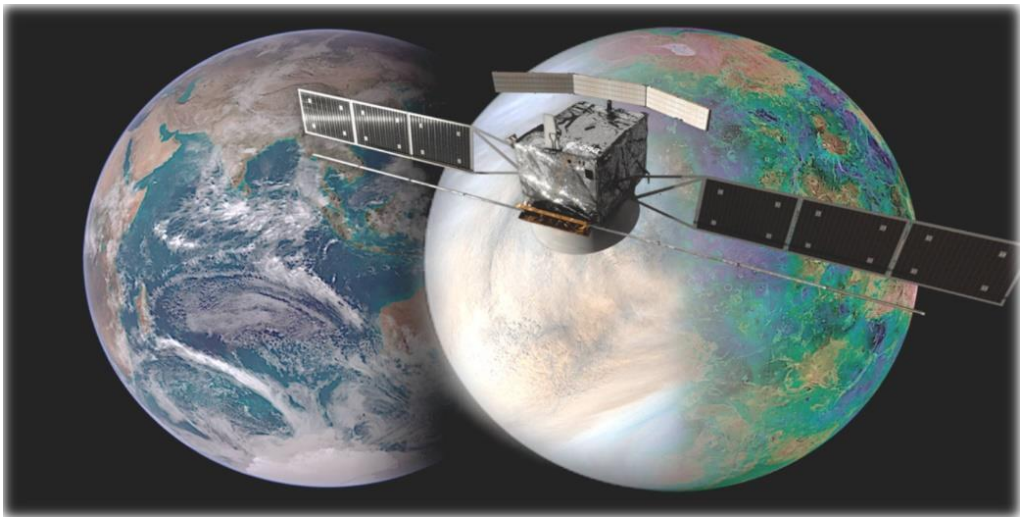
Co-funded by the Erasmus+ Programme of the European Union

Study on the employability in Planetary Geosciences (2020-2030)



Credits: ESA/JAXA/Damia Bouic/VR2Planets

"Artist's impression of the evolution of Venus through an Earth-like phase to what we see today."

Study conducted by the University of Nantes and its international Partners in the framework of the Erasmus+ Strategic Partnership GeoPlaNet-SP (ref 2020-1-FR01-KA203-079773).

https://geoplanet-sp.eu

LPG

UNIVERSITÉ DE NANTES

INDEX

Introduction

The spectacular progress of space exploration during the last 30 years has allowed the **development of Planetary Geosciences**, which are characterized by a fertile and increasing involvement at the international level, of specialists of the Earth (geologists, geophysicists, geochemists) in understanding evolutionary processes of other planets. Planetary Geosciences are as interdisciplinary as Earth sciences and combine experts in observation, experimentation and modelling and is a development axis of the industry of the future, through the preparation of future exploration missions requiring advanced science in space technology and information processing with major spin-offs beyond the space domain.

The training in Planetary Geosciences suffers from a lack of structuration, at least at the European level and very few elements of statistics are available so far to identify and estimate the needs of training in this strategic sector. Compared to other disciplines which necessitate a quick response in adapting training to the fast-evolving market, **the very long timescale of a space exploration mission can be used efficiently to develop ambitious education programmes specifically designed to train young scientists to design the future missions and to analyse and interpret the data in relation to their scientific objectives**. This training is particularly relevant to guarantee a continuity in the expertise in Earth and Planetary Science as the very long timescale of space missions offers hardly the opportunity for a scientist to get involved in the whole mission time span.

The aim of this report is to identify the needs associated to these missions. This analysis is conducted by GeoPlaNet Strategic Partnership, as IO 2 of project 2020-1-FR01-KA203-079773) and led by the Laboratoire de Planétologie et Géodynamique within the University of Nantes. All the institutes of the partnership have already developed their own education programmes based on their involvement in space missions and are working on the **preparation of a Joint Master Programme in Planetary Geosciences**, combining their expertise, which could be propelled by a successful application to an Erasmus Mundus Joint Master Programme funded by the European Commission. **This study will therefore be also particularly relevant to determine the academic needs of the future Earth and Planetary exploration programs that will allow the Partnership to design the most relevant joint training programme in Planetary Geosciences.**

Objectives

This review aims at identifying:

→ the upcoming scientific challenges associated to planned space missions for the coming 10 years

→ the needed scientific expertise and skills of the future workers in Planetary Geosciences

→ the job opportunities and careers of the students trained in Planetary Geosciences

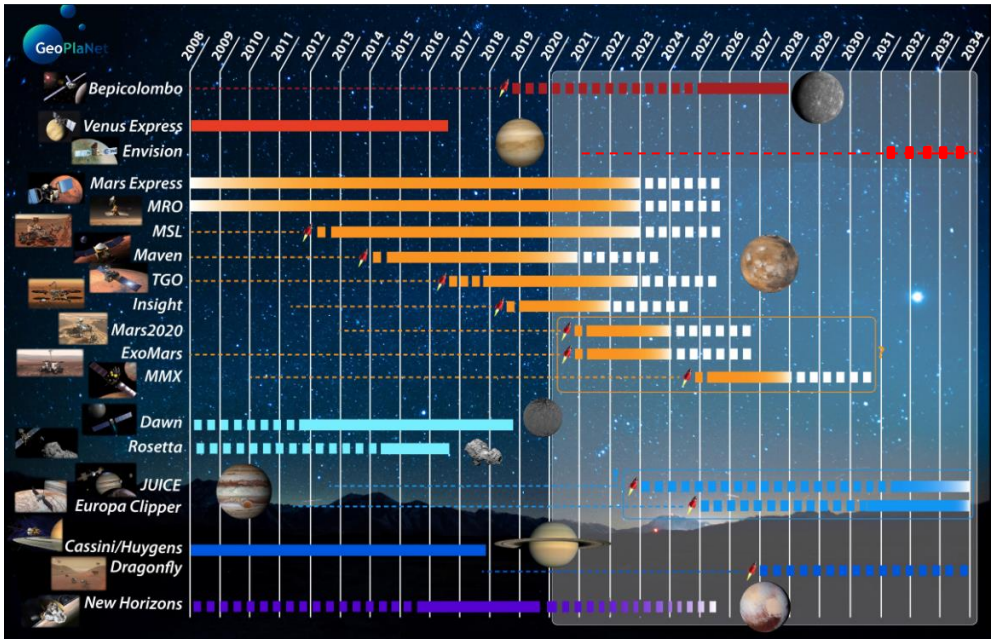
1. Presentation of the study

This study was based on the following sources of information:

1.1. A survey on the employability in the international Planetary Geosciences domain

Considering that there was **currently no existing statistics and analysis at EU level on the employability and career prospects in the space exploration sector,** the consortium conducted **a qualitative survey aiming at getting an overview of the career opportunities as well as the needs of industrial and research fields (skills, competences and profiles) foreseen in Planetary Geosciences** for the next 10 years. The survey has been conducted within the Erasmus + Geoplanet Strategic Partnership among ESA, NASA as well as academic and research field stake holders in Planetary Geosciences in Europe and worldwide through the consortium GeoPlaNet.

The GeoPlaNet Consortium was very well represented in the proposition of ESA White Papers as 35% of the Solar System exploration papers were led by GeoPlaNet institutes, whereas 60% of them include collaboration from at least 2 GeoPlaNet members.
Even if not all the members of the consortium work on the manufacture of the instruments, our expertise allows us to contribute to the definition and monitoring of these instruments, to the argumentation of the scientific objectives of the missions and to the project management, and thus to contribute to the definition of the major space programmes. The involvement of the consortium members is thus from the preparation of the missions well before the launch (for example, work on the JUICE mission to Jupiter began about 15 years ago for a mission that will launch next year) and extends to the operations and data analysis phases, which can last well after the mission has ended, as shown in the following figure.



Main missions in which the GeoPlaNet consortium is involved as principal Investigator, co-Investigator or Team Members, half of which are European missions

Together, the GeoPlaNet Consortium is involved in all major Earth and planetary missions and the data collected in this survey may therefore be considered as a representative sample of the global market in planetology.

The survey is still available on this link:
https://questionnaires.univ-nantes.fr/index.php/788137?lang=en

Survey about employability in international Planetary Geosciences:

I - The geopolitical aspect of research in planetary geosciences

1 - In your opinion, which organisations/companies/nations/etc have the greatest influence on research in planetary geosciences and on space exploration in general? In the world / in Europe?

