



SPACE RACE: Commercialising the Path

Point-of-View

July 2021

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From race of superpowers to race of billionaires

What is shaping the space
exploration industry of today?

Roads to success in exploring space

Who are in the space
race of today?

Future of in-space economy

What benefits will
space exploration bring
for the economy?

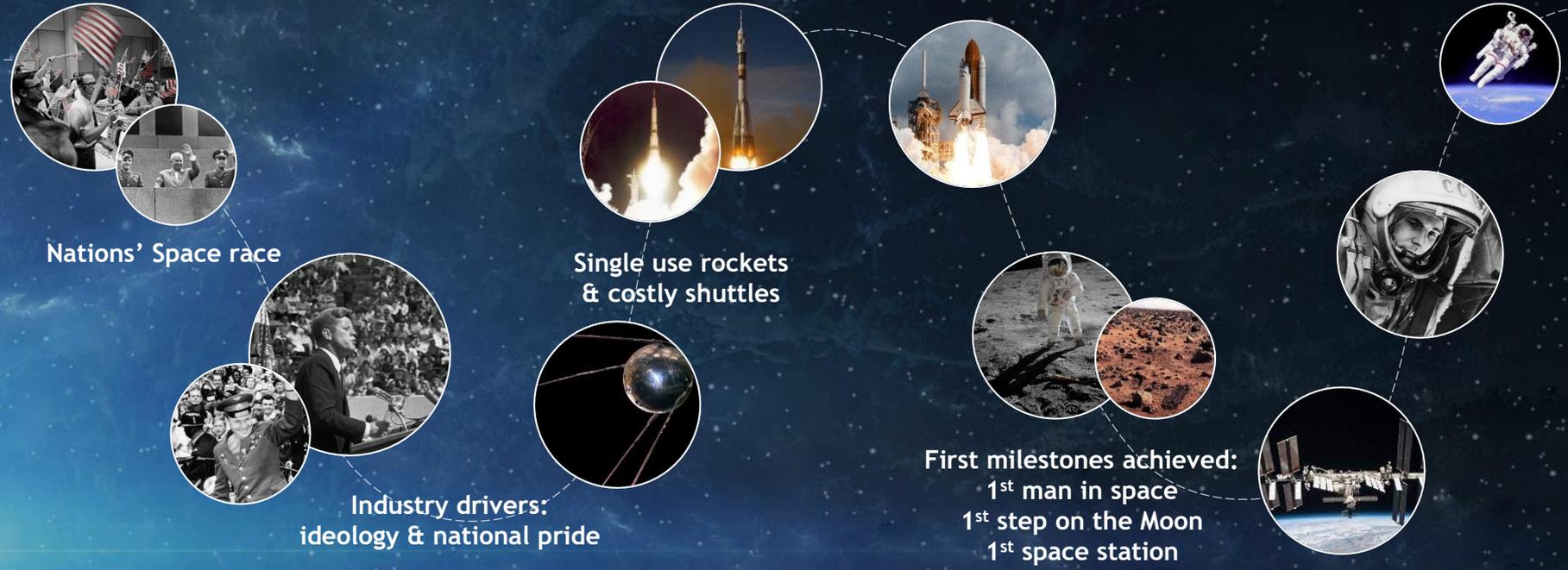
Introduction to a space journey

Executive summary



Journey into space started 50 years ago with nations' race making first steps using moderate technology at hand...

Key elements of space journey 50 years ago





...and continues with visionary leaders driving space into the era of affordable travel and game-changing projects

Key elements of space journey now



Active exploration and rapid growth of the global space industry enable multilateral perspectives in the future

Key space players



SPACEX
Elon Musk 

Enable the colonisation of Mars



BLUE ORIGIN
Jeff Bezos 

Build the low-cost road to space to enable near-Earth colonisation



GALACTIC
Richard Branson 

Build the Spaceline for Earth to make space travel available for everyone

Prospective in-space industries



Space mining



Space logistics & Orbital transportation



Space hospitality & Travel



Space manufacturing & Construction



Space farming

2020



315 Bn USD

85 countries operating in space in 2021



Upcoming missions

Governmental agencies		Private companies
 MOON	 Artemis	 SpaceX  Rocket Lab
 MARS	 ESA  Roscosmos	 SpaceX

Predictions of future development



Asteroid settlements



International Moon village



Artemis Base Camp



Greenhousing in space



Sustainability in space

2040



1,053 Bn USD

A background image of space featuring the Earth's horizon on the right and the Moon on the left, set against a starry sky. A white vertical bar is positioned at the top center, and a white horizontal line is located below the main title.

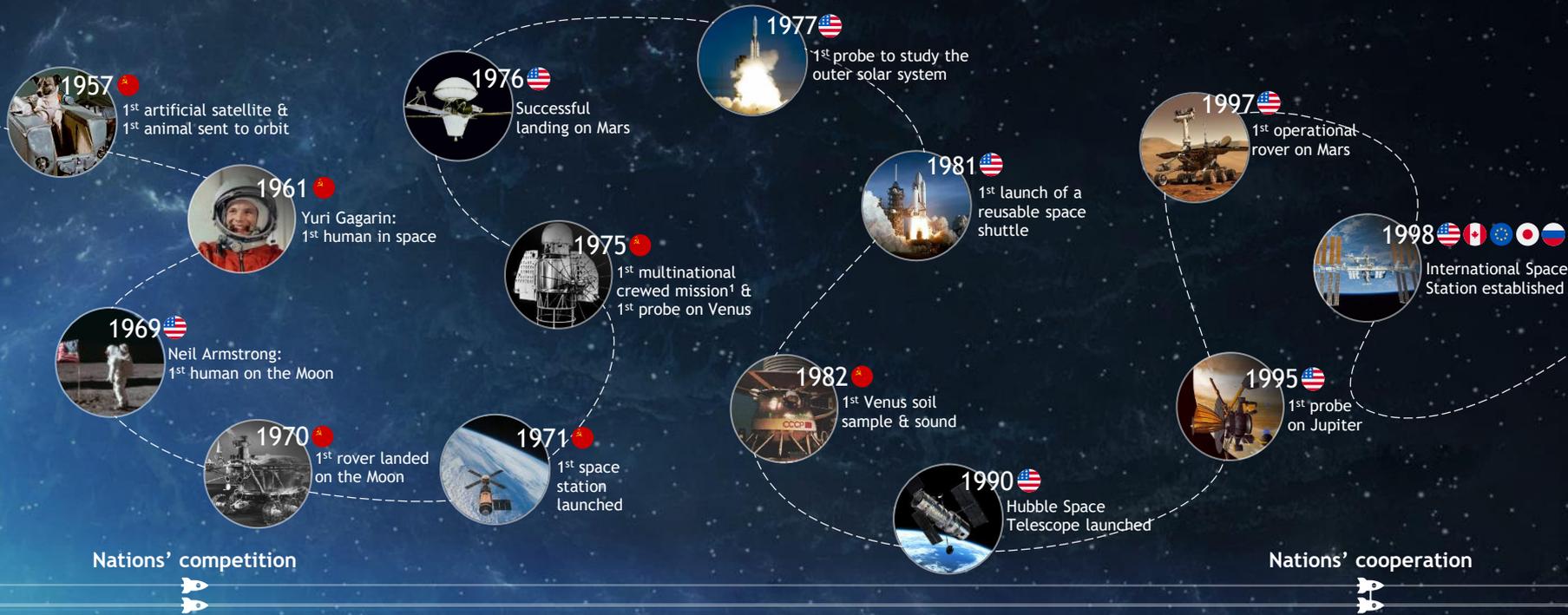
FROM RACE OF SUPERPOWERS TO RACE OF BILLIONAIRES

Space exploration started more than 50 years ago from small steps in satellites assembly... 50 years ahead and the world observes a tremendous boost in space technologies and missions... Future of space exploration has become close to humanity like never before





In just 50 years of exploration, there was a tremendous boost in the space industry, starting from the Moon mission

