to the Associate Administrator of the NASA Science Mission Directorate and served as Adjunct Professor in the Department of Sciences of the Front Range Community College in Westminster, Colorado.

Dr Durda's research interests include the collisional and dynamical evolution of main-belt and near-Earth asteroids, the search for vulcanoids inside the orbit of Mercury, the dynamics of Kuiper belt comets, and the physics of interplanetary dust. Dr Durda has authored or co-authored dozens of articles, both in peer-reviewed journals and other professional publications, as well as in general-interest publications popularising planetary science and human exploration of space. He was also the recipient of the American Astronomical Society's Division for Planetary Sciences 2015 Carl Sagan Medal 'for excellence in public communication in planetary science'. Dr Durda's own space art has appeared in many magazines and books and has been internationally exhibited. Dr Durda is also an instrument rated pilot, flying multiple airframes, and serves as a flight astronomer for the Southwest Universal Imaging System, an airborne astronomical camera system flown aboard NASA and military high-performance, high-altitude aircraft. He has also accumulated almost two hours' time in zero gravity conducting experiments on NASA's KC-135 Reduced Gravity Research Aircraft, famously known as the 'Vomit Comet'.

CONTACT

T: (+1) 303 541 9084
E: durda@boulder.swri.edu
W: http://www.boulder.swri.edu/~durda

KEY COLLABORATORS

Genevieve Devaud, Ball Aerospace and Technology Corporation
Alex Fischer, Ball Aerospace and Technology Corporation
Diego Paul Sánchez, University of Colorado
Daniel J. Scheeres, University of Colorado
Shane E. Roark, Ball Aerospace and Technology Corporation
Richard W. Dissly, Ball Aerospace and Technology Corporation

FUNDING

The work summarised in this article was funded by a grant from the NASA Planetary Geology & Geophysics Program.

SwRI

Ball Aerospace & Technologies Corp.

University of Colorado Boulder