2 - What is the involvement of your institution and your country in ongoing space missions and missions planned in the next 10 years?

II - Statistics in Planetary Science

Where can we find the employment statistics for Earth and planetary geosciences graduates and/or qualitative information on which jobs/employment sectors they go into?

III - Challenges in planetary geosciences

In your opinion, what are the major axes of exploration and technical challenges in the next 30 years in planetary geosciences?

IV – Skills requirements

Who are / will be the major employers in planetary geoscience (can be private/academic/state) and what skills portfolio is / will be required for new employees?

V – Private sector

1 - In your opinion what are the most influential companies in the private planetary science sector? Where are they located? What are their specialities? Market, figures, recruitment data, profiles sought?

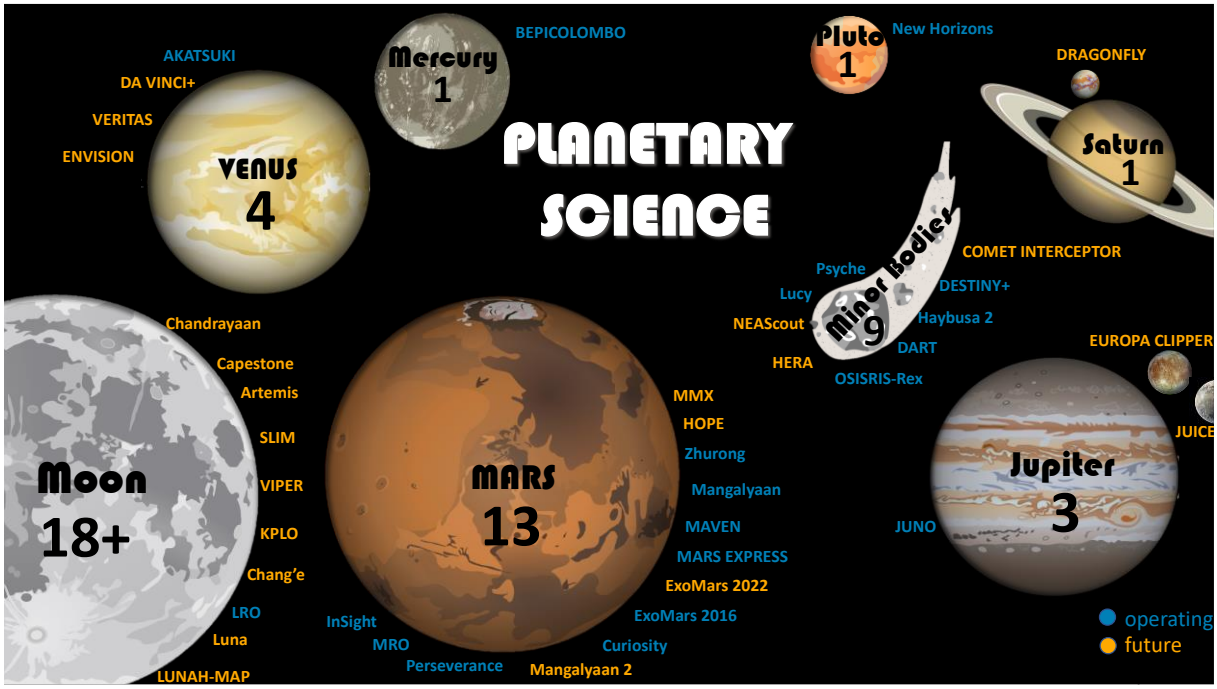
2 - What are the existing collaborations between private companies and academic institutions?

We received to this exploratory investigation feedback from 10 institutes from the GeoPlaNet Consortium, sampling 9 countries: Laboratoire de Planétologie et Géodynamique (Université de Nantes, FR), University of Coimbra (PT), University of Porto (PT), JPL-Jet Propulsion Laboratory (USA), Observatoire Royal de Belgique, International Research School in Planetary Science (IT), Université de Berne (CH), CUNI-Charles University (CZ), Agricultural University of Athens (GR), Open University (UK).

1.2. The analysis of the European Space Agency (ESA) white papers and of the political strategies of the European Institutions (Council of Europe, European Commission) with regard to Space:

> **The ESA** published its white papers in 2019, detailing the long-term planning of the ESA Science Programme "Voyage 2050" (https://www.cosmos.esa.int/web/voyage-2050/white-papers).
> **Council of Europe**: *"Why an EU Space policy?"* https://www.consilium.europa.eu/en/policies/eu-space-programme/
> **European Commission** about EU space policy: https://ec.europa.eu/growth/sectors/space. About EU investment in space: https://europa.eu/rapid/press-release_IP-18-4022_fr.html

1.3 Identification of Earth and Planetary missions in operations/post-operations and ongoing/forthcoming space missions from the main space agencies websites



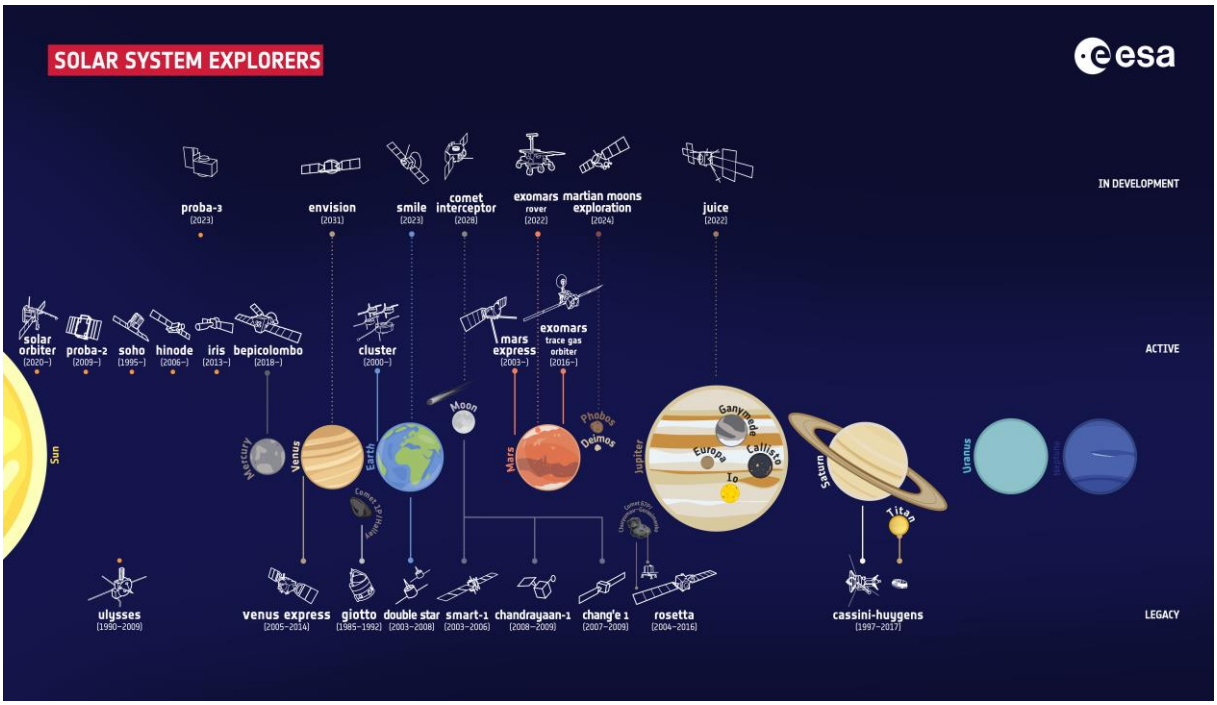
Planetary fleet of Solar System explorers. Overview in 2021. Credits: Sabrina Carpy, LPG

Currently, in the solar system, a certain number of missions are in operation, there are represented them in blue here around different planetary bodies (fig: planetary fleet) in which Earth/Sun/Astrophysics missions are not represented for more legibility. This mapping shows that it still seems difficult to go near or far from the Sun, with only one mission for each extreme. The Mars space programme is still attracting interest with a large number of missions still active or extended, and new missions to come with mobility and sample return challenges for a total of 13 missions. The sample return topic also concerns the minor bodies, with 2 missions on return (osiris-rex and hayabusa2). There is renewed interest in Venus, with 3 new missions selected this year, and the Moon, which will see a veritable fleet of missions over the next decade with 18 proposed. Finally, the journey to the ice satellites of the giant planets is back on the agenda with 4 missions.

