News Feature: Breakthrough Discuss 2025

More reports and a wider perspective

Gurbir Singh

Our last issue P49 included David Gahan's report on proceedings. Here Gurbir Singh (astrotalkuk.org/) delivers two specific reports on topics which caught his eye, *Soaring over the surface of Titan* and *Tiny Cubesat with interstellar Ambitions: The Toliman Space Telescope*.
But we begin with his wider personal perspective on Breakthrough, the conference and its long established chair Dr Pete Worden.
The conference was recorded and is available at -
www.youtube.com/playlist?list=PLyF3OMOiy3nEM6rWMGZ9oTbFX2Kt5W_I3

Breakthrough Initiative - A Decade On

On 14 October 1959, a spacecraft Luna 2, impacted the Lunar surface close to Mare Ibrium. It was launched by the USSR and arrived on the Moon two days after launch. It is the first object made on Earth to travel to the surface of another world. A decade later, spacecraft from Earth arrived on Venus and Mars. In the 21st century, spacecraft have arrived on the surface of Titan, asteroids, and even a comet. Five spacecraft have left or are on a trajectory to leave the solar system. In one lifetime, Interplanetary exploration has become almost routine. But where are we on our quest for interstellar exploration?
So far, exploration of the Solar system has been in the purview of national governments, predominantly the USA and the Russian Federation (formerly the USSR) and, in the case of Cassini-Huygens and Hyabusa, the European Space Agency and Japanese Space Agency. Interstellar exploration is many orders of magnitude a more challenging ambition. The immense challenges of interstellar exploration include vast distances, technological innovations, enormous timescales, and a novel funding source. Could the Starshot Initiative from the Breakthrough Foundation be the solution?

The Breakthrough Initiatives are the brainchild of a physicist, entrepreneur and investor - Yuri Milner. Breakthrough Starshot is a $100 million research and engineering program aiming to demonstrate proof of concept for new technology, enabling ultra-light uncrewed space flight at 20% of the speed of light and laying the foundations for a flyby mission to Alpha Centauri within a generation. The Starshot initiative is a proof-of-concept launched by Yuri Milner and Stephen Hawking in 2016 and is funded by the foundation established by Yuri and Julia Milner.
Milner identified the discrepancy between the outstanding scientific question of our time, Life in the Universe. But he says, "On the bright side, that means it could offer considerable scientific return on investment".
Initiated in 2012, the Breakthrough Prizes are a set of annual international awards in the fields of Mathematics, Life Sciences, and Fundamental Physics. The awards are part of the "Breakthrough initiatives" founded by Yuri Milner and his wife, Julia Milner. Laureates receive $3 million each in prize money (funded by Yuri and Julia Milner and others, including Sergey Brin and Mark Zuckerberg) during a televised award ceremony designed to celebrate their achievements and inspire the next generation of scientists. Breakthrough Prize was the first and is now joined by Breakthrough Listen, Breakthrough Watch, Breakthrough Message and Breakthrough Starshot.

- Breakthrough Listen is targeting the 1,000,000 closest stars to the Earth, is the largest-ever scientific research program looking for evidence of civilisations beyond Earth. The radio and optical surveys will cover more of the sky, deploy more instruments in more locations, have higher sensitivity and take advantage of state-of-the-art digital signal processing and artificial analysis tools.
- Breakthrough Watch is a program to look for Earth-like planets within 20 light years, starting with the nearest Alpha Centauri system. If life exists on these planets with Earthlike characteristics (of temperature, pressure, rocky surface, and potentially water), then the tell-tale signs of biosignatures and techno signatures could make that breakthrough and detect the very first unambiguous signs of extraterrestrial life.
- Breakthrough Message is an initiative designed to address the question, if the existence and the whereabouts of the first extraterrestrial intelligent civilisation is finally confirmed, what do we say to them? The content of the message is the primary focus, but so are the questions of who decides what form (language) the message will take, how it is constructed and who will send it. As the Apollo 8 astronauts recalled following their 1968 trip to the Moon, "We set out to explore the moon and instead discovered the Earth". This is perhaps the most profound of all the initiatives, as it will allow us to learn about ourselves - even if no message is ever sent.

