ROOM

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Musk's Mars colony vision

Stephen Ashworth, p.10

Citizens join space nation

Janis Hunt, p.53

Future fashion

Annalisa Dominoni, p.102

#4 (10) 2017

Igor Ashurbeyli
Editor-in-chief

Frank De Winne
ESA astronaut

Making the world a better place for everyone

Dreaming big in my book was always the only way worth dreaming. For as long as I can remember I was always convinced that the world should be good for everyone, that the more people are happy, the better place for all it becomes, irrespective of the country of birth, race or gender.

I dreamt of flying and that is why I became a pilot. I dreamt to preserve peace and that is why I joined military - to work hard on safeguarding peace. I made an astronaut selection and I was privileged to fly to space.

And this is where it all came together - as I was looking out of the window of the International Space Station I saw with my own eyes that borders do not exist. I saw continents, I saw the most magnificent colours, I saw day and night changing every 45 minutes, I saw familiar shapes from the map - you would all recognise Italy - the natural shape of the peninsula.

But I did not see any borders, even though I instinctively tried to look. The only contours I could see from space were the contours of the continents which naturally formed on Earth over the millions and millions of years, under the influence of our entire galaxy, as it evolved, while planets and stars were forming; our galaxy being a small part of the infinite Universe.

Life in space as a metaphor has inspired people for many centuries. Life in space as an activity has so far been available only to a select few. Life in space as a goal is nowadays driving the inspiration and the break thoughs of the great thinkers of the 21st century.

One such life-changing ideas was brought to public view on 12 October 2016. Nothing less than a new nation, the space nation - Asgardia.

Dreaming big is what resonates with me the most in the Asgardia concept. I wholeheartedly invite you to read about it on page 53 and I hope you share in my excitement of the vision.

While I would love to fly to space again, it is clear that it is going to be somebody younger than me who will be the first human to fly to Asgardia by the time it launches its first habitable platform.

It will happen only a few generations of launches later than the launch of the first Asgardia satellites. And yet, it is a vision which I find the most inspiring in its complexity, as it offers a renewed philosophy of humanism, a long awaited interplanetary (literally, interplanetary, as opposed to just global) approach to legislation and a sound technical roadmap for achieving it.

Reflecting the Asgardia project, this issue of ROOM has much to inspire. There is a commentary on Elon Musk's equally ambitious plans for Mars (p10) and a detailed report by engineers from Lockheed Martin on the practical implications of NASA's own 'Journey to Mars' (p16).

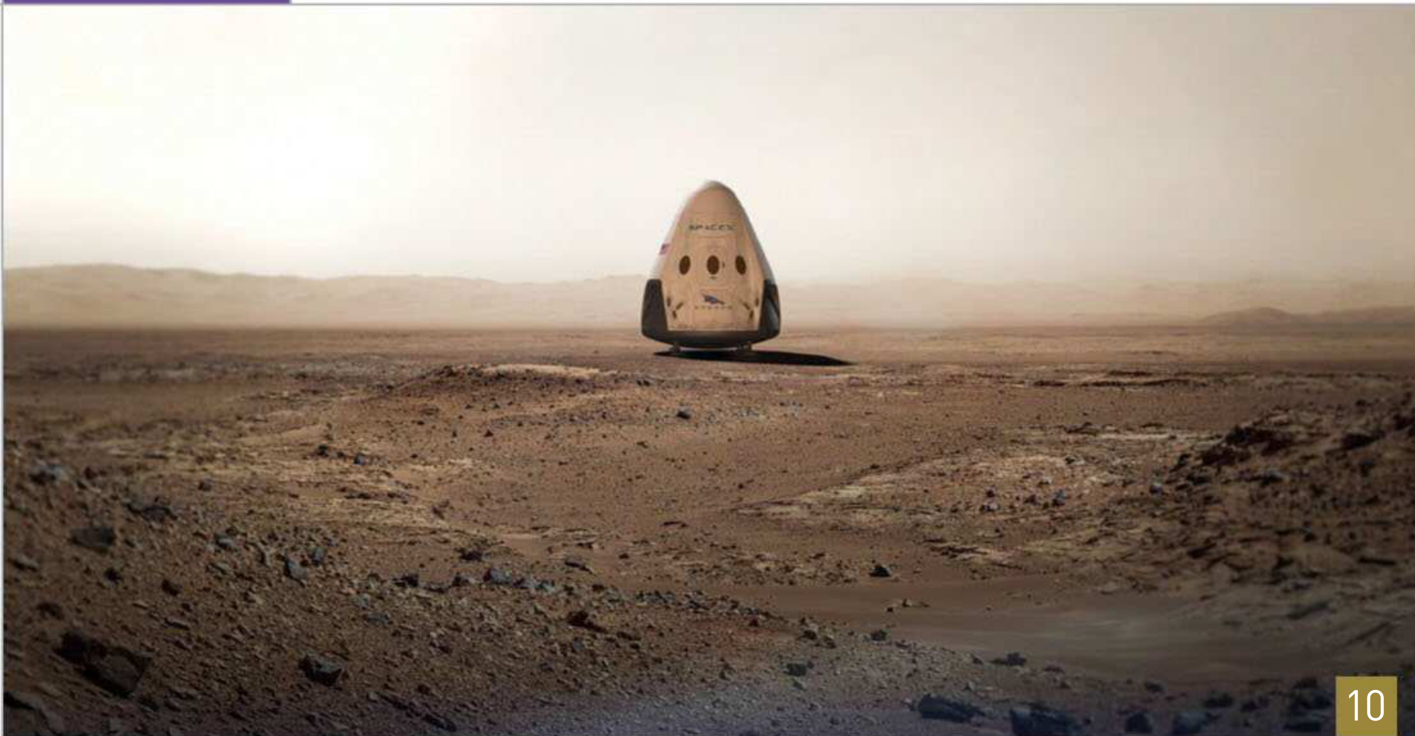
Articles from graduate scientists and engineers (Micehab p43) and (CosmoCrops p48) look at some of the practical issues for future human Solar System exploration, while Rick Tumlinson (p64) and Joe Pelton (p68) argue for political changes that will allow humanity's expansion into space.

Author Arthur C Clarke once predicted, "In the new wilderness of the Solar System may lie the future preservation of mankind." So, it seems, we are finally at the dawn of a new frontier. Things once foreseen by the great dreamers of the previous centuries and decades may come true in our life time - a space nation aspiring to be an independent country - the first ever state in space.

One might question if that is possible. All I can say is that enough people questioned whether it was possible for me to become an astronaut. My answer - dream big, dream for the good of the humankind.

Frank De Winne
ESA astronaut, UNESCO EOLSS
'The Science of Space' committee

Things once foreseen by the great dreamers of previous centuries and decades may come true in our life time



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Ram S. Jakhu

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Joseph N. Pelton

Conference Co-Chair

For more information please visit http://www.mcgill.ca/iasl/events/mlc2017 or contact Aram Kerkonian at: mlc.iasl@mcgill.ca

Cassini heads for spectacular finale

NASA's Cassini spacecraft, launched in 1997, is in the final months of the last phase of its mission since making its first close dive past the outer edges of Saturn's rings on 30 November.

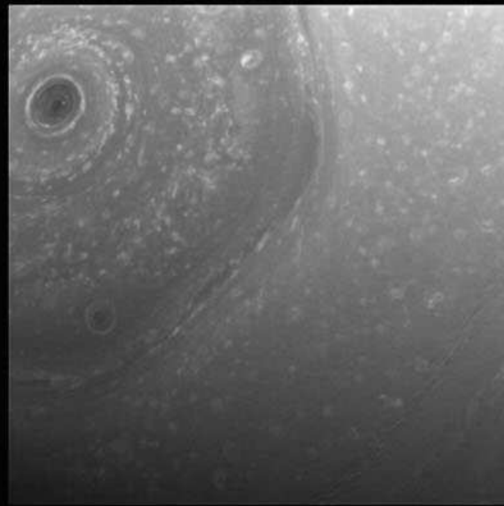
Cassini's imaging cameras only obtained views of Saturn about two days before crossing through the ring plane because the main focus was an engine manouevre and observations by other science instruments. Future dives past the rings, however, will feature some of the mission's best views of the outer regions of the rings and small, nearby moons.

"It's taken years of planning but now that we're finally here, the whole Cassini team is excited to begin studying the data that come from these ring-grazing orbits," said Linda Spilker, Cassini project scientist at JPL. "This is a remarkable time in what's already been a thrilling journey."

Each of Cassini's orbits for the remainder of the mission will last one week. Ring-grazing orbits - 20 in all - will continue until 22 April when the last close flyby of Saturn's moon Titan will reshape Cassini's flight path. With that encounter, Cassini will leap over the rings, making the first of 22 plunges through the 1,500 mile-wide gap between Saturn and its innermost ring on 26 April.

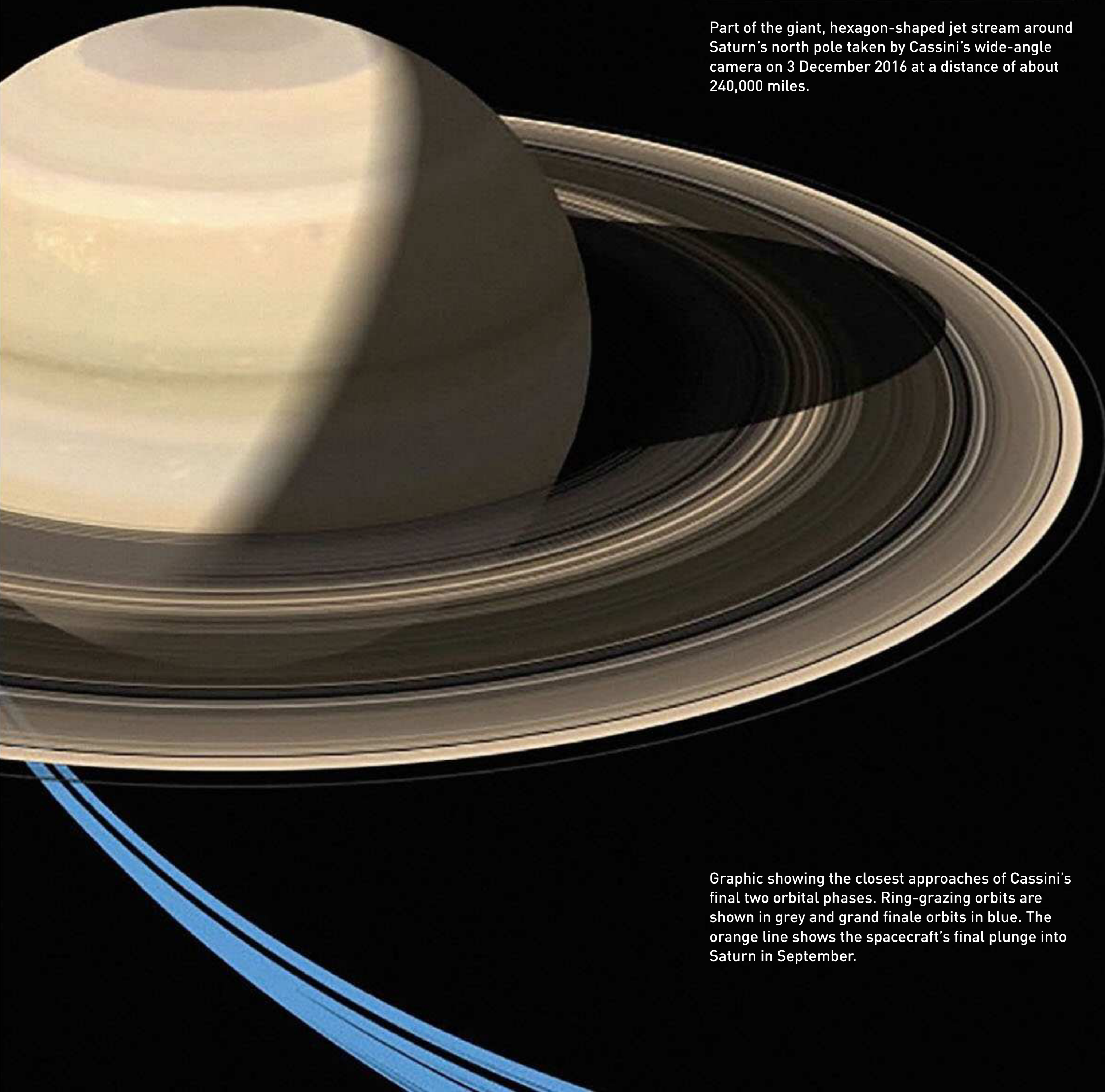
Its mission will conclude on 15 September 2017 with a final plunge into Saturn's atmosphere during which Cassini will transmit data on the atmosphere's composition until its signal is lost.

NASA/JPL-Caltech



NASA/JPL-Caltech/Space Science Institute

Part of the giant, hexagon-shaped jet stream around Saturn's north pole taken by Cassini's wide-angle camera on 3 December 2016 at a distance of about 240,000 miles.



Graphic showing the closest approaches of Cassini's final two orbital phases. Ring-grazing orbits are shown in grey and grand finale orbits in blue. The orange line shows the spacecraft's final plunge into Saturn in September.

Heart of gold

Entrepreneur Elon Musk brought high drama and a remarkable vision of the future to the International Astronautical Congress (IAC) held in the Mexican 'Silicon Valley' city of Guadalajara in September.

Musk took centre stage on the second day of the conference to outline his plans to establish a human colony on Mars at an affordable ticket price of US$200,000. Speaking to an audience of more than 2,000 delegates, students and media - many of whom had queued for around 90 minutes to secure a seat in the cavernous presentation hall - his presentation was punctuated with woops and cheers.

Mr Musk, who founded private spaceflight company SpaceX in 2002, said his colonisation plan uses a fully reusable transportation system that would take 100 people to Mars, with trip time eventually cut from 80 to 30 days.

His system consists of a spaceship that is refuelled with methane and oxygen in Earth orbit and also on Mars after landing there, and he explained that to achieve the target US$200,000 price the entire transportation system has to be reusable.

He suggested Mars could eventually have a colony of a million people which would make it self-sustaining and that, with his plan, this could be achieved in 100 years. "I want to make Mars seem possible, something we can do in our lifetimes - and that anyone can go if they wanted to," he said.

According to a timeline outlined by Mr Musk, the first crewed Mars flight could take place as soon as 2022 in a spacecraft he would like to name 'Heart of Gold', after the starship in Douglas Adams' book, The Hitchhiker's Guide to the Galaxy.

A prototype spaceship is planned to make test flights in four years, initially going into space, but not into orbit. Initially SpaceX will use Pad 39A at Kennedy Space Center, which is being leased from NASA, and later a second launch base developed in Texas.

Mr Musk announced that SpaceX had carried out its first test of its Raptor rocket engine that will power the spaceship and the booster that puts it into orbit. A prototype booster fuel tank has also been built and tested.

The combination of the booster and spaceship is called the Interplanetary Transportation System (ITS) and together they stand 122 m tall, bigger than an Apollo-era Moon programme Saturn V rocket. The booster will have 42 Raptor engines arranged in concentric circles. His interplanetary spaceship will have nine Raptor engines, carry 450 tonnes of crew, life support and cargo, and would be designed as a "fun" place to live and work. Initial development is being funded by profit from SpaceX and Mr Musk's own wealth.

SpaceX plans to launch its first Red Dragon capsule to Mars in a couple of years when the Earth and Mars are closest, and at regular intervals thereafter, effectively offering its own 'shuttle' service for delivering payloads and science experiments to the red planet.

Asked whether he would be on his first crewed spaceship to Mars, Mr Musk was a little more hesitant, saying there were "pros and cons", especially as the first trip would probably be the most dangerous.

Clive Simpson
Managing Editor

In the first of two 'Special Report' articles for *ROOM* on future Mars exploration, Stephen Ashworth of Oxford University's Voltaire Foundation examines the Musk-Mars phenomenon and asks what is behind the entrepreneur's expansive vision to colonise the red planet. Our second article, 'Blueprint for NASA's journey to Mars' (page 16), outlines a very different approach aligned with NASA's 'Journey to Mars' plans. Written by senior engineers and architects at Lockheed Martin Space Systems, it provides fascinating detail on the company's 'Mars Base Camp' concept to get humans into Mars orbit.

▼ The diminutive figure of Elon Musk commands a giant panoramic stage before an audience of over 2000 at the 2016 International Astronautical Congress (IAC) in Mexico.

Stephen Ashworth,
Voltaire Foundation,
Oxford University,
England

Elon Musk and Mars - looking for a snowball effect

Elon Musk, speaking to a wildly enthusiastic audience at the International Astronautical Congress (IAC) in Mexico on 27 September 2016, has finally revealed his vision for setting up a self-sustaining human colony on the planet Mars. His starting point was the perceived need to make humanity a multi-planetary species in order to secure our long-term future. This strategic goal is widely shared in the astronautical community. But one problem with it was raised in 2011 by Jeff Greason, then president of XCOR Aerospace. In his own inspirational address to the International Space Development Conference, Greason said: "It is actually the national policy of the United States that we should settle space. But everybody's kind of afraid to say it because they're not sure we can do it."

Elon Musk believes that it can be done, given a suitable Earth-Mars transport system, which his company, SpaceX, is planning to provide. As a result, his presentation was heavy on rockets and spacecraft, light on other key factors which would be necessary for success. His precondition for a self-sustaining civilisation on Mars is a population of one million people, who would be transported there, together with at least 10 tonnes of cargo per person, over a period of half a century or more.

While an outrageous number in comparison with the current spaceflight activity of 12 to 15 individuals flying to low Earth orbit and back per year, it would be modest compared with the mass emigration from Europe to the United States before the First World War. At its peak around 1907, the flow of migrants topped one million people per year. But the steamships which carried them were the product of 400 years of maritime development since the earliest transatlantic voyages.

Musk's proposed transport system has been designed to be as simple as possible, relying for its effectiveness on the sheer size of its component parts and their full reusability. The launch rocket is three to four times the size of the Saturn V in terms of engine thrust and payload capacity. The interplanetary spacecraft which it carries is intended to accommodate 100 people for the four months or so of the journey, and a supporting tanker version is to hold a couple of hundred tonnes of propellants for transport to low Earth orbit (LEO).

> Musk's ambitions are immense - yet at the same time his approach to them is disarmingly modest

▶ Launch site in Florida for SpaceX Interplanetary Transportation System.

Musk's proposed transport system has been designed to be as simple as possible, relying for its effectiveness on the sheer size of its component parts and their full reusability

The mission architecture involves a flight straight to the surface of Mars, and another flight straight back to the surface of Earth. This is another application of the principle of maximum simplicity, complicated only by the need to refuel the spacecraft in low Earth orbit with about four tanker flights before it can depart, and then again on the surface of Mars with locally manufactured propellants before it can return to Earth. Musk suggested a timeline in which flights begin in the mid-2020s, leading to a self-sustaining Martian branch of civilisation before the end of the century.

Questions and comments

The talk triggered a wave of comment and criticism. Doug Messier and John Logsdon on the internet blog Parabolic Arc saw the SpaceX Mars ships reviving Wernher von Braun's vision of gigantism from the 1950s: "a pleasant and ultimately frustrating illusion". Robert Zubrin, founder of the Mars Society, while broadly supportive of Musk's initiative, devoted an article in The New Atlantis to describing how he would correct the "conceptual flaws" of Musk's "extremely sub-optimal" plan, and likewise commented adversely on its gigantism.

Bill Nye, CEO of the Planetary Society, pointed out in interviews that living on Mars would be like living in Antarctica, only worse, and questioned whether people would really want to live there permanently. The same point had indeed been raised some years earlier by Charles Cockell, an experienced polar explorer, in a paper published in Interdisciplinary Science Reviews in 2002.

Loren Grush at The Verge raised questions as to how Musk's passengers would survive the journey and live safely on Mars itself, criticising his offhand assurances that exposure to cosmic radiation would not be a serious health risk. And Maddie Stone at Gizmodo raised ethical objections to large-scale human passenger flights to Mars, and asked Joanne Gabrynowicz, director of the International Institute of Space Law, whether Musk's plan would even be legal. She suggested that, under the Outer Space Treaty, any Martian colonists would be regarded as "squatters, or pirates". Other commentators raised questions of planetary protection, fearing speculative worst-case scenarios in which terrestrial micro-organisms caused a mass extinction of hypothetical Martian ones, or Martian microbes proved fatal to human life.

These responses explored a number of important aspects of the plan, but in one way they were missing the point. What is Elon Musk really trying to achieve?

My first reaction, too, was to start picking on some of the crucial aspects of going to Mars and living there which Musk had omitted to mention.

▶ Musk was keen to point out that his plans were not all based on artist's impressions. This shows a successful Raptor engine test in September 2016.

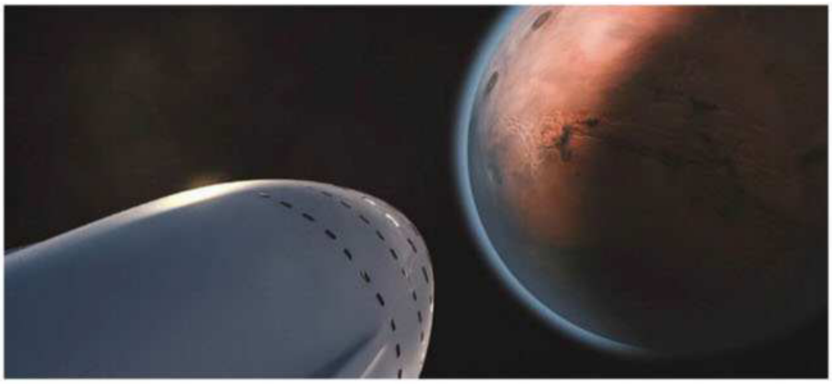
The questions which occurred to me were obvious enough and have been raised many times before:

- Can humans adapt successfully to living permanently in low gravity (0.38 that of Earth)?
- Can a sustainable life support system be made completely independent of Earth?
- Can rocket engineers get transport costs down to economically sustainable levels at the same time as getting the reliability up to acceptable safety levels?

But then I listened to his talk again, and I realised I'd misunderstood what he was trying to achieve. The enormous Mars launch rocket and spacecraft which he described in some detail, and visualised in the supporting video, are striking and seductive, but they're really somewhat of a side-track.

Recall some of the key points Musk made in his talk: "So obviously it's going to be a challenge to fund this whole endeavour. We do expect to generate pretty decent net cash flow from launching lots of satellites and servicing the Space Station for NASA, transferring cargo to and from the Space Station, and then I know that there's a lot of people in the private sector who are interested in helping fund a base on Mars, and then perhaps there'll be interest on the government sector side to also do that.

"Ultimately this is going to be a huge public-private partnership. And I think that's how the United States was established. And many other countries round the world, as a public-private partnership. So I think that's probably what occurs. And right now we're just trying to make as much progress as we can with the resources that we have available and just sort of keep moving the ball forward. And hopefully I think as we show that this is possible, that this dream is real - not just a dream... I think the support will snowball over time."



▲ Arrival at Mars.

What it comes down to is that there are two ways to approach human expansion on an interplanetary scale at this time

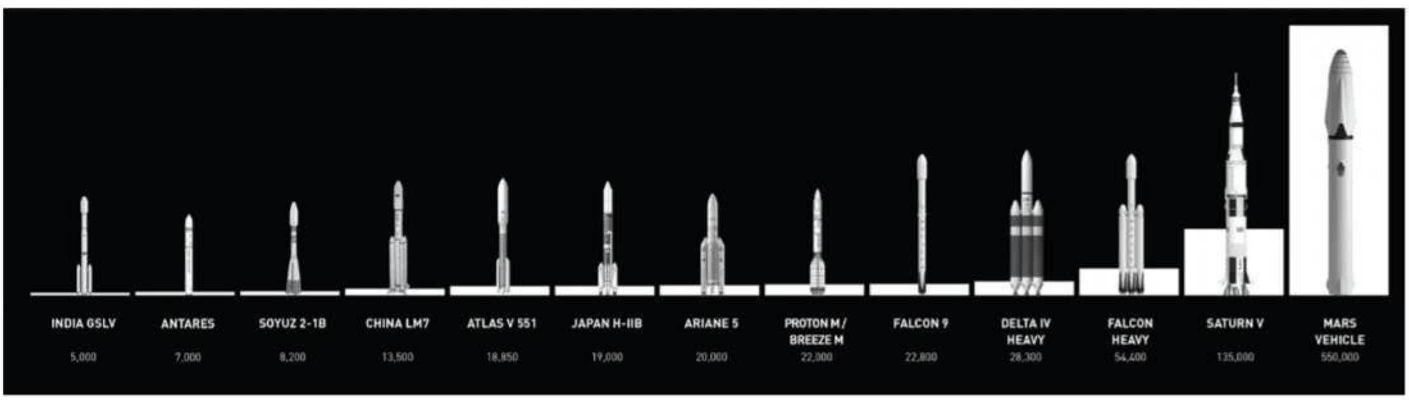
When he founded SpaceX in 2002 Musk stated: "I came to the conclusion that if there wasn't some new entrant into the space arena with a strong ideological motivation then it didn't seem like we were on a trajectory to ever be a spacefaring civilization and be out there among the stars."

Grateful to NASA

But entering the space arena was not easy going, and after his Falcon 1 rocket had repeatedly failed it was a contract from NASA which saved his company: "I just want to say I'm incredibly grateful to NASA for supporting SpaceX, despite the fact that our rocket crashed. It was awesome - well I'm NASA's biggest fan. So thank you very much to the people that had the faith to do that, thank you."

Musk's ambitions are immense, yet at the same time his approach to them is disarmingly modest. "We're going to try to make as much progress as we can," he said in Mexico. "Obviously it's with a very constrained budget, but we're going to try and make as much progress as we can on the elements of the interplanetary transport booster and spaceship. There's a good chance we won't succeed, but we're going to do our best and try to make as much progress as possible."

▼ Comparison of rocket sizes and payload capabilities to low Earth orbit.



Trying to kickstart the hare is a gamble. The general public does not normally think much about colonising other worlds.

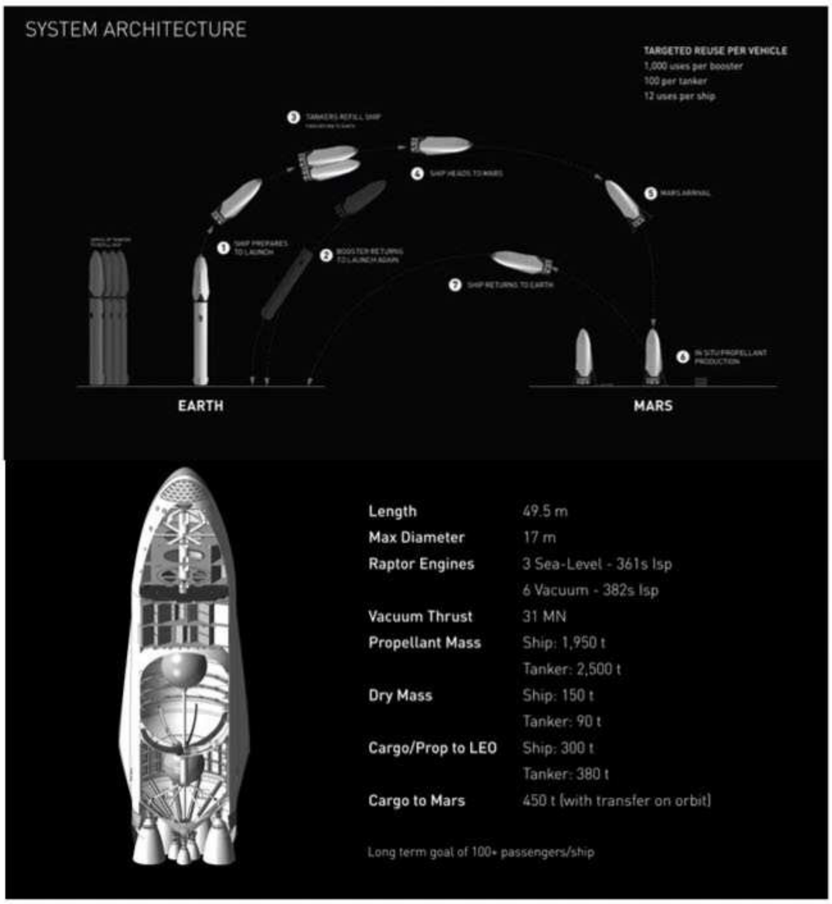
So what Elon Musk is doing here is not to try to go it alone to Mars, or to solve all the problems himself. And he's not trying to compete with NASA. Clearly his plans conflict with NASA's existing 'Journey to Mars' but that programme is still quite vague at present. NASA is not a monolithic entity and I think it must be assumed that he has support from within NASA, if not from those parts of NASA most directly interested in the Orion-SLS (Space Launch System) programme.

What he is clearly trying to do is to start a snowball effect to which a variety of entities from both the private sector and the government, and in a variety of countries around the world, can all contribute. He's trying to build a coalition.

We should applaud Musk for publicly raising the necessity of making humanity a spacefaring, multi-planetary species, if our civilisation and ultimately our species is to survive and prosper in the long term - though, of course, he is not the first to do so.

Again, he is absolutely right to downplay the significance of getting to Mars first, and stress instead the importance of "being able to send a large number of people, like tens of thousands if not hundreds of thousands of people, and ultimately millions of tons of cargo".

▼ System architecture for SpaceX crewed missions to Mars and back. Bottom: Basic technical parameters for SpaceX Mars craft that would carry crew on interplanetary flights.



Getting these points out into the open makes a refreshing change from the standard official view that the Moon and planets are sacred ground, too dangerous, difficult and expensive to be reached by ordinary mortals, and which can only ever be visited by a tiny elite of government specialists, a sort of ethically pure knighthood of the elect, on missions which, in the familiar phrase, "take only photographs, leave only footprints".

Two ways to colonise Mars

What it comes down to is that there are two ways to approach human expansion on an interplanetary scale at this time: one, make a giant, heroic leap forward; and two, take small, systematic, incremental steps forward.

So the hare and the tortoise. The hare can get to Mars within a decade, and have a self-sustaining colony of around a million people there within 50 to 100 years. But it needs the kind of political support that is normally reserved for such things as fighting a war.

Yet there are historical analogies, such as the spreading of monotheist religion in the Roman Empire, the later Arab world or the early modern Spanish and British empires, or in the 20th century the spreading of democracy: a movement driven by intellectual conviction more than by tribal politics, trade or money - the 'ideological motivation' that Musk was talking about.

Trying to kickstart the hare is a gamble. The general public does not normally think much about colonising other worlds. In fact, the general mood of the age (in the West, at any rate) is one of post-colonial guilt and grim forebodings about the future. People tend to want to talk about existential risk, the evils of capitalist consumerism society and ecological collapse, with technology posed as the problem, not the solution. The tendency is to associate sustainability more with wind turbines than Mars rockets; with millions fewer living on Earth, not millions more on Mars.

But if the astronautical community can turn that around and centre the popular mood instead on a positive, expansive vision of the future, then Mars would be the best thing that ever happened to Earth.

It makes more sense to me to adopt the approach of the tortoise, thus fostering an evolutionary process rather than a revolutionary one. Clearly my thinking has been shaped by the Apollo programme: the quintessential giant leap forward which led quickly to project cancellation and retreat. My preferred strategy is therefore founded on the assumption that large-scale political support for colonising Mars will continue to remain absent, demanding a step-by-step approach.

The main steps should be obvious enough:

- A build-up of commercial space tourism to hotels in low Earth orbit. Between 2001 and 2009 the pioneers of private passenger spaceflight made eight flights to the International Space Station (ISS). The solution to the problem of economic, reliable access to orbit would enable thousands of people to fly per month, at a ticket price of under a million dollars a head.
- Extension of this trade to space hotels in Earth-Moon cycler orbits, creating a market for rocket propellants in low Earth orbit and generating experience with life-support and radiation protection above the Van Allen belts, as well as with artificial gravity in due course, as the cycler stations grew in size.
- Robotic exploration of the Moon and near-Earth asteroids with the specific goal of extracting and processing water and hydrocarbons for an entirely space-based commercial refuelling network.
- Extension of the by now technologically mature Earth-Moon cycler stations to Earth-Mars orbits for interplanetary passenger transport.
- Crewed Mars landing craft would then be based on decades of experience with lunar landings and with aerobraking and supersonic retro-propulsion at Earth.

In other words, instead of an all-or-nothing push to Mars with new, purpose-built vehicles, the focus is on the painstaking and unglamorous growth of a broadly based, sustainable space economy, one which can then take Mars exploration and settlement in its stride.

The disadvantage with this approach, of course, is the relatively long timescale, and the greater risk of an economic downturn during that time sufficient to kill growth. The first human landings on Mars would not occur until perhaps the latter half of the century.

Having observed developments in spaceflight since the Apollo days, my conclusion is that, providing humans can adapt successfully to its low gravity, Mars colonisation will become possible. But getting the transport and life-support technologies up to the required standards of high reliability and low cost will inevitably require several decades of development.

▲ Looking further into the future and Musk sees his interplanetary spacecraft taking people as far as Jupiter and Saturn.

Therefore, the painstaking growth of a space economy with high levels of traffic in low Earth orbit (10,000 to 100,000 passengers/year) and lower levels in high orbits and on the Moon cannot be sidestepped. If SpaceX's proposed interplanetary rocket can send 100 people to Mars at affordable prices, then an earlier version can send a great many more to space hotels in orbit and on the Moon even more economically, generating profits which could be used to support the Mars programme.

Yet Elon Musk and others like him are showing that they are not afraid of proposing that humans should indeed settle space and other worlds. If this growing sense that a multi-planetary civilisation is really feasible does succeed in setting off a growing snowball of support for humans to Mars among the broader public, then the process of growth could be much accelerated, and the damage inflicted by its inevitable setbacks much reduced. Therefore, I applaud his speech, and urge everyone interested in the future growth and prosperity of humankind to support his broad vision, while keeping a grip on reality when it comes to the details. ■

About the author

Stephen Ashworth works at the Voltaire Foundation, part of the University of Oxford, which specialises in publishing on the 18th Century Enlightenment. He has been convinced of the importance of space exploration and settlement ever since watching as a teenager the first televised moonwalk. His astronautical writing includes an online blog *Astronautical Evolution* and science-fiction novel *The Moonstormers*. He also plays jazz saxophone.

The disadvantage with this approach, of course, is the relatively long timescale, and the greater risk of an economic downturn

Blueprint for NASA's journey to Mars

Lockheed Martin has developed its own Mars Base Camp concept to get humans to Mars orbit. The plan - which would transport scientist-astronauts from Earth to the moons of Mars to answer fundamental science questions and prepare for a human Mars landing - is being used to determine the feasibility of a Martian moons human exploration architecture within roughly a decade. It would involve human exploration of both Martian moons and provide an opportunity to obtain samples from Mars by operating robotic assets pre-deployed in orbit and on the surface of Mars. In essence it lays out a proposed technology road map to support NASA's Journey to Mars and is a mission designed to be led by NASA along with international and commercial partners.

Timothy Cichan,
Space Exploration Architect, Lockheed Martin Space Systems Company

Stephen A. Bailey,
President, Deep Space System, Lockheed Martin Space Systems Company

Scott D. Norris,
Business Development Analyst Principal, Project Orion, Lockheed Martin Space Systems Company

The Lockheed Martin study is a high-level assessment to identify architecture drivers and science opportunities. There are some key tenets for this architecture. For this first human interplanetary mission, system redundancy and a self-rescue capability is required. The number of system developments is minimised, and the use of the already developed systems like the Space Launch System and Orion, is maximised. To minimise the number of events that could lead to the loss of the whole crew, the architecture does not require rendezvous and docking of pre-staged elements necessary for crew survival during the mission. This architecture study shows that a near term Mars mission is compelling and feasible.

To address some key science questions, the Mars Base Camp (MBC) systems are designed to perform remote sensing and teleoperation of science ground assets on the surface of Mars; in-situ investigations and sample returns from Phobos and Deimos, and rendezvous and capture of Mars surface sample canisters in Mars orbit.

The Mars Base Camp concept is built on a strong foundation of today's technologies – making it safe, affordable and achievable – including currently mature and rapidly maturing programmes and systems.

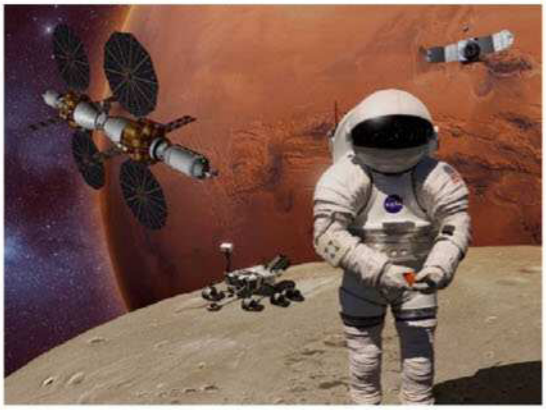
Orion, the world's only deep-space crew spacecraft, is the core of the Mars Base Camp vehicle. Its capabilities include long duration, independent operation in deep space with layers of redundancy for mission robustness and crew safety. Orion can perform high-speed, precision Earth re-entry from any lunar return trajectory and all MBC-designed Mars return trajectories. Some of the roles Orion performs in the Mars Base Camp architecture are command and control flight deck, Phobos and Deimos sortie vehicle, contingency lifeboat, and integral Earth re-entry vehicle.

For a first human interplanetary mission, system redundancy and self-rescue capability is essential. Aborts from low-Earth orbit (LEO) take as little as 90 minutes to be safely back on Earth's surface. Aborts from cis-lunar space take on the order of five to ten days depending on the orbit type. When it comes to Mars, an abort is much less feasible and would take months if executable.

The crew of Mars Base Camp will need to be able to move to redundant elements if there are system failures in order to plan out and perform repair operations. They will also need to be able to perform rescue operations for any sortie missions. For the Mars Base Camp architecture there is no required rendezvous and docking operation of pre-staged elements at Mars or upon return to Earth that, if failed, would lead to loss of the crew. Examples of pre-staged elements include scientific modules, equipment, and consumable supplies not required to sustain the crew. For this reason, the Earth re-entry vehicle remains with the crew, which also avoids single events that lead to loss of the crew.

The MBC architecture is designed to include participation of commercial and international partnerships. From flight-proven hardware, such as robotic arms and laboratory modules on the International Space Station (ISS), to innovative concepts surrounding in-space propulsion and deep space habitats, utilisation of technologies through government and industry partners is not just an ideal scenario to consider but one that is essential to turning MBC from concept to reality.

Some possibilities for international collaboration include providing modules like the science laboratory or the centre node, and providing major elements like a cupola, robotics arm or solar arrays. Robotic science elements, such as rovers, that are pre-staged on Mars are another contribution possibility. Logistics flights will also be required both during the cis-lunar proving ground phase and during the build-up of the Mars-bound vehicle, which could be provided by international and commercial entities.



◄ Mars Base Camp composite illustration.

Robert P. Chambers, Production Strategy Senior Manager, Project Orion, Lockheed Martin Space Systems Company

Steven D. Jolly, Research Engineer Senior Principal, Lockheed Martin Space Systems Company

Joshua W. Ehrlich, Systems Engineer, Project Orion, Lockheed Martin Space Systems Company

DATE	MISSION	DESCRIPTION
2018	EM-1	SLS and Orion are certified for human deep space exploration
2019	Ascent Abort Test	Orion's Launch Abort System, the crew escape method during a launch or ascent emergency, is certified
2020	Mars Rover 2020	Perform Mars surface exploration and sample cache
2021	EM-2	Begin the outpost's assembly in cis-lunar space
2022	Next Mars Orbiter EM-3	The Next Mars Orbiter will provide an improved communications relay system essential for providing high bandwidth communications back to Earth and images of Mars sites at high resolution. EM-3 will continue the outpost's assembly in cis-lunar space
2023	EM-4	Cis-lunar exploration enabled by solar electric propulsion - proving the ability to pre-deploy components to Mars
2024	EM-5	Conduct cis-lunar scientific exploration using propulsion and the deep space laboratory - demonstrating tele-operations and sample retrieval capabilities
2025	EM-6	Long-duration, low-gravity science operations with ARM - gives astronauts an opportunity to test-drive a Mars-class mission
2026	Mars 2026	Pre-deploy Mars Base Camp science assets with solar electric propulsion
2027	EM-7 & EM-8	Conduct full system tests of the assembled Mars Base Camp ahead of departure for Mars
2028	MBC-1	Depart for Mars

◄ Table 1. Proposed proving ground mission campaign.

▶ The MBC launch sequence through 2026 includes Stepping Stone missions in Cis-Lunar Space.

Mission campaign

A series of missions, starting with EM-1 in 2018, will be required to meet NASA's objectives for the Mars proving ground in cis-lunar space and to build up the Mars Base Camp system.

EM-1 includes a full system test of Orion and the Space Launch System (SLS) during a cis-lunar multiple week exploratory mission, certifying the system for human deep space exploration and demonstrating autonomous operations and on-board automation balanced with the ground mission operations.

An ascent abort test will certify Orion's Launch Abort System by performing an ascent abort off a test booster launched from Cape Canaveral. Mars Rover 2020 is critical for understanding the Mars surface and preparing for Mars Base Camp robotic science missions and the subsequent human landing. The mission includes Mars surface exploration and sample caching.

EM-2 will be the first crewed mission for SLS and Orion, and the first flight of SLS's Exploration Upper Stage (EUS). It is also proposed to be the start of the outpost missions in cis-lunar space to begin addressing proving ground objectives.

A near term Mars mission is compelling and feasible

The initial outpost, delivered by commercial launch, would also provide opportunities for scientific experiments, both during crew-tended periods and the untended periods between missions.

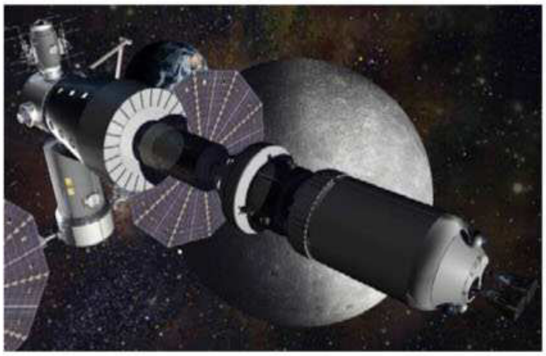
The Next Mars Orbiter is planned to provide enhanced remote sensing capabilities, high-rate communications, and possible sample storage or transportation. EM-3 will continue the outpost's assembly in cis-lunar space.

Before the crew arrives in Orion for EM-4, the prototype assembly platform will be delivered by solar electric propulsion. The Asteroid Redirect Mission (ARM) will also be demonstrating solar electric propulsion (SEP) capability to transport large masses in deep space in this timeframe. A prototype of crew quarters will be co-manifested with Orion.

As the proving ground missions proceed and mission durations increase, supplies and consumables will be delivered by commercial or international partnership launches. During EM-4, the crew will check out systems, perform science experiments and make progress against proving ground objectives.

The Mars Base Camp concept is built on a strong foundation of today's technologies

Before the crew arrives for EM-5, a prototype propulsion module will be launched. A prototype laboratory will be co-manifested with Orion and EM-5 will be able to conduct cis-lunar scientific



exploration using the propulsion module and the deep space laboratory. They will demonstrate tele-operations and sample retrieval capabilities.

Co-manifested with EM-6 will be the first element of the Mars Base Camp vehicle, the large habitat (Hab). Along with the prototype modules already assembled, EM-6 will be a year-long shakedown cruise to test out systems.