Sources:

> **European Space Agency (Europe)** about Science & Exploration missions (Sun, Solar System, Astrophysics and fundamental physics) in operations or post-operations, in implementation and cosmic vision program (2015-2025):

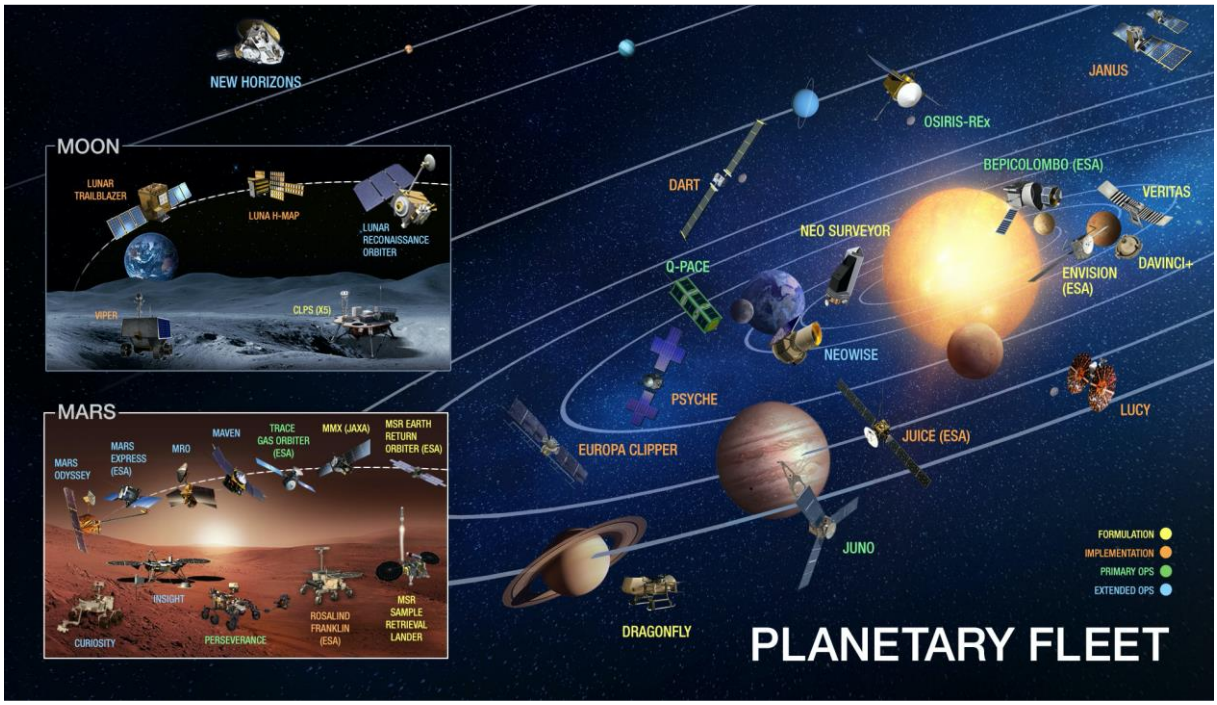
https://www.esa.int/Science_Exploration/Space_Science/Mission_navigator



ESA's fleet of Solar System explorers.

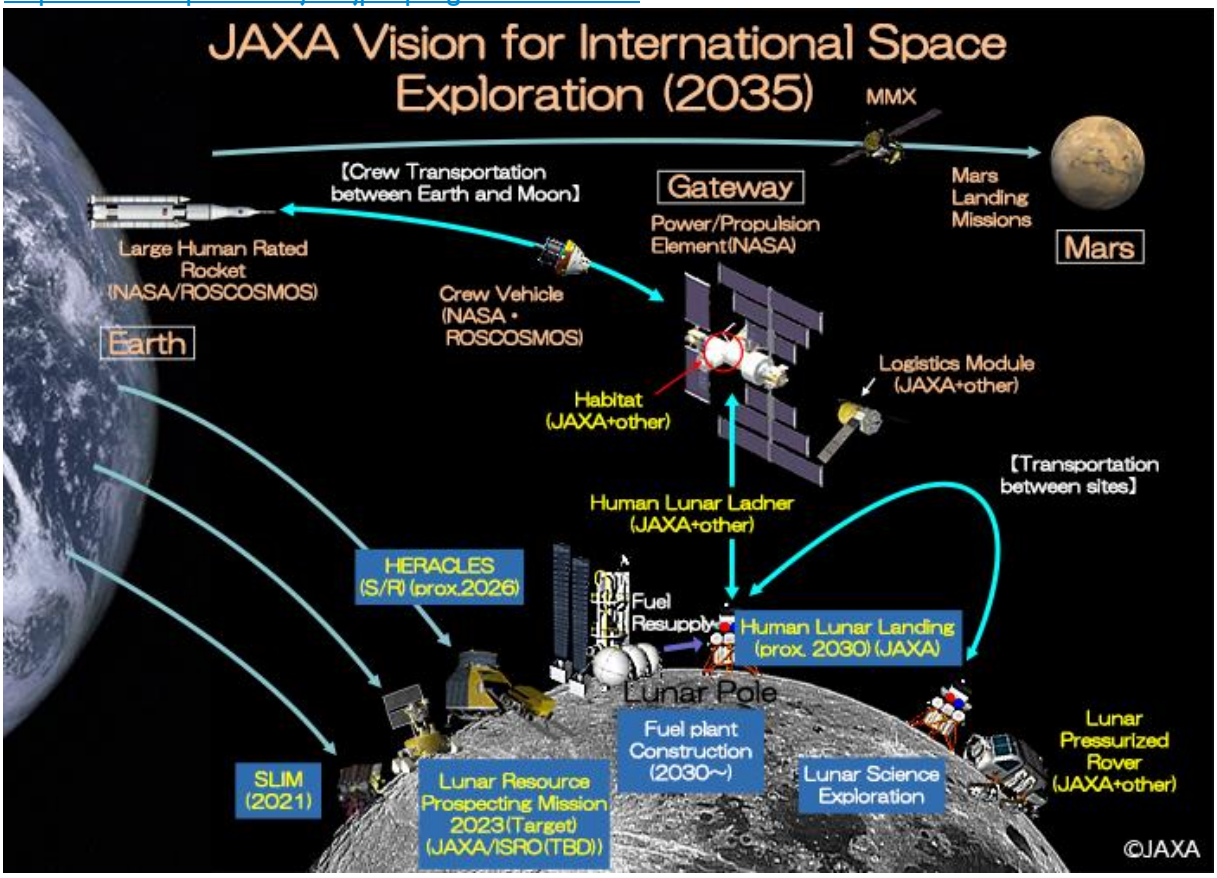
https://www.esa.int/ESA_Multimedia/Images/2019/02/ESA_s_fleet_of_Solar_System_explorers

> **NASA (United States)** about Solar System exploration active missions : https://science.nasa.gov/missions
and programs https://science.nasa.gov/solar-system/programs



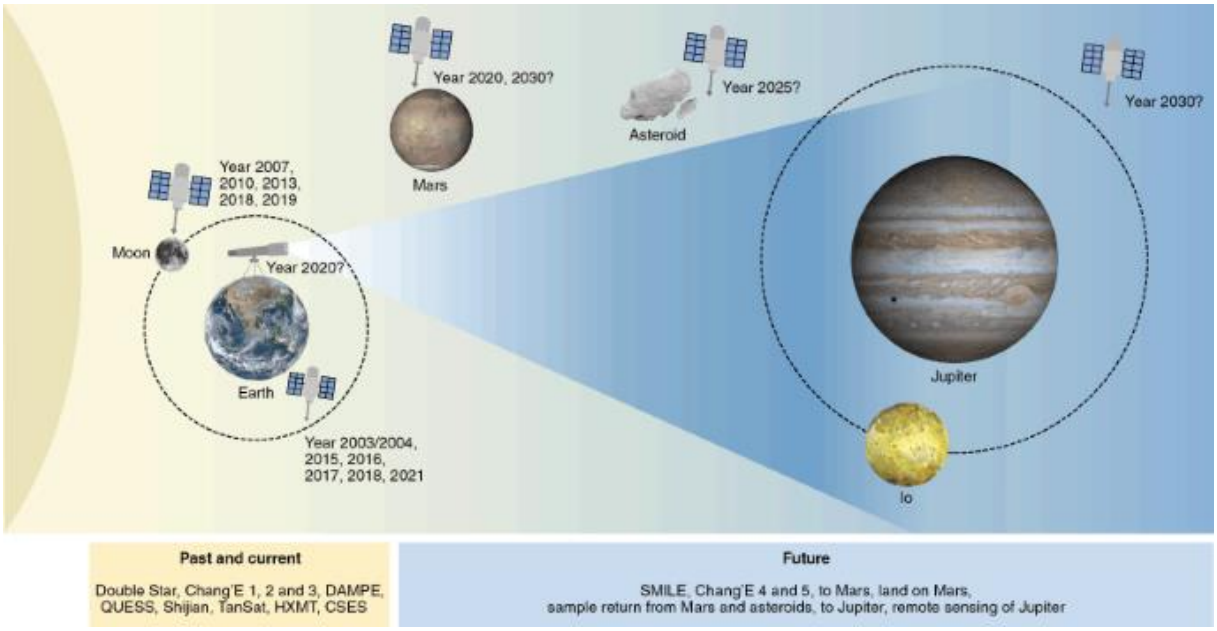
NASA Science Mission Fleet Chart (2020): https://science.nasa.gov/toolkits/planetary-mission-posters