These Breakthrough Initiatives can inform and direct each other. Results from Watch and/or Listen may direct Starshot and message.

Dr Pete Worden

Pete Worden chairs the Breakthrough Discuss conferences and actively discusses the themes of all the Breakthrough initiatives, emphasising their interdisciplinary nature and focus on fundamental questions about life and intelligence. His interest in space and astronomy started as a boy when he asked his mother, "'Okay, what do people do that study stars?' And she called astronomers.".

Pete Worden had a long distinguished career with a background in the military, specifically mentioning work with the Air Force, Space Command, missile defence, and being instrumental in the responsive space program during his active duty. He worked on arms reduction with the USSR during the Cold War. In around 1982, long after the Apollo program, Pete Worden applied unsuccessfully to NASA's astronaut program. During his time as the director of Ames Research Centre, he met Apollo 15 Command Module Pilot Al Worden. Both came from Michigan and were able to determine that Al Worden's family was part of the extended Warden family in Michigan that had adopted Pete Worden's grandfather. In 2015, he left as head of NASA AMES Research Centre to become the chairman of the Breakthrough Foundation. In this role, he provides strategic leadership and oversight of the Breakthrough Initiatives suite. Reflecting on his 2015 meeting with Yuri Milner, he recalls, "he asked me to be the chairman of the overall foundation, not just the executive director of the initiatives, and so we've been at it about 10 years, and I think we've made major accomplishments".

Dr Worden at Breakthrough Discuss 2025, Oxford UK

In his 2021 publication "Eurika Manifest", Yuri Milner asserts that "unlike organisations, businesses, companies or even nations, human civilisation can be seen as an entity that lacks a common mission. In the absence of that vision, humanity hinders its collective progress and, thus, in the end, its potential for long-term survival." But he does not simply assert his views as words on a page; by funding a series of apolitical, multidisciplinary, international initiatives, he hopes to make progress in the most challenging questions of our times.

Reflecting on the big question at the root of all the initiatives, Worden says, "I think we're going to find pretty strong evidence of life within a decade. Probably with our own solar system... so I think we'll find life within a decade.... but I'm virtually certain we're going to find life everywhere within a decade". On the question of intelligent life, he said "whether we find evidence of intelligent life that's .. who knows. You know and again it depends on what we mean by intelligence."

Links

breakthroughinitiatives.org/
breakthroughinitiatives.org/yuri-milner
breakthroughinitiatives.org/manifesto
en.wikipedia.org/wiki/Pete_Worden

