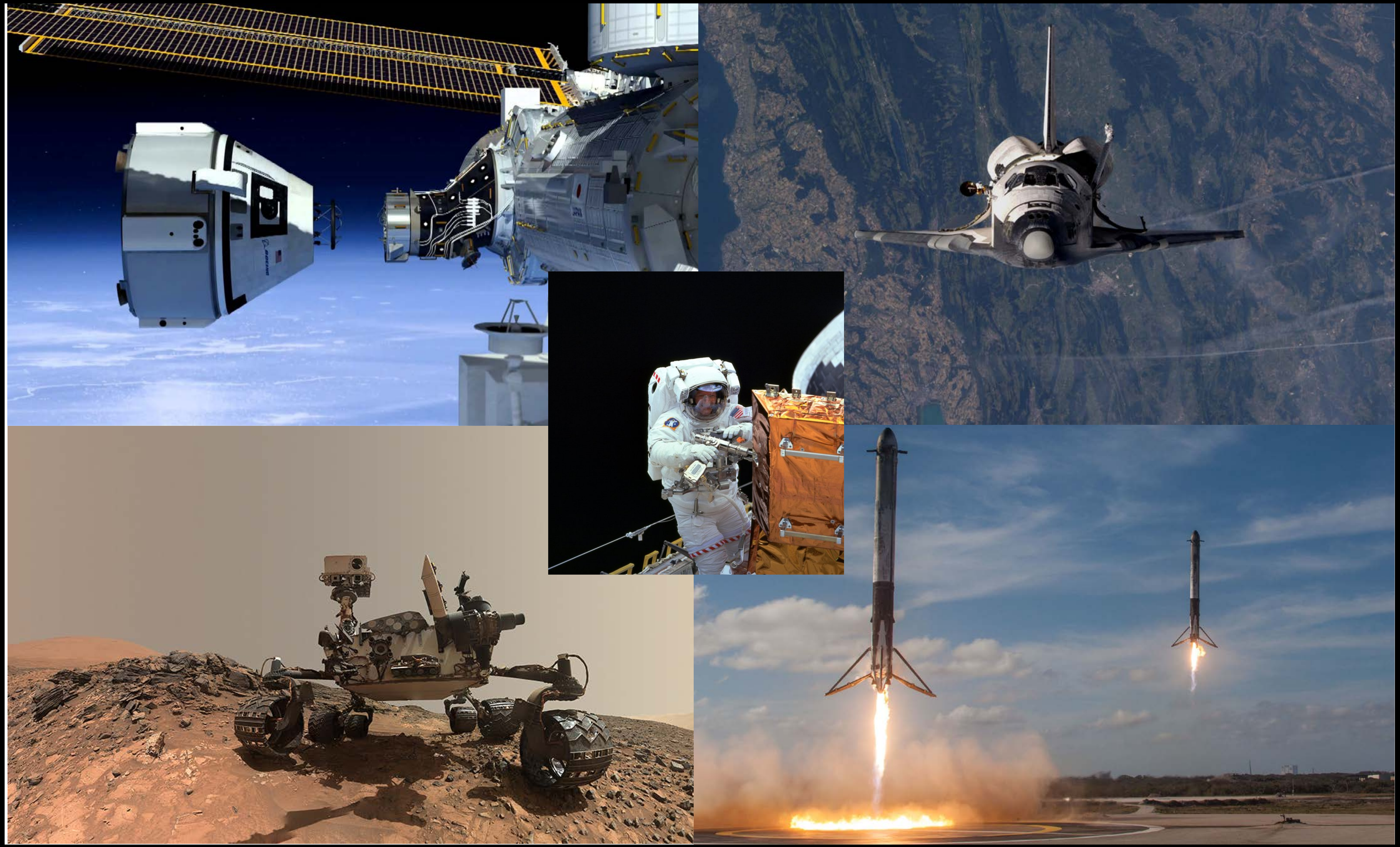
Space Mission Design and Operations

Course EE-585

Introductory Lesson

February 17, 2020

Space Mission Design and Operations



Objective of this course

EPFL

The objective of this course is to present concepts in use for the design and the execution of missions beyond the Earth's atmosphere, with an emphasis on human space exploration.

This course may help you decide if you really want to become an aerospace engineer or, why not, an astronaut!

Today’s topics

- Introduction and admin
- Course description
- Time table and content
- Brief history of (mainly human) space exploration
- Space Institutions and Agencies
- Space utilization and exploration

The course

Title: SPACE MISSION DESIGN AND OPERATIONS

Claude NICOLLIER

Optional course, Masters level, E&E Engineering

Course EE-585

EPFL semester 6 or 8

Total hours 28

Per week 2 in average, with exercises

EPFL credits 2

Examination oral

Teaching Assistants

- Tatiana Volkova – PhD student @ Swiss Space Center EPFL
Email: tatiana.volkova@epfl.ch

- Michaël Juillard – PhD student @ eSpace EPFL
Email: michael.juillard@epfl.ch

Claude Nicollier info

- EPFL PPH341 (Station 13)
  Office phone: 021 693 6659
  Cell phone: 079 223 9636
  e-mail 1: claude.nicollier@epfl.ch
  e-mail 2: claudenicollier@yahoo.com

My office is always open for questions, clarifications and help

Martine Harmel is the course secretary:

- Martine Harmel - Swiss Space Center, PPH338
  Email: martine.harmel@epfl.ch
  Office: 021 693 6948

Course program - some features

The course…

- will start with a review of fundamental laws of Newtonian mechanics and conservation laws.

- will present some basic concepts for mission strategies, and for the design of automatic, robotic or manned missions. It will also present some operational aspects of space vehicles. There will be a special emphasis on the Space Shuttle.

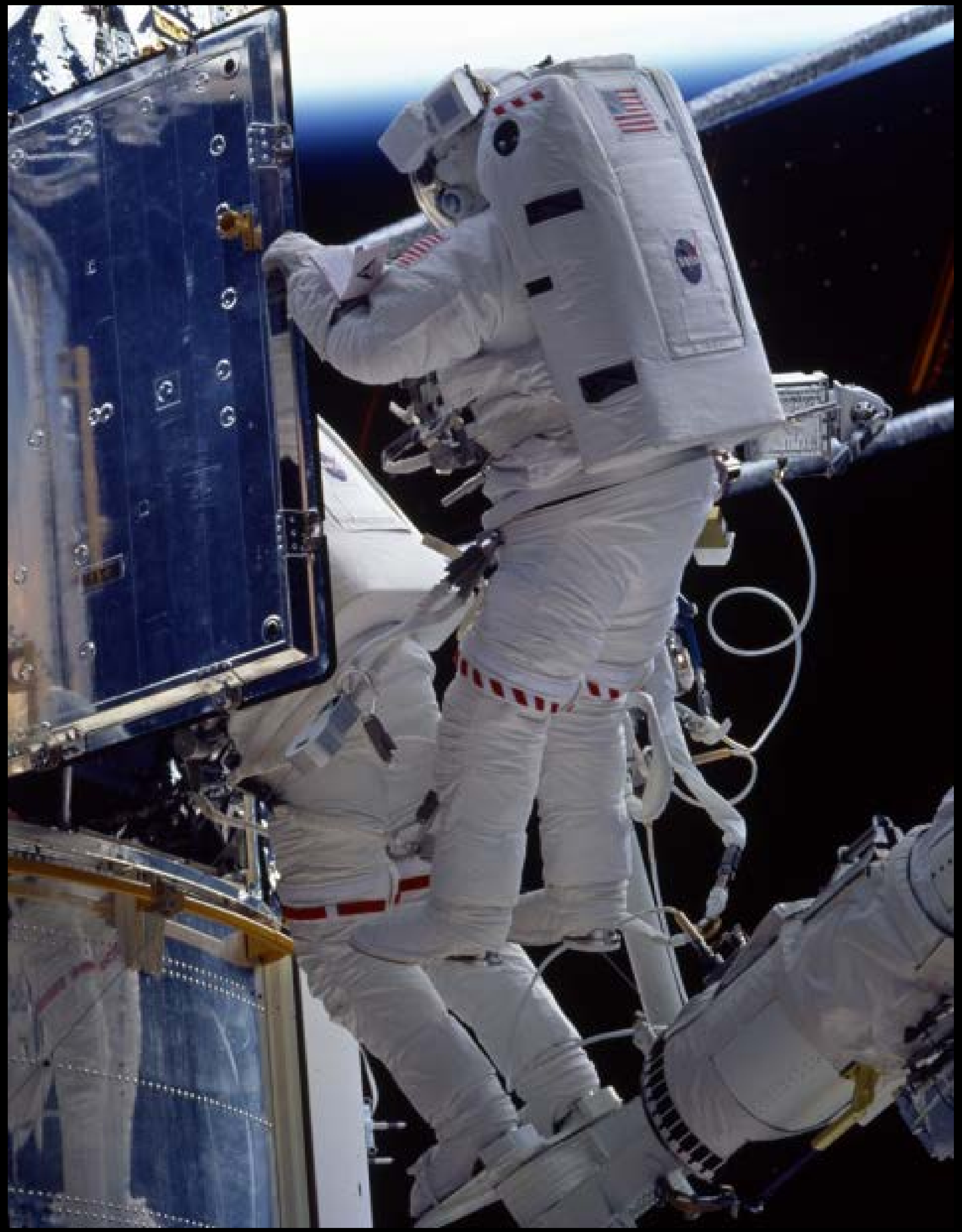
- is a strongly recommended prerequisite for some courses of the EPFL "Minor" in Space Technologies.

Course program - some extra features

- Share with students the privilege of “having been in space” (technical, operational…)

- Inform students on current space programs and events

- Help students in their participation in space related projects at EPFL, Swiss aerospace industry, ESA, as well as in their participation in projects to be flown on parabolic flights.



Timetable and locations 2019 (see is-academia.epfl.ch)

- Monday February 24 and Wednesday February 26, ELA1
- Then every other week Monday and Wednesday starting March 9 and 11, ELA1
- Monday 2x45 minutes course, 1715 -1900
- Wednesday 30 minutes course and 60 minutes exercises ending at 1900
- Last course Monday May 18
- Wednesday May 20 course review and discussions/questions (optional)
- Oral examination period June 22 to 27, 2020

Course and Exercises

- The course slides for the week will be available (sometimes slightly abbreviated) at 13h00 each Monday when the course is given, on the following EPFL site

  http://moodle.epfl.ch

- For EPFL students, access to the course notes in Moodle will be via the Gaspar User ID and password, key for access: “welcomeinspace”

- Similarly, the problems to be resolved at the exercise sessions will be available on Moodle the Wednesday of the exercise session at 16h00

Course and Exercises

- Exercise sessions are essential to consolidate knowledge acquired in the course. Active participation is highly recommended. Opportunities for presentations by students in the oral exams style.

- Exercises will not be graded. They will normally be resolved at each session and presented by students or assistants, and solutions will be available on Moodle, in the days following the exercise session.

- One “Mini-Project” will be proposed about half-course, to be accomplished in a two to three-week period.

Important note on MOOC

- MOOC EE-585x will run in parallel with this course, starting March 11 and for 8 weeks.
- It will be divided in 8 Units, each unit lasting one week, including summaries and tests
- There will be an exact match of Units designation presented in this course and in the MOOC. Content essentially similar but variations in illustrations material and videos.
- The MOOC will just run faster, in 8 weeks vs. 14 weeks for this course.

More on MOOC

- For MOOC registration, follow the link:

https://www.edx.org/course/space-mission-design-and-operations

- Will start March 11, 2020

Course outline

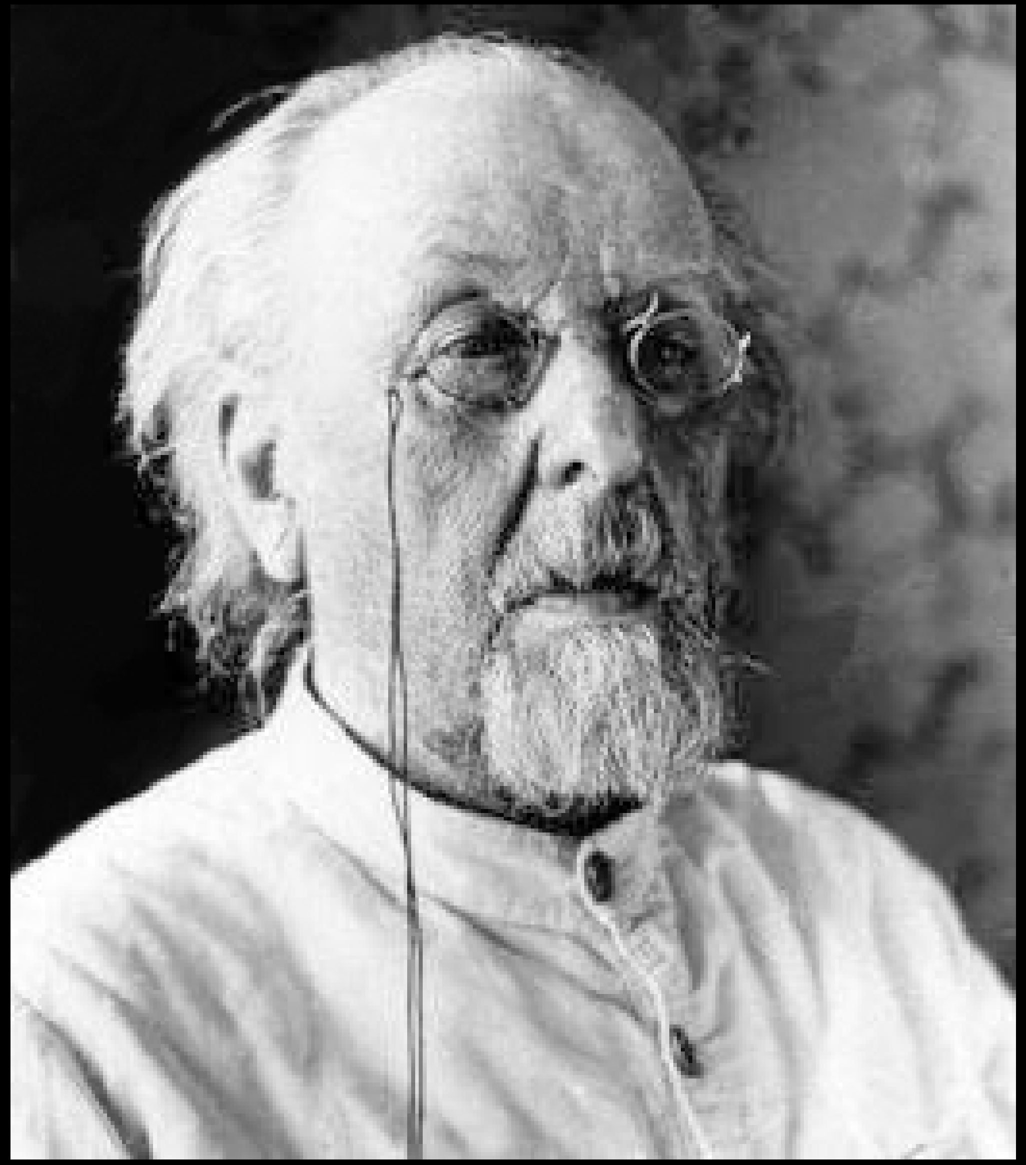
Date (2020)	Course content and MOOC equivalent	Section in MOOC
Today Feb 17 Week 0	Space pioneers Milestones in the early space programs Race to the Moon Space stations, Space Shuttle, and international cooperation The Outer Space Treaty Space Agencies and private companies providing spaceflight Space Utilization Space Science and Exploration Access to space	0.4.1 0.4.2 0.4.3 0.4.4 0.4.5 0.5.1 0.5.2 0.5.3 0.5.4

Course outline

Date (2020)	Course content and MOOC equivalent	Section in MOOC
February 24 & 26 Week 1	Review of the Laws of Mechanics Introduction to the near space environment Magnetic field and Sun Radiation environment Orbital lifetime, space debris and asteroids/comets collision threats	1.2 1.3 1.4 1.5 1.6
March 9 & 11 Week 2	Concept of gravitational well and dynamics of spaceflight Orbital motion and Kepler's laws Case of circular and elliptical orbits Reference frames Orbital maneuvers Special orbits	2.2 2.3 2.4 2.5 3.2 3.3
March 23 & 25 Week 3	Rendezvous The case of ATV Interplanetaty trajectories (partial)	3.4 3.5 4.2

Course outline

Date (2020)	Course content and MOOC equivalent	Section in MOOC
April 6 & 8 Week 4	Interplanetary trajectories (continuation to end) Aerodynamic braking and slingshot trajectories Spacecraft propulsion Ascent into space and re-entry	4.2 4.3 4.4 4.5
April 20 & 22 Week 5	Attitude control Electrical power generation: Classical and alternative methods Reliability of space systems	5.2 5.3 5.4
May 4 & 6 Week 6	Space Shuttle Space Shuttle selected missions ISS including access and supply	6.2 6.3 6.4
May 18 Week 7	Extravehicular Activities Space robotics Astronaut selection and training Suborbital spaceflight New projects in human space exploration Course conclusion	7.2 7.3 7.4 7.5 7.6 7.7
May 20	Course review & discussions/questions (optional) (not in the MOOC)	

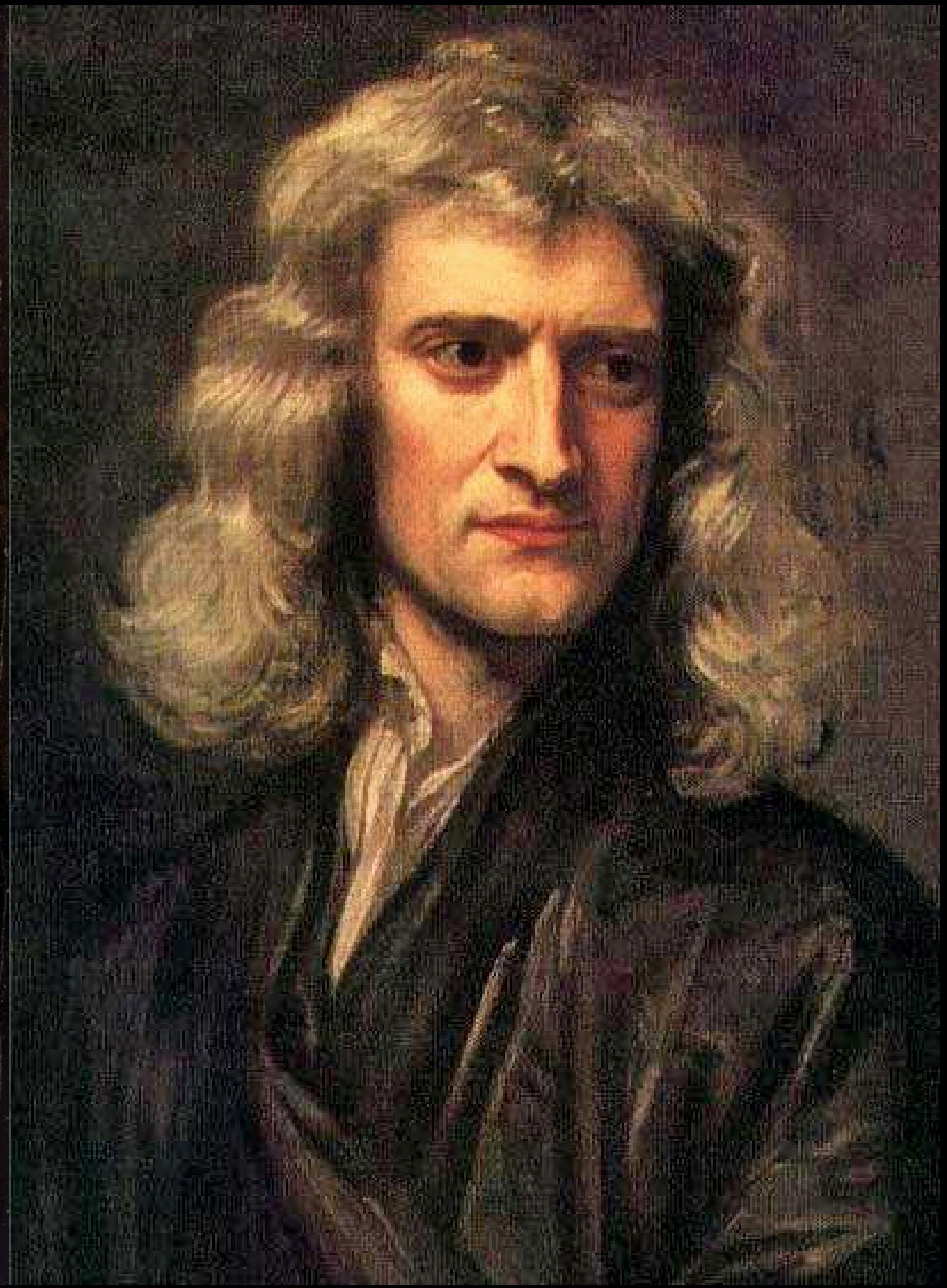


0.4.1 Space pioneers

Space Mission Design and Operations

Prof. Claude Nicollier

Pioneers in astronomy and celestial mechanics



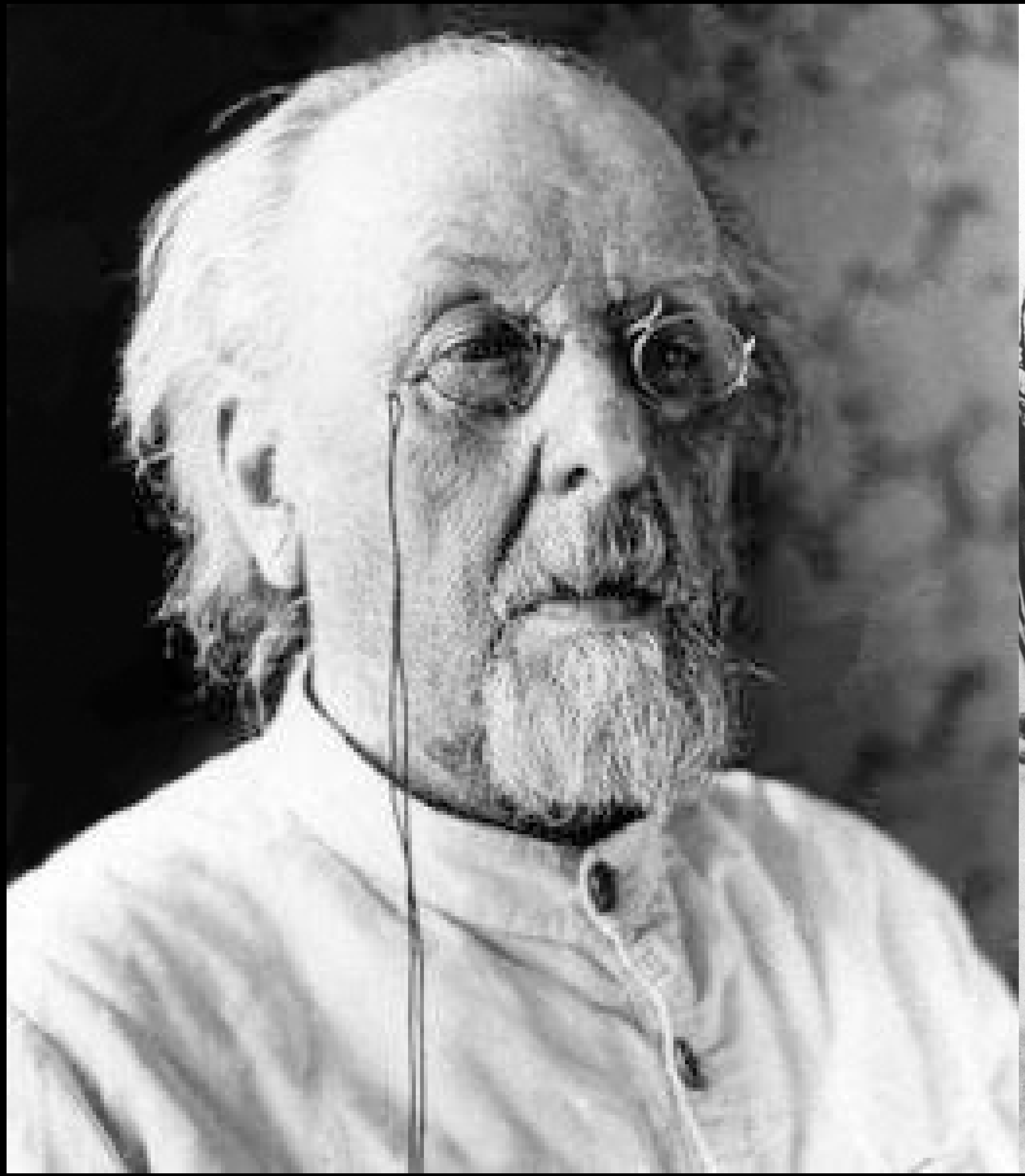
Tycho Brahe
(1546-1601)

Galileo Galilei
(1564-1642)

Johannes Kepler
(1571-1630)

Isaac Newton
(1642-1726)

Pioneers of rocket theory and practice



Konstantin Tsiolkovsky
(1857-1935)

Robert H. Goddard
(1882-1945)

Pioneers of rocket theory and practice

Hermann Oberth
(1894-1989)

Wernher von Braun
(1912-1977)

Sergei Korolev, Chief Designer of the Soviet space program

Sergei Korolev (1906-1966), here with Yuri Gagarin

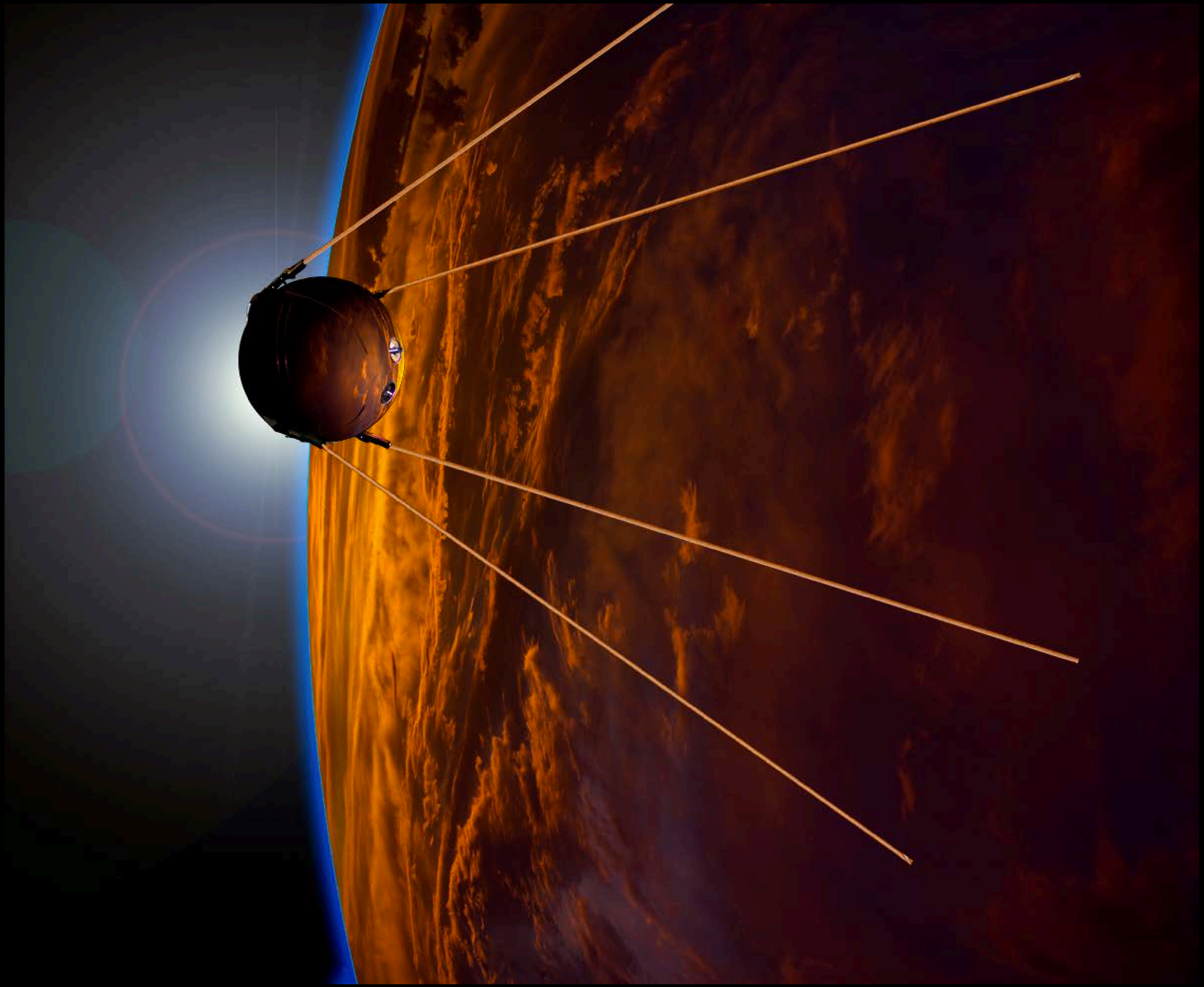
0.4.2 Milestones in the early space programs

