

SPACE

KARMAN

10

Ten space headlines in 2030.

Inspired by facts & figures, tech & business innovation, and the arts.

INTRODUCTION

The Karman Project is an independent foundation which fosters trust and cooperation between global leaders in tech, science, business, politics and the arts, who want to positively impact space.

This artistic science-fiction document has been prepared in cooperation with the artist Michael Najjar whom we deeply thank.

The views expressed in this document are independent, inspirational and artistic.

2010

**STANDING ON THE
SHOULDERS OF GIANTS**

2020

STANDING ON THE

2010

Tech Breakthroughs

◆
Oxygen / Methane full flown staged engine

◆
3D-Printing in and for Space

◆
Space-Space Laser Communication

Business Breakthroughs

◆
Emergence and Growth of Space Startups

◆
Revival of Constellations

◆
Reusability for Launchers & Spacecraft
Works and Is Worth It

Outstanding Achievements

◆
Landing on the Far Side of the Moon

◆
Landing on a Comet

◆
Successful Demonstration of in-Orbit Refuelling

2020

SHOULDERS OF GIANTS

2010

2010

2012

2014

2016

2018

2020

2020

◆
Dragon achieves its first demo flight.

◆
The International Space Station is almost finished with the delivery & integration of the Tranquility, Cupola and Rassvet modules.

◆
Curiosity lands on Mars.

◆
Philae performs the first landing on a comet.

◆
First space-space laser communication.

◆
First 3D-printed parts in space.

◆
Falcon 9 successfully lands on a drone ship.

◆
First fire test of the Raptor, the first liquid Oxygen / Methane full flown staged engine.

◆
Maiden flight of Falcon Heavy.

◆
Starlink launches a demo-satellite.

◆
First 3D-printed engine operational in orbit.

◆
The Chinese positioning system BeiDou-3 is deployed and operational.

◆
Momentus, the space last mile delivery startup, strike a deal to go public with a SPAC at \$1.2B valuation.

◆
Final mission of the Space Shuttle.

◆
China launches its first space station module.

◆
The Grasshopper rises 744m altitude and lands.

◆
Planet launches its first Earth Observation micro-satellite.

◆
NASA demonstrates in-orbit refuelling capabilities.

◆
Planet raises \$118M at \$1.13B valuation.

◆
Rocket Lab raises \$75M at \$1B valuation and achieves the first flight to orbit of its micro-launcher Electron.

◆
Yutu-2 lands on the far side of the Moon.

◆
OneWeb and Starlink launch their first batch of operational satellites to provide Internet from space.

◆
Google and NASA achieve Quantum supremacy.



MICHAEL NAJJAR

Installation view Wittenstein Innovation Factory, Germany
2019



gravity turn
2016



The super-heavy rocket [...] launched another batch of 350 satellites, positioning them in a parking orbit from which space tugs brought them to their final orbital destination.

While space transportation is increasingly resembling Earth transportation, we have perhaps reached a point of equilibrium in the race for heavier rockets. Super-heavy launchers were designed to launch to the Moon and/or to Mars +20t spacecrafts with men and equipment on-board. Big rockets also mean a lower price/kg - a competitive advantage to launch satellites. But with last-mile delivery tugs and in-orbit refuelled spacecrafts, inter-operability and international standards are taking the spotlight to become more important than further increasing the power of such rockets.

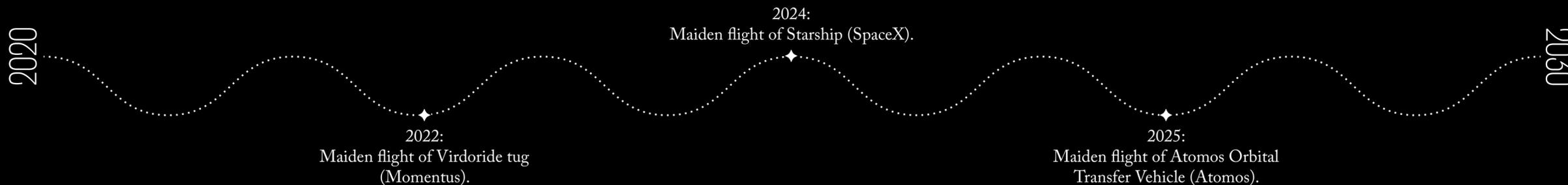
FACTS & FIGURES 2020

◆ Super Heavy Launchers (+100t to Low Earth Orbit) in development in 2020: Starship (SpaceX), SLS (NASA), Long March 9 (China), Yenisei (Russia).

◆ +15 last-mile delivery startups worldwide.

WILL THE RACE FOR SUPER-HEAVY ROCKETS EVER END?

INSPIRATIONAL TIMELINE







COULD THE ALLIANCE OF FARMERS AND SPACE TECH CUT WATER CONSUMPTION BY HALF?

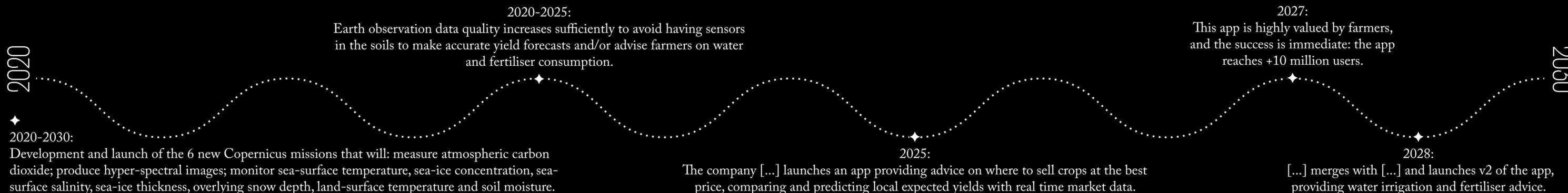
The long-awaited I.P.O. of [...] has officially launched with early success, garnering support from tech and impact investors alike. But will the space tech company be able to deliver according to its promises?

So far its services to farmers have triggered a startling 50% reduction of water consumption for irrigation, but the largest chunk of the market remains to be conquered. “User- friendliness and added-value local services are the recipes for growth,” explains the CEO.