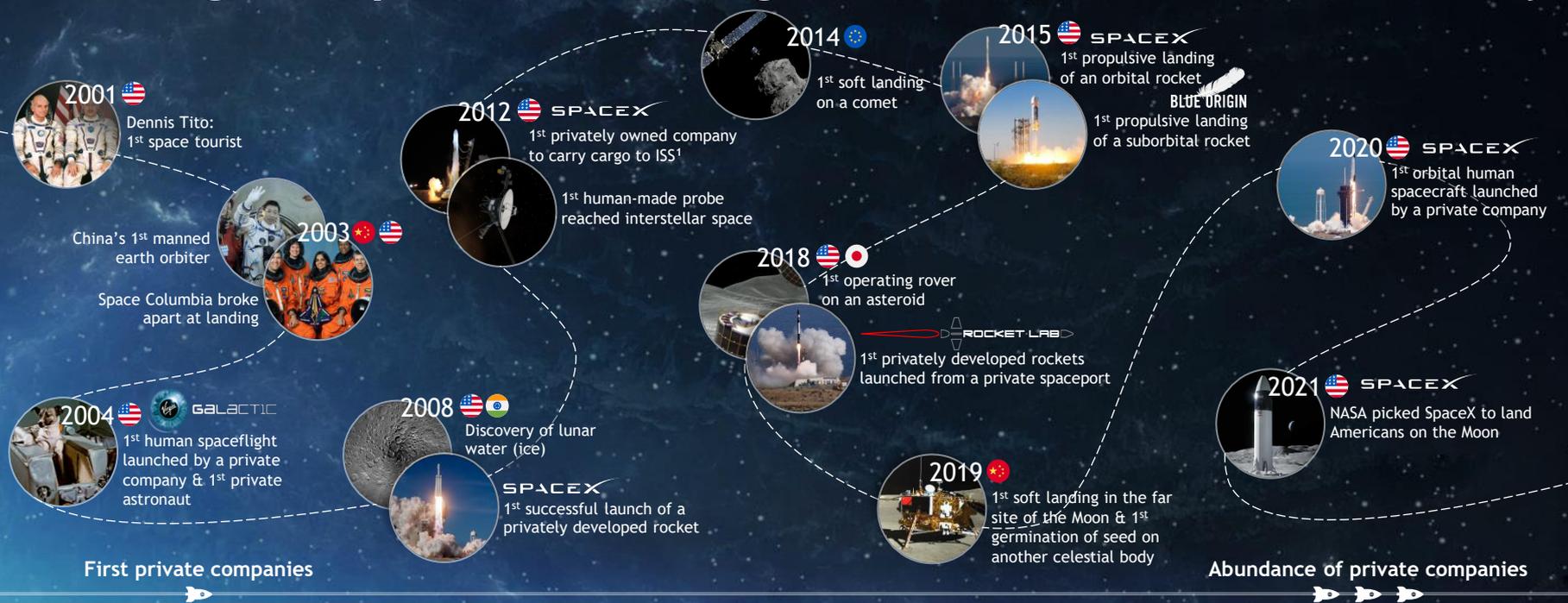


Source: Space – The Timeline: 50 Years of Spaceflight – [2012]; John M. Logsdon, Britannica – Space exploration – [2021]

7 Notes: (1) Included members from the USSR and the USA



A New Space Age is boosted by big private companies entering the space, indicating commercialisation of industry



Source: Space – The Timeline: 50 Years of Spaceflight – [2012]; John M. Logsdon, Britannica – Space exploration – [2021]
Notes: (1) International Space Station

In XXI century, the cooperation of countries & companies is the most effective approach to conduct space exploration



Humanity, governments, and big enterprises have common goals in space



Increase capabilities and decrease costs for future human and robotic space missions



Space-based research and observation of Earth to improve life on Earth and deal with environmental problems



Extend human knowledge of space, understanding of Earth, solar system, and the universe that may support life



Explore and expand human presence beyond Earth and after that beyond the solar system



Stimulate economic growth by the development of space-to-earth and space-to-space economy



Artemis Moon programme is nowadays the biggest space exploration programme with the broad cooperation of countries & companies, both in public and private sector¹



Space agencies cooperation

- NASA** (USA): Sending first woman and next man on the Moon in 2024
- International space agencies**: Establishment of sustainable and robust presence on the Moon

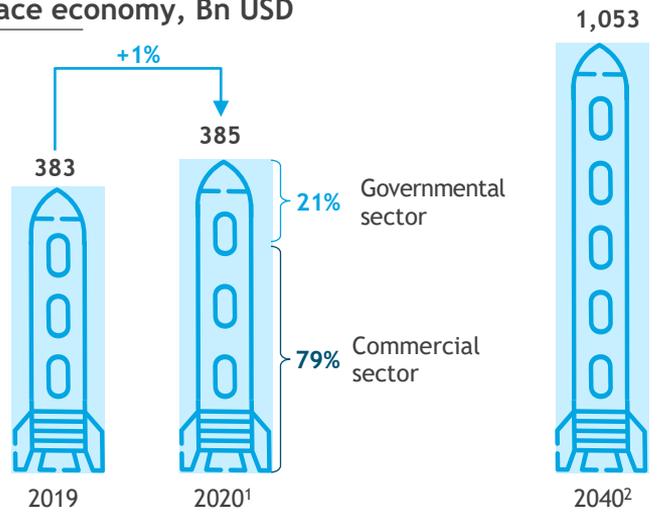
Companies cooperation

- Orion spacecraft**: LOCKHEED MARTIN
- Space Launch System**: AERJET ROCKETDYNE, NORTHROP GRUMMAN, BOEING
- Exploration Ground System**: Jacobs
- Human Landing System**: SPACEX
- CAPSTONE launch**: ROCKET LAB

At the bottom, flags of participating countries are shown: USA, Canada, Japan, Australia, Italy, Hungary, UK, and UAE.

The global space economy is projected to reach 1 Tn USD by 2040 with the commercial sector driving the market

Global space economy, Bn USD



Governmental investment on space exploration during 2019-2029, % of total

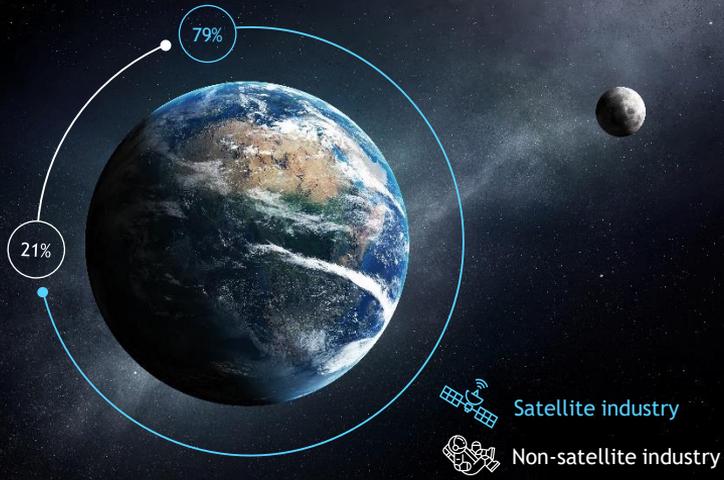


85 countries operating in space³ **NASA** — leading space agency **466** spacecraft deployed
 Budget 2021: **23.3** Bn USD **54%** — by private companies⁴

The satellite segment makes up 79% of the space economy with the USA as a leader in satellites quantity and launches

Global space economy
by segments in 2020

385 Bn USD



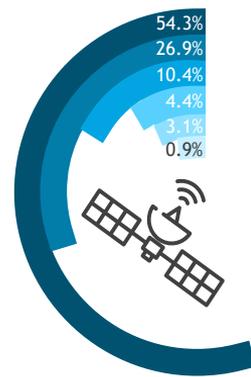
3,372 satellites are active in 2021^{1,2}