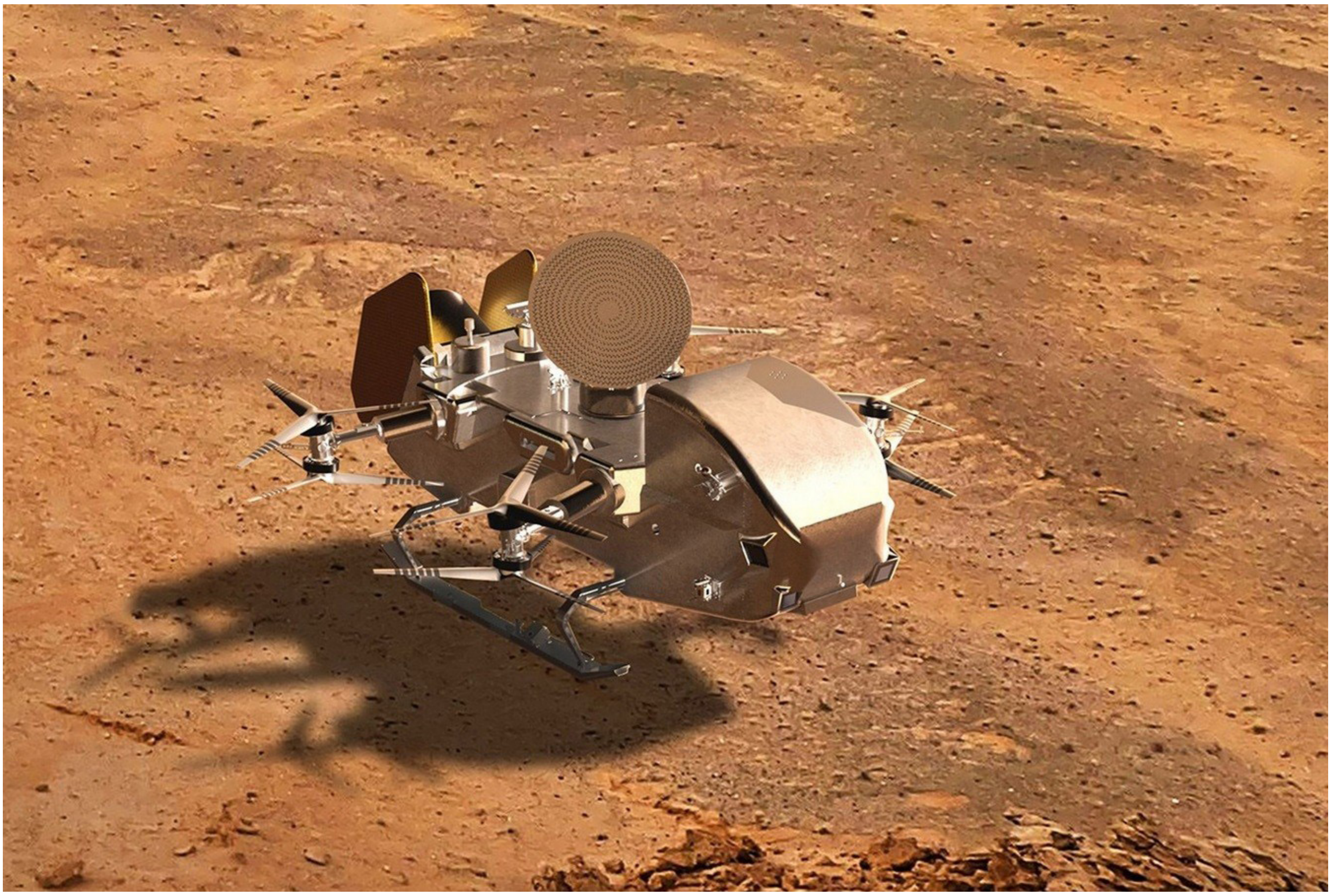
Soaring over the surface of Titan

In December 2034, a spacecraft will enter the atmosphere of Titan. Two hours later, it will softly land at the equatorial region and begin a 3-year-long exploration of Titan's atmosphere, surface and subsurface. It does not have wheels but rotors. In dozens of hops over the duration of the mission, it will investigate different regions of Titan using various instruments to investigate the nature of the prebiotic chemical process still active on Titan. It is probably similar to the chemical processes that prevailed on the early Earth before life and biology transformed the land, oceans and atmosphere that we experience today. This NASA spacecraft, Dragonfly, will be launched in July 2028.
Sometime in the very distant future, an uncrewed interstellar probe made by humans will arrive for the first time on the surface of another planet orbiting another star. How that future spacecraft will explore the alien world will be modelled by what Dragonfly will do on arrival at Titan in December 2034.