FACTS & FIGURES 2020

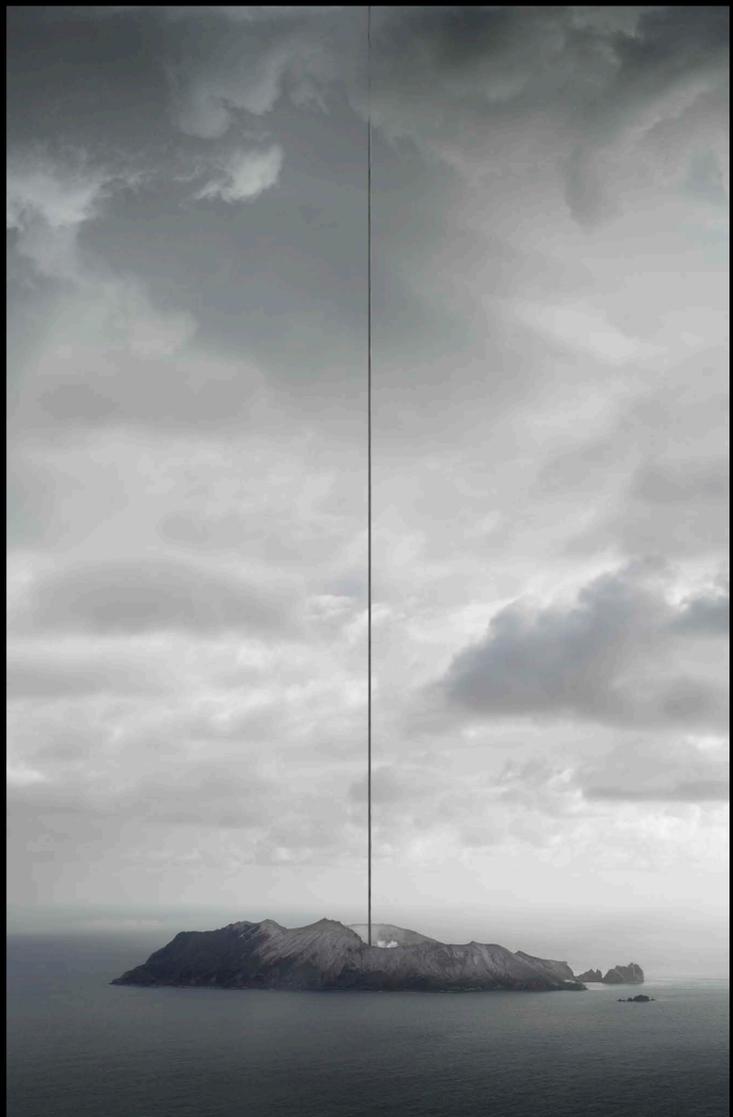
- ◆ Space data for forestry and agriculture is expected to grow at a 12.5% CAGR in the next ten years, accounting for a \$1.5B yearly market.
- ◆ Irrigation accounts for 70% of fresh water used worldwide. This percentage is higher in OECD countries (e.g. 80% in the USA).
- ◆ With satellite measurements, it is possible calculate soil humidity and evaporation at a specific location, hence to provide farmers with water consumption advice.
- ◆ Water in many countries is almost free to use, and paying for tech advice without a significant added-value is useless for farmers.

INSPIRATIONAL TIMELINE





ascension
2020



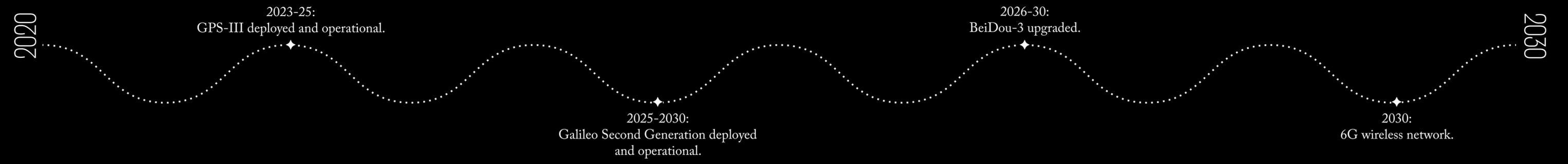
US DEPARTMENT OF TRANSPORTATION GIVES GREEN LIGHT FOR FULLY AUTONOMOUS DRIVING ON HIGHWAYS.

Ultra-precise positioning is now providing the sufficient level of safety to unlock the autonomous car market. Indeed, the combination of the new 6G wireless networks and the next-gen space-based positioning systems (GPS III F, Galileo Second Generation and BeiDou-4) enables a <math><0.5\text{cm}</math> positioning accuracy.

FACTS & FIGURES 2020

- ◆ Current best accuracy of:
 - ◆ GPS-II, Galileo and/or BeiDou-3: 10-40cm.
 - ◆ 5G: 1m
 - ◆ Together: 10-20cm

INSPIRATIONAL TIMELINE





starlink
2020



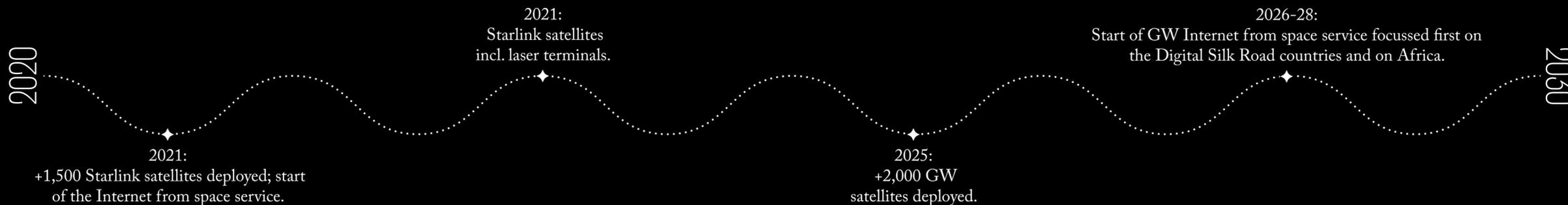
Thanks to the 20,000 satellites flying in orbit, the global population is online.

Starlink (SpaceX, US) and GW (China) have achieved their mission to connect the world. UNESCO has leveraged this global coverage to negotiate with satellite operators and telco companies the right for all governments to use one canal to broadcast educational content to their populations free of charge.

But with progress comes new challenges as experts note that scientific space observation from the Earth is becoming increasingly difficult, while the risk of satellites colliding to create thousands of debris - that would ultimately ban the use of some orbits - is hundredfold.

99% OF WORLD POPULATION CONNECTED TO BROADBAND INTERNET: NEW ERA FOR ACCESSING KNOWLEDGE ALSO BRINGS NEW SPACE POLLUTION CHALLENGES.

