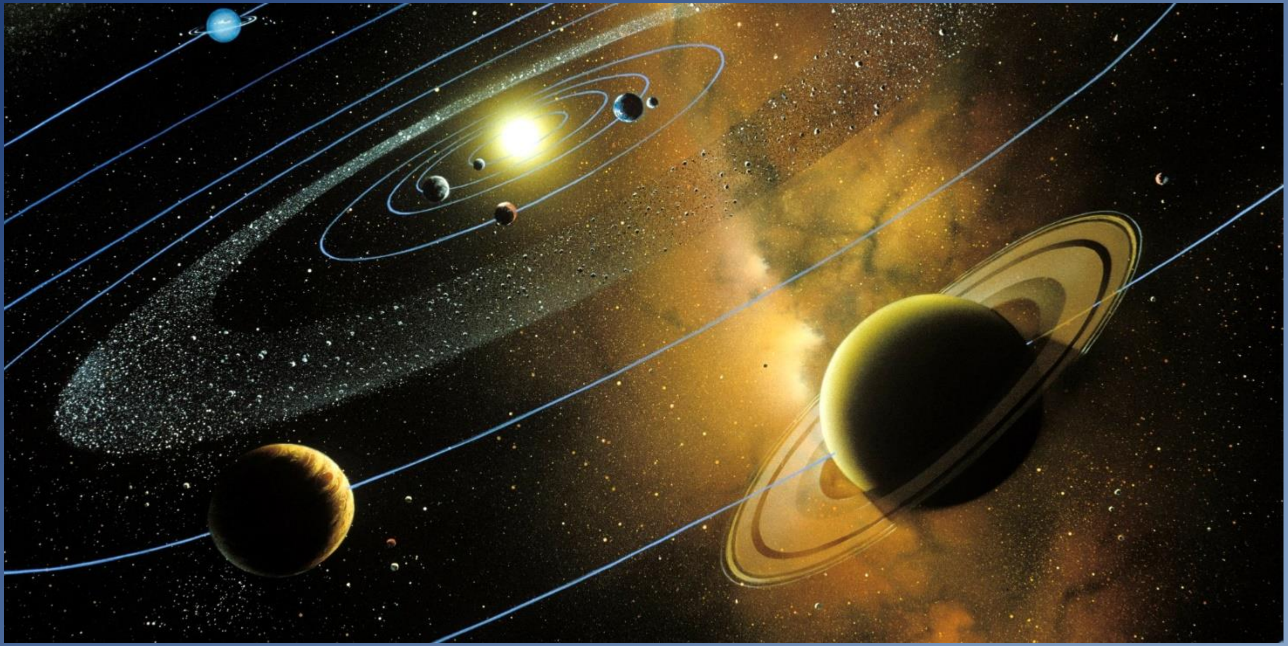
Exploration of the Solar System



Bilateral University of Kharkiv – INAF workshop

March 22-23, 2018

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Coordinator of the Division "Planetology and Exploration of the Solar System" of INAF Scientific Directorate
INAF-Osservatorio Astronomico di Capodimonte, Napoli, Italy

Main questions and Science Priorities in Planetary Science

(NASA Vision & Voyages, ESA Cosmic Vision, INAF Vision)

1. Which are the processes that determined the formation and evolution of the Solar System?

2. Which are the processes determining the appearance and properties of the bodies of the Solar System?

3. Which are the evolutionary processes giving origin to the emergence of life? And what does determine the fate of life on a planet?

Comparative planetology as key tool for answering the questions.

Comparison with extrasolar planetary systems.

Main questions and Science Priorities in Planetary Science

1. Which are the processes that determined the formation and evolution of the Solar System?

   - Initial stages, conditions and processes of Solar System formation

   Key o*bservations: 'primitive' bodies: comets, asteroids, Trojans, Kuiper belt objects, Main belt objects*

   - Accretion process of giant planets and associated satellite systems; migration

   Key o*bservations: outer planets, their satellites (Enceladus, Titan, Io, Europa, Ganymede) and rings, Kuiper belt objects*

   - Accretion, supply of water, chemistry, and internal differentiation of the inner planets; evolution of their atmospheres and the role of bombardment by large projectiles.

   Key o*bservations: Mars, Moon, Mercury, Venus, Trojans, asteroids and comets*

Main questions and Science Priorities in Planetary Science

2. Which are the processes determining the appearance and properties of the bodies of the Solar System?

- How do the giant planets serve as laboratories to understand Earth, the solar system, and extrasolar planetary systems?

Key o*bservations: Jupiter system (JUICE and Europa Orbiter missions), Uranus Orbiter and Probe, Saturn Probe*

- Can understanding the roles of physics, chemistry, geology, and dynamics in driving planetary atmospheres and climates lead to a better understanding of climate change on Earth?

Key o*bservations: giant planets, Venus, Mars*

- How have the myriad chemical and physical processes that shaped the solar system operated, interacted, and evolved over time?

Key observations: All SS bodies

Why super-Earths did not form in the Solar System?

Main questions and Science Priorities in Planetary Science

3. Which are the evolutionary processes giving origin to the emergence of life?

- What were the primordial sources of organic matter, and where does organic synthesis continue today?

Key o*bservations: Mars, comets, asteroids, Trojans, Enceladus, Europa, Ganymede*

- Did Mars or Venus host ancient aqueous environments conducive to early life, and is there evidence that life emerged?

- Beyond Earth, are there contemporary habitats elsewhere in the solar system with necessary conditions, organic matter, water, energy, and nutrients to sustain life, and do organisms live there now?

- What solar system bodies or processes endanger Earth’s biosphere, and what mechanisms shield it?

Hints on the most important discoveries

Main scientific results with INAF contribution

Rosetta mission

Objectives:

To study the origin of comets, the relationship between cometary and interstellar material, and its implications with regard to the origin of the Solar System.