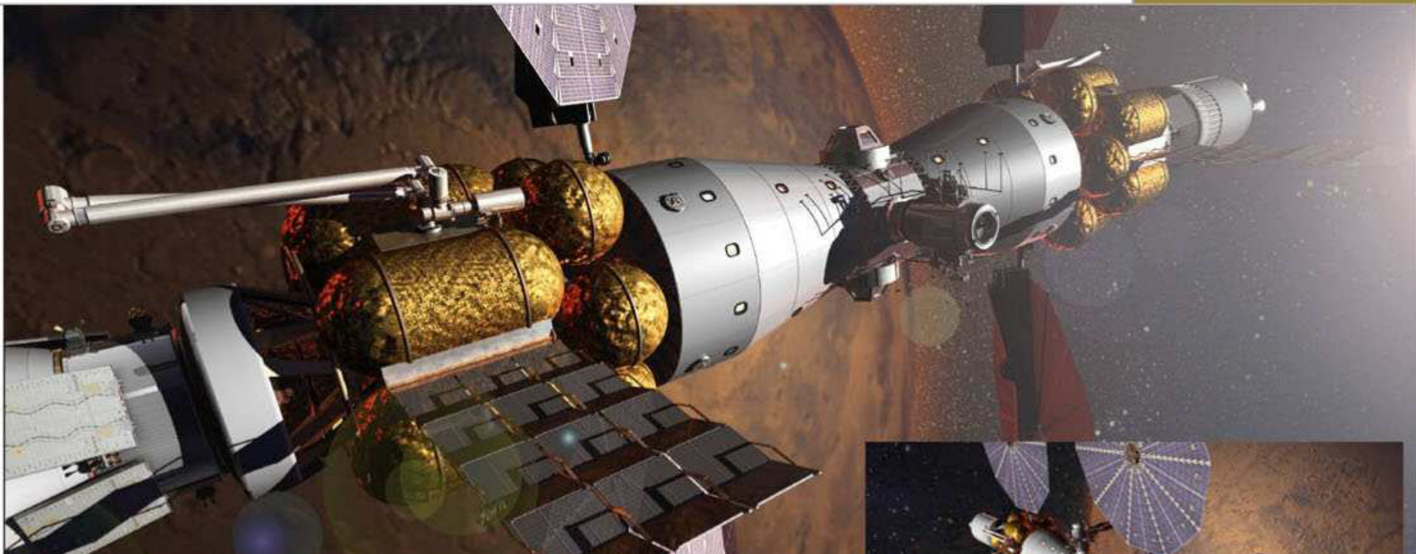
This mission will include low gravity EVA operations during the ARM portion of the mission. A visit to an asteroid in its native orbit is also being considered. In 2026, during the time frame of the shakedown cruise, science assets like the excursion system/assembly platform, laboratory, and robotic assets will be pre-deployed to Mars with SEP stages.

In 2027 and 2028, the MBC crew quarters/ propellant tanks, propulsion stages and consumables will be launched. EM-7 and EM-8 will be dedicated to assembly and full system tests. By the end of EM-8, all of the proving ground objectives will be completed, including transportation, crew transportation, heavy launch capability, in-space propulsion, deep space navigation and communication, working in space, science, deep space operations, in-situ resource utilisation, deep space habitation and crew health.

This progression of missions to a Mars Base Camp is not focused on minimalism, and could arguably be reduced in scope or bypass certain cis-lunar steps in order to reduce cost.

However, the mission sequence is intended to be executed without any substantial increase in the current inflation-adjusted NASA human exploration budget, given a phased retirement of the ISS beginning in 2024.

The key to a cost-effective near-term human exploration programme for Mars, which begins with an orbital Mars Base Camp, is the choice of mature and nascent technologies throughout the architecture. The main emerging technologies upon which the MBC is dependent do not require any fundamental breakthroughs.



Ambitious missions

The initial steps to enable a Mars Base Camp mission have already begun. Exploration Flight Test-1 was successfully accomplished and EM-1 is in assembly and test at the Kennedy Space Center for launch in 2018, while EM-2 is on track for launch of the first deep space exploration crew, establishing a pathway that leads to Mars Base Camp. That path leads through cis-lunar space, the proving ground for increasingly ambitious missions, in a logical progression that demonstrates capabilities in near Earth space before departure on missions of 1000 days and more.

The expedition begins with the prepositioning of mission elements that are important for mission success but are not essential for the survival of the crew. This includes the pre-placement, via 350kW class SEP, the Phobos/Deimos Excursion System, the Laboratory and science equipment, the Center Node, and certain consumables that are not required for survival.

While these pre-placed system elements are in transit to the 1-sol Mars Base Camp orbit, the final assembly of the Base Camp Transit Configuration is completed in high-Earth orbit (HEO). Depending on the cis-lunar precursor mission architecture, this HEO may be a lunar distant retrograde orbit (L2 Halo Orbit) near rectilinear orbit, or simply a highly elliptical Earth orbit. A HEO orbit is chosen based on its relatively low departure delta velocity and the ability to support crew/ground training for increasingly remote operations, microgravity operations, and telerobotics and telepresence operations on planetary surfaces from orbit.

The Transit Configuration is essentially identical for both trans-Mars and trans-Earth transportation of the crew and consists of two copies of all modules that are necessary for safe crew return in the event of a major elements-level malfunction.

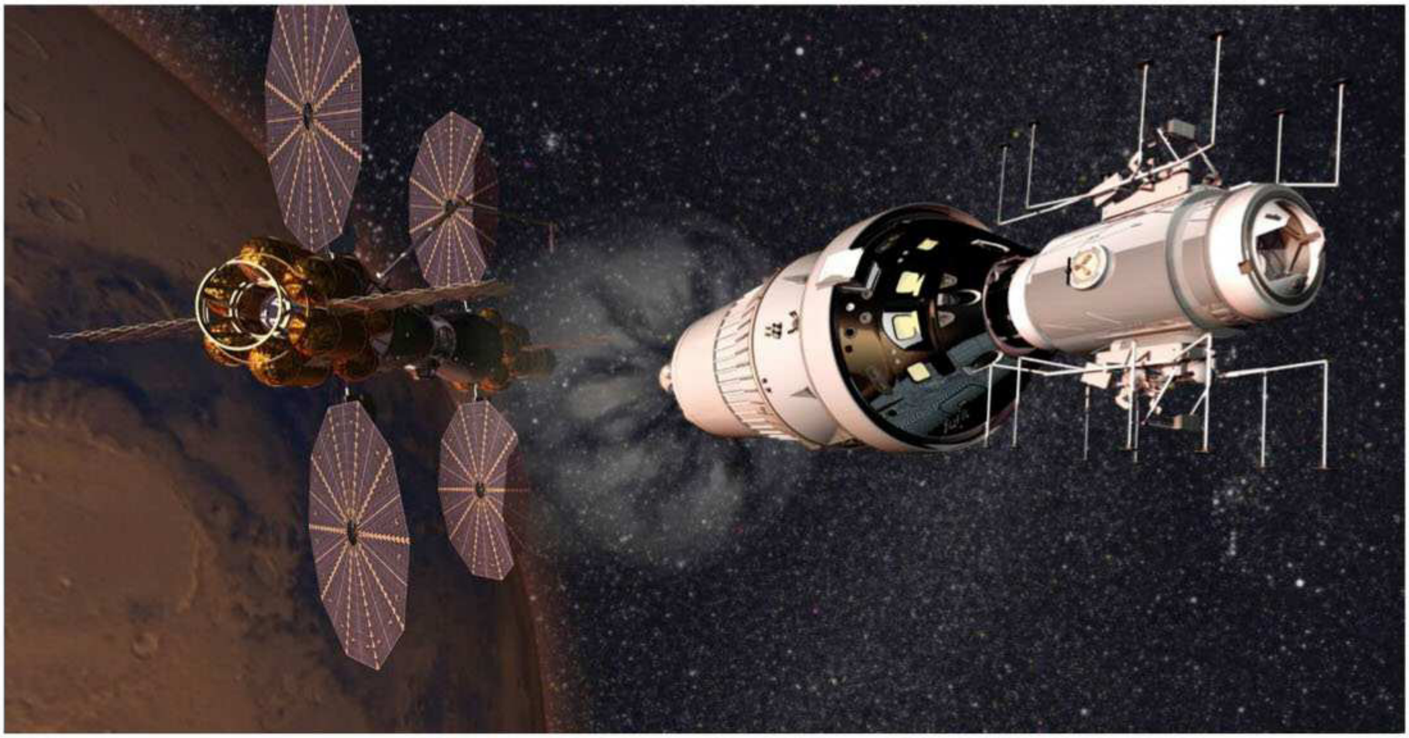
The prototype Lab, Node, and Excursion System stay behind for further use in cis-lunar space. Once the Transit Configuration arrives in the 1-sol Science Orbit, it is mated with the elements pre-placed via SEP to form a unique expedition-class planetary science vehicle capable of supporting human exploration sorties to both Phobos and Deimos as well as robotic telepresence exploration and sample return from the surface of Mars.

▶ The MBC Assembly, integrated with SEP-delivered stages, in Mars orbit.

▲ The Transit Configuration completes trans-Martian assembly for a 2028 departure.

▼ Table 2. Mars Base Camp element descriptions.

MODULE	FUNCTION
Orion	Command and control through entire mission, re-entry vehicle
Crew Quarters	Crew living space, life support systems
Tank Farm	Propellant storage
Habitat/ Laboratory	Living and working spaces
Solar Array	Power generation
Center Node	Center module of MBC
Excursion Module	Human transportation on Phobos and Deimos; airlock and landing legs
Cryogenic Propulsion Stage	Provides high thrust in-space propulsion
Solar Electric Propulsion Stage	Delivers elements and cargo for cis-lunar staging and Mars
Robotic Arm	MBC assembly
Radiators	Thermal control



▲ An artist's rendering of the Deimos Excursion Vehicle departing from the Mars Base Camp with a crew of three to visit this milligravity moon.

The 1-sol Science Orbit is chosen to allow surface synchronized telerobotic operations while optimizing the delta velocity split between the large Transit Configuration, the smaller Phobos and Deimos Sortie Systems, and the robotic Mars ascent vehicle that delivers samples to Mars orbit for recovery by the Phobos Sortie Crew in the vicinity of Phobos.

The Laboratory Module and science equipment arrives in Mars orbit prior to the crew and remains in Mars orbit when the crew departs for Earth in the Transit Configuration. The only element of the Transit Configuration that is not mirrored for system level redundancy is the large Hab, which is designed to provide habitable volume but could actually be jettisoned in the event of an emergency.

The Hab could be discarded in a crisis situation because the closed loop environmental life support system hardware is contained in the smaller Crew Quarters modules that are surrounded by the cryogenic hydrogen and oxygen tanks (Tank Farms). The Tank Farms surrounding the Crew Quarters provide an excellent storm shelter for Solar Particle Events, and a partial but significant attenuation of the galactic cosmic ray environment during sleep and rest periods. Orion is also designed to function as a radiation shelter.

The Hab includes work, recreation, dining and exercise areas comparable in volume to the Skylab module. Without the Hab, crew well-being is compromised and the return trip in particular takes on aspects of the rather spartan Mars Direct Mission [14]. However, even with the loss of a Propulsion Stage, a Crew Quarters, or an Orion vehicle, the entire Crew can be still be returned safely to Earth.

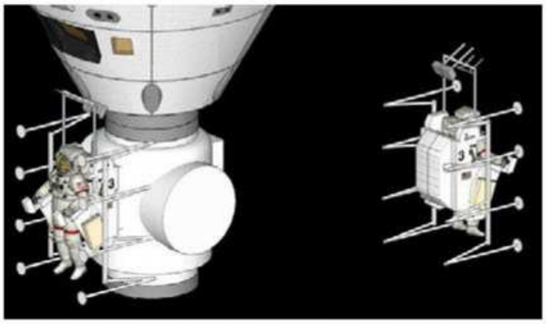
There is no need to do new complex development programmes if solutions already exist

The Crew Quarters and Orion elements, normally each configured for three, will accommodate all six crew members in case of emergency. The Mars Base Camp architecture provides the crew with the resources necessary to support self-rescue throughout the mission if no other option exists.

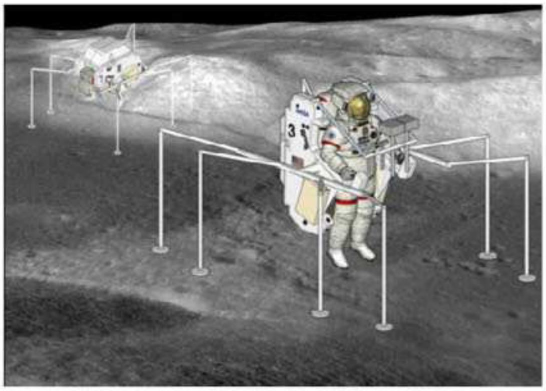
In this respect the MBC architecture is unique compared to most other Mars human exploration architectures. It could be argued that the Mars Base Camp mission could be done with a single Orion and a single Crew Quarters, and that the Propulsion Stages could be more efficiently combined into a single stage that still supported two sortie missions, but the added security of self-rescue provided by element-level redundancy is a reasonable mass trade-off.

The Mars Base Camp mission places humans on the two alien worlds Phobos and Deimos, whose origins, histories and compositions are largely unknown. In the low gravity environment of Phobos and Deimos, care must be taken to avoid kicking or pluming the surface with thrusters as this will propel surface material into orbit or escape velocities.

For free-roaming exploration in this environment, the Excursion System allows suited crew to



◀ The Spider Flyer/Walker undocks from the MPCV excursion node.



◀ EVA's via Spider Flyer/Walker allow mobility and science activities on the Martian surface.

perform extravehicular activities (EVAs) with a Spider Flyer/Walker. This system is devised to allow scientist/astronaut crew to interact directly with the surface and robotic/science equipment on the surface, and to move freely about the surface using jumps to avoid pluming the surface.

The system has a blended reaction control system that maintains contact with the surface, pushing towards the surface as necessary, to keep in contact while in walking mode. During the EVAs, one crew member would remain in Orion. Multiple EVAs would be possible during the roughly two-week sortie mission.

The crew of the Phobos Excursion vehicle will also collect samples from Mars that have been placed in orbit near Phobos by robotic systems that are under the direction of the MBC crew. Teleoperations and telepresence are used to interact with rocket-propelled airplanes that target the source methane emissions on Mars, rovers on the surface and the robotic Mars Ascent Vehicles that bring samples up to Phobos orbit altitude. The crew will stay in Mars orbit for about 11 months before undertaking the year-long journey home to Earth.

The crew returns to Earth in the same Transit Configuration as was used to reach Mars. The Lab, Central Node and Excursion System remain in Mars orbit for the next mission. The Habitat and multiple Crew Quarters and Orion Crew Modules provide sufficient partitionable habitable volume to support Crew well-being and safety for the long voyage home.

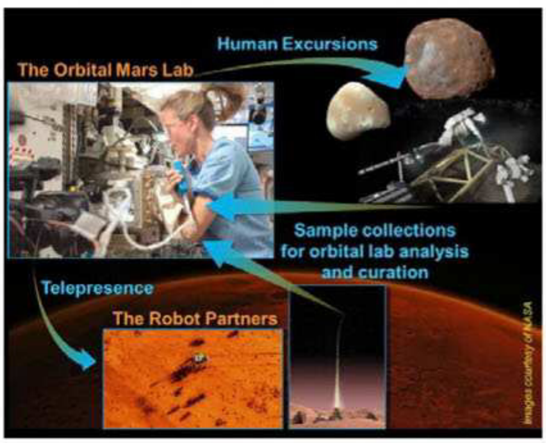
In a nominal mission re-entry, the crew is divided into two groups of three along with containers of samples from Mars, Phobos and Deimos on both Orion vehicles. The mission is designed to limit the return velocity relative to Earth's atmosphere to be consistent with Orion's capabilities.

Well prior to entry, the Cryo Propulsion Modules are removed from the Orion vehicle. The Astronauts suit up and transfer to their Orion return vehicles the day before Earth encounter. The two Orion vehicles can remain docked nose to nose until the time comes to manoeuvre to their respective entry coordinates.

Each Orion Crew Module (CM)/Service Module (SM) is a free-flying vehicle that separates from the MBC system and positions itself for entry, descent and landing. The CM and SM separate as in any Orion return, and the CM descends on parachutes for a mid-ocean recovery. In the event of an anomaly or system level malfunction, the entire six-person crew can return in a single Orion Crew Module.

Depending on the quantity of residual cryogenic propellant remaining, it may be possible to propulsively brake the remaining MBC elements into a high elliptical Earth orbit. This could allow the two Cryo Tank Farms/Crew Quarters and the Habitat to be retrieved via an SEP tug and reused in the future, either in cis-lunar space or on a subsequent mission to Mars. Planning ahead for sufficient residual propellant provides some radiation shielding for the return journey, allows for recovery of MBC elements, and provides additional options for mission contingencies and emergency responses. The Cryo Tank Farms and Cryo Stage total propellant volumes are somewhat oversized to account for this possibility or potential mass growth elsewhere in the system.

The initial steps to enable a Mars Base Camp mission have already begun.



◀ MBC mission science elements.

Science

The mission accelerates scientific discovery of origins and the search for life using scientist-astronauts and advanced robotics to conduct unprecedented field science and in-situ sample analysis in the Martian system, pinpointing the right human landing zones and bringing back the right samples.

A preliminary allocation of 7.0 metric tons of science equipment is allocated to the Laboratory Module on MBC, along with 40 kW of dedicated electrical power. These allocations are intended to be a starting point for the discussions of science objectives, measurement types, instruments and support equipment, sample curation, external robotic elements, interfaces, operational concepts, and the identification of driving functional and performance requirements.

It takes advance planning to engage the science community in examining the MBC mission concept, focusing on the most effective roles and use of robotic/automated and human/manual capabilities, and systems for the advancement of key science objectives.

Of particular interest are definition of the robotic systems, elements and missions, outside of the Mars Base Camp vehicle, that best complement the capabilities and limitations of the crew and science systems aboard the MBC vehicle. This will include factoring in the current and future plans of NASA, the objectives of international partners, and perhaps commercial interests in resource prospecting.

Mars Base Camp is intended to address the very fundamental questions of origins and evolution of Our Solar System as well as the fundamental question of life on Mars. The MBC architecture provides the ability to send robotic elements to locations on Mars, to return samples for analysis to a laboratory in Mars orbit, and to return those samples to Earth for in-depth analysis. The robotic elements may be launched to Mars as separate missions or may be deployed from Mars Base Camp.

A key objective of the Mars surface robotic operation will be to place a sample into Martian orbit near the orbit of Phobos for the Phobos sortie mission to retrieve. This sample may be one of the samples selected and cached on the surface by the Mars 2020 rover, a sample selected by a later robotic mission, or a sample selected during the Mars Base Camp telerobotic operations.

Crewed sorties to Phobos and Deimos will attempt to answer questions including the moons' origins. A three-person crew will conduct missions at these locations for about two weeks, utilising the excursion vehicle elements (propulsion stage, MPCV, airlock, Spider Flyer/Walker) to perform sortie rendezvous and MBC crew 'landings'.

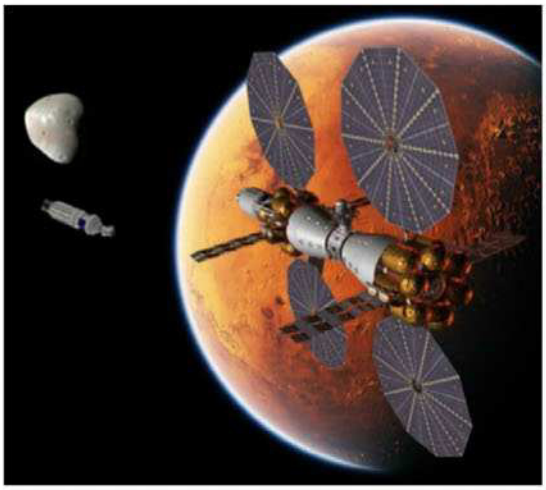
Mars Base Camp architecture provides the crew with the resources necessary to support self-rescue throughout the mission if no other option exists

Before landing, the crew will map out the surface in more detail and select landing spots from the orbiting excursion vehicle. Astronauts will venture via Spider Flyer/Walkers to the surface, perhaps to multiple sites. While in the Spider Walker configuration, which provides the crew the ability to conduct scientific operations with minimal geologic disturbance in the milli-gravity of these 'alien' worlds, astronauts will collect various samples to be delivered back to the MBC Laboratory for study and analysis.

The progression of Stepping Stones missions in cis-lunar space also provides opportunities to develop and validate sample return and low gravity body mission elements, systems and protocols prior to their use at Mars. In particular, the return of lunar samples from the south pole Aitken Basin meshes the accomplishment of a key Decadal Survey science objective with the complementary development of cis-lunar and Mars crewed and robotic system capabilities.

Since well before the first Viking lander touched down on Mars some 40 years ago, humanity has been fascinated with the Red planet. Lockheed Martin built NASA's first Mars lander and has been a part of every NASA Mars mission since. The Mars Base Camp concept builds upon existing deep space technologies in development today and provides a blueprint for NASA's Journey to Mars.

This plan provides the opportunity for significant scientific discovery, can be evolved to accommodate specific mission objectives, and ensures the safety of our astronauts. The results of this architecture study show that a near term Mars mission is compelling and feasible. ■



▶ Deimos sortie returning to Mars Base Camp.

Protecting our space interests

▲ A kinetic energy weapon launched to destroy a satellite.

The safety and security of space activities in Earth orbit are becoming a matter of grave concern, according to Gerard Brachet who has served as chairman of the UN Committee on the Peaceful Uses of Outer Space (COPUOS). From first-hand experience he provides an insight into the quagmire of international relations and the fight to establish a framework that will ensure a sustainable future for activities in outer space.

Gerard Brachet
Space Policy Consultant, France

While security issues in outer space were mostly handled at a bilateral level between the Soviet Union and the United States during the Cold War, most actors in outer space, space agencies and commercial satellite operators, realise today that our use of outer space since 1957 has been rather careless of its long-term sustainability. The situation might be compared to that of the 19th and 20th centuries with respect to maritime shipping and exploiting the oceans' resources where there was a wilful ignorance of the negative impact of pollution and a general blindness to the long-term effects of over-fishing.

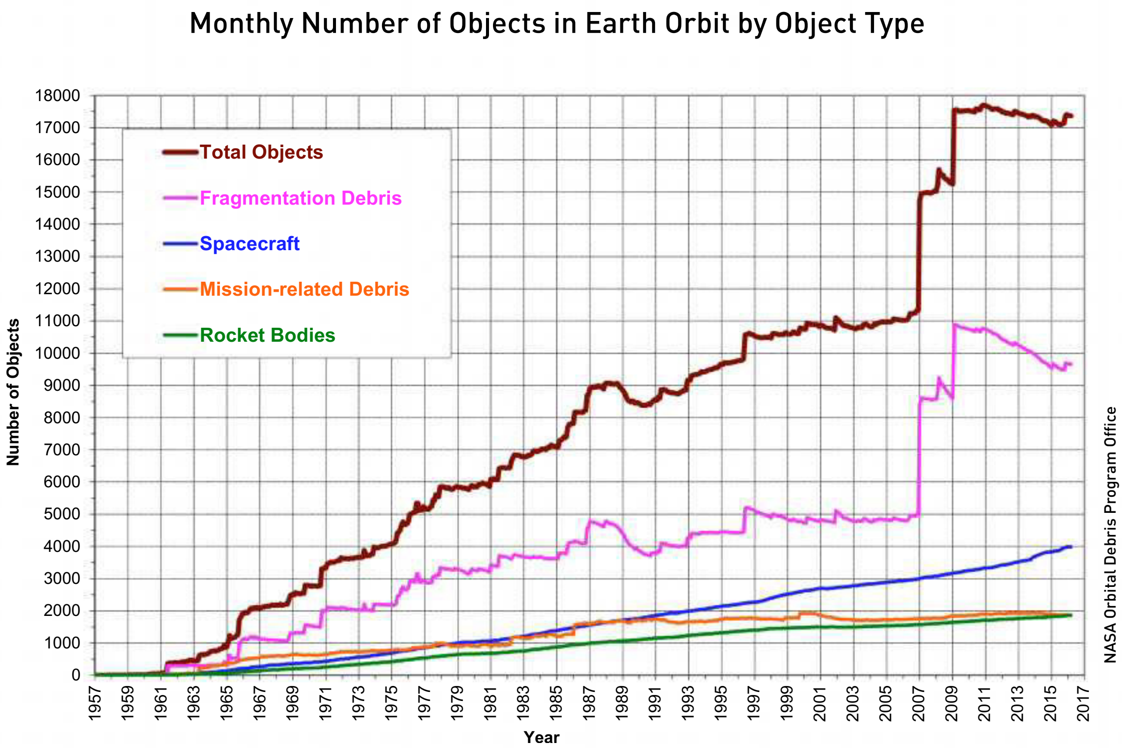
The successful use of near-Earth space systems to support national security and to deliver many now indispensable services to society has resulted in a massive increase in the number of operating systems in space, both government and private, which has in turn generated problems associated with overcrowding security.

A rapid increase in the amount of associated orbital debris is perhaps the most pressing problem and although measures have recently been adopted at international level to limit its future growth, the result of this self-imposed discipline will not be seen for decades.

Second - and directly affecting the security of space systems - is the potential use of weapons in outer space and the risk that outer space will become another battlefield. This risk was high during the Cold War but both the Soviet Union and the USA decided that self-restraint was a better option.

Today, the availability of more diversified weapons, some of which are very discreet, combined with rapidly changing geopolitical situations and the high risk of regional conflicts

▶ Evolution of the population of space objects catalogued by the US Space Surveillance Network from 1957 to 2016.



The availability of more diversified weapons increases the vulnerability of space-based systems

involving some major space powers, increase the vulnerability of space-based systems.

A third concern relates to the complex issue of managing the finite available electromagnetic spectrum and the orbital slots allocated to geostationary satellite operators. This increasingly challenging task is managed by the International Telecommunication Union (ITU), which is based in Geneva. However, the ITU operates under United Nations rules of consensus for most of its activities and lacks a strong enforcement power.

To better appreciate the situation, let's look at some numbers:

- Twelve states have demonstrated their own space launch capability but only six of these conduct regular launch operations: China, Europe (via Arianespace), India, Japan, Russia and the USA. Collectively, they conduct 80-90 launches per year (86 in 2015, of which 81 were successful). However, more and more launches deliver multiple spacecraft to orbit, sometimes up to 12 small satellites at a time.
- Between 1957 and the end of 2015 there were 5,165 successful space launches.
- About 22,000 objects are being tracked by the US Space Surveillance Network and a high proportion (17,255) have been catalogued, that is, they have been identified and tracked over long periods with sufficient certainty. However, among this large number of objects, only 23 per cent are functional or non-functional spacecraft. Of the remaining 77 per cent, 11.5 per cent are spent upper stage rocket bodies, 11.5 per cent other mission-related objects and 54 per cent fragments - an increase from 41 per cent before China's anti-satellite (ASAT) test of 11 January 2007. The tracked objects are typically larger than 10 cm in size (1 m in geostationary orbit at 36,000 km altitude), but a much larger amount of smaller debris, several hundred thousand items between 1 cm and 10 cm, are also orbiting the Earth. These smaller debris are not catalogued individually and are much more difficult to track but can still cause significant damage to operational spacecraft because of the high relative velocity of objects in low Earth orbit (LEO).
- Sixty-five states and regional governmental organisations operate satellites in Earth orbit, and an increasing number of private companies operate commercial

satellite systems, either in geostationary Earth orbit (GEO), where most telecommunications satellites are located, or in LEO, which are widely used for meteorology and remote sensing, as well as telecommunication satellite constellations. There are currently about 1,200 operational satellites, or functional satellites delivering a service, of which 450 are operating in GEO. Most of the rest are either in LEO or in the medium Earth orbits (MEOs) used by GPS and other global navigation satellite constellations.

Orbital debris concern

The proliferation of space debris on and around the most widely used orbits is out of control and must be restricted, with solutions found to the significant threat that debris poses in some LEO altitude/inclination combinations.

The Inter Agency Debris Coordination Committee (IADC), which published its Space Debris Mitigation Guidelines in 2002, is the prime driver on this issue and is to be commended for its excellent work.

The IADC brings together national space agencies from 12 countries plus a regional space agency, the European Space Agency (ESA). It consists of a Steering Group and four specific Working Groups (WGs) covering measurement (WG1), the environment and databases (WG2), protection (WG3) and mitigation (WG4). A primary purpose of the IADC is to exchange information on space debris research activities between member space agencies, to facilitate opportunities for cooperation on space debris research, to review the progress of ongoing cooperative activities and to identify debris mitigation options.

In 2013, the IADC completed a major study on the future LEO environment, confirming the instability of the current LEO debris population. It also confirmed that compliance with mitigation measures - such as the rule whereby spacecraft in LEO should re-enter Earth's atmosphere in less than 25 years - is the first line of defence against an increase in orbital debris.

Battlefield potential

The risk of outer space becoming a battlefield is hard to quantify and whilst the deployment of 'traditional' weapons' in outer space has not taken place there is no clear definition of what is a weapon in outer space.

Objects orbiting in LEO travel at 7-8 km/second and two such objects would present a very high relative velocity, in the order of 10-16 km/s, which means any spacecraft with some degree of manoeuvrability could be used as a weapon simply by being directed at another spacecraft. Neither do weapons need to be based in space to present a threat to orbiting operational satellites. Ground-based weapons can also be used, as the 2007 Chinese ASAT test against a spacecraft in LEO demonstrated.

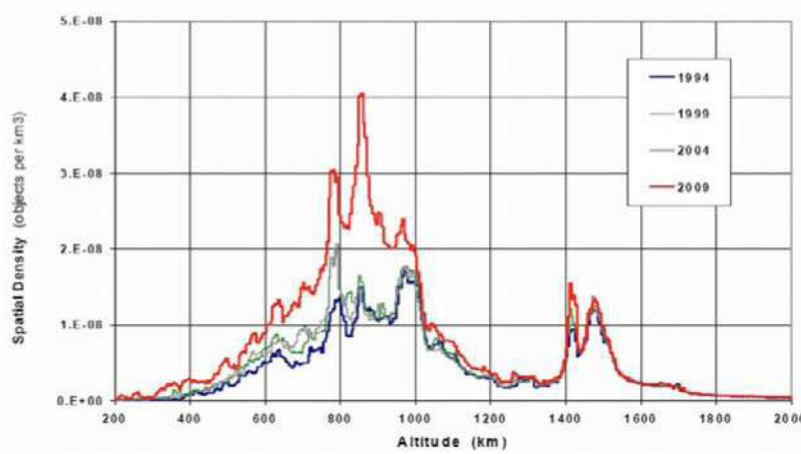
Non-kinetic energy weapons, capable of interfering with operational spacecraft by jamming communications with ground control or blinding detectors, are already available and have been tested on several occasions. Even without destroying a spacecraft, such weapons still pose a threat to safe and secure operations in outer space.

The USA has developed powerful ground-based and airborne radar and high-energy lasers as part of its ballistic missile defence programme. These could easily be adapted for use against space objects and any state that has reached a reasonable technological level would be capable of acquiring some capacity in this field. The deployment of such weapons requires a parallel space surveillance capability to be able to monitor space objects and estimate the position of the target satellite with a sufficient degree of accuracy.

Less powerful lasers can be used to temporarily blind reconnaissance satellites in LEO, thereby preventing the collection of intelligence data over a specific territory, whilst jamming of radio-frequency uplinks and downlinks is regularly used in certain parts of the world to jam broadcasting satellites carrying radio or television programmes that displease the local regime. The ITU has been asked to handle several complaints from

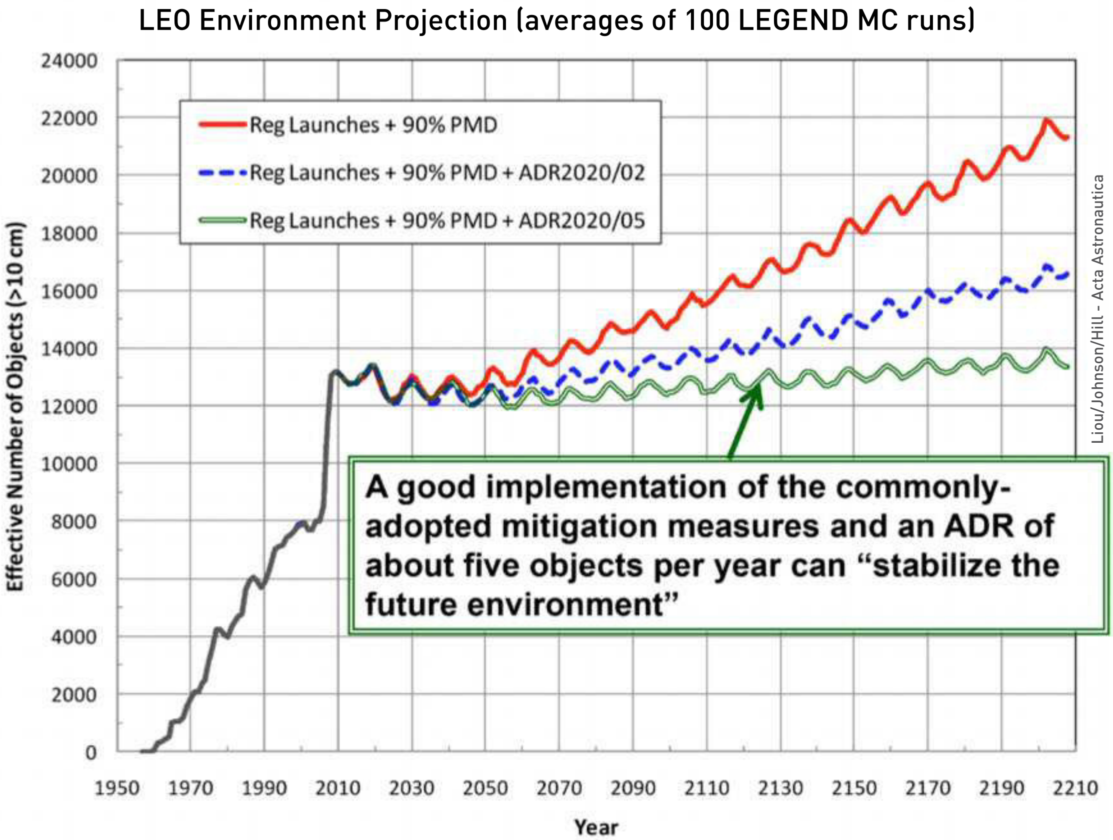
The proliferation of space debris on and around the most widely used orbits is not under control

▼ Spatial density of orbital debris vs. altitude in Low Earth orbits.



NASA Orbital Debris Program Office

▶ Forecasting the long-term evolution of the space debris population. This figure describes the results from of a large number of Monte Carlo simulations of the long-term evolution of the orbital debris population in LEO. Number of launches per year is assumed to be about constant. 'PMD' refers to Post Mission Disposal - 90 per cent PMD means that 90 per cent of active satellites are disposed of at the end of their mission according to internationally agreed debris mitigation guidelines. 'ADR' means Active Debris Removal.



Liou/Johnson/Hill - Acta Astronautica

telecommunications satellite operators but lacks the required enforcement mechanisms to truly resolve such issues.

A more sophisticated threat is the potential takeover of a satellite by a third party, be it a terrorist organisation or another state, which would require access to codes and the bypassing of existing cyber protections.

International initiatives

The IADC's work and subsequent adoption of its Space Debris Mitigation Guidelines in 2007 by COPUOS provides a good model of how the international community can progress towards a regime on sustainable space operations.

The development of debris mitigation guidelines was very much a bottom-up process. It started with a detailed assessment of the situation by technical experts from the IADC agencies, was complemented by many tests and simulations, and continued with technical discussions of possible mitigation measures and finally the development of a consensual basis for orbital debris mitigation guidelines based on robust technical grounds.

The first version of the IADC Debris Mitigation Guidelines, published in 2002, formed the basis of the discussion within the COPUOS Scientific and Technical Sub-Committee (STSC) when it took up the issue in 2003. The advantage of such a bottom-up, technical approach is that the recommendations that emerge are agreed to by all parties, which makes it difficult to reopen and thus disrupt the debate at the political level.

This positive assessment of the IADC model and the subsequent COPUOS/STSC debate on ways to mitigate the growth of space debris and the threat this represents to safe operations in Earth orbit led the author, at that time chairman of the COPUOS, to float the concept of a Working Group dedicated to developing 'rules of the road for space traffic'.

At the 52nd session of COPUOS in June 2009, the French delegation formally proposed the 'long-term sustainability of outer space activities' as a new agenda item for COPUOS in 2010. After including the topic for its Scientific and Technical Sub-Committee (STSC), the COPUOS/STSC then decided to set up a formal Working Group to address the issue, as it had done in 2003 for space debris. Dr Peter Martinez (South Africa) was appointed chairman and its first meeting took place alongside the 53rd session of COPUOS in Vienna in June 2010.

The UN COPUOS Working Group continued its work until 2015, relying on four expert groups set up to examine the various aspects of the long-term sustainability of space activities, and preparing a number of proposed guidelines.

Following lengthy discussions at the 53rd session of COPUOS/STSC in February 2016, where no consensus could be found, a special informal session of the WG took place in Vienna in June 2016, just before the 59th session of the COPUOS plenary session. During this session, COPUOS delegations agreed on a first set of 12 guidelines and extended the mandate of the WG until 2018 to complete its discussion and, hopefully, agree on the other draft guidelines.

European Union proposal

The COPUOS initiative did not focus on space security per se because COPUOS addresses the peaceful uses of outer space. Space security activities fall under the mandate of the Conference on Disarmament (CD), which meets in Geneva. Unfortunately, there has been little progress at the CD on the Prevention of an Arms Race in Outer Space (PAROS) agenda item, largely because the CD has failed to agree on an overall work plan.

Faced with this lack of progress on the security of outer space, ambassadors to the CD from European Union (EU) member states suggested in 2007 that the EU take the initiative outside of the CD framework to elaborate and propose to the international community of spacefaring nations a 'code of conduct' for outer space activities. A first version of the EU draft for an International Code of Conduct (ICoC) was approved by the European Council in December 2008 and then widely circulated.

Bilateral consultations with many spacefaring nations were conducted by the Council of the European Union in 2009-2010, leading to the publication of a new version of the ICoC in September 2010. A series of open-ended multilateral consultation meetings took place in 2012, 2013 and 2014, with new versions of the proposed Code being distributed at each of these meetings. The next step was to start a formal negotiation on the text of the ICoC, which was planned to take place at UN headquarters in New York in July 2015. However, negotiations did not take place during this session as several delegations objected either to certain aspects of its contents or to the process followed by the EU in developing the draft. On the latter question of process, it is fair to say that many states, such as India, had expressed reservations as early as 2011.

So, after more than eight years, the EU initiative seems to be in the doldrums. One aspect troubling many countries was that it was not placed under the umbrella of the United Nations, a framework that the EU excluded from the beginning probably out of fear that the process would be slowed by UN procedures and processes.

It is rather sad that this initiative was not successful but if it is to be taken up again, by the EU itself or by any other actor, a new approach will be needed, based on a better understanding of the negative perceptions of emerging nations and building on the positive statement on the usefulness of such a code included in the 2013 report of the United Nations GGE on Transparency and Confidence-Building Measures in outer space activities.

Treaty proposal

Since the beginning of the century, China and Russia have been active at the Conference on Disarmament in promoting their proposed draft Treaty on the Prevention of the Placement of Weapons in Outer Space and of the Threat or Use of Force Against Outer Space Objects, widely referred to as the PPWT, which would forbid the deployment of weapons in outer space.

According to Russian and Chinese supporting statements, such a treaty would reinforce Article IV of the 1967 Outer Space Treaty, which only forbids the deployment of weapons of mass destruction in outer space. A first version of the proposed PPWT was tabled by the Russian delegation at the CD in February 2008.

From the start, the proposal was strongly opposed by the USA, particularly by the administration of President George W Bush, which expressed opposition to any normative attempt in international law that would tie US hands in the area of space security. More specifically, the USA and many European states expressed strong reservations about the proposed treaty because it did not directly address the threat posed to space-based objects from ground-based ASAT missiles. The USA was also quick to point out that the proposed PPWT did not contain a verification clause.

A revised version of the proposed PPWT containing some marginal corrections but still not addressing the issue of ground-based anti-satellite weapons was tabled by Russia and China at the CD on 10 June 2014.

The proposed treaty received political support recently at the BRICS (Brazil, Russia, India, China and South Africa) summit held on 15-16 October 2016 in Goa, India, but many other states are still not ready to support it. However, Russia and China can be expected to continue to push for a binding

More ground must be covered before we will have a framework ensuring a secure and sustainable future for activities in outer space

There is no clear definition of what a 'weapon' in outer space is

treaty of some form that would forbid the use of force in outer space despite it being clear that the United States and many of its allies are not ready to even discuss such a proposal.

In 2010, at the initiative of Russia, a request to the Secretary-General of the United Nations to set up a Group of Governmental Experts (GGE) to conduct a study on Transparency and Confidence-Building Measures (TCBMs) in outer space was included in General Assembly Resolution 65/68 on TCBMs in outer space activities. And for the first time in many years, the USA agreed to support the resolution and it was adopted unanimously.

The GGE was formally set up at the beginning of 2012 with representatives from 15 countries: Brazil, Chile, China, France, Italy, Kazakhstan, Nigeria, Romania, Russia, South Korea, South Africa, Sri Lanka, Ukraine, the United Kingdom and the USA. Under the chairmanship of Victor Vasiliev, at that time Deputy Chief of the Russian Permanent Mission to the United Nations and the CD in Geneva, the GGE worked rather efficiently. It finalised its report which was adopted by consensus at its last meeting in New York in July 2013. The GGE report was submitted for endorsement to the First Committee of the General Assembly in September 2013 before being endorsed unanimously by the General Assembly in its Resolution 68/50 adopted in December 2013.

In its conclusions and recommendations section, the GGE endorses efforts to pursue political commitments, for example, in the form of unilateral declarations, bilateral commitments or a multilateral code of conduct to encourage responsible actions in, and the peaceful use of, outer space. The Group concluded that voluntary political measures can form the basis for considerations of concepts and proposals for legally binding obligations.

Clearly, while not directly quoting the EU's proposed ICoC for outer space activities, the GGE report recognises the value of such an approach as a step towards more transparency and more international confidence in the conduct of space activities. The fact that the GGE report was adopted by consensus among its experts and was later unanimously endorsed by the First Committee and by the General Assembly indicates strong support from the international community for the direction of progress.

Where next?

The various international initiatives described above illustrate the serious concern that both spacefaring nations and non-spacefaring nations have for the future security and sustainability of the use of outer space for government-sponsored as well as commercial applications.

How do we convince the new actors in outer space, commercial entities as well as emerging spacefaring nations, that their best interests lie in abiding by the recommendations and guidelines that will emanate from the bodies and organisations mentioned above?

The positive outcome of the GGE exercise and the slow, but real, progress made by the Long-Term Sustainability Working Group of COPUOS are encouraging signs - but much more ground must be covered before we will have a framework ensuring a secure and sustainable future for activities in outer space. ■

▼ Members of the UN Group of Governmental Experts on Transparency and Confidence-Building in Outer Space on the grounds of the UN premises in New York.

United Nations

► Flags of member nations flying at United Nations Headquarters in New York.

Prospects for progress on space security diplomacy

The diplomacy of space security is a difficult realm in which to assess progress. There are no set benchmarks and little movement on which to base a call as to whether matters are progressing or regressing and to a degree it resembles a 'glass half full or half empty' type of determination. Paul Meyer, a Professor of International Studies and Fellow in International Security, outlines the situation and suggests some possible answers.

Paul Meyer
Simon Fraser University and The Simons Foundation, Vancouver, Canada

At the same time there is no question that the use of space is growing exponentially with some 1400 satellites currently active and over 60 states or consortium owning space assets. Every country on the globe is benefiting from space-enabled services and the collective contribution of space to the world's security and well-being is enormous if hard to quantify. All of this activity is premised on continuation of the relatively benign operating environment of space, free up to this point from man-made attacks or threats against space assets.

The legal basis for this situation lies in the 1967 Outer Space Treaty with its far-reaching provisions that provide space with a special 'global commons' status, forbid stationing of WMD in orbit or militarisation of celestial bodies, and specify that the use of space should be for 'peaceful purposes' and in the interests of all.

This neglect of the Outer Space Treaty by the very states that championed its creation speaks to a disturbing trend in contemporary space security affairs

The Outer Space Treaty was a major accomplishment in international cooperation and merits celebration at its 50th anniversary next year at a level commensurate with its significance for the outer space regime we all benefit from today.

It would be appropriate for the over 100 states party to the treaty to convene the first ever meeting to mark this landmark agreement and its golden anniversary. Unfortunately, the three depositary governments of this treaty (Russia, US and UK) have shown scant interest in undertaking any commemorative action on behalf of the treaty let alone an innovative step such as convening such a meeting.