INSPIRATIONAL TIMELINE

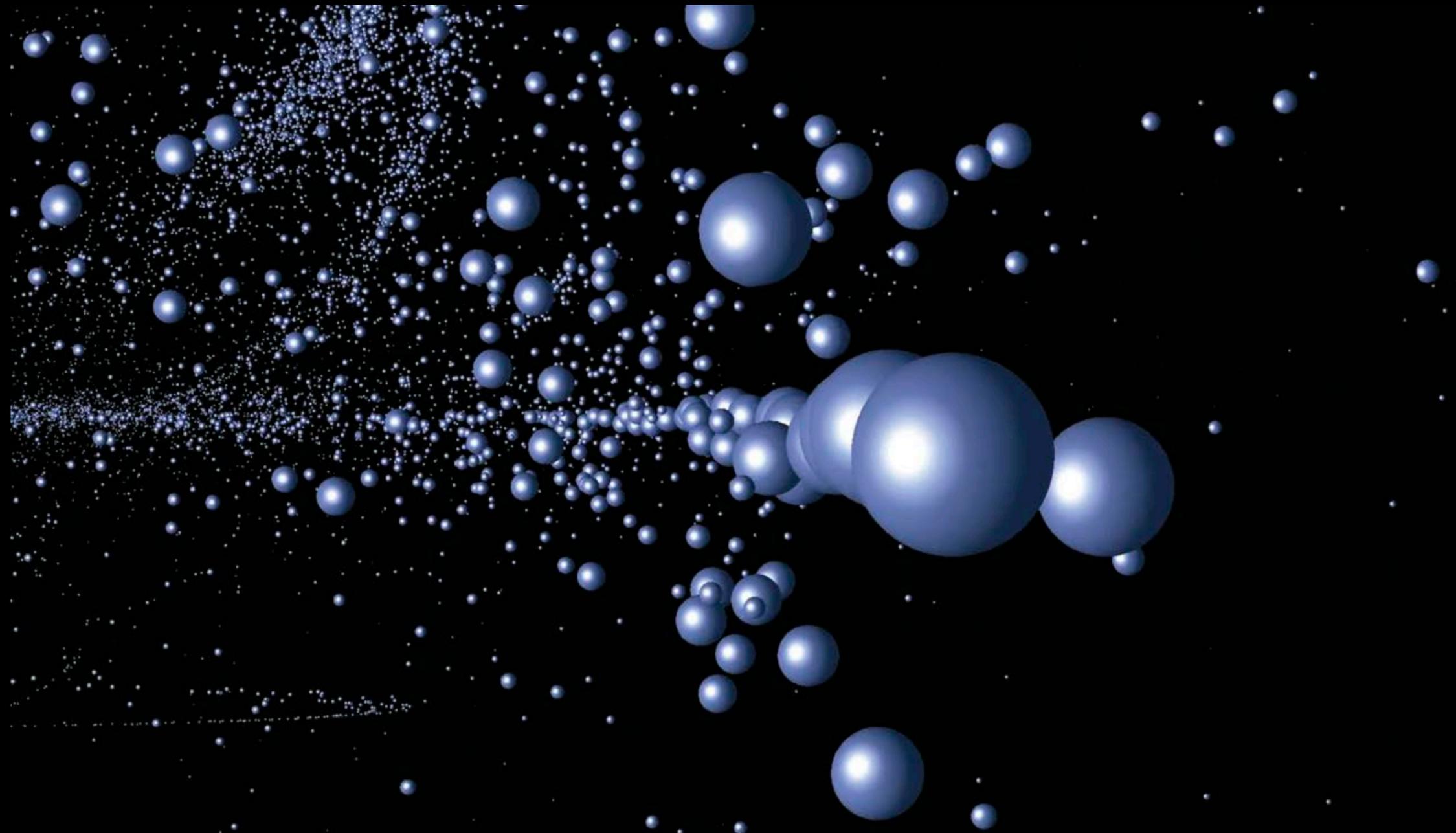


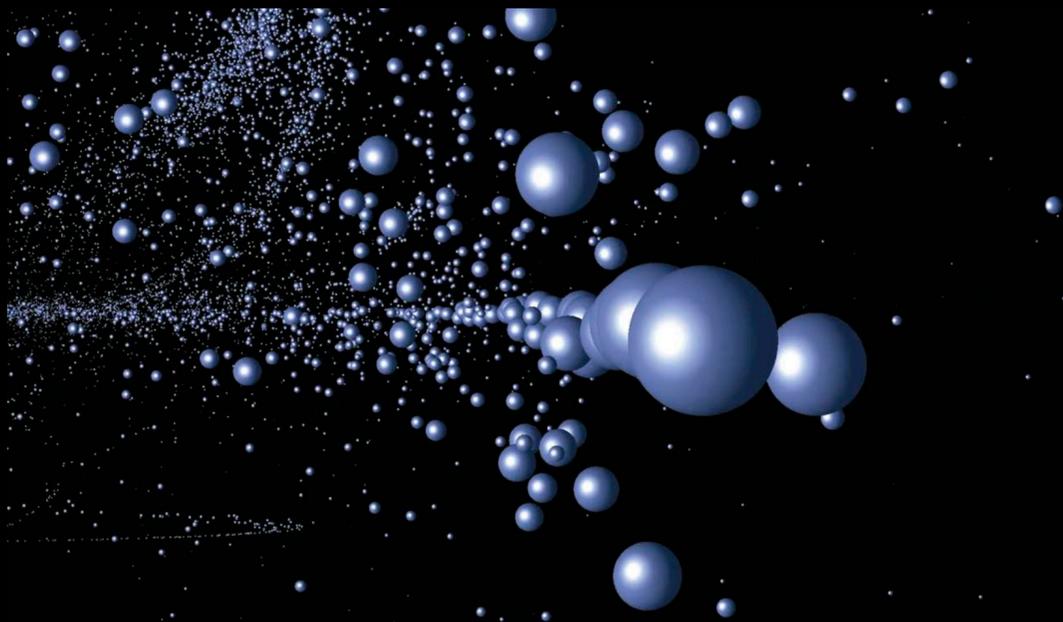
FACTS & FIGURES 2020

◆ 2016-19: SpaceX filed with and gained approval from the Federal Communications Commission for ~12,000 Starlink satellites.

◆ 2020: 835 Starlink and 74 OneWeb satellites deployed.

◆ 2020: GW (China) filed for 20,000 satellite constellation authorisation with the International Communication Union.

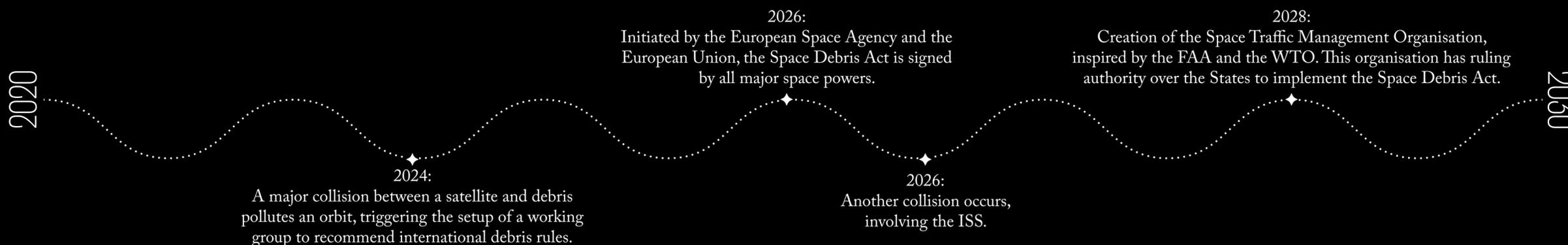




Recalling the two recent collisions that polluted an orbit and threatened the ISS, the Space Traffic Management Organisation has sanctioned [...] for its failure to adopt measures to implement the Space Debris Act. [...] faces a fine of \$1 billion and a 2-month interdiction of launching - this interdiction can be withdrawn as soon as the Space Debris Act is proven to be implemented.

THE SPACE TRAFFIC MANAGEMENT ORGANISATION RULES AGAINST [...].

INSPIRATIONAL TIMELINE



FACTS & FIGURES 2020

◆ The Federal Aviation Agency was created in 1958, after a major crash between airplanes in 1956. Its ancestor, the Civil Aeronautics Authority, was also created in 1938 in the aftermath of two major airplane crashes in 1931 and 1935.

◆ 2020: Debris estimates are as followed: 34,000 objects >10cm; 900,000 objects 1-10cm; 128 million objects 0.1-1cm. Debris in 2030 are estimated three times more than in 2020, provided no collision. 2030 collision probability is estimated above 1%.



f.a.s.t.
2017



GROUND STATION AS A SERVICE: UNLEASHING OR CONTROLLING SPACE DATA APPLICATIONS?