Space Mission Design and Operations

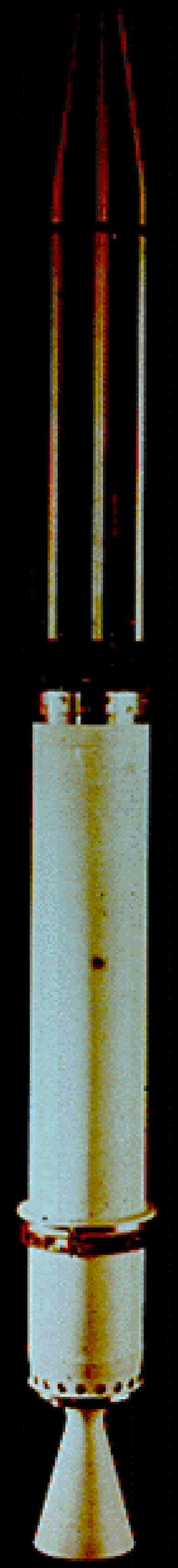
Prof. Claude Nicollier

Credits: NASA, ESA

Sputnik 1 / Explorer 1 – First satellites – 1957 / 1958

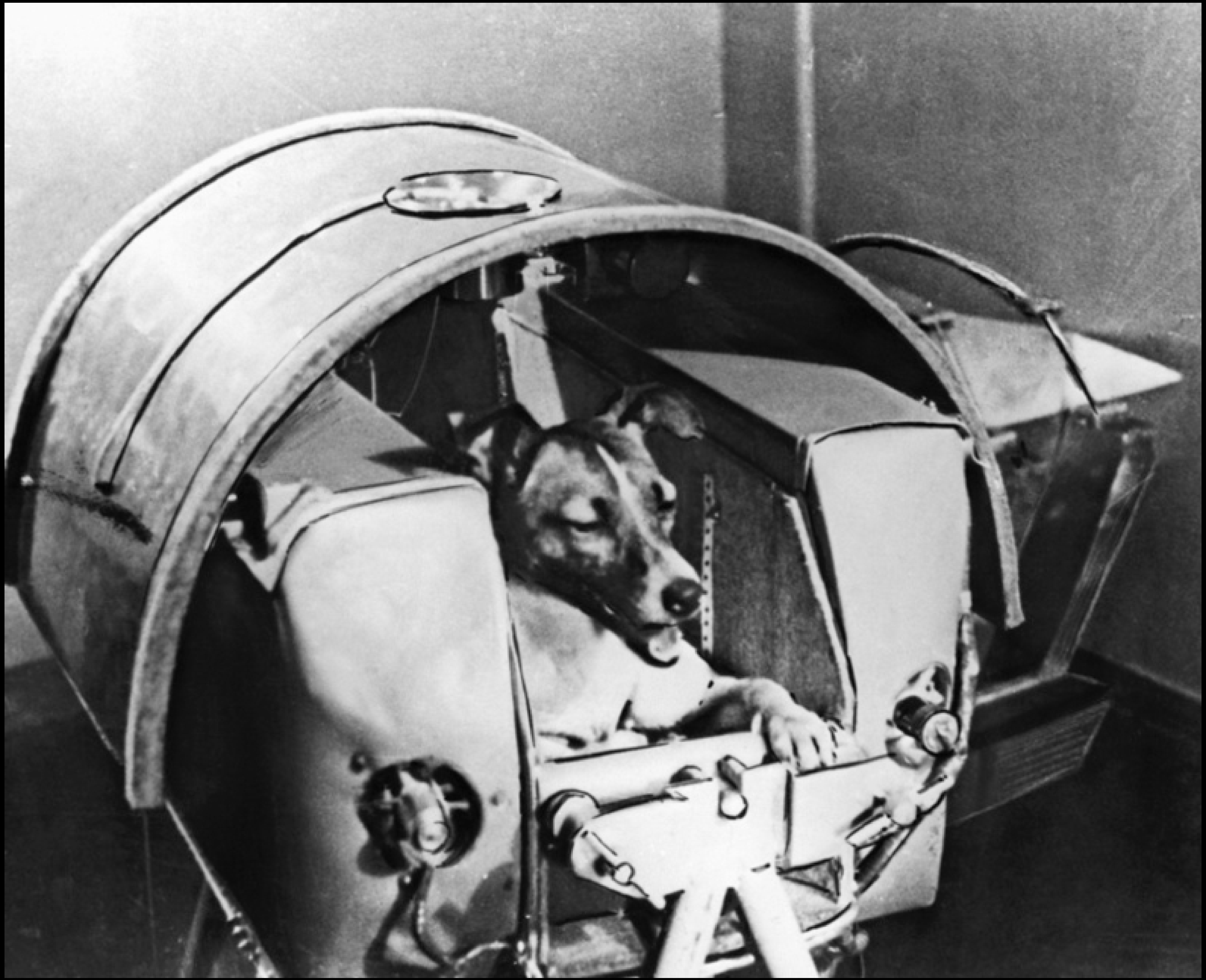


- Sputnik 1
  - October 4, 1957
  - First artificial satellite around the Earth
  - Bip, bip…
- Explorer 1 ⟶
  - January 31, 1958
  - Lifetime of 12 years
  - Discovery of Van Allen's radiation belts



Credits: 1. Wikipedia, Gregrory R. Todd 2. NASA

Laïka – First living creature in Earth orbit – Sputnik 2, Nov 3, 1957



Credits: Flickr, Bobbie

Ham – First tasks performed during spaceflight – January 31, 1961

Credits: NASA

Yuri Gagarin – First human in space – April 12, 1961

Alan Shepard – First US astronaut – May 5, 1961

Credits: NASA

John Glenn – First US orbital flight – Feb 20, 1962

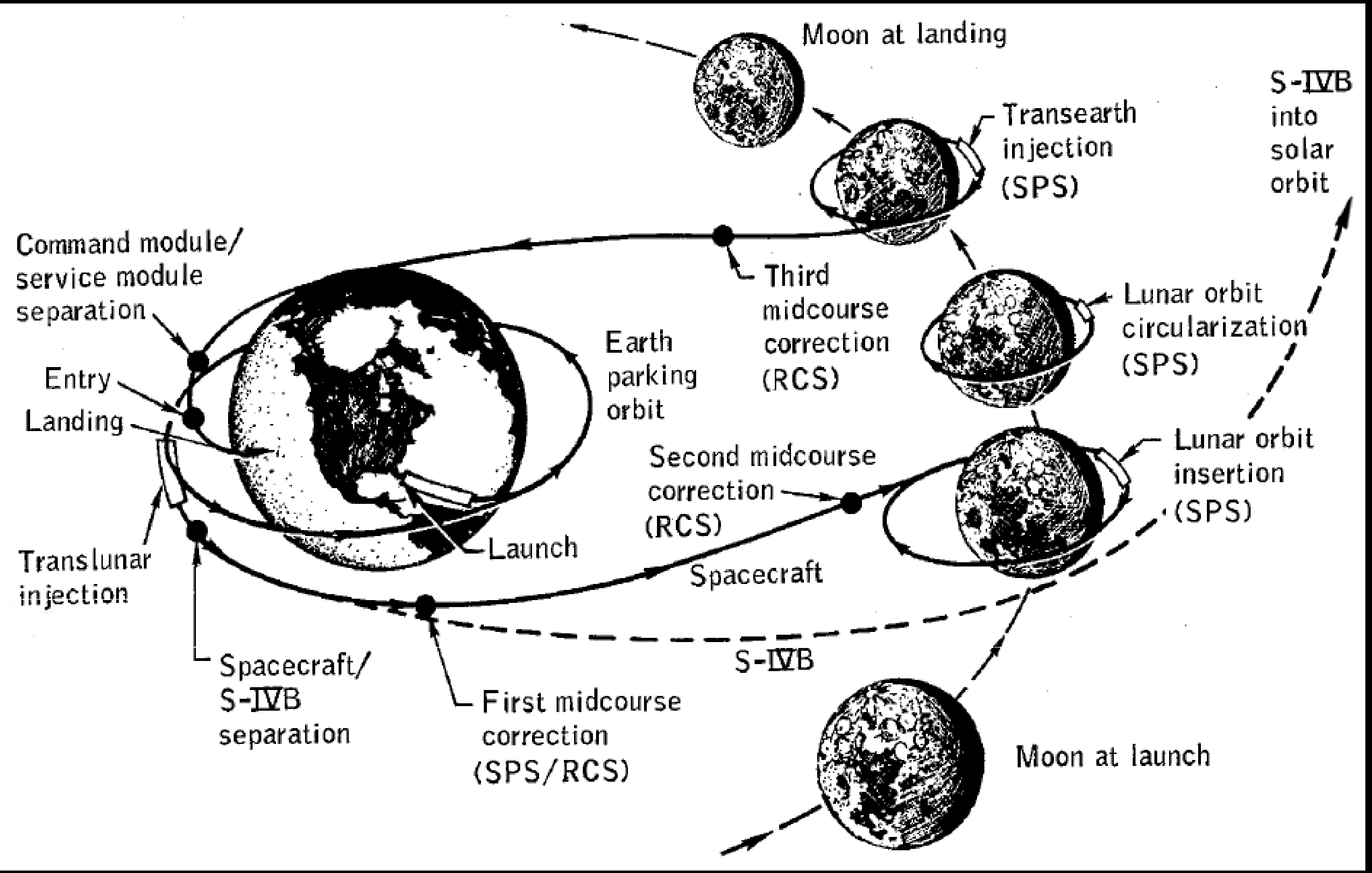
Credits: NASA

Valentina Tereshkova – First woman in space – June 16, 1963

Alexei Leonov – First spacewalk – March 18, 1965

Ed White – First US spacewalk – June 3, 1965

Credits: NASA



0.4.3 Race to the Moon

Space Mission Design and Operations

Prof. Claude Nicollier

Credits: NASA

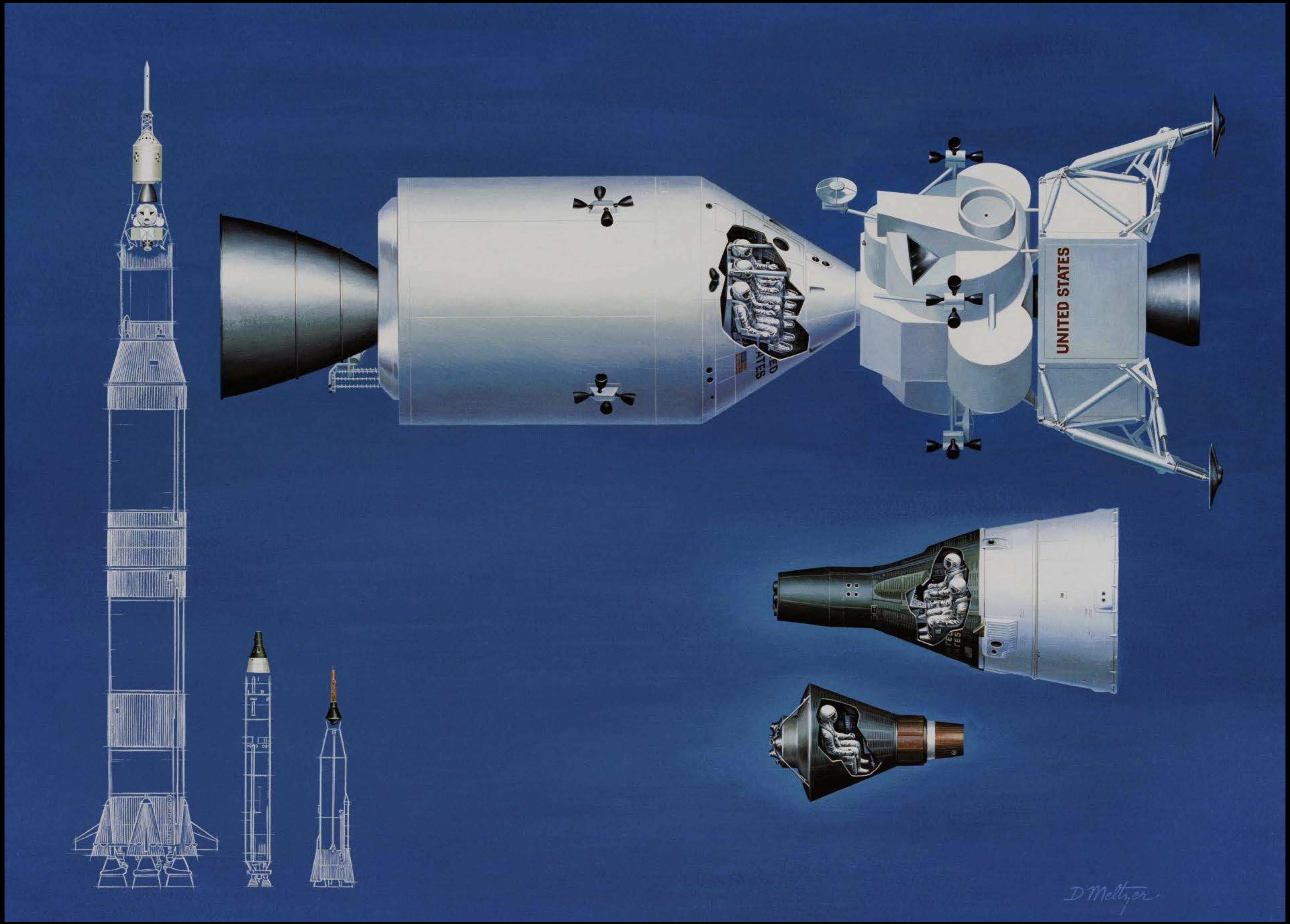
The Apollo program - John F. Kennedy's decision in 1961

Public talk in September 1962,
Rice university, Houston:

"We choose to go to the Moon. We choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one which we intend to win..."

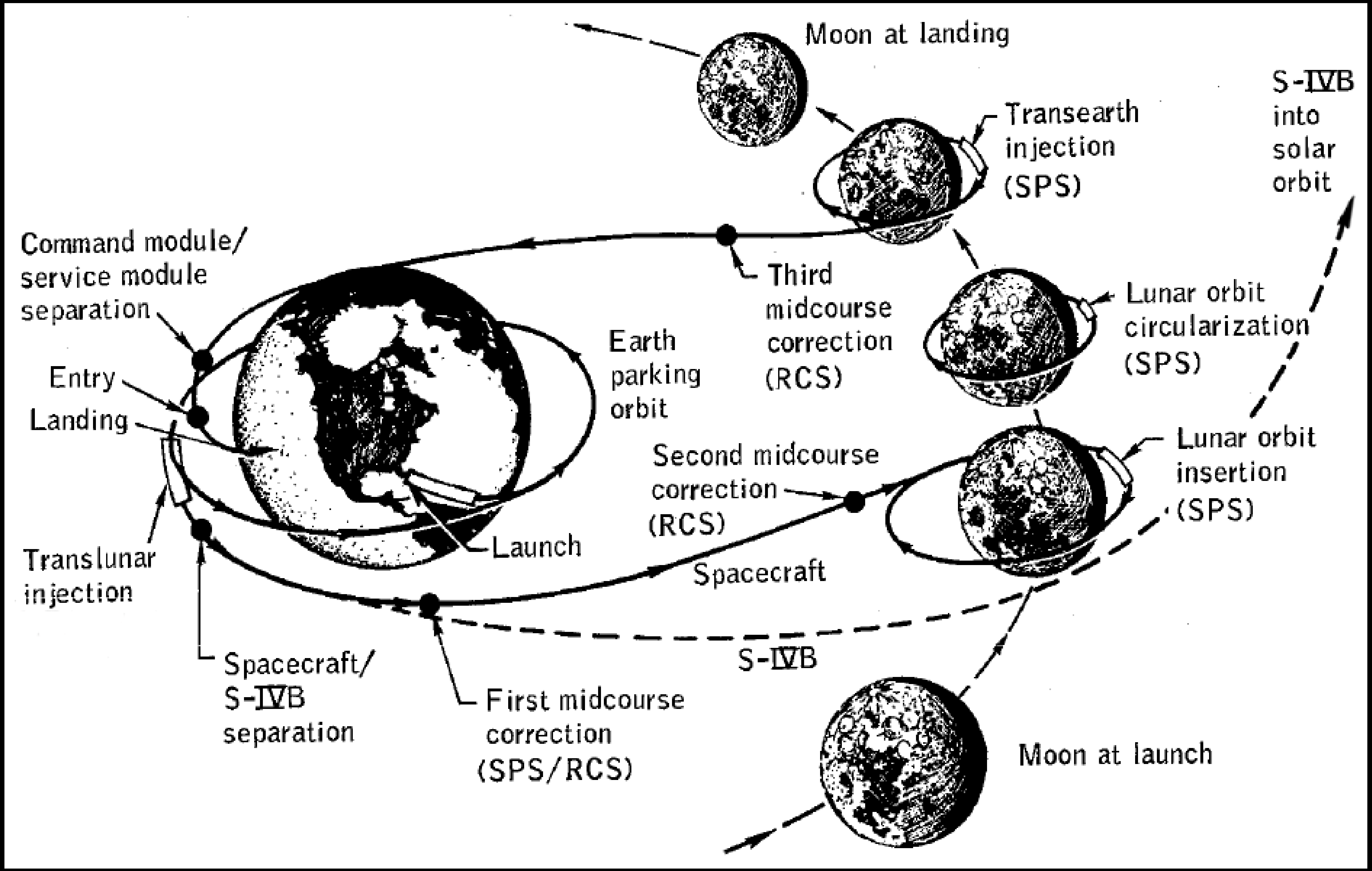
Credits: NASA

Mercury, Gemini, Apollo



Credits: NASA

Trajectory to the Moon



Apollo 8, December 1968

Credits: NASA

Apollo 11 crew

Michael Collins

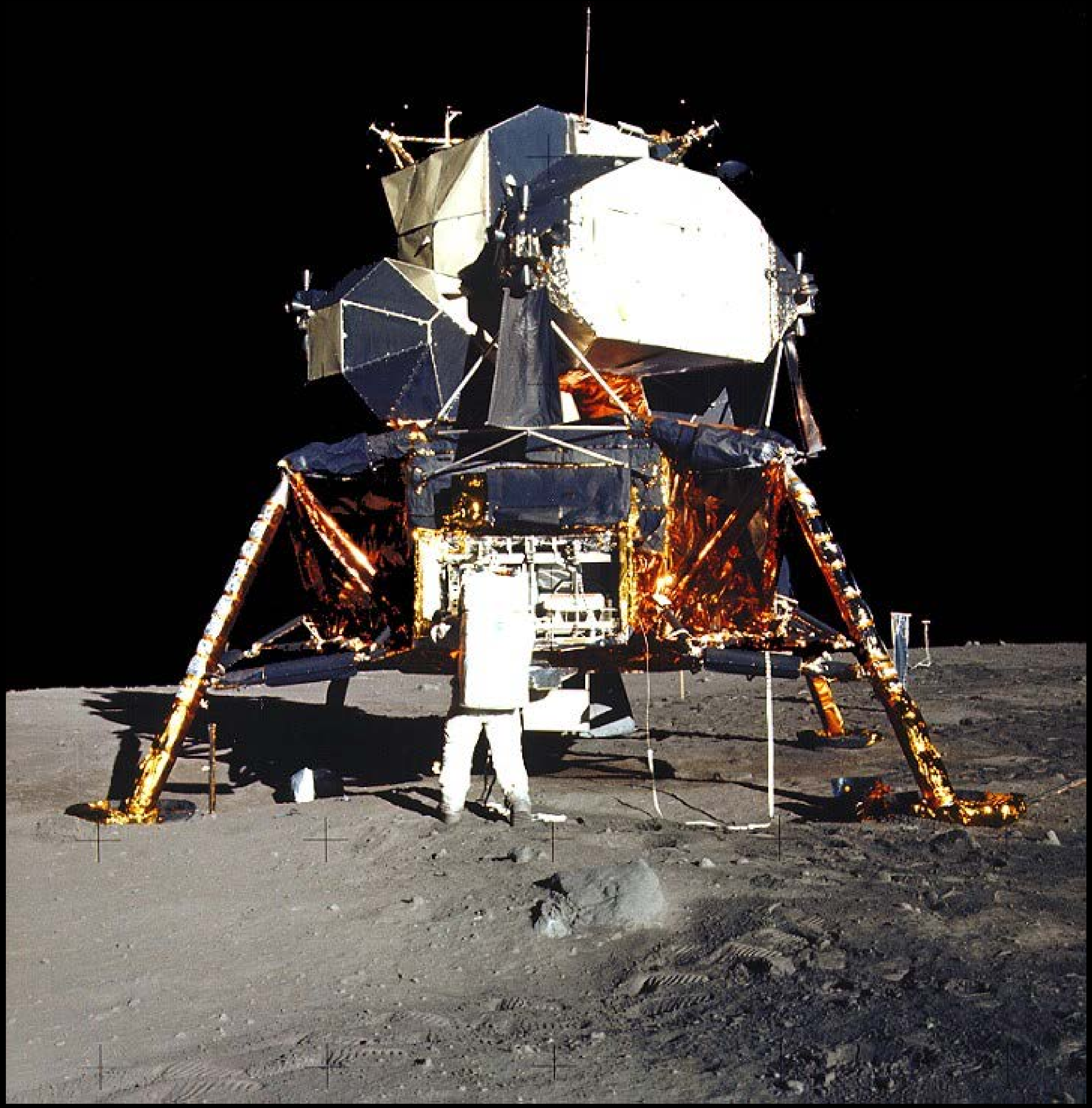
Neil Armstrong

Buzz Aldrin

Credits: NASA

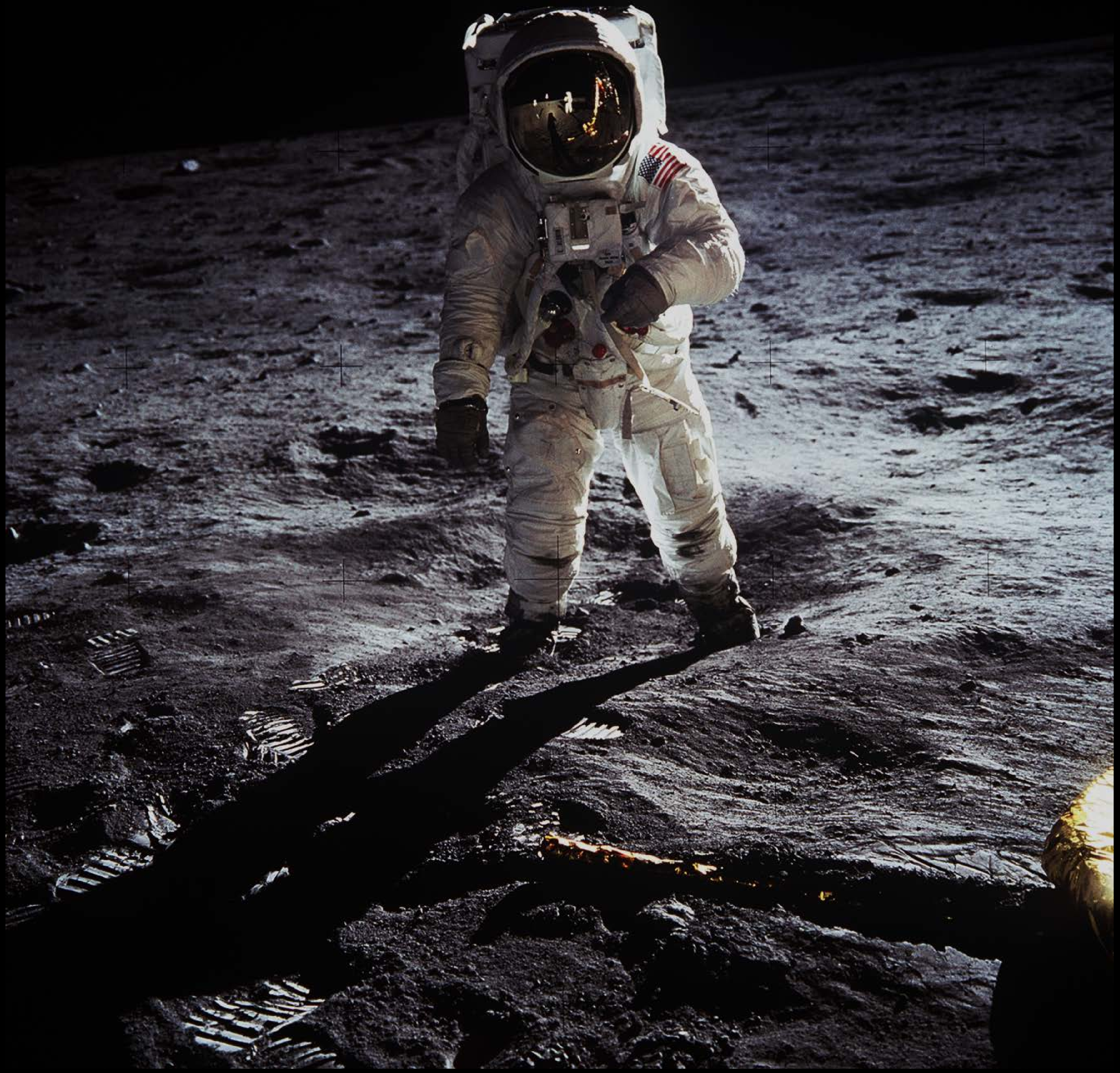
Apollo 11 descent to the Moon and landing