This neglect of the Outer Space Treaty by the very states that championed its creation speaks to a disturbing trend in contemporary space security affairs, one that ignores the constraints on the actions of actors in space (even those voluntarily entered into by these same actors) in favour of emphasising unrestricted freedom of action and the development of national security-related capabilities to support unilateral moves.

Despite the major role the Outer Space Treaty has played in delineating the scope of permissible action in outer space, the international community has long recognised that it is not sufficient to preserve security in outer space.

Via the UN General Assembly resolution on 'The Prevention of an Arms Race in Outer Space' (PAROS) that has been a regular feature of the Assembly's First Committee (Disarmament and International Security) since the early 1980s important further policy direction has been given.

The widely-supported PAROS resolution (only two abstentions and no opposing votes) has long affirmed that 'the legal regime applicable to outer space by itself does not guarantee the prevention of an arms race in outer space...[and that consequently] there is a need to consolidate and reinforce that regime and enhance its effectiveness'.

The resolution goes on to stress the need for 'further measures' and for states 'to refrain from actions contrary' to the peaceful-use-of-outer-space objective. While this policy direction is clear and important, regrettably from the perspective of practical diplomacy, the PAROS resolution has called on the Conference on Disarmament to establish a working group on this item to carry forward this work. It is as if its sponsors have failed to notice that the Conference on Disarmament has been in a state of gridlock for 20 years unable to establish a subsidiary body on space or on any other theme.

This disconnect between goal and process regarding space security has persisted for many years. There appears to be a strong consensus on the part of states in favour of reinforcing and consolidating the existing regime but little in the way of tangible achievements in that regard. The major initiatives to supplement that regime proposed in the last decade have failed to come to fruition and have tended to highlight differences amongst states rather than overcome them.

In this category I would put the Sino-Russian proposed treaty for prevention of placement of weapons in outer space (PPWT). The treaty officially tabled in the Conference on

▶ Signing ceremony for the Outer Space Treaty in 1967.

Agreement on the more demanding proposed guidelines will prove more elusive

Disarmament in 2008 with a revision tabled in 2014 has drawn criticism from some quarters for its lack of definitions, verification provisions and for its restricted scope. Consideration of the draft treaty has also suffered from the lack of a relevant subsidiary body within the Conference on Disarmament to discuss it and the refusal of its sponsors to bring the treaty before any other multilateral forum.

Also in this category of diplomatic 'failure to launch' I would place the EU-initiated Code of Conduct for Outer Space Activities, a voluntary set of measures designed to promote the safety, security and sustainability of space activity.

Some readers may be aware that this proposed Code was brought before a multilateral meeting in July 2015 in New York with the hope of finalising the text. This was not to be, however, as a significant number of states argued that such a Code needed to be developed pursuant to a mandate authorised by the UN General Assembly. At present this Code seems in a kind of diplomatic limbo with no evident champion willing to seek authorisation to commence a new multilateral negotiation based on its text.

Finally, I believe that the Russian-initiated resolution on 'No First Placement of Space Weapons' adopted at the UN General Assembly for the first time in 2014 and again in 2015, represents another problematic development for space security.

This resolution was viewed by several states as potentially establishing a justification for the development of space weapons in order to retaliate if a state actually was responsible for being the first to introduce weapons in space.

These concerns help to explain why a substantial subset of member states (some 50) either abstained or opposed the resolution. This divisive outcome regrettably detracted from the general consensus that has characterised UN General Assembly declaratory policy on space up until this point.

A more positive development in the sphere of space security was the consensus report issued in 2013 by the UN Group of Governmental Experts (GGE) on 'Transparency and Confidence Building Measures' (TCBMs) in outer space.

This GGE report set out a substantial list of TCBMs that could contribute to space security. The report also recommended a joint session of the First and Fourth Committees of the General Assembly to combine the two dimensions (or solitudes) of the UN's traditional involvement in

▲ The International Space Station is a symbol of cooperation. Here, three vehicles are simultaneously attached - Orbital ATK's Cygnus cargo craft (left), Russia's Soyuz MS-01 vehicle (middle) and the Russian Progress 64 cargo craft (right.)

The international community needs some fresh approaches in order to make progress on the space security issue

space policy and activity. This joint session was duly held last year and a further joint meeting is envisaged for next year. The jury is still out, however, on whether the other recommendations of the GGE will be embraced by states and actually implemented.

In part, because of the protracted deadlock in the Conference on Disarmament, the centre of gravity for further development of space policy has shifted to Vienna and the UN's Committee on the Peaceful Use of Outer Space (COPUOS) at the expense of explicit coverage of the security aspects of outer space use. This summer at its annual session, COPUOS was able to agree on an initial set of guidelines emerging from a multi-year working group on the long-term sustainability of outer space.

Some will view these guidelines as the realisation of the GGE's recommendations. But here again the proof of the pudding will be in the eating, i.e., how state practice actually changes via these guidelines. It is also fair to say that the adopted guidelines represent the low-hanging fruit of the working group's production and agreement on the more demanding proposed guidelines will prove more elusive.

Objectively, I would have to assess that the prospects for advancing space security at the current time are not bright. Differences among leading space powers are being exacerbated while threat perceptions and rhetoric associated with these are darkening.

Suggestions that other space powers view one's own space assets as vulnerable targets do not contribute to fostering a cooperative security climate. The diplomatic initiatives that have been put forward have either stalled or generated serious opposition. They will require renewed attention and creative thinking if advances are to be made. The international community needs at this juncture some fresh approaches in order to make progress on the space security issue. It is especially important to reaffirm, and reflect in action, the core commitments of the Outer Space Treaty. In particular, the obligation to abide by the peaceful purposes orientation of the treaty and to ensure that the use of space is carried out in the general interest and provides benefits for all and not just to those engaged in the activities. International cooperation needs to be re-instated as the pre-eminent aim for space action. It is also increasingly obvious that preserving space for humanity is too important an endeavour to be left only in the hands of governments. The wider stakeholder community (the private sector and civil society) needs to get more engaged on behalf of responsible policies that provide for space security for all the years to come. ■

About the author

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▼ Meeting of the Committee on the Peaceful Uses of Outer Space.

MASTER II Robotic telescope on the island of Tenerife, Canary Islands, at the Teide Observatory at the Instituto de Astrofísica de Canarias.

Global robotic network for monitoring near-Earth and outer space

With a commanding name such as MASTER, it is expected that the Russian-made global robotic system for monitoring near-Earth and outer space has big things in store - and indeed it does. MASTER has already proved its worth by surpassing all of the world's optical telescopes, including the best American observational telescope PanSTARRS, when it reported on the first optical follow-up observations of the historic gravitational wave event GW150914 that occurred in 2015. Aside from tracking potentially dangerous asteroids and helping to shed light on mysterious bursts known as kilonova, the MASTER network also has plans to help ascertain the true expansion rate of the Universe.

The MASTER network has discovered about one thousand new optical transients of all types - from astrophysical explosions to potentially dangerous asteroids and comets

V.M. Lipunov
Space Monitoring Laboratory, Moscow State University, Moscow

At the beginning of the 21st century it became obvious that using small-diameter (up to one metre) robotic telescopes in astronomy allowed for breakthroughs in observing non-stationary and short-lived events in the Universe. With the help of robotic observatories that were built in developed countries it was possible to discover the optical emissions of some of the brightest emissions in the Universe – gamma-ray bursts (GRBs).

By analysing the light from a number of exploding stars (Type 1a supernovae), robotic observatories have also helped in the discovery that the Universe is expanding at an accelerated rate due to the existence of a mysterious force known as dark energy. The astronomers who studied this phenomena have since won the Nobel Prize for Physics in 2011. Not only that, but robotic telescopes now discover hundreds and thousands of new small bodies in and outside of the Solar

System from exoplanets to dangerous asteroids and meandering comets.

However, it should be emphasised that robotic telescopes are not simply automated systems capable of working remotely under human guidance. Some are able to work autonomously by selecting observation strategies while automatically receiving and processing images, locating new objects from those images and reporting these discoveries to interested parties (such as emergency services, agencies, etc), or publishing the information in special scientific or departmental online publications. Indeed, this is what the MASTER network was developed to do

In 2002, the first Russian robotic telescope MASTER was created under the supervision of myself. As a result of a six-year-long field test of this telescope, the small double wide-field telescope (40 cm in diameter) MASTER II was developed and produced, and this became the basis of the global monitoring network with sensitivity to apparent magnitudes 19-20, the fastest in the world.

Over the last five years, the MASTER network has discovered about one thousand new optical transients of all types - from astrophysical explosions to potentially dangerous asteroids and comets. The MASTER II network is internationally recognised and its telescopes have been invited to the best observatories north and south of the equator, and the objects discovered by the network have become research subjects for the largest telescopes in the world's space observatories.

The fact that the world's largest physical experiments on neutrino registration (ANTARES, IceCube) and gravitational waves (LIGO/VIRGO) work with MASTER speaks of its quality. MASTER II's decade-long working experience has shown that Russia, with its giant longitudinal expanse is ideally placed for the creation of a network of robotic observatories. The unpredictability of many burst events and their near isotropic dispersion in the sky makes Russia, as the largest country in the world, an unparalleled location for this innovative research.

It is not just the telescopes that are fully automated but the robotic network too

Wide-field optical complex

Robot-telescope MASTER II is a wide-field optical complex - an observatory that can work autonomously, without human participation. The observatory consists of an automated pavilion, a powerful and fast (up to 30 degrees per second) lever, two wide-field telescopes with a diameter of 40 cm and focal distance of one metre, that are equipped with photometers, including astronomical

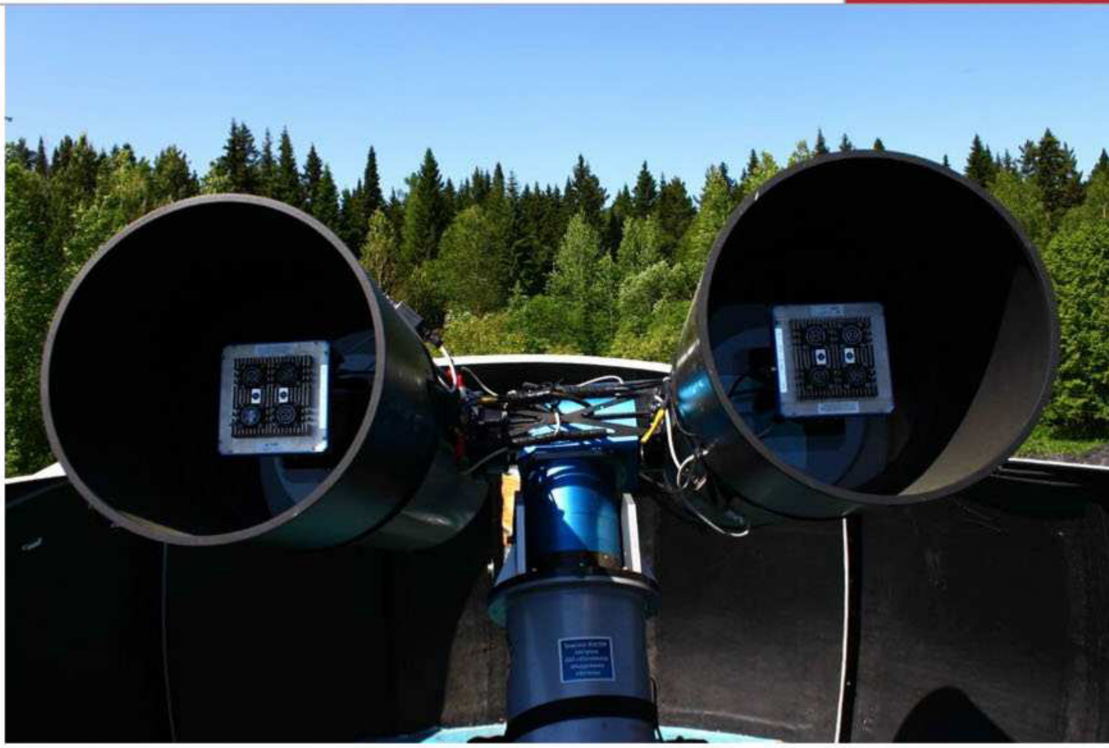
filters and polaroids, each with a CCD matrix with a covering power of 2 x 2 square degrees.

The telescope's lever has an automated, limited displacement axis which allows the separation of the telescopes to be adjusted. The telescopes are parallel and, when pivoting, MASTER II can provide synchronous imaging of the interesting part of the sky in colour or polarized mode.

MASTER II is the only colour polarizing wide-field telescope in the world. This view mode is used in cases of receiving alerts from outside information sources, including space-based systems. During autonomous work in search (monitor) mode, the tubes part and this allows for the full field of vision available for the optical complex, with the same scale of image at eight degrees squared.

Each of the MASTER II optical complexes is equipped with powerful data processing and storage servers, with open source code databases that are quickly accessible online. Unique software provides secure management of all software (opening the dome based on cloud detection data, the choice of observational direction, receiving images and image processing in real time, the search for new, uncatalogued objects and final data transmission. The latter is accomplished either online or through other robots, including robots of the MASTER network, control systems and international astronomical union or other international agency robots.

MASTER II robotic telescope is made by MO OPTIKA, a public limited company, and there are



two versions of MASTER II - one for cold zones, such as Siberia, that was specifically developed for temperatures down to -40 degrees Celsius (Buryatia and Amur Region). The 'cold' MASTER II has a specially crafted metallic dome and a secure cable opening system that works even during snowfall, ice and heavy winds. In milder climates, fibreglass pavilions, especially modified for the robotic telescope's intense work, are used. All of the pavilions are fully able to open and provide access to any point in the sky above.

Global Robotic Network

MASTER Global Robotic Network for Monitoring Outer and Near-Earth space was created and is being developed at Lomonosov Moscow State University. The main purpose of monitoring is the search for new and previously unknown objects that are fundamentally interesting to researchers.

For example, after the impact of the Chelyabinsk asteroid, much attention was paid to searching for potentially dangerous bodies in the Solar System, such as asteroids and comets, particularly those approaching the Earth. Such observations demand a constant upgrade to the mathematical software, as potentially dangerous asteroids change their path in near-Earth space very quickly. This has been achieved and, as a result, during the last few years its has discovered seven potentially dangerous asteroids and two comets (Table 1).

The main network junction point is the optical robotic complex MASTER, currently installed in a number of locations: Blagoveshensk, Baikal, Ural, Kislovodsk and at the MSU Crimean observatory. Segments outside of Russia are currently being built on the Canary Islands and in South Africa and Argentina, financed by private donations and under supervision of the Space Monitoring Laboratory at Moscow State University.

It is not just the telescopes that are fully automated but the robotic network too. Everything from the automated closing dome, imaging of the sky, image processing, the search for undiscovered objects, including moving objects, determination of initial orbit and 'catching" it for additional imaging and the adjustment of orbit calculations are all done automatically without the need for any human supervision. To finish off, the collected data is then transmitted online from the robotic telescope to the MSU data centre.

The MASTER II robotic network of telescopes is a last-generation system of robot telescopes with the ability of a fully automated or remote space scanning mode. Today there are eight robot-telescopes located on five continents and islands.

Sixteen telescope tubes are in use, providing the quickest view in the world of the sky up to stellar absolute magnitude 19-20 of non-moving objects. To put this into perspective, Callirrhoe, a satellite of Jupiter which is 8.6 km in diameter, has an absolute magnitude of 21 and the visible light limit of the Hubble Space Telescope is 32.

The angular speed of movement can reach 20-50 degrees per second. In recent years, the MASTER system has discovered over a thousand

▲ Double wide-field telescope MASTER II. The telescope is located by Kislovodsk, operated by Lomonosov MSU and Pulkovo Observatory Sun Station. Elbrus can be seen on the right.

We have developed and are ready to launch the production of a third-generation robotic telescope MASTER III

The MASTER projects are unique in Russia as there are no other fully robotic optical systems that could carry out fundamental and applied research simultaneously

explosive objects and previously un-catalogued objects, located anywhere from a few hundred kilometres to billions of light-years away.

These include the optical doubles of gamma-bursts (creation of black holes), supernovae (collapse and/or nuclear burn of dying stars), novae (star collisions and/or nuclear burning around white dwarves), dwarf novae (non-stationary falling of matter onto white dwarves in small dual-star systems), eruptive variables (accretive white dwarves), active galaxy nuclei flashes (blazars, quazars, supermassive black holes), dual star systems of unknown origins, superfast flashes of stars of the UV Kit type (the dissipation of the magnetic field on red dwarves - analogous to Sun flares), potentially dangerous asteroids (Solar System) and space debris (near-Earth space).

The software used on MASTER telescopes allows for automatic monitoring of near-Earth and outer space at all the observatories that use MASTER (Blagoveshensk, Irkutsk, Ekaterinburg, Kislovodsk, Crimea, South Africa, Canary Islands and Argentina) and it details full information about every object on every image 1-2 minutes after they're downloaded from the CCD camera, including moving objects and calculated parameters of their movements. To date, we have received over a million images with an angular size of four square degrees. For comparison, when viewed from the surface of the Earth, the full Moon covers only about 0.2 square degrees of the sky.

However, the field of synoptic searching is constantly developing. The USA and some European countries have already moved or are moving to larger wide-field systems (Pan-STARRS (USA), OGLE III (Poland-USA), ePTF (USA), CRTS (USA), VST, etc).

The move is caused by new tasks that will have to be performed in the near future, such as researching the nature of the accelerated expansion of the Universe. The appearance of next-generation gravitational wave interferometers has made researching neutron star mergers and black holes possible, whereas medium and large diameter telescopes can find the furthest objects in the Universe, such as the optical doubles of gamma-bursts at red shifts of over 10. These telescopes are also capable of locating potentially dangerous asteroids and comets.

MASTER III

Long-term experience of working with search systems shows that it is time for the next step and that the utilisation of medium-sized telescopes with a 1 m diameter is the most reasonable ambition to strive for. We have therefore developed and are ready to launch the production of a third-generation robotic telescope MASTER III. These telescopes can be created within two to three years and will allow Russia to remain at the forefront for detecting dangerous asteroids and to be a world leader in optical transient research.

The unique MASTER II software, which after over a decade of work on the part of a number of highly regarded programmer-astronomers, will be modified and enabled to discover cosmological transients up to stellar absolute magnitude 22-23, while helping to resolve the following fundamental tasks:

Table 1. Potentially dangerous asteroids and comets discovered by the MASTER network.

NAME	DISCOVERY DATE	MAG.	SIZE	OBSERVATORY	INDEX AT THE INTERNATIONAL SMALL PLANET RESEARCH CENTER
2015 UM67	2015 Oct 28	16.9	940	MASTER-SAAO	MPEC 2015-V01
2011 QG21 (rd)	2015 Aug 17	17.2	300	MASTER-IAC	MPEC 2015-Q28
2014 UR116	2014 Oct 27	16.8	750	MASTER-Kislovodsk	MPEC 2014-U121
1998 SU4 (rd)	2014 Sep 26	17.7	350	MASTER-Tunka	MPEC 2014-S14
2014 EL45	2014 Mar 09	16.4	750	MASTER-Kislovodsk	MPEC 2014-E80
2013 SW24	2013 Oct 27	16.3	190	MASTER-Tunka	MPEC 2013-S74
2013 UG1	2013 Oct 22	15.6	240	MASTER-Tunka	MPEC 2013-U31
COMET C/2015 K1 (MASTER)	2015 May 17	16.3	?	MASTER-SAAO	IAUC #4105
COMET C/2015 G2 (MASTER)	2015 Mar 30	11.6	?????	MASTER-SAAO	MPEC K15G28

▲ Global MASTER network. Identical robotic MASTER II telescopes are located in the Northern and Southern hemispheres, Eastern and Western longitudes. As of 2016, the network provides the quickest view of the sky up to magnitude 20.

- Researching the laws of accelerated expansion of the Universe with the use of type 1a supernovae. The discovery of these objects in the red shift range of $0.1 < z < 0.8$, where the decelerated and accelerated expansion of the Universe occurs, will allow Russia to participate in the leading research of vacuum space energy.
- Discovery of further objects of the Universe at distances of $z > 10$ by using fast-alert observations of gamma-bursts and observing the precursors of supernovae and the appearance of kilonovae – a phenomena that occurs when two neutron stars merge. Identified by a short gamma ray burst lasting just one-tenth of a second, and shining 1000 times brighter than a nova, the true nature of a kilonova was only revealed a few years ago. Registering new optical flashes related to kilonovae is therefore of particular interest in this growing branch of astronomy.
- Detecting and observing these explosive events produced by relativistic stars (including supermassive black holes) and white dwarfs, will thus allow Russian scientists to increase knowledge in this fascinating area. In addition, MASTER III telescopes will help discover potentially dangerous asteroids about the size of the Chelyabinsk meteorite between five and seven days before they get to Earth.

Location, location

Given the success of the MASTER II system telescopes, MASTER III telescopes will be installed in the same locations. This is advantageous for many reasons, paricularly as the universities that are already equipped with the telescopes have scientific and technical staff at hand to service and work with robotic telescopes and to date, the current locations seem optimal in regards to the astro-climate.

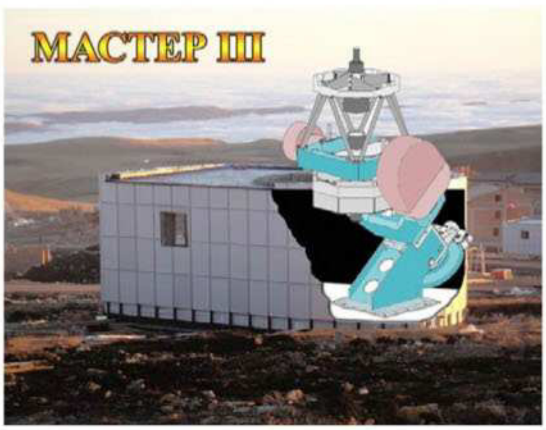
One of the elements of the future network is the fully robotic wide-field MASTER III complex which provides an autonomous imaging mode and image processing for finding new objects (both moving and not). An automated 'alert' work mode is also possible for externally set targets, including those from space observatories.

The MASTER projects are unique in Russia as there are no other fully robotic optical systems that could carry out fundamental and applied research simultaneously. The projects are also unique in the world because of Russia's physical location on the globe, as well as the unique mathematical software on which the project is based.

Observation experience and the discovery of potentially dangerous asteroids on MASTER II telescopes shows that the Russian network of MASTER III robotic telescopes will cover about 20 per cent of the world's longitudinal and temporal field of sky monitoring.

In addition, the network has incredible potential for development and cooperation with foreign-run observatories where MASTER II is located, for example, the Canary Astrophysical Institute Observatory (Tenerife, Spain), the 10 m SALT telescope observatory (Sutherland, South Africa) and the Felix Aguilar Observatory (Argentina) to name but a few.

With a projected timeline of around two and half years for financing and product launch, it is anticipated the first discoveries made with MASTER III will follow shortly afterwards and that within 10 years, objects in the farthest universe will be discovered. It is expected that the project will last for two decades, so who knows what else MASTER III might uncover? ■



◀ MASTER III - third generation anti-asteroid cosmological robotic 1 m diameter telescope with fully automated computer system and connectivity with space and emergency systems. Early warning time for asteroids like the Chelyabinsk one is about a week.

◀ NanoSail-D2 was a small satellite which was used by NASA to study the deployment of a solar sail in space. It was a three-unit CubeSat measuring 30 x 10 x 10 cm. The NanoSail-D2 was built by the NASA Ames Research Center and the solar sail was provided by the NASA Marshall Space Flight Center. The mission flew successfully in 2010.

Les Johnson
George C. Marshall Space Flight Center in Huntsville, Alabama, USA

New oceans beckon for solar sail technology

Solar sailing is finally becoming a reality. After many false starts, launch vehicle failures and funding cuts, NASA, The Planetary Society, ESA and JAXA have all flown solar sails in space and are planning ambitious new missions for the future. The promise of propellant-less propulsion offered by solar energy is becoming a reality.

As their name implies, solar sails 'sail' by reflecting sunlight from a large, lightweight reflective material that resembles the sails of 17th and 18th century ships and modern sloops. Instead of wind, the sail and the ship derive their thrust by reflecting solar photons.

It is a common misperception that solar sails use the solar wind for propulsion. This is incorrect. The solar wind is composed of atoms, typically hydrogen and helium, and their interaction with the solar sail produces no significant thrust. Photons have no rest mass but, thanks to quantum mechanics, they do have momentum. And, like any particle with momentum, they can impart some of it to an object that either absorbs or reflects them. Reflecting photons is preferable because it imparts approximately twice the momentum as absorption.

The physics of solar sail propulsion is relatively easy to understand. Newton's Second Law of Motion says that Force is equal to mass times acceleration. The force (F) of sunlight at a given distance from the Sun can therefore cause a spacecraft of mass (M) to accelerate with acceleration A, F = MxA, an equation familiar to introductory physics students everywhere.

> It is a common misperception that solar sails use the solar wind for propulsion - this is incorrect

While the force exerted by sunlight is extremely small, it's relatively constant, resulting in a slow but constant acceleration that pushes the sail, and the spacecraft attached to it, to higher and higher speeds. And it can do so without the use of any fuel.

This last point is hugely significant. Given that launching anything into space costs on the order US$7000 - 10,000 per pound, not having to carry fuel can result in significant cost savings. Not requiring fuel also means the spacecraft will not 'run out of gas' and can, in theory, continue operating as long as the Sun is 'shining'.

Solar sails have their limitations, of course, and they are not the best solution for all space missions. For one, they only work well near the Sun. Without sunlight, they have no way to produce thrust. And that's not all. The amount of sunlight, hence the thrust, varies as the inverse square of the distance.

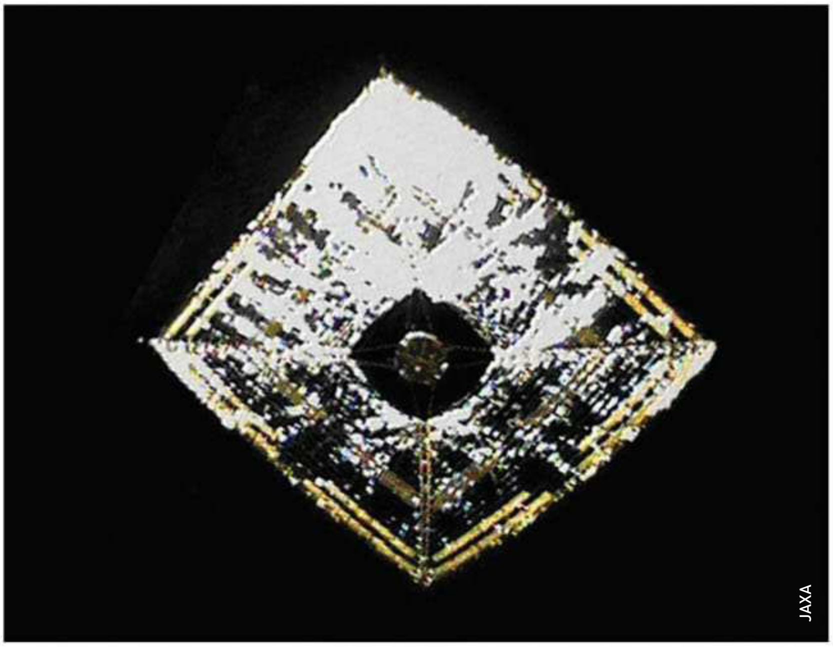
In other words, moving the sail from one Astronomical Unit (AU) [the Earth-to-Sun distance] to two AU's doesn't cut the thrust in half, it reduces it to a quarter of the original amount (one over two squared). Going to 3 AU's decreases the amount of propulsively useful sunlight to one ninth of the original. This can also work in our favour if, for example, a sail is deployed near Mercury, which is at 0.39 AU and will give you 2.5 times the thrust available at Earth.

Like a sailboat, a space sail-craft can use its sail to steer. If you tip or tilt the sail, you can change the angle by which the sunlight reflects from it, also changing the direction of the net force acting on the sail. Tip it one way so the net force is acting in the direction you are already moving and you will accelerate. Tip it the other way and decelerate. If you accelerate, you will slowly spiral away from the Sun; decelerate and you will move toward it.

This, taking into account the way the thrust changes as a function of distance [the inverse square law explained above], means it is actually easier for a sailcraft to use its sail to fly toward the Sun than it is to fly away from it!

If you tilt the sail so that the net force is acting perpendicular to the plane in which you are moving then your orbital inclination relative to the Sun will change. This capability is significant due to the equivalent propulsion system that would be required to achieve an inclination change propulsively - it would require so much fuel as to be impractical or impossible.

So, the creative people behind many interplanetary missions use planetary gravity assists, flying by large planets to steal some of their orbital energy, to change a spacecraft's orbital inclination around the Sun. This can add years to the duration of a space mission as well as increasing its cost and complexity. A solar sail can get the same result by flying closer to the Sun and tilting its sail to leave the ecliptic plane.



▲ Figure 1 - The Japanese Space Agency's IKAROS solar sail in flight.

Solar sail limitations

Before describing some of the exciting new solar sail missions that will soon be flying, we need to discuss their limitations. Other than needing to be in the proximity of the Sun in order to produce useful thrust, sails are limited in their applicability by the extremely low thrust they produce. For example, a sail with the area of two American football fields would produce the thrust equivalent of the weight of two coins held in the palm of your hand. Sails are, for now anyway, limited in their use to very small robotic spacecraft flying near the Sun.

Sails have flown successfully in space. In 2010, NASA launched its first Earth orbital solar sail, the NanoSail-D, a 10 square metre sail that deployed from a 3U CubeSat in low Earth orbit. [A CubeSat is a small spacecraft built from modular 10 cm x 10 cm x 10 cm cubes, each cube being 1U. A 3U CubeSat is built from three 1U modules.]

NanoSail-D was a simple deployment demonstration and served as a proof of concept for sail missions to follow. That same year,

Before committing a crew to visit a NEA or Mars moon, carrying out precursor robotic missions is important to assess candidate objects

NEA Scout will fly on the first flight of NASA's new rocket, the Space Launch System (SLS), in mid-2018

▼ Figure 2 - Artist concept drawing of the NASA Near Earth Asteroid Scout.

the Japanese Space Agency (JAXA) flew an approximately 200 square metre solar sail in deep space that successfully demonstrated deep space propulsion and navigation as it flew in the inner solar system near Venus (Figure 1). The Japanese mission was called IKAROS (Interplanetary Kite-craft Accelerated by Radiation Of the Sun).

In 2015, the private space advocacy group, The Planetary Society, flew in Earth orbit their own demonstrator, LightSail-A. This was a 3U CubeSat mission that deployed a 32 square metre sail similar to the NanoSail-D, only larger. The Planetary Society plans to fly LightSail-2 sometime in 2017 to demonstrate deployment and control of a sailcraft in Earth orbit.

NEA Scout

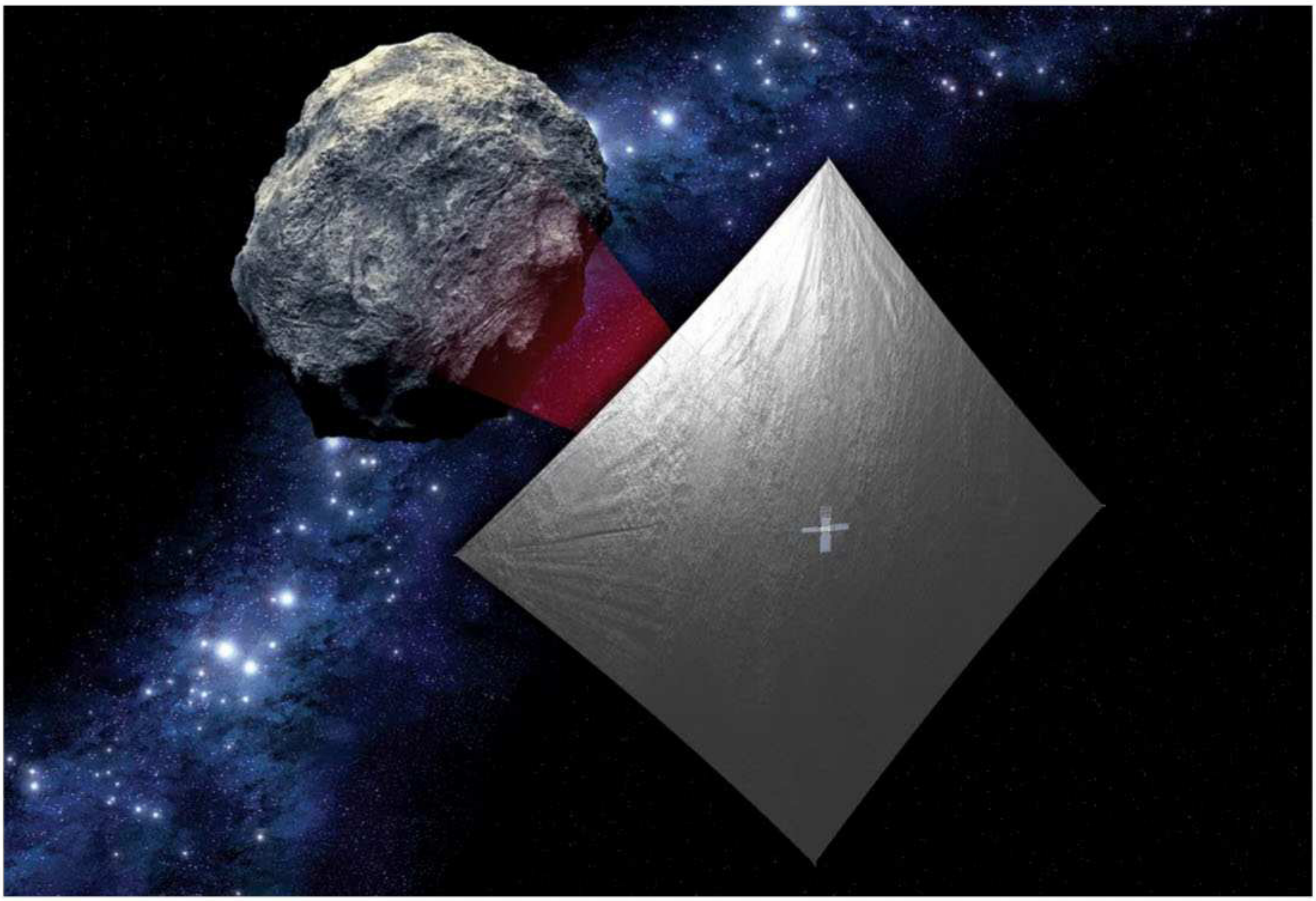
NASA is developing its own deep space solar sail mission called the Near Earth Asteroid Scout. NASA plans to send humans to a Near Earth Asteroid (NEA) in the early part of the next decade as part of a long-range plan to send humans to Mars orbit before attempting a human mission to the surface.

Before committing a crew to visit a NEA or Mars moon, carrying out precursor robotic missions is important to assess candidate objects adequately enough that crew systems appropriate for target environments can be developed. The NEA Scout, scheduled to launch in 2018, will use its solar sail propulsion system to send the spacecraft to flyby asteroid 1991VG and conduct reconnaissance of it (Figure 2).

NEA Scout will fly on the first flight of NASA's new rocket, the Space Launch System (SLS), in mid-2018 and deploy from it after the Orion crew capsule is separated from the upper stage and on its way to the Moon.

After NEA Scout's first lunar encounter, the 86 square metre solar sail will deploy, and the sail characterisation phase will begin. Once the system is checked out, the spacecraft will perform a series of lunar flybys until it achieves optimum departure trajectory to the target asteroid. The spacecraft will then begin its two year-long cruise.

About one month before the asteroid flyby, NEA Scout will pause to search for the target and



start its approach phase using a combination of radio tracking and optical navigation. The solar sail will provide continuous low thrust to enable a relatively slow flyby (10-20 m/s) of the target asteroid under lighting conditions favourable to geological imaging. The relative size of the NEA Scout spacecraft and solar sail can be seen in Figure 3. The sail is enormous!

The University of Surrey has also developed a 3U CubeSat sail, called InflateSail, which was scheduled to fly in late 2016 or early 2017.

NEA Scout is a collaborative project lead by the NASA Marshall Space Flight Center (MSFC) where the solar sail is being developed. The Jet Propulsion Laboratory (JPL) is building the spacecraft. The sail team is now building the flight sail and, as part of its development, conducted multiple sail deployments in the MSFC ground test facility. Figure 4 shows one such deployment, completed in August 2016.

The NEA Scout sail is made from a 2.5 micron-thick polyimide film coated with aluminium. The sail is unfurled using four, 7 m metallic booms that are deployed from two spools located in the central part of the spacecraft bus. The sail will be kept under tension to help minimise the effects of wrinkles in the sail material.

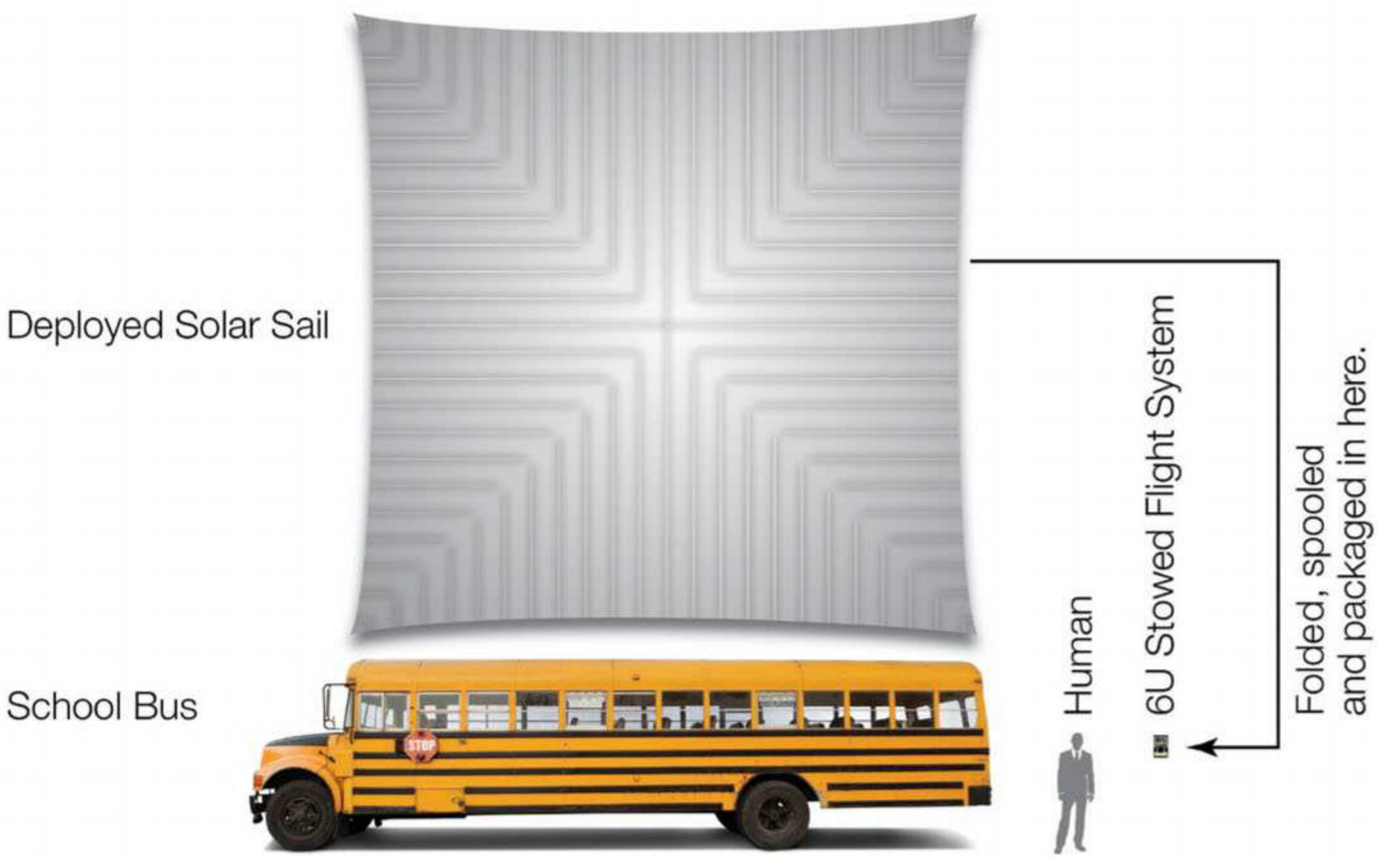
Future missions

Once the technology is sufficiently proven, there are several future missions possible - many of which are simply impossible to implement without the use of a solar sail. For example, the National Oceanic and Atmospheric Administration (NOAA) has expressed interest in placing a long-duration solar storm warning spacecraft closer to the Sun, yet always between the Earth and Sun, so as to enable rapid warning of an impending solar storm - potentially preserving some space satellites and ground infrastructure by allowing them to take action as the solar storm approaches Earth. The mission, notionally called 'Heliostorm', is enabled by a solar sail. The continuous thrust on the sail allows it to fly closer to the Sun near the Earth-Sun Lagrange region than is otherwise possible.

Taking advantage of the inclination-changing capability of solar sails, solar scientists have

A larger solar sail, deployed very close to the Sun, could send a spacecraft on a very rapid exit from the Solar System

▼ Figure 3 - The NEA Scout solar sail is the length of a school bus and will be folded to fit into a box 10 cm x 10 cm x 20 cm on a side.



proposed missions to encircle the Sun with multiple, solar-sail propelled spacecraft, each flying at a different inclination to more closely study the Sun than is possible from our Earthly vantage point.

A larger solar sail, deployed very close to the Sun, could send a spacecraft on a very rapid exit from the Solar System travelling three to five times faster than the Voyager spacecraft, allowing rapid scientific study of nearby interstellar space. The mission, called Interstellar Probe, has been studied for years and is of high interest to space science. The Voyager 1 spacecraft, launched in 1977, is now about 137 AU from Earth, taking nearly 40 years to get to this point. The interstellar Probe would reach this same distance in under 13 years.

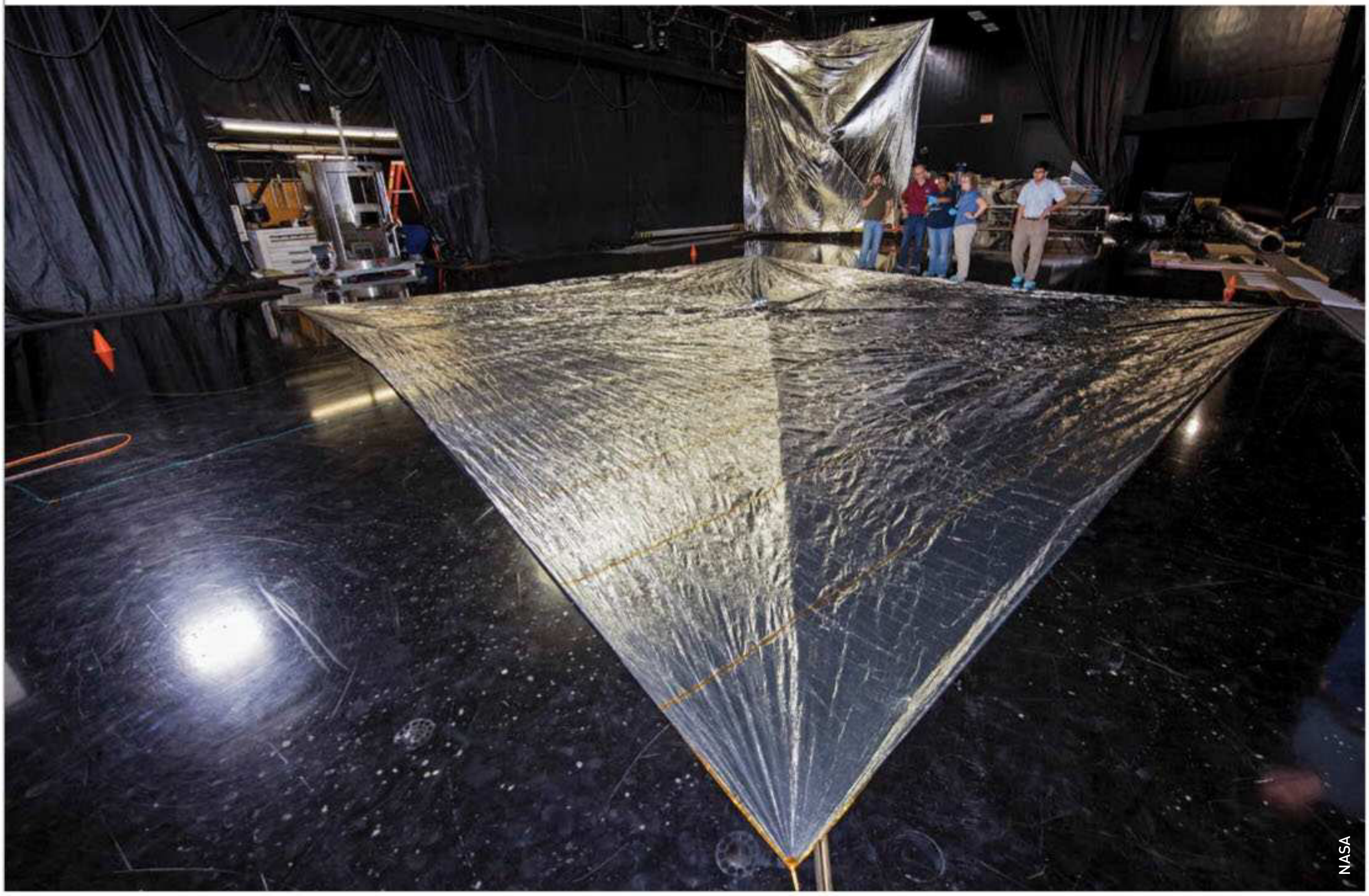
Finally, in the very far term, extremely large and lightweight solar sails, perhaps the size of Texas, could be deployed very close to the Sun and receive enough solar-induced thrust to reach the nearest star in under 1000 years. While this is still a very long travel time, it is far shorter than what can be provided with a conventional chemical rocket: 40,000 years!