The European Commission has opened a competition case against [...], accusing the company of abusing its dominance position in the Ground Station as a Service market. The news has sparked new concerns around Big Tech Big Brother. The infrastructure behind Ground Stations as a Service, i.e. dedicated antennas and servers already used for the cloud business, have indeed facilitated a reduction - in the order of magnitude - of the ground segment costs, allowing new businesses to grow. However, it is also creating somewhat of a monopoly in the space and web data market as a small number of top players dominate the field.

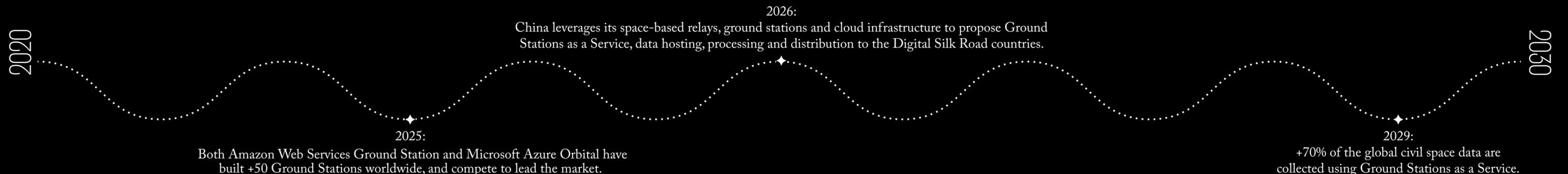
FACTS & FIGURES 2020

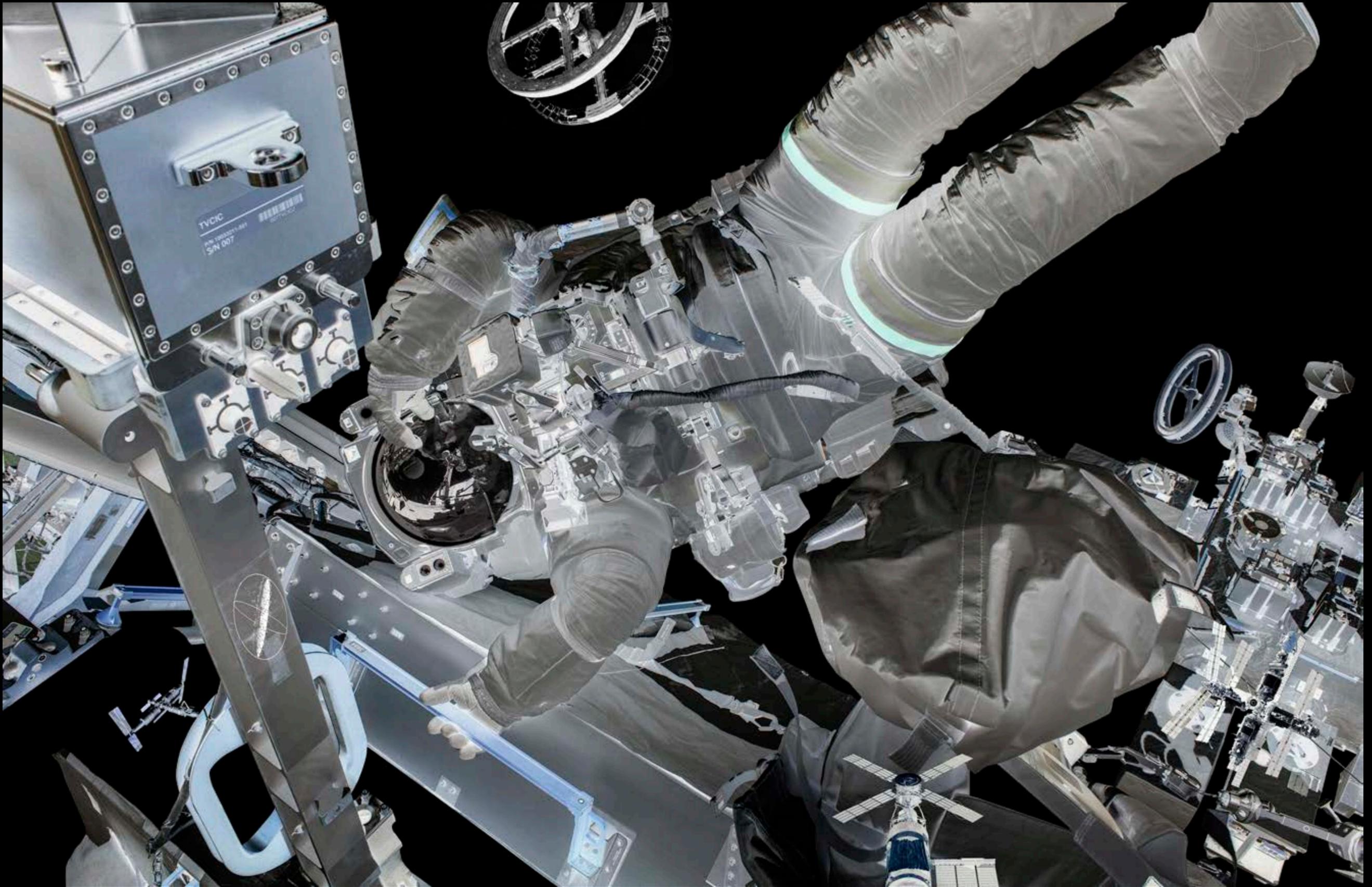
◆ 2018: Amazon launches Amazon Web Services (AWS) Ground Station, its Ground Station as a Service business. AWS Ground Station uses AWS Cloud to store and process data, and AWS Global Infrastructure to distribute them.

◆ 2020: Amazon has built 6 ground stations, and it forecasts to build 20 more in 2021, based on customer feedback.