Hints on Top Discoveries:

- 67P/C-G is a **primitive body** born in a very cold region of the protoplanetary nebula far from the Sun → *comets are likely ancient leftovers of early SS formation*
- Between the sizes of 0.1 and 1 mm, 99% of dust mass is due to **compact particles**, denser than the nucleus → *much of the nucleus is in the form of mineral aggregates (silicates, sulfides) coming from the inner hot-proto-solar nebula, while the volatile ices formed in very cold regions.*
- Presence of **fluffy particles** (density < 1 kg/m^3 and sizes up to few mm) uniformly distributed over all the nucleus (whereas compact particles come mainly from the neck). → *they could represent the primitive proto-solar component, survived during the accretion history (vel < 1m/s) → comets accretion by gentle gravitational collapse of a cloud of cm-sized pebbles, confined in a Hill sphere by the flow instabilities at the end of proto-planetary nebula gas phase.*

Orbiting a comet for the 1st time; Landing on a comet for the 1st time

Event	Date
Launch	2/03/2004
Arrival at 67P/Churyumov-Gerasimenko	6/8/2014
Philе landing	12/9/2014
End of mission	30/09/2016

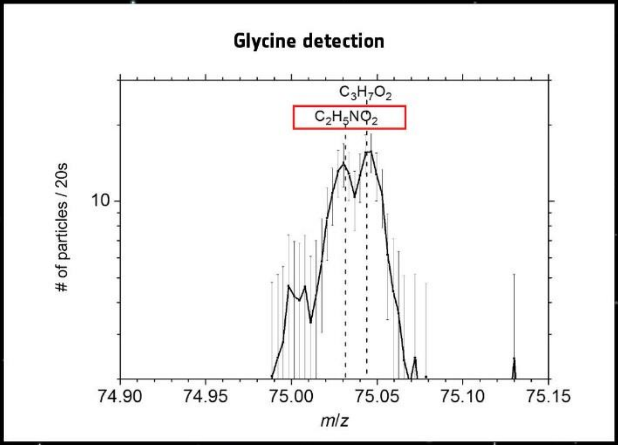
INAF: VIRTIS, GIADA

Main scientific results with INAF contribution
Rosetta mission

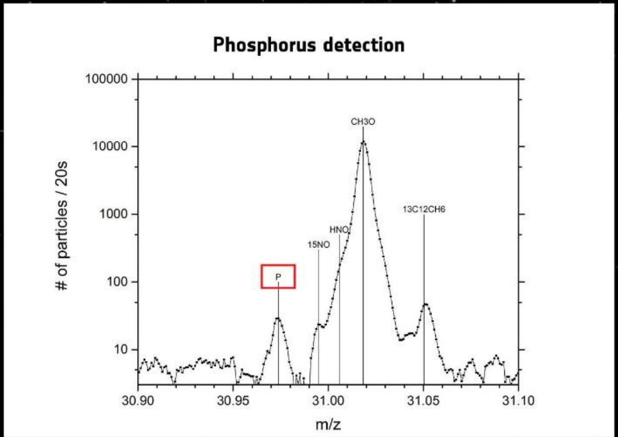
Objectives:
To study the origin of comets, the relationship between cometary and interstellar material, and its implications with regard to the origin of the Solar System.

Hints on Top Discoveries:

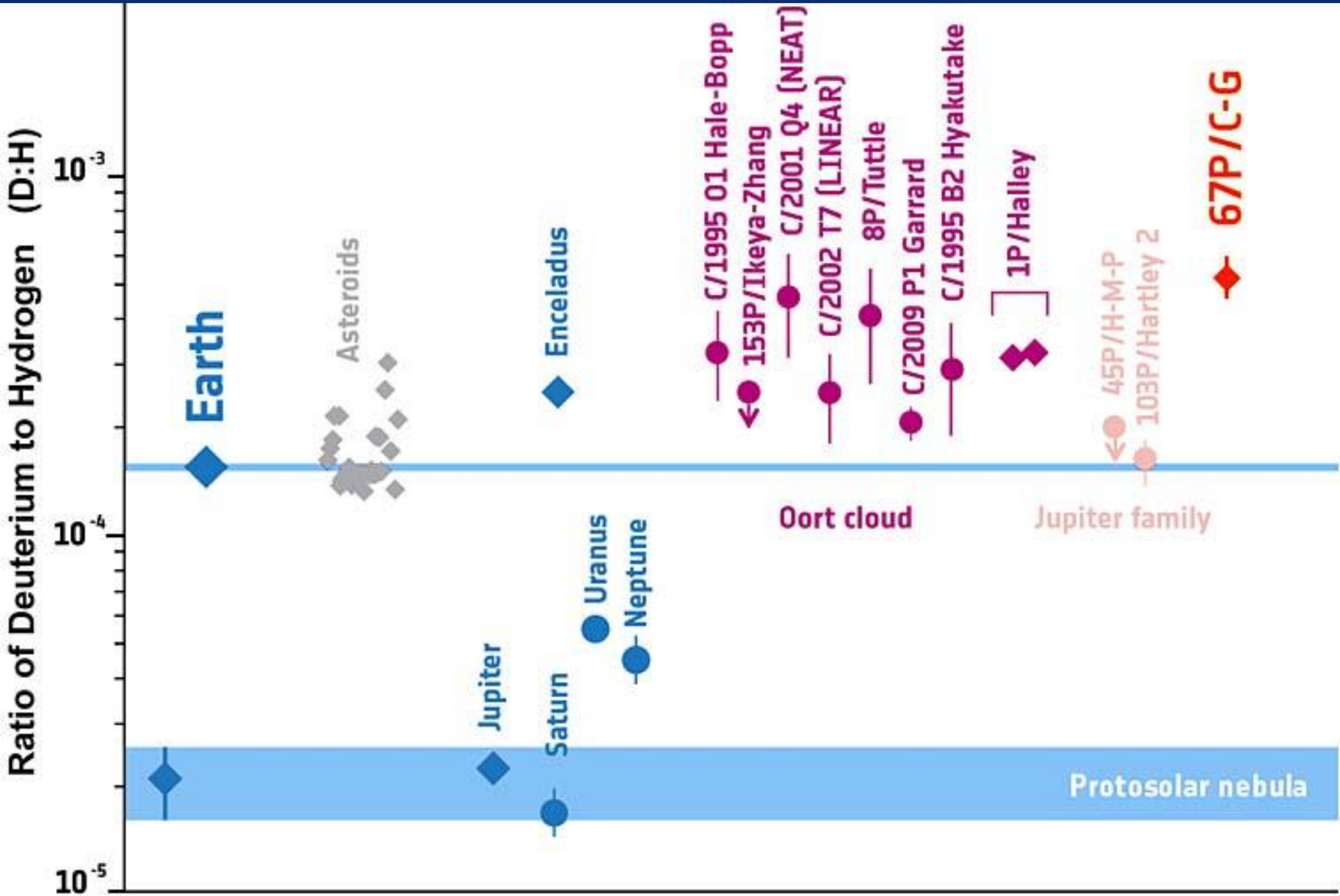
- Dust to water ratio ~6 (dust to gas ratio ~4) → *comets are **not dirty snow ball**. Water ice < 15% on the nucleus surface. Thermo-physical models of cometary nuclei may provide misleading results. Microporosity (scale < 1mm) of ~85%. Accretion region for 67P drier than that of CI chondrites.*
- Detection of **organic compounds** such as glycine, the simples amino acid → *comets could have helped bring life on Earth*
- **D/H ratio**: very different from Earth's water → *Earth's oceans have not been formed by comets' water.*