Dr Elizabeth Turtle, principal investigator on the Dragonfly mission

In an interview during the Breakthrough Discuss conference on April 24, 2025, Dr Elizabeth Turtle, principal investigator on the Dragonfly mission, provided an overview and update on the Mission. She characterised the mission by saying, "Dragonfly really is fundamentally a chemistry mission". Titan has a "very complex carbon chemistry with large carbon-rich molecules forming in the atmosphere and falling onto the surface, where the bedrock is water ice, and there might be places where it has melted". A key objective is to "understand how chemistry has progressed in this world in the outer solar system and what that can teach us about the kinds of complex chemistry that occur before chemistry takes the leap to biology".
Dragonfly was selected in 2019. It is the second mission to Titan following the Cassini-Huygens mission, which was launched in 1997 and arrived at Saturn in 2004. It was a joint mission—NASA provided the Saturn Orbiter Cassini, and the European Space Agency developed the Titan lander Huygens. Saturn orbits the sun every thirty years. Dragonfly is targeting this next launch window of July 2028. The Dragonfly spacecraft has recently successfully completed the Preliminary and critical design review, so the project team based at the Johns Hopkins Applied Physical Laboratory is engaged in building and testing the spacecraft and its subsystems.
Dragonfly will not have wheels but skids and will not rove on the surface of Titan but fly through its atmosphere. As Ingenuity has demonstrated on Mars, exploring a new world by flying from one spot to another offers opportunities to sample multiple locations and a wider aerial view of a new landscape. With its five instruments, Dragonfly is primarily a portable, flying chemistry lab that will investigate the chemistry of Titan's atmosphere, surface and even subsurface over a nominal three-year lifetime.
The five instruments include a Mass Spectrometer that will analyse Titan's chemistry and look for amino acids, fatty acids and sugars. A drill (actually two - one on each skid) will dig a few centimetres into Titan's surface and pass the contents to the mass spectrometer for analysis.
The Gamma-ray and neutron spectrometer is a two-part instrument. An onboard pulsed neutron source generates and fires a stream of neutrons at the surface. The interaction between this beam and the constituents of Titan's surface generates gamma rays. These gamma rays are detected and analysed to identify the presence and relative quantities of elements such as hydrogen, nitrogen, oxygen and minor inorganic elements like sodium and sulphur. Interesting results may be followed up by collecting samples from the identified interesting locations for further analysis by the mass spectrometer.
A collection of sensors make up the Geophysics and Meteorology instrument. Between them, they will measure atmospheric conditions, including temperature, wind speed and direction, and humidity (of methane) that will help understand Titan's methane cycle. The Earth has a water cycle; Titan has a Methane cycle. It is possible that Dragonfly may detect and measure methane rain and snow. One of the sensors will be capable of detecting seismic activity. If such activity is detected, it will allow scientists to understand the internal structure and activities deep below the surface.

Dragonfly will carry a suite of cameras. Downward-facing cameras will capture images during initial descent, landing, and subsequent flights. A series of forward-looking cameras will capture the ambient landscape and closely examine the surface immediately below Dragonfly. Multi-spectral LED illumination will mitigate the weaker illumination on Titan's surface and be capable of detecting certain organics (especially polycyclic aromatic hydrocarbons) via fluorescence. On Earth, some life forms make use of fluorescence. The Dragonfly is not expecting such sources, but if they are present - well, who knows! Dragonfly's instruments and subsystems, including the motors that allow it to fly, will be powered by a Multi-Mission Radioisotope Thermoelectric Generator. It will provide power for everything, including communications, using the 1 m high-gain antenna. There is no relay satellite. Cassini served that role in the case of Huygens in 2005. Dragonfly will communicate directly with Earth from the surface of Titan. Dr Turtle indicated that Dragonfly will collect the "same amount of data that we got from the Huygens probe every Titan day". Given the Earth-Titan distance of around ten astronomical units, where a round trip (Titan-Earth-Titan) will take around 90 minutes. The data rate is expected to be low due to the very low temperature and thick atmosphere.



Artist's concept of NASA's Dragonfly on the surface of Saturn's moon Titan. The car-sized rotorcraft will be equipped to characterize the habitability of Titan's environment, investigate the progression of prebiotic chemistry in an environment where carbon-rich material and liquid water may have mixed for an extended period, and even search for chemical indications of whether water-based or hydrocarbon-based life once existed on Titan.

Credit (image and caption) NASA/Johns Hopkins APL/Steve Gribben

The end of life for Cassini was disintegration during a high-speed encounter into the atmosphere of Saturn in September 2017. Huygens had transmitted for around 2.5 hours during its descent to the surface and another 2.5 hours from the surface. Huygens's mission ended when Cassini, its communication relay to Earth, lost line of sight of Titan. Huygens remains frozen where it landed. That will ultimately be the fate of Dragonfly. The limiting factor is the heat output from the MMRTG. Eventually, this heat will not be sufficient to keep the interior of the lander warm. Despite that point being in the far future, Dr Turtle, with a voice broken by emotions, says, "It's a little heartbreaking to say, but the final state of the mission will be frozen on the surface of Titan".