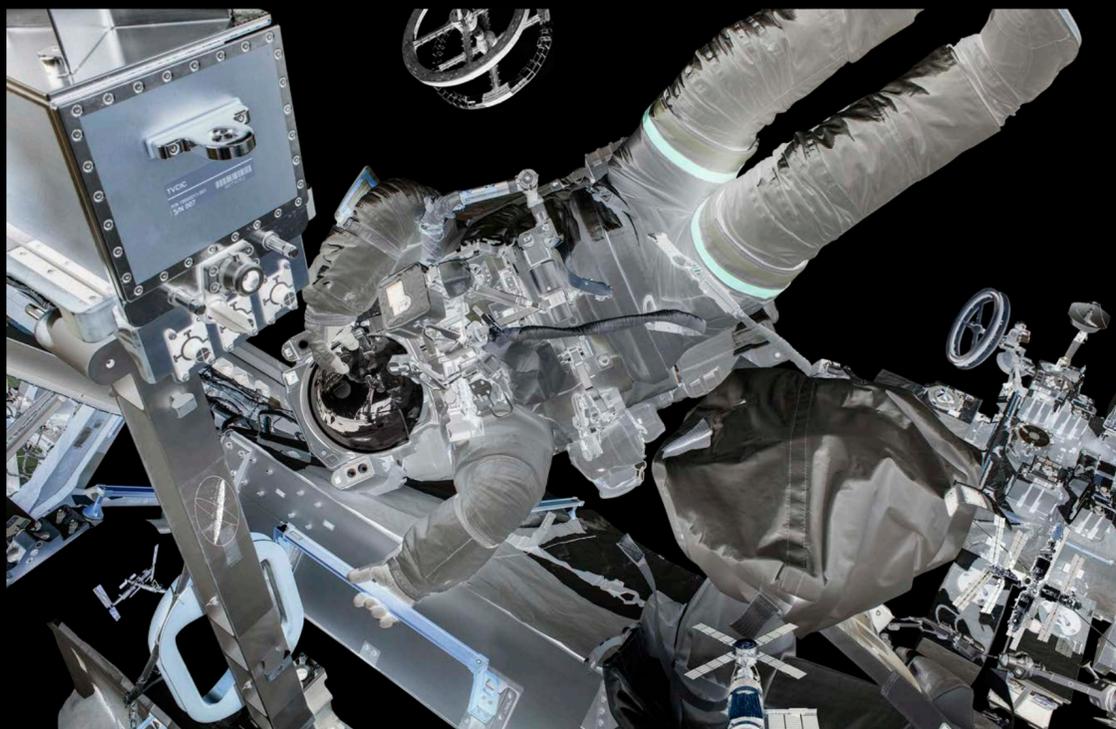
◆ 2020: Microsoft launches Azure Orbital, a Ground Station as a Service, leveraging Microsoft cloud infrastructure. SES and SpaceX are partners of this service.

INSPIRATIONAL TIMELINE





orbital outpost
2018

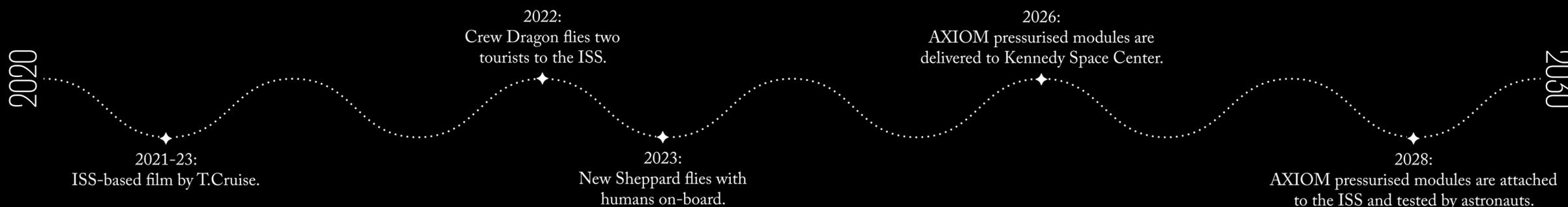


After years of anticipation, the first commercial space station has come to life. Among the first private astronauts are two billionaires and one Head of State.

It has taken almost 100 years to democratise commercial aviation, from the first commercial flight in 1914 to the creation of Ryanair and EasyJet in the 1990s. Major aviation safety, tech and affordability progresses have been mainly triggered by the development of commercial aviation, while aircrafts have become the safest and most common way to travel long distance. Will the same patterns apply for space tourism?

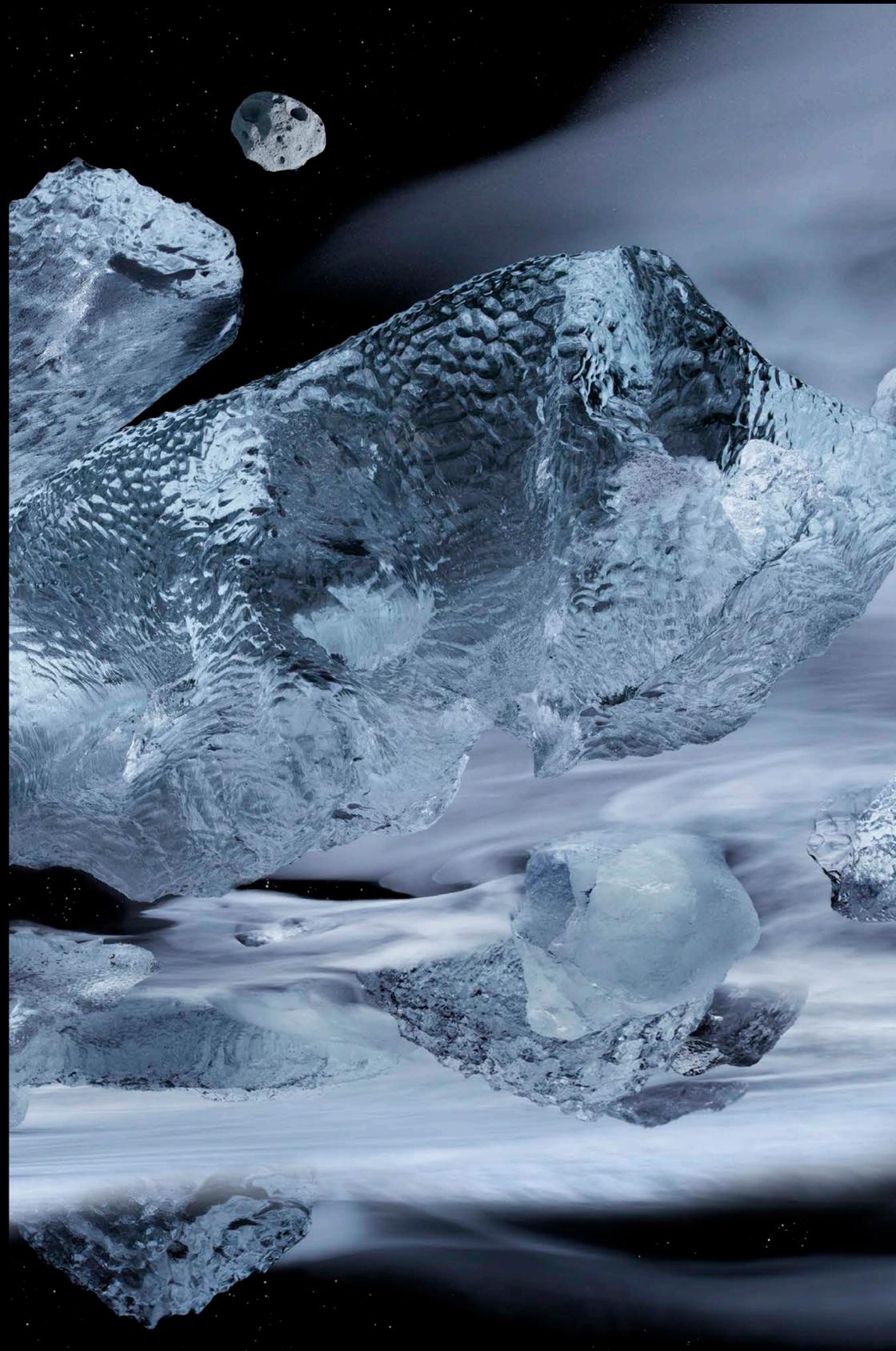
THREE TOURISTS INAUGURATE THE FIRST COMMERCIAL SPACE STATION. COULD THIS BILLIONAIRE DESTINATION OF TODAY BECOME A DEMOCRATISED HOLIDAY SPOT OF TOMORROW?