Spectrum indicating glycine ($C_2H_5NO_2$) detection on 9 July 2015. The simple amino acid glycine is a biologically important organic compound commonly found in proteins.



Spectrum indicating phosphorus (P) detection, along with other gases, on 26 October 2014. Phosphorus is a key element in all living organisms. It is found in DNA, RNA and in cell membranes, and it is used in transporting chemical energy within cells for metabolism.



Ratio of Deuterium to Hydrogen (D:H)
10^{-3}
10^{-4}
10^{-5}
Earth
Asteroids
Enceladus
Jupiter
Saturn
Uranus
Neptune
C/1995 O1 Hale-Bopp
153P/Ikeya-Zhang
C/2001 Q4 (NEAT)
C/2002 T7 (LINEAR)
8P/Tuttle
C/2009 P1 Garrard
C/1995 B2 Hyakutake
1P/Halley
45P/H-M-P
103P/Hartley 2
67P/C-G
Oort cloud
Jupiter family
Protosolar nebula

Main scientific results with INAF contribution
Dawn mission

Objectives:

To deeply investigate the two largest bodies in the asteroids belt – Vesta and Ceres (dwarf planet).
They are the largest protoplanets remaining intact since their formation. Very different evolutionary path.
Vesta is rocky, Ceres appears to be icy. Together they bridge the rocky worlds of the inner solar system and the ice bodies far beyond Saturn.

Hints on Top Discoveries:

- **Vesta**
  - Confirmation that Vesta is the **parent of the HED meteorites**
  - **Iron core.** Vesta's gravity field is consistent with an iron core of the size predicated by HED-based differentiation models.
  - Confirmation that Vesta experienced pervasive, even global melting.

Event	Date
Launch	09/2007
Vesta exploration	07/2011-09/2012
Ceres arrival	03/2015
End of prime mission	06/2016 Now at the 2^{nd} extension

INAF: VIR imaging spectrometer

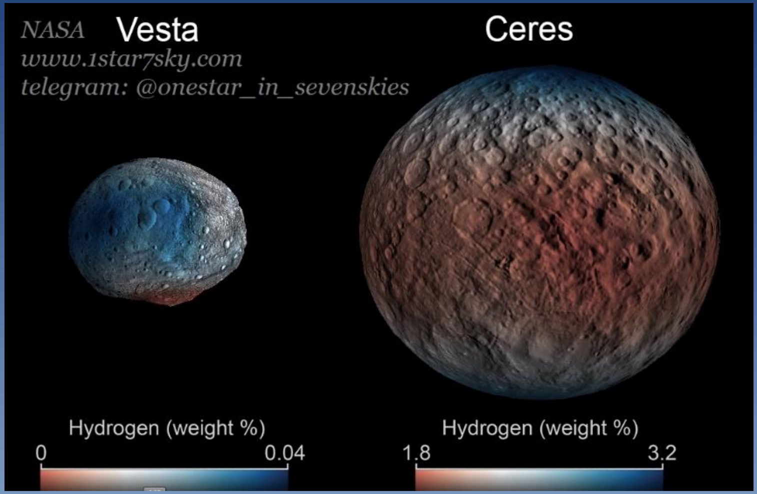
Main scientific results with INAF contribution
Dawn mission

Hints on Top Discoveries:

- **Ceres**
  - **Ocean world?** → Data suggest that Ceres is a frozen ocean world, whose expression on the surface is in the form of salts and carbonates.

  - Suggestion that there is a softer, easily **deformable layer beneath Ceres' rigid surface crust**, which could be the signature of residual liquid left over from the ocean, too. → *Is there residual liquid water in the subsurface?*

  - **Geologically active.** Cratered surface, mostly homogeneous but punctuated by bright features.
    Complex landscape: young and older terrains.
    Chemical or physical transformation still in progress. Ceres is geologically active.