The Dragonfly Mass Spectrometer (DraMS) is a central instrument for analysing Titan's chemistry. Derived from previous successful Mars missions, its primary objective is to identify the inventory of prebiotically relevant organic and inorganic molecules on Titan's surface. It can analyse samples from different geologic settings, measuring molecular masses up to approximately 2,000 Daltons. DraMS helps determine if complex organic synthesis has occurred and searches for potential building blocks for life like amino acids and sugars. It operates in multiple modes, including analysing samples collected by DrACO and atmospheric gases.
The Drill for Acquisition of Complex Organics (DrACO) is the system responsible for collecting physical samples from Titan's surface and near-surface for delivery to DraMS. Developed by Honeybee Robotics, it consists of two rotary-percussive drills mounted on the landing skids, providing redundancy. DrACO is designed to obtain samples from the top few centimetres of the surface. Once collected, samples are pneumatically transferred through a hose using a blower mechanism, similar to a vacuum cleaner, into the mass spectrometer for detailed chemical analysis.
The Dragonfly Gamma-Ray and Neutron Spectrometer (DraGNS) instrument is used to determine the bulk elemental composition of the ground beneath and around the lander without requiring sample collection. Because Titan's atmosphere blocks cosmic rays, DraGNS uses a pulsed neutron generator to excite gamma-ray signatures from the surface. It measures the abundances of major elements such as carbon, nitrogen, hydrogen, and oxygen and minor inorganic elements like sodium and sulphur. This provides a rapid chemical reconnaissance of landing sites, classifying surface materials and guiding decisions on which locations are most scientifically interesting for sampling with DrACO and DraMS.

The Dragonfly Geophysics and Meteorology package (DraGMet) is a comprehensive suite of sensors dedicated to monitoring Titan's atmosphere and subsurface. It measures atmospheric conditions like temperature, pressure, wind speed and direction, and methane humidity, contributing to understanding Titan's methane cycle. Additionally, sensors on the landing skids assess the properties of the surface material and electric fields, which can probe the depth of Titan's subsurface ocean. DraGMet also includes a seismometer to detect ground motion and Titanquakes, providing insights into the moon's internal structure and seismic activity.
The Dragonfly Camera suite (DragonCam)/NavCams, the DragonCam, including the navigation cameras (NavCams), provides the mission's imaging capabilities for both science and operations. It includes panoramic cameras for detailed site surveys, forward and downward cameras for in-flight imaging and landing, and microscopic imagers to examine high-resolution sampled materials. DragonCam's images characterise geologic features, terrain morphology, and surface materials' size, shape, and colour, providing crucial context for sample analysis and understanding material transport. Cameras are also vital for navigation, scouting potential landing sites, and safe flight operations.

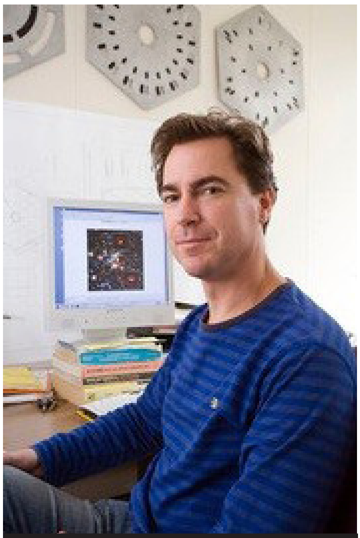
Links to more on Dragonfly
www.nasa.gov/missions/dragonfly/nasas-dragonfly-tunnel-visions/
astrobiology.nasa.gov/news/nasas-dragonfly-mission-will-seek-clues-about-titans-habitability/

Tiny Cubesat with interstellar Ambitions: The Toliman Space Telescope

The very first confirmed detection of an extrasolar planet came in 1992. It is called PSR B1257+12 b and is also named Draugr. It is about the mass of the Earth orbiting a millisecond pulsar in the constellation of Virgo, more than 2,000 light years away. Detecting extrasolar planets is tricky because they are tiny, very far away, and usually so close to the host star that they are lost in its glare. Traditionally, large aperture Earth-based and highly specialised space-based telescopes are required to detect and observe extrasolar planets. A new Cubesat with a single instrument, a 12.5 cm telescope, has the potential to reframe capabilities associated with CubeSats. It’s called the Toliman Space Telescope.
Just as the Moon has been our stepping stone for interplanetary exploration, the Alpha Centauri, our nearest star system, will be a stepping stone for interstellar exploration. The TOLIMAN (Telescope for Orbit Locus Interferometric Monitoring of our Astronomical Neighbourhood - should you be interested!) space telescope is a new low-cost mission concept for detecting exoplanets. It has a single instrument, a 12.5 cm telescope and (initially) a single target - the Alpha Centauri System (toliman.space/). The technology around which this mission is centred is the science behind high-resolution astronomy.