INSPIRATIONAL TIMELINE



FACTS & FIGURES 2020

- ◆ 2020: Crew Dragon docks with ISS.
- ◆ 2020: NASA awards Axiom the right to dock its commercial space station to the ISS.
- ◆ 2020: 600 people have bought tickets (~\$250,000 each) at Virgin Galactic.
- ◆ 2020: Successful New Sheppard mission for the 13th time in a row (no humans on board yet).



asteroid mining
2017



REFUELLING SPACECRAFTS WITH MOON WATER IS PROVEN FEASIBLE.

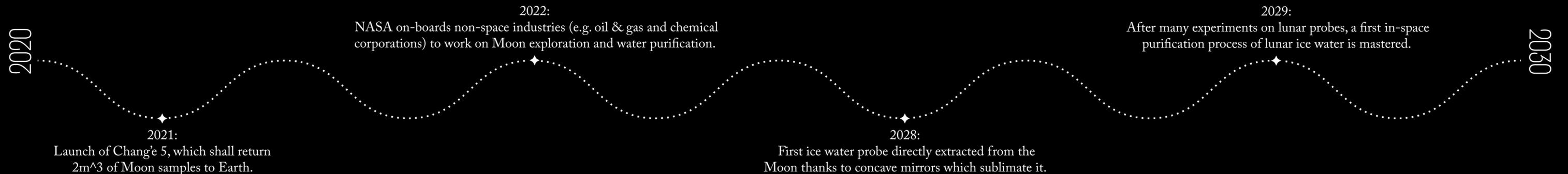
Astronauts have successfully conducted the mission of extracting ice water from the Moon, returning it safely to the lunar orbital station, purifying it and splitting it into Hydrogen and Oxygen - the two chemical elements necessary to propel spacecrafts.

With refuelling in-orbit being mastered, all the key tech bricks are now available to refuel spacecrafts in orbit, using propellant from the Moon. But from the lab to industrialisation, many challenges still lie ahead.

FACTS & FIGURES 2020

- ◆ 2011-18: Successful NASA Robotic Refuelling Mission demonstrates the capability to refuel spacecrafts in orbit.
- ◆ 2018: NASA confirms water ice at the Moon's Poles.
- ◆ 2019: China Chang'e-4 lands on the far side of the Moon.
- ◆ 2019: The startup Orbit Fab refuels the International Space Station with water.
- ◆ 2020: NASA awarded Intuitive Machines \$47 million to deliver a drill combined with a mass spectrometer to the Moon by December 2022.

INSPIRATIONAL TIMELINE







The terrorist organisation (...) has claimed responsibility for the disappearance of three (...) spy drones.

They succeeded in jamming and spoofing the satellite positioning signals, leading to a trail of false information regarding the drones.

Next generation positioning constellations, currently under development, are designed to be more resilient to potential threats, using stronger signals, a higher number of satellites and partnerships with Low Earth Orbit commercial constellation infrastructures to double the signal in cases of attack.

HOW VULNERABLE ARE G.P.S., BEIDOU, GALILEO AND GLOSNASS?

INSPIRATIONAL TIMELINE

2020

2030

Regular demonstrations of more powerful and refined counter-space capabilities by the USA, China and Russia.

Critical infrastructures are designed to be more resilient, e.g. using more satellites and space data relays, being protected against threats (e.g. by special materials), as well as leveraging commercial infrastructures as back-up and/or complementary assets.

Key space mid-powers (e.g. EU, India) master key counter-space capabilities and have demonstrated their credible capability to trigger a massive destruction response in case of an attack against (one of) their critical space infrastructure(s).

FACTS & FIGURES 2020

- ◆ 2015: Creation of the People Liberation Army Strategic Support Force which integrates space, cyber and electronic warfare capabilities.
- ◆ 2019: Creation of the United State Space Force.
- ◆ 2020: Publication of the first doctrine of the US Space Force.
- ◆ 2020: Space Situational Awareness, Directed Energy Weapons (laser), Electronic Warfare (jamming and spoofing), Cyberspace Threats, Orbital Warfare, Kinetic Energy Threats (anti-satellite missiles): among these six main counter-space capabilities, all are mastered by the USA and China. Russia would master all of them but laser which is under development.



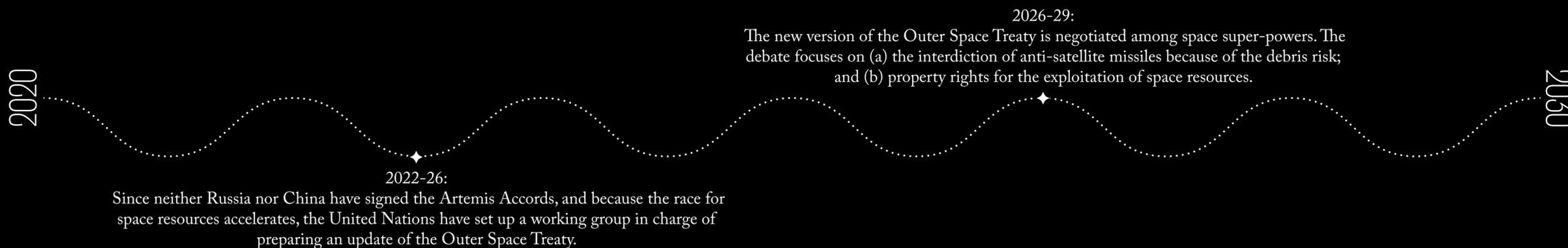
moon mining
2016



The beginning of mining on the Moon rendered the former Outer-Space Treaty obsolete as its ambiguity regarding property rights led to ownership tensions. Similarly, the Artemis Accords issued in 2020 by the USA and signed by many of its allies was not recognised by China and Russia. The signature of the updated Outer Space Treaty comes highly welcomed by the international space community as a key step towards the peaceful use of space resources.

37 SPACE POWERS HAVE SIGNED THE OUTER SPACE TREATY II, PROHIBITING WEAPONS OF MASS DESTRUCTION AND CLARIFYING PROPERTY RIGHTS IN SPACE.

INSPIRATIONAL TIMELINE



FACTS & FIGURES 2020

◆ The Outer Space Treaty does not answer new questions raised by the upcoming exploitation of space resources.

◆ NASA Artemis Accords, while abiding by the Outer Space Treaty, details some of its content w.r.t. space resources. In particular, signatories are obliged to transparently inform each other about their space resource projects; it also advocates for interoperability between the next generation of space resource exploration & exploitation equipment, & systems. The Artemis Accords are signed by the space agencies of Australia, Canada, Italy, Japan, Luxembourg, the United Arab Emirates, the United Kingdom and the USA.



gravitation entanglement
2016

MICHAEL NAJJAR

In his artwork Michael Najjar takes a complex critical look at the technological forces shaping and drastically transforming the early 21st century. Michael's photographic and video works exemplify and draw on his interdisciplinary understanding of art. In his artistic practice he fuses art, science, and technology into visions of future social structures emerging under the impact of cutting-edge technologies.