> **JAXA (Japan)** about international space exploration program: https://www.exploration.jaxa.jp/e/program/index.html



JAXA'scenario for space exploration: https://www.kenkai.jaxa.jp/eng/research/exploration/exploration.html

> **National Space Science Center, Chinese Academy of Science** : http://english.nssc.cas.cn and **China National Space Administration** : http://www.cnsa.gov.cn/english/index.html



China's roadmap for planetary exploration: Wei, Y., Yao, Z. & Wan, W. China's roadmap for planetary exploration. Nat Astron 2, 346–348 (2018). https://doi.org/10.1038/s41550-018-0456-6

> **Roscosmos** http://en.roscosmos.ru/115/

Other sources:

> **Indian Space Research Organisation** about spacecraft : https://www.isro.gov.in/spacecraft/space-science-exploration

> **DLR** about new missions and projects**:** https://www.dlr.de/EN/research/space/missions-and-projects.html

> **CNES** about project library sort by https://cnes.fr/en/fiches_mission_alpha
> The **International Space Exploration Coordination Group** (ISECG) : https://www.globalspaceexploration.org/wordpress/?page_id=910

1.4 Employment statistics (FR, IT, PT) and qualitative data on employment of graduates in Planetary Geosciences disciplines

> **Europlanet industry database**: https://www.europlanet-society.org/europlanet-society/european-space-industry-database/
> **Portugal Space Agency** https://ptspace.pt
> **Employment outlook in the field of Geosciences by 2020** (Issued by French ministry of Research and HE): https://uncloud.univ-nantes.fr/index.php/s/G3JtE39x34kMwwK"
> **Report on the employability of Erasmus students** by the French Observatoire national de l'impact Erasmus: « Développement de l'employabilité et des aptitudes citoyennes au cours d'une mobilité Erasmus + », https://agence.erasmusplus.fr/wp-content/uploads/2019/12/2547_observatoire-4.pdf
> **Data about student & staff mobility, employment of graduates (following careers of students) of the universities of Coimbra, Porto, Chieti-Pescara and Nantes**
> **A short poll organized during the workshop ``Sciences and Technologies for Space – a ground up overview'' organized by the Coimbra and Porto partners from September 13th to 16th 2021.**

Poll organized during the workshop about employability in international Planetary Geosciences:

1. What is your status ?
2. For Master students only: if you had the opportunity, would you like to continue with PhD ?
3. Master students only: are you an international student ?
4. Master students only: have you connected with the private sector ?
5. For PhD/postdoc students only: would you prefer a career in the academic sector, in the private sector ?
6. For PhD/postdoc students only: are you an international student, with a nationality different from the host institute?
7. For PhD/postdoc students only: had some connection with private sector during your education program ?
8. Teacher/Resarcher: how many PhD thesis do you have in your institute (Master students) ?
9. Teacher/Resarcher: number of permanent positions (PhD thesis) in your institute (last 30 years).
10. Teacher/Resarcher:Dis you experience some connection with private sector (research project).
11. For privates companies: how much time do you spend on the collaboration with the public institutes?
12. For privates companies: do you consider Master/PhD students trainsing adated to the job offer?

2. Outcomes

2.1 Overview of geopolitical stakes in Planetary Geosciences

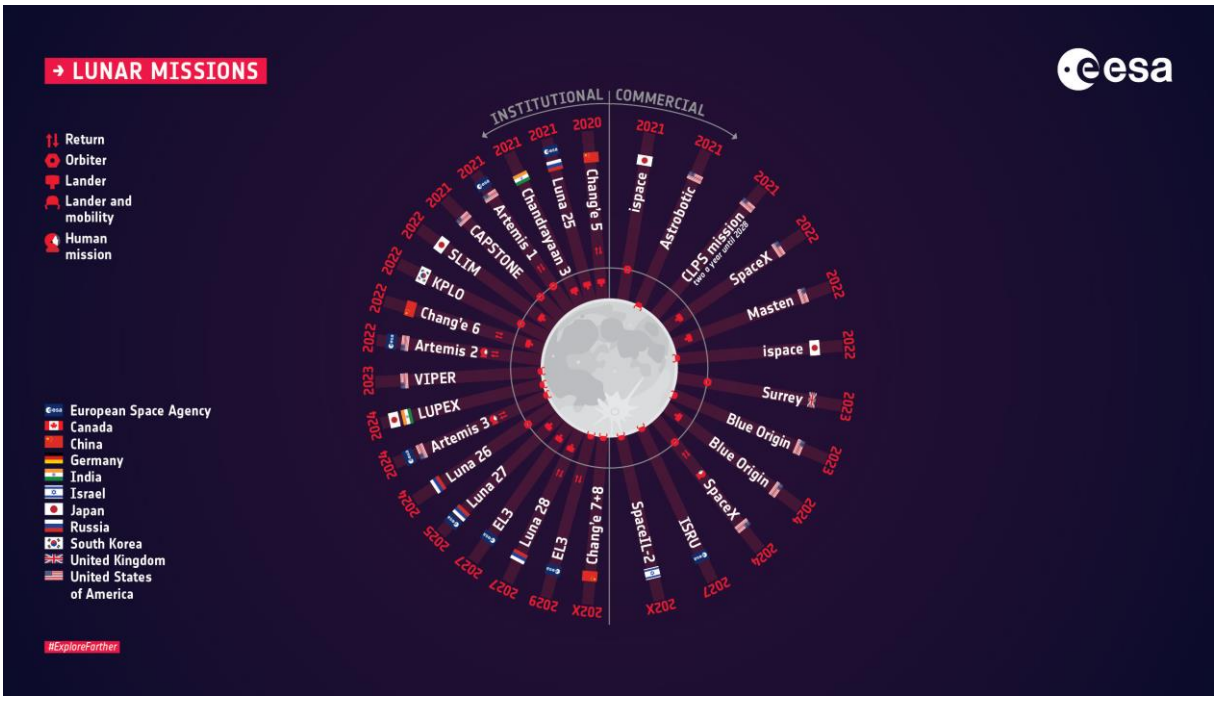
Space exploration has always been a **highly competitive zone of strategic political influence and potential economical profit** for states and private companies. Currently the **most influential nations in Planetary Geosciences and space exploration** (and their space agencies) in the world are: **USA (NASA), the international ESA, Japan (JAXA), China (CNSA), Russia (RSA), Germany (DLR), France (CNES), England (UK Space Agency), Italy (ASI) and India (ISRO).**

The beginning of the 21st century has been marked by the development of ambitious space exploration programmes by **new actors such as India and China** and more recently the Emirates (UAE). But **at this specific moment, USA has the greatest influence in the world by far**. Within its FY21 $21.3 billion, NASA allocates $2.7 billion to Planetary Science to run its ambitious programme that includes flagship missions to Mars and Europa, and smaller missions selected through the Discovery and New Frontiers programs (https://science.nasa.gov/solar-system/programs). The NASA laboratory leading Planetary Science exploration is the Jet Propulsion Laboratory (JPL) located in Pasadena (California) that, among other achievements, successfully landed rovers on the surface of Mars. Through its Planetary Science programme, NASA spends more than $200 million for research to be performed in US universities.