Apollo 11 Lunar Module Eagle



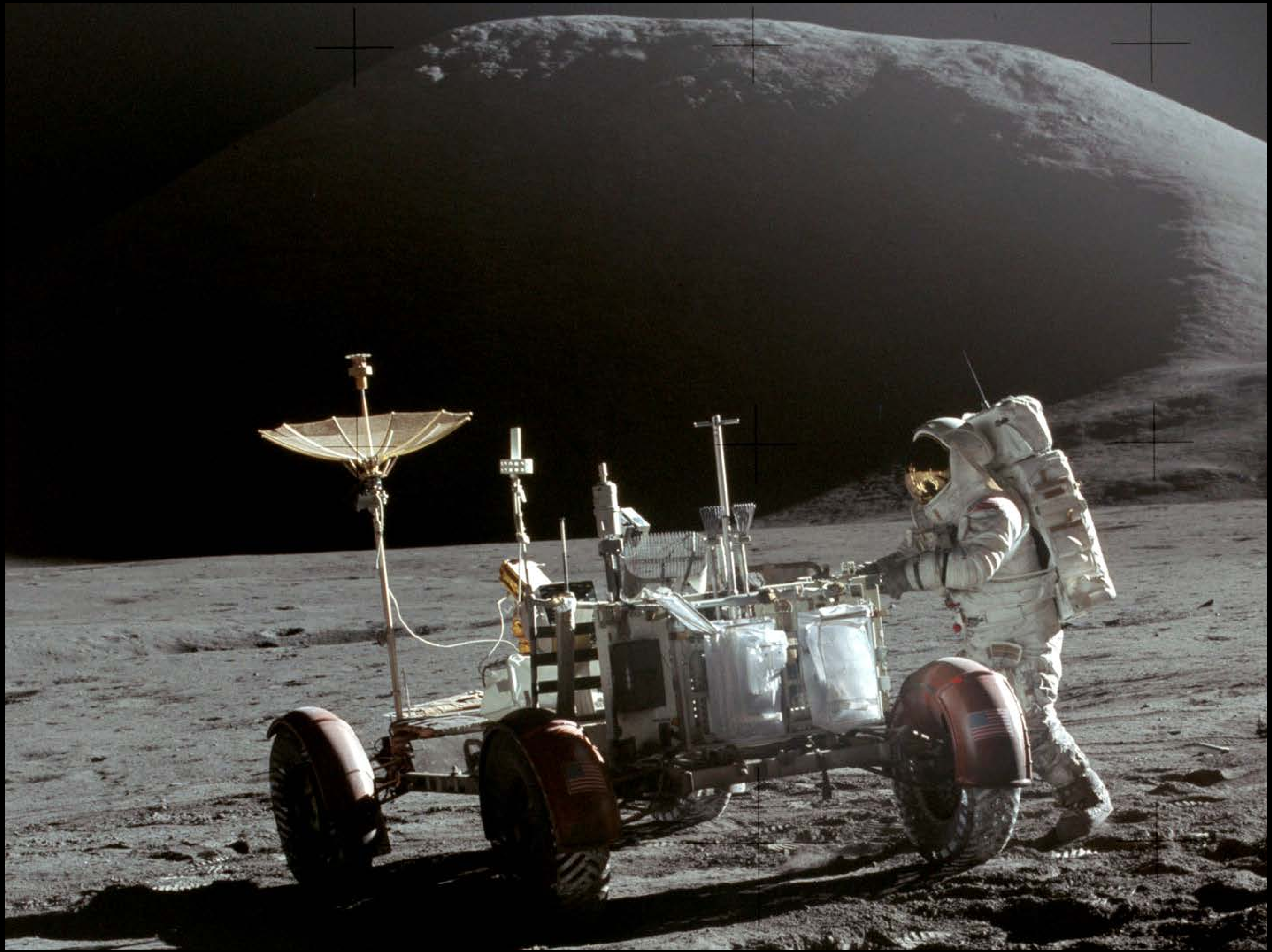
Credits: NASA

Buzz Aldrin on the Moon



Credits: NASA

Apollo 15 Lunar Roving Vehicle



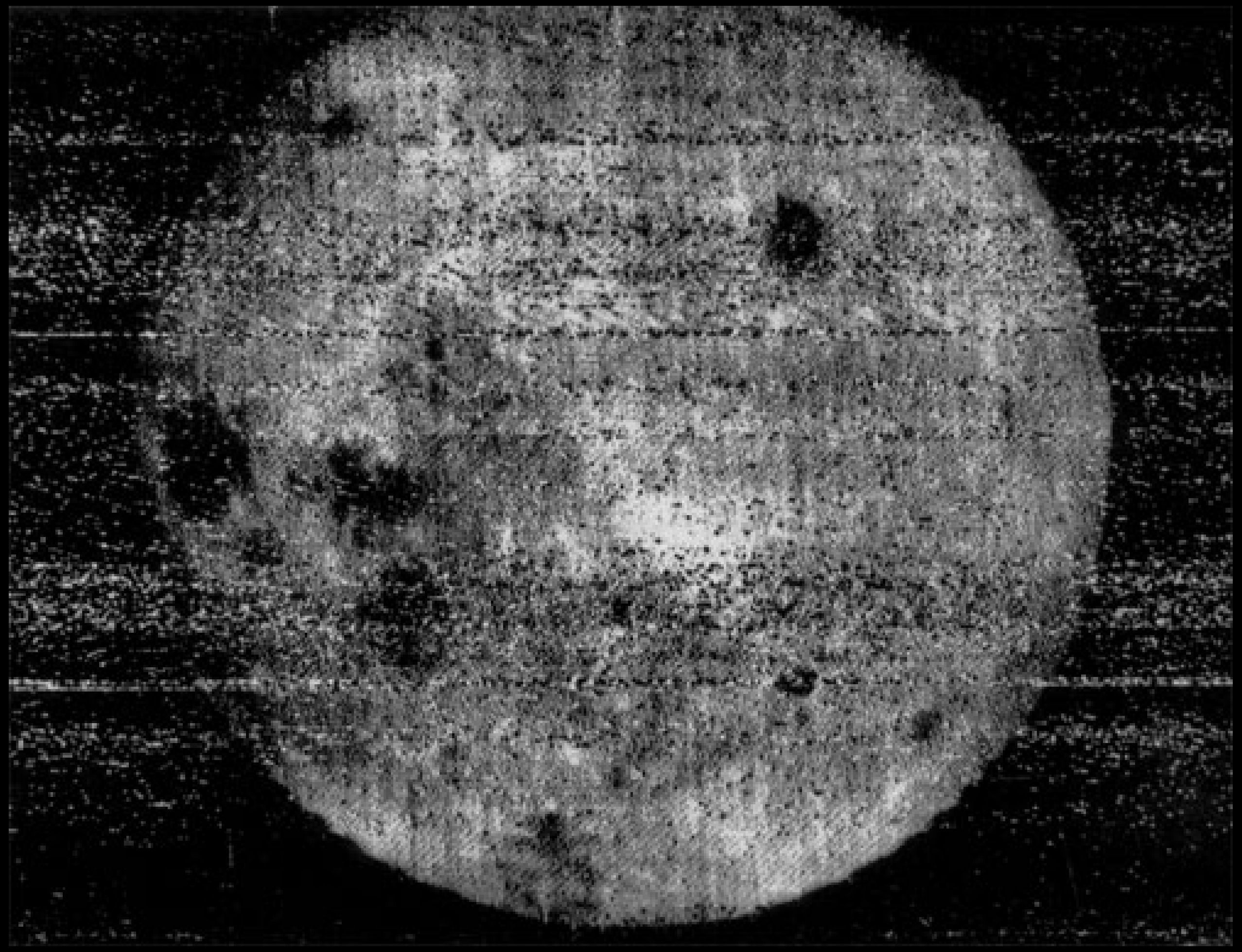
Credits: NASA

Apollo 17

Credits: NASA

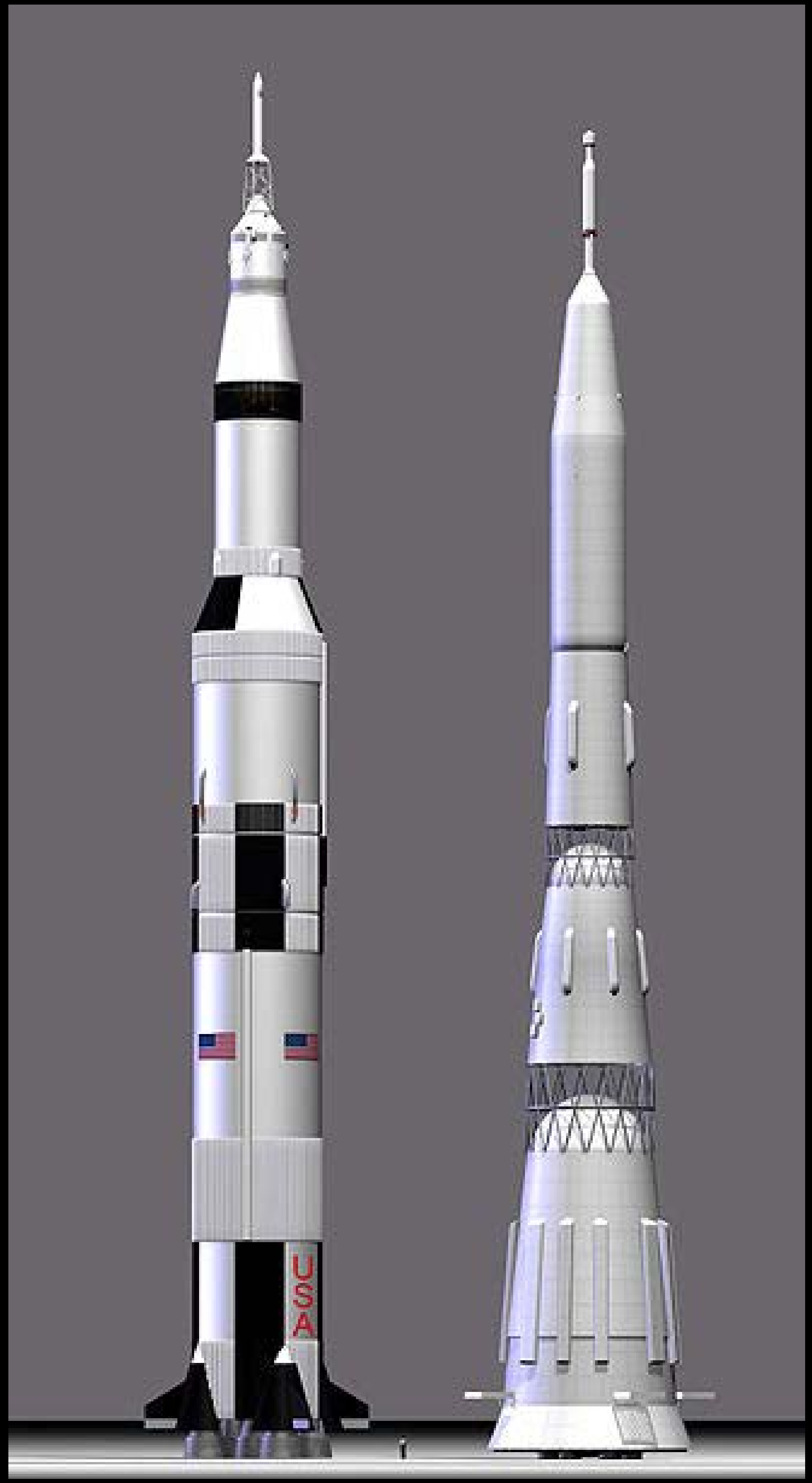
Soviet lunar programs

Luna 3
1959



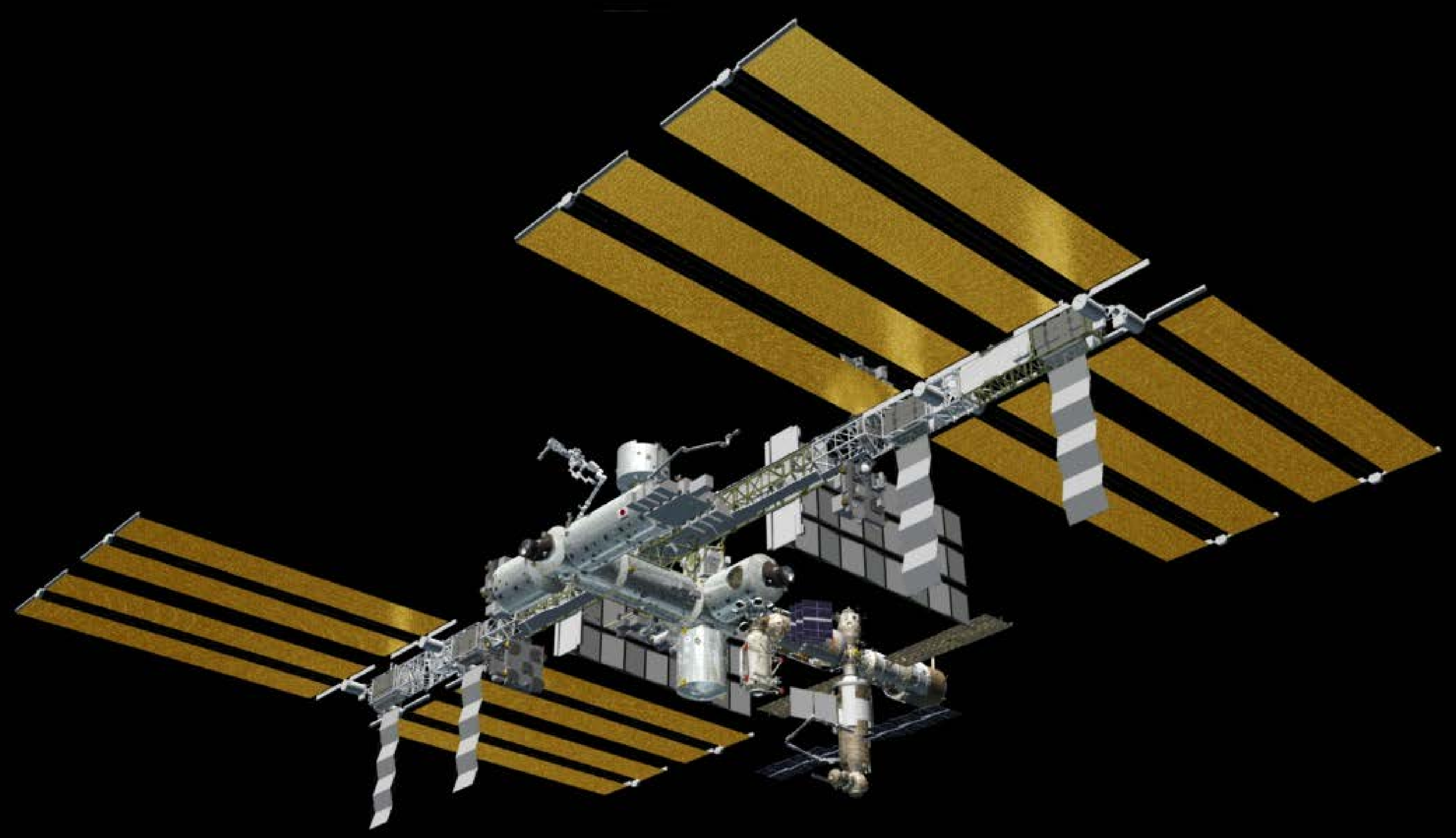
Lunokhod Moon exploration rovers, 1969 to 1977

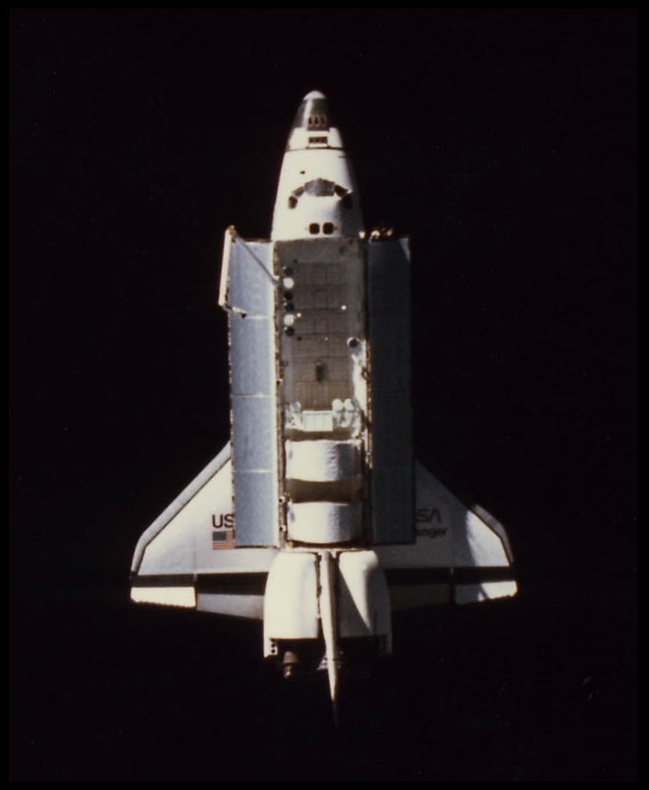
LRO picture
2010



Saturn V
and
N1

Credits: 1. PD, RSC Energia, 2. Museum of Cosmonautics 3. NASA





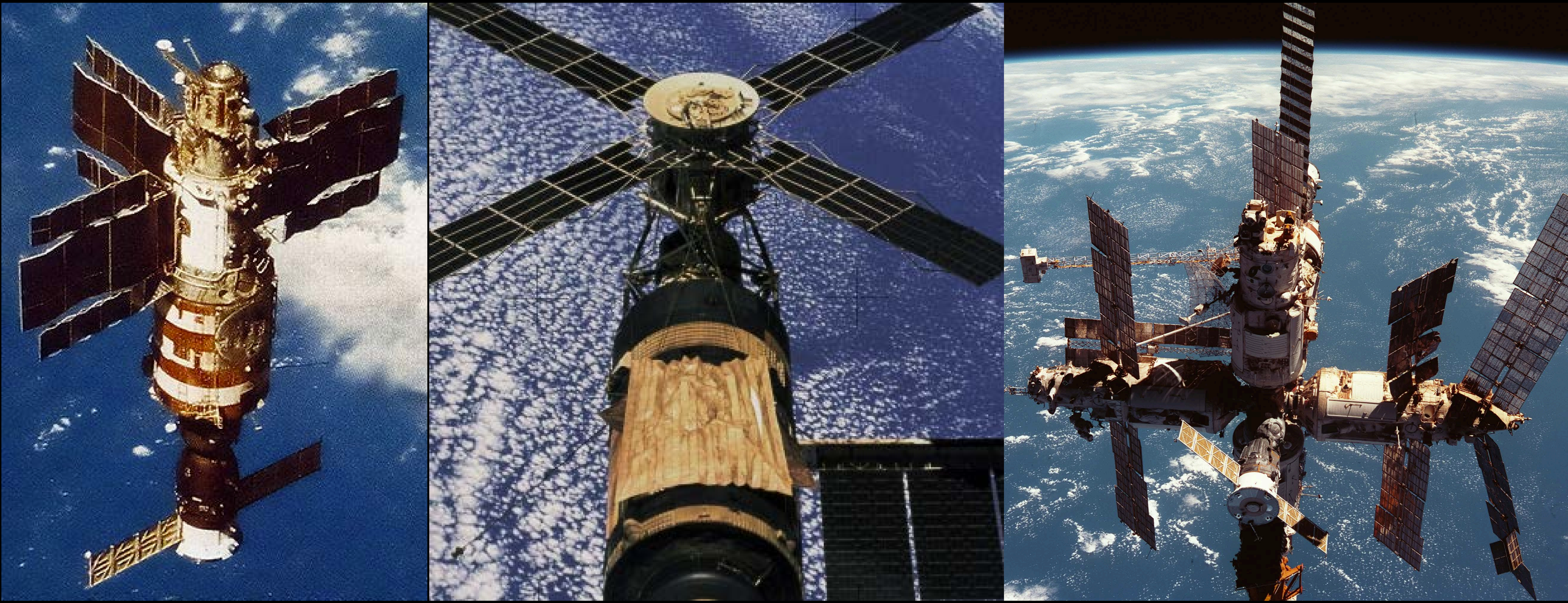
0.4.4 Space stations, Space Shuttle, and International cooperation