USA 56.3%

China 12.2%

Russia 5.2%

Satellite uses by operational purposes in 2021



Communications

Navigation / Positioning

Earth observation

Space science / Observation

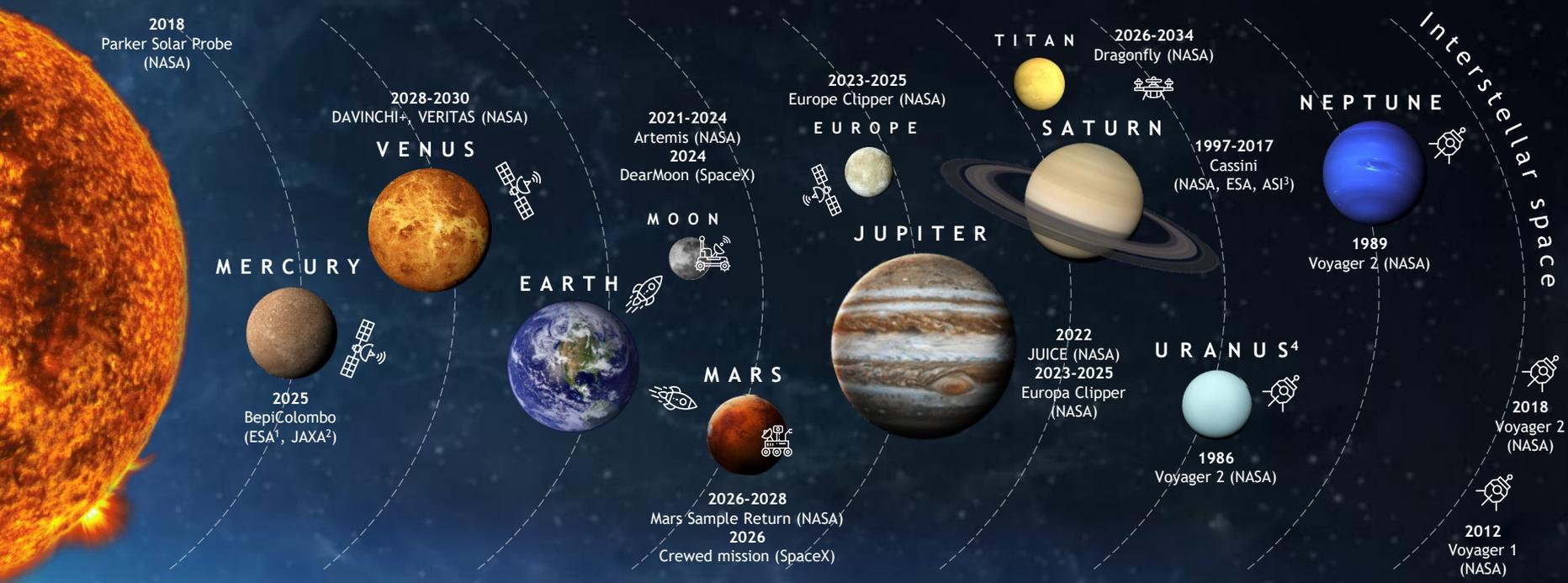
Technology development / demonstration

Earth science & Other purposes

Source: Space Foundation – The Space report – [Q2 2020]; Union of Concerned Scientists website; Statista website
Notes: (1) As of May 2021, the private company SpaceX owns 1,500 satellites; (2) Top-3 countries by active satellites with a total share of 73.7%



Exploration of space is focused on finding new ways to unlock the mysteries of the solar system and beyond



Source: NASA website; SpaceX website

Notes: (1) European Space Agency; (2) Japan Aerospace Exploration Agency; (3) Italian Space Agency; (4) A number of dedicated exploratory missions to Uranus have been proposed, yet none have been approved as of 2021



Moon exploration started with the US mission in 1969, yet nowadays more private companies enter the Moon race

Nations landed on the Moon¹



64 successful² Moon missions



Major upcoming moon missions of private enterprises



Distance travel by Moon rovers, kilometres^{3,4}



Key reasons to explore the Moon



Water and oxygen to produce rocket fuel and establish a human base

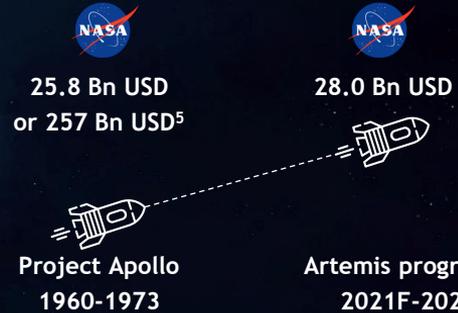


Precious metals, rocks, and rare earths to create building & raw materials



Helium-3 to create fuel suitable for fusion energy generation

NASA budget on the Moon missions



Source: NASA – NASA’s Lunar Exploration Program Overview – [September 2020]; Statista website; National Geographic website

Notes: (1) As of 22 July 2019; (2) Successful and partially successful missions only; (3) As of July 2020; (4) Diameter of the Moon is 3,474.8

13 kilometres; (5) Brought to current prices and inflation adjusted



The first human-crewed mission is the main focus in Mars exploration for the space industry in the next years

Nations completed successful missions on Mars¹



7-10

months average time of the trip to Mars



Major upcoming Mars missions

By countries

2022-2023

ESA / Roscosmos: ExoMars 2022 Rover and Surface Platform

2026-2028

NASA: Mars Sample Return with the aim to bring samples from the surface of Mars to Earth

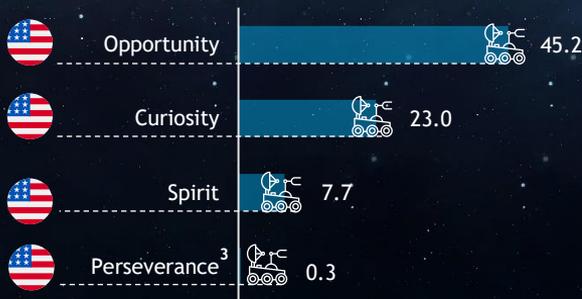
By private company

SpaceX:

2024 – uncrewed mission to Mars

2026 – crewed mission to Mars

Distance travel by Mars rovers, kilometres²



Key reasons to explore Mars



Mars's land area is almost equal to the surface area of Earth's continents



Water is locked into the Mars icy polar caps

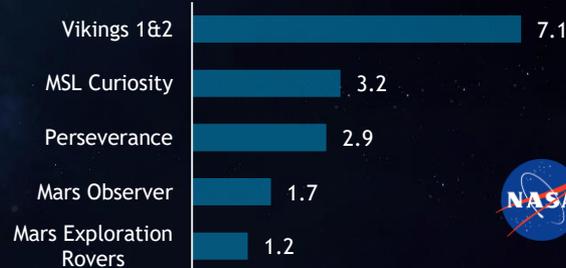


Mars still has decent sunlight as it is about half as far from the Sun as Earth



Middle-term goal – human missions to Mars

Estimated life-cycle costs of Mars missions by NASA, inflation-adjusted, Bn USD⁴





Except for the Moon & Mars, there are also other celestial bodies considered to be attractive to search for life



Venus

Key facts

225 Earth days
orbital period¹

1.1 times
smaller than Earth

4 months
average time of
the trip to Venus²

0.7 AU³
distance from
the Sun



Europa⁴

Key facts

3.5 Earth days
orbital period¹

4.1 times
smaller than Earth

>36 months
average time of
the trip to Europa²

5.2 AU³
distance from
the Sun

Current and past Venus missions by country⁵



Major upcoming Venus missions

VERITAS	DAVINCI+	EnVision
2028	2029-2030	2031-2033
Orbiter	Atmospheric probe	Orbiter

Key reasons to explore Venus

Venus and Earth are alike in size, density, and gravity

Astronomers detected phosphine, which is a possible sign of life

In some areas, pressure and temperature are quite Earth-like

Current and past Europa missions by country⁵



Major upcoming Europa missions

JUICE	Europa Clipper
2022	2023-2025
Orbiter	Orbiter

Key reasons to explore Europa

Liquid water ocean is present today and is in contact with the rock

Atomic particles trapped by Jupiter crash into Europa and produce compounds that could be used for living

Europa's seafloor could be heated by its constant flexing that could create primordial life

Source: NASA website; Media overview

Notes: (1) Length of the year; (2) Using existing humanity technologies; (3) Astronomical unit – approx.