Event	Date
Launch	09/2007
Vesta exploration	07/2011-09/2012
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INAF: VIR imaging spectrometer

Main scientific results with INAF contribution
Cassini-Huygens mission

Objectives:

To study the Saturn's satellite system and rings, to land and study Titan, the dynamic behavior of Saturn's atmosphere at cloud level, the 3D structure of the magnetosphere.

Hints on Top Discoveries:

- **The level of complexity of Icy Moons.** Evidence of subsurface oceans of liquid water on some of the moons, spotted geysers and other geologic activity, indication of prebiotic chemistry → *Saturn's moons can be hospitable to life. Help in search for life in other planetary systems.*
  - **Titan**

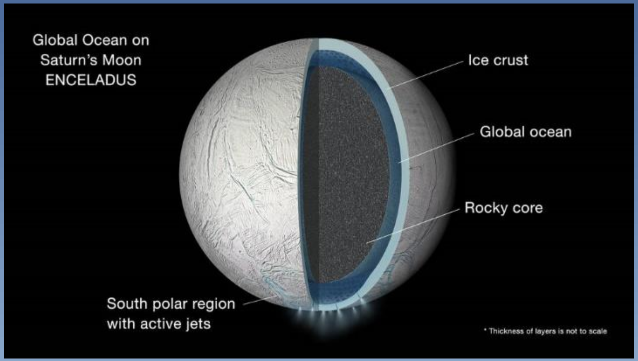
    The surface under the haze showed dunes, mountains of water ice and rivers and seas of liquid methane. Titan is the only moon in the SS with a dense atmosphere and large liquid reservoirs on its surface, making it more similar to a terrestrial planet. The atmosphere is nitrogen-dominated (95%) but with very little oxygen, the rest is mostly methane and traced amounts of other gases, including ethane.

Event	Date
Launch	15/10/1997
Insertion in Saturn orbit	1/7/2004
Landing on Titan	14/1/2005
End of mission	15/09/2017

INAF: VIMS-V

Main scientific results with INAF contribution
Cassini-Huygens mission

Objectives:
To study the Saturn’s satellite system and rings, to land and study Titan, the dynamic behavior of Saturn's atmosphere at cloud level , the 3D structure of the magnetosphere.



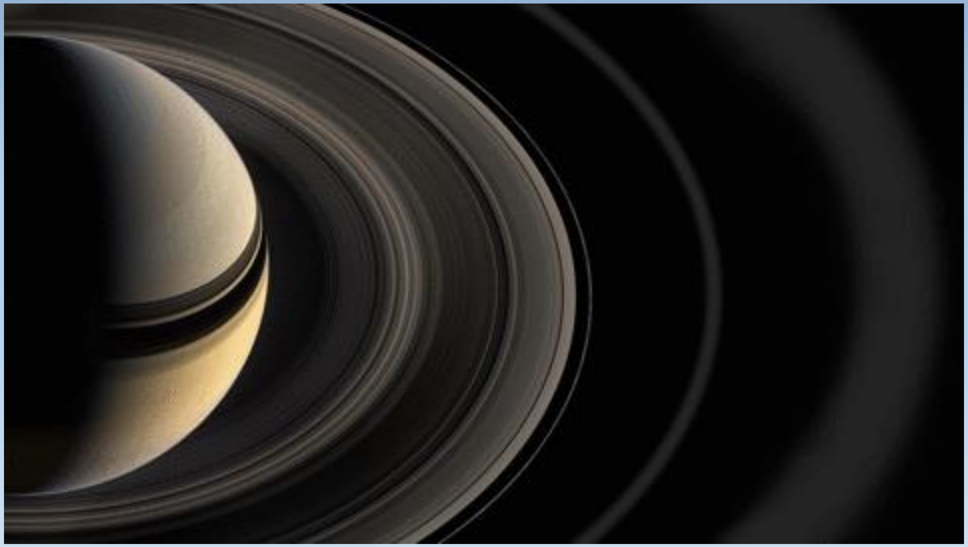
Hints on Top Discoveries:

- **Enceladus**

Presence of a global ocean of salty liquid water beneath the icy surface. The ocean might host hydrothermal vents. Some of that water even shoots out into space as geysers.
→ *presence of life?*

- **Rings**

Made of very large amount of particles of ice and dust.
Ring-moons interaction: formation of gaps and waves.
Enceladus is the source for Saturn’s E ring.



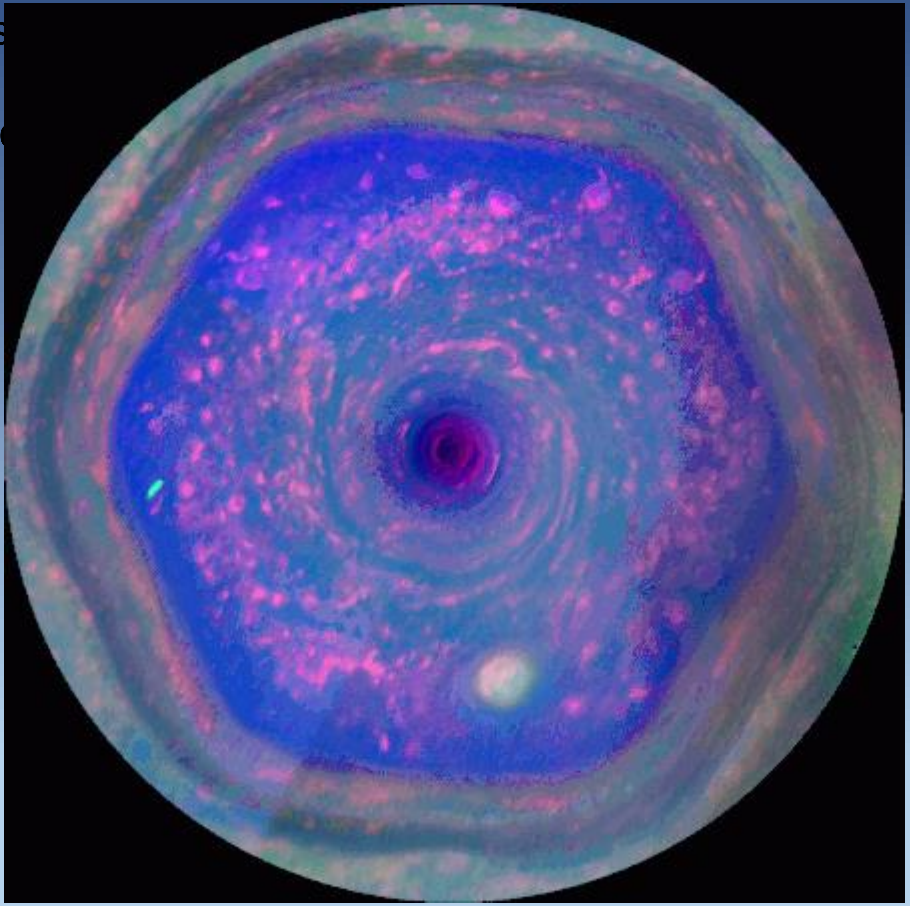
Main scientific results with INAF contribution
Cassini-Huygens mission