Space Mission Design and Operations

Prof. Claude Nicollier

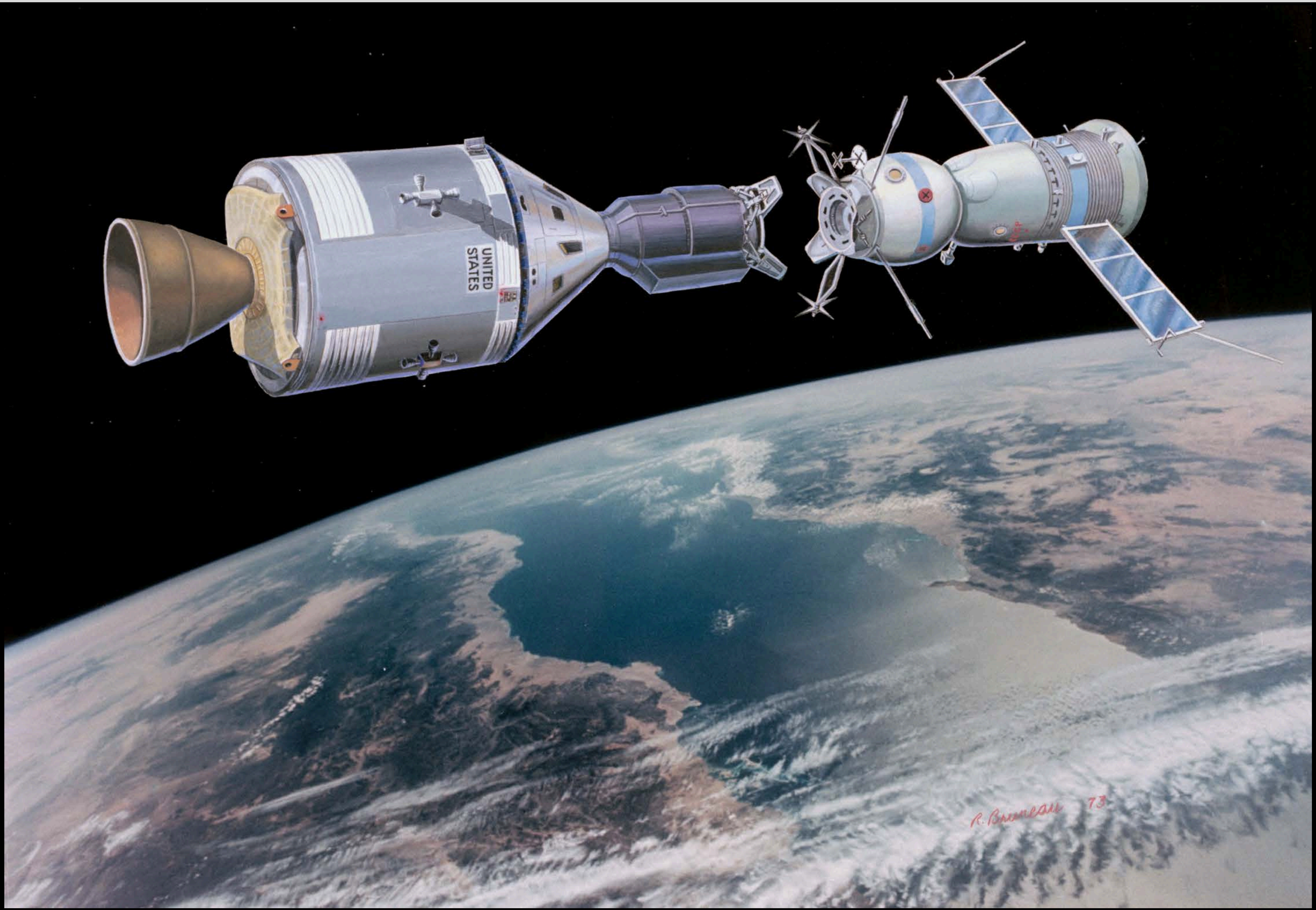
Credits: NASA

Space stations - Salyut, Skylab and Mir - 1971 to 2001

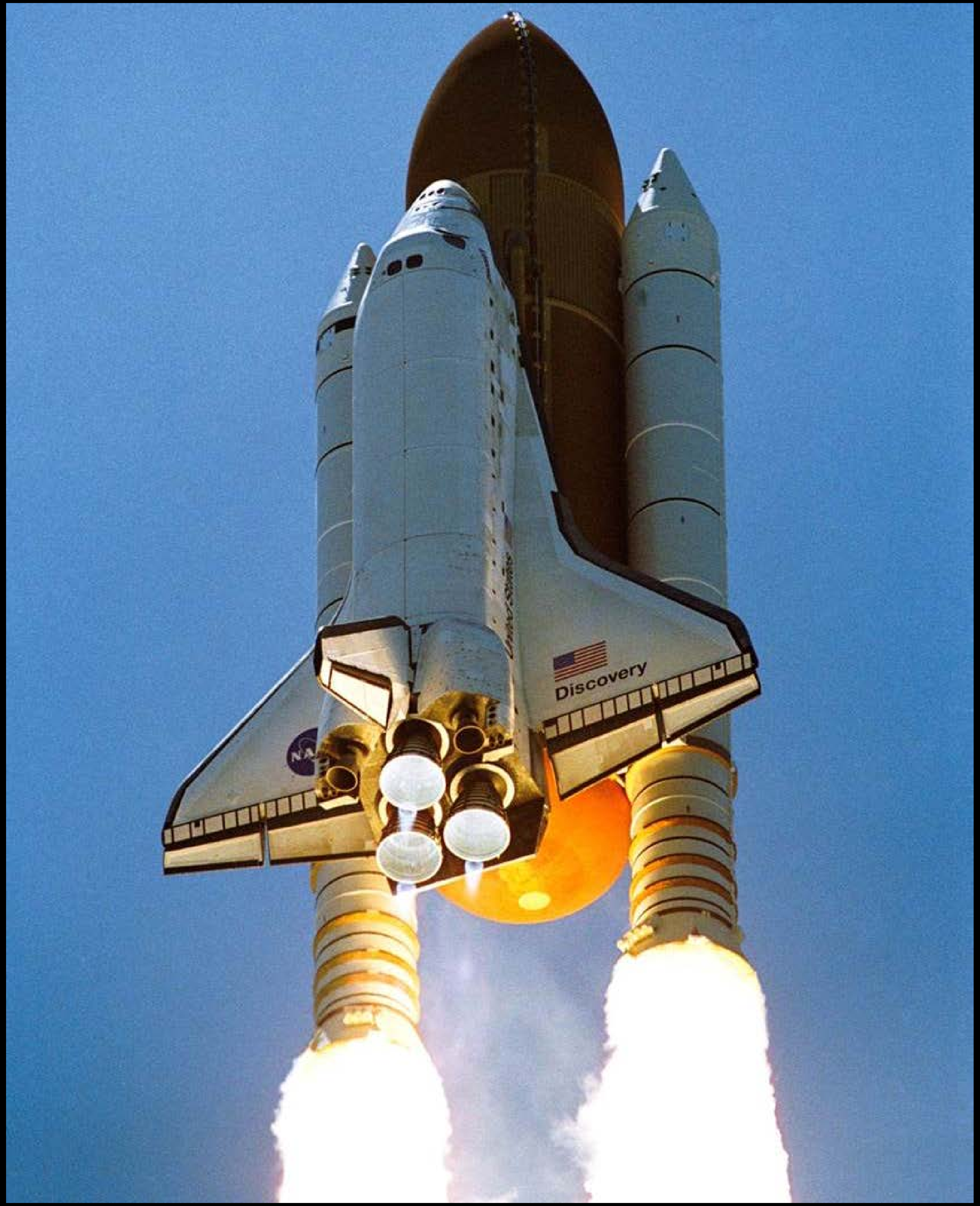


Credits: 1. Joachim Becker, SpaceFacts.de, 2. NASA, 3. NASA

Apollo-Soyuz Test Project (ASTP) - 1975



Space Shuttle - 1981 to 2011

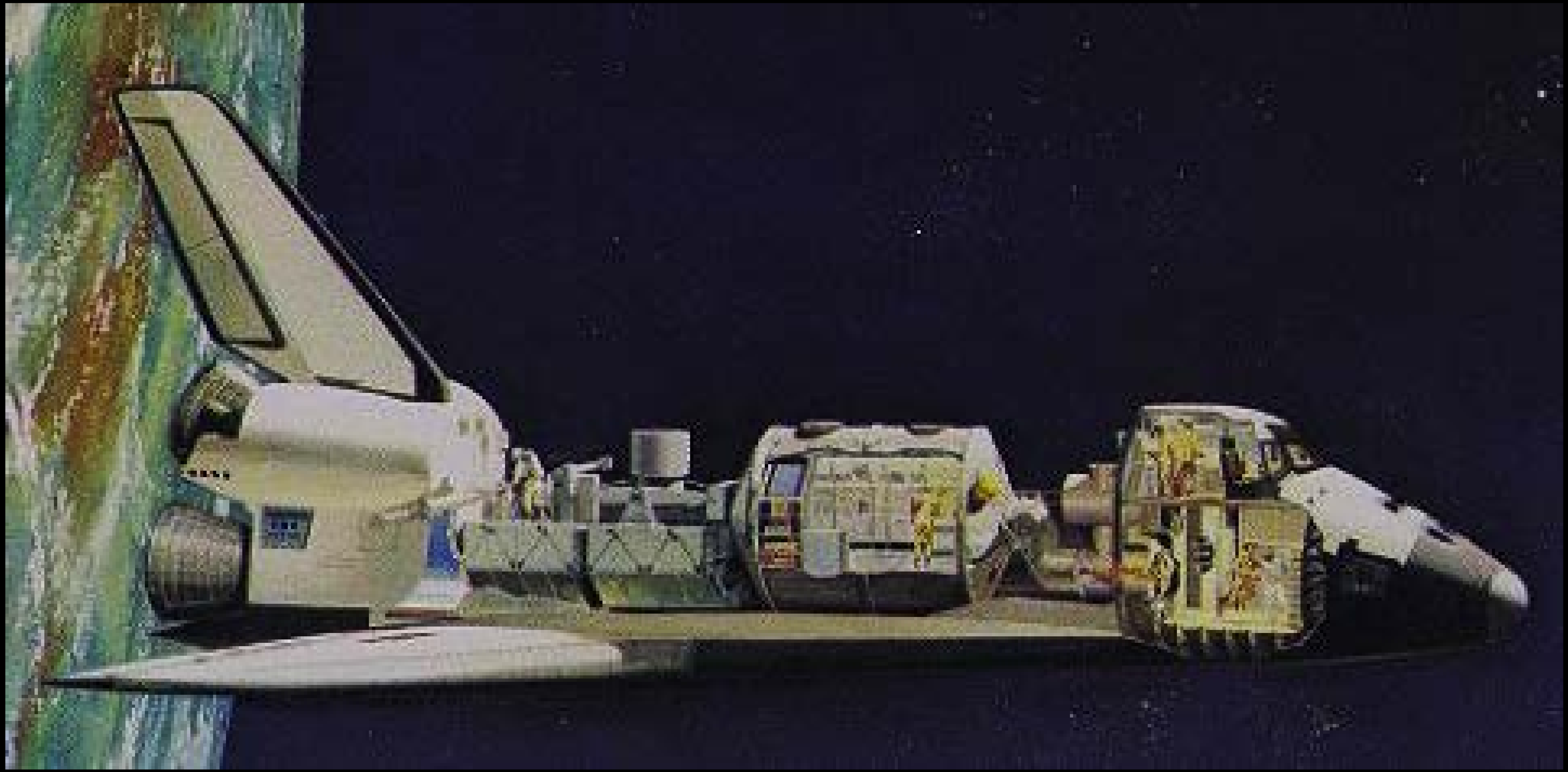


Credits: NASA

Space Shuttle – On-orbit and landing

Credits: NASA

Space Shuttle - Spacelab - First flight in 1983



Credits: NASA

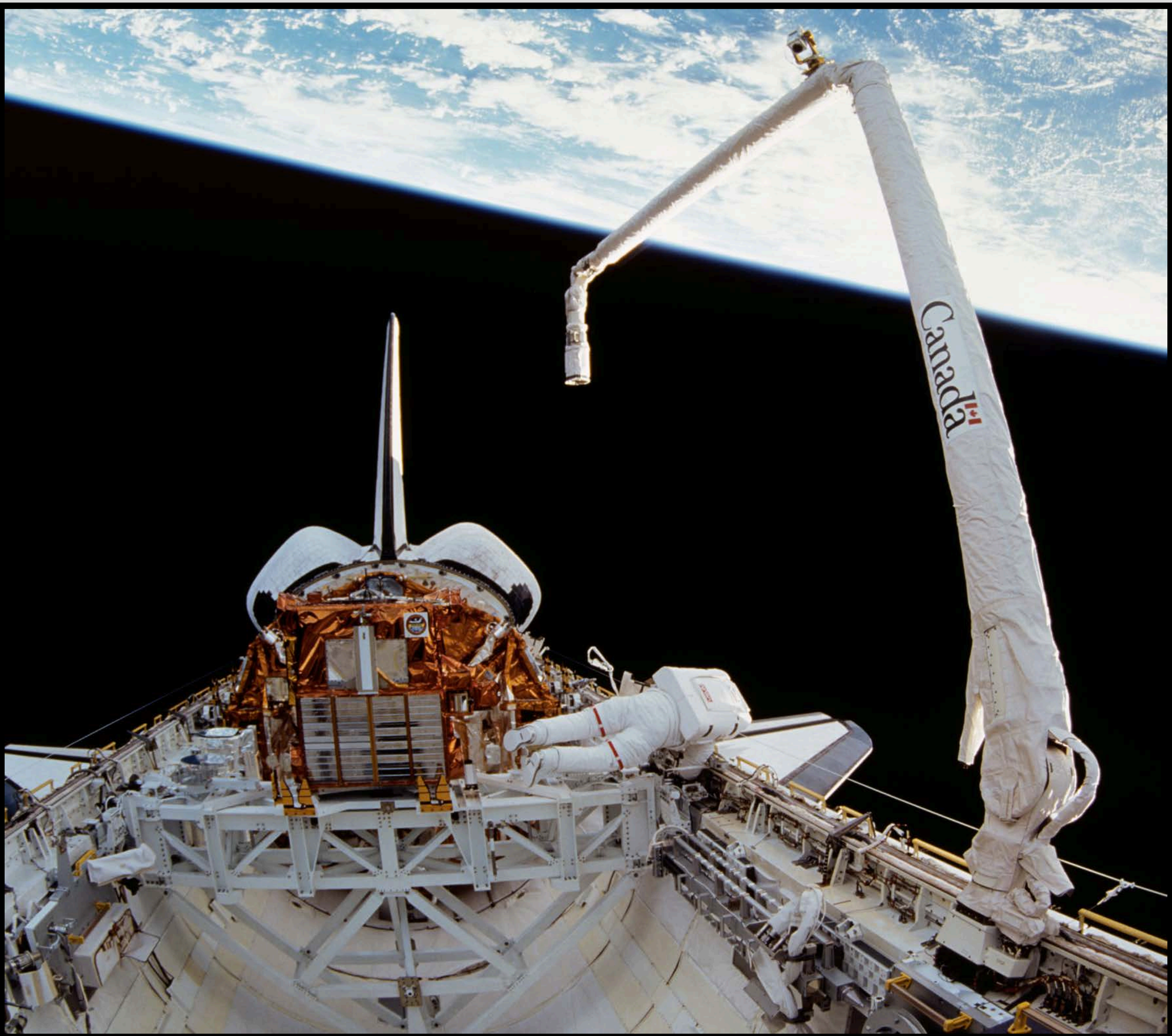
Space Shuttle - Spacelab

Credits: NASA

Spacelab interior

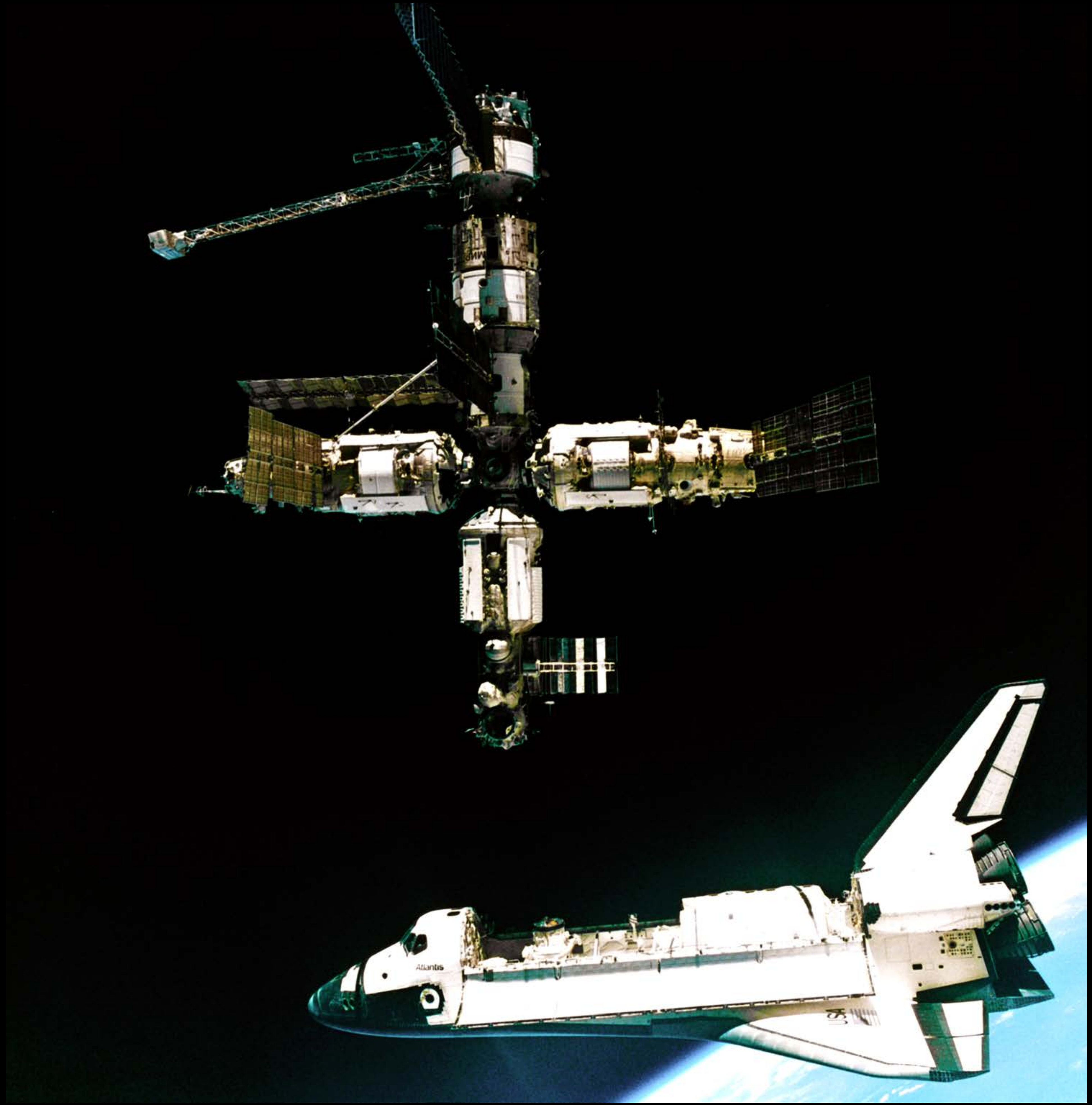
Credits: NASA

Space Shuttle - Remote Manipulator System (RMS, Canadarm)



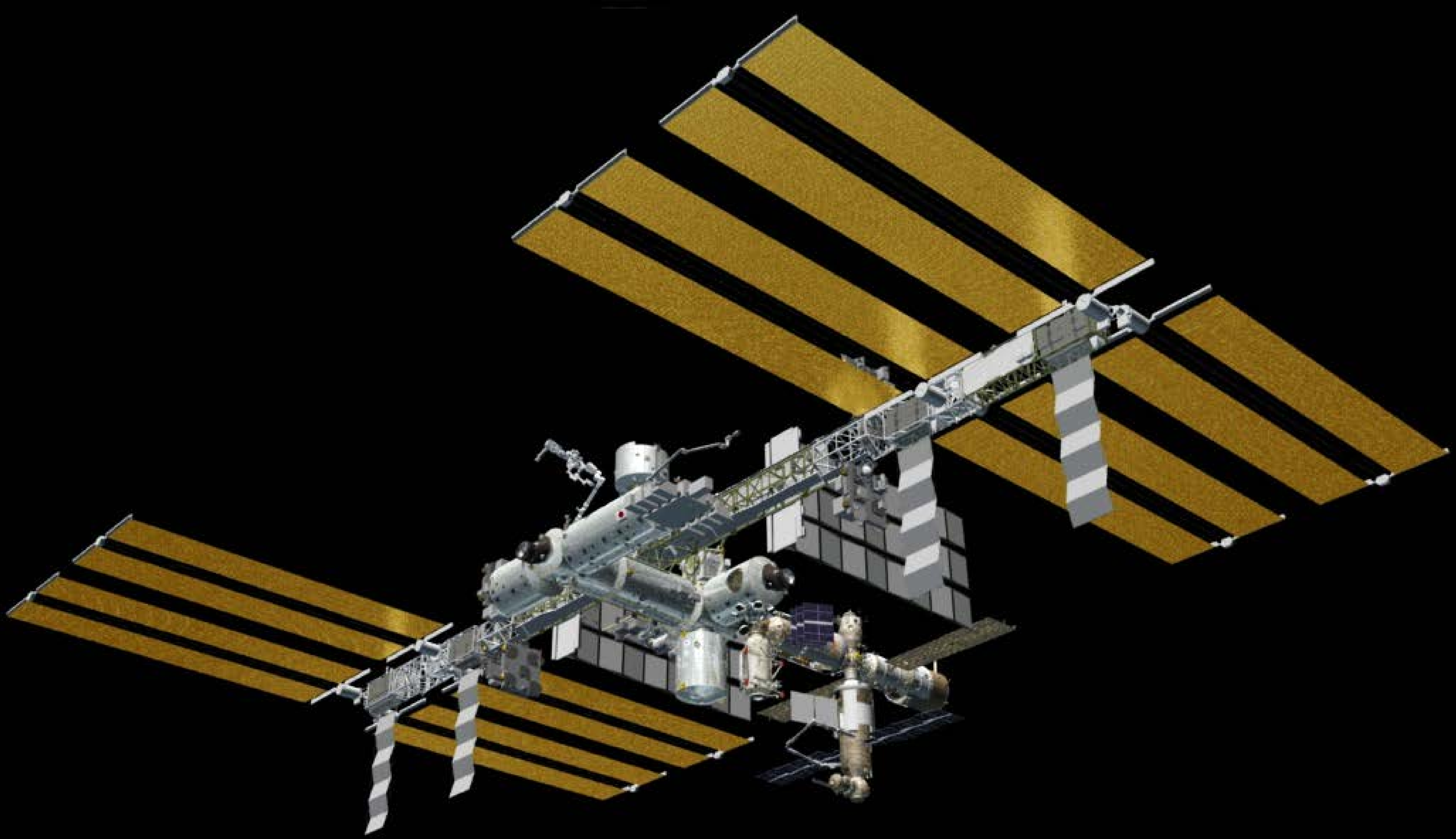
Credits: NASA

Space Shuttle - Mir - 1994 to 1998



Credits: NASA

ISS – Cooperation between 5 space agencies (15 nations)



Credits: NASA

Current crew on ISS (February 17, 2020)

Andrew Morgan (USA)

Commander Oleg Skripochka (Russia)

Jessica Meir (USA)

Current crew on ISS (February 17, 2020)

China – Shenzhou, Tiangong and Tianzhou spacecraft

Credits: CNSA

Shenzhou: Manned up and down spacecraft

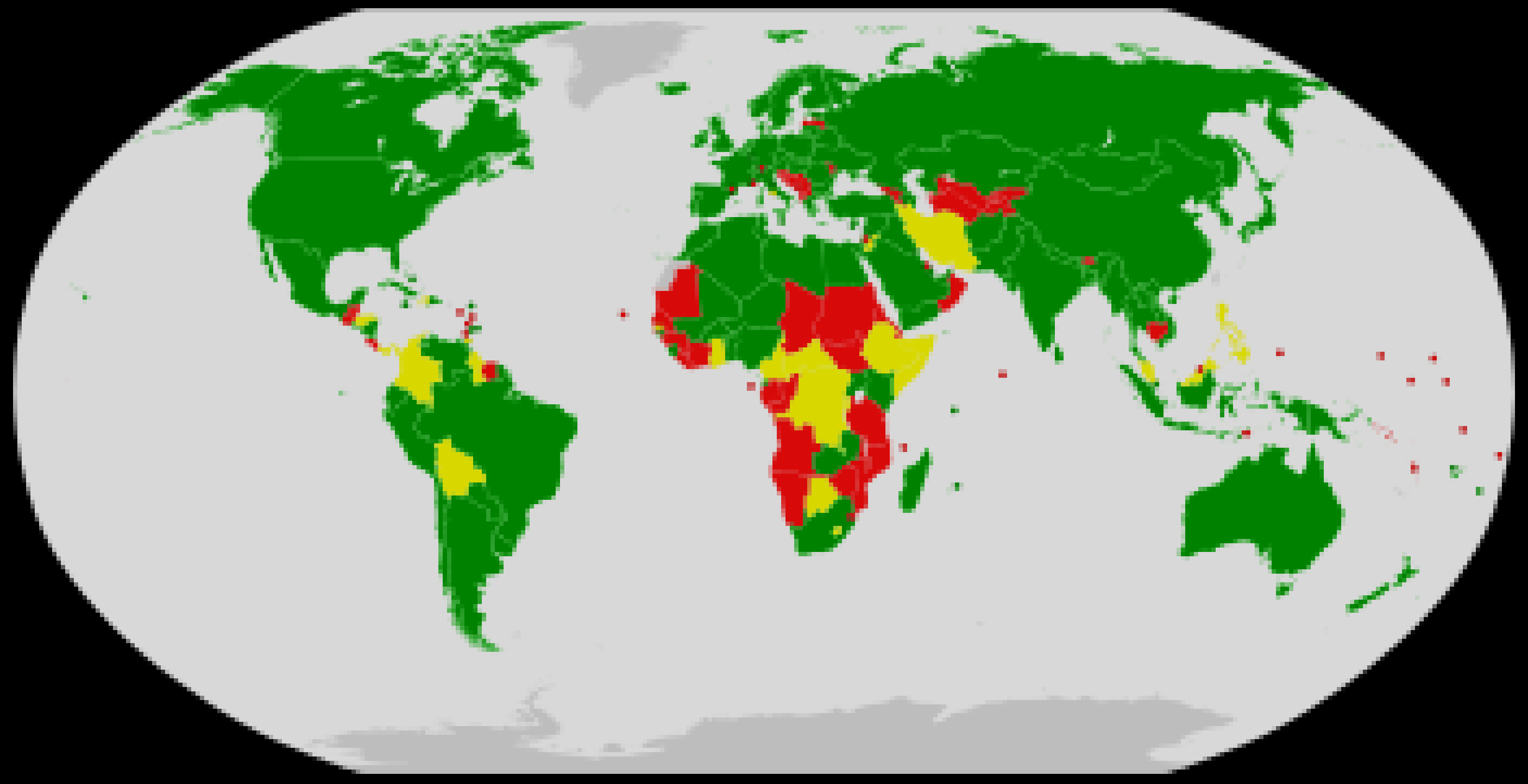
Tiangong: Man-tended Space Station

Tianzhou: Unmanned cargo/fuel resupply spacecraft

Tianzhou-1 was deorbited in 2017

Tiangong-1 came down to Earth in 2018

Tiangong-2 was deorbited in 2019



0.4.6 The Outer Space Treaty

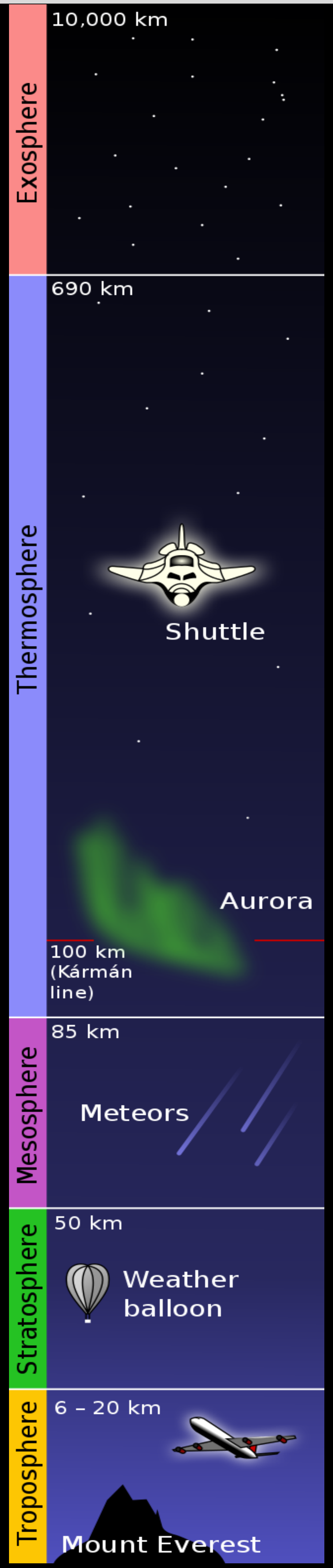
Space Mission Design and Operations

Prof. Claude Nicollier

Credits: NASA

Where does Space start?

The Kármán line is the altitude where the speed necessary to aerodynamically support an airplane's full weight equals orbital velocity (assuming wing loading of a typical airplane).

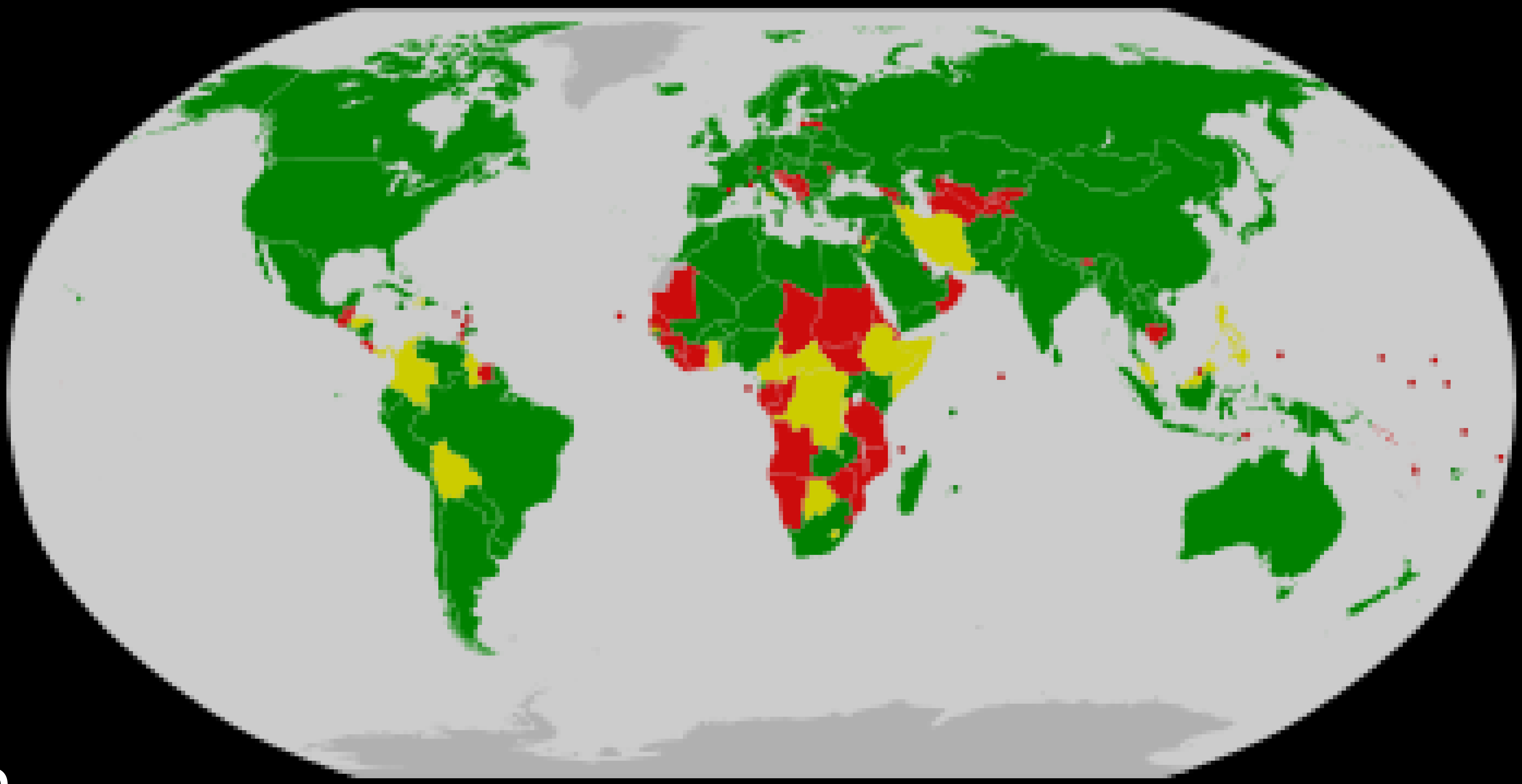


The Kármán line is the lower limit of space, and the boundary between aeronautics and astronautics.

The value 100 km or 63 miles was adopted by the FAI (Fédération Aéronautique Internationale)

The Outer Space Treaty of 1967

Treaty on principles governing the activities of States in the exploration and use of outer space, including the Moon and other celestial bodies.



As of July 2017, 107 countries are parties to the treaty, while another 23 have signed the treaty but have not completed ratification

Parties	green
Signatories	yellow
Non-parties	red

Key Points of the the Outer Space Treaty (1 of 3)

The Treaty bars States from placing weapons of mass destruction in orbit around Earth, installing them on the Moon or any other celestial body, or otherwise stationing them in outer space.

It exclusively limits the use of the Moon and other celestial bodies to peaceful purposes and expressly prohibits their use for testing weapons of any kind, conducting military maneuvers, or establishing military bases, installations, and fortifications.

Key Points of the the Outer Space Treaty (2 of 3)

However, the Treaty does not prohibit the placement of conventional weapons in orbit and thus some highly destructive attack strategies are still potentially allowed.

The Treaty also states that the exploration of outer space shall be done to benefit all countries and that space shall be free for exploration and use by all the States.

Key Points of the the Outer Space Treaty (3 of 3)

The Treaty forbids any government from claiming a celestial resource such as the Moon or a planet. Article II of the Treaty states that “Outer space, including the Moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means".

The State that launches a space object retains jurisdiction and control over that object. The State is also liable for damages caused by their space object.

The problem of space debris

Article IX of the Treaty addresses the legal base for debris mitigation and ADR*

In the exploration and use of outer space, ... States parties to the Treaty shall be guided by the principle of cooperation and mutual assistance and shall conduct all their activities in outer space with due regard to the corresponding interests of all other States parties to the Treaty. States parties to the Treaty shall pursue studies of outer space, ... and conduct space exploration so as to avoid harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose.

* ADR = Active Debris Removal

Measures in place for mitigation of the space debris problem

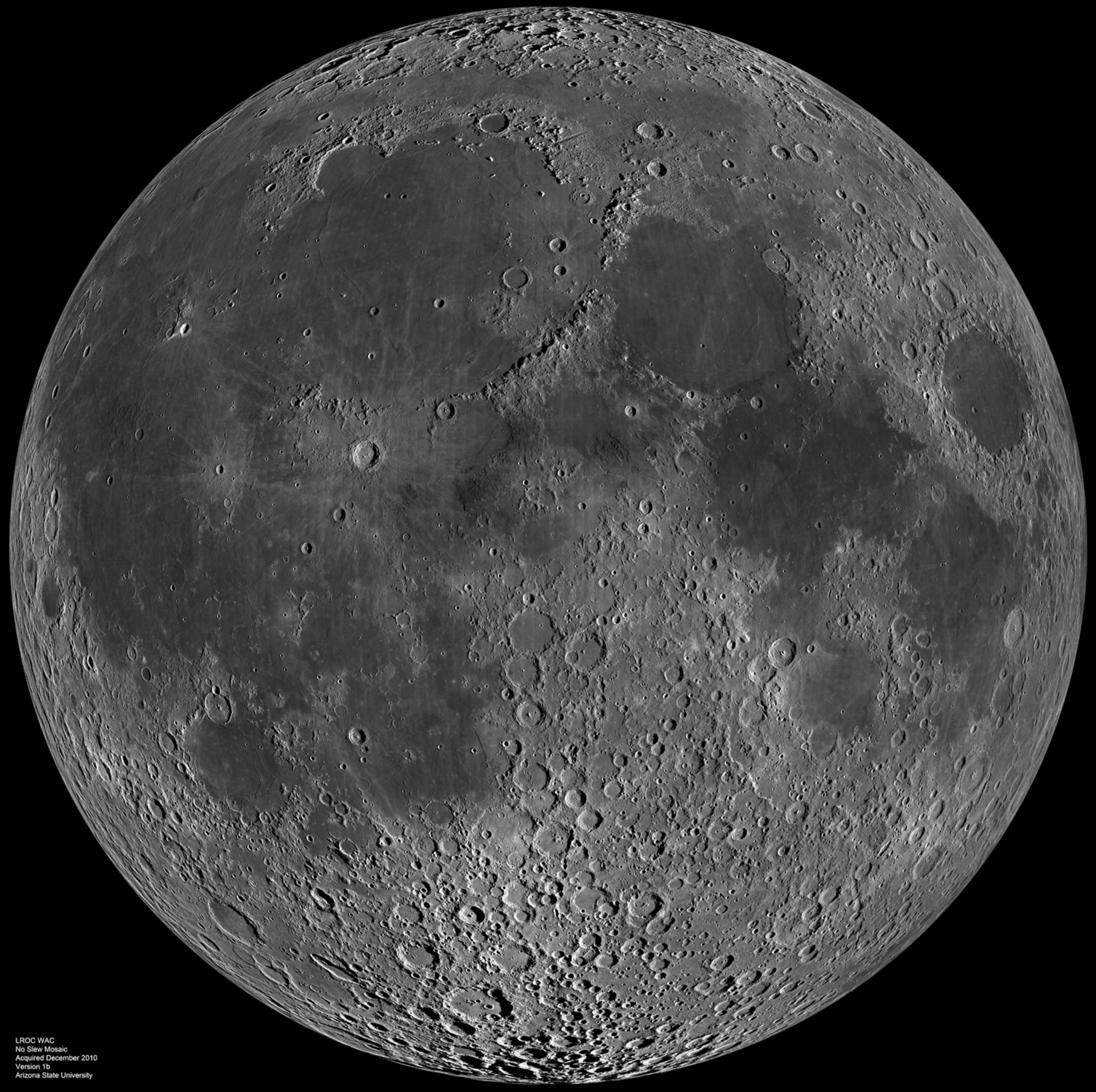
De-orbiting of a satellite at end of life (25-year post operational life limit).

De-orbiting of launcher upper stages reaching orbit status.

ADR techniques development is actively pursued by several Agencies and Institutions (e.g ESA's Clean Space Initiative, RemoveDebris of the Surrey Space Centre, CleanSpaceOne at EPFL/Clearspace, and others…).

The Moon Treaty of 1979 (1 of 2)

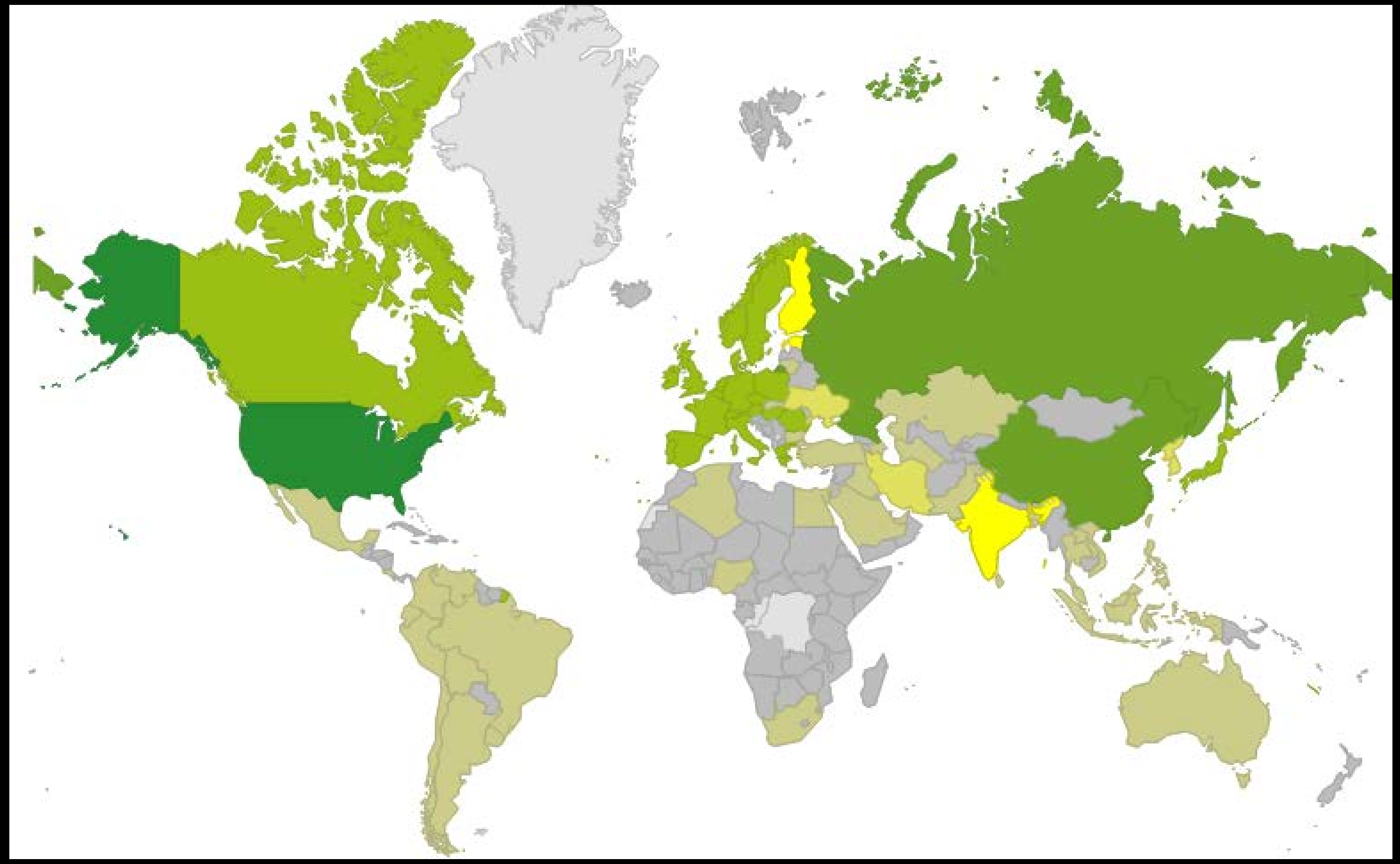
The Moon Treaty applies to the Moon and other celestial bodies in the solar system excluding the Earth. It stipulates that these bodies should be used exclusively for peaceful purposes, that their environments should not be disrupted, and that the United Nations should be informed of the location and purpose of any station established on those bodies.