ROADS TO SUCCESS IN EXPLORING SPACE

Reaching the stars and beyond – ambitious plans and big dreams of key players are becoming the powerful engine of space industry development nowadays



Active involvement of private investors in the commercial space race could take the space industry to new frontiers



Elon Musk



SpaceX

2.9 Bn USD

Starship takes astronauts to the Moon

Jeff Bezos



Blue Origin

579.0 Mn USD

Design a human-landing system

Peter Beck



Rocket Lab

10.0 Mn USD

Launch a CubeSat into lunar orbit

Max Polyakov



Firefly Aerospace

93.3 Mn USD

Deliver science and technology payloads

Richard Branson



Virgin Galactic

45.0 Mn USD

Flight and integration services

Tim Ellis & Jordan Noone



Relativity Space

3.0 Mn USD

Place CubeSats into low Earth orbit

Red Whittaker



Astrobotic Technology

279.0 Mn USD¹

Deliver payloads and VIPER to the Moon

 Amount of recent contract with NASA

Source: AERTEC Solutions website; CNBC website; NASA website; Companies' websites

Notes: (1) Total amount of two contracts



Elon Musk, Jeff Bezos, and Richard Branson are pioneers of the commercial space race in the XXI century



Jeff Bezos

Net worth: 198.9 Bn USD¹

Company: Blue Origin

Foundation year: 2000

Space goal: Enable Moon and near-Earth colonisation



Key milestones

1st successful vertical landing of the suborbital rocket

16 successful test flights of the New Shepard suborbital rocket

July 2021 scheduled launch of the first commercial tourist space flight

Q4 2022 first test flight of the new heavy rocket New Glenn is scheduled



Elon Musk

Net worth: 155.5 Bn USD¹

Company: SpaceX

Foundation year: 2008

Space goal: Enable Mars colonisation



Key milestones

1st private company to successfully launch a rocket into space

1st private company to bring humans to the ISS (10 astronauts)

May 2021 first full successful test flight of Starship

2026 cargo & crew missions to Mars



Richard Branson

Net worth: 5.0 Bn USD¹

Company: Virgin Galactic

Foundation year: 2004

Space goal: Build the Spaceline for Earth



Key milestones

>600 Seats booked on the commercial space flight



Collaboration of the development of supersonic jet

May 2021 spacecraft successfully completed the crewed suborbital test flight

Early 2022 start of the first scheduled commercial tourist flight

Source: Aerospace security website; SpaceX website; Blue Origin website; Virgin Galactic website; The Financial Times — Jeff Bezos's Blue Origin says it will take a civilian to space in July — [May 2021]; BBC — Virgin Galactic rocket plane flies to edge of space — [May 2021]

Jeff Bezos, the richest man in the world, applies his ‘slow and steady’ approach to building a solid space business



Jeff Bezos and his main companies

amazon BLUE ORIGIN
The Washington Post

Origin

Born on 12 January 1964
Albuquerque, New Mexico, USA

Worth and ranking

Net worth: 198.9 Bn USD¹
 in Forbes Billionaires List (2021)
 in Forbes Innovation Leaders (2019)

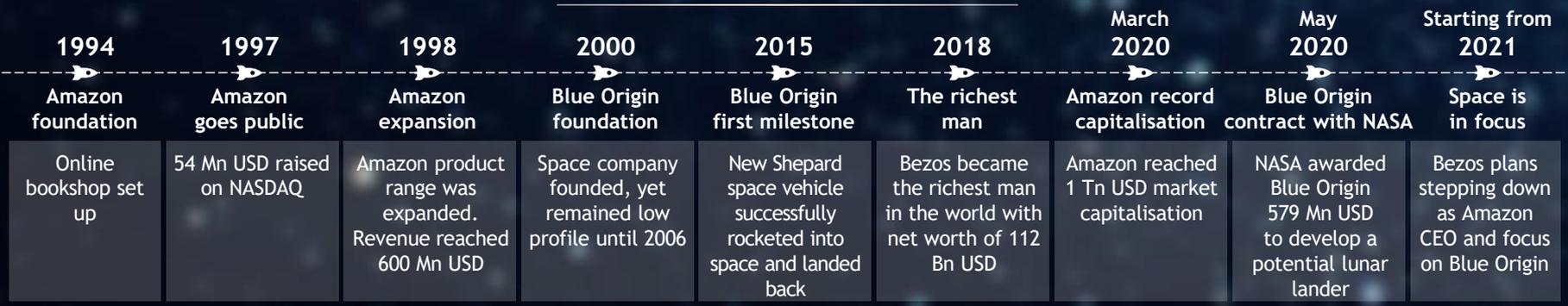
Social media¹

2.4 million followers on Twitter
 241 tweets

Space goal

Build the low-cost road to space to enable near-Earth colonisation

Road to success through making slow but relentless progress



Source: Biography – Jeff Bezos [2021]; Business insider – After Amazon, Jeff Bezos will devote his time to building multi-billion dollar rockets – [2021]; Forbes website
 Notes: (1) As of 22 June 2021

While performing test flights & competing for Moon mission contract, Blue Origin is yet to become commercially viable

KEY FACTS BLUE ORIGIN

 **Founded**
2000

 **Headquarters**
Kent, Washington,
USA

 **CEO**
Bob Smith

 **19 patents and
54 trademarks¹**

 **Funding²**
Bezos intends to fund
Blue Origin with 1 Bn USD
per year from sales of his
equity in Amazon

 **Number of
employees**
3,390³

KEY PROJECTS



Contract with NASA
on Earth observation
missions, planetary
expeditions, and
satellite launches

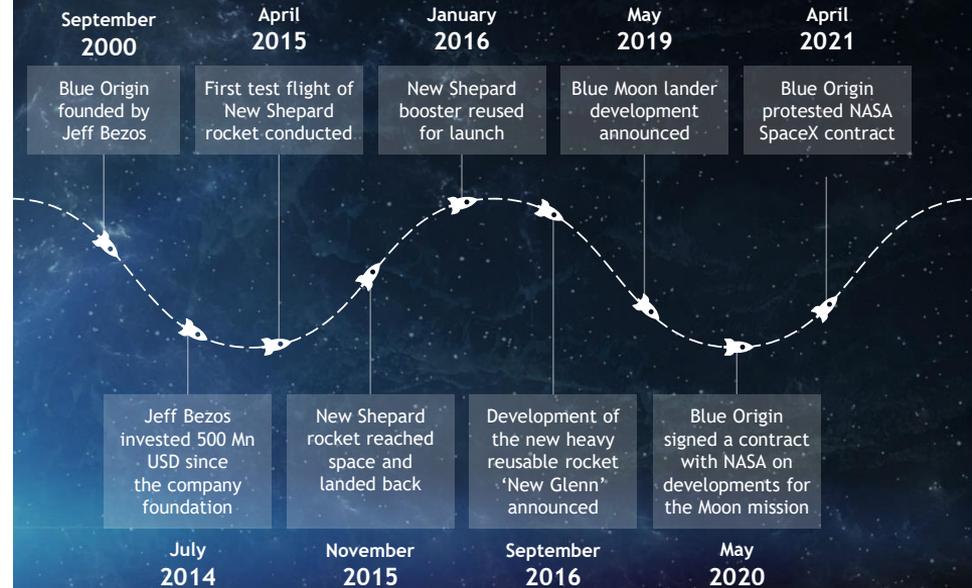


Contract with NASA
on the initial design
of a human-landing
system for the 2024
Moon mission Artemis

 **project kuiper**

Participation in the
Amazon Project Kuiper –
a launch of 3,236 satellites
constellation to provide
high-speed internet to
people around the world

STEP BY STEP TO SOLID RESULTS BLUE ORIGIN



Source: Craft website; Spacenews website; MIT Technology Review – Blue Origin could definitely use more
Jeff Bezos in the next decade – [2021]

20 Notes: (1) As of January 2021; (2) In 2017-2018; (3) As of June 2021

Preservation of the planet and near-Earth space colonies are at the heart of Bezos' vision for civilisation evolution

Bezos' concern:

In the XXI century, humanity will face a shortage of energy resources as well as an ecological crisis

10.9 billion Global population in 2100¹

124% Growth of global energy demand in 2100 vs. 2015²

Fossil fuel reserves will run out by³:

2052 Oil **2060** Gas **2090** Coal

+2.9°C Global warming by 2100⁴

1.1 m Sea level rise by 2100⁵

Bezos' vision:

Transfer of heavy, dirty manufacturing to space and development of near-Earth colonies will help humanity deal with the potential crisis



Source: UN website; Climate Action Tracker website; IPCC website; Arstechnica – Jeff Bezos unveils his sweeping vision for humanity's future in space – [2019]

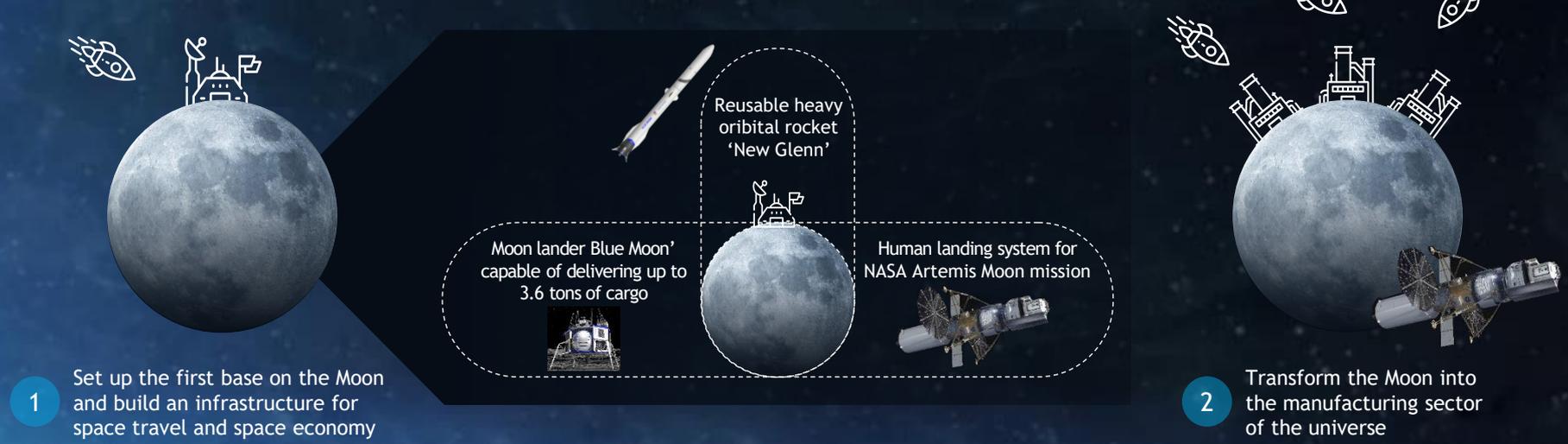
Notes: (1) According to the World Population Prospects 2019 by the UN; (2) Under the medium scenario of population growth by the UN; (3) According to the Millennium Alliance for Humanity and Biosphere website; (4) Global temperature increase compared to the pre-industrial level, projected under current policies;

(5) According to IPCC special report 2019; (6) Space settlement concept proposed by American physicist Gerard K. O'Neill in 1976

According to Jeff Bezos, base on the Moon is the first step to building an infrastructure for space colonisation

Idea of the Moon colonisation by Jeff Bezos

It is time to go back to the Moon – this time to stay. “”
Jeff Bezos



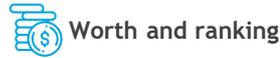
Elon Musk's out-of-the-box thinking made him one of the most influential businessmen in the space industry



Elon Musk and his main companies



Origin
Born on 28 June 1971 in Pretoria, South Africa



Worth and ranking
Net worth: 155.5 Bn USD¹
1 in Bloomberg Billionaires Index (2021)
2 in Forbes Billionaires List (2021)



Social media¹
57.3 million followers on Twitter
14.5 thousand tweets



Space goal
Enable the colonisation of Mars

Road to success through pursuing his technological passions



Source: Britannica – Elon Musk – [May 2021]; Observer website; Inc website; Forbes website; Media overview

Notes: (1) As of 22 June 2021; (2) Provided and licensed online city guide software to newspapers; (3) Provides online payments system; (4) Initial public offering; (5) Ultra-high-speed ground transportation system for passenger and cargo proposed

SpaceX is a game-changing aerospace manufacturer that designs and launches advanced rockets and spacecraft

KEY FACTS **SPACEX**

 **Headquarters**
Hawthorne,
California, USA

 **Revenue**
1.2 Bn USD¹

 **Number of successful launches:** 15¹

 **Value**
74 Bn USD²

 **Funding**
7.5 Bn USD
over 39 funding rounds

 **Number of employees**
9,500³

KEY ROCKETS of SpaceX

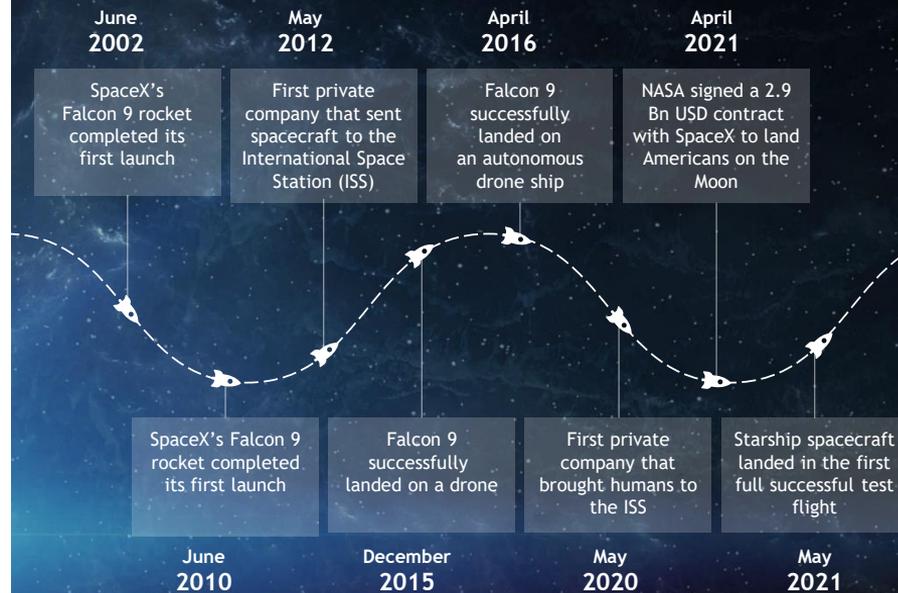
 **Falcon 9** is a reusable, two-stage rocket designed for transportation of people and payloads into Earth orbit and beyond.

 **Falcon Heavy** is the most powerful operational rocket globally with the ability to lift ~64 metric tonnes into orbit.

 **Dragon spacecraft** is capable of carrying up to 7 passengers to and from Earth orbit and beyond.

 **Starship** is a fully reusable transportation system designed to carry both crew and cargo to Earth orbit, the Moon, Mars, and beyond.

STEP BY STEP TO SOLID RESULTS **SPACEX**



Source: SpaceX website; Trefis website – What Is Driving SpaceX's Revenues & Valuation?; Forbes – Is SpaceX Really Worth 74 Bn USD? – [April 2021]; Crunchbase website; NASA website; Media overview

Musk aims to make life multiplanetary by launching the 1st civilian mission to the Moon and establishing a Mars colony

First civilian passengers on a lunar Starship mission



Yusaku Maezawa

The **dearMoon project** is the first civilian mission to the Moon that was first introduced in 2017. In 2018, Japanese entrepreneur Yusaku Maezawa bought all seats for a lunar Starship mission. The journey will happen in 2023 and continue for one week.

2024 – Cargo missions to Mars



The first mission will confirm water resources, identify hazards and build support infrastructure.

2026 – Cargo & Crew missions to Mars



The second mission will start building a base for future expansion and set up a propellant production plant.