The recently announced Breakthrough Starshot proposes to use a relatively small sail, on the order of a few square metres in area, illuminated by a high power laser (around 60 GW) to accelerate a 1 gram-scale spacecraft to a significant percentage of the speed of light as a means of sending multiple robotic probes to nearby stars in decades, not millennia. While just about every aspect of the Breakthrough Starshot is beyond today's engineering capabilities, it is nonetheless physically possible.

Solar sails are a technology whose time has come. NASA, private space groups and other governments are developing the technology for their next generation of scientific spacecraft and theorists are laying the groundwork for using them to take us to the stars. ■

About the author
Les Johnson is the Solar Sail Principal Investigator of the NASA Near Earth Asteroid (NEA) Scout solar sail mission. He serves as the Technical Assistant to the NASA Advanced Concepts Office at the George C. Marshall Space Flight Center in Huntsville, Alabama. He co-authored a book on solar sailing called *Solar Sails: A Novel Approach to Interplanetary Travel*. His latest novel, *On to the Asteroid*, was released by Baen books in August.

▼ Figure 4 - Members of the solar sail team inspect the fully-deployed NEA Scout solar sail (prototype) after a test at NASA's Marshall Space Flight Center. A half-scale solar sail is shown hanging in the background.



Mini space station for mice to study effects of reproduction in reduced gravity

◀ NASA astronaut Barry Wilmore setting up the Rodent Research-1 hardware in the Microgravity Science Glovebox aboard the International Space Station.

Dr Erica Rodgers,
NASA Langley Research Center, USA

Dr Matthew Simon,
NASA Langley Research Center, USA

There are many outstanding questions as to whether humans could survive as a species over multiple generations in another planetary environment. When it comes to Mars, perhaps the reduced gravity of the red planet could change human physiology or behaviour so as to prevent successful reproduction and development. If this is true, it might drastically reshape space exploration investments towards large, in-space, artificial gravity settlements which can replicate Earth gravity. While these considerations may seem far removed from near-term efforts to set foot on Mars, the historically long periods of use for space hardware suggest that potential alternate approaches should be studied early to prevent costly redirects should partial gravity prove untenable for settlement.

Short of landing on a planetary surface, artificial gravity offers the most practical platform to investigate long-duration partial gravity effects on human physiology. However, there is no current or planned partial gravity testing platform at the human scale.

An alternate approach using rodents as surrogates to study the effects of future exploration missions may be more feasible from a mass and volume perspective. A smaller, rodent-scale artificial gravity facility could serve to reduce risk for human-scale artificial gravity facilities and vehicles.

Rodent based mammalian development studies conducted in microgravity have been ongoing for around 35 years. Several research efforts used rodent analogues to study the effects of microgravity on rodent reproduction during short-duration (around two weeks) flight experiments aboard free flying satellites, the Space Shuttle, and the International Space Station (ISS). Longer duration (months and years) rodent analogue reproduction experiments aboard the ISS are currently ongoing, as well as planned for the future. Research has also been conducted on the ground in simulated microgravity laboratory settings where rotational devices lessen the effects of gravity on embryos or the hind limbs of rodents are elevated to mimic microgravity conditions.

Microgravity reporduction

Results from these flight and ground experiments identified potential microgravity reproduction challenges such as maternal-offspring system sensitivities to changes in gravity, mortality and feeding difficulties due to habitat design, reduced birth rate, and decreased oestrogen receptor levels.

These potential challenges require further studies to understand the relationship between time spent in microgravity and the extent of these potential effects on mammalian reproduction. These microgravity experiments focused on identifying challenges associated with specific portions of the mammalian lifecycle (breeding, birthing, nursing/weaning, and offspring development) and did not evaluate the comprehensive effects of microgravity on the life cycle as a whole.

Therefore, it is not well understood how these potential microgravity effects permeate through an entire mammalian life cycle, or change over time through multiple generations. For this reason, the Rodent Research-1 experiment recently flown aboard the ISS was the first experiment in a series of experiments designed to study the full mammalian life cycle in microgravity.

It is unknown how identified potential microgravity challenges carry over to partial gravity. Mars-like gravity (three-eighths Earth gravity) may mitigate some of these effects but may not be enough to enable successful reproduction and development.

▲ Astronaut Nicole Stott, Expedition 20/21 flight engineer, working with the Mice Drawer System (MDS) in the Kibo laboratory of the International Space Station.

Perhaps the reduced gravity of Mars could change human physiology or behaviour so as to prevent successful reproduction and development

Research conducted on the reproductive challenges mammals may encounter in partial gravity is the next step toward a comprehensive understanding of the mammalian life cycle in multiple gravity environments.

A partial gravity mammalian reproduction experiment using rodents as human analogues requires two things: 1) a long enough duration in which to study the full life cycle, and 2) a partial gravity environment in which to conduct the experiment. This type of platform would also be beneficial for testing synergistic human exploration systems requiring increased autonomy such as medical care and vehicle health management to achieve Mars missions.

A study was conducted at NASA Langley Research Center to design a conceptual, long-duration, autonomous habitat to house mice in an artificial partial gravity environment. This study, the Multigenerational Independent Colony for Extraterrestrial Habitation, Autonomy and Behavior (MICEHAB), investigated the challenges associated with partial gravity mammalian reproduction.

The goal of MICEHAB was to design a mission concept and facility to: 1) test biological responses to partial gravity with an emphasis on reproduction and 2) demonstrate vehicle subsystem performance and operations required for human exploration. MICEHAB is unique because its concept addresses the combined effects of long duration, partial gravity, and autonomous/robotic operations simultaneously.

MICEHAB elements

There are four elements which make up the MICEHAB vehicle: a habitat housing the rodents, a service module providing power and propulsive control of the vehicle, an extendable boom/tether connecting the service module and habitat that enables artificial gravity, and a free-flying communications asset that provides accurate communications transmission/reception from Earth.

The vehicle would nominally launch as a co-manifested payload on the NASA Space Launch System (SLS) to a lunar distant retrograde orbit, a stable lunar orbit where the service module would place the spacecraft into the desired orbit.

Once in orbit, a free-flying communications relay would separate from MICEHAB to be inserted in the same orbit trailing the MICEHAB vehicle. The remaining vehicle would then deploy using a coilable boom attached to the service module at one end, and the habitat at the other end.

With solar array panels placed at a node at the centre of mass, the entire facility would spin up using reaction control system jets attached to the service module and the habitat spacecraft. The rotation would induce a Mars-like partial gravity with a spin rate analogous to acceptable limits for humans. The facility would spin with its solar panels continuously facing the Sun to generate the power required to keep the habitat operational.

During operation, the vehicle would house a large colony of up to 200 mice in individual mouse enclosures designed for both microgravity and partial gravity environments. The interior consists of multiple cylindrical levels housing these enclosures along its circumference. These enclosures could be removed from the main cylindrical structure for cleaning and maintenance.

MICEHAB would use robotic systems to provide for all of the physiological needs of the mice including feeding, cleaning, life support, waste removal, and medical care.

Tunnel access between the enclosures would be controlled remotely by veterinarians on Earth following established breeding guidelines. Mice could be selectively bred to create generations which have only lived in partial gravity while preventing overbreeding. Physiological measurements could then be used to understand the effects of partial gravity when compared to Earth gravity and microgravity controls.

After each year of operation, the vehicle would spin down and the boom would retract both the habitat and the service module back toward the centre of mass. The semi-stowed vehicle would then transfer to the planned lunar orbit human habitat and dock, allowing the MICEHAB central robot to transfer samples to a caretaker robot aboard the human habitat during human occupation of the vehicle.

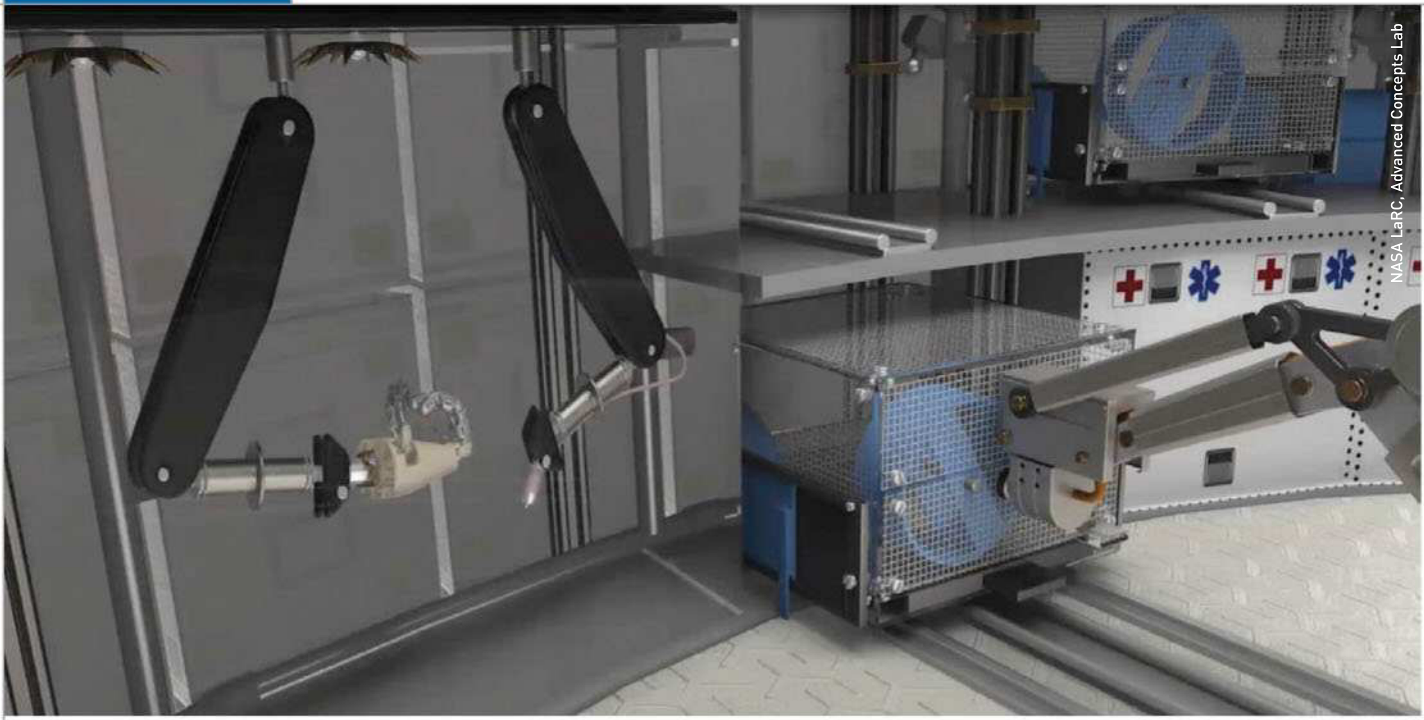
The yearly rendezvous with the lunar habitat would coincide with planned human missions in order for the MICEHAB samples to be loaded onto the Orion capsule for Earth return with the crew. Maintenance on the MICEHAB would also be performed if required while docked.

Additionally, logistics for habitat maintenance or animal care would be transferred from the human habitat to the MICEHAB during this time.

Versatile and reliable robotic systems are necessary to transport enclosures, handle mice delicately and perform medical checkups

▼ Individual mouse enclosure aboard MICEHAB designed for delivery of water and food, exercise, and nesting. Supports waste removal, ventilation, lighting, and cameras for health and science observations.

Giselle Payan/NASA LaRC



▲ Robotic capabilities inside of MICEHAB. Versatile and reliable robotic systems are necessary to transport enclosures, handle mice delicately, and perform medical checkups.

The MICEHAB vehicle would then undock and return to its orbit location, which trails the human habitat in a similar orbit. Once back to its original location, the MICEHAB facility would redeploy and resume its rotation and partial gravity operations.

The yearly transfer to the initial lunar habitat would continue for 10 years allowing for 12 full cycle experiments each based on a 300 day mission duration. Three generations of mice will be bred during each cycle.

The first generation of mice entirely bred in partial gravity will be established at the end of the first cycle. Analyses of relative physiology and behaviour changes over each subsequent mission duration (experiment cycle 2-12) will identify potential long-term reproduction effects of multiple generations living in partial gravity. This knowledge will be used to formulate hypotheses on how potential partial gravity effects may permeate through an entire mammalian life cycle, or change over time through multiple generations.

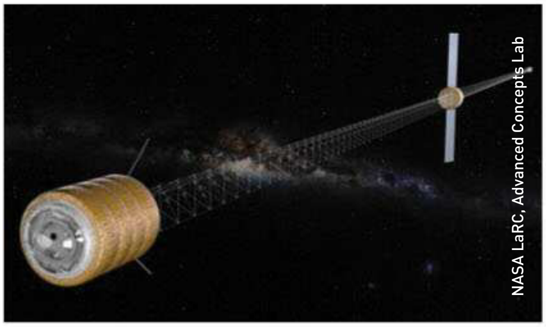
Mission design

Preliminary sizing estimates of the four described MICEHAB elements were used to perform a feasibility analysis demonstrating the viability of the concept. These sizing estimates provide the opportunity to calculate element masses based on the current mission concept design.

The element masses totalled 11 metric tons, while the SLS co-manifested cargo mass capability is 10 metric tons. Refined element masses based on additional trade studies and integrated systems sensitivity analysis will likely lead to a design that meets the 10 metric ton limit. Therefore, it is assumed that the current architecture is reasonable for the initial MICEHAB conceptual design.

There were several challenges identified in the design of the MICEHAB mission and vehicle that should be addressed in any autonomous biological research facility. First, the MICEHAB vehicle requires high data rate, mostly continuous communications to allow for video monitoring of all enclosures in both visual and infrared spectra.

Several technologies are available for enabling high data rate communications but these typically require utilization of transmission systems requiring accurate point control such as laser based communications. This need for high accuracy pointing is hard to achieve from a spinning facility. Therefore, a free-flying communications asset utilizing optical communications was chosen because a separate, non-spinning, communications relay, maximises the communication capability of the MICEHAB which is critical to its science mission.



▶ A conceptual, artificial partial gravity facility where rodents are used as surrogates to study the effects of future human exploration missions.

Robotic care-taking of the mice and vehicle also presented a technological challenge. Versatile and reliable robotic systems are necessary to transport enclosures, handle mice delicately, and perform medical checkups.

Designing such systems with appropriate autonomy architectures are integral to the overall design of the habitat and enclosures and should therefore be designed in parallel. Additionally, robotic operations in both microgravity and partial gravity places additional requirements on end effectors and enclosure design. All lessons learned and advances in robotic system designs feed forward into human exploration system designs.

Finally, there were several lessons learned from the challenge of achieving artificial gravity in mass constrained mission architectures. Rotation rates and radii of rotation must be set to avoid neuro-vestibular and sensorimotor issues often associated with artificial gravity (i.e., Coriolis effect).

However, large artificial gravity systems are often untenable for long duration missions with limited launches. Therefore, strategies to reduce the mass of artificial gravity systems were investigated, such as utilizing lightweight tether/boom concepts and strategically placing the center of mass to reduce overall tether/boom length. Additionally, the challenge of controlling a spinning spacecraft with complex dynamics led the study to consider more rigid boom structures which are re-deployable (i.e., which can be retracted to allow for easier control of the vehicle without large vibrational loads).

Future human exploration missions require the development of capabilities to live independently from Earth. This requires an improved understanding of how the human body reacts to different environments and the development of capabilities to live autonomously. MICEHAB would demonstrate both of these facets of human exploration.

Regardless of whether there is conclusive proof of partial gravity effects over multiple generations, it is important to test the combined effects of partial gravity and long duration on human physiology prior to sustained planetary surface missions.

We suggest consideration should be given to a partial gravity biological research platform in the vicinity of Earth to understand the long term effects of various gravities on multiple organisms to forge a sustainable path for future missions.

This platform could also be used to better understand the potential benefits of artificial gravity for long duration interplanetary transits, particularly in light of astronaut Scott Kelly's description of the potential hardships of long duration microgravity exposure following his One Year in Space mission.

Additional studies should be performed to understand the utilization of similar facilities to achieve other biological science purposes such as a deep space radiation testing and to accommodate other organisms, tissues and plant growth studies. ■

▲ MICEHAB will pave the way for the future human settlement of Mars.

The vehicle would house a large colony of up to 200 mice in individual mouse enclosures

About the authors

Dr Erica Rodgers is an aerospace engineer at NASA Langley Research Center where she evaluates capabilities and system maturation for integration into human spaceflight exploration architectures. She has 10 years of experience in designing and fabricating satellite and rocket instrumentation, and 20 years of combined experience in space physics and astrophysics science research.

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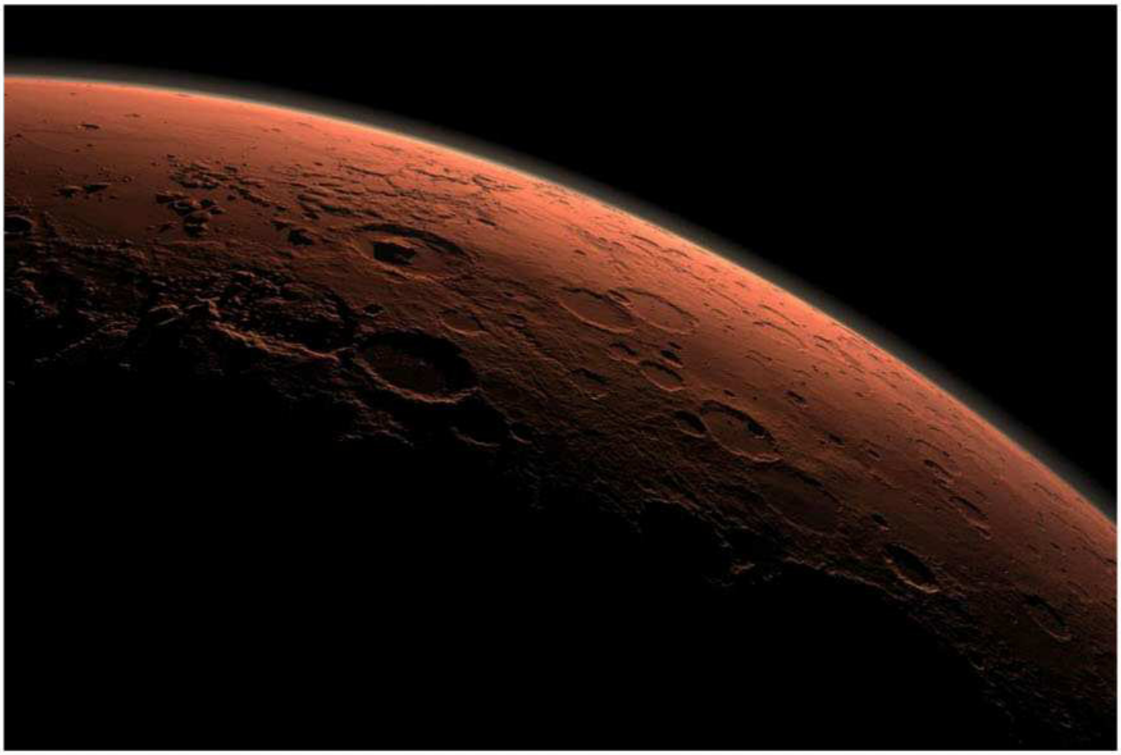

Growing plastic-producing bacteria in space

NASA plans to put humans on Mars in the near future but many obstacles lie ahead. At the University of Copenhagen an interdisciplinary team of students have taken on the task to support one aspect of future Martian settlement in project called CosmoCrops. The ultimate goal of the project is achieving self-sufficiency on future space missions by designing a flexible bioreactor with a plug-and-play system that allows onsite production of bioplastic for 3D printing, pharmaceutical compounds and nutrition supplements.

Throughout time the human race has displayed a strong desire to explore and conquer new lands and in modern times a completely new frontier has opened up - space. But space exploration is limited by very high cost and extreme risk. Experience in low Earth orbit (LEO) and on a handful of manned flights to the Moon have taught us that future long-duration missions will face exponentially difficult challenges associated with transportation, working in space and staying healthy.

To support one astronaut for one year in Earth orbit requires around 8000 kg of supplies, excluding fuel. With a current absolute minimum estimated price of US$6600 per kg sent to Mars it is obviously necessary to reduce the weight requirement of supplies and consumables.

With the prospect of crewed missions to the red planet and the resulting increase in mission distance and duration, shipping consumables from Earth or sending frequent resupply missions - as is currently the case for the International Space Station (ISS) - will be prohibitively expensive and probably impractical too.

Current scientific efforts are therefore being directed towards increasing self-sufficiency and thereby Earth independence in order to make long-term space missions such as NASA's 'Journey to Mars' both possible and practical.

This is where 'synthetic biology' could provide valuable solutions by supporting the design of metabolically engineered organisms that can produce components for astronaut survival. Such an engineered design may help solve the problem of weight and cost by on-site production of nutrients, medicine or equipment for use in the spaceship or on a planetary base.

An interdisciplinary team of students from the University of Copenhagen in Denmark have taken on this challenge in project CosmoCrops. Inspired by a project in 2015 called SpaceMoss, which genetically engineered moss to survive the harsh temperatures on Mars, the 2016 team decided to work with single celled organisms like bacteria.

Bacteria are often used in synthetic biology, partly because most natural environments harbour a diverse collection of bacterial species with unique capabilities. Crucially they were the very first organisms that dominated the early life on planet Earth.

CosmoCrops involves bachelor and master students from different fields of science, including computer science, physics, biotechnology and mathematics. Strong links between the different interdisciplinary areas has allowed the team to push the boundaries of each discipline at the same time as creating an inspirational environment for innovative science.

▲ Matt Damon growing crops on Mars in *The Martian*.

Synthetic Biology for space travel

The essential question is, how can biotechnology support and benefit future space missions? Carbon dioxide (CO_2) is exhaled by humans

It is important to make the bacteria 'familiar' with Martian conditions and make them adaptable

◀ First trial of B. Subtilis Co-culture with dialysis bag.

Strong links between the different interdisciplinary areas have allowed the team to push the boundaries of each discipline

while breathing and 92 per cent of the Martian atmosphere consists of CO_2.

The starting point for the CosmoCrops concept was therefore to design a biological system that uses the abundant CO_2 and naturally available sunlight to produce essential bio products, which has been achieved by creating a modular platform that enables production of bioplastic material for 3D printing.

CosmoCrops has created a self-sustainable bio production by using a modular co-culture system; a biological system that consists of two different bacterial organisms able to support, survive and grow together while exchanging nutrients.

In the designed biological system, a photosynthetic cyanobacterium, which uses CO_2 as a carbon source and sunlight for energy, produces sugar for another organism: the bacterium Bacillus Subtilis. The B. subtilis bacterium is then metabolically engineered to supply bioplastic PLA (Poly Lactic Acid) for 3D printing.

The two bacterial organisms are mechanically separated but are still able to exchange nutrients. This gives the opportunity of a plug-and-play mechanism where it is possible to interchange different subsets of manipulated B. subtilis organism in order to produce different compounds. Essentially it would be possible to change between production of bioplastic, chemicals, medicine etc depending on the exact need.

One advantage of B. subtilis is that its spores are an inactive form of the bacteria and can survive for several years without nutrients. This means that astronauts would have the possibility to store a variety of compound producing spores for an extended period of time when they were not needed.

Creativity on how ISS would look from a bacterial perspective, Bacillus Subtilis hosting.

CosmoCrops team members (from left): Joseph Parker, Thue Nikolajsen, Bastian Bakkensen, Charlie S Corde, Nikolaj P Christensen, Fouiza Hamid, Joachim S Larsen, Iris Madsen and Stael Naseri.

The essential question is, how can biotechnology support and benefit future space missions?

More than just biology

On a mission to Mars, astronauts will experience reduced gravity and their spacecraft drastic external temperature fluctuations, low pressure and exposure to UV radiation.

If a biological system for bio production is used for future Mars colonization, it is important therefore to make the bacteria 'familiar' with Martian conditions and make them adaptable.

For this reason, the Jens Martin Mars Chamber (JMMC) - located in the physics department at the University of Copenhagen - has been used to simulate temperature fluctuations, UV exposure and the low pressure found on Mars.

To highlight that the culture is a living thing, the team named their co-culture 'Ginny' after the old Nordic mythology concept of space 'Ginnungagap' (the bottomless abyss that existed prior to the beginning of the cosmos and into which the cosmos will collapse once again).

The long term goal is to create a 'survivor' bacteria that can not only withstand the hazardous Mars conditions but also still produce bio products. Prolonged exposure to the hazardous condition of the chamber will ultimately most likely result in natural mutation of the bacteria in order to adapt to the extreme environment.

By combining the different areas of natural sciences the CosmoCrops project is building a bridge between basic research and applied science. The project is not only an inspirational project that lays the base for further research and innovation in regards to space exploration but it can also be instantly and directly applied to solve problems on Earth. ■

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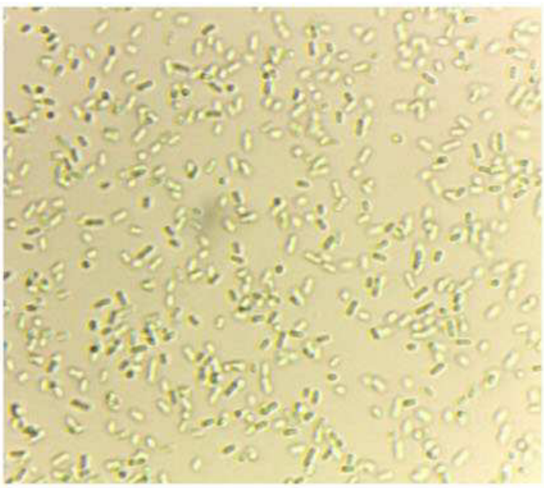
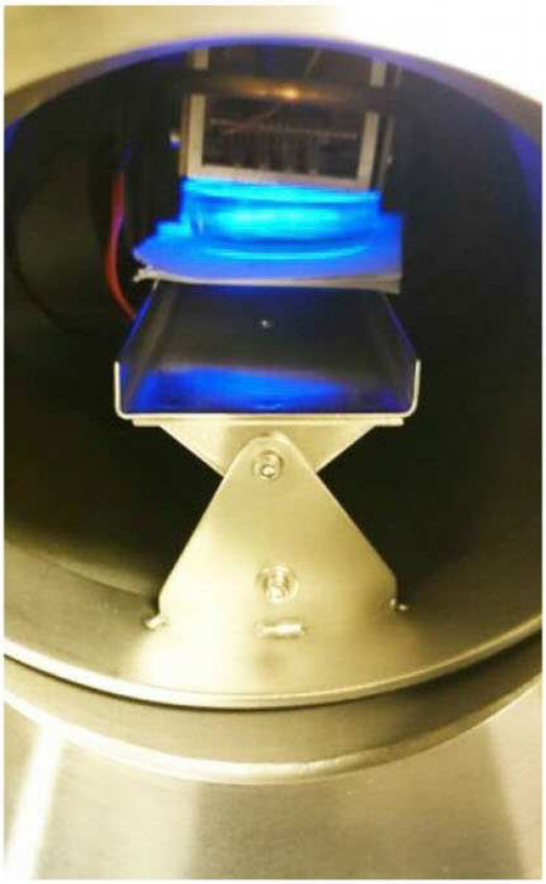




◀ Plate with Cyanoacteria (top left) after exposure to Martian stimulated UV; Cyano plate during the exposure to UV (right) and the microscopy of Cyanobacteria demonstrating the altered morphology due to the exposure (bottom left).

Creating a space nation

On 12 October 2016 project leader and founder Igor Ashurbeyli announced plans to create the new space nation – Asgardia, named after the Norse city in the sky that was home to the ancient mythical gods. The world's media was captivated by the drama and excitement of a space nation and what that might mean for mankind, and the story was enthusiastically reported, albeit with varying degrees of accuracy and understanding. Here, for readers of *ROOM* is a complete transcript of Dr Ashurbeyli's presentation.

▲ Asgardia plans a network of satellites, the first to be launched in late 2017.

Dear journalists, guests and colleagues who have come to show your support. Ladies and gentlemen. Thank you everyone for coming. I'll start by saying that I wouldn't be surprised if today or tomorrow, some or all of you write that some crazy Russian rocket scientist talked utter nonsense here today. It would be worse if you write nothing at all!

For my entire life I have always gone against the grain, which is why some people told me from time to time that I have crazy ideas. The very first time I was labelled crazy was in 1988, when I was a successful young scientist at a state university. I read Gorbachev's decree that allowed private business in the USSR for the first time in its history, and started my 'Socium" company.

Back in my home town of Baku, Azerbaijan, everyone knew my very old family, who lost everything they had owned during the Stalin era. But I took my wife and small son to Moscow, where I didn't know a soul, in order to start a private computer technology business from

▲ Igor Ashurbeyli and colleagues during Paris press confernce.

scratch. Everyone told me I was crazy, that it's safer to work for the government and that no one would let a private company flourish in the USSR.

The second time was in 1994, I was already a successful businessman. Government enterprises, however, were in quite a disastrous state after the fall of the Soviet Union. Suddenly I accepted the offer of a government position at one of the oldest and most famous defence companies in Russia in the air and space industry. It was in a desperate state. And again, I was told I was crazy. My wife's parents were living in Israel by then, my own father in Paris. He is now 80 years old. Despite having relatives abroad, I got the highest level of security clearance and for ten years I was the CEO of Almaz, the world-renowned company that designed the C-300 and C-400 aerospace defence systems.

The third time occurred in 2011. I had transformed Almaz into a highly reputable state company with multiple domestic and foreign customers. During that time, private business in Russia was under severe pressure and the state sector received a lot of government support. But I took another crazy step and returned to my private business.

And now, in 2016, I have a profitable high-tech private holding company "Socium" that has been around for 28 years, with almost nine thousand employees in 30 companies in six towns around Russia.

And again, for the fourth time in my life, I am doing something extraordinary that could cost me dear and destroy my reputation as a conservative engineer and businessman.

Now, we have decided to create the first ever space nation – this is a global, unifying and humanitarian project. So let's talk about that. The project's concept comprises three parts – philosophical, legal and scientific/technological. And it's hard to say which of these is more important.

The essence of Asgardia is 'peace in space', and the prevention of Earth's conflicts being transferred into space

One giant leap

Entrepreneur and scientist Igor Ashurbeyli has taken calculated risks with his career in the past but his announcement on 12 October at a high profile press conference in Paris could easily have destroyed his reputation as a conservative engineer and businessman.

As space experts and representatives of the international media waited curiously together or connected remotely from around the world, Dr Ashurbeyli stepped forward to present a truly 'out of this world' proposal.

Dr Ashurbeyli announced that together with an international group of researchers, engineers, lawyers and entrepreneurs he was creating the first ever space nation - to be named 'Asgardia', after the city of the skies ruled over by Odin in Norse mythology.

The independent nation of Asgardia is a global, unifying and humanitarian project aimed at fostering peace, providing access for all nations to space technologies, products and services, and protecting Earth from threats that may come from space.

The essence of Asgardia, Dr Ashurbeyli said, is peace in space and the prevention of Earth's conflicts being transferred into space. New space law will protect the interests of everyone and provide opportunities for every nation, not only those that already have active space programmes and commercial interests in space.

Asgardia's first satellite is planned for launch in late 2017 to coincide with the 60th anniversary of the launch of the first artificial Earth satellite, Sputnik 1. Looking further ahead, a protective space platform is ultimately intended to defend Earth from space threats.

Before taking questions from the press, Dr Ashurbeyli announced the launch of the nation's website 'asgardia.space', inviting members of the public to learn more about Asgardia and to apply for citizenship of the new nation.

Dr Ashurbeyli began his speech saying he wouldn't be surprised if many wrote that "some crazy Russian rocket scientist talked utter nonsense here today," but added, "it would be worse if you write nothing at all!"

In reality, the story of Asgardia was picked up by international newspapers, TV, radio, online and social media resulting in 400 plus articles across 37 countries around the world. Experts and members of the press hailed Asgardia as 'bold' and 'an exciting development'.

Asgardia is developing its own constitution, government and council and will seek United Nations recognition. Already, prospective Asgardians have been invited to design the nation's flag, insignia, anthem and motto.

It may seem like the stuff of science fiction, but humans really are taking the first steps towards building a nation in space. And as Dr Ashurbeyli said at the press conference: "It is the realisation of man's eternal dream to leave his cradle on Earth and expand into the Universe."

Janis Hunt, Editor at *ROOM*

It is the realisation of man's eternal dream to leave his cradle on Earth and expand into the Universe

Philosophy

The project's philosophy starts at selecting the name for this new country – Asgardia. In ancient Norse mythology, Asgard was a city in the skies, the country of the Gods. It is the realisation of man's eternal dream to leave his cradle on Earth and expand into the Universe.

Asgardia is a fully-fledged and independent nation, and a future member of the United Nations - with all the attributes this status entails: a government and embassies, a flag, a national anthem and insignia, and so on.

The essence of Asgardia is 'peace in space', and the prevention of Earth's conflicts being transferred into space. Asgardia is also unique from a philosophical aspect – to serve entire humanity and each and everyone, regardless of his or her personal welfare and the prosperity of the country where they happened to be born.

Asgardia's philosophical envelope is to 'digitalise' the Noosphere, creating a mirror of humanity in space but without Earthly division into states, religions and nations. In Asgardia we are all just Earthlings!

Legalities

Asgardia's legal aspects. Today, many of the problems relating to space law are unresolved and may never be solved in the complex and contradictory dark woods of modern international law. Geopolitical squabbles have a great influence, and are often rooted in the old military history and unresolvable conflicts of countries on Earth. It is time to create a new judicial reality in space.

It is of crucial importance that space law does not become the law of the jungle. Today, only 20 countries on Earth out of about 200 have a space presence, and have, for example, plans to mine in space and lay claim to exclusivity and monopoly. We feel that this is not permissible. New space law has to equally protect the interests of every human being on Earth.

It means protecting individuals and countries (particularly developing nations) from space threats as well as delivering the benefits of using space for creating new goods and services, and financial resources.

The question of Asgardia citizenship is also essential. After Asgardia is recognised as a member of the UN, the question of reasons for granting citizenship will inevitably arise. One opinion is that the first Asgardians will be those who work in the fields of space research and exploration, and space technology, as well as investors in these fields, including small investors.

Of course, special preference will be given to the first hundred thousand people who apply prior to the launch of the first satellite - and all the typical citizenship procedures that are used on Earth will be followed. This does not mean Asgardian citizenship will not be available to all people on Earth, regardless of their earthly jurisdiction.

A core legal principle is that Asgardia does not interfere in relations between states on Earth – and vice versa. Asgardia's legal envelope includes the creation of a new legal platform for the exploration of near-Earth and deep space. 'Universal space law' and 'astropolitics' have to replace international space law and geopolitics.

Scientific and technological

This component can be explained in just three words: peace, access and protection. These are the three most important scientific and technological goals of Asgardia.

▼ Chatting, comment and questions from attendees and international press at Asgardia's official launch in Paris during October.

The first is to ensure the peaceful use of space. The second is to protect planet Earth from space threats. There are seven threats in our classification system: sun storms and flares, known as coronal mass ejections; changes in Earth's magnetosphere that destroy the effective protective layer of our planet; potentially dangerous asteroids and comets; man-made orbital debris; changes in the climate stemming from technogenic factors and sun radiation; cosmic radiation from nuclear reactions in novae, supernovae and pulsars; and the danger of Earth infection by microorganisms from meteors and other small celestial bodies.

The third goal is to create a demilitarised and free scientific base of knowledge in space. This will provide free access to all, especially those from developing countries who do not have space access now. And such access should be free and direct.

We see Asgardia's technical structure in three segments: one or several core satellites; clusters of network-centric small satellites; and a protective space platform.

We are not going to talk about technical aspects and details today. It is not because we have nothing to say. It is because we want the widest participation in this open project – participation from all interested scientists and companies, without limiting them by our own vision of the technological side of things at the moment.

The scientific and technological envelope of Asgardia is a space arena for the scientific creativity of its citizens and companies in developing a broad range of future space technologies, products and services for humanity on Earth and humanity in Space.

Therefore, Asgardia is a sort of a matryoshka - made of philosophy, law and technology. Whatever else is hidden inside is something we will discover in the near future.

Economics

I would now like to say a few words on economics. The thing is, we are not selling pieces of land on the Moon or water in Antarctica. We're actually not selling anything at all at the moment. Only after we have proven this idea with a confirmed launch of an equipped satellite may we begin talking about Asgardia's budgets.

Right now, work on the project is funded entirely from our personal private funds. It's a clear-cut decision. We have now declared our concept and philosophy publicly and would like as many people as possible on the planet to find out about it.

And of course we are going to make use of crowd funding and sourcing, and private donations. And we welcome cooperation with new partners and investors.

Asgardia's technical, legal and philosophical team is in the process of being set up. Is it pioneering, futuristic and visionary - or madness? Call it what you will, and time will tell.

To sum up, I would like to announce that in a few minutes Asgardia's website beta version will be launched – Asgardia.space. It will accept preliminary applications for Asgardian citizenship. After the first 100 thousand applications have been received applications will be closed until the first Asgardia satellite is launched. We await you – the first potential citizens and volunteers of the first space nation! ■

Scientific and technological components of the project can be explained in just three words - peace, access and protection


James Vaughan

The making of a nation

The creation of a new country is, unsurprisingly, not a simple process. And in the case of a space nation many of the decisions that need to be made may never have been considered before. Posted on the Asgardia website just a month after announcing the creation of Asgardia, this is Igor Ashurbeyli's personal message to new and future citizens, informing them that work has begun and that their participation is crucial in establishing and developing the nascent nation.

▲ Igor Ashurbeyli, President of the Expert Society on Space Threat Defense, Founder of AIRC and founding father of Asgardia, announces the creation of the first space nation.

Greetings to over half a million Earthlings from over 100 Earth countries who have joined Asgardia!

1. One month has passed since 12 October 2016 when I announced the creation of the first space nation - Asgardia. We thought that the first 100,000 future Asgardians would register by the end of 2016 but we reached that number within the first 40 hours! And over 500,000 registered during the first 20 days; so today I want to say to all of you, THANK YOU!

2. At midnight on 31 October 2016 registrations were frozen and it was then time to start the second stage - verifying registrations to make sure they are unique; there are no bots, underage minors without permission, etc. For us to do this, you will be asked to create a personal profile. Those who confirm their identity will get a certificate with their unique Asgardian number and a symbol of Asgardia.

3. It is also time to vote for the Declaration of Unity of Asgardia, which will declare the core values of

Amazing Asgardians

With over one hundred thousand applications in less than two days, and more than half a million in under three weeks Asgardia took off at a truly cosmic speed.

With applicants from pretty much every country in the world today the Asgardian community is actively discussing on-line its future Constitution and Government structure, developing ideas for national symbols and attributes and brainstorming technical issues.

But most importantly it is forming a civil society which could become a prototype of the future of humankind. The community motivation and self-organisation is an inspiring example of how large groups can work together to achieve complex goals and take initiative in shaping their own future.

Rebekah Berg, Asgardia Lead Community Administrator and Guy Stroobants, Lead Chapter Administrator, are both very encouraged with the response.

"Some amazing Asgardians, like 'Nikari' Steve Miller and Cheyenne Voss from the United States, and Alex Fiume from Italy have stepped up and offered their time to help get things organised in collaboration with the lead administration team," said Rebekah.

"Others include the incredible administrators and moderators of the various groups and Chapter pages like Oriane Kaesmann of France in the law group, American Ryan Steel Zohar from the US on the artistic side of Asgardia, Jason Rainbow in the National Chapter of Puerto-Rico and Dominic Sturt in the National Chapter of New Zealand.

"Almost 100 talented folk are working together as chapter heads, group administrators and moderators, translators, writers and other important roles to help the community remain healthy with vibrant, civil discussions."

Lena De Winne
NGO Asgardia, President

▼ Hundreds of designs have been submitted for the Asgardia flag competition.

Asgardia and will become the basis for the preparation and ratification of the Asgardian Constitution.

4. Simultaneously, I would like to ask you to confirm my temporary authority as the Head of Asgardia, so that I can represent the Asgardian nation in talks with Earth countries and the United Nations (UN) in order to have Asgardia gain recognition as a full independent state and a UN membership.

5. A temporary government will immediately be formed, whose three main tasks will be to get Asgardia recognised as a nation, to hold elections in Asgardia and to launch the first Asgardian satellite.

6. After elections in 2017, Asgardia will have its own parliament, government and council at three levels: state-wide, continental, and regional chapters. Their main functions and powers will be determined after an all-nation discussion.

7. A contest for designing and choosing the Asgardian flag is in progress, and voting is already on-going. I ask you also to participate in the other contests on the Asgardian motto, salutation, etc.

8. A forum will be opened on Asgardia.space in the near future. I invite everyone to use it as a discussion space for all of the issues listed above and more, and for all questions concerning the development of Asgardia. I thank all of the volunteers for their initiative and excellent work - all the administrators and moderators of our existing team, and I invite new volunteers to join us.

9. Asgardia needs its own mass media outlets, the first of which will be an electronic newspaper in a completely new format that has never been used before. Follow the development of our interactive newspaper and please, participate!

10. There are currently thousands of letters and questions in the Asgardia email accounts that we have not physically been able to answer. All of them will be checked and sorted by the end of the

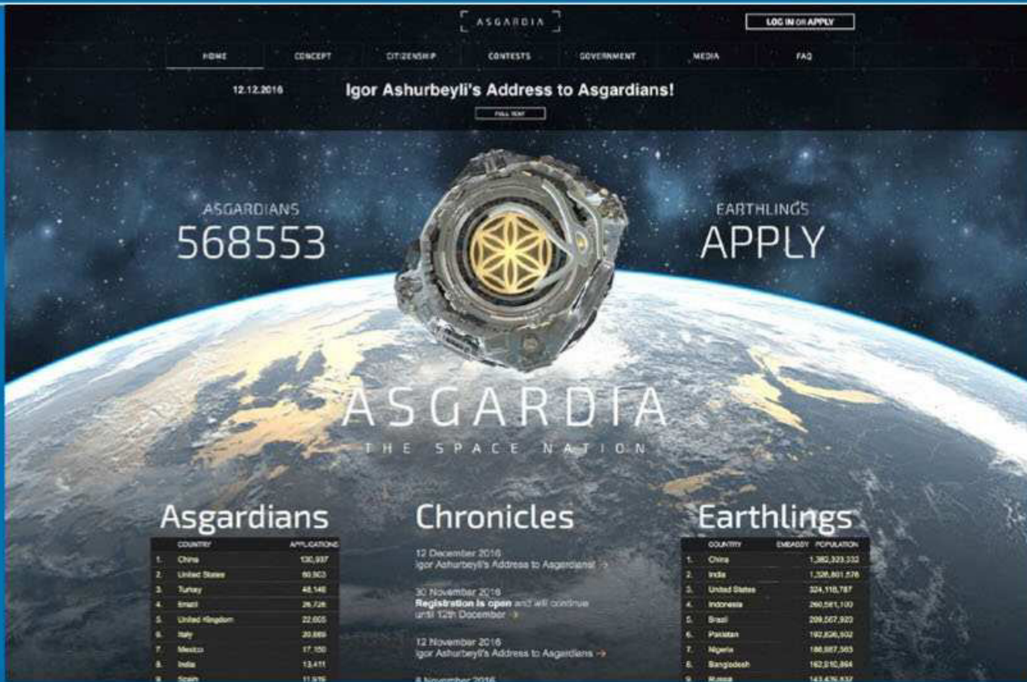
Asgardia has expanded at space velocity – just like a space nation should. Let's keep that dynamic going!