Objectives:

To study the Saturn’s satellite system and rings and study Titan, the dynamic behavior of atmosphere at cloud level , the 3D structur magnetosphere.

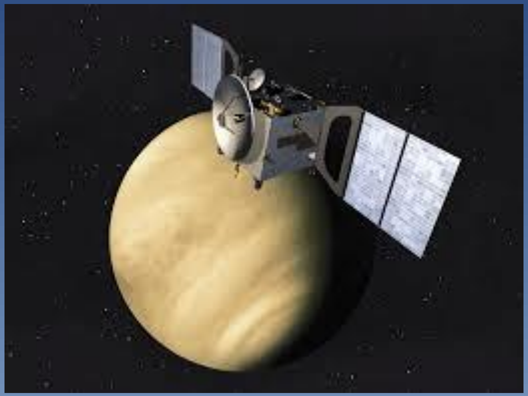
Hints on Top Discoveries:

- **Saturn atmosphere and magnetosphere.**
  - Discovered auroras due to the interaction of solar wind with the plasma in the upper atmosphere of Saturn’s poles, where it is channeled by the planet’s magnetic field.
  - Turbulent atmosphere. Severe storms and a striking, six-sided jet stream near its north pole.
  - Swirling storms at the poles. Lightening.



Main scientific results with INAF contribution
Venus Express mission

Objectives:
To deeply investigate Venus to understand the general evolution of the terrestrial planets in the Solar System.



Hints on Top Discoveries:

- **Water loss.** Confirmation that Venus was probably much more humid and Earth-like in its history. Data indicated that water is still being lost from the upper atmosphere.

- **Recent or present volcanic activity.** VIRTIS observed anomalously high emissivity values in 3 hot spots around volcanos. → lava flow relatively unweathered and therefore recent (few thousands of years?). Discovered variation of sulphur dioxide in the upper atmosphere — volcanoes still erupting?

- **Complexity of southern vortex.** VIRTIS observed great variability and instability. Complex weather pattern.

Event	Date
Launch	11/2015
Orbit insertion	11/04/2005
Last contact	18/01/2015

INAF: VIRTIS
(IR Thermal Imaging Spectrometer)

Main scientific results with INAF contribution
Venus Express mission

Objectives:
To deeply investigate Venus to understand the general evolution of the terrestrial planets in the Solar System.

Hints on Top Discoveries:

- **Snow on Venus?** Discovered regions high in the atmosphere cold enough for CO_2 to freeze out as ice or snow (-175 °C).

- **Thin ozone layer**. SPICAV detected (via stellar occultation) a tenuous layer of ozone gas in Venus atmosphere.

- **No ozone in the antisolar point**. It was expected due to the dissociation of H_2O due to solar UV. Perhaps destroyed by chlorine-based compounds transported in the antisolar point in the same way than oxygen. → processes in act similar to those responsible for the Antartic 'ozone hole' on Earth?