Currently, in **Europe, with its FY21 $6.49 billion, ESA is the most influential actor in the field**, as well as several companies active in technological development. **Through its ambitious science program, ESA missions aimed to provide answers to fundamental questions about the origin and evolution of the Solar System, along with the emergence of life, or the identification of the physical fundamental laws of the Universe.** (Source : https://www.esa.int/About_Us/Business_with_ESA/Business_Opportunities/Science_Programme). The **main European nations involved in Planetary Geosciences and space exploration are France, Germany, Italy and UK** (source: https://www.esa.int/Newsroom/ESA_budget_2021).

One characteristic of the Solar System Exploration is that instruments on a given mission are provided by national agencies in collaboration with their research laboratories. The national agency provides the funding of the instrument and delegates the development of this instrument to a research laboratory. For example, the recently selected ESA mission EnVision will have its main instruments provided by Italy, Germany, France, and the US. On the NASA VERITAS mission, some instruments are provided by Germany and Italy. The instruments onboard the NASA InSight mission were provided by the US, the UK, France, and Germany. And the list of missions and instruments is very long. It is therefore important to train the younger generation of scientists who will take over from the previous generation and will check that the performances of the instruments provide the high-quality data required to answer the science questions they are supposed to address. The typical cost of an instrument is between 10 and 100 M$. This money is awarded by a national agency to a laboratory.

Another aspect is the trend to involve private companies in Solar System Exploration. For example, NASA relies on private companies such as Blue Origin and Space X to develop lunar landers. Such landers will carry science instruments that will be provided by national agencies. Recently, NASA awarded three grants to three different US laboratories to develop instruments that will be embarked on these landers. It is very likely that with the involvement of European countries in the Moon initiative (Artemis program), similar opportunities will exist for European laboratories.



Commercial and institutional organisations that plan to launch spacecraft to the Moon. https://www.esa.int/ESA_Multimedia/Images/2019/07/Lunar_missions_overview

Europe also hosts strong influential companies such as Thales Alenia (FR-IT); Airbus, Ariane Group and Sodern (FR), Swedish Space Corporation (Sweden), Logica (space and defence systems) and E2v (for detectors) UK. A few smaller SMEs such as ACRI-ST are coming into the field. *(source: Europlanet industry database).* In **Russia, Roscosmos** is a state company and sole shareholder of all industrial companies in the Russian space sector.

The coming decades will see an **increasing enthusiasm for private companies in the race for space**, not only **in the technological development such as today but also in the resource exploitation.** Some companies in the US and also in Europe (e. g., Asteroid Mining Company) are planning asteroid mining missions and were able to capture significant investments. Tesla is one example and there will be many companies ready to invest in this field as soon as technologies will become cheaper.

According to the new president of the CNES (the French National Center for Space Studies), "the **sector has a major economic impact, with a big leverage effect and the spatial share in the GDP will explode"**. The new stake is **Internet by satellite** in which players of the "New Space" are rushing (SpaceX, OneWeb*). (source: Le Monde, "L'espace, zone d'influence et de profits", 24 April 2021)*.

National agencies with their strategies and decisions strongly determine the success of the national planetary science community. Through their dialogue with national agencies, many actors, such as ESSC (European Space Sciences Committee), **Europlanet** and from industry, Eurospace and Airbus, as well as large labs such as DLR, Max-Planck (Germany) contribute to this success.

In this context, **Europe will be part of the game as a result of the *European Commission's* plan to allocate an envelope of 16 billions euros "to stimulate the space leadership of the European Union for year 2021-2027". This funding is mainly focused on Galileo and EGNOS navigation systems, Copernicus programme of Earth observation and Earth communication satellites**. The Earth observation programme aims to provide accurate data in order to better understand our environment and climate. In complement to Earth observation, comparative planetology offers the most suitable

way to deeply understand the phenomena occurring on the Earth, by analyzing their analogues on other planets. On such topics, Europe has a strong know how and technology to export by training scientists from countries newly involved in space missions. *(Source: see reference links quoted in 1.2)*.

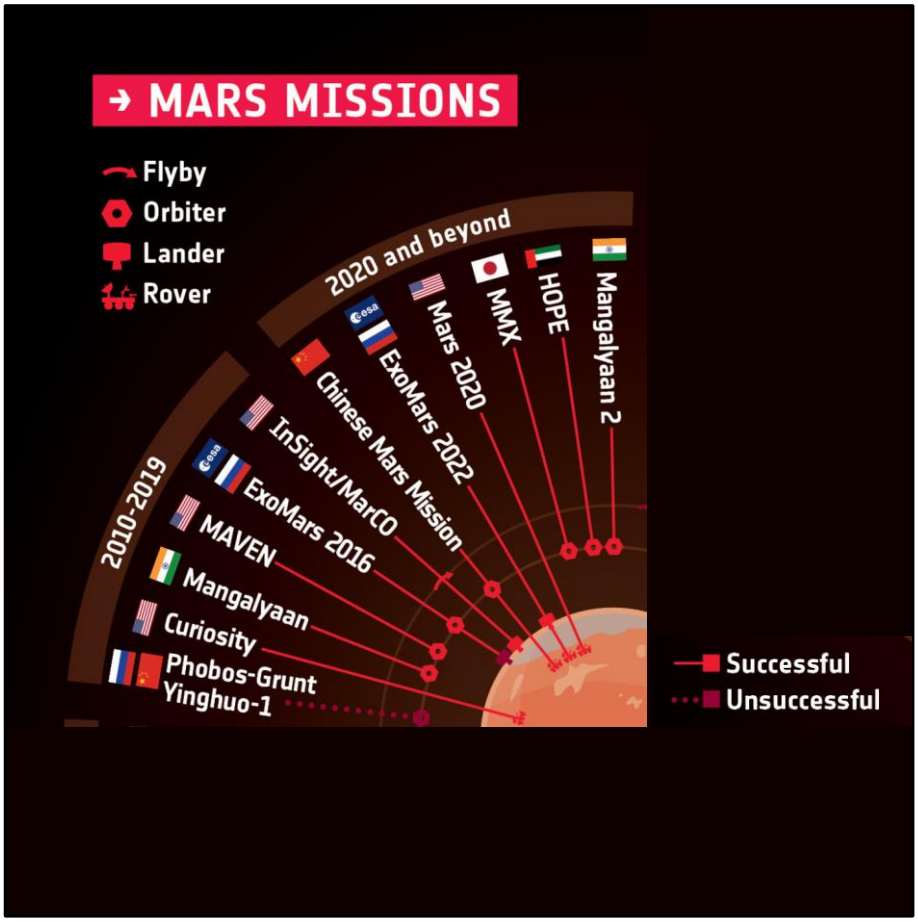
2.2. Axes of exploration and specific skills

In combination with the analysis of ESA white papers (Voyage 2050) and of the political strategies of the European institutions with regards to space, the survey highlights that:

2.2.1 Axes of exploration

ESA's white papers are good indicators of future axes of exploration for the next decade. From 2019, of the 20 white papers devoted to the solar system exploration, 6 were about Giant Planets moons, 3 were about Mars, 3 about Uranus and Neptune and 2 about Venus. Seven white papers additionally dealt with the exoplanet's characterization.

The identification of the **moons of Mars, Giant Planets, and Venus** as priority targets for the future exploration of the solar system can also be acknowledged by the number of space missions devoted to them in the planned missions from ESA and NASA.
There are currently 7 Mars missions underway (5 mentioned in the following graph for the period 2010-2019 to which are added 2 missions that were launched in the previous period but are still active: Mars Express and MRO) and 6 planned mission already implemented or under study. In the next decade a number of countries will be sending missions to Mars in addition to the American and European missions. This is already the case with the Chinese rover Zhurong, which arrived in spring this year. 3 new orbiters will be added to the fleet of 8 orbiters already in place and 1 lander is planned in addition to Insight.