Since 2011 he works on the topic of space exploration. His "outer space" work series deals with the latest developments in space exploration and the way they will shape our future life on Earth, in Earth's near orbit and on other planets. The cultural dimension represented by the transition process towards a larger human presence in space is very much at the center of Michael's work.

One essential hallmark of his work is the way it is deeply informed by an experiential hands-on approach. The performative aspect has also become a fundamental part of Michael's work process and will culminate in his own flight into space. As one of the pioneer astronauts of Virgin Galactic, he will be embarking on SpaceShipTwo on one of its future spaceflights where he will be the first artist to travel in space.

For the past 25 years Michael's work has been subject of prominent solo and group shows at international institutions around the globe. His artworks form part of museum, corporate and private collections across the world, and are constantly featured in numerous magazine and book publications.



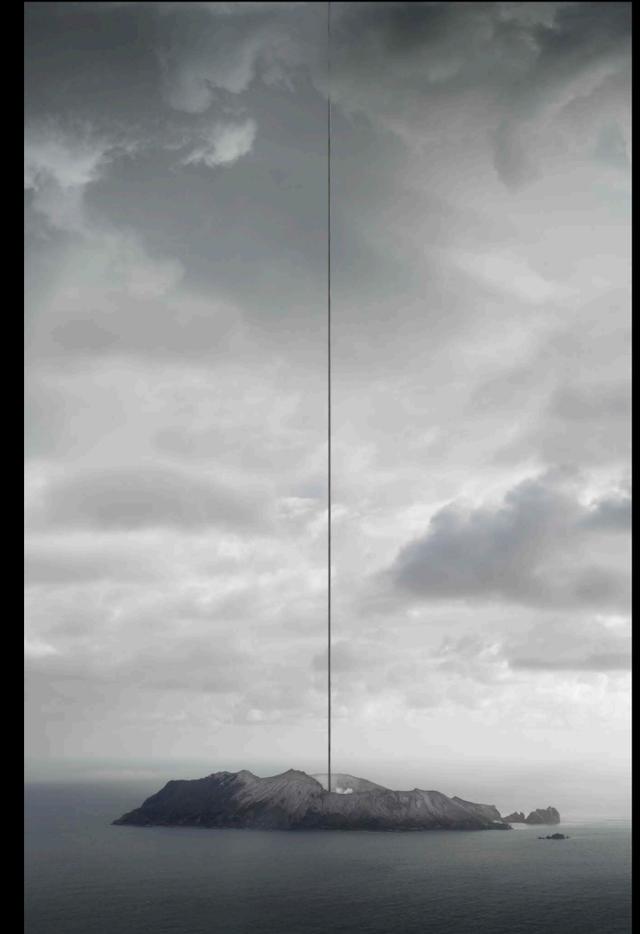
gravity turn (2016)

“gravity turn” visualizes different perspectives of the launch of an Ariane 5 rocket at the Guiana Space Centre by combining a skywards view photographed by the artist from the ground near the launch pad with a view from sky towards earth photographed from an airplane flying over French Guiana. Orbital launch vehicles like the Ariane 5 commonly take off vertically, and then progressively tilt, usually following a smoothly curved trajectory. Once above the dense part of the atmosphere, the vehicle carefully angles the rocket engine jet, slowly pointing the launcher horizontally which permits the vehicle to progressively aim at the required orbit while increasing its speed. The launch vehicle and its smoke column of solid propellant combustion were photographed during the pitch-over manoeuvre about 90 seconds after lift-off, shortly before booster separation.



planetary overview (2017)

“planetary overview” highlights satellite observation of glacier change from space. Development of a planetary overview system is one important outcome of advanced space exploration that has revolutionised glaciology by creating new ways to map large terrestrial landscapes. It helps us map glacier snow cover and mass balance in much larger scale as well as to track changes in ice sheet thickness and ice flow velocities. Yet this new way of measuring and visualizing the globe carries a stern ecological warning, and the dawning of a planetary overview system might intensify awareness of ecological damage to our planet. The artwork combines images taken on Iceland’s Breiðamerkurjökull glacier with several satellite images of the same glacier from an orbital position high in space, fusing a micro- and macro-perspective, the inside view of the fragile glacier with the extreme distance view from outer space.



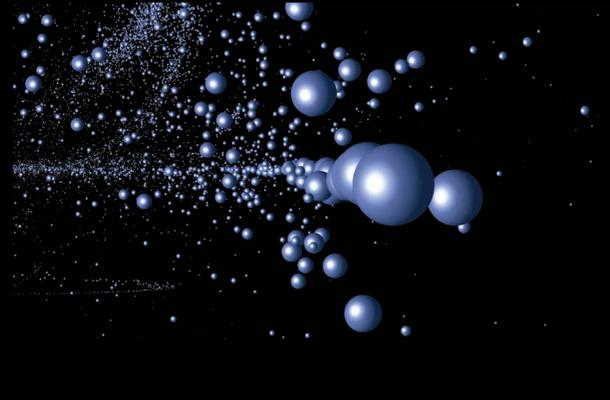
ascension (2020)

“ascension” visualizes the utopian vision of a space elevator. Its composition brings the three elements of ocean surface, island and clouds together, forming a sublime landscape bathed in dramatic light and divided in the middle by a vertical black line that also serves as a connecting element. Viewers approach the picture from a distance with an elevated gaze which glides over the surface of the water. In the background the horizon softly dissolves into clouds, the surface of the earth merges seamlessly with the sky. The horizontal breadth, the elevated gaze and the vertically rising line conjoin the terrestrial world with space above it. The natural landscape has an added disruptive technological element, the taut cable of the space elevator connecting Earth with outer space. Reaching the upper edge of the picture and disappearing into the clouds, it opens an infinite transcendental space in which the viewer's imagination can freely roam.



starlink (2020)

“starlink” visualizes light pollution in our sky at night, underscoring the likelihood that our starry night sky will soon drastically change forever. SpaceX plans to envelop the Earth with a global network of satellites, a mega-constellation of up to 42,000 satellites. The advent of such a global satellite network would seriously impede the research work of astronomers throughout the world. The composition shows a hilly landscape, a starry night sky photographed by a telescope in the Atacama Desert in Chile and crossed by multiple diagonal trails of light with a long flat building embedded in-between, connecting them. Entrenched in the Atacama Desert at an altitude of 2600 meters, this enigmatic building is home to research scientists and astronomers. The Starlink satellite network is destined to have a major lasting impact on the aesthetics and purity of our sky at night as technology inscribes itself intrusively on our star-studded heaven.