Joining up

Applications for Asgardian citizenship were expected to reach around 100,000 by the end of 2016 and the original intention was to close applications at that point until the first Asgardia satellite is launched.

But such was the massive level of response that this target had been reached within 40 hours of launching the website. When applications closed on 31 October the number of future Asgardians stood at more than half a million. The top five countries for applications currently are China, USA, Turkey, Brazil and UK.

Once logistics were sorted a decision was then taken to continue taking applications. Now anyone can register for Asgardian citizenship by completing an application form found on the asgardia space website.



year. Answers to the most common questions will be posted in the Asgardia.space FAQ section. I will answer non-standard questions and offers myself personally in my new blog on asgardia.space, which will become available in the next few weeks.

11. During its very short history, Asgardia has already suffered from several attacks - cyber-attacks as well as attacks on its reputation. There have also been cases of pressure, threats and blackmail attempts on our telephone lines and social media. I am declaring that Asgardia is a peaceful nation, but a strong one. We will protect planet Earth from space threats, but we will also not compromise in protecting Asgardia and our citizens to the fullest.

12. The 2017 Asgardia budget will be made public in December. In order to fulfill our budget, we will open a second, commercial website – Asgardia.com. We are happy to discuss your offers and ideas for generating revenue for Asgardia, both through business projects and through charitable projects.

In closing, I would like to remind you that we are continuing to accept applications for Asgardia.

During the first month of its existence, Asgardia has expanded at space velocity – just like a space nation should. Let's keep that dynamic going!

Igor Ashurbeyli

NASA/JPL

UN strategy lifts capacity for non-spacefaring countries

▲ Artist's view of Dream Chaser in Earth orbit.

The United Nations Office for Outer Space Affairs (UNOOSA) is pursuing a remit to ensure all of humankind can benefit from the use of space. Its latest initiative is a partnership with the space firm Sierra Nevada Corporation (SNC), which was announced in June 2016 with further details provided at the International Astronautical Congress (IAC) in Mexico in September. From 2021, the UN will partner with SNC to use the company's Dream Chaser vehicle to offer Member States affordable unmanned reusable flights to low-Earth orbit (LEO) on the first ever United Nations space mission. In her article for *ROOM*, UNOOSA Director Simonetta Di Pippo explains why this is such an important initiative and how it will benefit developing countries.

Simonetta Di Pippo
Director of the United Nations Office for Outer Space Affairs, Vienna, Austria

At UNOOSA we promote increased access to and use of space-based technology and applications, including by helping Member States develop their own capabilities. In 2010 we launched our Human Space Technology Initiative (HSTI) to involve more countries in activities related to human spaceflight and make space exploration a truly international effort, inclusive and open to everyone.

Our partnership with SNC forms part of a wider strategy under HSTI of building space capacity of non-space-faring countries, particularly developing countries, so that they too can benefit from space technologies and activities.

We already have a number of other projects under the HSTI that complement the SNC partnership. KiboCUBE, an initiative with the Japan Aerospace Exploration Agency (JAXA), offers educational and research institutions from developing countries the opportunity to deploy cube satellites from the Japanese Kibo module of the International Space Station (ISS).

With JAXA, we recently selected the first successful candidates for this programme - a team from the University of Nairobi. The launch of their cubesat later in 2017 will allow Kenya to have a satellite in orbit for the very first time.

◀Simonetta Di Pippo and Mark Sirangelo, head of Corporate Systems at SNC, after announcing further details of the partnership at the IAC in Mexico.

A fellowship programme has given research teams in recent years the opportunity to conduct microgravity experiments at the Bremen Drop Tower in Germany. Also under the HSTI, an agreement signed this year between UNOOSA and the China Manned Space Agency will enable Member states to conduct space experiments onboard China's future space station.

We have received significant interest and a large number of applications for the projects already underway, such as KiboCUBE and the Bremen Drop Tower, and we expect even more interest for using the China Space Station and the Dream Chaser.

Through these projects we facilitate developing countries' access to a range of space activities. Partnerships, such as the United Nations Dream Chaser mission, will progress one of our core activities - capacity-building - into a more innovative approach for the 21st century.

Developing countries

The dedicated United Nations Dream Chaser mission will provide UN member states - with a focus on developing countries - the opportunity to develop and fly experiments in microgravity conditions for an extended duration in orbit.

This will be especially beneficial to countries which cannot afford their own standalone space programme but will, through this initiative, have the possibility of conducting research in space.

One of UNOOSA's key roles in the mission will be to collect and select research proposals, which can be on any topic that supports the fulfilment of the Sustainable Development Goals, such as studying climate change, food security, global health, or water resources.

In other words, UNOOSA, thanks to the United Nations Dream Chaser mission, will enable developing countries, even if not exclusively, to access space to perform experiments in orbit in line with the objectives of the 2030 Agenda for Sustainable Development.

In order to make the programme more accessible to nations without a highly developed space industry, UNOOSA will offer technical support to countries that lack expertise or experience in developing space science experiments to fly in microgravity.

Support might include activities such as assisting selected entities in further designing their projects, training researchers, or developing university curricula. These actions are in line with our effort to define innovative and effective approaches to capacity-building, as mandated by the Committee on the Peaceful Uses of Outer Space (COPUOS).

By developing and implementing a research project for the United Nations Dream Chaser mission, countries can also gain benefits outside of just the mission. We expect our efforts in building capacity in this way to have long-term impacts, especially in space-related science, technology,

We are working with Sierra Nevada Corporation to explore innovative funding mechanisms to further assist selected countries in defraying the costs of their participation

▶ Graphic showing SNC's Dream Chaser spacecraft and cargo module attached to the ISS.

engineering and mathematics (STEM) education programmes, and that these results will flow to the wider economy as a whole.

Countries selected to provide mission experiments will be asked to pay a pro-rata portion of the mission cost, based on the resources required to host the payload and their ability to pay. In addition, we are working with SNC to explore innovative funding mechanisms to further assist selected countries in defraying the costs of their participation, so that this mission can really enable inclusive access to space for all.

Dream Chaser

Sierra Nevada Corporation's Dream Chaser is about the size of a regional jet and is expcetd to accommodate about 20 to 25 laboratory stations. It is the only reusable, lifting-body, multi-mission spacecraft capable of landing at commercial airports or spaceports that currently accommodate large commercial aircraft.

Dream Chaser is a safe, affordable, flexible and reliable system capable of crewed and un-crewed transportation services to LEO destinations. SNC is currently working with airport and spaceport authorities in pursuit of the necessary licenses for missions.

After successfully completing early test flights with NASA, Dream Chaser was recently selected to provide cargo delivery, return and disposal services for the ISS under NASA's Commercial Resupply Services 2 (CRS-2) contract. Dream Chaser has successfully completed its first milestone under this contract and is now being prepared for the next round of tests. Its first flight to the ISS is planned for 2019.

The mission is innovative and means traditional boundaries between the different space sectors are no longer as definitive or limiting as they once were

Wider framework

As well as being part of our HSTI, this exciting initiative with Sierra Nevada Corporation for the first United Nations Dream Chaser mission is also part of a wider UN framework focused on the future of international space cooperation - UNISPACE+50.

UNISPACE+50 will be a special segment of COPUOS in June 2018 to mark the 50th anniversary of the first UN Conference on the Exploration and Peaceful Uses of Outer Space.

This will be an opportunity to build a new concept of space governance that aims at achieving the 2030 Agenda for Sustainable Development, including the 17 Sustainable Development Goals, and is based on the peaceful exploration and uses of outer space. UNISPACE+50 will bring together space actors from around the world to consider issues based around four thematic areas: space economy, space society, space accessibility and space diplomacy.

Capacity-building and access to space for developing countries, through initiatives like our partnership with SNC, will be especially considered under the 'space accessibility' pillar.

▲ Dream Chaser during a flight test.

We want to make sure that space technology and applications are used to bring concrete benefits to humankind while, at the same time, ensuring that space remains sustainable.

Space accessibility is essential because it keeps space from being a producer of economic and social inequality. It contributes to equal distribution of opportunities, broadens economic gain, fosters research and innovation, and supports decision-making processes on the basis of accessible and transparent data.

Dedicating an entire microgravity mission to United Nations Member states, many of which do not have sufficient infrastructure or financial backing for their own space programme, gives more countries access to space and the ability to use space technology as a tool for the achievement of the Sustainable Development Goals.

Diplomacy

Our partnership with SNC on the United Nations Dream Chaser mission is also relevant to the topic of 'space diplomacy', which is defined as constructive and knowledge-based cooperation in using space technologies and applications to address common challenges facing humanity.

It is also important to note in this context that private actors such as Sierra Nevada Corporation have a key role to play in addressing global issues, especially in line with the 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals; this role was affirmed in the Dubai Declaration that emerged from the recent High Level Forum on space as a driver for socio-economic development.

Our partnership with Sierra Nevada Corporation is a good example of how public/private partnerships in the space sector can be beneficial to all. This mission is innovative because it acknowledges that the traditional boundaries between the different space sectors - security, commercial and civil - are no longer as definitive or limiting as they once were.

Space accessibility is essential because it keeps space from being a producer of economic and social inequality

Dubai declaration

The High Level Forum on space as a driver for socio-economic development was held in Dubai, United Arab Emirates, from 20 to 24 November 2016.

It brought together more than 100 participants from the broader international space community to identify ways to harness space technology and applications for socio-economic development.

After five days of presentations and discussions, participants made concrete recommendations in the form of the Dubai Declaration, outlining how to move forward in utilising space for development and assisting states to attain the Sustainable Development Goals.

The Declaration will be presented to the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space in early 2017. The Declaration is available on UNOOSA's website at http://www.unoosa.org/oosa/en/ourwork/hlf/first-hlf-meeting.html.

Uniting effort

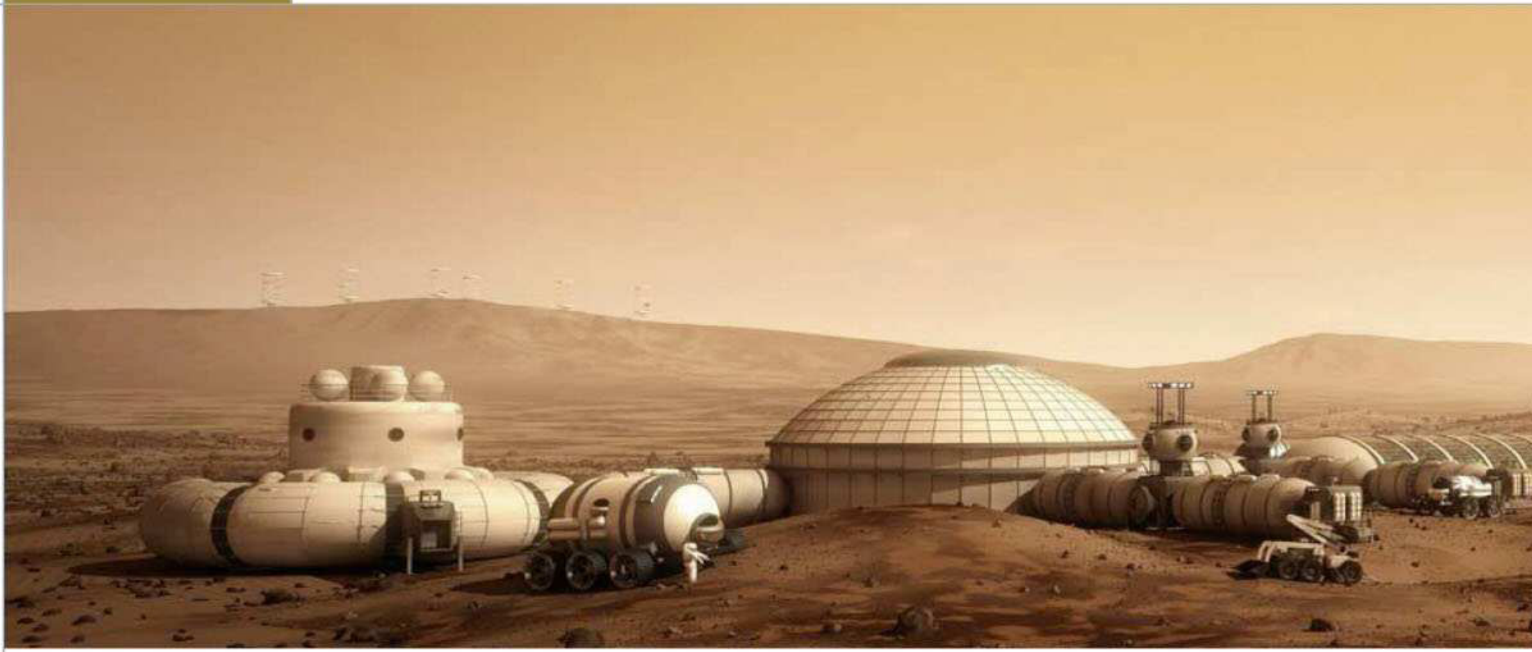
Going forward, common issues and concerns in the space arena will have to be considered in a collaborative approach that unites the efforts of the space sectors. And, importantly for UNOOSA and UN Member States, all players, including the private sector, can be key contributors to global sustainable development.

We believe that our partnership with SNC on the United Nations Dream Chaser mission will achieve these goals. Furthermore, by giving emerging space nations cost-effective access to space and the opportunity to conduct research that cannot be done on Earth, we are fostering space innovation and exploration

This mission is an exciting endeavour, and we at the United Nations Office for Outer Space Affairs are looking forward to bringing the benefits of this partnership to many all around the world. ■

About the author

Simonetta Di Pippo has been Director of UNOOSA since 2014 and was previously Head of the European Space Policy Observatory at Agenzia Spaziale Italiana (ASI) in Brussels. She also served as Director of Human Spaceflight of the European Space Agency from 2008 to 2011, and Director of the Observation of the Universe at ASI from 2002 to 2008.



▲ A habitat design for future living on Mars, by artist Bryan Versteeg.

Opening up the infinite frontier

Rick Tumlinson recently spoke at a high level United Nations forum designed to feed into the 50th anniversary of the first UNispace Conference, taking place in 2018. Filled with policy makers, representatives from governments and others, he was one of only a couple of people from what he calls the 'Frontier Movement'. While it is variously referred to as new space, commercial space or private sector space, many outside this cause-based movement have trouble actually understanding it. In a provocative 'opinion' article for *ROOM*, he urges us all to embrace a movement that will ultimately see the human settlement of outer space.

Rick Tumlinson
Chairman of the New Worlds Institute & Deep Space Industries, United States

There is an old Indian fable about six blind men describing an elephant, each coming to a different conclusion as to what it is they are describing. And thus it is today as world leaders, legislators, policymakers and academics try to understand what is happening in the Frontier Movement. Often well-meaning, each seems to be describing something that is different or merely part of a much larger whole that is looming over them and whose powerful momentum is about to change everything.

Some say it is about commercial space. Some describe it as New Space versus Old Space. Some see it as a new gold rush led by the wealthy. It is neither and it is all. The danger is that, based on partial understanding and wrong information, wrong actions can be taken, actions that might be useless, or even harm this amazing cause.

What is happening right now is not simply about commercial business - although it requires the successful application of the rules of commerce and business - or about the new versus old. It is a transformation built on the first 50 to 60 years of space investment by states and companies around the world - simply approached and applied in new ways.

It is also not so much about the acquisition of private wealth as it is about the innovative use of wealth by those who believe at a deeply spiritual level in making something happen to increase the wealth of the human species materially, scientifically and in terms of inspiration while transforming our relationship to the universe and life itself.

For those part of the Frontier Movement settlement is our touchstone - and that means developing the means to travel to and live in space. It also means creating the expectation, the demand that in the end we are going to space to make of it a new home for our species. We are talking about expanding life beyond the Earth and opening the Solar System to human civilisation.

For 30 years, my compatriots and I in the United States have been leading a space revolution, and at last, after decades of battling bureaucracies, changing laws, investing time and money and creativity, it has begun. Brought to public attention by the arrival of many of the world's top billionaires who have linked arms with the rest of us who have been inspired by the giants of the space race, to build on the technology and policy work we and our space program heroes have created since Gagarin touched the edge of space.

And the excitement is spreading. Light bulbs are going off in the minds of government managers long caught in dead end lacklustre projects as they realise they too can participate in this revolution, benefitting from the lower costs and greater access to space that competition brings, and the excitement created by working towards such an important goal.

Citizens too are stepping up to join in what they realise is going to be a major new human and economic activity as new space companies and initiatives spring up around the world. This is something we not only invite but need – as ultimately it is about humanity and creativity being given the chance to rise out of anyone and anywhere in the form of a better future for all.

There is, however, still much work to be done. Joy rides and cool animations aren't enough. States can't just start buying a few rides on commercial rockets or declare support for Moon villages whilst retaining their old ways. Real changes have to be made. The power of government must unite with the creativity of the people if we are to succeed.

Primarily, both parties must at last align behind the same goal - the human development and settlement of space. Next, governments must redefine their role vis-à-vis private citizens when to comes to space. Rather than seeing us as the audience, contractors to carry out their will or nuisances who might damage their universe, they must begin to see us as partners, and customers, and frankly, the ones for whom they work - so we can realise our ambitions and goals. To do so the very nature of national space investments and national space agencies must change, as must the intent and effect of national policies, treaties and laws.

The Frontier Movement is comprised of two parts: New Space (or what some call commercial space) and the settlement movement.

New Space

This is the economic engine of the revolution, comprised of profit-orientated companies directly or indirectly supporting the opening of the new frontier. They have investors who seek a financial return on investment and though there may not be a direct line between their projects and people living in space they were founded by or because of inspiration from the cause, with the intention of supporting it or enabling a person or group to participate.

It is not so much about the acquisition of private wealth as it is about the innovative use of wealth

Some of these are creations of what I call the billionaire cavalry, those who shared the same roots and inspirations of the grass roots early entrants but who arced out into the world and made their fortunes elsewhere, only to return to their core drivers and invest (and in some ways donate) their funds and fortunes to making the dream happen.

People like Jeff Bezos, whose life was changed by the work of Gerard K. O'Neil's High Frontier and it's laying out of a critical path to human space settlement, or Paul Allen of Microsoft and others like him who share the dream and see commercial opportunities in helping make it happen.

Next come companies like Virgin Galactic and Sierra Nevada Corporation, founded and run by those clearly part of the frontier movement. Whilst working towards being profitable, they are also doing things that are aligned with and can enable space settlement.

Some young Earth orbiting constellations fit this description, as they were started by people who intend to participate or support human space settlement. There is, however, little if any straight line between them and the technologies or systems one would need to say, build a house on Mars. Yet they do bring in ideas, innovations and technologies that will allow outward leverage. A good example areis the Cubesat technologies that allow earlier and cheaper participation in the use and exploration of space, and create more entry points for those without a few billion dollars in their pockets.

There are also companies that don't fly rockets, like Made in Space, or my own Deep Space Industries, that are very clearly designed to create profits for their investors and to provide technologies and systems that will be part of the space settlement toolkit. Being able to manufacture in space and to use space resources are core elements of the critical path.

Most of these projects have high commercial potential yet may also benefit from government support. Elon Musk, Bezos, and Robert Bigelow, along with some of us at the smaller end of this community, do indeed work with government funds at times but are also working on commercial projects and have to follow the rules of business..

SpaceX is a prime example of a highly visible company that harvested the fruit of many years of activist policy work to create programmes to support getting them into space, resulting in they and others now having the sole responsibility for supplying and soon carrying staff to and from the International Space Station (ISS). But SpaceX and Orbital ATK in particular also exist in a commercial space launch industry as competitive players.

On the other hand, Elon Musk's Mars programme is not really a commercial project though it could easily become one and, should it succeed, could be hugely profitable in ways perhaps not anticipated.

There is no business plan in the commonly understood sense because it is a plan to allow people the chance to go live on Mars as settlers. It is not designed to create profit for investors. In fact, it is essentially a charitable donation to the future of humanity that Elon is funding using the proceeds of his other projects. This is not only perfectly fine but a necessary part of the mix.

Some people or groups who ride his ships will be motivated by businesses and a new Martian economy while others will be interested only in settling or establishing colonies in space. To these groups profit will be defined in other ways, or be a rationale around which to build support or acquire funding.

And therein lies the defining aspect of the second part of revolution. It isn't all about money. It is about a dream, an inner drive to explore and expand the realm of humanity and life beyond the Earth – and enabling anyone who wishes and does the work the right to join in and help make it happen.

Technical and industrial capabilities must be combined with enlightened planning

◀ Jeff Bezos, founder of Amazon. Among his many internet pursuits he is also the founder of Blue Origin, a private spaceflight company that hopes to take tourists into space.

◀ Entrepreneur Sir Richard Branson, founder of Virgin Galactic.

◀ US businessman Robert Bigelow, owner of the hotel chain Budget Suites of America and founder of commercial space company Bigelow Aerospace.

At the centre of all of this is one clarion point: we must let the people go. In the end it is people - not governments - who will be the occupiers of these new spaces, new places and new domains.

Supporting, leading to or enabling settlement must be the core of all new human space initiatives. It cannot be a veneer or an afterthought. It cannot be a grudging hand off. It must be baked into the very philosophy from which all such initiatives and plans are derived. It must be agreed by all to be the reason we go in the first place.

When this is adopted by our governments we will have a metric, a clear means to measure success, a re-direction of national investments in space and the creation of an entirely new partnership between explorers and scientists on the one hand, and the frontier movement's commercial space and settlement communities on the other.

The global science community must also embrace the new frontier. In fact, after many years of resistance due to confusion, fear and lack of understanding, many in the research and academic communities are realising this is not an either or equation, It will be a mutually beneficial relationship, for if we make it easy to get out there we can learn more, and the more we learn the further we can go.

Thinking evolution

And finally there are the policy makers, legal and academic communities, national and international regulatory bodies. Already I see an evolution in their thinking as they respond to the revolution occurring around them. On the one hand and for most of history, space exploration has been the domain of governments, and so most of the treaties and regulations were designed to restrain nationalistic and military activities within the cage of the Earth's gravity, not to encourage and enable the people themselves to go out beyond it and do what they want.

The world's academic, policy and legal experts are engaged in a vibrant if sometimes quaint and slightly behind the curve discussion of what all of this means. Some academics and international policy bodies are like those a few hundred years ago, caught in the outmoded teaching of dogmatic Aristotelian world views even as the Copernican revolution swirled around them.

They are having a hard time adopting higher level rationales that are exactly the opposite from those that have defined human culture from the dawn of industrial civilisation.

Prime among these is the idea that, while a specific framework of laws and restrictions is completely necessary to protect life in the closed system of planet Earth, once we break out into the dead yet resource-rich realm that is the rest of the Solar System, the opposite becomes true. And what is required is to enable rather than restrict industrial activities, and to encourage large-scale human development as opposed to trying to control it. It is literally a paradigm shift – on many levels.

So now we must expand and accelerate this change - as hard as it is - from old ways of thinking to new, from the central command economy-driven programmes of the past, to programmes supporting people who will build a new future, and from systems designed to protect the status quo to those that embrace the idea the status may never be quo again as we sail out of the closed bubble.

If we do these and the other things, in years to come this decade will be seen as the beginning of the Frontier era in space. Moreover, it will be the biggest and most important shift in the trajectory of the human species and the life of Earth itself since we became a species.

By 2030 there will be people on the Moon, Mars and in the free space between worlds. The first permanent communities beyond Earth will be founded, the first harvests of resources and energy from space will begin and the first fortunes based on frontier related activities in space will be made, and life here at home will begin to change – for the better.

And yes, as I often say when I end my talks, there will be trees on the Moon and butterflies on Mars. There will be children living in the free space between worlds. They will know no bounds, no limitations and have no fear of the darkness - as they will own it and see in it not only nothing to fear but view it as the home of hope, their home, their Frontier. ■

About the author

Rick Tumlinson is a space entrepreneur, activist, speaker and writer. He co-founded several space companies and non-profit organisations, including Deep Space Industries, Orbital Outfitters, the New Worlds Institute, and the Space Frontier Foundation, signed the first commercial space tourist, led the commercial take over of Mir, and also helped start the International Space University, the X-Prize and the Lunar Exploration Analysis Group.

Traditional firms and institutions will have to adapt to the new situation and the global science community must also embrace the new frontier

◀ A garden setting inside a giant dome on a future Mars settlement, by artist Bryan Versteeg.

▲ Illustration showing the proliferation of space debris around the Earth - a rapidly worsening problem.

Growing space agency dilemma

ROOM **is an open forum for comment and opinion - and actively encourages contributions. To promote debate, discussion and inspiration we regularly publish commentaries and opinions by space leaders and those involved directly or indirectly in aerospace and space exploration. Here, Dr Joseph Pelton urges space agencies to break away from their traditional comfort zones and take a lead in helping defend our planet from cosmic hazards.**

Joseph N. Pelton
Executive Board member of the International Association for the Advancement of Space Safety (IAASS)

Around the world space agencies have tight budgets. National legislatures are pressed for a wide range of vital services. More recently, private space commerce, known as 'new space' seem to offer lower cost services. NASA, ESA, CNES, DLR, JAXA, CNSA and ISRO - among other space agencies - face questions that include:

- What is your longer term vision, and key goals?
- Shouldn't you let private space commerce take over near Earth space activities and just concentrate on the really hard stuff like deep space probes?
- Why should the public pay for expensive space programmes when there are so many public unmet needs? or
- Should we just concentrate on national defence when it comes to space?

In short, many see space as a frill - a luxury. Over the years space officials have tried to make the case that space research gave birth to new technologies and services that aid education, health care, transportation, energy, chemistry, materials and more.

Space agencies argue they have stimulated vital new space services like communications and defence satellites, remote sensing, space navigation and weather forecasting. But in terms of public support, such arguments have mostly been a large yawn. It has only been the big, dramatic and visionary space challenges that created huge global television audiences and worldwide media attention. These accomplishments excite national pride.

Space events like landing astronauts on the Moon, deploying Russian, US, Chinese and international space stations, developing entirely new space vehicles and systems like the Hubble Space Telescope, the Kepler Space Telescope, the Rosetta mission to land on a comet, Japanese missions to the Moon, Indian mission to Mars, and US probes to Pluto and beyond have brought space to the attention of the man or woman in the street. These accomplishments and rocket systems such as Proton, Soyuz, the H-2, Ariane 5 or the Space Shuttle have helped the public embrace the wonder and vision of space.

This article, however, argues that space agencies should now embrace their most vital mission - saving Earth and humanity. This goal is planetary defence against cosmic hazards. Don't laugh became this threat is real, creditable and growing in size and there is much more that space agencies can and should do.

The world community writ large is generally unaware of a basic fact. Humans live on a large six sextillion ton mud ball that travels at 100,000 km/hr (66,000 mph) around the Sun. As our world population swells in this century from seven billion to 12 billion people, our dependence on complex infrastructure grows. Althpough Van Allen belts protect us from massive solar storms, we are becoming more and more vulnerable to cosmic hazards.

The bottom line is that we, as a rapidly growing global civilization, are more and more at risk. Solar storms, asteroid and comet strikes, and orbital debris problems are all real threats we need to start taking quite seriously. In a very real sense we are dealing with cosmic fire.

The National Intelligence Council of the United States identified a future giant coronal mass ejection as a very likely 'black swan' event. A Lloyd's of London study concluded that a solar storm could cause trillions of dollars of damage to our electrical power grids, pipelines and information and communications networks with an inestimable number of fatalities.

As our population continues to grow, as our dependence on modern infrastructure expands, and as the changing geomagnetosphere brings our shields against solar storms to a level that is only 15 per cent of what it is today, we need to understand that the world community - and space agencies in particular - are largely ignoring a giant risk to life on Earth as we know it.

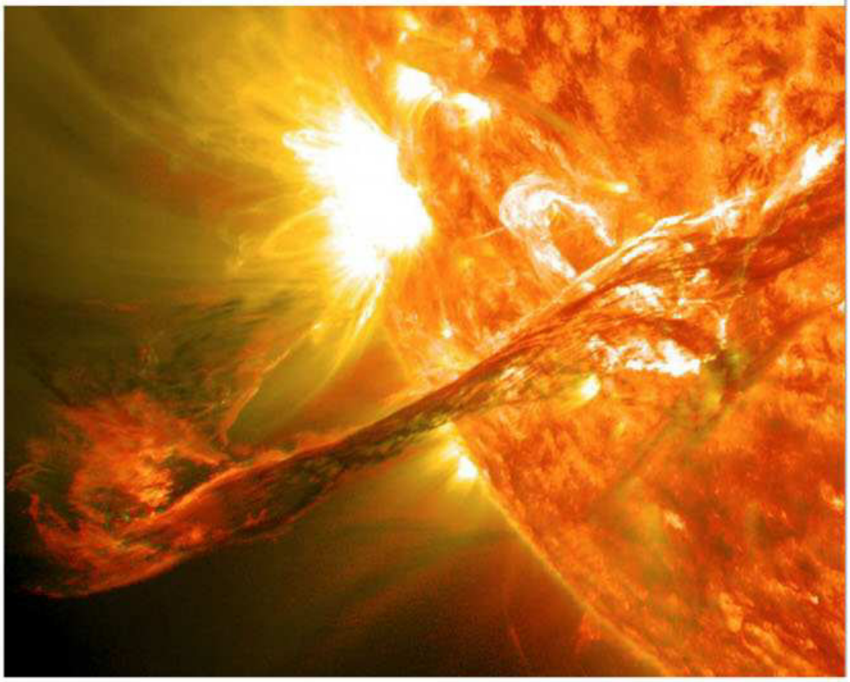
We really could be facing something like a massive disaster where a giant megacity like New York City, Beijing, London, Mexico City or Sydney could be wiped out, or much worse. We might within the next century face a mass-extinction event like the K-T catastrophe that killed off the dinosaurs and up to 75 per cent of all species on Earth.

And in virtually all scenarios it will be the space agencies that will garner the blame for this global catastrophe. It will be the world's politicians that will quickly point the finger at NASA, at ESA, at JAXA, at Roscosmos, at the Chinese National Space Agency or the Indian Space Research Organisation. They will say the space agencies did not warn us sufficiently of the danger nor seek the funds to protect the world community against cosmic disasters. The time for some action is yesterday.

It is the modern dilemma of space agencies that they now have the technological know-how to much better detect a number of different cosmic hazards. Even more importantly they also have the evolving scientific and technical knowledge to create preventive systems - so-called planetary defence mechanisms.

Yet they do not have the legislative mandate nor the funding to truly cope with the cosmic hazards that are becoming much more clearly known and understood. With some vision and leadership, they would alert world political leaders that the danger is growing and that

Space agencies should now embrace their most vital mission - saving Earth and humanity



▼ A spectacular coronal mass ejection (CME) erupts from the Sun's solar corona releasing plasma and magnetic field.

▲ Since its launch in October 2016 the Asgardia space nation initiative has been overwhelmed with applications for citizenship - www.asgardiaspace.com

preventive action should be started soon rather than later.

The key question is whether protecting our planet against catastrophic loss is more important than the current agenda for space research. Is an astronaut to Mars or a colony on the Moon or a new launch system or satellite more important than saving Earth? Fortunately, creative thinking and some synergy aligned with 'out of the box' thinking can combine planetary defence with designing and deploying space technology and systems that can also help reveal the mysteries of the universe and allow space science to be developed as well.

In Arthur C. Clarke's classic sci-fi novel *Rendezvous with Rama*, Earth space leaders finally wise up and launch 'Safeguard' to protect Earth - as of 2077. The question to political and space agency leaders is: can we realise the extent and nature of cosmic dangers and pursue opportunities for creative systems for planetary space defence - now!

Recently, through the leadership of Dr Igor Ashurbeyli, Chair of the new UNESCO Space Committee, an unusual step was taken to launch the new Asgardia space nation. The three prime objectives of this amazing new effort are: (i) more access to space by developing nations; (ii) peaceful uses of outer space; and (iii) identification of space hazards and global initiatives to undertake planetary defence.

What the Asgardia space nation can add is a global megaphone to reach the world's public with clear and accurate information about cosmic hazards

All the space agencies of the world should carefully take notice of Asgardia and welcome this initiative to get the world community excited about space again as well as making opportunities available for new space participation to millions of new people.

The official launch on 12 October 2016 in Paris, France, of the new Asgardia space nation may well herald a new era in space activity along with new forms of global heartfelt involvement in space activities.

When I signed up on asgardiaspace.com later that day I was already a member of a 10,000-strong community of space enthusiasts from around the world. In just three weeks half a million new 'citizens' had enrolled, five times more than the original target.

One might logically ask what something like the Asgardia space nation can do to promote better awareness of cosmic hazards and new planetary defence initiatives? After all, many organisations - such as the Secure World Foundation, the International Association for the Advancement of Space Safety (IAASS), the Association of Space Explorers, the B612 Foundation, NASA's JPL cosmic hazards programmes, ESA's Earthguard programme, the UN COPUOS Working Group on the Long Term Sustainability of Outer Space Activities, the International Asteroid Warning Network (IAWN), the Space Mission Planning Advisory Group (SMPAG), and the International Academy of Astronautics with its annual Conference on Planetary Defense, among many others - are all already concerned with cosmic hazards and planetary defence. What I believe the Asgardia space nation can add is a global megaphone to reach the world's public with clear and accurate information about cosmic hazards.

Indeed, Asgardia could also promote new research into possible protective programmes that could provide planetary defence against coronal mass ejections, asteroid strikes, geomagnetic shifts, and even new ways to address orbital debris problems.

For too long the assumption has been made that the complexity and difficulty of cosmic hazards are beyond the kin of human science. This is not true. We are now evolving the technology that can save Earth from the fate of the dinosaurs. Sci-Fi writer Larry Niven's famous quote from decades ago is still relevant today: "The dinosaurs became extinct because they didn't have a space programme. And if we become extinct because we don't have a space programme, it'll serve us right!"

The problem is that the space agencies today still have inadequate programmes for viable space

◀ How a six-mile-wide meteor might appear seconds before impacting Earth.

defence of our planet. These programmes are inadequate both in terms of research to understand and detect cosmic hazards, and even more lacking in their ability to provide protection to humanity.

So what should the space agencies of the world be doing? The chart on this page is a draft 'Manifesto on Cosmic Hazards and Planetary Defence' that outlines critical next steps forward to save humanity from real cosmic hazards.

It only addresses the most urgent problems that could arise - even within the next decade. NASA calculations have suggested that there is greater than a 10 per cent chance of a major solar coronal mass ejection (CME) catastrophic event within the next decade. For the longer term there are other issues that will be added. Perhaps, in time the Earth should be gradually moved further from the Sun as it expands in size.

Ironically, on 13 October 2016, the Obama White House took formal note of the problem. The US President issued a new Executive Order concerning Space Weather noting the importance of cosmic hazards and outlined the responsibilities of the Department of Homeland Security, the Department of Defense, the National Science Foundation and NASA, among others, to address the problem of solar storms. This is an important step forward and one that other countries around the world might look to as a model to consider. This, however, just the start of a process and far from its finish.

One of the missions of the new Asgardia space nation should be to help perfect this manifesto in cooperation with the other organisations and agencies identified above. Its most vital role would then to be to energise the hundreds of thousands of 'citizens' of the Asgardia space nation to make sure that funding necessary to protect Earth and humanity from very real cosmic hazards is provided. Everyone needs to think of Earth as a cosmic apple travelling through space with only the very thin skin of planetary shielding protecting it from disaster. As our population expands and modern infrastructure grows we become more and more vulnerable. Now is the time to act. ■

About the author

Dr Joseph Pelton, former Dean of the International Space University, Arthur C. Clarke Foundation . Founder, and the first President of the Society of Satellite Professionals. He is currently on the Exec. Board of the International Association for the Advancement of Space Safety. He is a space enthusiast, futurist and author of some 50 books on space and technology.

The key question is whether protecting our planet against catastrophic loss is more important than the current agenda for space research

Manifesto on cosmic hazards and planetary defence

Greater detection abilities and understanding of cosmic threats

This must include new research on solar storms, solar Max/Min cycles, CME destructive effects on the power grid, pipelines, satellites and ICT networks, geomagnetic shifts, Van Allen belt protective shielding, and differences between electromagnetic pulses from thermonuclear devices and solar events.

Development of asteroid and comet detection and protection systems

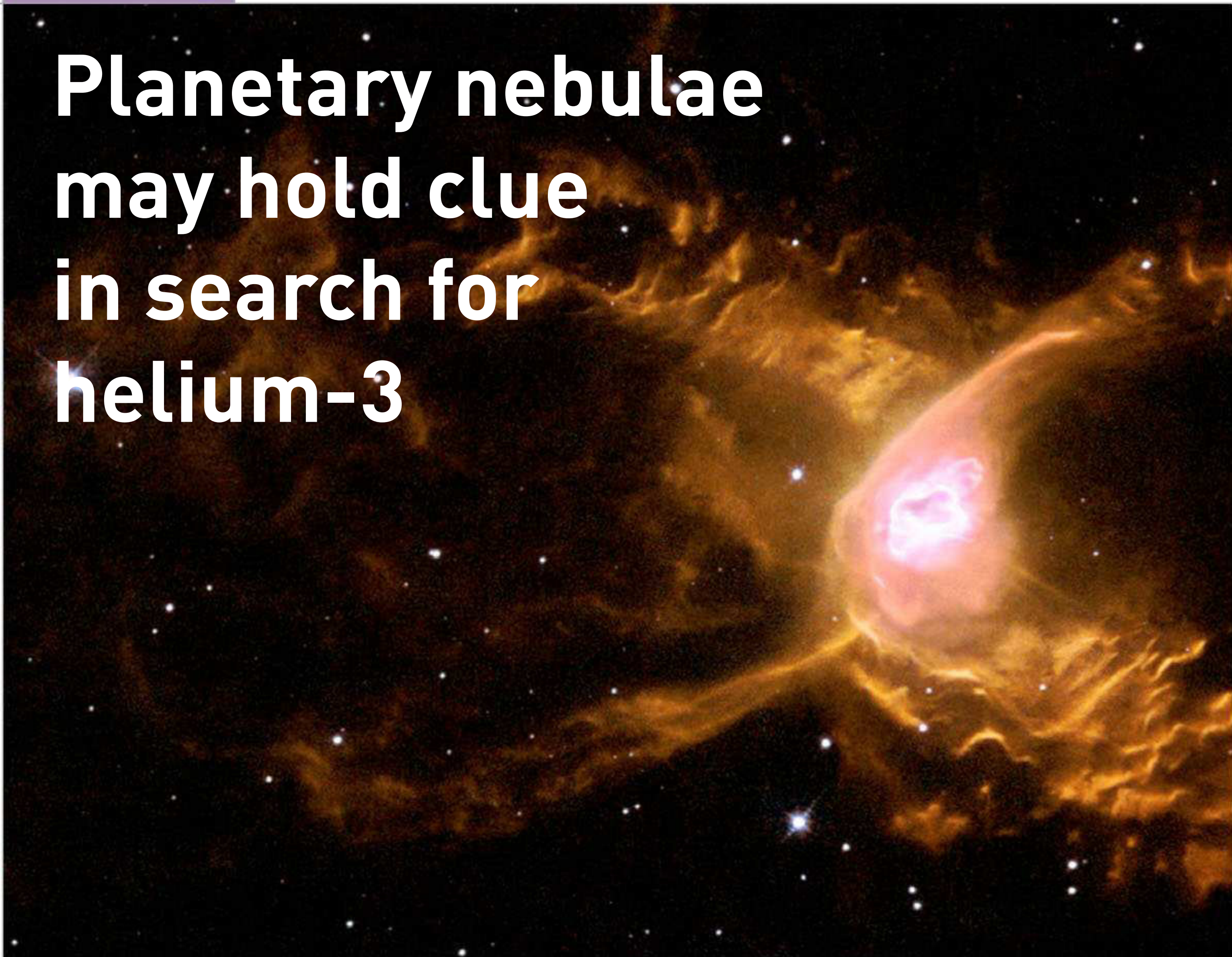
This must include infrared space telescopes that can detect potentially hazardous asteroids and comets down to 30 m in size and accelerated research in cooperation with IAWN and SMPAG to be able to divert 'city killer' (30 m and above) cosmic threats.

Development of protective systems against solar storms and cosmic radiation

It is now possible to consider space shielding systems that can protect Earth from excessive solar radiation and CMEs, such as magnetic or lens systems at Lagrange Point 1 or perhaps even artificial magnetic effects at the Earth's poles. This must involve world space and scientific agencies in cooperation with research institutes, universities, and non-governmental organisations.

Other planetary defence efforts

There are other cosmic hazards such as proliferation of space debris, anti-matter events, etc. that should also be addressed. More stringent measures to avoid the buildup of space debris to avoid the Kessler Syndrome that could deny us access to space and other efforts to should be undertaken.



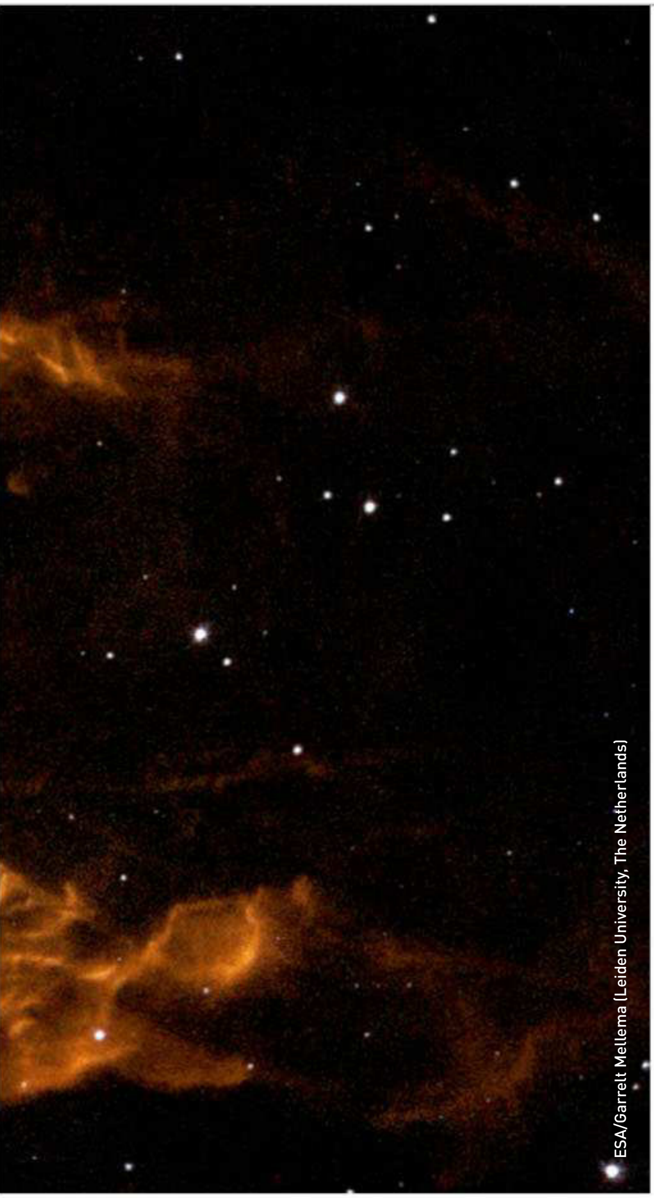
Planetary nebulae may hold clue in search for helium-3

Dr Lizette Guzman-Ramirez
Leiden Observatory, The Netherlands

When scientists began to calculate how much helium-3 (^{3}He - the main helium isotope) there is in the Universe they stumbled upon a problem. As a primordial nuclide, ^{3}He was forged shortly after the Big Bang. It is also produced through nuclear reactions in the cores of stars and subsequently expelled into the interstellar medium. Considering that the first stars formed around 200 million years after the Big Bang, a significant amount of ^{3}He should now be scattered throughout the Galaxy. However, this does not appear to be case. Scientists are now turning to planetary nebulae to help solve the missing ^{3}He problem.