Main scientific results with INAF contribution
Mars Express mission

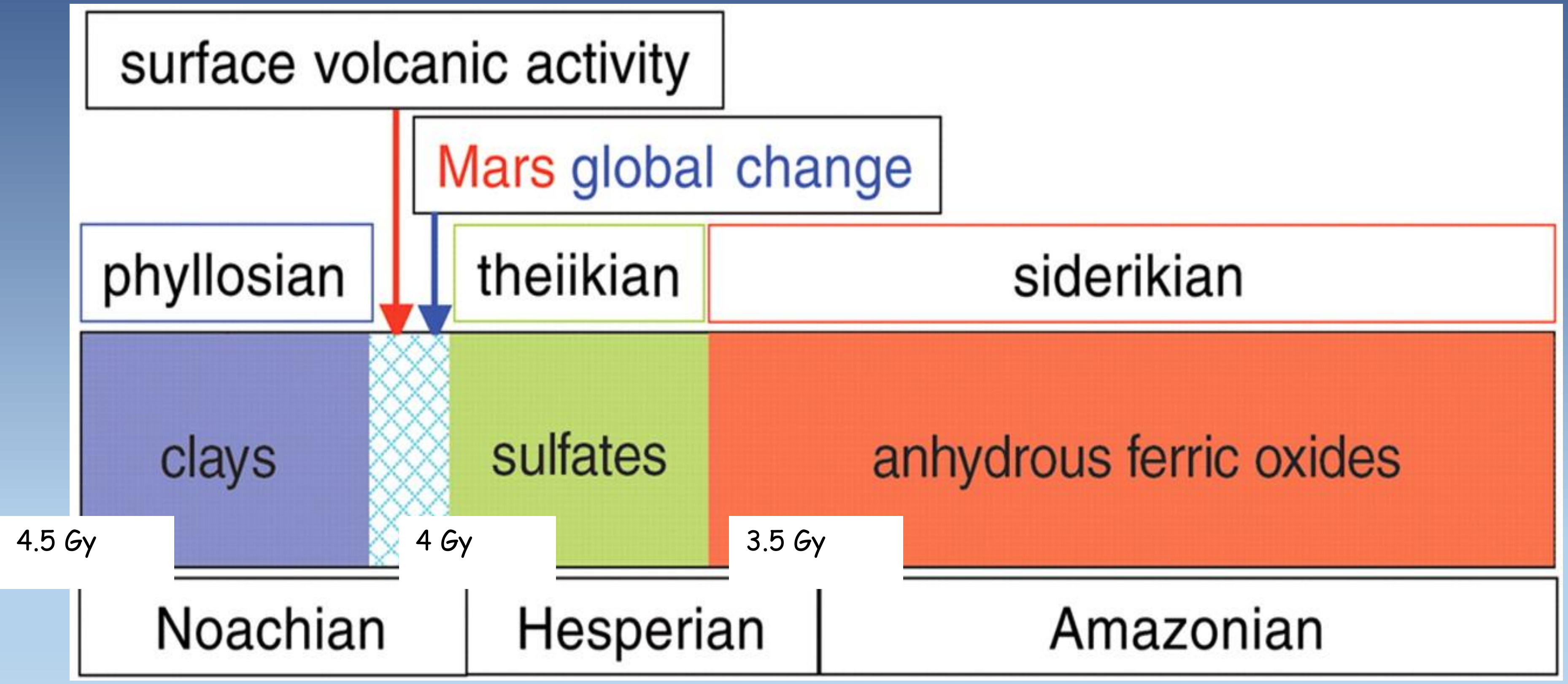
Objectives:
To deeply investigate Mars to understand the general evolution of the terrestrial planets in the Solar System.

Hints on Top Discoveries:

- **First evidence of liquid water evolution on Mars**. Hydrated materials detected.
- Possible detection of **methane** in the atmosphere.
- First detection of **water ice at Martian South Pole**
- **Recent and episodic volcanism**. It was thought that Martian volcanic activity ceases around 500-600 Ma ago. MEX found evidences of recent (20 Ma) resurfaces of central calderas of major volcanoes and very recent (2 Ma) possible lava flowing. Small-scale surface activity? Hydrothermal systems?
- First evidences and estimation of current **atmospheric escape** into the space
- Detailed study of **Phobos**

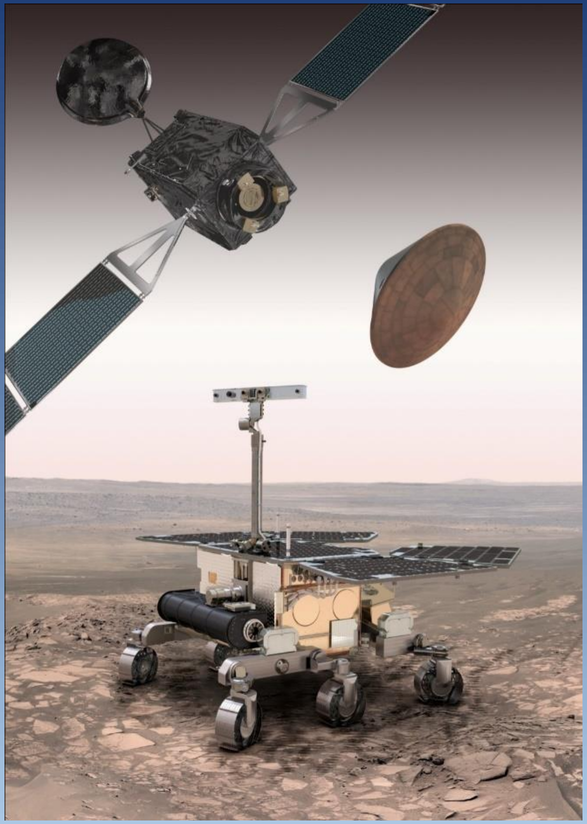
Event	Date
Launch	2/6/2003
Orbit insertion	12/2003
End of mission	2020

INAF: PFS, OMEGA, MARSIS


surface volcanic activity
Mars global change
phyllosian
theiikian
siderikian
clays
sulfates
anhydrous ferric oxides
4.5 Gy
4 Gy
3.5 Gy
Noachian
Hesperian
Amazonian

Near future science

Future missions: INAF major contribution
ExoMars mission



Objectives:

To understand if life may arose on another planet.

Description:

Technological achievements:

- EDL of a payload on the surface of Mars;
- Surface mobility with a rover;
- Access to the subsurface to acquire samples;
- Sample acquisition, preparation, distribution and analysis

Scientific achievements:

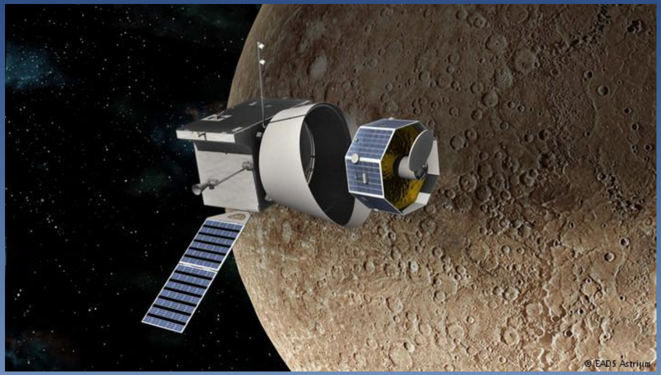
- Search for signs of past and present life on Mars;
- Investigate how the water and geochemical environment varies;
- Investigate Martian atmospheric trace gases and their sources;
- Measuring key meteorological parameters during the statistical dust storm season;
- Study the electrical properties of the Martian atmosphere

Event	Date
Launch	7/2020
Arrival	1/2021
End of nominal mission	1/2022

Future missions: INAF major contribution
BepiColombo mission

Objectives:

To deeply investigate Mercury and its environment to understand the general evolution of the terrestrial planets in the Solar System.