◀ One of the pioneers of this technology is Professor Peter Tuthill. He has led the development of the aperture masking interferometry at the heart of the Toliman Space Telescope. He is a professor of physics at the University of Sydney and the principal investigator on the Toliman mission.

Dr Karel Valenta
Toliman Space Telescope project director,



Professor Peter Tuthill,
The University of Sydney
Principal Investigator on the Toliman mission

In an interview conducted during Breakthrough Discuss in Oxford in April 2025, the Toliman Space Telescope project director, Dr Karel Valenta, outlined the project's origins, objectives and current status. The origins were directly linked to a call for proposals by the Breakthrough Foundation aimed at exploring the Alpha Centauri system. The fundamental scientific goal of the mission is explicitly stated as searching for Earth-equivalent planets in our stellar neighbourhood, with a particular focus on Alpha Centauri. Regarding the current state of the project, he said, "We are currently at the stage when we are really actively building and integrating the spacecraft .. almost the entire telescope is ready… we are aiming for launch in 2026".

What makes the mission possible includes several novel technologies. The 12.5 cm aperture TOLIMAN Space Telescope is designed for the detection of exoplanets using the astrometry method. It involves precisely measuring stellar positions to track the tiny angular displacements of the star imposed on it by the gravity of orbiting exoplanets. The goal is to find potentially habitable rocky planets, particularly Earth-mass objects, in the habitable zone of Alpha Centauri A or B. Subsequent to the primary object, other stars will be targeted.

The Diffractive Pupil Optical Mask is affixed to the front of the telescope. It contains features embedded in the pupil that cause starlight to diffract in the image plane, creating a complex pattern of interference fringes. This provides the micro-arcsecond astrometric precision needed to detect the small wobble induced by Earth-mass planets.

Embedded Spectrometer. The diffractive pupil carries an embedded spectrometer or a second set of diffractive features. These features function as a slitless spectrograph performing real-time spectral monitoring of the star. Dr Valenta emphasised the precision involved with the Toliman mission. Measuring a star's wobble, representing only 100,000th of a pixel on the sensor, is "unbelievable" and "many many folds times harder than finding the needle in the haystack."

An onboard Space Edge Computer running custom-built software from an Australian start-up will process massive amounts of data in real time using AI technology. It will use dLux, an open-source differentiable optical modelling framework for image processing. This onboard assessment, reduction and compression of the data will minimise the quantity of data (expected to be around 6 TB) and the time needed for regular (every other day) downlink. Toliman will only be able to observe for around 25 minutes during each 90-minute orbit. Toliman will use a commercial ground station operator called Leaf, which is based in Italy. Ground stations in Patagonia, Europe, Australia and Alaska may be used to collect the data from orbit. Following initial processing, the data at an online location will then be shared among its partners.

Three-axis satellite stabilisation has been around for decades. Toliman will employ a bespoke Tip tilt system and critical thermal control systems to maintain the high-precision pointing and stability required for high-precision scientific observations.

Despite its relatively small size and low cost, it will involve scientists, engineers, commercial companies and organisations from multiple nations, including Australia, Japan, Italy, France, the Netherlands, the UK, the USA and Korea.

Toliman is expected to be launched to a 600 km polar orbit. The launch costs are estimated to be around half a million USD. The launch provider has not yet been finalised, but it could come from the USA, Korea, Japan, or New Zealand. The primary target for Toliman, the Alpha Centauri system, dictates specific orbital characteristics that the launch provider must meet.

Cubesats have traditionally been the starting point for space missions for students, startups, and non-profit organisations. The challenges for the Toliman mission are not unlike those for any space mission. However, with low cost, a small team located around the globe, and an array of innovative technologies, it could be a mission that elevates the capabilities of CubeSats. ■