The Moon Treaty of 1979 (2 of 2)

The most controversial section of the Moon Treaty deals with natural resources on the Moon (or other celestial body). The Moon Treaty stipulates that the Moon and its natural resources are the common heritage of mankind and the harvesting of those resources is forbidden except through an international regime.

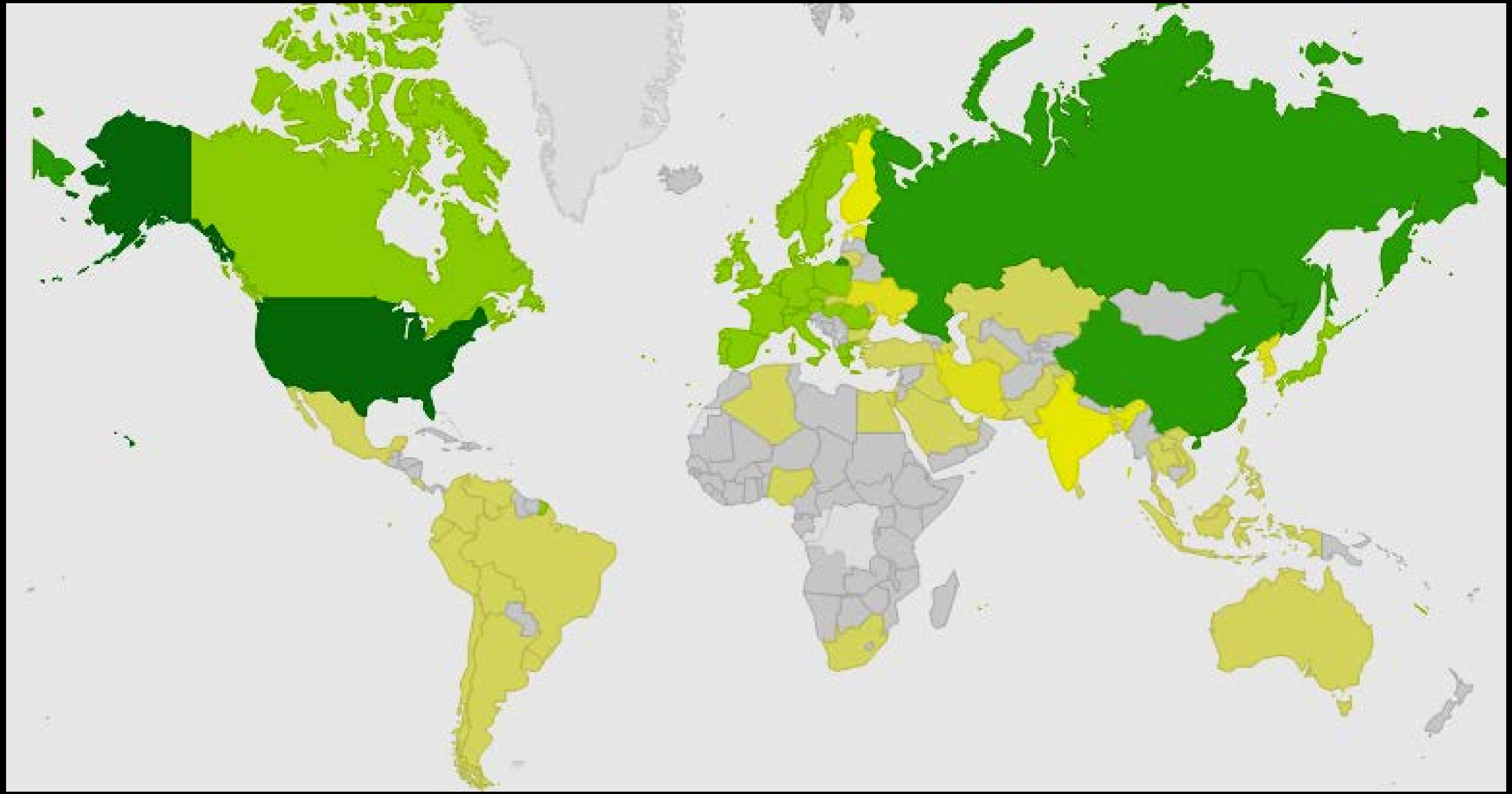
The Moon Treaty is in fact a failed Treaty because it has not been ratified by most States that are engaged in human space exploration (the United States, Canada, nearly all members of ESA, Russia, China and Japan). In November 2016, it had been ratified by 17 States.



0.5.1 Space Agencies and private companies providing access to space

Space Mission Design and Operations

Space activities in the world



	Manned extraterrestrial exploration + operates space station + manned space flight + operates extraterrestrial probes + launch capability + operates satellites
	Manned space flight + operates space station + operates extraterrestrial probes + launch capability + operates satellites
	Operates space station + operates extraterrestrial probes + launch capability + operates satellites
	Operates extraterrestrial probes + launch capability + operates satellites
	Launch capability + operates satellites
	Operates satellites
	None of the above
	No information

Space Agencies (non-exhaustive list)

EPFL

NASA

esa

РОСКОСМОС

JAXA

CSA ASC

इसरो isro

CNSA

cnes
CENTRE NATIONAL
D'ÉTUDES SPATIALES

DLR

asi
agenzia spaziale
italiana

UK SPACE
AGENCY

Private companies in the US providing access to space (in 2020)

SPACEX

BOEING

NORTHROP GRUMMAN

SNC SIERRA NEVADA CORPORATION

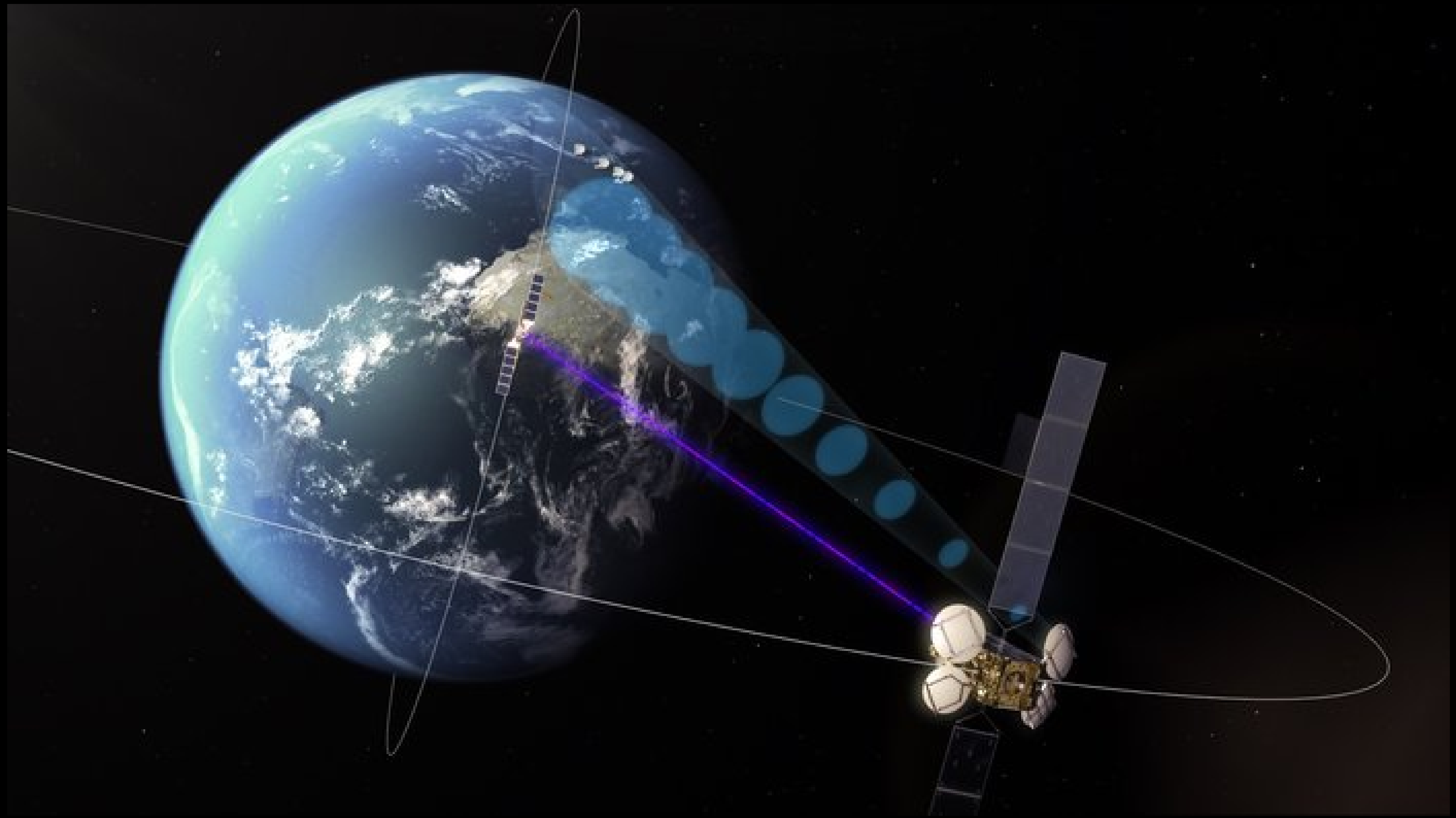
SCALED COMPOSITES

BLUE ORIGIN

Virgin GALACTIC

The case of Switzerland

- Switzerland is a space nation, small because the country is small!
- Swiss Space Office in Bern, with a mandate to “conceive, propose, and implement the Swiss Space Policy defined by the Swiss Government. It also provides the Swiss delegation to ESA.
- eSpace and Swiss Space Center at EPFL , look at espace.epfl.ch and space.epfl.ch
- Minor in Space Technologies, an option at EPFL
- Contact eSpace: candice.norhadian@epfl.ch
- Contact Swiss Space Center: martine.harmel@epfl.ch



0.5.2 Space utilization

Space Mission Design and Operations

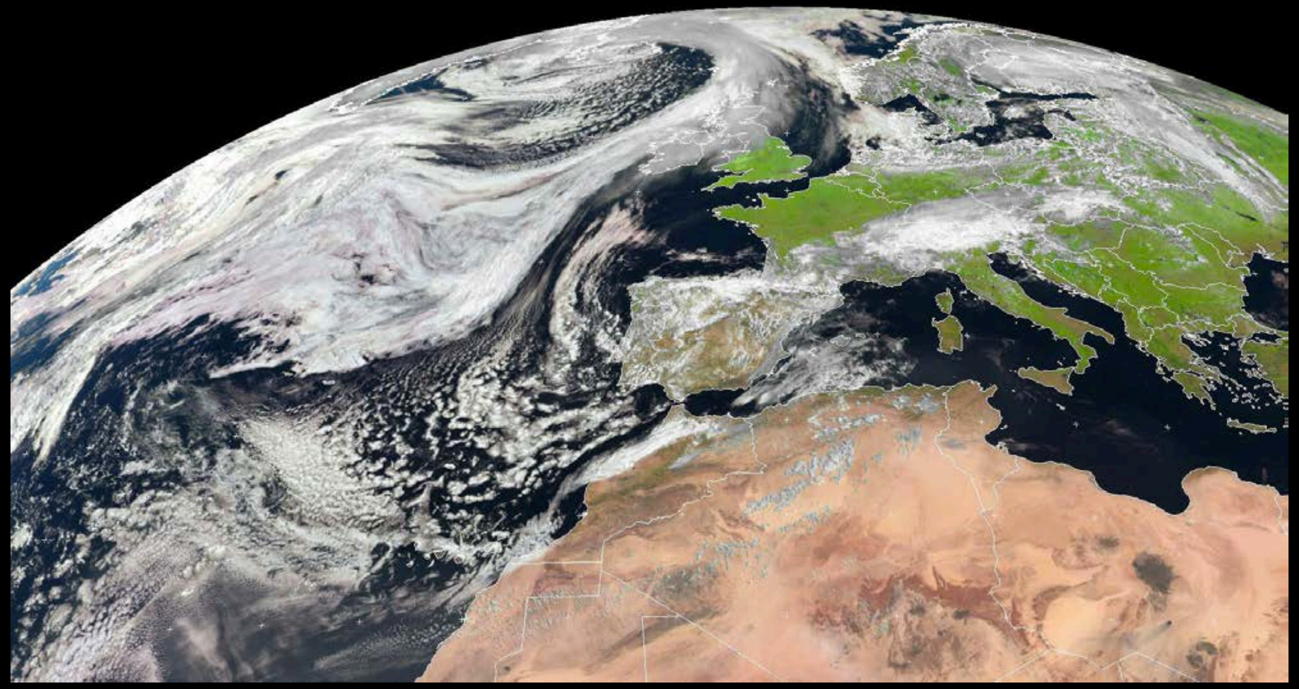
Prof. Claude Nicollier

Credits: ESA

Outline – Three main fields of space utilization

1. Communications

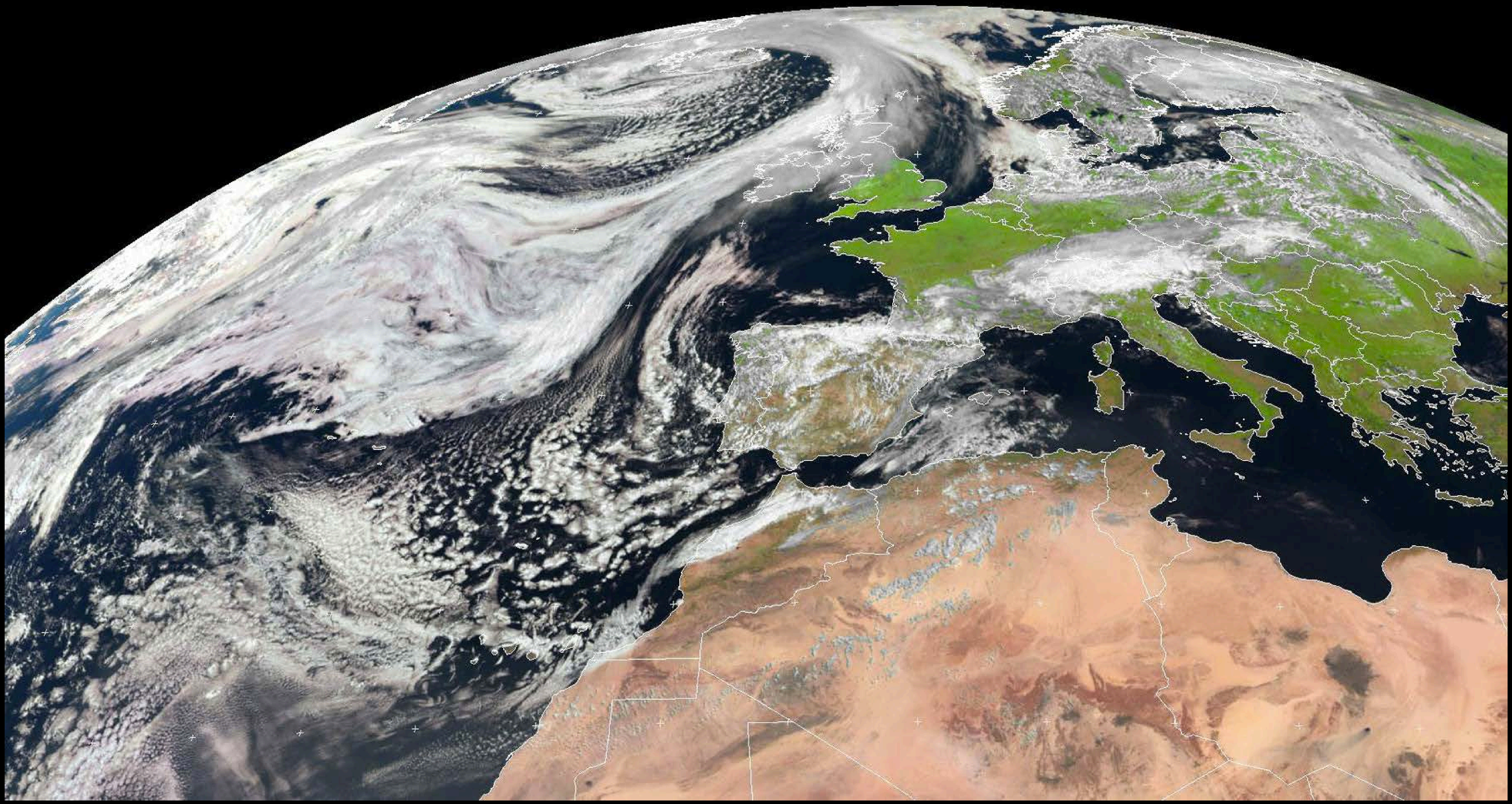
2. Precise navigation



3. Observation of Earth and its atmosphere

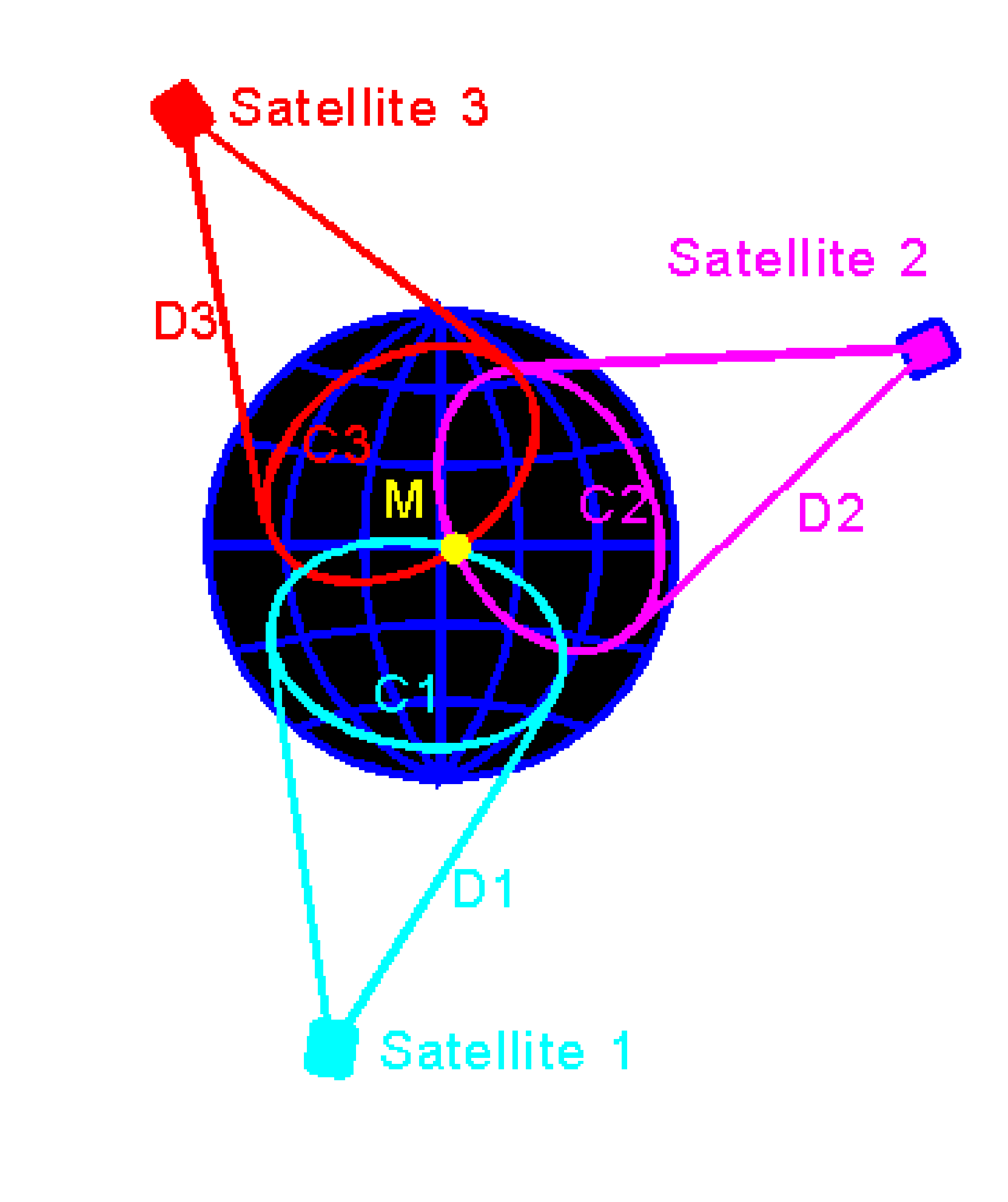
Credits: 1. Boeing artist's concept, 2. ESA, 3. Meteosat

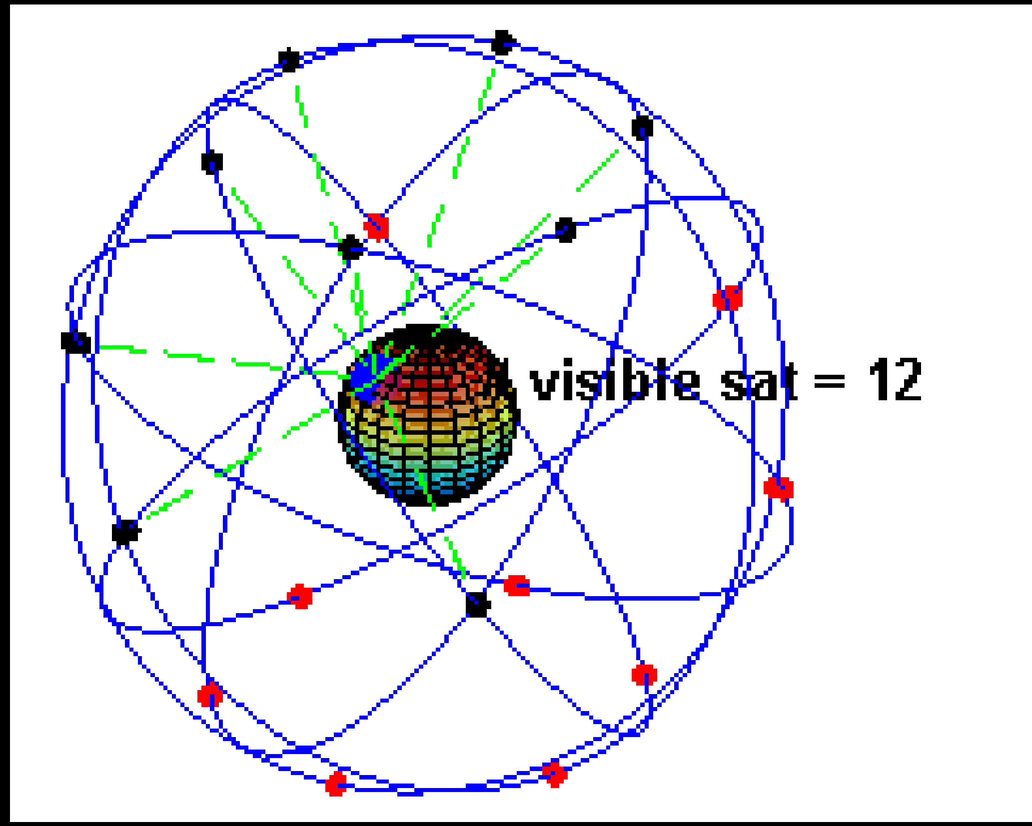
Observation of the Earth and its atmosphere



Credits: Meteosat

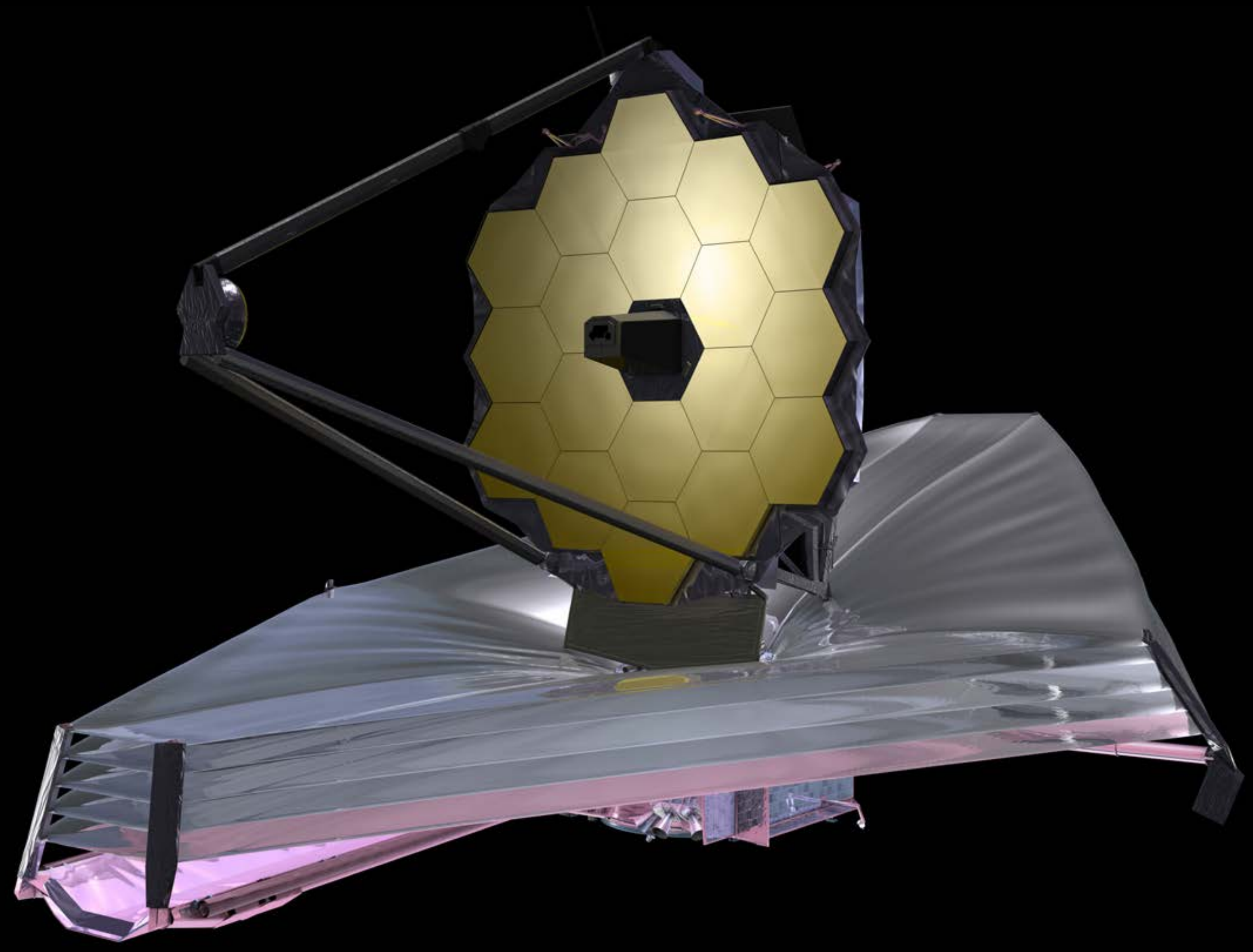
Precise navigation – Principle and applications





- US: GPS
- Russia: GLONASS
- EU: Galileo
- China: Beidou
- India: IRNSS

Credits: 2. Wikipedia, El pak, 3. ESA



0.5.3 Space science and exploration

Space Mission Design and Operations

Prof. Claude Nicollier

Credits: ESA

Space - A unique and valuable environment for science

General disciplines

- Astrophysics
- Solar physics
- Space weather
- Fundamental physics
- Earth science

In addition, onboard space stations:

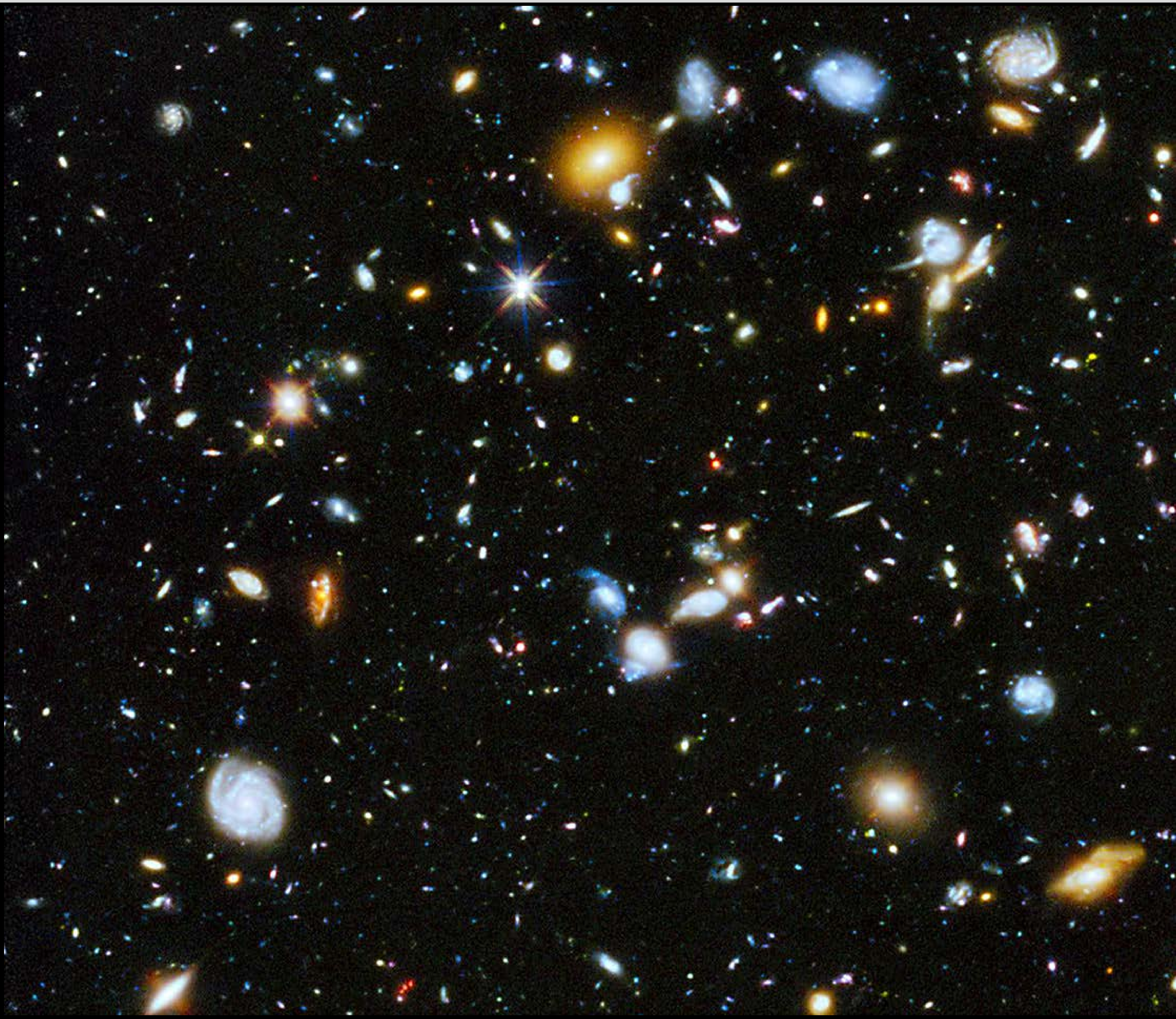
- Biology
- Plant growth
- Physiology
- Material and fluid physics

Credits: NASA

Hubble Space Telescope (HST), and the Hubble Ultra Deep Field

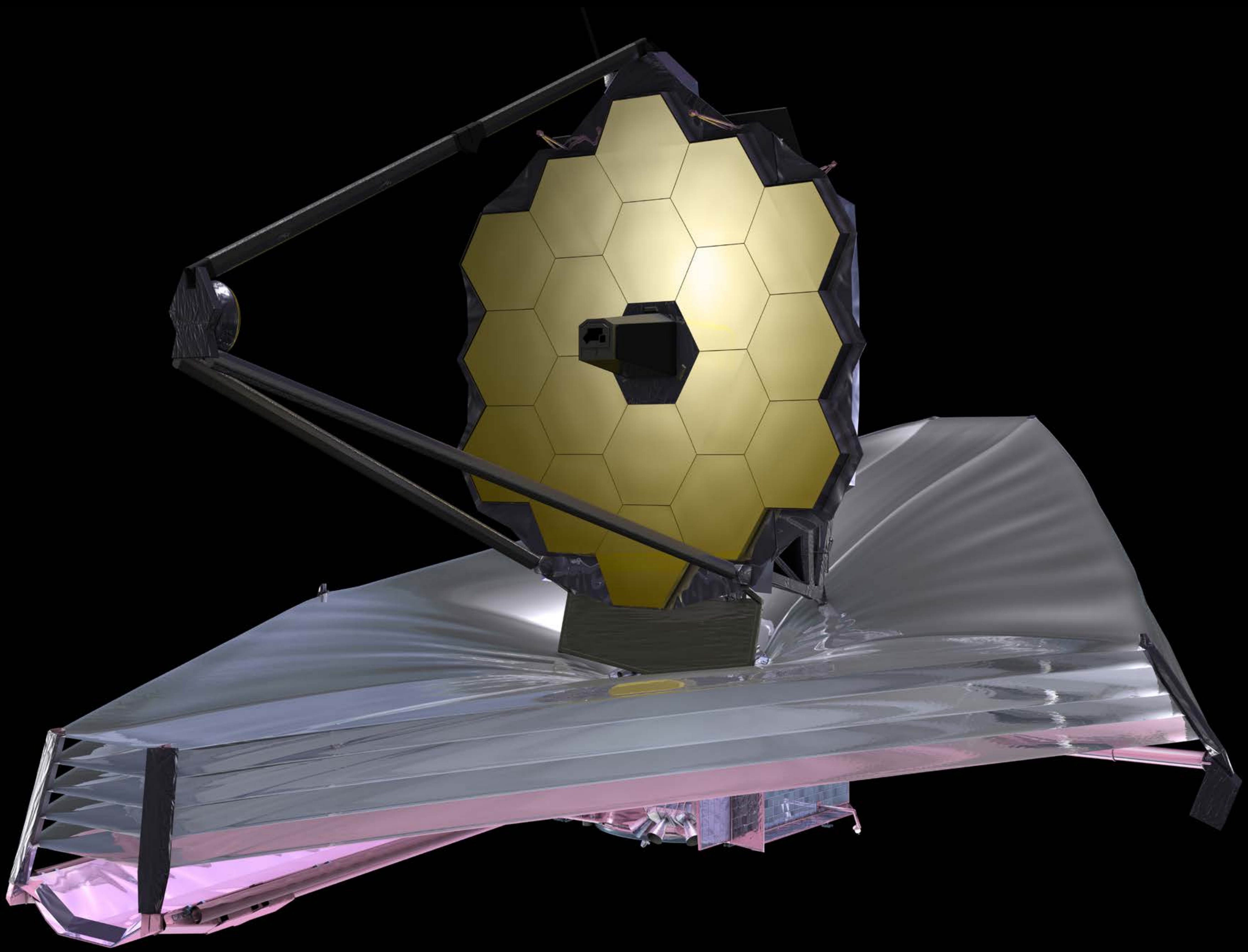
Achievements:

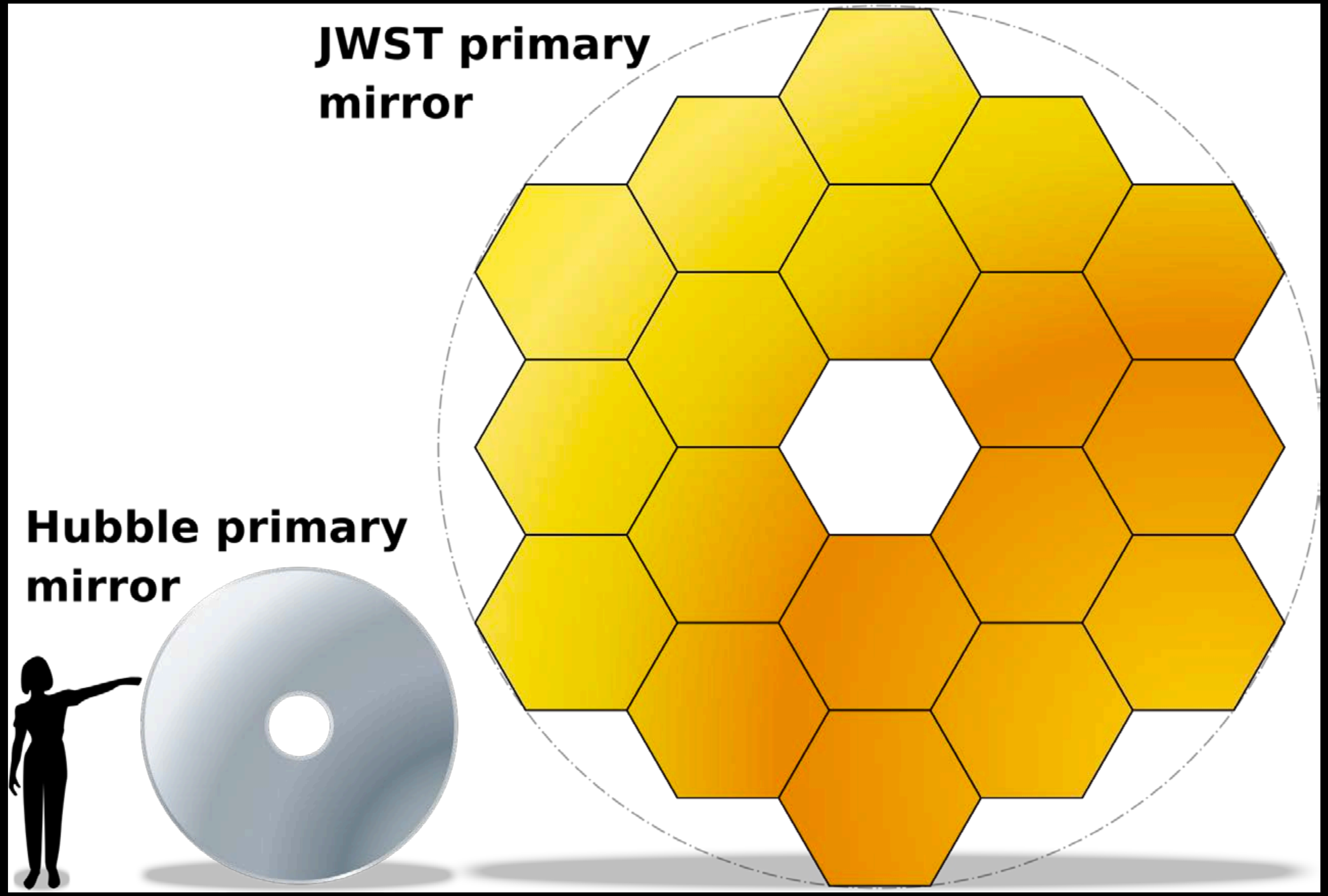
- The Hubble Deep Fields
- Supermassive black holes at the center of galaxies
- Expansion and age of the universe measured
- Star formation studies, planetary nebulae



Credits: NASA, ESA, S. Beckwith (STScI) and The HUDF Team

James Webb Space Telescope (JWST), successor to Hubble

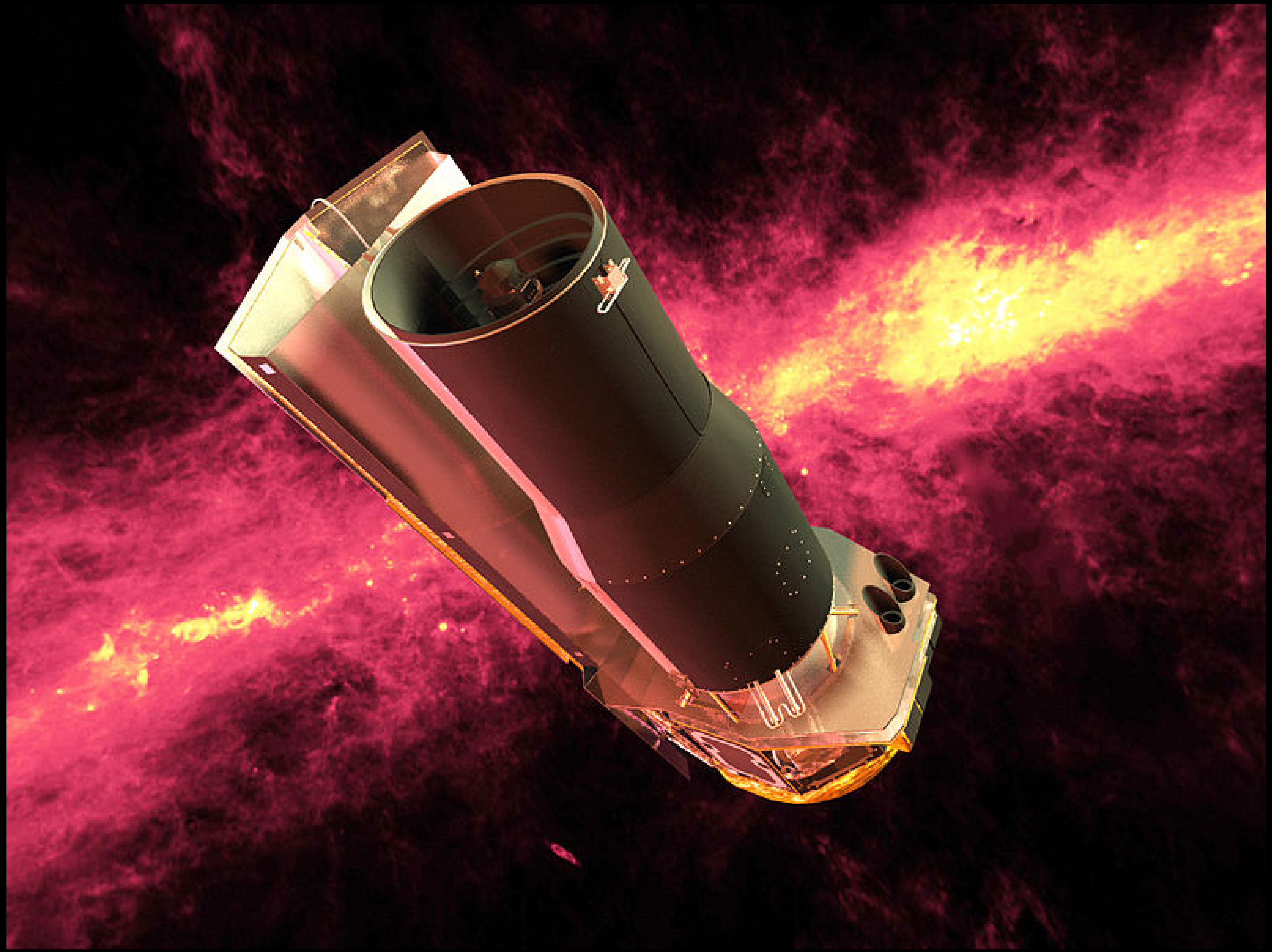




Cooperation between NASA, ESA and CSA

Credits: 1. NASA, 2. Wikipedia

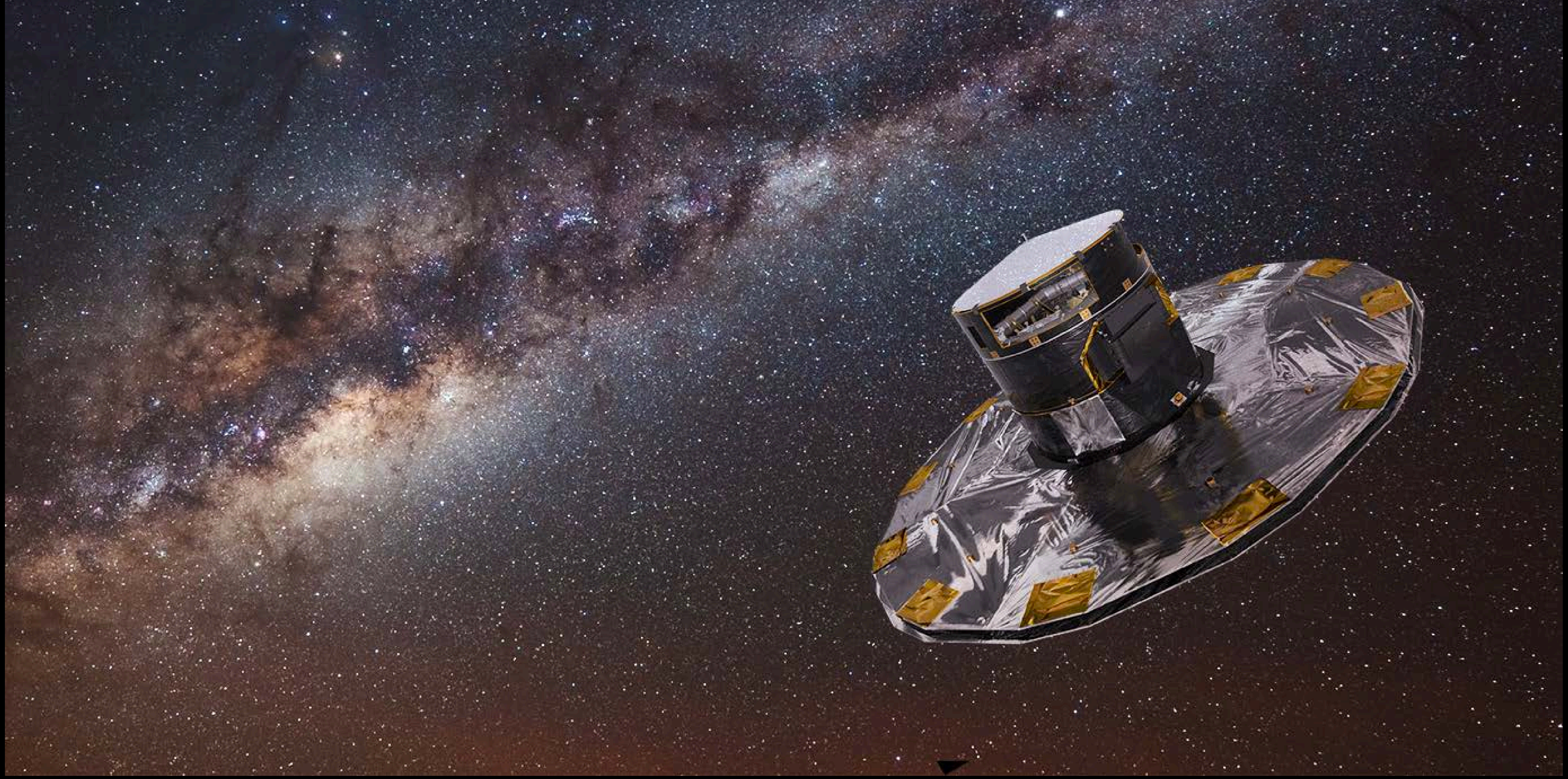
Spitzer (IR) and XMM-Newton (X-ray) telescopes



Credits: 1. NASA, JPL-Caltech, 2. ESA, D. Ducros

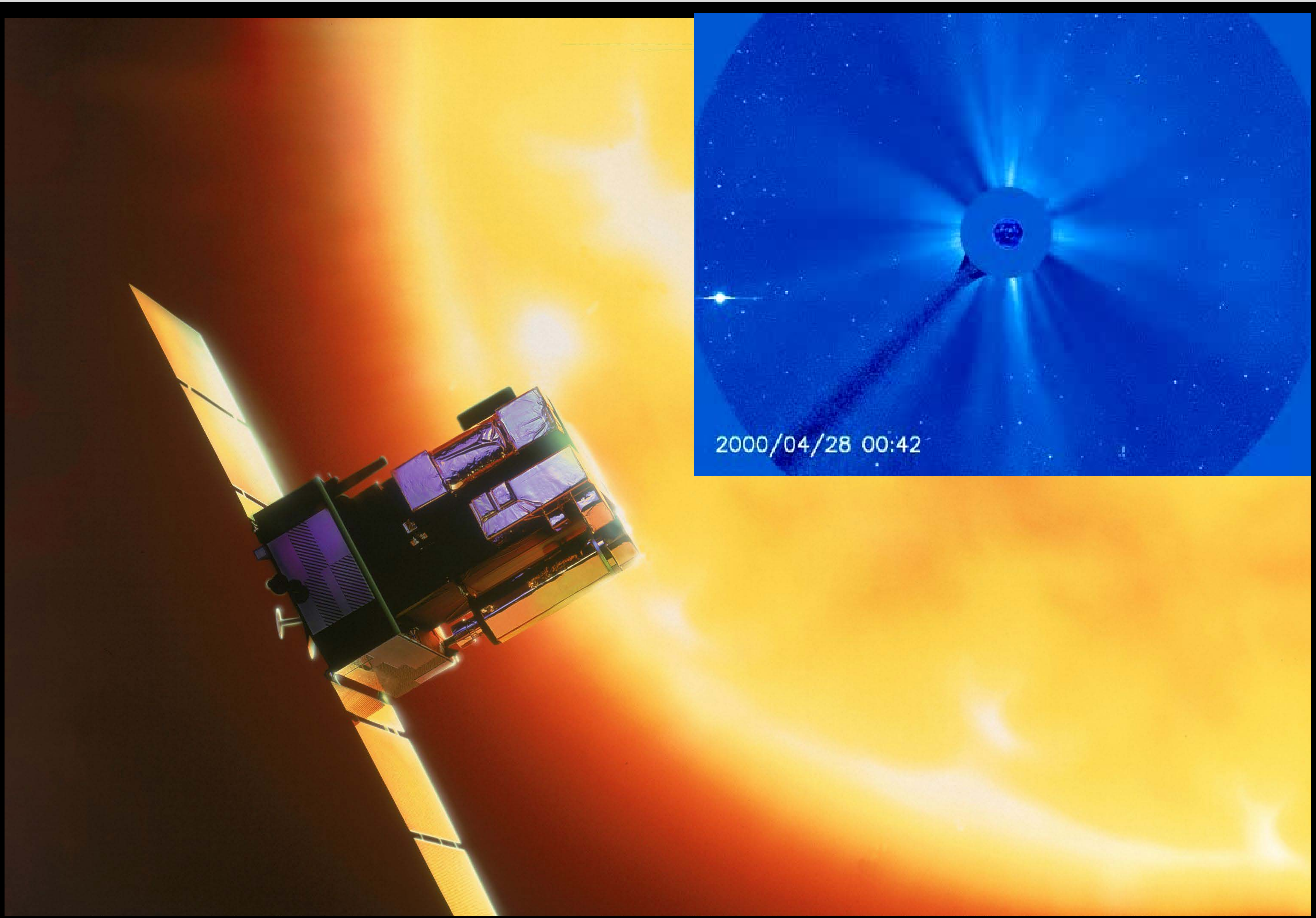
Gaia spacecraft (ESA) - very high precision astrometry satellite

Objective: To create the largest and most precise three dimensional chart of our galaxy by providing unprecedented position, photometric and radial velocity measurements for more than one billion stars in our galaxy.