Mars colony by 2050

1,000,000 people will live on Mars

100 Starships per year will be built

1,000 Starship flights per year, 3 flights per day

Cost of a single launch – 2 Mn USD

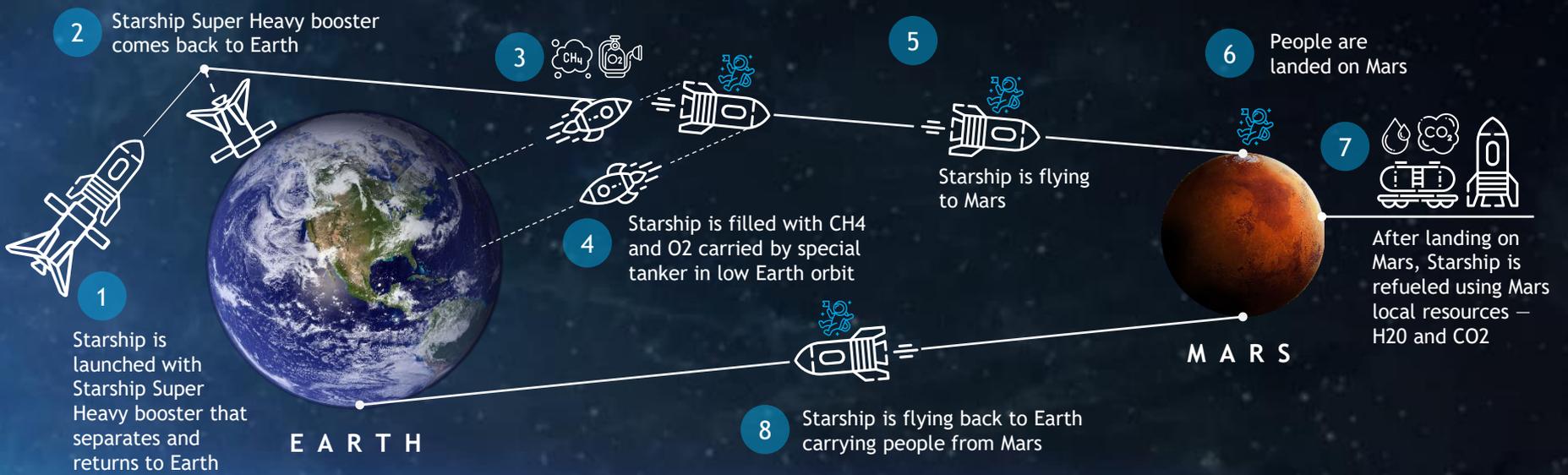
The Mars colony should be a **self-sustaining city**, a 'back-up drive' for civilisation

The **first human colony** on Mars will be built inside glass domes

Direct democracy will be implemented on Mars – the inhabitants will make decisions for themselves and there will be fewer and less complicated laws

Musk plans to set up a permanent human base on the red planet, with Starships carrying people to and from Mars

Road to Mars by Elon Musk



Richard Branson, the world's famous entrepreneur and adventurer, aims at pioneering and leading space tourism



Richard Branson
and his main companies¹



Origin

Born on 18 July
1950
London, England,
UK

Worth and ranking

Net worth: 5.0 Bn USD²
most admired business leader over
the past five decades (2014)³
in the 100 Most Influential British
Entrepreneurs (2018)⁴

Social media²

12.4 million followers
on Twitter
25,6 thousand tweets

Space goal

Build the Spaceline for
Earth to make space
travel available for
everyone

Road to success via the implementation of an adventurous approach to business and diversification



Source: Virgin Group website; Virgin Galactic website; Forbes website; Media overview

Notes: (1) Virgin Group operates more than 40 companies as of 2021; (2) As of 22 June 2021;

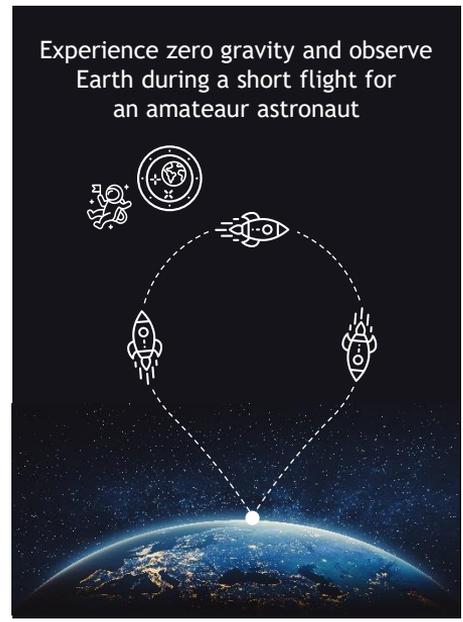
(3) According to The Sunday Times; (4) According to UK-based company Richtopia

As an adventurer himself Branson sees an opportunity in opening space for explorers who are ready to pay for it

Demand



Opportunity



Virgin Galactic offer

-  **Offer:**
Suborbital flight to 100 km altitude and back to Earth

-  **Price:**
250,000 USD

-  **Spacecraft:**
 - ▶ Fully reusable spacecraft system, incl. carrier and spaceship
 - ▶ Capacity for 8 people, incl. 2 pilots

-  **Launch site:**
Spaceport America, New Mexico, USA

-  **Customer experience:**
 - ▶ Safe and enjoyable high acceleration flight
 - ▶ 6 minutes of weightlessness
 - ▶ Spectacular view on Earth from space

-  **Virgin Galactic benefits:**
 - ▶ Regular and frequent schedules
 - ▶ Flights for tourists and researches
 - ▶ Expected cost decline driven by the economy of scale

Branson aims to establish the Spaceline with regular suborbital flights executed by a reusable spacecraft system

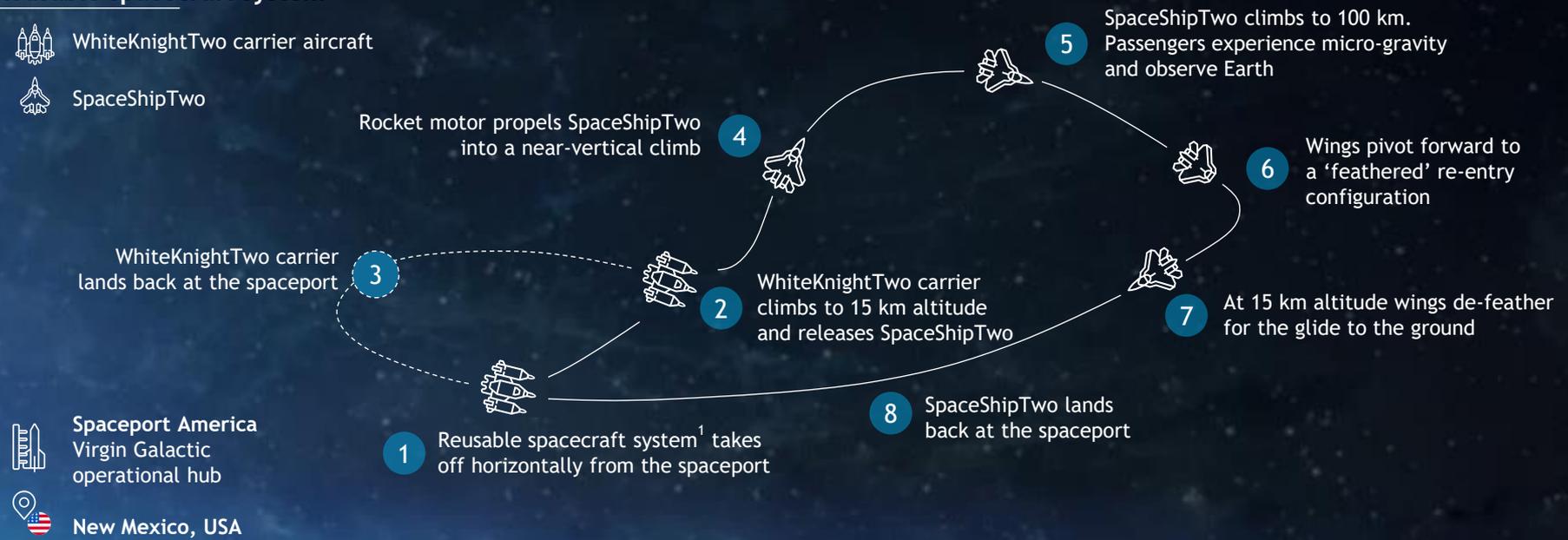
Reusable spacecraft system



WhiteKnightTwo carrier aircraft



SpaceShipTwo



Source: Virgin Galactic website; The Guardian – Richard Branson’s Virgin Galactic prepares to go public – [July 2019]

NASA actively cooperates with space companies to achieve maximum success in its Lunar mission – Artemis



Peter Beck
Rocket Lab

Foundation: 2006



Mission: open access to space to improve life on Earth

Key products: rockets – Electron & Neutron; Photon Lunar spacecraft

Launch complexes: 2 – in New Zealand and the USA¹



In 2021, Rocket Lab will launch a CubeSat² into lunar orbit for NASA using an Electron rocket and Photon Lunar spacecraft. The contract for the dedicated launch is valued at 10.0 Mn USD.