Missions to Mars, modified from: https://www.esa.int/esearch?q=martian+moons+exploration+MMX

The following Table presents an overview of the missions that target moons of the Giant planets:

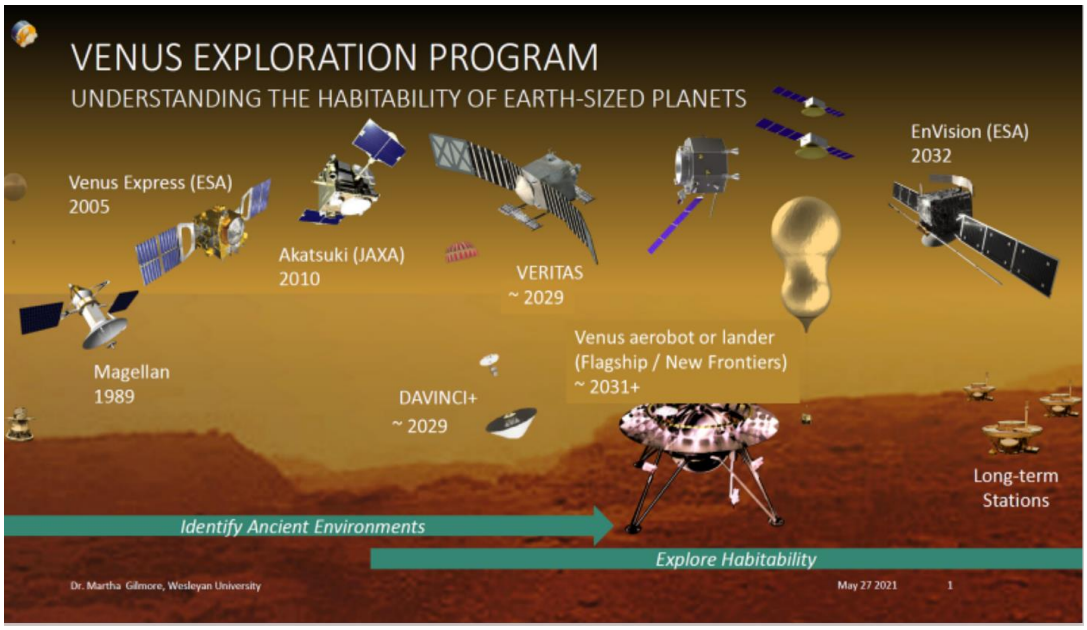
Jupiter's moons Saturn's moon

Space missions : name + country organization	L = Lander F = flybys O = Orbiter P = Probe SR = Sample return R = rover	Programme	Status Under Study SELECTED IMPLEMENTATION OPERATIONS POST-OPERATIONS	Scientific aim	Selection	Launch	Orbit phase/arrival	mission duration	possible extension	sources
JUNO			**OPERATIONS**							
NASA	O	New Frontiers	2016-	gas giant's gravitational and magnetic fields, magnetosphere, aurora, atmosphere.	2005	05-août-11	05-juil-16	1 year	sept-25	https://www.nasa.gov/mission_pages/juno/main/index.html https://solarsystem.nasa.gov/missions/juno/overview/
Europa Clipper			**IMPLEMENTATION**							
NASA	O	Solar System Exploration	2017 -	Mission NASA Europa Multiple Flyby.	2012	oct. 2024	april 2030	3 years		https://europa.nasa.gov
JUICE			**IMPLEMENTATION**							
ESA	F = Ganymede, Callisto, and Europa O = Ganymede	ESA's Cosmic Vision 2015-2025 (L1 mission)	2022-	Scientific expertise for the study of the ice moons of Jupiter by the ESA-JUICE mission, with a particular focus on Ganymede. Five LPG researchers are co-I, an IDS sits in the Science Team.	2012	2022	2029	3years		https://sci.esa.int/juicehttps://sci.esa.int/documents/33960/35865/1567260128466-JUICE_Red_Book_i1.0
Europa Lander			**Under study (concept)**							
NASA	L		2019-	portential future mission to look signs of life	2019	2024				https://www.jpl.nasa.gov/missions/europa-lander
Dragonfly			**IMPLEMENTATION**							
NASA	RL	New Frontiers		sample and measure the coposition of Titan's organic materials	27 june 2019	2026	2034	2.7 years		https://dragonfly.jhuapl.edu

The scientific interest of these axes has been recognized by ESA in June 2021 by identifying moons of the giant planets and temperate exoplanets as two of the three future themes for its large-class science missions for the timeframe 2035-2050 (Voyage 2050 Programme). The study of ice moons is arousing new interest particularly in terms of habitability, since they will contain deep oceans that could contain the ingredients needed for the emergence of life.

Two missions to the moons of Jupiter are planned and will take off very soon: 2022 JUICE (European mission) and 2024 Europa Clipper. The objective of these missions will be, among other things, to determine the depth and thickness of the ice layer (radar, spectro, etc.) and to understand the processes of material and chemical transfer that could take place between this ocean and the surface ice layer and how to characterize them. The mission to Titan, a satellite of Saturn, is a follow-up to the Cassini Huygens mission. Mobility is the main criterion for this mission: the dragonfly (a six-bladed rotorcraft) will be able to move over greater distances than those covered by a simple rover.

Venus will also be a major exploration target with 3 missions selected this year, two American and one European, in the coming decades. These new missions will join the orbiter already in place operating in Venus orbit. The complexity of Venus' diverse realms will require multiple missions to explore its diverse zones. The different but complementary capabilities of VERITAS, DAVINCI+ & EnVision make them suitable next steps in a Venus exploration programme.



History of the exploration of Venus and that highlights the growing interest for such planet with 3 missions planned in the 2029-2032 period.

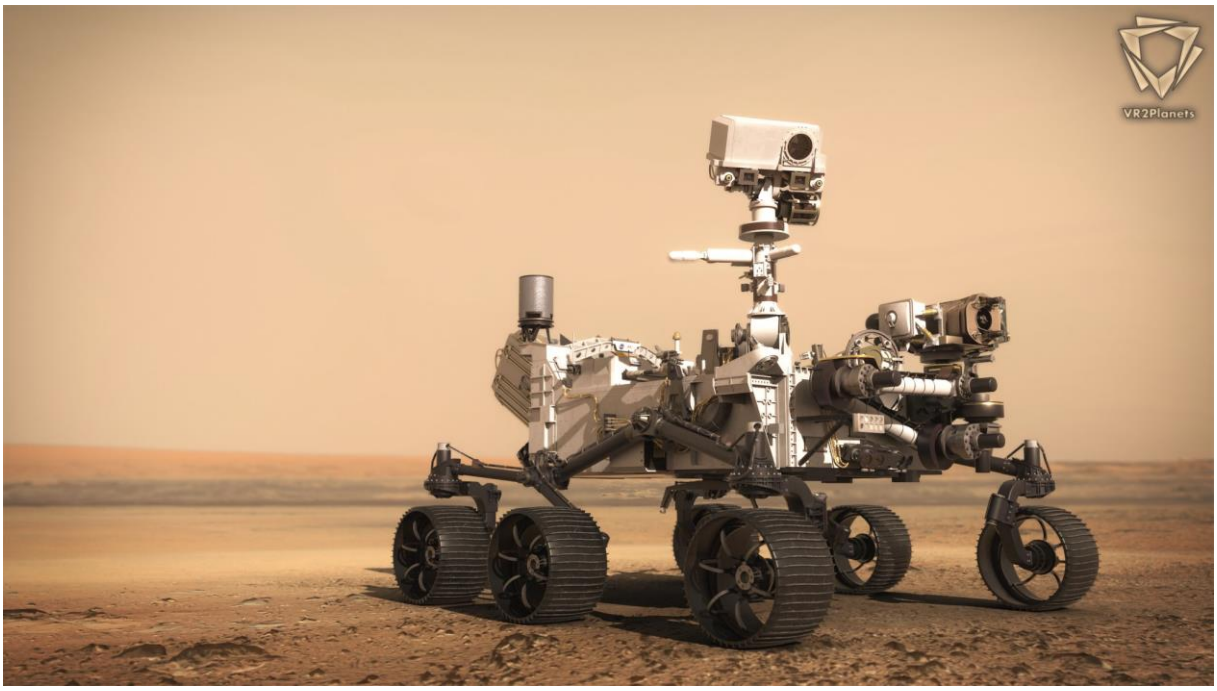
Space missions : name + country organization	L = Lander F = flybys O = Orbiter P = Probe SR = Sample return R = rover	Programme	Status Under Study SELECTED IMPLEMENTATION OPERATIONS POST-OPERATIONS	Scientific aim	Selection	Launch	Orbit phase/arrival	mission duration	possible extension	sources
Envision			**SELECTED**							
ESA	O	Cosmic Vision 2015-2025 (M5 mission)	2031-	Interdisciplinary approach targeting the Venusian atmosphere, surface and interior to understand why Venus and the Earth evolved so differently.	10 june 2021	2031	2032	4 years		https://www.esa.int/Science_Exploration/Space_Science/ESA_selects_revolutionary_Venus_mission_EnVision
Akatsuki			**OPERATIONS**							
JAXA	O			Targeting the atmosphere of Venus. Investigating the flow and constituents of the atmosphere as well as detecting possible lighting and volcanic activity.		21 May 2010	7 december 2015	2 years	until now	https://akatsuki.isas.jaxa.jp/en/mission/purpose/
Venera-D			**Under study**							
ROSCOSMOS	O+P+L		2030s	Surface composition and meteorology						
VERITAS			**SELECTED**							
NASA	P+O	discovery		Global and high resolution radar mapping as well as composition determination of the Venus surface, and probing of its interior.	2 June 2021	2028-20130		32 months		https://www.jpl.nasa.gov/news/veritas-exploring-the-deep-truths-of-venus
Davinci+			**SELECTED**							
NASA	P+O	discovery		Origin and evolution of Venus atmosphere. Characterizing the high plateau at the surface (Tesserae). Primitive Ocean at the surface? Volcanic activity?	2 June 2021	2028-2030		P: 63 minutes		https://www.nasa.gov/feature/goddard/2021/nasa-to-explore-divergent-fate-of-earth-s-mysterious-twin-with-goddard-s-d
Shukrayaan-1			**Under Study**							
ISRO	O			High resolution radar mapping of the surface, as well as determination of the structure, compositon and dynamcis of the atmospheric clouds and of the ionosphere.		2024/2026				