Description:

- 2 different modules: MPO from ESA with 11 instruments and MMO from JAXA with 5 instruments.

- MPO (Mercury Planetary Orbit) will study the surface from UV to thermal IR, the exosphere and internal magnetosphere, the internal structure of the planet and the fundamental physics such as the General Relativity constants.

- MMO (Mercury Magnetospheric Orbiter) will study the planet's magnetosphere.

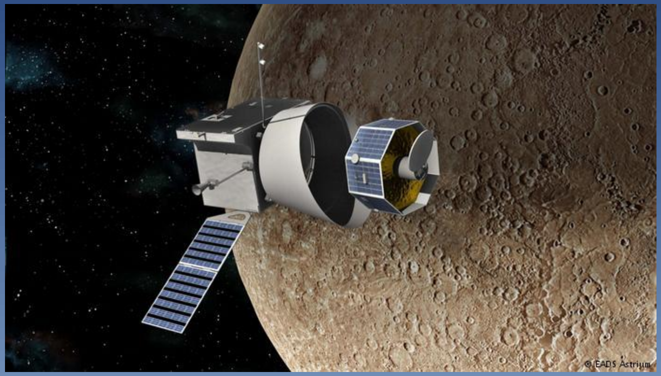
Event	Date
Launch	10/2018
Arrival	12/2025
End of nominal mission	12/2026

Future missions: INAF major contribution
BepiColombo mission

Italy and INAF contribution:

- 4 PI instruments (the first 3 have INAF PI):
    - **ISA** (Italian Spring Accelerometer), an high sensitivity accelerometer that, in synergy with radioscience experiment, will contribute to geologic and fundamental physics studies;
    - **SERENA**, a suite for the analysis of energetic particles in the circumplanetary environment;
    - **SIMBIO-SYS**, a suite for the geomorphological and compositional observation of the surface. It is composed by HRIC high resolution camera, STC stereo camera (medium resolution) and VIHI NIR-VIS spectrometer.
    - **MORE** radio science experiment (Uni. La Sapienza, Rome) for the determination of planet's gravitational parameters through accurate measurement of the spacecraft's position and acceleration (via the on-board transponder).

- Important Italian involvement also on other instruments: **PHEBUS**, **MIXS**, **SIXS**, **MEA**.

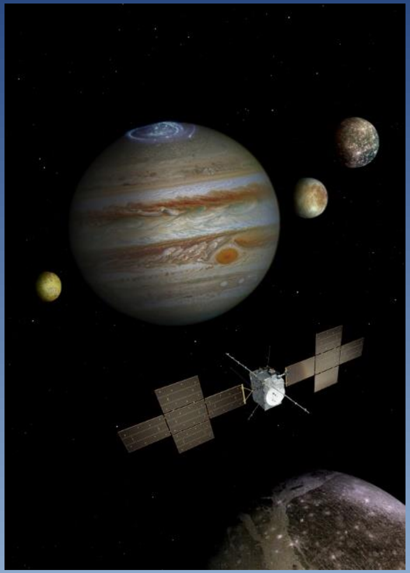


Event	Date
Launch	10/2018
Arrival	12/2025
End of nominal mission	12/2027

Future missions: INAF major contribution
Juice mission

Objectives:

Investigation of Jovian system through detailed observations of Jupiter, Europa, Callisto and Ganymende. Particular emphasis on Ganymede as a planetary body and potential habitat.



Description:

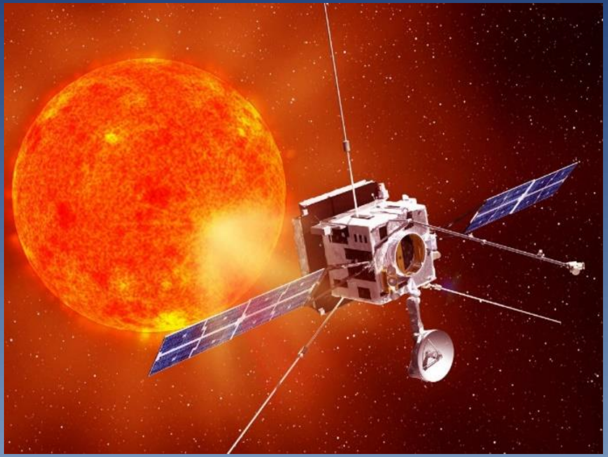
- In response to ESA Cosmic Vision questions: *What are the conditions for planet formation and emergence of life? and How does the Solar System work?*
- Jovian system as a mini Solar System. Better insight into how gas giant planets and their satellite system form and evolve.
- Understanding the habitability of icy worlds.
- Potential for the emergence of life in Jupiter-like exoplanetary systems.

Event	Date
Launch	2020
Insertion in Jovian orbit	2030
End of nominal mission	2033

Italy and INAF contribution:

- Piship or Co-PI-ship in 4 instruments (over 10 total): JANUS camera, Imaging spectrometer MAJIS, radar RIME, 3GM radio science instrument
- Italian industries involved in the development of instrument and some spacecraft subsystems.

Future missions: INAF major contribution
Solar Orbiter mission



Objectives:

Solar and heliospheric studies. In response to ESA-Cosmic Vision questions: development of planets and the emergence of life, how the Solar System works, the origins of the Universe, and the fundamental physics at work in the Universe.