Our Universe has been evolving for 13.8 billion years and throughout this epoch many stars have formed and ended their lives, enriching the interstellar medium and in turn the Universe with elements that make up everything we see around us today.

Only the first few of the lightest elements on the periodic table have been around since the beginning - helium and its isotopes (helium-3, also known as ^{3}He), small amounts of deuterium (D) and a very small amount of the lithium isotope (^{7}Li). These elements were formed in the first 10 seconds to 20 minutes after the Big Bang in a process known as nucleosynthesis, when free-floating protons and neutrons bonded together to produce atoms of increasing mass. Essentially all



of the elements that are heavier than lithium were created much later, by stellar nucleosynthesis in evolving and exploding stars.

Nonetheless, using only the current density of baryonic matter, it is possible to work out how much of one element was first produced in the Universe's early history and it turns out that for ^{3}He, for example, the abundance relative to hydrogen is around $1.0{\times}10^{-5}$. While scientists do not have a problem with this figure, when calculated, they do have a problem with how much ^{3}He should be in the Universe today - and in the case of this infamous isotope, the numbers do not quite add up.

^{3}He - where else does it come from?

Stellar evolution models predict that stars with masses less than 2.5 the mass of the Sun should produce ^{3}He. At the end of their tumultuous lives, these low mass stars end up as a planetary nebula, ejecting any (or all) of the ^{3}He produced via nuclear reactions taking place in the star's core. The models predict that the amount of 3He that should be produced (relative to hydrogen) is around 10^{-4}.

As would be expected, as the Universe ages and stellar populations grow, and as more and more stars pass into 'old age' their ejected envelopes should in principle enrich the interstellar medium with the elements forged inside their cores. Taking into account the number of stars that produce 3He and the timescales involved, the numbers tell us that the ^{3}He abundance in the Galaxy right now, should be at least a factor of five higher than what it was after the big bang nucleosynthesis.

To corroborate these numbers with actual abundances of ^{3}He scattered throughout the Universe, ^{3}He is measured in a number of different astrophysical environments. HII regions are places where stars form and are therefore comparatively young objects compared with the age of the Universe. These represent zero-age objects and their ^{3}He abundance is the result of 13.8 billion years of Galactic chemical evolution. Another preserver of ^{3}He is the Solar System. Our solar backyard traces the abundances of 3He at the time of its formation 4.6 billion years ago.

Observed values of ^{3}He in pre-solar material and the interstellar medium (ISM) imply that the abundance of this isotope (relative to hydrogen) should be around 2.5×10^{-5}. This figure, coupled with that from the ISM are approximately twice that of the Big Bang nucleosythesis value, implying that the ^{3}He abundance has increased only a little in the last 13.8 billion years. Indeed, predictions obtained from stellar models show that the current ^{3}He abundance should be around 5×10^{-5} - substantially higher than observed. Therein lies a problem and this discrepancy, first presented over 20 years ago and known as 'The ^{3}He Problem'.

Can we fix it?

There are a number of solutions that could be invoked to overcome this problem and help reduce the predicted abundances of ^{3}He. First, some researchers suggest that the ^{3}He formed inside the core of the stars is destroyed before the star has chance to pulsate and eject its material into the interstellar medium. Second, it is possible stars do produce ^{3}He and release it to the interstellar medium but that it is destroyed via processes such as spallation from cosmic rays. At present, this latter theory is totally speculative and has yet to be tested, so it is unknown as to

◀ Huge waves are sculpted in this two-lobed nebula some 3000 light-years away in the constellation of Sagittarius. This warm planetary nebula harbours one of the hottest stars known and its powerful stellar winds generate waves 100 billion km high. The waves are caused by supersonic shocks, formed when the local gas is compressed and heated in front of the rapidly expanding lobes. The atoms caught in the shock emit the spectacular radiation seen in this image.

Scientists have a problem with how much 3He should be in the Universe today

▲ The bright clusters and nebulae of planet Earth's night sky are often named after flowers or insects, as with the 'Butterfly Nebula' (NGC 6302), which has a 'wingspan' covering over three light-years.

whether this mechanism destroys ^3He in this manner or not.

Nonetheless, there are no such limitations on the first theory as stellar models have been used to test if and how low-mass stars could destroy their ^3He before they reach their last stages of stellar evolution. It turns out that, after lots of modifications to the models, including adding extra mixing in a phase known as the red giant branch stage, surface abundances of ^3He are affected and the degree to which ^3He is destroyed is dependent on the mass of the star.

Estimates show that while 90 per cent of the ^3He is destroyed in one solar mass stars, only 40-60 per cent is destroyed in a two solar mass star model, depending on the speed of mixing. Therefore, stars with masses between two and 2.5 solar masses will still be the net producers of ^3He and a large portion of it will not be destroyed in the core. Consequently, in a star's final stage of evolution, some 3He should be preserved and ejected to the ISM.

One way to test whether ^3He is expelled from a dying star is to look for it in a planetary nebula, which is the final evolutionary phase of low- and intermediate-mass stars, where the extensive mass lost by the star is ionised by the emerging white dwarf. During this stage, the ejected envelopes of the star often create stunning and complex nebula that can take on forms from bubbles to butterflies - the butterfly or bug nebula (NGC 6302) is a classic example of how stellar winds can shape the shell of diffuse gas into a beautiful structure, before dispersing elements into the surrounding ISM.

Finding and calculating the abundance of ^3He is a complicated task; it can only be derived from the hyperfine transition of ionised ^3He (represented as $^3He^+$) and this transition can only be observed in the radio portion of the electromagnetic spectrum at the rest frequency of 8.665 GHz.

Unfortunately, this transition is not very common, making the line very weak, hence detecting $^3He^+$ in planetary nebulae challenges the sensitivity limits of all existing radio telescopes.

Finding and calculating the abundance of ^3He is a complicated task

Hunt for the $^3He^+$ emission

A whole host of radio telescopes and hundreds of hours observing time have been involved with trying to detect this line, including telescopes such as the Effelsberg 100m dish, the National Radio Astronomy Observatory (NRAO) 140-foot telescope, the NRAO Very Large Array, the Arecibo antenna, the Green Bank Telescope, and only just recently, the Deep Space Station 63 antenna from the Madrid Deep Space Communications Complex. All have met with limited success, except with this latter array whereby $^3He^+$ was observed in the planetary nebula IC 418.

Some positive developments have been forthcoming, and the analysis of spectra from six planetary nebulae (NGC 3242, NGC 6543, NGC 6720, NGC 7009, NGC 7662, and IC 289), using Effelsberg, Arecibo and Green Bank Telescope has yielded results that show the abundance of ^3He (with respect to hydrogen) as being a few x 10^{-4}.

Not all searches have proved fruitful, however. After another batch of observations using the Very Large Array, totalling yet more hundreds of hours, three promising planetary nebulae candidates - IC 418, NGC 6572 and NGC 7009 - showed no sign of the elusive ^3He atom.

So, after more than two decades of looking, researchers can count on one hand the number of objects with sufficiently large enough quantities of ^3He to be detected - J320, NGC 3242 and IC 418.

On the plus side, these limited detections have provided researchers with a number of aspects that need further consideration:

- the derived $^{3}He^{+}$ abundance found is well above model expectations for all three planetary nebulae. This confirms that stars do produce and release ^{3}He into the interstellar medium
- the $^{3}He^{+}$ line profile shape for all the three objects differs from what is expected and shows a double peak instead of a gaussian line shape. All of the recombination lines that are seen in the same object with the same telescope are gaussian, but for some reason, the ^{3}He line is not. This is the same for the other two planetary nebulae where this element has also been detected and it has therefore prompted an explanation as to why this might be the case.

One way to test whether ^{3}He is expelled from a dying star is to look for it in a planetary nebula

The double-peaked profile could arise because the telescope beam does not cover the whole planetary nebulae, meaning that the beam size of the telescope is smaller than the size of the planetary nebulae.
The double-peaked profile could arise because the telescope beam does not cover the whole planetary nebulae, meaning that the beam size of the telescope is smaller than the size of the planetary nebulae.
However, it is has been proposed that a low density but high mass halo surrounding the planetary nebulae is the more likely scenario and this would also result in a double-peaked line profile shape. [Balser et al. 1999].

This suggestion can at least be substantiated, as previous observations of both J320 and NGC 3242 show that along with their double peaked 3He profiles both objects also have haloes. In the case of NGC3242, its halo is possibly as large as 18 by 24 arc minutes in diameter. This equates to about eight parsecs and, to put that in context (as the distance from here to our nearest star is 1.3 parsecs), the halo diameter is massive to say the least.

Whether helium in such a halo could be photo-ionized by the star is not clear. Analysis of the

► The 100-m radio telescope of the Max-Planck-Institut für Radioastronomie (MPIfR) is located in a protected valley near Bad Münstereifel-Effelsberg, Germany. It is one of the two largest fully steerable single-dish radio telescopes in the world and a unique high-frequency radio telescope in Europe.

▶ Planetary nebula NGC 3242, also known as the 'Ghost of Jupiter'. A notable feature is the presence of the two red 'fliers' on both poles of the nebula, the gas comprising these objects is believed to be younger and moving at a much faster rate than that of the nebula.

▼ Artists rendition of the SKA-mid dishes in Africa shows how they may eventually look when completed. The 15 m wide dish telescopes, will provide the SKA with some of its highest resolution imaging capability, working towards the upper range of radio frequencies which the SKA will cover.

structure of NGC 3242 shows that the planetary nebulae has an inner shell and an outer elliptical envelope, but the inner shell is optically thick to He^{+} ionizing photons, meaning that the photons will be trapped in the inner shell, making it difficult for them to escape and ionise atoms in the larger outer shell.

Where to go from here

The values observed in these objects prove that ^{3}He is produced at the centre of low-mass stars and is ejected into the interstellar medium at the end of their lives. However, the large amounts of ^{3}He produced in these models is at odds with the abundance of ^{3}He observed in the interstellar medium and the Solar System.

The contribution of planetary nebulae to the ^{3}He abundance is crucial for understanding the Galactic chemical evolution and further research on other planetary nebulae will be needed to solve the ^{3}He problem, which is compounded by its extremely weak emission making it hard to detect.

At present, there is only one transition that can be detected and this is at 8.6GHz which falls in the radio portion of the electromagnetic spectrum. Not many telescopes or arrays have the sensitivity required to observe this elusive element, though hopefully this will soon change.

One array that has the sensitivity required to observe lots of planetary nebulae but in a much shorter time compared with any radio telescope that exists now is the Square Kilometre Array (SKA). The SKA is an international project that it is currently in development in Australia and South Africa, and will be the world's largest and most sensitive radio telescope. Construction of the SKA is scheduled to begin in 2018 for initial observations by 2020. With a total collecting area of approximately one square kilometre, its size would make it 50 times more sensitive than any other radio instrument, making it the ideal tool to help solve the ^{3}He problem. ■

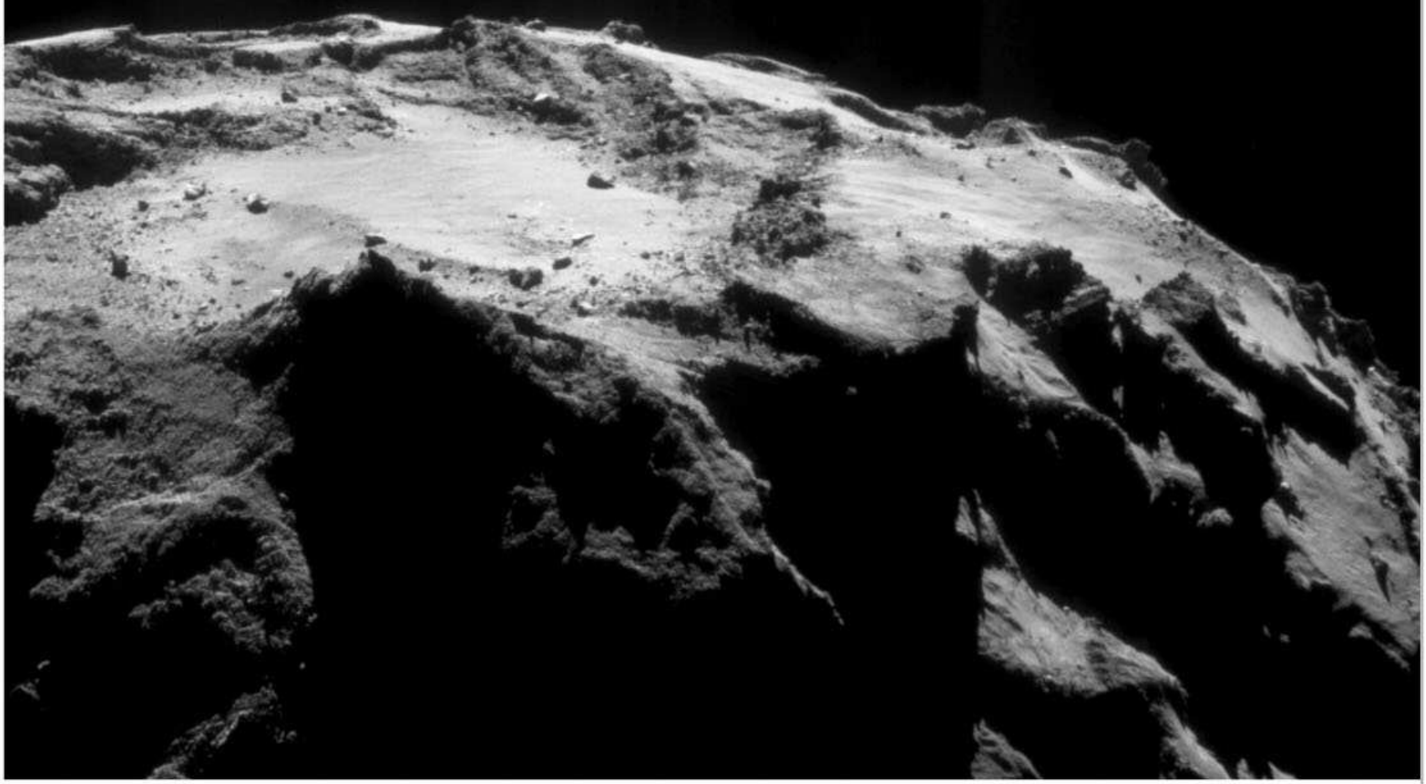
About the author

Dr Lizette Guzman-Ramirez is a post-doctoral researcher in astrophysics, a European Southern Observatory (ESO) Fellow at Leiden Observatory in The Netherlands and a member of the ALMA Arc node (Allegro). Her research interests include stellar evolution, chemical enrichment of the Galaxy, and formation of molecules in low-mass stars.

After more than two decades of looking, researchers can count on one hand the number of objects with sufficiently large enough quantities of 3He to be detected

ROSETTA AND PHILAE

Outstanding climax to pioneering mission



Paolo Ferri concludes his unique and personal view of the ground-breaking ESA Rosetta mission based on his two decades-long association with the pioneering ESA space mission. In the fourth in his series of exclusive articles for *ROOM*, he recalls the challenging and unexpected events after Rosetta's arrival at Comet 67P/Churyumov-Gerasimenko, the first ever deployment of a lander on a comet's surface, and the mission's final spectacular conclusion.

▲ All pictures in this article credited to: ESA/ Rosetta/Philae/Civa/ OSIRIS Team/ MPS/ UPD/ LAM/ IAA/ RSSD/ INTA/ UPM/ DASP/ IDA

Paolo Ferri
Head of Mission Operations, ESOC, Darmstadt, Germany

The long years of hibernation, out of contact with Rosetta, were spent completing the preparation for the comet phase of the mission, defining operations concepts, designing and testing software tools and procedures, hiring and training the newcomers in the flight control team. Never before in the history of space exploration had a space probe reached a comet and tried to orbit around it.

The flight dynamics and overall flight operations challenges were huge: we had to gradually approach the target comet, and then try and fly around it while building up our knowledge of the nucleus and its dynamical environment. Our Flight Dynamics colleagues had prepared a model of the comet, including its mass, shape and the dynamical forces that would act on our spacecraft, and integrated it into the orbit determination software. However, the model could only be built up and refined by using the Rosetta spacecraft itself as a 'sensor' of the dynamic perturbations. It was an iterative process that could only start when we were in proximity of the nucleus: it was like learning to fly by doing it!

In the meantime, Manfred Warhaut, the first ground segment manager of Rosetta back in 1996 when the project started, and since 2006 Head of the Mission Operations Department at ESOC, retired, and I took his place. As had already happened back in 2006, Andrea Accomazzo was selected to fill the post I had left vacant, and became Head of the Solar and

▲ Perihelion jet.

Planetary Missions Division, as such also taking up the Rosetta Flight Director role.

It was hard for me to leave the active operations role on my beloved mission but I knew I left it in good hands, and after all I was still in charge of mission operations for the managerial aspects, as part of my new responsibilities. To fill in for Andrea's former role as Rosetta Spacecraft Operations Manager we selected Sylvain Lodiot, who had come back to the team a few years earlier.

On 20 January 2014 the moment of truth arrived: Rosetta was back at Sun distances short enough to allow us to safely reactivate all its systems and re-establish permanent radio contact with Earth. We set Rosetta's wake-up timers for 10:00 UTC on-board time. The timers would automatically initiate a series of activities on the spacecraft, involving the warm up of various units, stopping the rotation, acquiring the stars and three-axis stabilisation, directing the high gain antenna towards Earth and activating the transmitter.

Only at the end of this sequence, that we estimated to last about six hours, would we receive the long-awaited signal from the spacecraft, indicating that it was still there, healthy and ready to perform its fantastic mission. At this time Rosetta was at about 800 million km from Earth, so the radio signal would take almost 45 minutes to reach us. Overall, taking into account the uncertainties in all the automatic activities and the possible drift of the on-board clocks over 2.5 years, we calculated that we would receive the first signal between 18:30 and 19:30 local time in Darmstadt, Germany.

Never before in the history of space exploration had a space probe reached a comet and tried to orbit around it

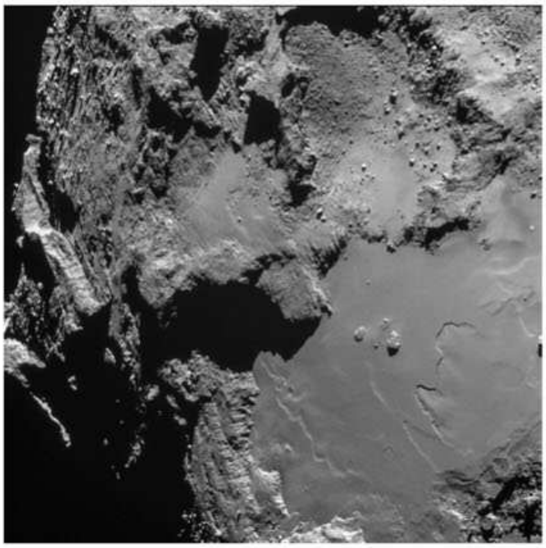
Sylvain with his team, Andrea, Manfred, myself and a few others were eagerly waiting for the signal in the main control room. In another building, our communications people had organised an event with ESA management, VIPs and press. We were surprised by the large attention the wake up of Rosetta had attracted around the world, and this increased the level of tension in the operations team.

Waiting for a signal

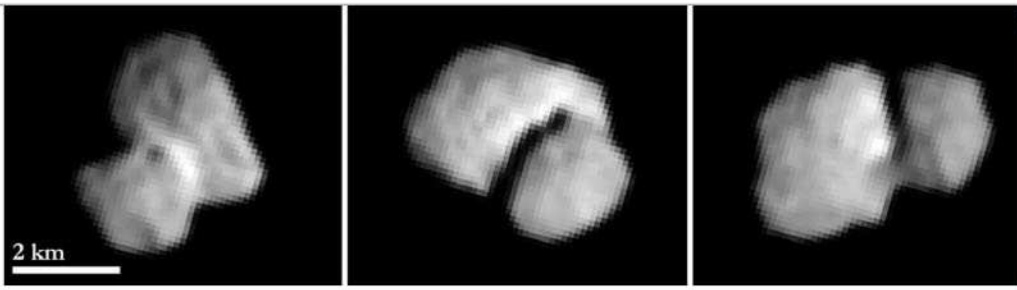
Two NASA Deep Space Network 70 m antennas - Goldstone in California and Canberra in Australia - were pointed to the place in the sky where Rosetta was predicted to be, waiting for the signal. I was nervous all the time, while Andrea, Manfred and most of the others looked very relaxed at the beginning. But time went on and at 19:00 we still had no signal. I could see the tension growing, and found myself mentally counting the seconds to the end of the window.

My Director, Thomas Reiter, sitting in the Press event, was bombarding me with text messages, trying to get my feelings about the situation. I managed to keep cool, at least in my responses, not showing the unbearable tension that was growing inside me: I knew that at 19:30 I would have had to go on the event and explain to the audience why we had not received a signal… At 19:18, very close to the end of the predicted one-hour window, a small feature slowly appeared in the spectrum analysers of the ground stations. It was small, but it was present in both stations and it seemed to constantly grow. It took about one minute for us to realise: it was real, it was a signal from our spacecraft, it was Rosetta calling home!

In the night following the wake-up, the team



▶ Close flyby.



configured the spacecraft to its normal flight mode and looked at the few telemetry indications we had from the long hibernation period. It turned out that due to a software problem a re-boot of the on-board computer had occurred back in 2012, and a second one at the start of the hibernation exit sequence. This explained the delay in the reception of the wake-up signal, the longest 18 minutes in my professional life.

Now we had daily contact, and most of the seven billion km journey behind us. But the final approach to the comet was still long. First we had to gradually activate all instruments on-board, one at a time due to the very slowly increasing power output of the solar array while the distance to the Sun was decreasing. Then we had to perform the second part of the rendezvous manoeuvre, to finally match the comet orbit. It was only on the 20 March that a first picture of the target comet could be taken with the OSIRIS scientific camera. It was still just a dot, but psychologically it was a very important moment for the whole team: it was like seeing land in the distance after a 10 year-long ocean crossing trip.

Only in July, at a distance of 12,000 km from the target, could the on-board cameras resolve the shape of the comet: and this was a huge surprise, as we found a very odd, rubber-duck shaped object instead of the expected usual potato shape. The scientists started speculating about the formation process of such object, while our operations team was concerned about the difficulties of modelling and orbiting it.

Preparations for landing

On 6 August we 'stopped' the spacecraft at a distance of 100 km. The characterisation phase had begun, with orbits that gradually decreased the distance and mapped the whole surface. While the scientists were enthusiastically analysing the initial pictures and measurements, our flight dynamics experts worked day and night to keep the spacecraft on the right trajectory and with the right pointing, while their models of the comet gradually improved in accuracy and stability.

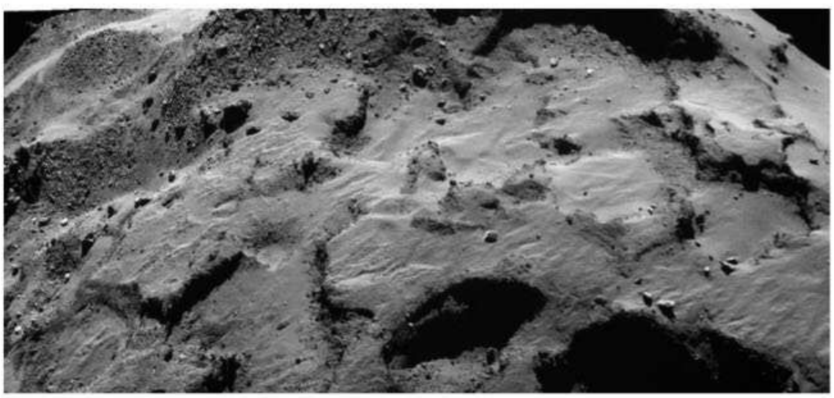
They used new optical navigation techniques - identifying landmarks on the camera pictures of the comet and using them for triangulations to determine the position and velocity of the spacecraft relative to the surface - also developed for the first time for this phase of the mission. This was initially a manual process, that they managed to progressively automate in the first months around the comet.

The final characterisation phase was a close observation of several candidate landing sites for Philae. The selection of the landing site, involving the scientific community and the lander experts, was extremely complex but the process ran much more smoothly than expected, and rapidly converged on the winning candidate: Agilkia, on the 'head" of the duck-shaped nucleus. A nice, relatively flat and sunny area, where the chances of landing success were the highest (though still not extremely high!).

Landing had to occur not earlier than 11 November, when the comet and Rosetta would approach the Sun down to a distance of three Astronomical Units (AU), or about 450 million km. But also not much later than that date, since the activity of the comet, approaching the Sun, would soon start to grow, preventing Rosetta from flying the trajectories needed for the delivery of the lander to the surface.

▲ Rosetta views of comet on 20 July 2014 and (right) Philae lander contact signal in June 2015.

◀ Waiting for Rosetta's signal at hibernation exit on 20 January 2014.



▼ Philae landing site image from a height of arpound 10 km.

▲ Flight directors after Philae landing.

Finally, we were all ready for 12 November, the selected landing day. The night before separation, which was planned for 10:30 in the morning Darmstadt time, the Philae lander was activated and prepared for the process, and we started to experience the first problems: the priming of the cold gas thruster that our colleagues from the Lander Control Centre in Cologne had planned to use to press Philae to the surface after touch down did not work. Also the conditioning of Philae's batteries did not work as planned.

Nevertheless, our Cologne colleagues concluded that these problems were either not important or not solvable, and declared Philae ready for landing. In the meantime, Rosetta's navigation was perfect, and the spacecraft performed a smooth manoeuvre to dive towards the comet before releasing the lander for its ballistic descent. We were 'go' for separation, which was commanded as planned. After that, Rosetta manoeuvred to a good visibility position and turned towards Philae, picking up its radio signal to relay it to Earth.

Philae fell for the planned seven hours, from an altitude of 22.5 km, and at 17:30 touched down, within 30 seconds from the predicted time, and less than 120 m away from the centre of the large landing error ellipse: a masterpiece of navigation by our flight dynamics experts and our great spacecraft and its propulsion system!

But Philae decided to keep us further under tension: the harpoons designed to anchor it to the surface after touch down did not fire, so that the lander started bouncing over the surface. We did not realise this immediately, as Philae was still in radio contact and had happily started to perform its scientific measurements, but after 20 minutes the confirmation came from Cologne: Philae was still flying!

Selection of the landing site, involving the scientific community and the lander experts, was extremely complex but the process ran much more smoothly than expected

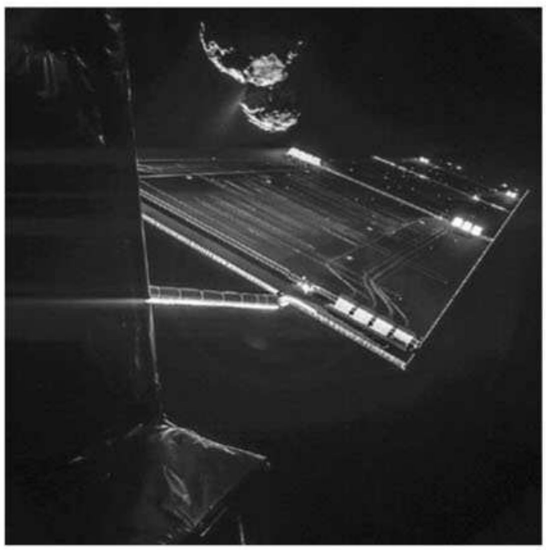
Fortunately, the radio signal to Rosetta was never interrupted and after more than two hours Philae came to a rest in a dark corner, trapped by some extremely interesting comet surface 'rocks'. The lander had been cleverly designed to run for about 60 hours on a primary battery, and execute its main sequence of all experiments. And it did so: we had five contacts with Rosetta of about two hours each in the next two days (one contact every 12 hours due to the comet rotation period), downloading all the scientific data collected by the Lander instruments.

Philae falls silent

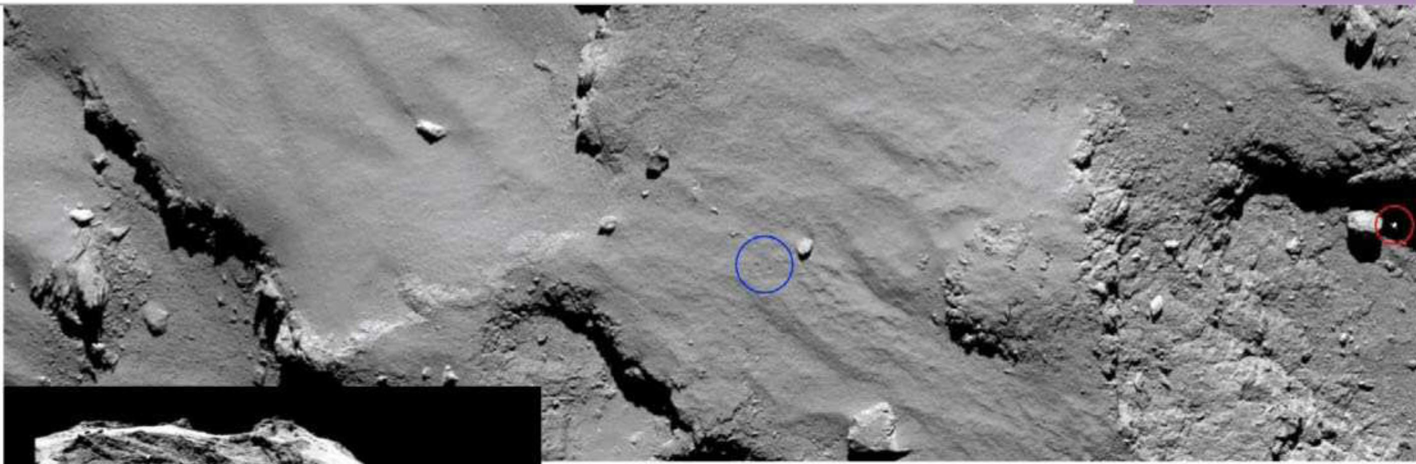
After that, in the night of Friday, 14 November, the batteries ran out of energy and Philae went silent: in its final position on the surface there was not enough sunlight to recharge the secondary batteries, which we had hoped could give Philae the chance to operate for a few more weeks on the surface.

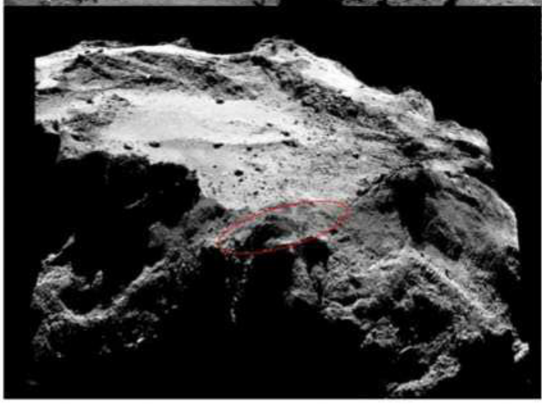
Now Rosetta could devote its operations to the orbital science, which was the primary objective of the mission: it had to follow the comet and observe its evolution around the perihelion, at least until the end of 2015. And this was very challenging, as the activity of the comet started to rapidly increase at the beginning of the new year.

At the end of January, we had to leave the closed orbits - which were too inaccurate due to the high activity of the comet - and started to perform close flybys. During one of these the star trackers were blinded by the high density of dust and resulted in a very dangerous situation for the spacecraft, which could no longer properly control its attitude. This was the signal that we had to gradually increase the distance to the



▶ The famous Rosetta 'selfie' showing the mothercraft's solar array with the comet above.



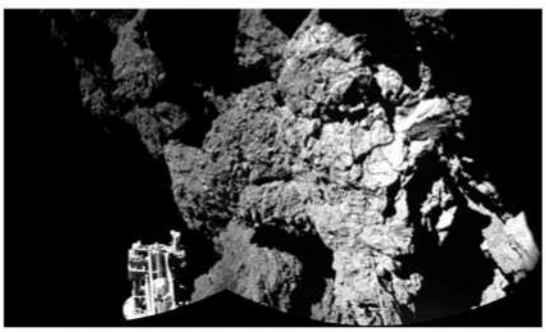


▲ Philae after first touchdown and (inset) the lander search area (red ellipse).

comet until the high activity decreased after perihelion in summer.

While the spacecraft was at distances of about 200 km from the surface, suddenly one Saturday night - on 13 June - Rosetta received a feeble radio signal from Philae! Springtime had come also on the comet and the better illumination conditions and the higher surface temperatures allowed Philae to collect enough solar energy to boot-up its computer and try transmitting to Rosetta.

After the initial burst of joy our confidence to be able to ever operate with Philae again rapidly decreased: we were too far from the surface to be able to establish a stable radio link with the lander. We tried to decrease the distance but the comet activity was making it very difficult for us to fly in the thick cloud of dust. We managed to go down to 150 km from the surface and to establish nine short contacts with Philae until early July. After that, and a few days of silence, we had to increase the distance again. We never heard from Philae again.



◀ Philae's first picture from the comet surface.

After the perihelion in August and a planned ‘excursion’ to study the coma structure at distances up to 1500 km from the nucleus, we started to gradually decrease the spacecraft distance to the surface, and by the end of 2015 we were back to closed orbits.

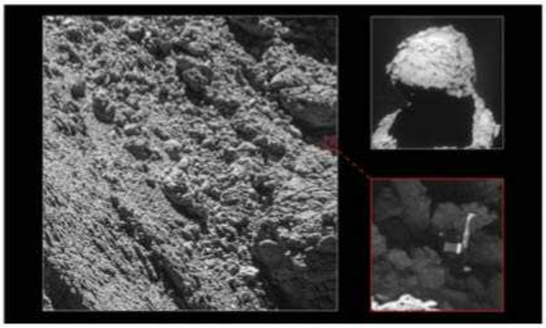
In the meantime, the huge success of the mission made it easy for the Science Programme Committee to approve an extension of the mission into 2016. At the same time, we knew that we could only operate Rosetta until the autumn of 2016: after that the distance to the Sun would have forced another long hibernation, even longer than the original one and at larger distances. The aging instruments and spacecraft, the depletion of the fuel reserve, and the risks involved in another hibernation were strong reasons to decide to stop the mission on 30 September 2016. However, we decided to finish it in a glorious way, with an attempted soft ‘touch down’ of Rosetta onto the surface of the comet.

This explained the 18-minute delay in the reception of the wake-up signal, the longest 18 minutes in my professional life

More navigation challenges

The year 2016 was dedicated to close observations and scientific investigations of the comet and its changes after the perihelion passage. The amount of scientific data delivered by Rosetta was enormous, and the fact that we could observe the comet from close proximity over a large part of its orbital period was a fantastic opportunity for our scientists and a giant leap in comet and solar system science. The team also tried to use all occasions to take pictures of the area where we assumed Philae had ended its bouncing over the surface, but we did not succeed over many months.

In the final weeks we could take increasing risks and fly Rosetta on three day elliptical orbits with a pericentre very close to the surface: we started from 7.5 km from the surface with the objective to try to go as close as 2 km by mid-September.



▶ Philae is found on the surface.

This phase was even more challenging from the navigation point of view than the initial one after comet arrival.

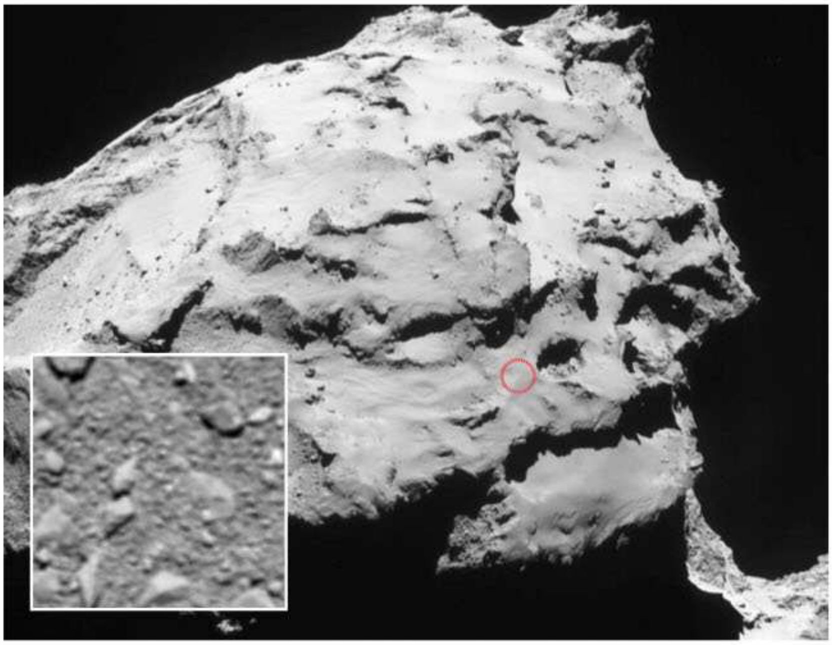
Our flight dynamics people had to update software tools and procedures, and design very sophisticated strategies to be able to satisfy the needs of our scientists while keeping the risks on the spacecraft under control. It was during this phase that, on 2 September, during the last but one attempt to take a picture of Philae, from an altitude of 2.7 km, that we eventually succeeded!

These pictures were not only emotionally very important for the operations teams but they were extremely useful for the analysis of Philae's scientific measurements, that could be calibrated and put in the context of the orbital measurements from Rosetta now that the exact position of the lander was known.

Finally, after the last close pericentre on 24 September, we manoeuvred the spacecraft to a higher orbit and then in the evening of the 29th we performed a 35 cm/s manoeuvre that put Rosetta into collision course with the comet.

Rosetta is the last of the pioneering space missions and its end marks the end of the pioneering phase of space exploration

▼ Rosetta's final target destination circled in red and (inset) the spacecraft's last image.



The selected area for touchdown was close to the Ma'at pits, large holes in the surface of very high scientific interest. During the last hours of descent Rosetta's instruments could measure the comet environment and take pictures of the surface over the last range of altitudes, from 2 km to zero, which had never been 'visited' before by our spacecraft.

Emotional ending

Rosetta was programmed to transmit data in real time, and everything worked perfectly until touch down at 10:39 UTC on-board time. At that point, Rosetta switched itself off, as it was programmed to do by our last commands three hours before. A spectacular end to a fantastic mission. Sylvain and his Flight Control Team gave me the honour - about one hour and 20 minutes before the impact - to send the last command to Rosetta. It was a very emotional moment for all of us.

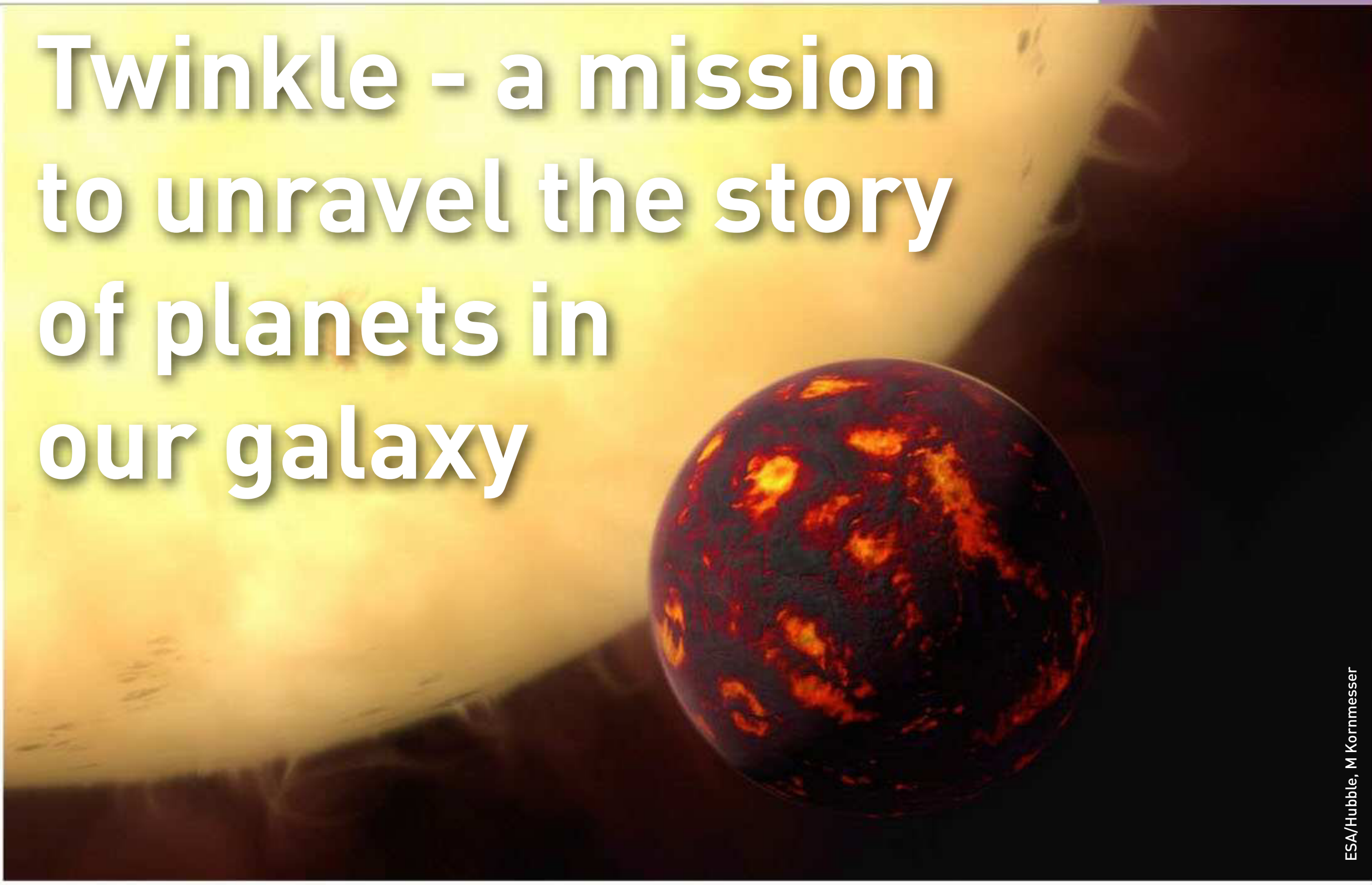
I am writing this final article just two days after the end of the Rosetta mission. This adventure has been a major part of my professional and private life for almost exactly 20 years, since I was nominated spacecraft operations manager back in November 1996. I have accompanied the mission throughout the initial phases of the spacecraft design up to the dramatic moments of the missed launch, the mission redefinition and then the long and often challenging cruise.

I have hired young engineers and scientists and seen them growing professionally with this mission, taking over the tasks from the older people, reinventing solutions and workarounds when problems were developing on board or on ground. I have lived the strong emotions of arriving at an unknown celestial object, exploring it for the first time over more than two years and even 'living' two and a half days with the Philae lander on its surface.

Seeing the last telemetry frame freezing on the screens on 30 September was an unfortegttable moment for me. I have seen the end of other missions but this was something more than that. Rosetta was the last of the pioneering space missions and its conclusion marked the end of the pioneering phase of space exploration.

The new generations of spacecraft, of scientific instruments, of design and operations engineers will have to tackle the next challenge: the establishment of an operational exploration infrastructure in the Solar System, which will pave the way for a possible future human exploration of the planets, moons, asteroids and comets. ■

Twinkle - a mission to unravel the story of planets in our galaxy



▲ Artist's impression of the super-Earth 55 Cancri e in front of its parent star.

The study of exoplanets has rarely left the news since their first discovery two decades ago [1] - and the headlines are unlikely to stop anytime soon. With a variety of future-planned space programmes in development to find even more systems, the number of detected planets will increase three-fold, if not more. But aside from knowing that exoplanets are ubiquitous and can be found around all types of stars, what else do we really know about them? Very little as it turns out. Not content with merely counting other worlds, scientists at UCL are developing a mission to study the atmospheres of at least 100 bright exoplanets in the Milky Way in a bid to add substance to planet style.