Name: Electron

First launch: 2017

Total number of launches: 19

Delivered satellites: 104

Peculiarity: the only reusable orbital-class small rocket



Name: Photon Lunar spacecraft

First launch: June 2020³

Usage in missions: operational payloads, hosted payloads, science research, technology demonstrations, exploration



Tim Ellis & Jordan Noone
Relativity Space

Foundation: 2015



Mission: provide shift toward software-defined manufacturing by using 3D printing, AI, and autonomous robotics in space manufacturing

Key products: Terran 1, Aeon 1, Terran R



Relativity Space has a 20-year use agreement for a factory building at NASA Stennis Space Center that it uses to house one of Stargate factories. In 2020, NASA selected Relativity Space to place CubeSats into low Earth orbit as part of its VCLS Demo 2 contract. The launch will take place by June 2022. The contract value is 3.0 Mn USD.



Name: Terran 1

Planned first launch: September 2021

Total number of components: 600⁴

Time to print: 60 days⁵

Maximum payload: 1,250 kg to 185 km low Earth orbit

Peculiarity: world's first entirely 3D printed rocket

Source: AERTEC Solutions website; Rocket Lab website; Relativity Space website; NASA website; Media overview

Notes: (1) The launch rate of the base in New Zealand is 120 flights per year, while the launch complex in the USA provides up to 12 missions per year; (2) Small satellite developed by NASA; (3) Aboard an Electron rocket; (4) Compared to 60,000 parts in other rockets; (5) All rockets are printed on the Stargate factory

Griffin and Blue Ghost landers will be used by NASA as part of the Artemis programme to carry payloads to the Moon



Red Whittaker
Astrobotic Technology

Foundation: 2007

Mission: develop space robotics technology for lunar and planetary missions

Key products & services: Peregrine Lander, Griffin Lander, planetary mobility services, DHL MoonBox



Max Polyakov³
Firefly Aerospace

Foundation: 2014⁴



Mission: provide economical access to space for small payloads through the manufacture of launch vehicles

Key products: Alpha, Blue Ghost, Beta, Gamma, Space Utility Vehicle, Launch Facilities, DREAM 0



NASA selected Astrobotic to deliver payloads to the Moon in 2021 (contract for 79.5 Mn USD) and VIPER¹ to the Moon's South Pole in 2023 (contract for 199.5 Mn USD).



In 2021, Firefly Aerospace signed a 93.3 Mn USD contract with NASA to deliver 10 science and technology payloads to the Moon surface. This mission is a part of the Artemis programme.



Peregrine Lander

Used for: delivering payloads to lunar orbit and surface

First launch: Q4 2021

Payload capacity: 90 kg



Griffin Lander

Used for: medium-class lander to accommodate a variety of rovers and other large payloads

First launch: 2023²

Payload capacity: 475 kg



Lunar lander Blue Ghost

Used for: carry instruments to study several aspects of the lunar surface in preparation for future human missions to the Moon

First launch: 2023

Payload capacity: 94 kg – NASA payloads

50 kg – remain available for commercial use

Source: Astrobotic Technology website; NASA website; SpaceFlightNow website; Firefly Aerospace website

Notes: (1) Volatiles Investigating Polar Exploration Rover; (2) Griffin Lander will be launched from the Kennedy Space Center on a SpaceX Falcon Heavy rocket; (3) Ukrainian and American space technology and IT business entrepreneur; (4) Formerly Firefly Space Systems. After going bankrupt in March 2017, Firefly Space Systems was bought by Noosphere Ventures (owned by Max Polyakov) and renamed to Firefly Aerospace

FUTURE OF IN-SPACE ECONOMY



What is waiting for us out there in the stars... And how the development of the space industry will impact big corporations on Earth... To succeed in the next 50 years, many businesses will need to combine space romanticism with innovative commercialisation stories

Active space exploration extends the space ecosystem and encourages the future development of the space industry

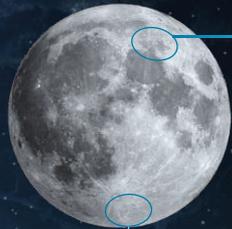


Source: NASA website; Global Space Fund website

34 Notes: (1) Systems for spacecraft which are used to accelerate the spacecraft for orbit-insertion, station-keeping, or attitude control

Space mining opens new opportunities for deep space exploration, however, it demands further legal regulation

 NASA encourages private companies to start fossil fuels extraction on the Moon as a part of the Artemis programme¹



Lacus Somniorum

 ispace Japan 
 Japanese lander
 2022

The South Pole

 ispace Europe 	 Lunar Outpost 	 Masten Space Systems 
 Japanese lander	 Blue Moon	 Masten XL-1 lander
 2023	 2023	 2023

NASA estimates that the mineral wealth of all asteroids between Mars and Jupiter amount to 100 Bn USD per person on Earth

 The space mining industry value is estimated to reach 3.9 Bn USD by 2025

Top-3 opportunities

- ▶ Rare metals / minerals extraction might boost the complementary industries on Earth as the supply will be increased
- ▶ Space mining could increase the decarbonisation of Earth, since fewer extraction activities will be provided on Earth
- ▶ Space refuelling might substantially decrease costs in space exploration and travel activities

Top-3 challenges

- ▶ Outer Space Treaty of 1967 excludes possession of any celestial bodies by any country, which may put legal constraints on mining
- ▶ Propulsion systems are the major limitation factor of the payload mass that could be transported by the spacecraft
- ▶ Minerals extraction with minimal area contamination, which might possess the scientific interest, could be a limitation factor

Source: NASA website; Statista website; The Washington Post website; Milken Institute – Mining in Space Is Coming – [2021]; Frontiers in space technologies – Current Challenges and Opportunities for Space Technologies – [2020]

Notes: (1) The programme is less focused on the financial incentive (25 K USD only), with more focus on establishing the legal precedent that private companies can collect and sell celestial materials

Space hospitality & travel possess high potential in the luxury segment with the first hotel at the project stage

 Space hotels are becoming more realistic as Orbital Assembly Corporation (OAC) announced to build the first low orbital hotel

Station structure

24 modules (12x20 metres)

SPA Gym Living rooms
Cinemas Restaurants

Possible station capacity

 ~400

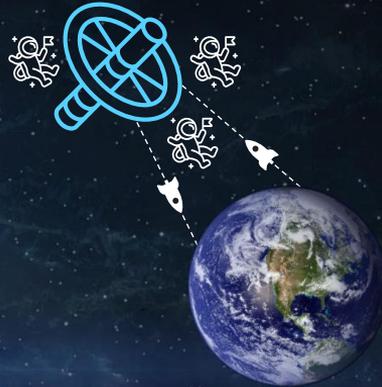
Possible construction period

 2025-2027

Price per night

 ~1.7 Mn USD

The Voyager Station



 The space travel industry value is estimated to reach 2.2 Bn USD by 2026

Top-3 opportunities

- ▶ Real estate development in space is one of the core points for the successful colonisation of other celestial bodies
- ▶ Space real estate development might assist with Earth's overpopulation
- ▶ Space real estate might **highlight the space theme** for the high-income class, as they are the target audience

Top-3 challenges

- ▶ **Space radiation** is still a big challenge, since there is no solid solution developed to fully tackle the space radiation issue
- ▶ Bases and hotels on Earth orbit will face **zero gravity**, which negatively impacts **human health**
- ▶ **Space farming technology** is still under development, hence ensuring a permanent food supply is challenging

Space farming demonstrates large potential both for deep space travel and Earth, albeit still demanding exploration