Technology now allows safe landing of rovers and instrumented platforms on planetary surfaces. Thus, space exploration now increasingly combines observations from orbits with **in situ investigations**. The perspective to **analyse return samples** from Mars, Asteroids or the Moon offers moreover the fascinating perspective to benefit from the additional expertise of scientists deeply involved in laboratory measurements and opens the door to the exploitation of planetary resources, which is of major interest for private companies. If remote sensing remains a powerful tool to characterize planetary surfaces, in-situ investigations require now a complementary expertise from the Earth Science community (geochemistry, geophysics, geology) to obtain **a full picture and understanding of surface, subsurface and interior processes**.

Space missions : name + country organization	L = Lander F = flybys O = Orbiter P = Probe SR = Sample return R = rover	Programme	Status Under Study SELECTED IMPLEMENTATION OPERATIONS POST-OPERATIONS	Scientific aim	Selection	Launch	Orbit phase/arrival	mission duration	possible extension	sources
Lucy			**IMPLIMENTATION**							
NASA	F	Discovery	2021-	Flyby of 6 Jupiter trojan asteroids	2017	2021	2027	12 years		http://lucy.swri.edu
DART										
NASA	P	planetary defence	2021-	planetary defense-driven test, Asteroid 65803 Didymos impactor, deflection	2018	24 Nov. 2021	44805	1 year		https://dart.jhuapl.edu/Mission/index.php
Psyche			**IMPLIMENTATION**							
NASA	O			determine if Psyche is the core of a planet-size object (metal world)	January 2017	august 2022	January 2026	21 month		https://psyche.asu.edu
OSIRIS-Rex			**OPERATIONS**							
NASA	SR	New frontiers	2016-	sample return (Bennu)	2011	8 Sept. 2016	3 dec 2018	7 years	spet 2023	https://www.asteroidmission.org
Hayabusa2			**OPERASTIONS**							
JAXA	SR			return asteroid Ryugu (type C) and Itokawa (Type S) samples	2010	3 dec. 2014	27 June 2018	6 dec. 2020	october 2021	https://www.isas.jaxa.jp/en/missions/spacecraft/current/hayabusa2.html
DESTINY+		**2024**	**IMPLEMENTATION**							
JAXA + DLR	F			observation and in situ analysis of cosmic dust of asteroid Phaethon	11 Nov. 2020	2024	2028			https://www.dlr.de/content/en/articles/news/2020/04/20201112_destiny-germany-and-japan-begin

These tables and figures highlights that:

- the next decade will be extremely fruitful for the exploration of planets and moons of the Solar System, with a total number of about twenty missions planned for ESA and NASA. This very large number is unique in the history of space exploration and does not include missions from Russia, India, China, which currently also develop ambitious space exploration programs. This strongly supports the growing strategic and scientific interest for space exploration for all nations,
- the diversity of targets, missions' scenarios, actors, or scientific instruments will require top-level scientists trained to work in a multidisciplinary and international collaboration,
- the GeoPlaNet Consortium is deeply involved in these missions with PI and CO-I responsibilities and offers a very valuable education by research environment to train students to address the future scientific challenges of Earth and Planetary exploration programs and to transfer knowledge.



Rover Perseverence landed on Mars in February 2021. Credits: VR2Planets.

2.2.2 Specific skills

Three types of specific skills were emphasised in the survey:

1) Strategic and project management skills required to develop ambitious programmes to explore and exploit planetary resources in an international and collaborative effort**.**

2) Data science: from the development of new softwares to numerical modelling, along with the **creation of new innovative numerical tools** such as machine learning techniques or virtual reality,

3) Space engineering and technology, from instrument design to the creation of new propulsion systems.

Additional skills were mentionned in the survey. Those are not specific to planetary geosciences but are particularly relevant in this context:

1) Ability to work in a multicultural and multidisciplinary environment (planetary geoscience and space engineering),

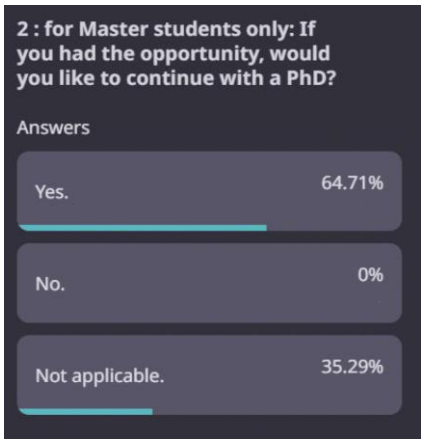
2) To be open-minded and eager to acquire knowledge in different and new scientific fields,

3) Innovative ideas would be welcomed to address new challenges triggered by space exploration.

2.3 Employment opportunities of students in Planetary Geosciences

A short poll organized during the workshop ``Sciences and Technologies for Space – a ground up overview'' organized by the Coimbra and Porto partners from September 13th to 16th 2021.

This workshop was the first activity of the Strategic Partnership and 50 participants from more than seven countries attended this online activity. This offered us the opportunity to get some additional information about employability, careers perspective, internationalization of education programs and link to private sector. The following table presents the questions and the results of this poll:



4: Master students: have you connected with private sector (lectures, seminars, internship)?

Answers

Yes.	22.22%
No.	50%
Not applicable.	27.78%

5: for PhD/postdoc students only - Would you prefer a career

Answers

in the academic sector.	10%
in the private sector.	10%
no preference.	10%
Not applicable.	70%

6:PhD/postdoc:Are you an international student,with a nationality different from the host institute?

Answers

Yes.	30%
No.	0%
Not applicable.	70%

7. for PhD/postdoc students: had some connection with private sector during your education program?

Answers

Yes.	22.22%
No.	50%
Not applicable.	27.78%

8: Teacher/Researcher only: How many PhD thesis do you have in your institute (Master students)?