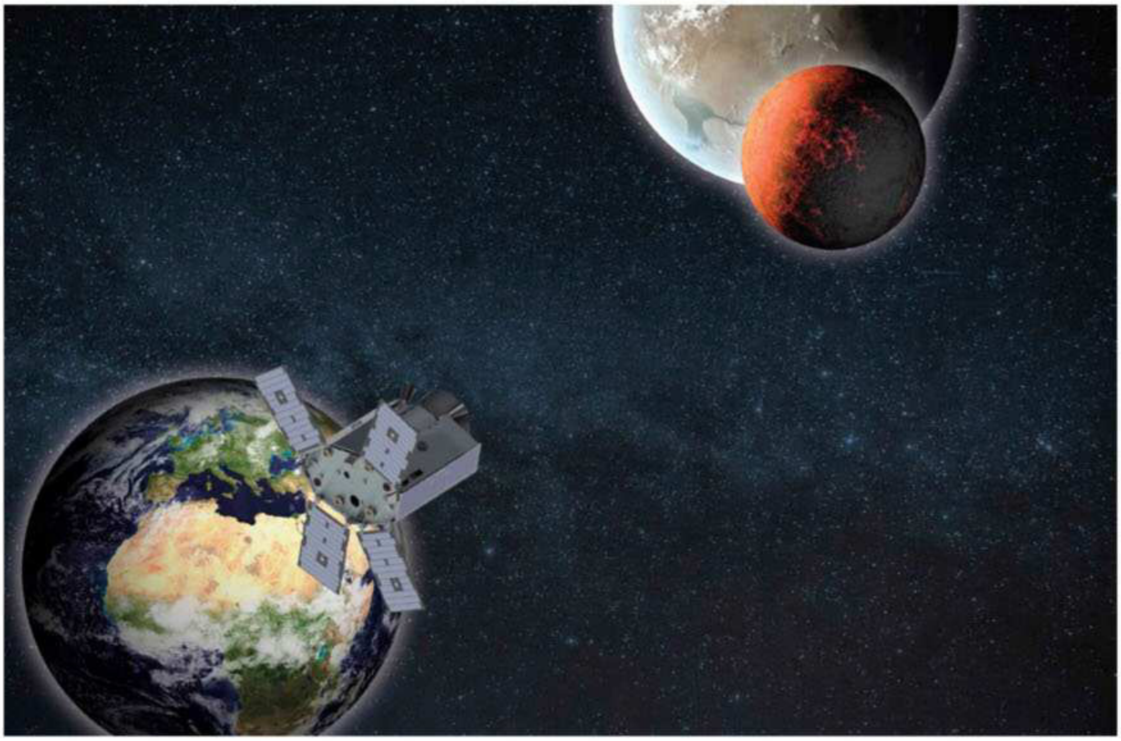
Since the discovery of 51 Pegasi b (also known as Dimidium) just over 20 years ago, the list of planets discovered orbiting distant stars has reached well over 3000. Ongoing and planned ESA and NASA space missions such as GAIA, Cheops, PLATO, Kepler II and TESS will increase the number of known systems to tens of thousands. Exoplanets have been detected around every type of star and our current statistical estimates suggest that, on average, every star has at least one planetary companion. That means that there are hundreds of billions of planets in the Milky Way alone.

To the gas giants, rocky terrestrial planets and ice-worlds that we find in our own solar system, we have added a broad spectrum of new, exotic planetary types: giant hot-Jupiters orbiting their sun in hours or a handful of days, super-Earths with masses up to ten times that of our planet, gas dwarfs, temperate Neptunes. The sheer range of planetary bodies discovered has caused a paradigm shift in how we think about planetary systems and our understanding of how they form and evolve.

But in reality, what do we know about the individual planets? The answer is very little. For most, we simply know that they exist and where they are. For about a third of them, we know how big they are, their mass and how often they orbit their star. For about one per cent, we have used spectroscopy to extract a few clues about their atmospheric temperature and composition.

Giovanna Tinetti
Professor of Physics and Astronomy at University College London

▶ Artist's impression of the Twinkle spacecraft.



The list of planets discovered orbiting distant stars has reached well over 3000

Even this limited information has challenged many assumptions based on our own Solar System [2]. Super-Earths, of which we have no close-by examples to study, appear to be the most common type of planet. Near-circular orbits turn out not to be the standard - more than 60 per cent of exoplanets discovered to date have elliptical orbits, some of which are highly eccentric.

The discovery of planets around every type of star opens up new possibilities for habitability around M-dwarfs, stars cooler than our Sun that are by far the most common type of star in our galaxy. If giant planets form in the cold, outer planetary disc where most of the gas, ice and dust is located, what are the migration mechanisms experienced by hot-Jupiters that cause them to dramatically shift towards their host star?

We haven't yet found any discernible pattern linking the presence, size or orbital parameters of a planet to what its parent star is like. To make progress in understanding the diversity we see in planetary formation and evolution, we need a significantly bigger dataset of remote sensing spectroscopic observations that will permit comprehensive and meaningful study of their chemical composition.

Characterising exoplanet atmospheres

We can extract spectroscopic information on exoplanet atmospheres using both direct imaging and the transit method. In 2010, [3] the first spectral observations were made using direct imaging of a hot, giant planet at an orbital separation from its host star similar to that of Neptune from the Sun. Those observations were made with the SPHERE instrument on the ESO Very Large Telescope (VLT) and, as larger facilities come online over the next decade, direct imaging is expected to provide insights about hot, young planets in the outer regions of their solar systems.

For the transit method, spectroscopic observations can be derived both as an exoplanet passes in front of the star and just before and after it enters eclipse behind the host star. Transmission spectra are derived from primary transits with stellar radiation filtered through the annulus of atmosphere surrounding the planet as it passes in front of the star. This was first demonstrated successfully in 2002, [4] with the detection of sodium trace element absorption features in Hubble Space Telescope observations at visible wavelengths. Since then, transmission spectroscopy using Hubble, Spitzer and ground-based facilities has provided detections of ionic, atomic and molecular species [5].

Transmission spectra of hot-Jupiters and warm-Neptunes seem to be dominated by the signature of water vapour and sometimes clouds. Innovations in processing techniques have helped make us more successful in extracting spectral features and removing noise from data, which has allowed us to start to probe the atmospheres of smaller planets. Earlier this year, a team led by our group at UCL made the first successful detection of gases in the atmosphere of a super-Earth. Results showed the presence of hydrogen and helium, but no water vapour, in the atmosphere of 55 Cancri e (recently named by the IAU as Janssen) [6].

Emission or reflectance spectra can also be derived from just before and just after an exoplanet passes behind the star. These can reveal the presence of clouds and information on the thermal structure of exoplanets e.g. we can find evidence of whether there is a stratosphere that causes a temperature inversion, as in the case of the Earth, Titan or the giant planets.

A need for data and an opportunity

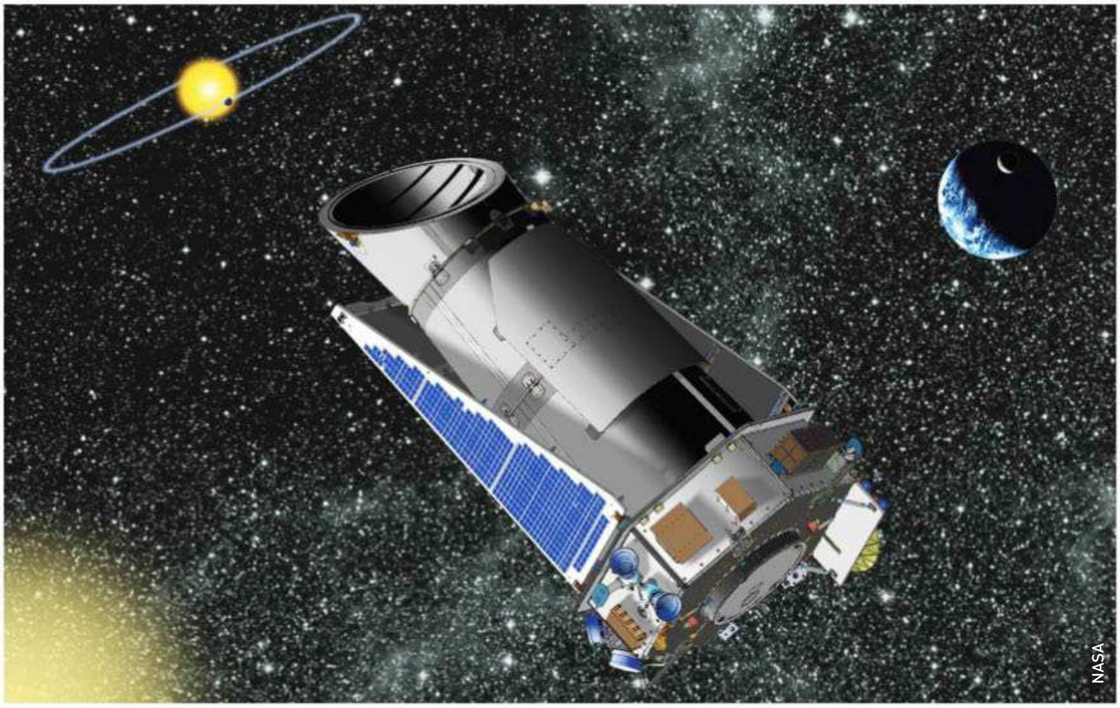
Despite successes to date, current data are very sparse with large uncertainties. There is not enough wavelength coverage: the reflected or scattered stellar flux may peak in the ultraviolet, visible or near infrared range, depending on the type of host star; thermal emission dominates at longer wavelengths. From studying planets within our own Solar System, we have found that we need observations in multiple spectral bands with different intensities for a robust analysis of any given atmospheric species. Moreover, multiple bands give us the opportunity to probe different layers within planetary atmospheres to study the vertical structure and understand cloud coverage.

Hubble is almost at the end of its life and, with the degraded performance of Spitzer, no data is currently available in the mid-infrared. The James Webb Telescope is due for launch in late 2018 and the European Extremely Large Telescope (E-ELT) will start operations in 2024. Both these facilities will have large collecting areas that will allow the acquisition of more light from exoplanets, compared to those currently available, especially from fainter targets. However, given the demand for observation time from the wider astronomical community, exoplanet researchers will have limited opportunities for access. In addition, if we focus on planets orbiting very bright stars, a small telescope can do wonders.

A bespoke space mission for characterisation of exoplanet atmospheres would have several advantages: experience with Hubble and Spitzer indicates that the instrument's stability and precision are as important as sensitivity. Effects of stellar variability can mean that combining measurements at different wavelengths taken at different times is not possible. Instruments are generally not calibrated at the level needed to combine multiple observations. Thus, instrumentation in orbit can make detections of faint spectral features that would be drowned out by Earth's atmosphere in ground-based observations.

Nonetheless, no space agency is planning a mission dedicated to exoplanet atmospheric observations for at least a decade. ARIEL [7] is one of the three candidates for the next ESA

> We haven't yet found any discernible pattern linking the presence, size or orbital parameters of a planet to what its parent star is like



◀ The number of confirmed exoplanets discovered has dramatically increased recently. In 2016 the science team behind NASA's Kepler spacecraft has announced a further 1,284 objects verified as being more than 99 percent likely to be a planet, bringing the overall total to more than 3,200 known worlds orbiting stars in our galaxy, out of nearly 5000 candidates.

medium class mission expected to be launched in 2026. This mission will be devoted to observing spectroscopically in the infrared a statistically significant population (500-1000) of known transiting planets in our galaxy. ARIEL is based on a 1 metre-class telescope and a spectrometer covering the mid infrared (from 1.2 to 7.8 micrometres), in addition to photometric bands in the visible and near-infrared that will allow it to monitor the stellar activity, measure the albedo and detect clouds. ARIEL will be placed in orbit at Lagrange Point 2, where the spacecraft is shielded from the Sun and has a clear view of the whole night sky. This will maximise its options for observing exoplanets discovered previously by other missions.

A decade is a long time to wait, and my colleagues and I at UCL are not the only exoplanet researchers hungry for data. Exoplanet spectroscopy is one of the fastest growing fields in astronomy. Hubble has had an over-subscription rate of 640 per cent for exoplanet science over the past five years and Spitzer, by the end of its cold operations phase, had reached an over-subscription rate of 1200 per cent for exoplanet spectroscopy. Access to facilities tends to be restricted to researchers located in countries that have participated in the construction of the satellite. This means that there is a growing unmet global market for high-quality spectroscopic data for exoplanet atmospheres.

The team behind ARIEL had already completed an Assessment Phase study for an ESA medium class mission, the Exoplanet Characterisation Observatory (EChO). By combining the instrumentation developed for EChO with flight proven spacecraft systems designed by Surrey Satellite Technology Ltd, a world leader in building and operating commercial small satellites, we saw an opportunity to develop an innovative, independent new model for astronomy and astrophysics space missions based on commercial delivery. Hence, the Twinkle space mission was born.

Twinkle space mission

Twinkle is a small, low-cost mission that will study the atmospheres of at least 100 bright exoplanets in the Milky Way using optical and infrared spectroscopy. The targets observed by Twinkle will comprise known exoplanets discovered by existing and upcoming ground surveys in our galaxy (e.g. WASP or HATNet) and space observatories (Kepler-2, GAIA, Cheops and TESS). The Twinkle satellite will be built in the UK and launched into a low-Earth, sun-synchronous orbit by 2019, using a platform designed by Surrey Satellite Technology Ltd and a payload built by a consortium of UK institutes led by UCL [8].

Twinkle is a small, low-cost mission that will study the atmospheres of at least 100 bright exoplanets in the Milky Way

The satellite structure is based on the SSTL-300 design, which has been adapted to house a slightly wider than usual payload, and with upgraded light shielding and stability.

Twinkle will collect light from its target planetary systems using a modified telescope system developed by STFC's RAL Space Facility for Earth observation missions. Behind a 50cm-class primary mirror, a series of small mirrors will fold the light to fit the space limitations. To compensate for the small movements of Twinkle during science observations, a steerable 'tip-tilt' mirror will focus a steady beam of incoming light into the science instrument package. There, the light will be filtered to remove unwanted wavelengths and divided into inputs for the two spectrometers.

The Exoplanet Light VIsible Spectrometer (ELVIS) is a visible spectrometer channel (0.4-1 micrometres) based on the Ultraviolet and Visible Spectrometer (UVIS) instrument channel, built by the Open University and launched on the ExoMars Trace Gas Orbiter (TGO) in March 2016. Adaptations to ELVIS (optimising the wavelength range of the detectors, using an alternative diffraction grating and making a few minor

▼ Artist's impression of the super-Earth exoplanet GJ 1214b orbiting the nearby star GJ 1214. The exoplanet, orbiting a small star only 40 light-years away from us, has a mass about six times that of Earth.

changes to the electronics) will allow Twinkle to monitor stellar variability in the exoplanet systems and to detect signs of cloud cover for some of the largest, brightest exoplanets in its target sample.

Twinkle's infrared science instrument consists of two interconnected spectrometers that cover spectral bands in the near-infrared (1.3-2.4 micrometres) and mid-infrared (2.4-4.5 micrometres). The bands are optimised for studying atmospheric features in bright exoplanets, such as hot-Jupiters and warm super-Earths orbiting close in to their star. The wavelength range will allow detections of all the expected atmospheric gases, including water vapour, carbon dioxide, methane, ammonia, hydrogen cyanide, hydrogen sulphide, as well as exotic metallic compounds such as titanium monoxide, vanadium monoxide and silicon oxide. The infrared spectrometer has been designed by STFC's UK Astronomy Technology Centre (UKATC) and incorporates design heritage from the James Webb Space Telescope's MIRI infrared instrument.

Although Twinkle's instruments will struggle to produce full spectra for planets at habitable temperatures, simulations suggest that Twinkle may be able to obtain a handful of data points in the infrared for small, rocky planets. This means that as well as delivering the spectral signatures of bright exoplanets, Twinkle can also help identify targets of interest for further observation by larger telescopes in the future.


ESO/L. Calçada

We will be drawing up a preliminary list of potential targets over the coming months and will be enlisting a group of amateurs to assist with observations of stellar variability. Our education programme, EduTwinkle, also aims to involve school students in research needed to lay the groundwork for the Twinkle mission. We are currently piloting a project linking young PhD and post-doc scientists with groups of secondary school students to compile molecular data points essential for modelling atmospheres of cool stars and exoplanets.

With Twinkle, we've aimed to do things a little differently. We are funded outside the usual agency programmes: preliminary work and the instrument study have been funded through a grant from the European Research Council, UK universities and industry. Funding for the overall mission will come from a combination of public and private sources.

We've chosen a name for our mission that is easy to remember and doesn't require background knowledge of science, history or culture. As a transiting planet makes the host star appear to twinkle, this seemed an appropriate choice. The words of *Twinkle, Twinkle Little Star*, one of the most well-known songs in the English language, sum up perfectly the starting point for any scientific discovery: 'How I wonder what you are?' Observations with Twinkle, alongside those from traditional space missions and ground-based campaigns, will take our current wondering about exoplanets to a new level of understanding. ■

Observations with Twinkle will take our current wondering about exoplanets to a new level of understanding

About the author

Prof Giovanna Tinetti is Lead Scientist of the Twinkle space mission, Principal Investigator for the ARIEL ESA Candidate mission and Professor of Physics and Astronomy at UCL.

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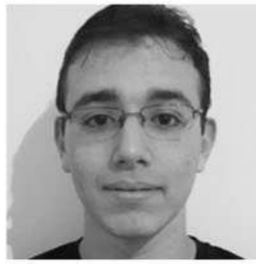
Israeli students inspired by nano-satellite projects



Roy Orbach
Herzliya Space Laboratory, Herzlyia, Israel

◀ Students working on Hoopoe with Donald James (NASA's associate administrator for the Office of Education) and Avigdor Blasberger (Head of the Israel Space). Agency).

As the space industry moves forward in the 21st century, satellites are becoming easier to build and launch. One particular type of low cost satellite is the CubeSat - a small spacecraft built from multiples of 10×10×11.35 cm cube-shaped units. Soon after the CubeSat concept was proposed in 1999 and the first launch in 2003, it was quickly adopted by research facilities, space agencies and universities all around the globe. But these weren't the only institutions that decided to use the advantages of CubeSats. In Israel one pioneering institute had its own slightly different idea on the options the new platform offered to high school students.

The idea of using the new Cubesat platform to educate Israeli school grade students was conceived in 2003 by Dr Anna Heller, who had worked in the aerospace industry as a researcher for the development of the new ErosB and Ofek6 Israeli satellites projects and rocket detection IR technologies.

After a few months of searching, the newly formed idea turned into reality and the project was accepted by the Israeli high school Handasaim and later on by the science centre in the city of Herzliya, soon after getting mentors from Israel Aerospace Industries and funding and help from various sources from all over Israel - including the Ministry of Science.

The project was named 'Duchifat' after the Hebrew name for the Hoopoe bird - Israel's national bird - and the first satellite was called Duchifat-1.

During the first 10 years of the project, a laboratory was created in the city of Herzliya specifically for designing and developing the first student nano-satellite global network. In this lab, students worked hard to create the facilities required to build a satellite: first a clean room with a pressure system to run an environment with minimal levels of dust and humidity. Such a room requires

A laboratory was created in the city of Herzliya specifically for designing and developing the first student nano-satellite global network

▲ Ground station in Herzliya Science Center, used daily by students communicating with Duchifat-1 and other radio amateurs satellites.

high standards, because during construction the satellite must be kept in a clean environment.

The students also worked on a ground station for satellite communications, with the help of amateur radio enthusiasts. Today, the ground station is also used by amateur radio hobbyists, and students who participate in amateur radio, to communicate with others like them around the world, using satellites to strengthen their connection. Using the ground station, students also tracked and communicated with various satellites to learn about satellite communications - they contacted amateur-radio satellites, weather satellites and research facilities - and even made contact with the astronauts aboard the International Space Station (ISS).

But even after having developed such facilities, a number of problems remained to be solved. How could the project continue attracting students until the real work began? And, how would students be assigned to work on the satellite?

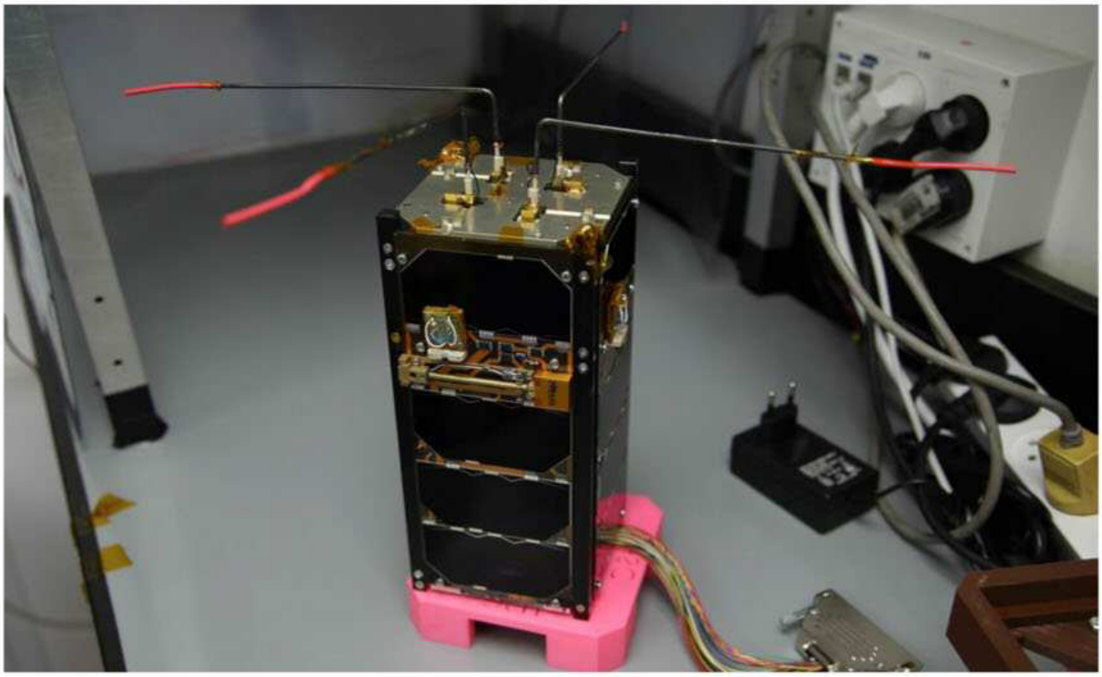
Surprisingly, the answer to both of these questions was found with the same solution. Every student is assigned one of the main aspects in the design of a satellite subsystem - thermodynamics, communications, software, etc. The teams and their mentors cooperate - just like branches of a start-up company, except the final product is not an app or a new gadget - but rather a new, student-built satellite.

After finishing their part, the students present their work as a final project in front of their mentors and school staff. In the initial stages their work was largely theoretical and often related to studying existing satellites. But by around 2011, the theoretical part was over and work on the satellite's components and the practical research began.

At a basic level, Duchifat has several goals:

- Education - which consists of two parts. The first is to prove that students can really build satellites and teach teenagers from all around Israel about satellites, both in terms of construction and communicating with them. The second part is focused on giving the student an inside look at the space industry. The satellite was also used to teach satellite communications in different schools around Israel.

Every student is assigned one of the main aspects in the design of a satellite subsystem



▶ Hoopoe (Duchifat-2) in clean room after integration with its payload (multi-Needle Langmuir Probe) deployed.

◀ The launch of a Dnepr launcher (converted ICBM), used today to launch small satellites like Duchifat 1.

- Amateur radio satellite - amateur radio had been a large part of Duchifat since its beginning. Hobbyists helped create the ground station, guided the communications team and generally helped the project to thrive. As a result, it became obvious that Duchifat would be an amateur radio satellite, detecting radio frequencies used by amateur radio hobbyists and forwarding their messages. By doing so, it could help improve connections between amateur radio hobbyists around the world.
- A search and rescue satellite - the main mission of Duchifat-1 is to serve as a search and rescue satellite that helps lost travellers. It uses an experimental communications protocol called APRS (Automatic Packet Reporting System) which allows sending messages and location using radio signals.

To facilitate its main mission, Duchifat's orbit passes above both of Earth's poles at a height considered a low Earth orbit (LEO) - which is about 600 km high. Because of its special orbit, it passes in range of every location on Earth twice a day, with the second passing occurring 90 minutes after the first. After getting a signal, Duchifat stores the request, along with the location from which it picked up the information. It keeps the information stored for 24 hours and downloads the data whilst flying over a ground station. The ground station forwards this information to rescue teams in the area around the incident.

The information Duchifat-1 receives is sent by mobile radio communicators, devices that don't need a phone signal and, due to that trait, can be used to help save travellers who are in areas which have bad phone signals or no phone signals at all. Even though its search and rescue payload is still going through tests and thus it is not yet active, the ground station is daily visited by the project's students, who communicate with Duchifat-1 and store its data.

On the evening of 19 June 2014, Duchifat-1 was successfully launched from Russia's Yasny launch base aboard a Dnepr converted ICBM, in a launch that broke records for most satellites launched at once (36 other satellites were launched alongside Duchifat-1).

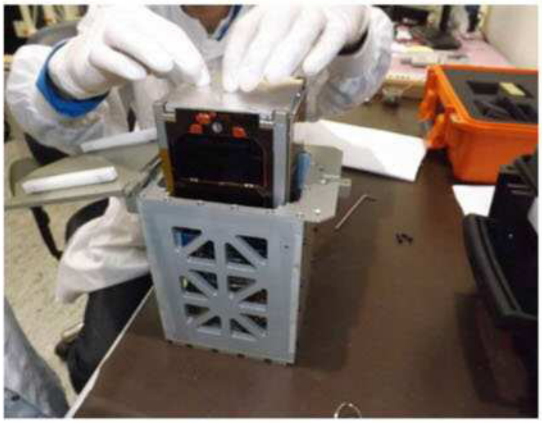
A few chosen students and the project's director and founder Dr Heller travelled to the launch site while the rest of the team held a press conference in the Herzliya laboratory, watched live video of the launch process and had a video chat with the team in Russia. It was an emotional event, which concluded over a decade of never-ending hard work by the project's Dr Heller, and the director of the Herzliya Science Centre Dr Meir Ariel, as well as many more that contributed to the project. Among them were current and past students, many of whom had already graduated before Duchifat's conception turned into reality.

The mission selected for Hoopoe in 2010 was to conduct research on the density of plasma in the ionosphere

◀ The ground station's amateur radio section, where students practice and learn radio and amateur radio communications.

▶ Duchifat-1 in its final integration stage.

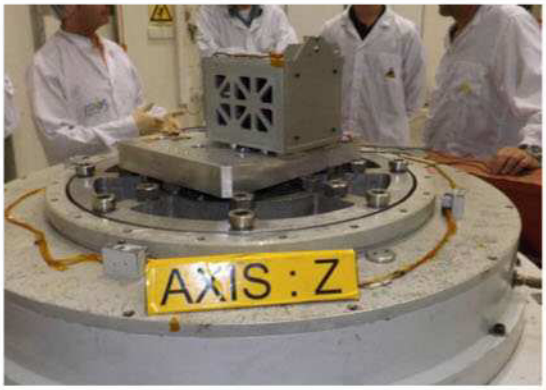
▶ Far right: Duchifat-1 being inserted into the pod used in the vibration and thermal-vacuum tests.



After Duchifal-1 was launched, the team successfully enrolled Duchifat-2 (also known internationally as Hoopoe) in the QB50 - a project that consists of 50 nano-satellites built by universities and research facilities around the world.

The satellites were given different goals and tasks that involve research in the lower layer of the thermosphere - the ionosphere, at about 300 km high and a largely unexplored area. Different research facilities and universities were chosen and, among them, only one Israeli applicant was selected. It was also the only applicant where the engineers making the satellite were high school students - a group of five Israeli high schools led by the Herzliya Space Lab.

▶ Duchifat-1 during the vibration tests at Israel Aerospace Industry MBT Space Division.



▼ Students in the clean room preparing Hoopoe for delivery to the launch site.

In order to promote science in the outskirts of Israel, Duchifat 2 was built by five different high school teams - our group from Herzliya, who led the project, and four groups from Yeruham, Ofra, Ofakim and Ahed-Beduin.

Each team was led by professional engineers and had its own missions - mechanical design, atitude determination and control sub-systems (ADCS), mission control centre, etc. The teams met every couple of months for design reviews.

And so, the team started working again. There was no time to rest after the launch of Duchifat-1, and the challenge of Duchifat 2 had started - to construct a high-tech communications and research satellite in a short period of time, with launch scheduled for the end of 2016 along with the rest of the satellites.

The mission selected for Hoopoe in 2010 was to conduct research on the density of plasma in the ionosphere. The satellite will start from an altitude of about 400 km - as the satellites are planned to be launched from the Space Station - and will quickly descend due to atmospheric drag. After some nine months its mission will end when it burns up in the atmosphere. Data collected during the mission, along with normal information regarding the satellite, is to be sent to QB50.

Even though the basic educational objective remained after Hoopoe started, there are many striking differences between Duchifat-1 and Hoopoe. The most notable is the size - Duchifat comprises two CubeSat units making it twice the size of Duchifat-1, which was one CubeSat unit.

The difference in size means a few other changes had to be incorporated - it required a strong thermal system and a more complicated electric power system. Another difference is that Hoopoe will be able to rotate on its hinges - an ability it requires for aligning its payload to the direction of the velocity vector. Its payload - multi-Needle Langmuir Probe, sends electric shocks out of its needles, attracting the plasma particles in the atmosphere, and measures the results.

With the satellite finished and headed towards its launch to the ISS at the beginning of 2017 and the release into orbit from the Space Station later in the year, Dr Meir Ariel, the director of Herzliya Science Centre, already has plans for the future.

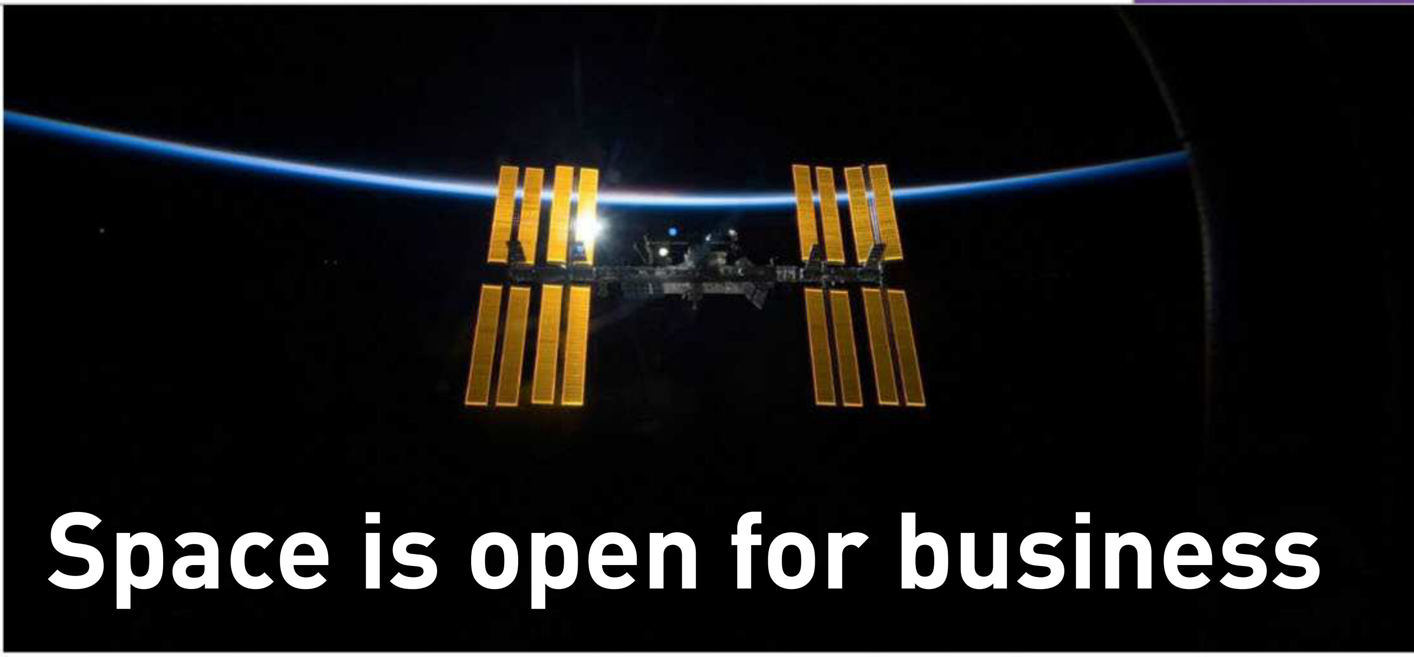
Work on Duchifat-3 has already started. This three unit CubeSat will likely include a different kind of payload and, unlike its predecessors, will include a camera, which will be used to teach students about downloading data from satellites, about the weather and Earth observation satellites.

A successor project to Duchifat is planned to start in a few years. The project, considered a giant step for education in Israel, is called the 'Israel 70' project, a national collaboration celebrating Israel's 70th year of independence.

The ambitious project will be based on the knowledge and experience gained from building the Duchifat satellite series and will be led with the help of the students of the Herzliya Space Lab. Over a few years, some 70 satellites will be built by high schools and universities all over Israel. The satellites planned will include two different layouts: some satellites will be a one CubeSat unit (named Pawns) structure, like Duchifat-1, however the bigger ones will be 3U satellites (called Knights) like Duchifat-3. The question raised is what will come after Israel 70? Well, as they say in our lab, the sky is not the limit. ■

Some 70 satellites will be built by high schools and universities all over Israel

▼ Students working on Hoopoe with Robert Cabana (Director of NASA's Kennedy Space Center) and Moshe Fadlon (Mayor of Herzliya).



Space is open for business

A new space era is slowly coming into focus. It is a future where space agencies won't be the only actors and will increasingly expand their partnerships with the private sector. As part of its policy to actively cultivate this new space agenda, the European Space Agency (ESA) organised a new kind of event in London during the autumn to which it invited space and non-space industry representatives to sit together for the first time and exchange ideas on what the future of space exploration holds for them - both on Earth and in space. The 'Space for Inspiration - ISS and beyond' event was an open invitation to a broader community to join the space club. It was also a unique opportunity to build cross-sector relationships and learn about promising research taking place in orbit.

Bernhard Hufenbach
ESA Directorate of Human & Robotic Exploration, ESTEC, The Netherlands

When nearly 300 people gathered in one of the world's most renowned science venues, the London Science Museum, on 14-15 September, just one third of the audience came from industry. This was part of the plan because the idea was to engage new stakeholders from institutional and private sectors with the non-space community.

"We want to draw more people into the future, and explain how they can get involved. The opportunities are unlimited," said David Parker, ESA Director of Human Spaceflight and Robotic Exploration. "We all have to take advantage of the amazing thing we have created in the International Space Station."

There was much talk about the value and benefits resulting from the International Space Station (ISS), a global platform for research and development with scientists from over 90 nations running experiments to drive innovation.

The major assembly of the Space Station was completed in 2011 and we now have five years behind us of intensive research, pointed out Rainer Horn, from SpaceTec Partners. "The ISS is the fastest moving incubation centre and it has proven itself as a business accelerator," he told delegates.

Its impact can be quantified and a recent study presented during the event tried to assess the economic and wider impact of the investment in the ISS programme. Figures unveiled were quite revealing: one euro spent on the ISS produces

One euro spent on the ISS produces a total of 1.8 euros of value for the European economy

◀ Discussing how to feed the planet (from left): Roy O'Mahony, Øyvind Mejdell Jakobsen, Pierre Magnes, Rob Suters and Frank Zimmermann. Roderik van Grieken moderated the panel.

ESA/M Alexander

▶ Beth Healey.

ESA recognises that agencies won't any longer be sole customers and so is seeking to strengthen the economic dimensions of space exploration

a total of 1.8 euros of value for the European economy. The Space Station is also a job generator - for each new job supported in the space sector thanks to the ISS programme, one additional job was supported in the wider economy.

More and more, this platform in low Earth orbit is becoming a place that is not just limited to what space agencies do and during the two-day conference expert speakers repeatedly called for broader access and use of the Space Station, with more flexible and open-minded approaches.

For Marybeth Edeen, NASA manager of the ISS Research Integration Office, the formula is clear. "We should allow companies as much time, effort and risk as they are willing to accept. Whether their research is going to be successful has to be their discussion, not our decision. We need to scale back our requirements to make it as simple as we can for them to get to orbit."

Scientists and private companies were invited to take advantage of the Space Station. David Parker even made an offer - a third of all the research opportunities should be offered to industry. Figures from NASA suggest about 30 per cent of ISS users should be commercial users.

However, there was also the acknowledgement that research in space is not an easy thing to take on. "It is not immediately obvious where microgravity experimentation can come in handy for industry," explained Chris Bee, ESA Technology Transfer Broker for the UK.

When contacting companies to promote research and development of their products and ideas in space. "We just have about a hundred to one success rate. It is like truffle hunting," Bee added. According to him, the event was key to improving that success rate.

ESA had already committed to participate in the exploitation of the Space Station up to 2020 and during the ESA Council at Ministerial level in December 2016 European Member States agreed to continue funding ISS exploitation activities through to 2024.

The international partners wish to keep it orbiting Earth as long as they can, taking into account that it has been technically certified for operations up to 2028. However, there is the need to find a way to transition smoothly from the ISS

▶ Namira Salim, Space Tourist and Founder of Space Trust.


ESA/M Alexander

▼ Pictured (from left): Gerd-Ulrich Grün, Sylvie Duflot, Olivier de Laet, Walt Aldred and Chriss Bee.


ESA/M Alexander

◄ Discussing cultural aspects of space (from left): Duncan Copp, Thorsten Schmidt, Angelo Vermeulen, Annalisa Dominoni, Benedetto Quaquaro and Helen Keen.

to a new platform. NASA intends to cede low Earth orbit to commercial ventures.

When more and more people regularly enter orbit we could “industrialise spaceflight - and that will allow us to explore deep space in a sustainable way”, believes Michael Suffredini, president of the commercial space division of Stinger Ghaffarian Technologies.

Space goes commercial

In March 2015, ESA launched an initiative aimed at opening new opportunities to the private sector. It invited industrial partners to come forward with partnership ideas that will help advance objectives for exploration but underpinned by an industrial business plan.

ESA recognises that agencies won’t any longer be sole customers and so is seeking to strengthen the economic dimensions of space exploration, and ultimately contribute to the sustainability of space exploration in low Earth orbit and beyond. It is offering a ‘launch pad’ to develop products and services. Following a call for ideas, ESA and eight private partners have concurred on their mutual interest in projects that will be carried forward through a pilot phase to assess its feasibility and commercial viability.

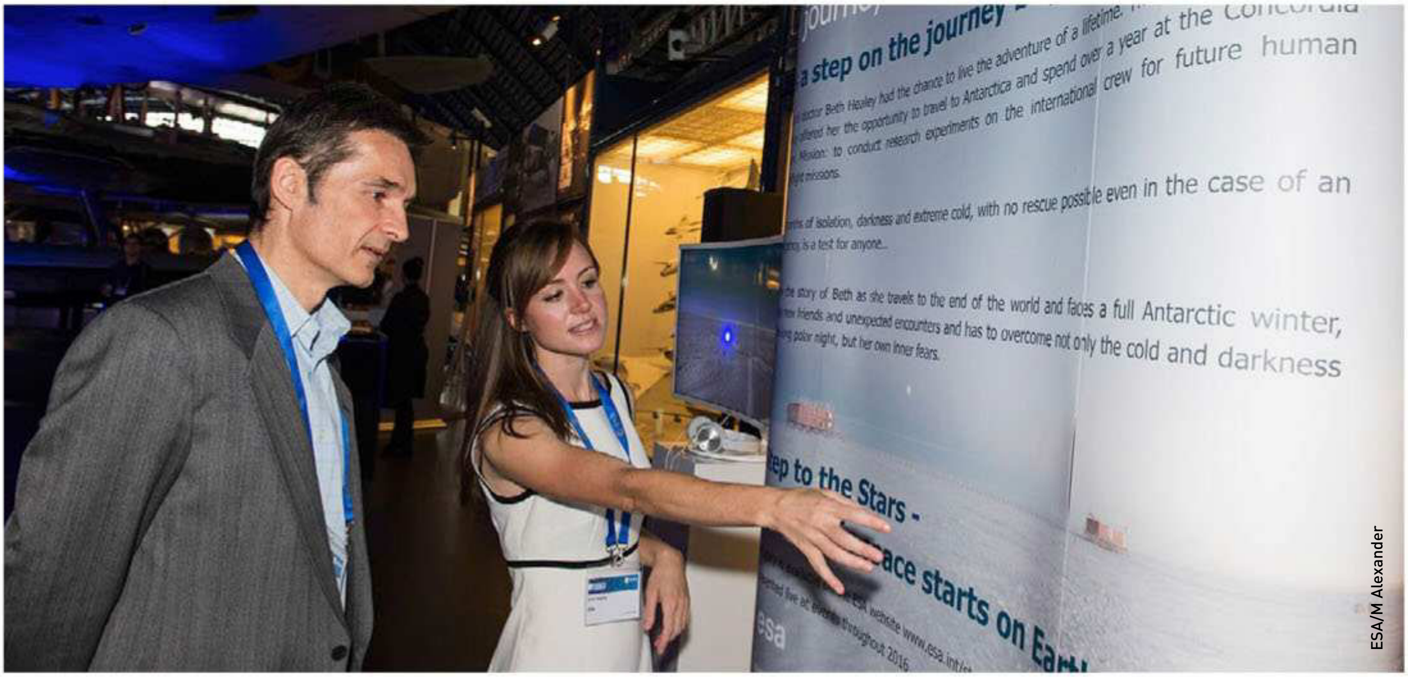
Most of the attendees confirmed this trend. During a live audience poll, most participants voted for industry having a driving role in the push for commercial utilisation of space, an opinion shared by Walter Cugno, vice president of Exploration and Science Domain at Thales Alenia Space Italia. “The role of the private companies in LEO should be increased with business plans put in place,” he said.

John Roth, who works in strategy and business development at Sierra Nevada Corporation, echoed these thoughts. “In the US there is a tremendous amount of risk taken. It takes some guts, passion and long term commitment going after commercial space,” he added.

Public-private partnerships seem to be the key for low Earth orbit operations. “The end users of LEO commercialisation will be hybrid,” suggests

▼ Maria van der Hoeven, former Dutch Minister of Education, Culture and Science.

Solutions ‘made in space’ are helping to shape our daily lives and address global challenges on Earth in areas such as energy, health and food production



▲ Promoting the role of the private sector in space during a networking session.

Bart Reijnen, head of the Bremen site for Airbus D&S. Now is the time to plan new ways of working together - and the clock is ticking.

New space

The new space is a crossroad of sectors, resources and people. ESA is already forging new partnerships with the private sector and planning new ways of working together. Mariana Mazzucato, professor of Science Policy Research at the University of Sussex, highlighted the success of mission-oriented organisations like ESA, and the role of the governments supporting them.

"I want to debunk the dichotomy between the boring-but-needed fix-the-basic-problem-public sector versus revolutionary Elon Musk. Elon, be part of the new conversation. Government is more than just the money it collects from taxes," she asserted.

Rainer Horn explained that while billionaires like Elon Musk attract other entrepreneurs into the game, this New Space is "very particular" in the way it motivates a unique type of personnel. "The talented staff is not motivated for technological perfection but to achieve ambition," he said.

"Why don't we provide our platforms to entrepreneurs, investors and the public to enable them to start working with all these technologies?" asked Rob Suters, of Melissa X. "We've decided to move away from the classical technology transfer model and change the paradigm."

ESA Director General Johann-Dietrich Woerner has coined the concept 'Space 4.0'. In his own words, this new version of space is "innovation and information to inspire and to interact".

Space to inspire

Exploration is not only science but also economic gain. It is not only international cooperation, but it is also inspiration for everyone on planet Earth. Engagement is an important part of the process. "Whether you work in the fashion, farming, food or film industries, the message is to be as inclusive as you can," said film producer Duncan Copp. "The more we assimilate the idea of space into the fabric of society, the easier people will accept it," he added.

▼ Rainer Horn.

◀ ESA Director of Human Spaceflight and Robotic Exploration David Parker.