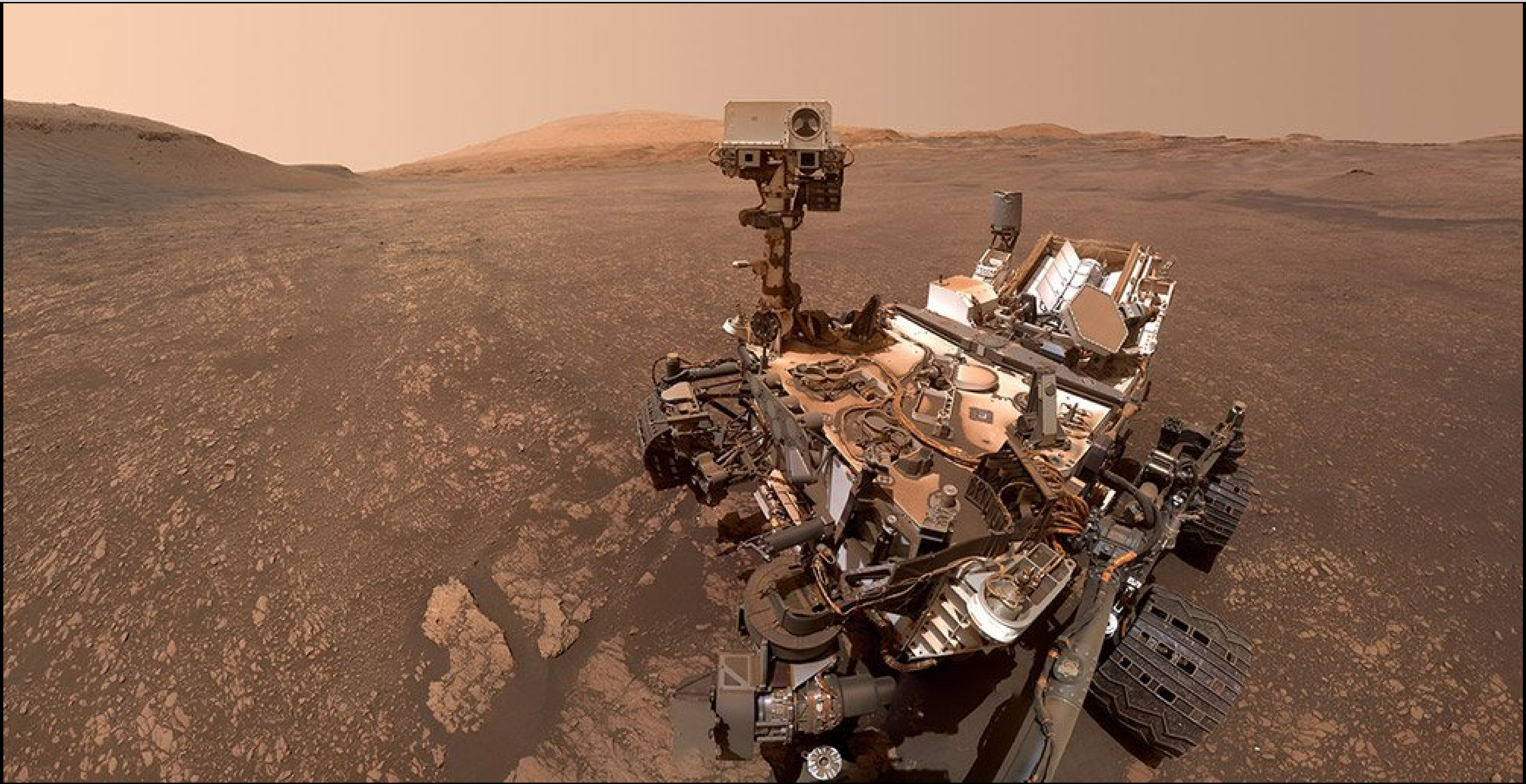
Credits: ESA

Solar and Heliospheric Observatory (SoHo) - Launched in 1995



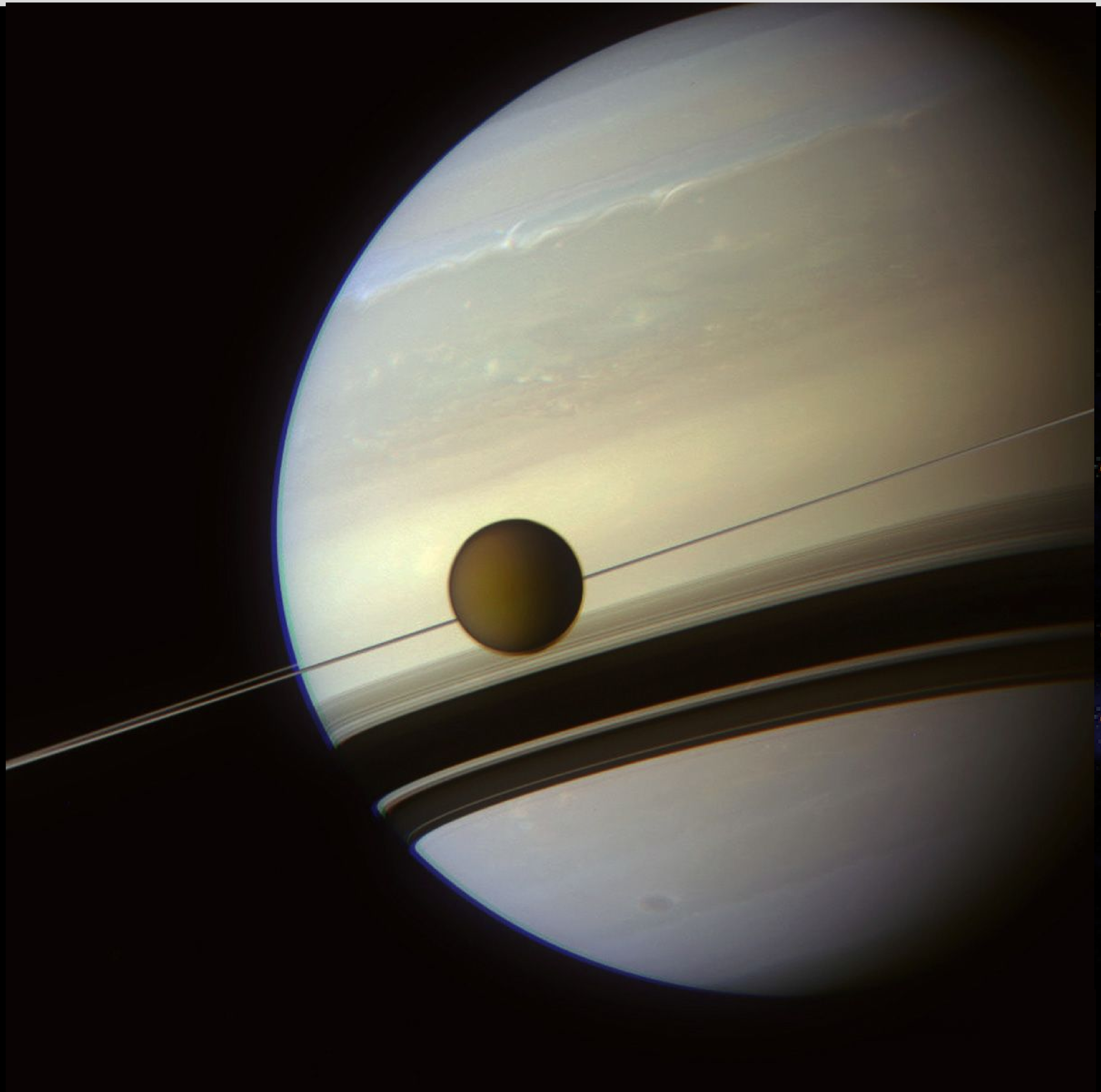
Credits: ESA

Solar System in situ exploration, Curiosity on Mars

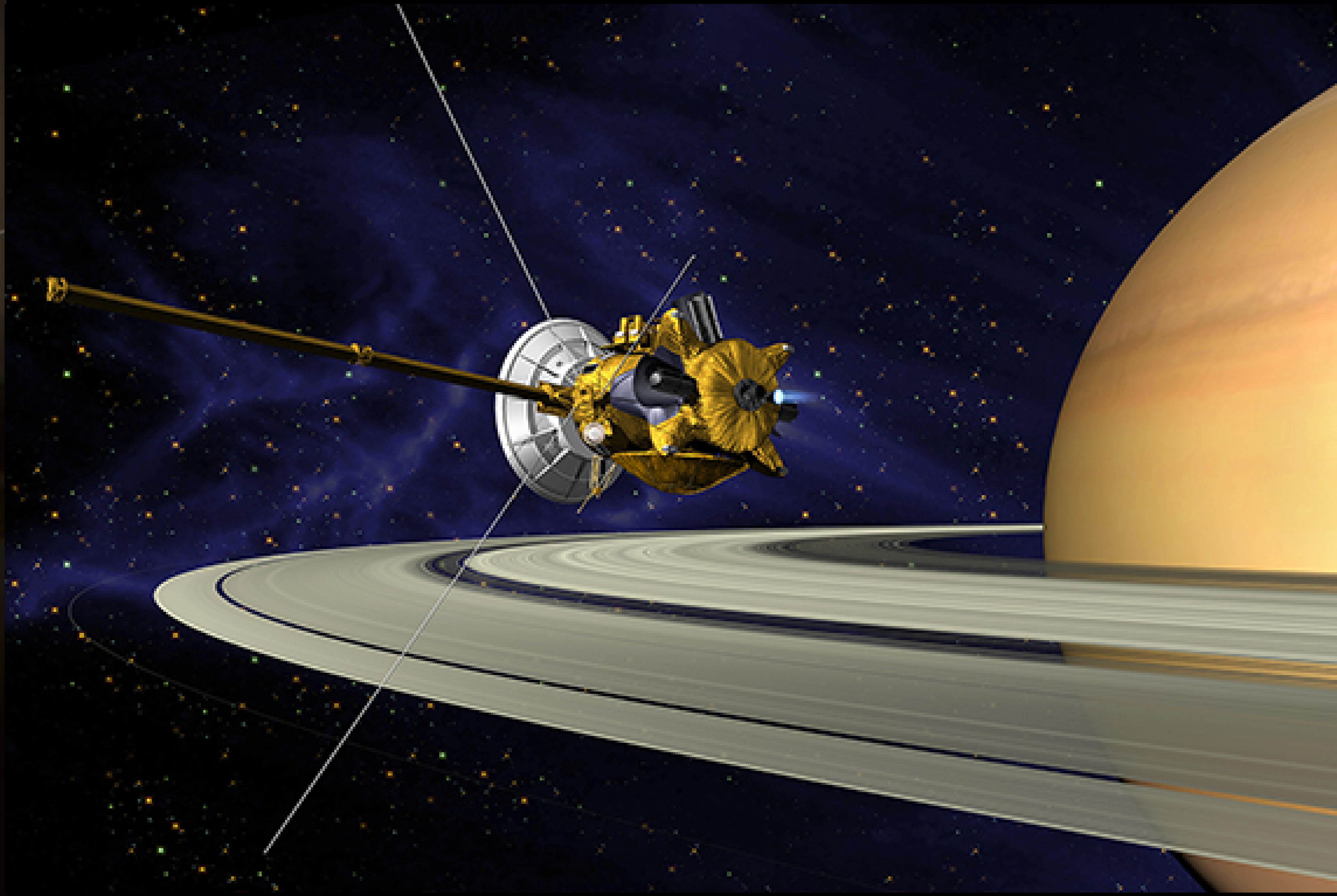


Credits: NASA/JPL-Caltech

Cassini-Huygens exploration of Saturn and its satellites



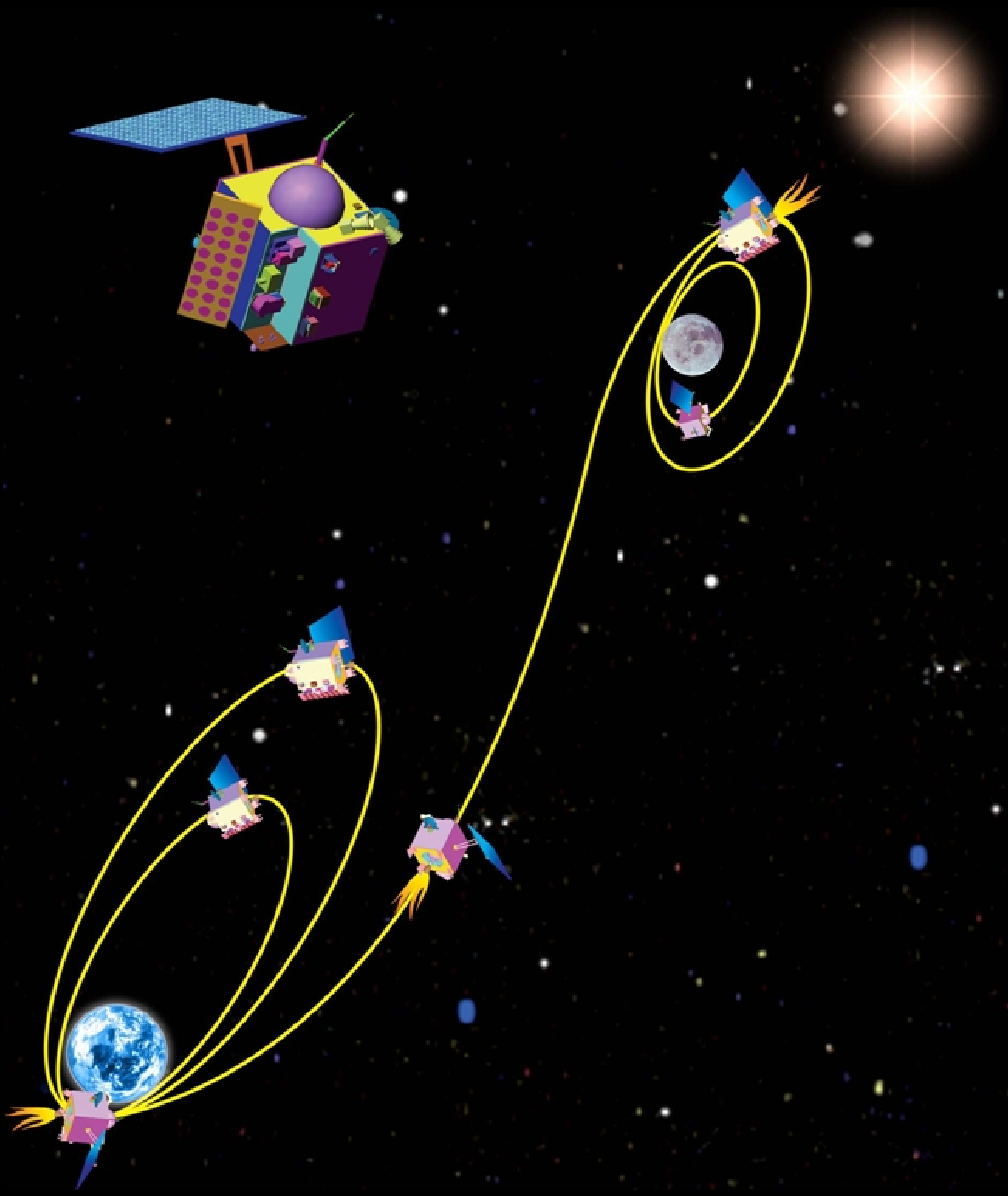
1997 - 2017

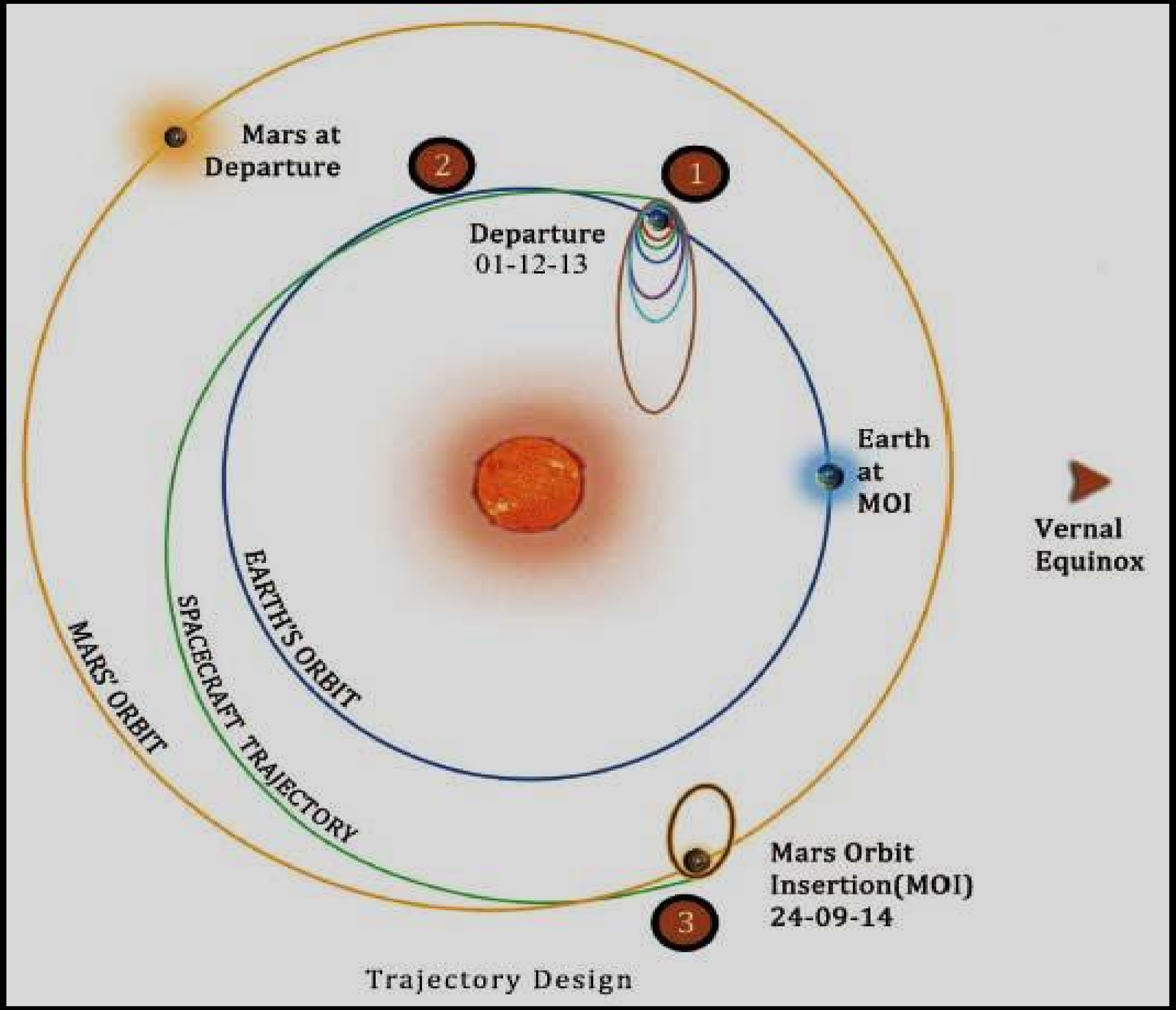


Huygens (ESA) – First landing in the outer solar system

India to the Moon and Mars – Chandrayaan and Mangalyaan

Chandrayaan was launched in 2008 to the Moon.



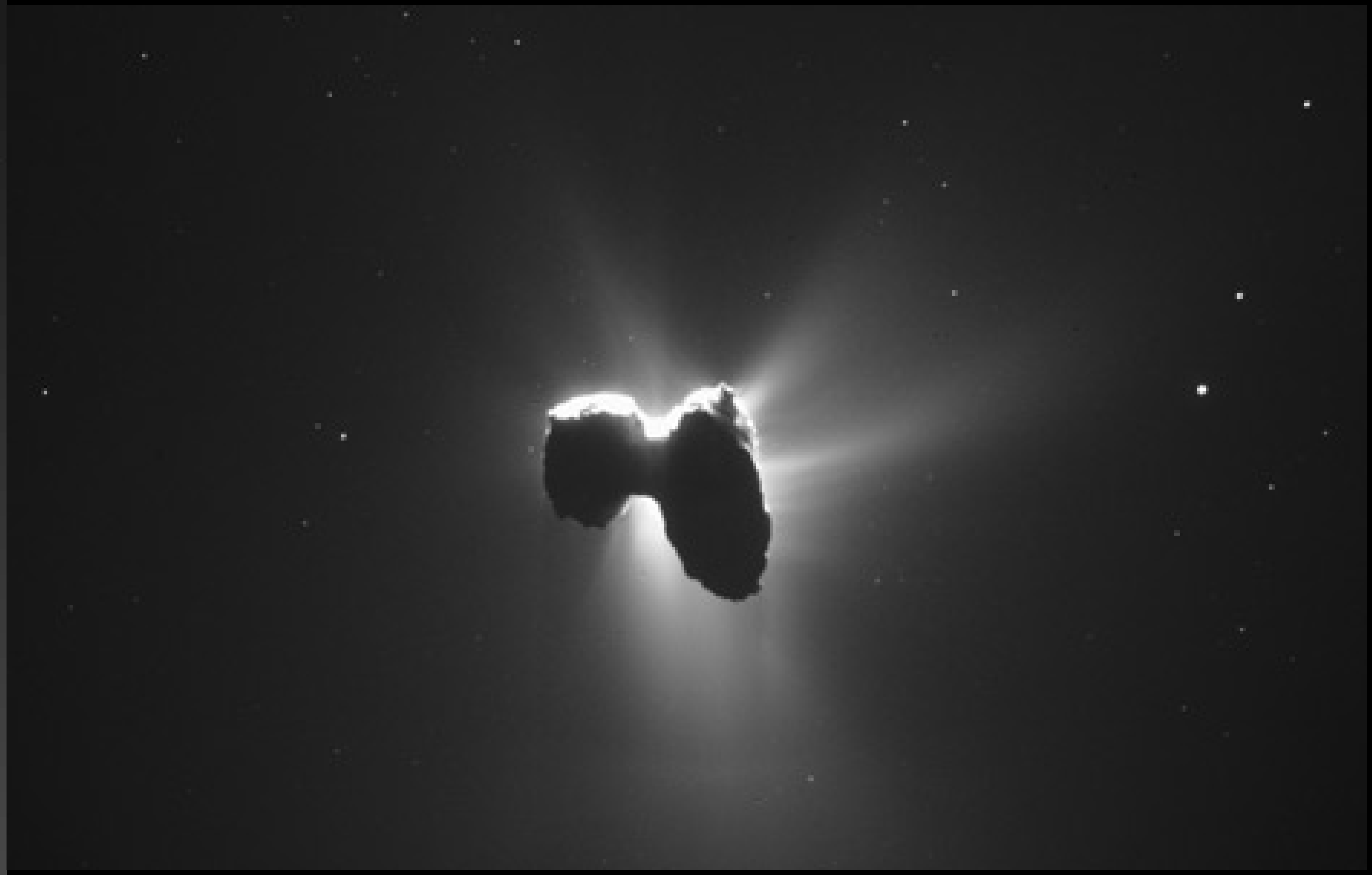


Mangalyaan or Mars Orbiter Mission (MOM) was launched in 2013.

Credits: ISRO

Rosetta mission to a comet (ESA)

2004 - 2016

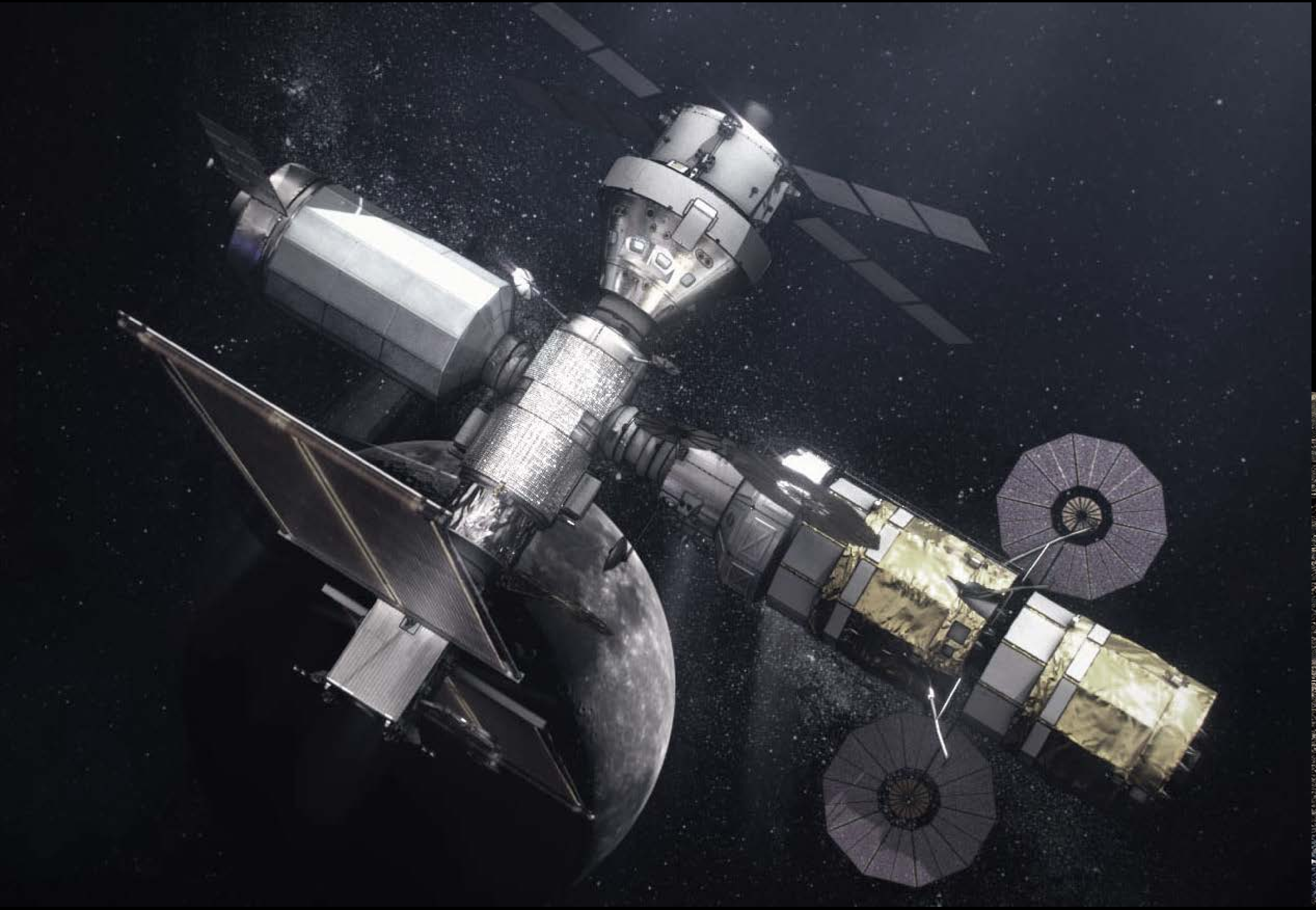


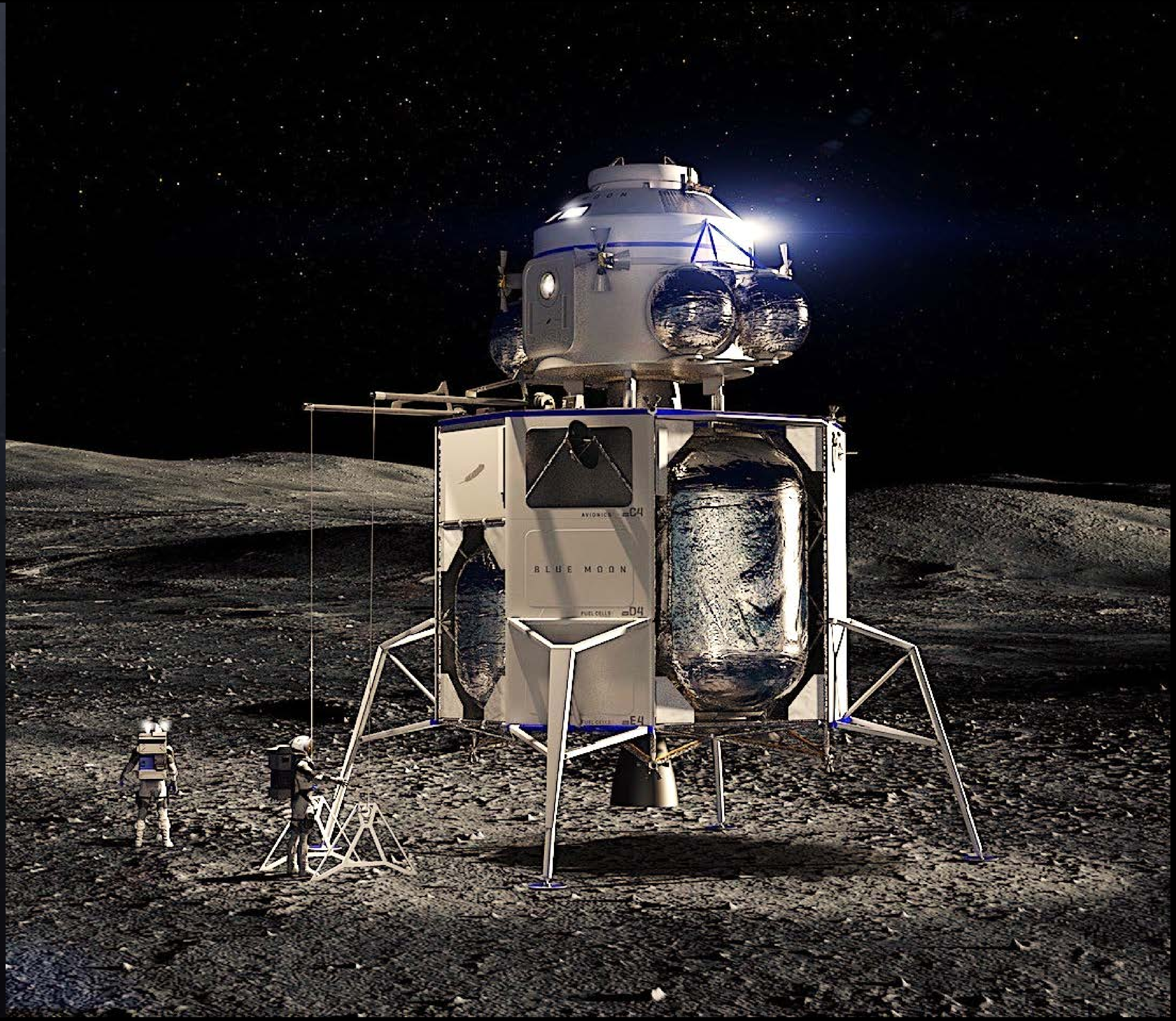
Chang'e 4 Landing on thew far side of the Moon – January 2019

Credits: CNSA

Human exploration of Moon - Artemis program, back on the Moon in 2024

The Orion spacecraft, with an ESA provided Service Module, a Gateway, and a Lunar lander





Credits: NASA/ESA and Blue Origin

Mars – a clear goal for human space exploration

Credits: "The Martian" movie

0.5.4 Access to space

Space Mission Design and Operations

Prof. Claude Nicollier

Credits: Northrop Grumman

Methods of access to space

Normally, access to space starts with the vertical lift off of a launcher (rocket or spaceship) from the Earth surface all the way to orbital conditions (examples are the Space Shuttle, Soyuz and Falcon 9).

An alternative way, possible only for relatively low mass space vehicles, is to bring this vehicle to the stratosphere with a carrier aircraft, detach it, and let it reach space with its own propulsion system (examples are the Pegasus launch system, and Virgin Galactic Spaceship 2).

Other strategies, like single stage to orbit, could also be used.