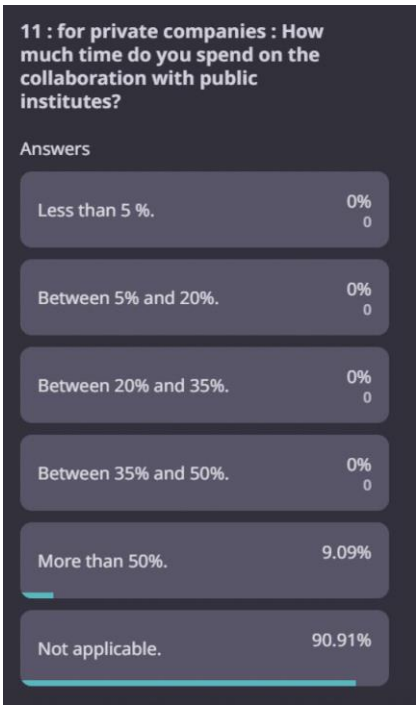
Answers

Less than 25%.	0%
Between 25% and 50%.	18.18%
Between 50% and 75%.	9.09%
More than 75%.	9.09%
Not applicable.	63.64%

9: Teacher/Researcher: Number of permanent positions (PhD thesis) in your institute (last 30 years)

Answers

Less than 100%.	25%
Between 100% and 200%.	0%
Between 200% and 300%.	25%
Between 300% and 400%.	0%
Between 400% and 500%.	50%
More than 500%.	0%



This poll highlighted that:

a) employability and career perspective

- Question 1: the public of this workshop was composed at 57,14% of Master students. This is totally in line with the public planned for this training activity which was completely designed for Master and PhD students. As this public was not represented in the online survey sent to the GeoPlaNet Consortium, this poll offers a complementary view of the survey and is more focused on the expectations of young researchers aiming to work in Earth and Planetary Science.
- Questions 2 and 8: all the Master students attending this workshop want to continue their education by PhD studies. Of course, this study is biased by the fact that all the student present are interested by a career of researcher, which required a PhD. Nevertheless, this clearly highlights the needs of a larger funding of PhD activities, as the answers to question 8 shows that in 50% of the institutes, the number of PhD thesis with respect to Master students is between 25% and 50%.
- Question 5: public and private sectors are equally attractive for PhD and Postdoc students. One third of the students finds the public sector more attractive, one third finds the private sector more attractive and the last third is attracted by both.
- Question 9: this question is about the ratio of the number of thesis over 30 years with respect to the number of permanent positions. This number indicates a kind of take over ratio in the academic sector. If it is equal to one, this means that there is just the number of PhD students needed to replace permanent teachers/researchers when they will retire. The answers to this question lead to a number of 3, which means that there will be three times more PhD students than academic jobs offered to them. Of course, career perspectives are not limited to the academic sector as many other public or private companies offer jobs opportunities for PhD students (see section 2.3).

b) internationalization of education programmes

Questions 3, 6: only 14.3% of the Master students are international students but all the PhD and Postdoc are international students. This clearly highlights the growing

internationalization of education programs and the large international mobility at PhD level. This also underlines the opportunity to develop international Master programmes in Earth and Planetary Science.

c) link to private sector

Questions 4,7,10: there is a growing evolution of connections with private sector during education and career in public institute, from 31% of the participants at Master/PhD/Postdoc level to 50% at permanent position level. This clearly demonstrates the existence of strong and important connections of the academic sector with private companies as early as Master level.
Question 11: this question was about the time devoted to collaborations between public and private sectors. The poll answer to this question is more than 50% for all the participants to this workshop from private companies. This result cannot be however considered as representative as this poll was organized through a workshop organized by Coimbra University and all the private companies attending this workshop have contact with Coimbra.
Question 12: 100 % of the participants from private companies find the training of Master and PhD students very well adapted to job opportunities.

Planetary Geosciences, as multidisciplinary science, offers multiple employment opportunities.
Planetary Geosciences is not limited to space missions and studies of the planets. Master students often come with a Bachelor degree in maths, chemistry, physics, geology or engineering and can choose to go for jobs that refer with their initial study choices in sectors of Earth sciences. A French Ministry of Higher Education and Research (MESRI) prospective in 2020 has highlighted the **growing demand in the world for expertise in exploration and sustainable exploitation of natural resources**.

(Employment outlook in the field of Geosciences by 2020 (Issued by French ministry of Research and HE): https://uncloud.univ-nantes.fr/index.php/s/G3JtE39x34kMwwK**)**

Students in planetary science become experts in using up to date technologies (e.g., remote sensing, computing facilities, analytical equipments, synthesis of materials, ...), handling and analysis of huge amounts of data (e.g. signal processing, computing skills, innovative mathematical and numerical methods, ...). All these skills are also highly valuable in the industry, even outside the spatial domain.

The employment opportunity types after a Master in Planetary Geosciences are as followed:

Activity sectors	Higher education, Public/private research institutes, International companies related or not to geosciences
Positions available	Researcher, Professor in academia and in industry; R&D engineer in industry; Experts in numerical modelling, lab experiments, physics, chemistry and geology; Project manager, consultant in various companies
Employers	**Academic careers:** Master followed by a PhD and Post doc prior to getting a teacher/researcher position in HEIs or national public research institutes. Research engineers in public research labs in geosciences /planetary sciences. Our survey has demonstrated that about, 20% of PhDs in the field will have long-term possibilities in academia. **National or International Space Institution agencies:** ESA, NASA, Centre National d'Etudes Spatiales (CNES), Agenzia Spatiale Italiana (ASI), Portugal Space Agency **Public Industrial and Commercial Establishment or Scientific and Technological Public Institute for geosciences:** > Examples in **Italy**: - CNR: Consiglio Nazionale delle Ricerche - ISPRA: Istituto Superiore per la Protezione e la Ricerca Ambientale - INGV: Istituto Nazionale di Geofisica e Vulcanologia

	- INAF: Istituto Nazionale di Astrofisica > In **Portugal**, in Geosciences and GIS: - LNEG (National Laboratory of Energy and Geology, https://www.lneg.pt/en/homepage/) - IPMA (The Portuguese Institute for Sea and Atmosphere, https://www.ipma.pt/en/oipma/) - Direção Geral do Território (DGT, https://www.dgterritorio.gov.pt/) > In **France**: - BRGM: Bureau de recherches géologiques et minières - Université Gustave Eiffel - IRD: Institut de recherche pour le développement IRSTEA: L'Institut national de recherche en sciences et technologies pour l'environnement et l'agriculture - IFREMER, Institut français de recherche pour l'exploitation de la mer - EDF: Electricité de France **Engineering consultant offices:** requiring specific expertise in mapping, geology, data analysis. **Private companies:** with strong R&D activities, can fund PhDs and offer jobs. They will have a growing importance in the view of resource exploration and exploitation in the coming decades. (source: survey, Ministère de l'Enseignement Supérieur, de la Recherche et de l'innovation (MESRI) prospective). Recent actualities with SpaceX have demonstrated the success of the public/private collaboration in the space sector, highlighting the potential of private sector to contribute to the development of space exploitation by designing rockets, spacecrafts softwares or applying space technology on Earth utilities.

Several points in relation to employability were also identified:

1. Planetary Geosciences has become a highly competitive and rapidly evolving market. Employers need very well trained workforce (with both hard & soft skills) and express the difficulty to find multidisciplinarity in their recruits 'academic background.
2. The cooperation between academia and the private sector is still limited. Some private companies exchange knowledge and data with research institutes. Some local companies host licence and master internships to develop technology and software for space (survey, poll) . But the connections are still not as strong and interactive as they could be. The common problems "remain of differing goals, timescales and culture" (*survey*), although there is a large interest for private sector jobs from students and a strong interest for university students from private companies (poll)

Note that this report focuses on the employability in planetary sciences. Earth is also a planet and the observation of the Earth is also a large source of employability since this activity is strategic for both politicial and scientific reasons. This major interest is acknowlieged by 16 billions euros EC funding ofGalileo and EGNOS navigation systems, Copernicus programme of Earth observation and Earth communication satellites, along with the 22,2% of its budget that ESA devotes to Earth observation in 2021 (source : https://www.esa.int/Newsroom/ESA_budget_2021).

3. Conclusion

The combination of the different sources of information of this report have highlighted that:

- there is a g**rowing demand in the world for expertise in exploration and sustainable exploitation of natural resources**

- the forthcoming decade will be extremely fruitful for Earth and Planetary exploration programs in Europe and world-wide with more than 20 ESA and NASA missions planned,

- these missions will require the expertise of many scientists trained to work in an international and multidisciplinary collaborative effort to gain a maximum return from these missions,

- skills on identification of natural resources, data science, from numerical modelling to machine learning or VR, and knowledge of space engineering and technology will be very valuable in this context

- the link between academic and private sector is quite good and growing, with complementary mutual interests, from internships, PhD or jobs opportunities for the students to complementary research and technology expertise for public researchers and private companies.

A Master programme based on complementary education on geology, from field activity to numerical mapping, numerical data analysis and instrumentation for space, along with VR activities and a research internship in an international environment, with connection with private partners and industry seems particularly relevant to train the young scientists that will be involved in the future exploration programs and take over the strong scientific heritage in Earth and planetary sciences.