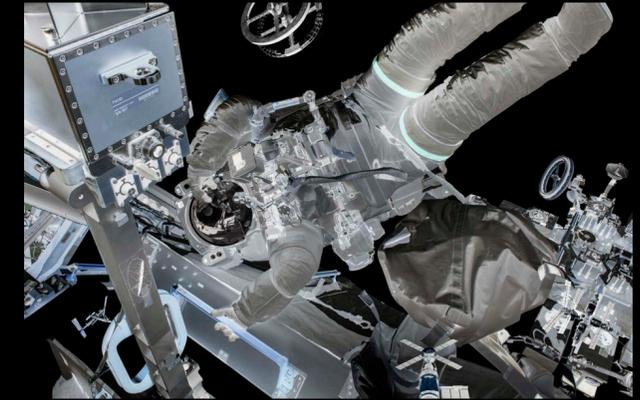
orbital cascade (2013)

“orbital cascade” visualizes the quantity of defunct objects in orbit around the Earth from 1957 to 2046. This includes everything from spent rocket stages, and old satellites to fragments resulting from disintegration, erosion, and collisions. Currently there are about 600,000 objects larger than 1 cm in space, orbiting Earth at a velocity of approximately 28,000 kmph and posing a severe threat to satellites, space stations, and manned space flights. Each spherule in the video represents a real existing object orbiting in space starting with the very first object in space, the Sputnik 1 satellite launched in 1957. The year 2013 marks the start of a simulated worst-case future scenario that assumes two realistic collisions, which would dramatically increase the amount of space debris, collisions known in aeronautics as the “cascade effect.” The visualization was realized in collaboration with the Institute of Aerospace Systems/TU Braunschweig.



f.a.s.t. (2017)

“f.a.s.t” pictures the largest astronomical radio telescope on Earth – with a diameter of 500 metres. China built this staggeringly large instrument called the “Five hundred-meter Aperture Spherical Telescope” in a remote and barely accessible mountainous region in the south of the country. One of its main objectives is to detect interstellar communication from alien civilizations. The composition of this artwork focuses on the relationship between the natural environment and the cutting-edge astronomical instrument which evokes a sense of the sublime simply through its overwhelming size in relation to the surrounding mountains. Searching for alien life means searching for the source of life in general and confronting a fundamental question facing humankind: where do we come from? The inconceivably vast size of “f.a.s.t” is also a metaphor for the immeasurability of time and space which ranges from our own birth to the birth of the Universe itself.



orbital outpost (2018)

“orbital outpost” explores space station utopia and the relationship between technology, the human body and weightlessness. It fuses outside shots of a spacewalk from the International Space Station with images of earlier space stations. Over the last century the technical futuristic vision of a crewed space station became the apogee of all speculative thought on outer space and the privileged locus for all extra-terrestrial aspiration. The orbital station formed the central element in the futuristic logic of expansion as the infrastructural prerequisite for human penetration of the depths of interstellar space. The artwork is centred on a human figure clad in its protective technological shell, in imminent danger of floating away, held only by one hand. Space still remains an inimical, deeply alien environment, making it a privileged realm for our imagination and a green screen for our musings on utopian worlds.



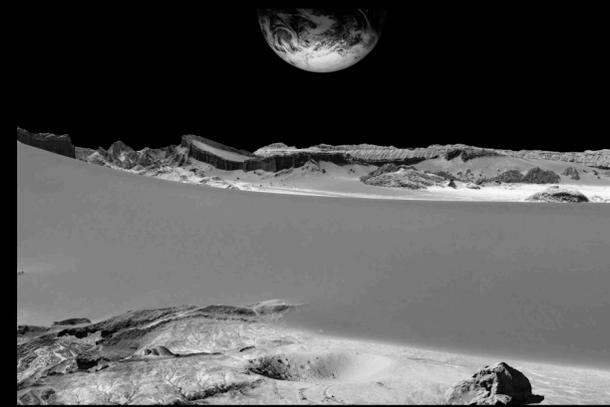
asteroid mining (2017)

“asteroid mining“ envisions future exploitation of raw materials, especially water, from asteroids and minor planets. Water is the most abundant chemical compound in the universe - ubiquitous in our own solar system and fundamental to all operations in space. As the core resource supporting humans in space it’s not only the key factor underpinning human habitation and civilization but can also be used as a propellant. It can be broken down into its constituent parts, liquid hydrogen and oxygen, and used as fuel. If that fuel could be manufactured and made available in space it could power aging satellites and other spacecraft or enable lightly fuelled rockets to take off from Earth and then re-fuel in space. Asteroid mining schemes might one day become reality and help us further explore and colonize our solar system.



orbital spy (2015)

“orbital spy” visualizes the futuristic space technology now being developed in the Membrane Optical Imager for Real-Time Exploitation (MOIRE) program commissioned by the DARPA agency of U.S. Department of Defense. This technology aims at replacing conventional glass optics with lightweight polymer membranes that will pave the way for a foldable plastic orbital telescope. Optical plastic membranes are mounted on thin aluminium panels which unfold in space like origami works to form a telescope of more than 20m in diameter. To create this artwork, a 3D model of the telescope was rendered based on what little information is available on the internet and combined with a view of Earth. The artwork gives a premonition of how this technology not only will revolutionize the way images are captured, but will also prove a watershed in terms of the capability of military and state-controlled surveillance to monitor the planet and the people who live on it.



moon mining (2016)

“moon mining” visualizes the future importance the Moon will have as a source of energy. It possesses an abundance of helium-3, a precious isotope that forms part of the solar wind which cannot reach the Earth’s surface. Helium-3 could well be the energy source of the future for fusion reactors, and various countries are now gearing up for the coming stiff competition for the Moon’s rich resources. Helium-3 is embedded in the regolith or lunar dust that takes up the major part of the artwork which is composed of photographs of Moon Valley in the Atacama Desert and original shots of the Moon’s surface taken by the Apollo astronauts. A mine on the left of the composition signals the future mining of resources.



gravitation entanglement (2016)

“gravitation entanglement” depicts the inevitable collision between our own Milky Way and our closest neighbor, the Andromeda Galaxy, also known as M31. NASA’s Hubble Space Telescope observations indicate that the two galaxies, pulled together by their mutual force of attraction, will crash in a near-head-on collision in about 4.5 billion years from now. The two galaxies would race by each other if it weren’t for the force of gravity pulling them together. The spiral galaxies will merge to form a single elliptical new galaxy. New planets and solar systems will be formed from the star dust produced by the crash. “gravitation entanglement” depicts what we will see looking up into the night sky—supposing that humankind still exists. The visualization of the heavenly bodies is based on measurement data from the Hubble Space Telescope, digitally transformed to simulate the encounter of the galaxies.

- ◆ 2019 Space Technology at a Glance, Bryce, 2020.
- ◆ Challenges to Security in Space, Defense Intelligence Agency, USA, 2019.
- ◆ China's Ground Segment Building the Pillars of a Great Space Power, China Aerospace Studies Institute, 2020.
- ◆ MIT Technology Review, Here's how we could mine the moon for rocket fuel, 2020.
- ◆ National Medium- to Long-Term Civilian Space Infrastructure Development Plan (2015-2025), PRC National Development and Reform Commission, Ministry of Finance, and State Administration of Science, Technology and Industry for National Defense, China, 2015.
- ◆ Longer Term Investments, Space, UBS, 2018.
- ◆ Science & Technology Trends 2020-2040, NATO, 2020.
- ◆ Spacepower, Doctrine for Space Force, United States Space Force, 2020.
- ◆ Startup Space Report, Bryce, 2020.
- ◆ The Future Technology in Space, London Technology Club, 2020.
- ◆ The Annual Compendium of Space Transportation, FAA, USA, 2018.
- ◆ The Space Arms Race: Global Trends and State Interests, Zeev Shapira and Gil Baram, 2019.