Credits: NASA

Air launch systems

The advantage of air launch vs. surface launch is that it minimizes both air drag and gravity losses for access to space

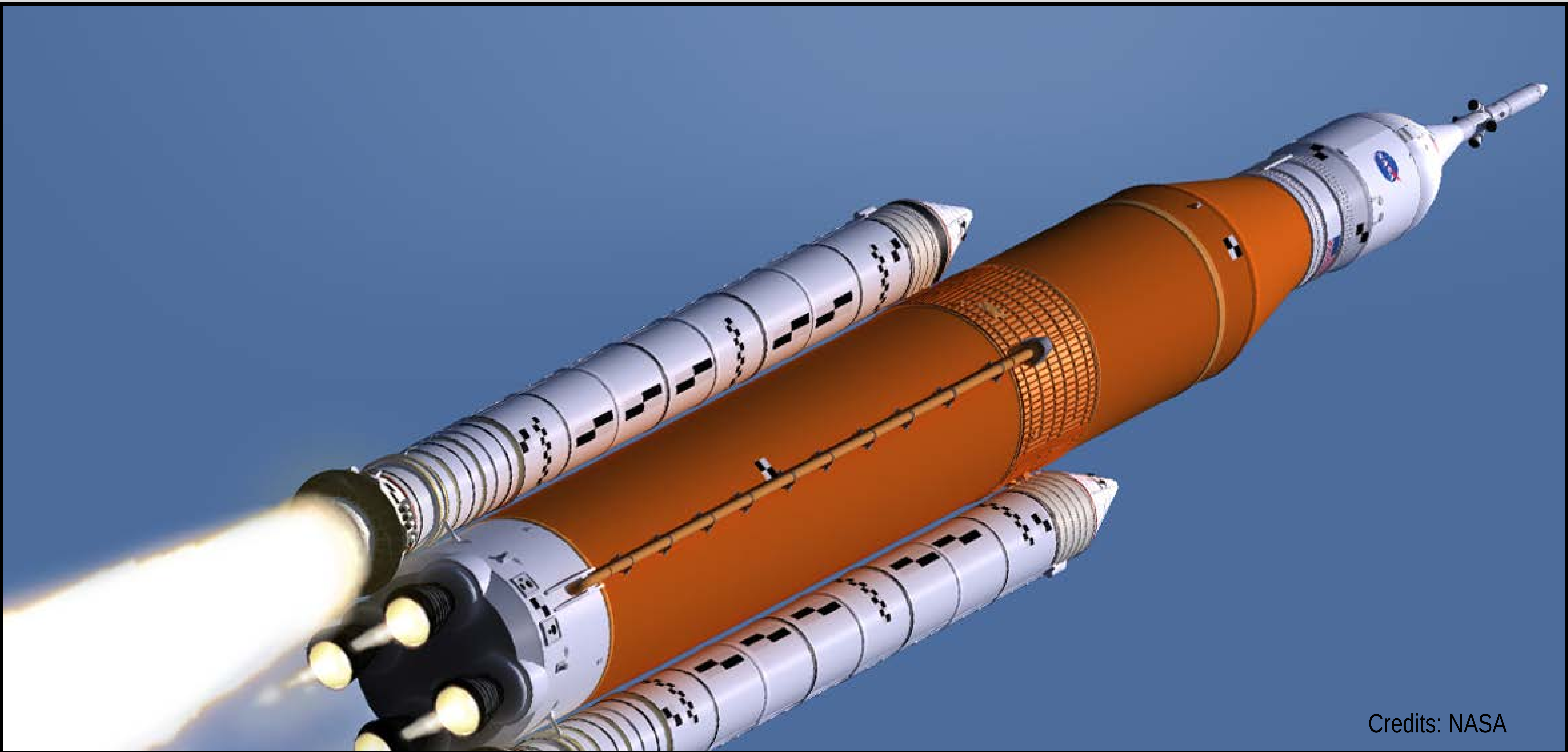
Pegasus Launch System, mounted underneath a Lockheed 1011 jet

Credits: Northrup Grumman / Orbital ATK

Virgin Galactic carrier aircraft just released Spaceship 2 spaceplane

Credits: Virgin Galactic

Space Launch System or SLS



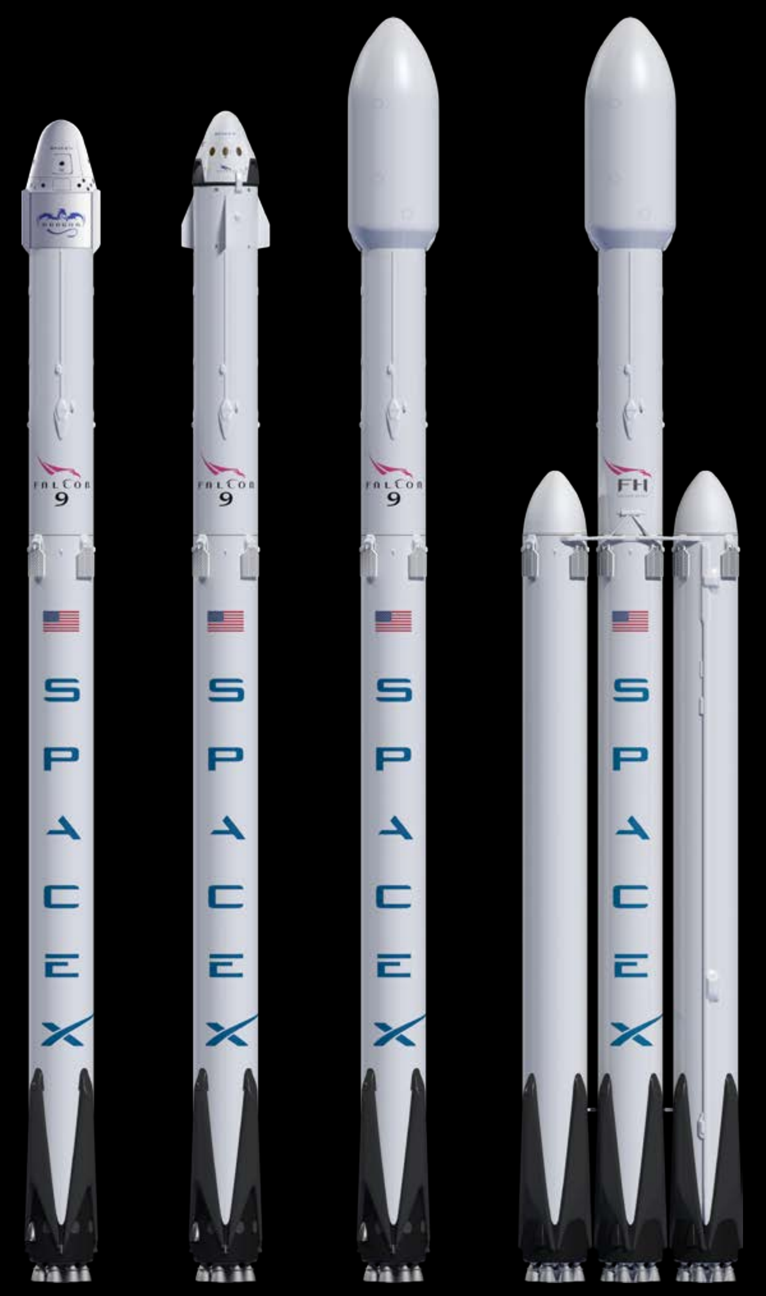
Credits: NASA

Private companies providing launch and other services to NASA

EPFL

SPACEX | BOEING | NORTHROP GRUMMAN | SNC SIERRA NEVADA CORPORATION

Falcon 9 + (Crew) Dragon
Falcon heavy



Credits: SpaceX

ULA Atlas V + Starliner

ULA/Boeing

Antares + Cygnus

Northrop Grumman

ULA Vulcan + Dream Chaser

ULA/SNC

Private companies in the US providing suborbital access to space (in 2020)

Blue Origin and SpaceX - Two different approaches for suborbital flights

Credits: Blue Origin

Credits: Virgin Galactic

Non US launchers in use around 2020

Europe

Two versions of Vega

Ariane 5

Two versions of Ariane 6

Russia

Soyuz

Zenit

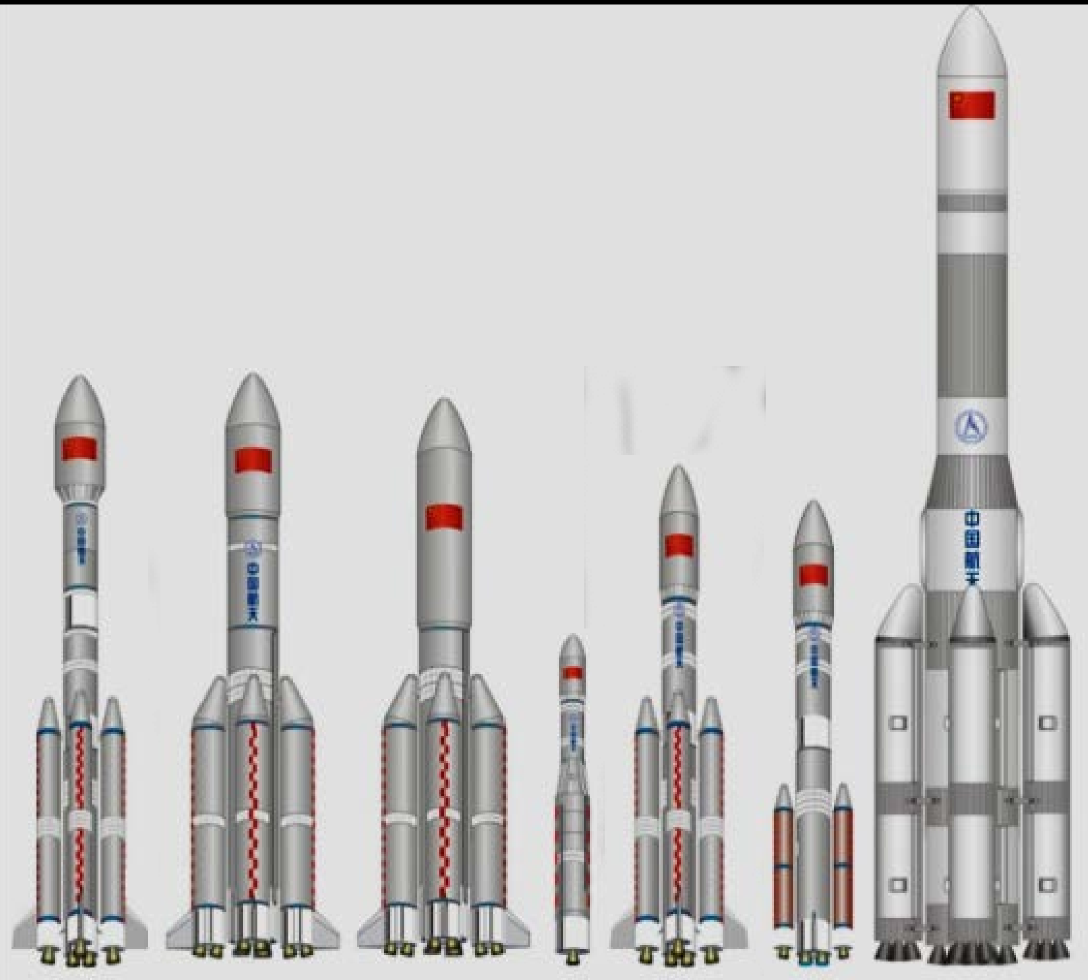
Proton

Angara (not shown here)

Japan

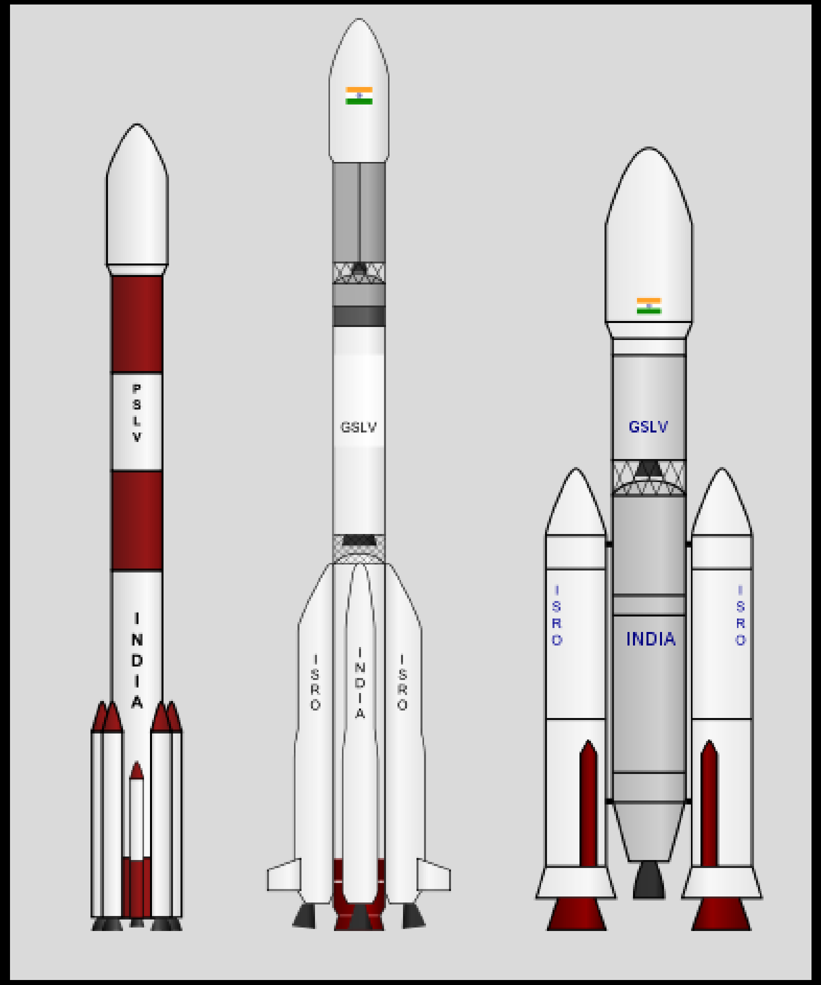
H2A, H2B, and three versions of the H3 launcher shown here

China



Long March 3B and later versions up to Long March 9

India



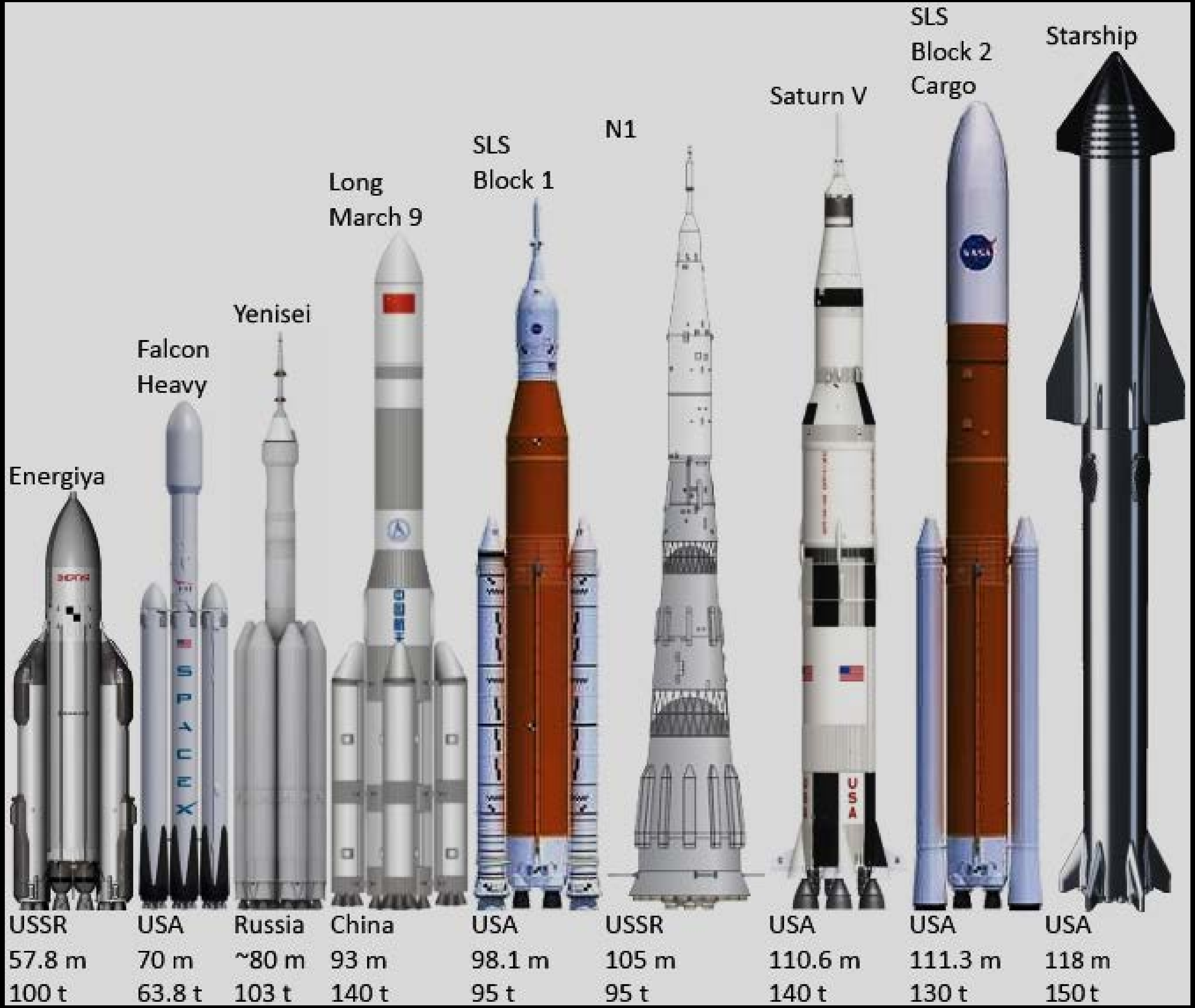
PSLV

GSLV

GSLV Mk-III

Credits: ESA Roscosmos JAXA CALT ISRO

Super heavy-lift launch vehicles



This illustration shows super heavy-lift launch vehicles used before 2018 (Energiya, N1, Saturn V), in 2018 and later (Falcon Heavy), and the rest to be tested and used in 2020 and later. The intention is to use these launchers mainly for human flights beyond the Low Earth Orbit (LEO). The SLS is part of the NASA human exploration program. Starship is a system developed by SpaceX, mainly for Moon and Mars access.

The numerical data show the height of each launcher, and the injected mass capability in LEO

Credits: Wikipedia

Major launch sites

Credits: Open StreetMap 2019

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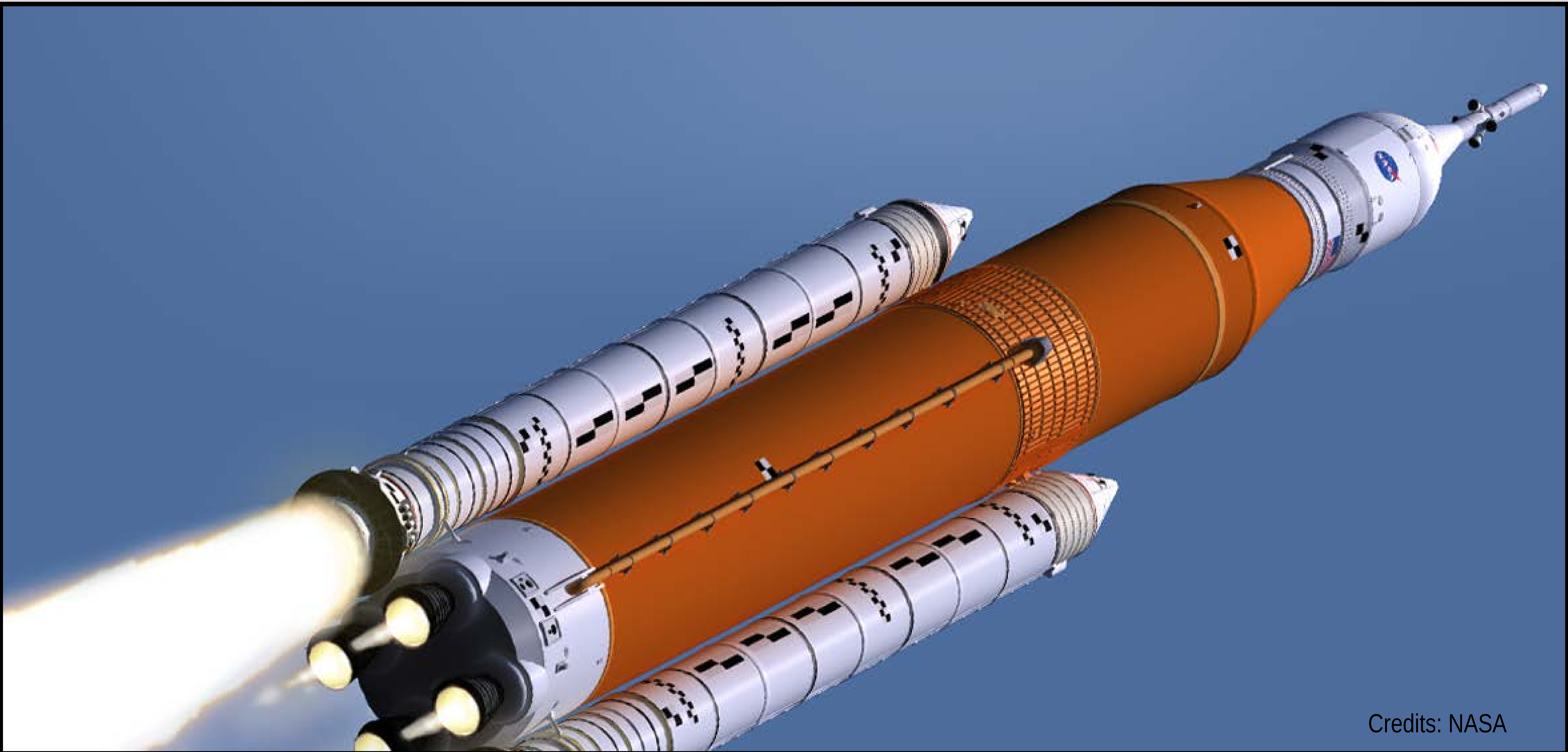
Credits: NASA

Private companies providing launch and other services to NASA

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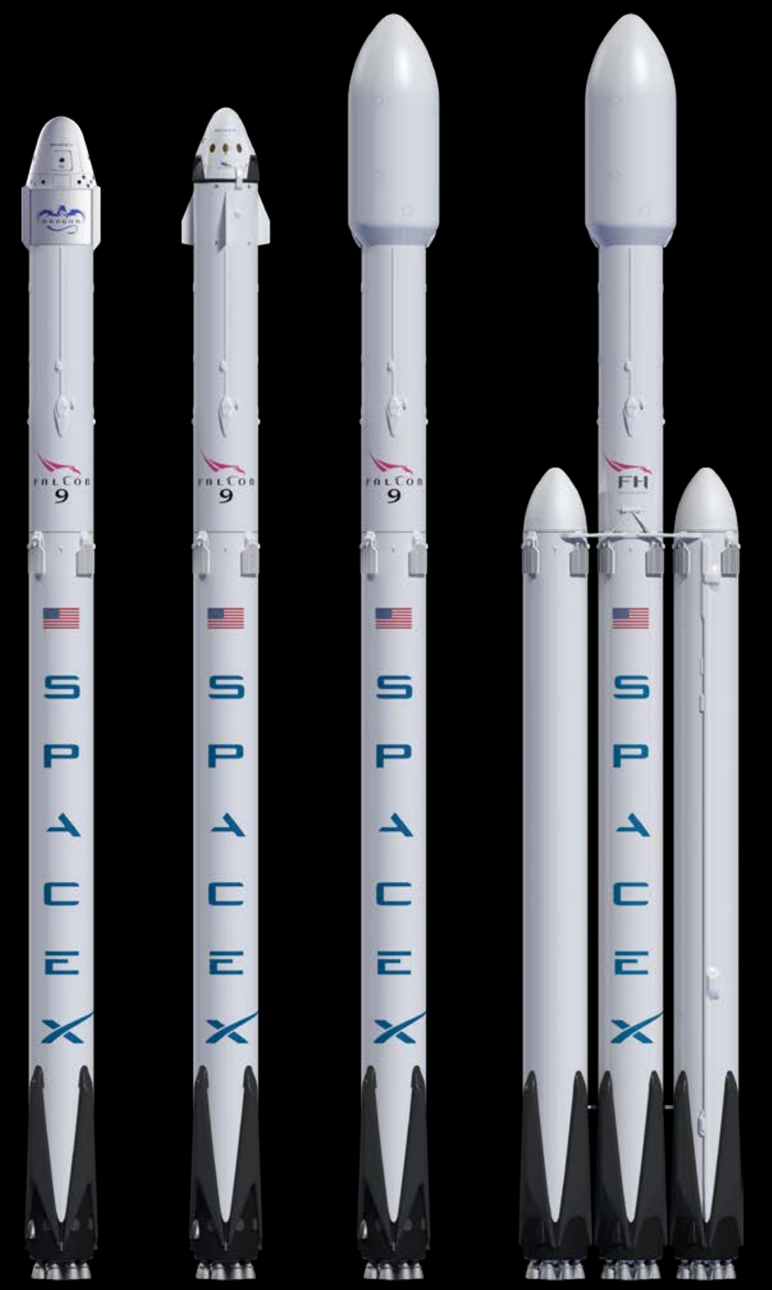
Falcon heavy



Credits: SpaceX

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EPFL

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Two versions of Ariane 6

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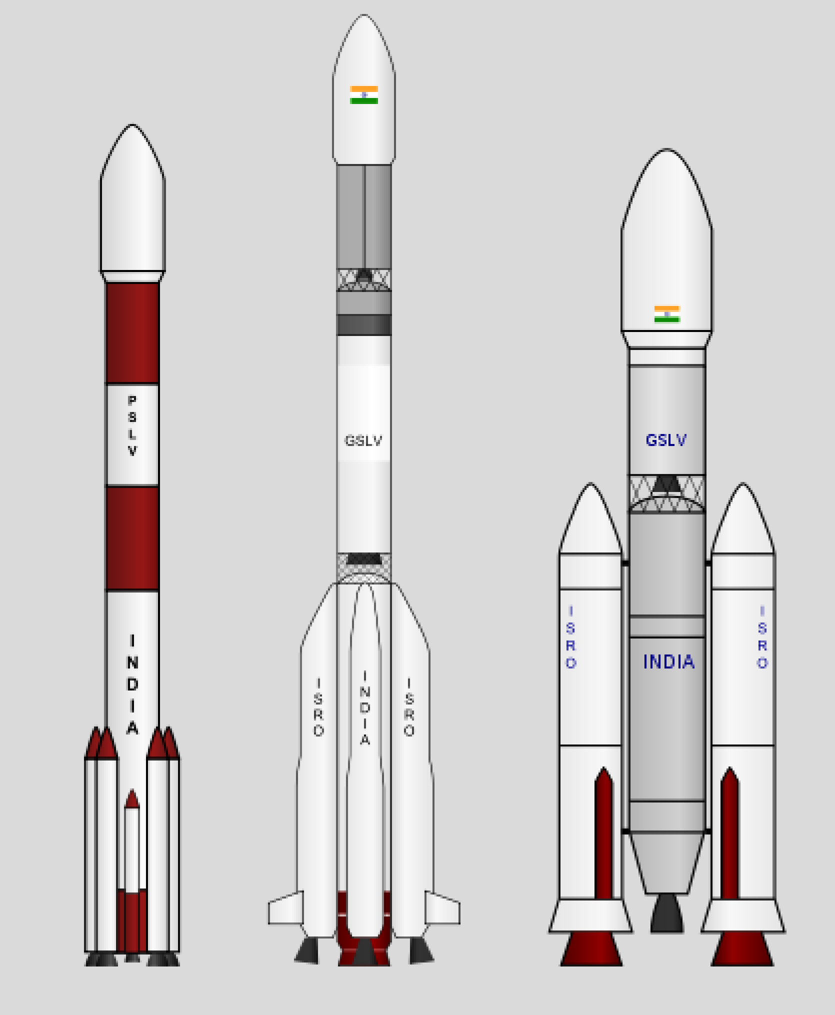
India



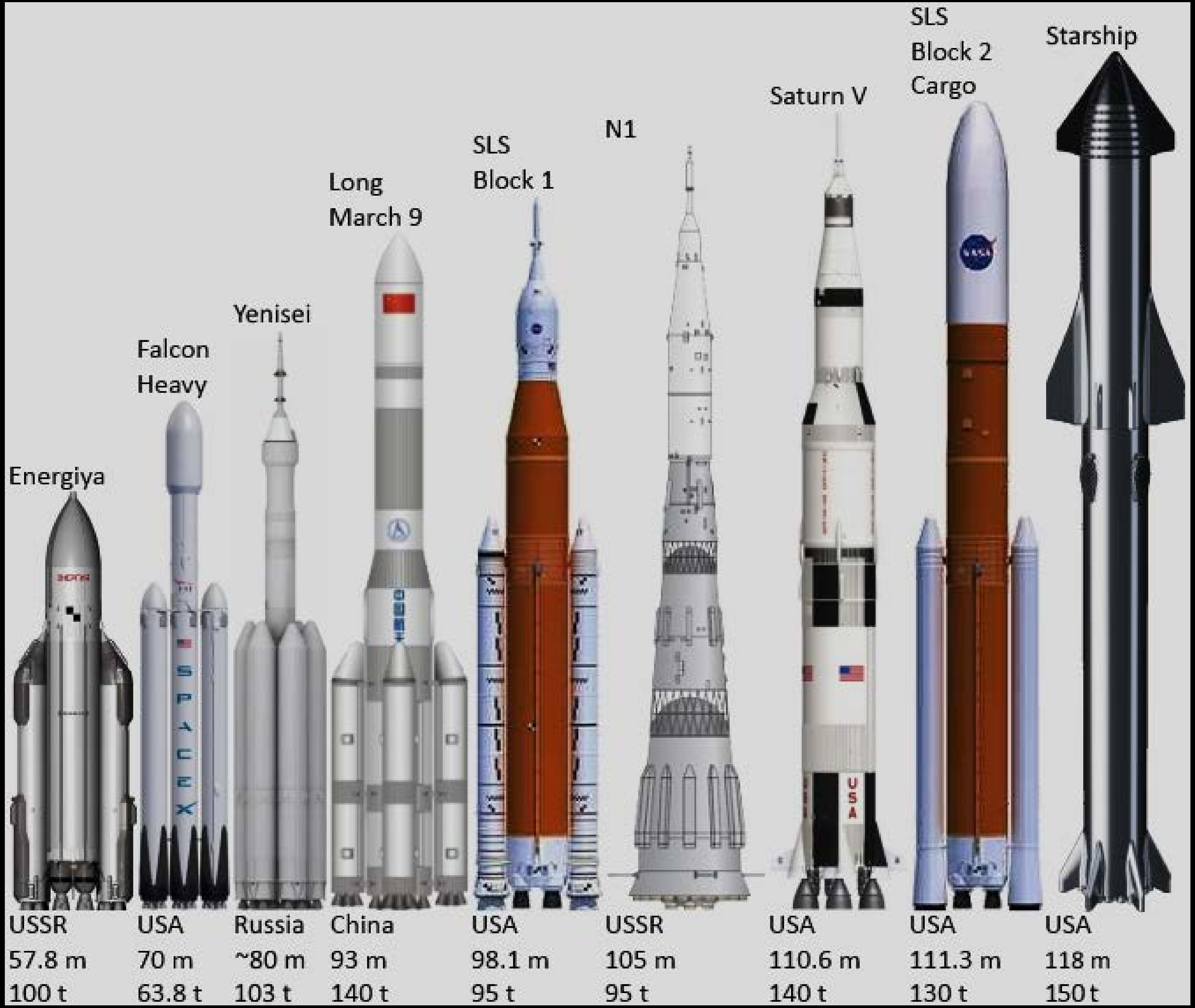
PSLV

GSLV

GSLV Mk-III

ISRO

Super heavy-lift launch vehicles



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Credits: Wikipedia

Major operational launch sites

EPFL

Credits: Open StreetMap 2019

SpaceX Falcon 9 with recovery of the first stage

SpaceX Falcon Heavy first launch, February 6, 2018

Credits: SpaceX

Falcon heavy 27 kerozene-fueled rocket motors for first stage

Credits: SpaceX

Recovery of the two Falcon Heavy boosters

Credits: SpaceX