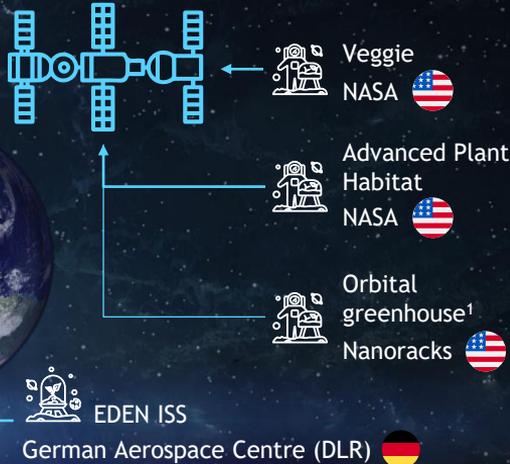


Space farming is an essential part of space travel with some farms already operating on the ISS and others being tested on Earth

Earth

 MarsOasis¹
Lab Technologies LLC 

International Space Station



The vertical farming industry value is estimated to reach 21 Bn USD by 2028²

Top-3 opportunities

- ▶ Space farming technologies are applicable **on Earth** allowing to grow plants in the arid climate, hence assisting the **food shortage issue**
- ▶ Space farming would lower the costs of **space hospitality, long-term flights**, since there will be less need in **food supply** from Earth
- ▶ Fresh food will allow to make **longer flights into deep space** as the astronauts will stay healthier and resilient

Top-3 challenges

- ▶ **Microgravity** is the major challenge for growing crops in space as delivering water to the plant is problematic
- ▶ High **Solar radiation** exposure could be harmful to a **crop's DNA** and may affect germination, growth, and reproduction
- ▶ **Space settlers might face a low yield harvest**, as the lunar or Martian soil is infertile due to the absence of organic compounds

Source: NASA website; E&T website; Horti daily website

Notes: (1) At the planning stage; (2) Technologies that are used in vertical farming might be used as a basis for space farming development in the future

Space manufacturing and construction are especially attractive due to favourable microgravity space conditions



Companies developing their in-space manufacturing & construction technologies

 **Space Tango**

Current Good Manufacturing Practice. Capabilities to manufacture products in automated laboratories on the International Space Station



MakerSat. Technology device that will demonstrate in-space manufacture of antennas, solar arrays, and telescopes larger than can be fit into a space rocket

 **MADE IN SPACE**

Archinaut. Combination of additive manufacturing with robotic assembly for remote in-space construction of large complex structures

NASA awarded 73.7 Mn USD for Archinaut demonstration

 **VARDA**
SPACE INDUSTRIES

Orbital manufacturing. Start-up focused on in-space manufacturing of specialised products that are difficult to produce due to material volatility or Earth's gravity

 **KLEOS**

FUTRISM. First in-orbit method of producing large-scale, carbon composite, 3D structures in space



The space manufacturing industry value is estimated to reach 5.5 Bn USD by 2027

Top-3 opportunities

- ▶ In-space manufacturing and construction could benefit from the **advantage of microgravity and vacuum conditions**
- ▶ In-space manufacturing would enable **sustainable space exploration missions at a reduced cost** compared to launching from Earth
- ▶ **Space manufacturing facilities would be able to become self-sustaining**, requiring only minimal imports from Earth

Top-3 challenges

- ▶ **Extreme environmental conditions** requiring innovative building materials and the adoption of work in the weightless vacuum
- ▶ Significant costs in **overcoming the energy hurdle** for boosting equipment and materials into space orbit
- ▶ **Shortage of high skilled labour force** able to be engaged in in-space manufacturing and construction processes

Space transportation is expected to develop enormously, enabling the growth of all the other space industries



The number of projects¹ in space transportation is expanding rapidly, ensuring the development of various types of services



EARTH



MOON



MARS



Space Mobility	On-orbit servicing	ISS utilisation	Re-entry services	Suborbital flight
				
Dragon is a free-flying spacecraft designed to deliver both cargo and people to orbiting destinations	Mission Extension Vehicle is the industry's first on-orbit satellite servicing vehicle	ICE Cubes is a platform for delivery of the experiment or technology on the ISS and for testing it onboard	HTV and HTV-X resupply ships are re-entry capsules designed to deliver cargo and return payloads from the ISS	New Shepard is a reusable suborbital rocket designed to take astronauts and research payloads to the Karman line
First launch: 2010	First launch: 2019	First launch: 2018	First launch: 2009	First launch: 2015



The space launch services market² is expected to reach 32.4 Bn USD by 2027

Top-3 opportunities

- ▶ In-space, lunar and planetary warehousing of satellites, equipment and food rations will create the demand for stable supply chains
- ▶ The chance to set standards and trends for the future of space logistics (for example, service expectations)
- ▶ The space logistics market is currently open to private operators for testing of technologies and business models

Top-3 challenges

- ▶ **Extreme physical conditions** create special requirements for modes of transports as well as for people and cargo
- ▶ Launch vehicle dimensions and weight restrictions **undermine the cost benefits** of economies of scale
- ▶ Commercial cost-benefit offers for space transportation providers **are untested** and a legal framework is **not yet created**

In the next 2-3 decades, space exploration will be driven by both existing and futuristic technologies



3D Printer

Advanced 3D printers can **manufacture objects out of plastic, metals, and other materials** (like regolith) both on Earth and in space.



High Performance Spaceflight Computing

Flight computing technologies will deliver a computational capacity that is more than **100 times higher** compared to current analogues.



RASSOR¹ Robot

The Robot allows to **excavate extraterrestrial soils on the Moon, Mars, and asteroids** that could be converted into oxygen, water, and other products.



Delay / Disruption Tolerant Networking

The technology allows to provide space missions with **reliable internetworking**, avoiding the loss of data when transferring it across extreme distances.

Present

Future

Portable Magnetic Highway (FLOAT²)

The project of the **robotic magnetic-based transport system**, which will allow to perform durable payload operations on the Moon.



Micro-swimmers (SWIM³)

The concept of **swimming micro-robots** deployed from a single robot mothercraft that will explore the **Ocean Worlds of Enceladus, Europa, and Titan**.



Making Soil for Space Habitats

The concept implies the **creation of soil from carbon-rich asteroid material**, using fungi that will degrade toxic substances and initiate soil formation.



Light Bender

The concept for the **generation and distribution of power on the Moon** through capturing and redirecting of sunlight with the use of telescope optics.



30 years ahead – humanity reaching new horizons and overcoming challenges in the solar system and beyond

Bases on Moon & Mars

Permanent bases will be created on the Moon surface – e.g. International Moon Village (ESA), Artemis Base Camp (NASA) with some bases on Mars as well.



Space agriculture & manufacturing

Greenhouses will be constructed on humans' bases on the Moon and Mars. The resources mined at asteroids will be used by orbital factories to construct space bases.



Innovations

Multiple innovations in the space industry will boost the world's economy. New propulsion space engines will be created and widely used⁴.

Settlements on asteroids

Temporary settlements for asteroid mining activities will be built. The value of all Near Earth asteroids¹ is estimated to be around ~100 Tn USD.



Space technologies on Earth

Long-haul flights will be conducted via spaceships instead of planes. Technologies in farming will allow to achieve high yields despite the arid climate.

Space transportation

Space transportation will be cheaper than the best currently available technologies⁵, advanced refuelling stations will be available in space.

Sustainability in space

Space-solar power arrays will generate 24/7 clean energy for the households on Earth using microwave arrays, hence lowering carbon emissions.



Pinwheel space stations

Manned space stations could be worth about 50 Bn USD between 2030-2050². Pinwheel space stations on LEO³ will be used as a gateway for space travel.

Space leisure

Suborbital and orbital flights will be affordable for the middle-class together with lunar tourism. Space tourism is expected to generate 850 Bn USD by 2030.

Source: NASA website; Interesting engineering website; BBC website; Media overview
 Notes: (1) Near Earth asteroids whose orbits are within 1.3 astronomical units of Earth; (2) According to SpaceWorks forecast; (3) Low Earth orbit;
 (4) For example electric ion, solar, and nuclear propulsion; (5) Compared to Falcon Heavy – 1,410 USD per kg

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