Space for Inspiration was also a celebration of the diversity and pervasiveness of space in technology, industry and culture. Other speakers introduced work that used space as inspiration, including Michelin-starred chef Thorsten Schmidt, research doctor Beth Healey - who spent a year in Antarctica - Politecnico di Milano professor of design Annalisa Dominoni, and the Raspberry Pi Foundation's education engineer David Honess.

Down to Earth

Solutions 'made in space' are helping to shape our daily lives and address global challenges on Earth in areas such as energy, health and food production. Many promising ideas were discussed.

An ESA-developed water treatment system was chosen as one of the 100 top climate technologies at the latest UN climate change conference. It was developed for the remote station Concordia in Antarctica and it is being used right now in Morocco.

Rob Suters, managing director of IPStar BV, maintained that the challenges in space are essentially the same as on Earth: water, waste, food and energy. And Abhay Bhagwat, senior director for sustainable innovation at Unilever, said: "I don't see any conflict between meeting the basic needs of the human population and thinking about the future of mankind."

In this context, Pedro Matos, project manager of the World Food Programme, believes that it would be unrealistic to ask mankind to stop dreaming about space exploration for two decades

Participants voted for industry having a driving role in the push for commercial utilisation of space

until we solve our problems on Earth. "Incredible technological advances in the past years have lifted a billion people out of poverty," he claimed.

Future steps

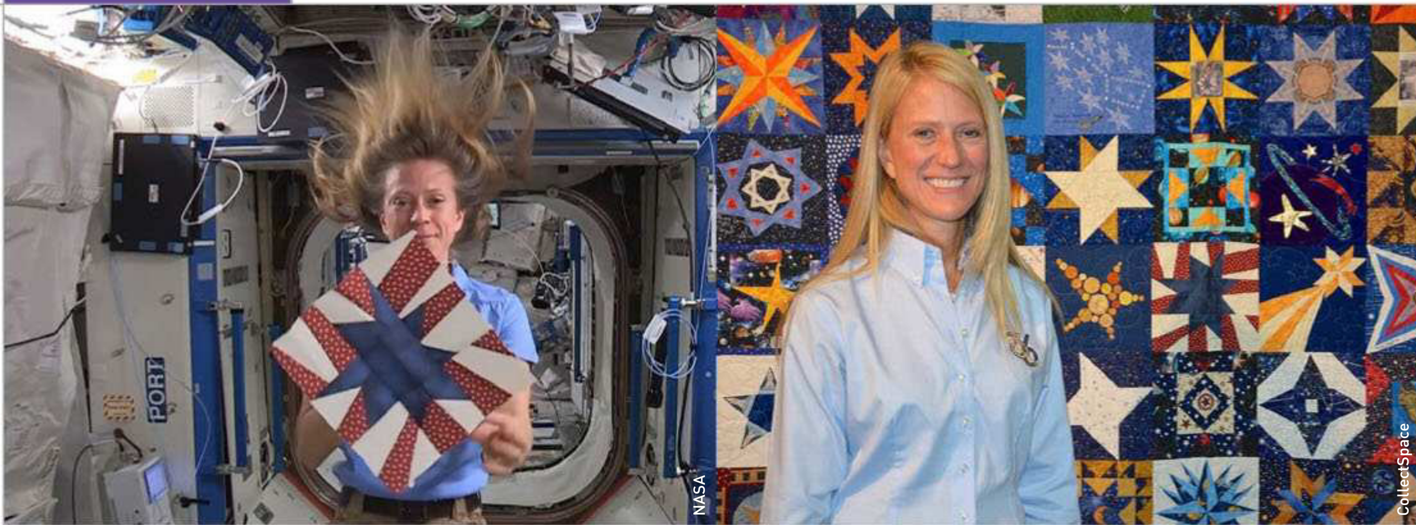
This event has been the start of a process, and it is not intended to be a one-off. "We want to build new partnerships and explain that the ISS is not just about space agencies. We want to use this opportunity today as a kick starter to interact with a broader community," said David Parker.

ESA wants to keep exploring our Solar System and beyond. It is at the beginning of an exciting adventure, mobilising efforts and ideas to get further into space, and not stop dreaming about a better future on Earth and in space. After all, as Kirk Shireman puts it in his role as NASA manager of the ISS programme: "Our teenagers have never known a time when humans didn't live and work in space. What a wonderful thing that is." ■

About the author

Bernhard Hufenbach is head of ESA's Strategic Planning and Outreach Office for Space Exploration, responsible for supporting ESA-wide strategic plans for space exploration and enlarging the stakeholder community engaged in the space exploration endeavour. He is involved in the definition of future space exploration missions and ESA roles, the development of strategic partnerships, and the stimulation of commercial activities related to space exploration.

▼ Gregor Morfill, CEO of Terraplasma GmbH, receives the award 'Solution to Global Challenges' for the success of his work in transferring cold plasma applications from space to Earth. He is pictured with Maria van der Hoeven and Jean-Claude Worms.



▲ Left: Astronaut/Artist Karen Nyberg, ISS Expedition 37, shares her star quilt block.
Right: Astronaut/Artist Karen Nyberg with the completed AstroBlock Quilt Challenge quilt that incorporates her star block in the centre.

Space for art
Quilting in orbit

The 'Space for Art' column is dedicated to the inspiration that comes from the interaction between space and art. One of the most interesting things about this inspiration is that it presents itself in many artistic forms - and it is always such a pleasure to be surprised by discovering some new and creative way that artists are presenting the story of space exploration.

One of these surprising and recent discoveries is the world of quilting. This is another whole world of fine art that I was completely unaware of but thrilled to have now discovered. Of particular interest, of course, has been space-themed quilts.

These are quilts created and sewn by 'fibre' artists - and in addition to simple fabric and thread, they also beautifully incorporate many forms of mixed media to add texture and dimension.

So, how did this wonderful discovery come about? You might recall in the last issue of ROOM, we featured the story of the Space Suit Art Project. HOPE - the first of the art suits - was created from the individual paintings by children at the University of Texas MD Anderson Cancer Center that were then beautifully quilted together by space suit manufacturer ILC Dover.

HOPE was invited to participate in a display at the 2016 International Quilt Festival in Houston, TX. This is where we made our acquaintance with the wonderful world of fine art quilting!

As a point of reflection and to highlight another first in the interaction between space and art, during her International Space Station (ISS) Expedition 37 mission in 2013, astronaut Karen Nyberg became the first astronaut and artist to quilt in space. Not only did she quilt in space but she did so by sharing her quilting experience in a global way.

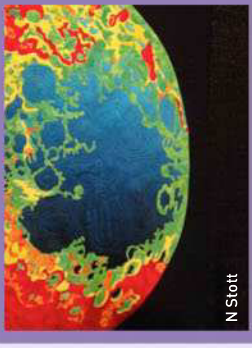
While in orbit, Karen sewed her own star-themed quilt block and - in partnership with the International Quilt Festival - she also invited fellow crafters to join her in stitching together a global community space quilt made from their own star-themed quilt blocks and to help celebrate her mission and passion for the quilting arts.

Karen's 'AstroBlock Quilting Challenge' received over 2000 quilt blocks from around the world! Too many for just one quilt so they made 28.

Karen's art and her own love of quilting certainly generated more excitement for the art of quilting, but at the same time did a great job opening up the world of space exploration to a group of people who might not otherwise have been interested. As a result, generating excitement about all the amazing things happening in space that are benefitting us all right here on Earth.

At this year's International Quilt Festival in Houston, the AstroBlock Challenge quilts were on display again and HOPE was displayed alongside the quilt that features Karen's star block at its centre.

Nicole Stott
Artist, Astronaut and SciArt Advocate



◄ Top left: The Moon in the Classroom" by Patricia A Hobbs.
'Top right: Leaving Home: Launch of the Apollo 8' by Tanya A Brown.
Bottom left: 'The Rocket that Grandpa Rode' by Joanne S Best.
Bottom right: 'Pseudo Lunar Topography' by Meggan Czapiga.

In Karen's own words, "I think it's extremely important to be well-rounded and exercise both sides of your brain - and sometimes if you build the creative part, you need that in the scientific part as well. I'm so happy the way this turned out because what I had in my mind, what I dreamed it turning into, actually did. In fact, it is bigger than that." 'Space for Art' agrees!

As if the AstroBlock Challenge quilts and HOPE on display with them wasn't enough, I was impressed to also find the story of the Apollo lunar missions being told through quilts.

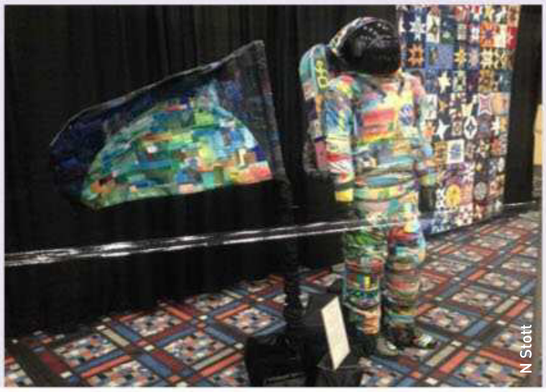
In an appropriately named collection 'Fly Me to the Moon', quilting artist Susanne Jones has curated art quilts from artists in eight countries around the world in celebration of humankind's first walk on the Moon.

As Susanne describes it, this multifaceted collection includes quilts that, "commemorate the iconic images from the news; recall personal memories of July 20, 1969; honour all of the Apollo missions; recognise all of the Apollo astronauts; investigate scientific Moon images; examine NASA's cool tools; explain myths associated with the Moon; define Moon idioms; replay music inspired by the Moon; visit pop culture icons; and make us fall in love again under the romantic Moon".

All of the quilts in this collection are 18 inches wide and 30 inches long and were curated to be a cohesive exhibit. Although the quilts are varied in style, the theme is always the same - the Moon - and the 179 art quilts tell the story of our fascination with our nearest planetary neighbour since the dawn of time through to the Apollo moon walks and beyond.

Both well-known and new fibre artists have stretched their creative muscles to draw the viewer in to the world of science, romance, history and fantasy. You can see all of the 'Fly Me to the Moon' quilts here: https://www.flymetothemoon.gallery/art-quilts/

I have vivid personal memory of watching Neil Armstrong and Buzz Aldrin take those first steps on the Moon, and my own memories of excitement about it, of going outside and looking at the Moon and my parents reminding me that that's where these two men were 'walking' - and of thinking about just how incredible that really was.



◄ HOPE, The Space Suit Art Project, on display with the Karen's AstroBlock Challenge quilt at the 2016 International Quilt Festival in Houston, Texas, USA.

The Moon has been inspiring us since human beings first looked toward the sky and recognised the glowing beauty and wonder of it. We have been there. My hope is that we will be going back in my lifetime, that we will establish a permanent presence there, and that our place on the Moon will inspire us to continue to explore even farther from our home planet to places like Mars and beyond.

Like this beautiful collection of quilts that tell our story of our history and experience with the Moon, I look forward to the quilts that will tell the stories of our future missions back to the Moon, on to Mars, and beyond!

When we go back to the Moon and when we make those first steps on Mars we will be wearing space suits. As we've seen, space suits designed for use in space have inspired space suit art, but they have also inspired fashion designers to think differently about our own Earthly clothing.

That inspiration has been based on the technology as well as on the 'cool' factor that comes from all things space! Continuing this edition's theme of the fine art of fibre artists, please continue reading and discover more in the following article by Annalisa Dominoni and Benedetto Quaquaro of the Politecnico di Milano, Italy about how 'Space research inspires innovation in fashion'. ■

Space research inspires innovation in fashion

▶ Moon Boot advertising campaign clearly displaying the inspiration from Armstrong's first lunar footprint. Innovative shape and material together with lightness and freedom of movement are the keywords of the success of the Italian brand.

Annalisa Dominoni
School of Design, Politecnico di Milano, and Co-Owner of (a+b) dominoni, quaquaro

Benedetto Quaquaro
School of Design, Politecnico di Milano, and Co-Owner of (a+b) dominoni, quaquaro

How many times has space inspired us? Our worlds of thought - science, philosophy, religion, technology, literature - have always looked into the universe. As have the many disciplines related to art and its practice - design, cinematography, communications, music and many more. The sky and stars continue to exert a strong influence on our culture - nowhere more so than in the world of fashion.

Innovation, shape, scenario and narration as well as technology can suggest to us new ideas and products destined to revolutionise the world of production and become best sellers on the international market. For example, from Neil Armstrong's lunar boots came a pair of sneakers with a strong power of absorption thanks to technology transfer.

At the same time and looking from another point of view, the Moon landing has also inspired great ideas, like the Venetian entrepreneur Giancarlo Zanatta, who in 1970 decided to clone the 'footprint' of Armstrong's foot to make the mythical Moon Boot snow boots.

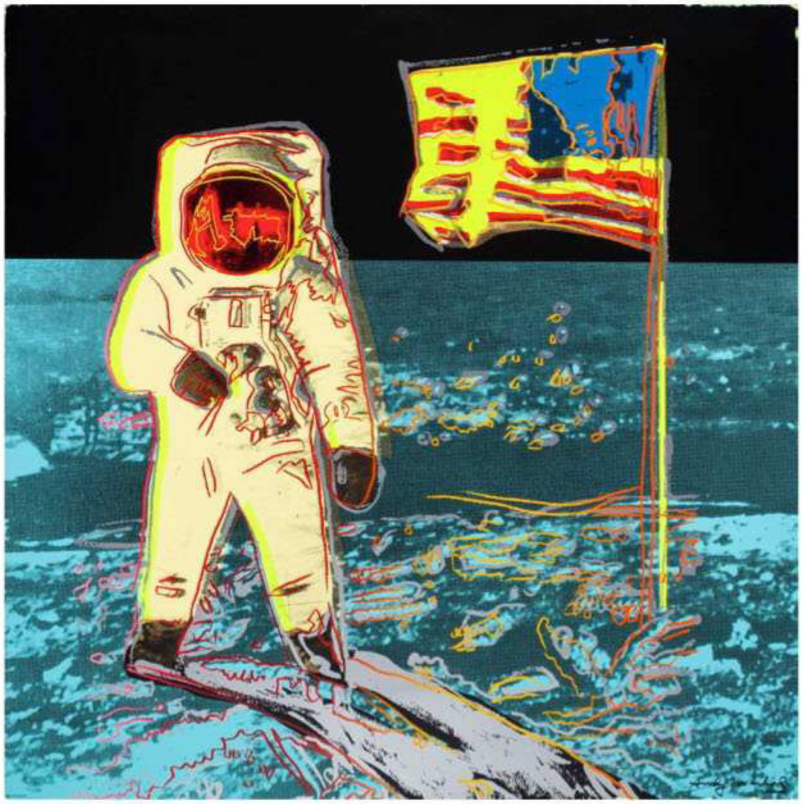
"America is thrilled and celebrates its conquest of space," says Zanatta in an interview by Claudio Trabona, 'Dal piede di Armstrong l'idea per i miei Moon Boot' for Corriere del Veneto in July 2009. Standing in front of a giant poster of Buzz Aldrin walking on the Moon, he says: "It's beautiful, it is strong, the man seems to come out from the image. I cannot take my eyes off those boots so special and from that imprint. Well, it happened to all of us if we think about it: the world's attention was not directed precisely at the foot of the astronauts?

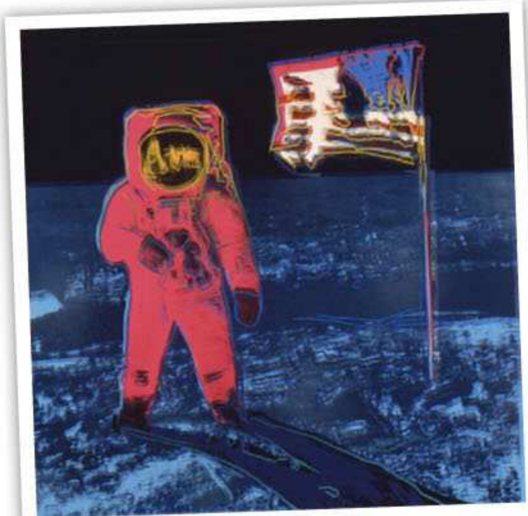
"If we strive to remember, each of us will think of Armstrong descending the ladder, the gait clumsy and bouncy, the famous phrase 'a giant leap for mankind' witnessed by so many and clear footprints on the dust from between the craters. Everything is focused on those feet. Here the bulb lights up. Why not copy those funny boots and make snow boots that leave a similar imprint on the snow? I came back to Giavera del Montello, in my factory, and decided to try it. Three of us worked on this product along with a designer for the logo. The only complication, if I may say so, was the sole that would have to reproduce the footprint on the Moon effect, actually later modified to make it more adherent to the slippery surface of the snow.

"Not everyone in the company is confident about this," he admits. "Some who asked, 'but where do we go with sta ciabatta? [from the Italian dialect word 'slipper'] were resoundingly contradicted. A few days after the launch, at a trade show in Germany, orders begin to rain in. Hundreds. Thousands. Today, some 40 years later, we can count 23 million pairs sold. And thanks to the Moon Boots, the Tecnica Group has risen to worldwide fame."

A pair of snow boots evoking the greatest of conquests has a very strong appeal to consumers: the result of subliminal marketing combined with strong product innovation. The Moon Boot was created using nylon fibre, the maximum in terms of modernity during the Seventies, a time when mountain shoes continued to use traditional raw materials - the skins and furs of animal origin.

Another big innovation was the introduction of a bright colour palette, which was revolutionary in the day. Of course, these were the times of Pop Art and Andy Warhol, who spread a new vision through presenting and valuing consumer goods as powerful visual communication signs, which were considered important enough to become privileged subjects of the art in themselves. In this international context, a company which proposes a new shoe that rejects the eternal brown leather is a striking thing! But that's not all: with ambidextrous footwear, and without size constraints, customers feel more free and light.





The Moon Boot can also be considered as one of the first examples of 'democratic' design: it is on the feet of movie stars and queens, but also of all of us, thanks to a simple construction and relatively low price.

This is an example of a brilliant idea that turns into a commercial success, an adventure that becomes almost poetic and ultimately a museum piece too. In the year 2000, the Louvre in Paris chose Tecnica's Moon Boot as one of the hundred objects of the 20th Century most representative of the history of world costume.

And today Moon Boot is one of the few trademarks allowed in the Italian dictionary: a product so successful as to become a common name, a word in current use. It is a very interesting case-study of a technological spin-off related to the innovation of meaning, innovation of emotional language and innovation of usability of the product.

The inspiration from Armstrong's footprint is the transfer of a unique image that reminds us of an extraordinary human challenge - and for that reason, this shape assumes an evocative meaning and exerts a strong power on our emotional choices.

◀ Andy Warhol's 'Moonwalk'. The brilliant use of the Pop Art colours spread a new vision to the value of consumer goods and had a major influence on the Moon Boot palette as it moved away for the first time from eternal brown leather.

A pair of snow boots evoking the greatest of conquests has a very strong appeal to consumers

Many fashion designers have often turned to science fiction and its associated futurism for inspiration

◀ Pierre Cardin's 'The Sputnik Girls'. Visions of the future from the likes of Pierre Cardin, André Courreges, Paco Rabanne started during the 1960s with experimental fashion based on space styles and innovative materials, with the aim to inspiring dreams and suggesting new ways to live and dress.

VEST project

The author experimented with a similar kind of spin-off project in terms of usability transfer during the feasibility study carried out for the VEST project [Clothing Support System for Intra-Vehicular Activities design by Annalisa Dominoni and tested onboard the International Space Station by astronaut Roberto Vittori during two European astronaut spaceflights in 2002 and 2005].

This involved retrieving and making use of methods and techniques that already exist in familiar clothes on Earth and transferring them to new garments for space, which have different needs and requirements.

Dominoni began identifying new wearability parameters to cater for the astronauts' discomforts, creating garments for microgravity around the Neutral Body Posture (NBP) that astronauts take on in orbit, which is very similar to a person's posture underwater, with their limbs bent, knees and elbows tending to move upwards and head tipped forward.

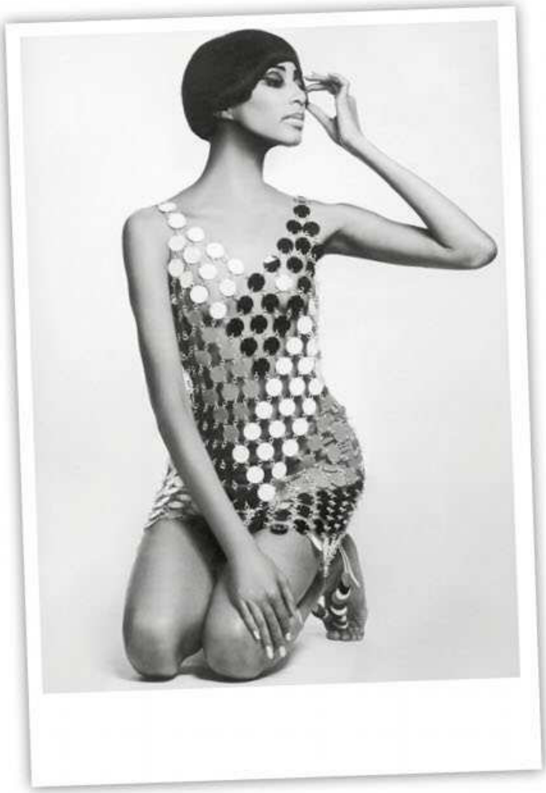
Surveys carried out during design research showed that the NBP is, in fact, very similar to the posture adopted by snowboarders, and correspondingly she decided to transfer certain functional adjustments designed to make clothing more comfortable for snowboarders - in terms of the cut, stitching and tailoring of garments - to the clothing system for astronauts. In this case the 'language of usability' allows transferring conventional outfits that are easier to handle, to another field, in this case space.

Fashion designers have been inspired by space, envisaging new scenarios explored by the first human missions and the astronauts' experiences. The microgravity effect, with the possibility to fly and move in weightlessness, and the possibility to look at our planet from an external point of view, are the two most innovative and extraordinary conditions able to generate visual suggestions that can be translated into shapes, colours and materials: rounded volumes, optical white, and silver nuances such as brilliant moon powder, mirroring metals and synthetic fibres.

Visions of the future from Pierre Cardin, André Courreges and Paco Rabanne started during the 1960s with research on experimental fashion based on 'space' styles and innovative materials, with the aim of foreseeing new ways of living and dressing capable of suggesting dreams and inspiring people.

Fashion designer Paco Rabanne was at the helm of the 1960s 'Space Age Fashion' movement thanks to his use of unconventional materials, making clothes from plastics and metals. Indeed, his inaugural 1966 collection was titled 'Twelve Unwearable Dresses in Contemporary Materials'. His signature dresses comprised of plastic discs

▼ André Courrege and the early influence of microgravity in haute couture during the early 1960s.



◀ Paco Rabanne was inspired to design space dresses comprising plastic discs or aluminium plates strung in a way that was reminiscent of chain mail.

or aluminium plates strung in a way that was reminiscent of chainmail.

Rabanne extended his research to popular science fiction when he designed the costumes for the classic cult film Barbarella in 1968, which is set in the 41st century. As for today, under the direction of Julien Dossena, the fashion house has been returning to its futuristic roots with chainmail skirts, sheer nylon and Perspex wedge boots.

Many fashion designers have often turned to science fiction and its associated futurism for inspiration. The distinctive costumes from cult science fiction films have proved lasting influences, from Jean Paul Gaultier's looks in The Fifth Element to the punk-rock garb of Ridley Scott's Blade Runner and the robot from the 1927 silent film Metropolis, which has been embraced by the likes of Karl Lagerfeld and Thierry Mugler.

And this trend continues. The Star Wars saga was an inspiration behind the new fashion show for men of Versace in 2016: tracksuits in optical fibre, shirts with luminescent piping as in astronaut suits, outwear with embroideries like space debris, leather jackets decorated with crystals, jeans with imprinted entire constellations, sneakers with lunar landing soles. "The Versace man has always been a pioneer connected with the future," suggests Donatella Versace, whose ambition is as big as the universe.

Studies across technology management have shown that innovation often comes from a recombination of existing pieces of knowledge. Henri Poincaré talks about creativity as the ability to create useful new combinations of existing elements and claims that the intuitive way of recognising the usefulness of a new combination is "that it is beautiful".

Of course, he is not talking about beauty in a strictly aesthetic sense, but as something related to elegance as a mathematician might understand it - harmony, simplicity of signs, practical correspondence to purpose. This definition applies to the sciences, arts, technology and also to design.

Indeed, it seems to overlap with the design-specific capacity to create innovation through the transfer of contexts, possible uses, technology and materials into a range of different sectors. This familiar practice among designers is generally referred to by the expression 'spin-off'.

Hussein Chalayan, Alexander McQueen and Iris Van Herpen are among contemporary fashion designers that have better explored the iconic world of Space, looking at technology and smart materials as a plus value to enrich their design proposals and translate them into 'science experiments'.

British-Cypriot fashion designer Hussein Chalayan is the master of metamorphosis. He views technology as "a way of pushing the boundaries of what's possible", and his dedication to sartorial innovation was particularly evident in his fashion show in 2007 when he presented a suite of computer-operated Transformer Dresses which morphed into silhouettes reminiscent of satellite solar panels.

The sky and stars continue to exert a strong influence on our culture - and nowhere more so than in the world of fashion

▼ Paco Rabanne extended his research to popular science fiction when he designed the costumes for the classic cult film *Barbarella* in 1968, which was set in the 41st century.

▶ *The Fifth Element* science fiction movie featured costumes inspired by a space future designed by Jean Paul Gaultier.

The traditional distinction between the haute couture and prêt-à-porter was based on the handmade and the machine-made but recently this has become increasingly blurred

The micromotor-powered garments crept across the wearers' bodies as sleeves shortened and hems lifted. In a poetic paradox, the actual aesthetics of these innovative pieces were inspired by mixing old-fashioned and Victorian styles morphing into flapper silhouettes. Chalayan paid homage to the digital era with his 'video' dress, which was made from led lights and played pixel cityscape scenes.

Fashion designer Alexander McQueen also caused a stir when reflecting and prophesying about the future. In 1999, during his time at the helm of Givenchy, he presented during a fashion show a truly artistic performance with robots spraying colours on the white dress of a model who was rotating herself.

The techno revolution of McQueen takes inspiration from space, science fiction and robots: his catwalk models are like cyborgs with their bodysuits covered in neat configurations of multicolour LED lights mounted on artificial skin made of moulded transparent Plexiglas to create a body-hugging bodice - which conjured visions of a human circuit board, with each model also wearing a 12-volt battery pack on her back.

Iris Van Herpen, the celebrated 'fashion alchemist' who was the first designer to create a 3D printed dress, has long explored the dynamic relationship with science and the digital world. Her visionary brand of sartorial creativity reached a climax with her human installation 'Biopiracy' in 2014.

In an uncomfortable voyeuristic display, models were vacuum-packed in plastic, similar to a piece of sous-vide supermarket meat, and suspended several feet above the ground. It wasn't the first time the Dutch designer had turned a fashion show into a science experiment: her haute couture show 'Voltage' in 2013 began with lightning-like electrical flashes emanating from a model standing on a pedestal.

If, traditionally, the distinction between the haute couture and prêt-à-porter was based on the handmade and the machine-made, recently this distinction has become increasingly blurred as both disciplines have embraced the practices and techniques of the other.

Today we can choose several handmade couture items, featuring techniques such as embroidery, pleating and lacework, but also machine-made dresses but tailored as handmade, thanks to new

▶ The early 1980s film *Blade Runner* continues to influence fashion design. Karl Lagerfeld and Thierry Mugler were among the first to embrace the punk-rock garb of 'replicants'. The film featured costumes inspired by a space future designed by Jean Paul Gaultier.

About the authors

Prof Annalisa Dominoni is director of the ESA Fashion in Orbit course at Politecnico di Milano, Italy. Her activities are focussed on teaching, design and research on space and extreme environments to facilitate human missions in microgravity and create new opportunities and spin-offs for space technology in the private sector. She is the Principal Investigator of two experiments on the International Space Station – VEST (Marco Polo mission) and GOAL (Eneide mission).

Prof Benedetto Quaquaro is a director of the ESA Fashion in Orbit course at Politecnico di Milano, Italy. He is designer and curator of exhibitions in the fields of art and technology specialising in Yacht Design and innovative materials. He works closely with Annalisa Dominoni on projects for ESA to spread the potentialities of space research to the business world in the fields of fashion, products, services and communication.

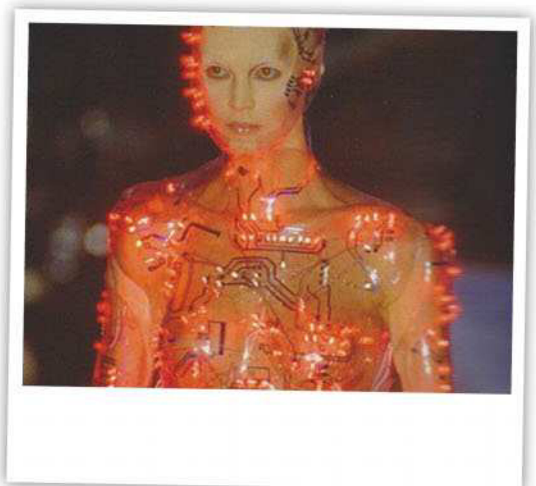
technologies like laser cutting, thermo-shaping and circular knitting, or items digitally produced by 3D printing.

The Chanel couture collection of 2015 show-cased prime examples with rich tweed suits woven through 3D printed lattices, and the Metropolitan Museum of Art in New York chose the theme for 2016 of 'Manus x Machina: Fashion in an Age of Technology' focussing on the dichotomy between handmade haute couture and machine-made fashion.

More often than not our fashion system looks at innovation as a big challenge and a great opportunity to experiment in new ways to create garments and new design languages inspired by space technology. Fashion designers try to interpret the new dimension we are all living by integrating the exciting new notions of digital, virtual and cyber with real life. ■

▲ The *Star Wars* saga continues to be a great inspiration for contemporary fashion designers, like the new fashion show for men in Versace during 2016.

▲ The collection of Transformer Dresses from Hussein Chalayan. open their shapes as solar panels during the show.



▲ Alexander McQueen's techno revolution with Givenchy in 1999 takes inspiration from space, science fiction and robots. His models are like cyborgs with their bodysuits covered in neat configurations of multicolour LED lights mounted on artificial skin made of moulded transparent Plexiglas to create a body-hugging bodice.

Mark Williamson
Space Technology Consultant

Book reviews

ROOM reviews books of interest to both the general reader and space professional. Our policy is one of impartiality and honesty, so if a book has failings we believe should be brought to the attention of potential purchasers we will do so. On the other hand, if it is useful, informative and entertaining, we will say so. In this way, we hope to provide a useful service to readers.

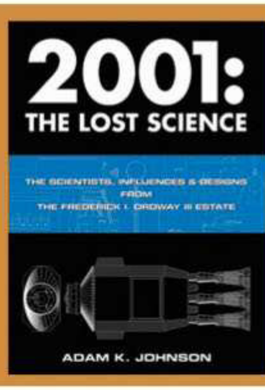
2001: The Lost Science – The Scientists, Influences & Designs

Adam K Johnson

Apogee Prime, 2016, 88pp, softback

$49.95

ISBN 978-1-137-43852-2



The film 2001: A Space Odyssey, released in 1968, has a place in the hearts of many a space buff, mainly because of its depiction of a future replete with shuttles, moon bases and crewed interplanetary spacecraft. This book is a highly-illustrated celebration of that forward-looking film and, in common with the first volume, draws on the archives of the late Fred Ordway, who worked with Stanley Kubrick on the movie. This volume summarises the work of some of the scientists and engineers who influenced Kubrick, Ordway and Arthur C Clarke (the main writing talent on the production team) and depicts some of the spacecraft designs that made it into the film.

By page count it's a short book but the large format (27 cm x 37 cm) pages and the density of information make up for this. Most of the graphic material is printed on pages with a black background, but in recognition of maintaining the readers' eyesight the text is standard black on white. Printed predominantly in colour, but with archive material in the original monochrome, this is a very well-produced book.

The early sections provide a fascinating insight into how historical writings and actual work on rocketry provided the background material for science fiction films: from the space station in Hermann Potocnik-alias-Noordung's 1929 book and Wernher von Braun's contributions to Collier's magazine to Walter Dornberger's writings on rocket-propelled commercial airliners – it's all here. And we mustn't forget Willy Ley, Krafft Ehricke, Ernst Stulinger and a host of other characters from those early, German-dominated days of rocket development.

Interestingly, Kubrick originally intended to include a prologue to 2001 featuring interviews with some top scientific minds to prove that his film was plausible. The idea was eventually abandoned and, although the original interview material is believed to have been destroyed, the transcripts remain. The book contains summaries of some of them, including contributions from Freeman Dyson, Fred Durant and Fred Whipple.

The second part of the book shows what the 'influences' of the subtitle led to in terms of interior design of spacecraft equipment and external spacecraft design. The four pages depicting the 2001 Moon Bus in multiple elevations (side, front, top, etc) are particularly interesting in that they don't look like science fiction; one could easily imagine a real moon bus based on this design skimming across the lunar surface.

And that, in a nutshell, is the beauty of the film: even today – almost half a century later – one can imagine seeing these same spacecraft in operation. Unfortunately, the word 'imagine' says more about our ability to fund real space exploration than it does about science fiction's ability to predict it.

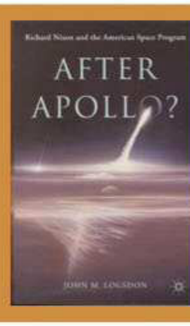
After Apollo? Richard Nixon and the American Space Program

John M Logsdon

Palgrave Macmillan, 2015, 356pp, hardback

$24.99/£22.00

ISBN 978-0-8248-5268-9



Some books are long in gestation, but 44 years for this one must be some kind of record – even for a history book. However, there is no downside to the delay in this case. Firstly, the author is – as the jacket reminds us – "a world-recognised historian and analyst of space issues" (so no potted histories here!). And secondly, the delay has allowed the author time to consult the archives of various NASA Administrators and political figures such as Caspar Weinberger and, of course, Richard Nixon. With its voluminous reference notes and substantial index, we can be assured of a professional treatment and, thanks to the skills of the author, it's also a fascinating read.

In 14 chapters, John Logsdon transports his readers from the end of the Apollo era to the 'What Next?' Space Shuttle era with some damning analysis on the way. "The space program was not high on Nixon's policy agenda", says the author with intentional understatement. He quotes the president's suggestion that Apollo 17 might be "the last time" in the century that men would walk on the Moon; Nixon, he opines, "ensured that his forecast would come true".

In the final analysis, Logsdon contrasts Nixon's space agenda with Kennedy's decision to go to the Moon. The Apollo programme "lasted only from 1961 to 1975", he says; Nixon's decision to build the post-Apollo programme round the shuttle "had a far more lasting impact". Indeed, he concludes that Nixon's decision to approve a "full capability shuttle" amounted to a "policy failure". The options for shuttle design and the reasoning behind this conclusion are fully explored in the book.

"I am sure that many people will not agree with my assessment of the Nixon space heritage, especially with respect to the space shuttle", says the author, but rightly makes no apology. After a career devoted to the programme, he regrets that his conclusions are "so downbeat" but hopes that "better days are ahead". You may or may not agree with his analysis but it offers plenty of food for thought with reference to the direction of future US space policy.

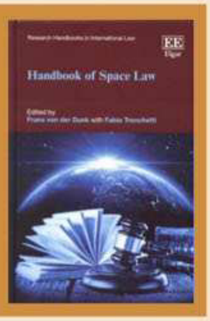
Handbook of Space Law

Frans von der Dunk & Fabio Tronchetti (Eds)

Edward Elgar Publishing, 2015, 1100pp, hardback

£215.00

ISBN 978-1-78100-035-9



Books on space law are not on everyone's wish list but the editor of this substantial tome makes a very good case for its existence with his 'why', 'what' and 'how' analysis of its contents. Put succinctly, most of the key reference sources in space law are getting a bit long in the tooth and, while the topic originally applied almost exclusively to governments, it is fast becoming relevant to commercial enterprises and individuals. Topics such as asteroid mining, lunar exploration and space tourism have seen to that.

Rusty Schweickart, Apollo 9 astronaut and co-founder of the B612 Foundation (a group with interests in defending Earth from asteroid impacts), makes an entertaining observation in his foreword. "As an astronaut I never expected to be interested in, let alone involved in, space law," he admits. "But that was back when I was the payload and not the purveyor" (he cites responsibilities in remote sensing and, later, asteroid deflection). Schweickart reveals that "in homage to the collection of nations" that made his 1969 flight possible, he took "copies of the Outer Space Treaty, the UN Declaration of Human Rights and (a bit more self-serving) the Return of Astronauts ('Rescue') Agreement" with him on his mission. He now has a better appreciation of the work that went into them, he says.

The book itself is divided into 19 multi-author chapters covering everything from the history of space law and its international organisational aspects to specific topics such as launch services, satellite communications and insurance. There is also coverage of trade, financing, property rights and the environmental aspects of space activities – in other words, something for everyone interested in space law. The massive index – at more than 50 pages – is a small book in itself! Of course, the price of the volume is likely to restrict sales to institutional purchasers but if you need a handbook of space law fit for the early 21st century, this has to be the one.

Jobs & careers in space

If you are seeking employment or a career in the global space industry then you'll find *ROOM's* regular reference page a helpful guide, with website links to some of the world's major employers - the page also appears on our website. To ensure your business, organisation or educational establishment is featured in future editions please send details to: jobs@room.eu.com

XPRIZE

Open positions - Vice President, Marketing & Communications, Technical Manager (Prize Operations), Prize Lead, Women's Safety XPRIZE.
http://www.xprize.org/about/careers/join-our-team

Planetary Resources

Joining the Planetary Resources team means you could play an active role in a pioneering vision to expand humanity into the Solar System - one spacecraft at a time. It also means that you will be joining a family of doers, innovators, comics, visionaries, expert BBQ-ers and friends.
http://www.planetaryresources.com/careers/#careers-intro

SENER

SENER attracts highly qualified people with a technical vocation, able to make significant technological or scientific contributions that create new solutions or improve existing conditions.
http://www.engineeringandconstruction.sener/work

SELEX Galileo Inc

Committed to recruiting the best talent in the defense and aerospace industry - a small company feel with big company opportunities.
http://www.selexgalileo.com/careers

Meggitt Control Systems

Working in extreme environments present new engineering challenges - opportunities worlwide in a fast growing business.
https://career8.successfactors.com/career?company=MeggittProd

Sky-Futures

Sky-Futures is the world's leading provider of drone-based inspection and data services to the industrial inspection market.
http://www.sky-futures.com/company/careers/

German Aerospace Centre (DLR)

The German Trainee Programme offers the opportunity to work on current space projects at the European Space Agency (ESA) including in satellite operations, robotics, manned and unmanned spaceflight, and Earth observation.
http://www.dlr.de/dlr/jobs

Space Systems Finland

Space Systems Finland (SSF), based in Espoo, Finland, is continually looking for people for future assignments. There are also opportunities for students looking for a subject for a final thesis which can be completed whilst working for SSF.
www.ssf.fi/careers/

Clyde Space

Clyde Space, based in Scotland, is committed to attracting talented and skilled individuals for roles across its business. Its current recruitment drive is looking for people to help support spacecraft development, manufacturing, business development and back-office functions.
https://www.clyde.space/about-us/careers

JAXA (Japan Aerospace Exploration Agency) - Japan

JAXA is looking for talented and motivated individuals who are willing to work at the frontline of Japanese space development, space science and aviation technology.
http://global.jaxa.jp/about/employ/

Space Telescope Science Institute - USA

The team that operates and manages the Hubble Space Telescope and its successor the James Webb Space Telescope for scientists and researchers across the world has a variety of current vacancies.
www.stsci.edu/institute/employment

Space business finance

***ROOM - The Space Journal* is pleased to welcome Mark Boggett to its Editorial Board. He is CEO of London-based Seraphim Capital and will support our future coverage of space funding and finance. Here, we provide a short profile of Seraphim Capital and then, in our Spring issue, we will publish an analysis of space business finance, including a close look the global support now available.**

Mark Boggett
CEO of Seraphim Capital, London

Recent years have seen unprecedented increases in space finance opportunities, reflecting the rapidly evolving and changing global commercial space market.

During 2015, for example, more venture capital money was invested into space technology companies than in the previous decade combined with, according to a report by The Tauri Group, some 22 companies receiving venture capital funding during the year.

The largest venture rounds (denoted by the series of stock sold - A, B, C and so on according to the majority of the company receiving funds) were SpaceX's US$1.0 billion series E and OneWeb's US$500 million series A. Other notable investments were series A funding for Oxford Space Systems, Astroscale and Orbital Insight, and series B funding for Mapbox and Spaceflight Industries.

To date these investments have been made by venture funds that are 'generalist technology' funds. However, a new breed of space-focused venture fund is emerging.

The first such fund to launch is the Seraphim Space Fund managed by a London-based venture team. The fund, which is focussed on early stage space-related technology businesses, will invest in commercial applications in both downstream and upstream opportunities, as well as in technologies that have potential space applications such as artificial intelligence, robotics and nanomaterials.

In particular the fund will focus on companies that use digital data from satellites that is already delivering commercial advantage and social innovations, ranging from intelligent transport and smart cities through to sectors such as insurance, maritime, agriculture or oil and gas.

Mark Boggett, Seraphim Capital's CEO, says: "As satellites get smaller, smarter and less expensive to launch, our reliance on them is growing exponentially.

"Many of the emerging new technologies that are moulding the future - from drones and autonomous vehicles to the Internet of Things - are ultimately underpinned by digital data from satellites.

"The average person in the UK interacts with a satellite 30 times per day and within five years we see that figure reaching 300, rising to 3,000 by the end of this decade.

"Just as low cost personal computing in the 1990s and the internet in the 2000s acted as a catalyst for waves of new technology innovations, the evidence is that low cost access to space will come to define the decade ahead."

The fund is well positioned to identify the most promising start-ups in these areas through its unique strategic partnership with the European Space Agency (ESA) providing it access to relevant space infrastructures, to companies with a portfolio of hundreds of downstream application projects as well as companies in ESA's 16 pan-European business incubators.

Michael Jones, the founder of Google Earth, and Google's former Chief Technology Advocate who joined the Seraphim Space Fund as a Managing Partner, will ensure the fund's reach into Silicon Valley.

In the UK, Seraphim Space will be supported by new initiatives led by the Satellite Applications Catapult and will be backing the creation of UK Space Tech Angels (a new venture from London Business Angels) that will put the Seraphim Space Fund at the heart of the space-related start-up ecosystem. ■

Low cost access to space will come to define the decade ahead

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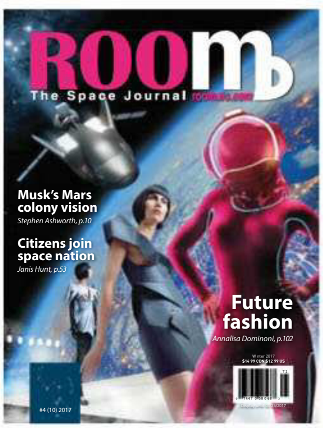
In the next issue of ROOM

Our next journal will be published in the Spring and will include a wealth of interesting, informative and challenging articles written by leaders and experts in their field, including:

- **David Ashford,** CEO Bristol Spaceplanes, UK
  To Mars on a shoestring
- **Margarita Levinskikh,** IBMP, Moscow, Russia
  Growing plants in space
- **Alfio Mantineo,** Head of Quality Control, ESOC
  Are humans reliable on space missions?
- **Alexander Mayboroda,** AVANTA Consulting, Russia
  How to build a Moon village
- **Andrea Ferrero,** Thales Alenia Space, Italy
  Challenges of BepiColumbo at Mercury
- **Makoto Yoshikawa,** JAXA, Japan
  Hayabusa 2 asteroid sample return mission
- **Todd Treichel,** Orbitial Technologies Corporation
  How artificial lighting affects astronaut health

If you would like to join our elite international community by telling your own story, presenting your opinion or discussing a specific project or aspect of research then please contact Managing Editor, Clive Simpson.



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- is distributed internationally to the heads of all major industrial and public space-related organisations, as well as being available at major international space conferences, and sold on bookstalls in the United States, Canada and Europe
- is a meeting place, and a discussion forum for intellectuals and experts directly and indirectly associated with the global space community.

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