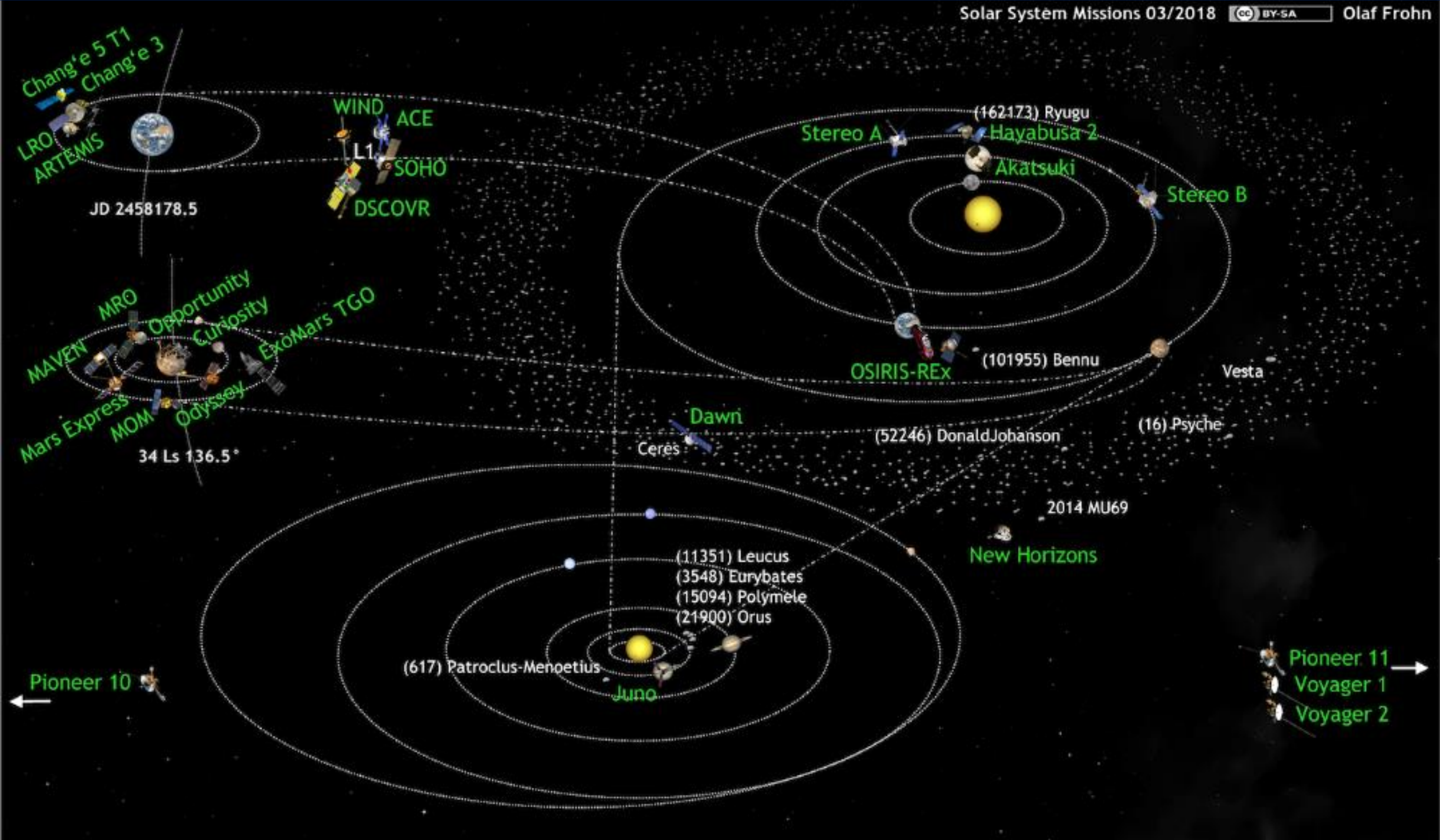
Description:

- In situ and remote sensing close to the Sun: to relate these measurements back to their source regions and structures on the Sun's surface.
- What drives the solar wind and where does the coronal magnetic field originate from?
- How do solar transients drive heliospheric variability?
- How do solar eruptions produce energetic particle radiation that fills the heliosphere?
- How does the solar dynamo work and drive connections between the Sun and the heliosphere?

Italy and INAF contribution:

- Piship or Co-PI-ship in 2 instruments (out of 10 total): METIS coronograph (VIS and UV) and SWA for the in-situ study of plasma and solar wind.
- Participation in the X telescope STIX

Event	Date
Launch	10/2018
Arrival	12/2021
End of nominal / extended mission	2025/2028



Upcoming Events

2018

Apr: Chandrayaan 2 Launch/SL Moon
May: InSIGHT/MarCO Launch to Mars
Jun: Chang'e 4 LRS Launch/OI Moon
Jul: Parker Solar Probe Launch
Jul: Hayabusa 2 App Ryugu
Sep: OSIRIS-REx App Bennu
Oct: Bepi-Colombo Launch to Merc.
Nov: InSIGHT EDL Mars
Dec: Chang'e 4 Launch/SL Moon
Dec: Hayabusa 2 Touchdown Ryugu
Dawn EOM? Ceres
Lightsail 2 Launch

2019

Jan: New Horizons FB 2014 MU69
Oct: OSIRIS-REx Sample Acq. Bennu
Hayabusa 2 Sample acq. Ryugu
Chang'e 5 Launch/SL Moon
SLIM Launch/SL Moon
Solar Orbiter Launch

2020

Dec: KPLO Launch/OI Moon
2020 Mars Rover Launch
Chang'e 6 Launch/SL Moon
Orion EM-1 Launch/FB Moon
+10 EM-1 Cubesats Launch/OI/FB Moon/Heliocentric Orbit
ExoMars Rover Launch
Hayabusa 2 EDL Earth
Luna 25 Lander Launch
Mars Hope Launch to Mars
MGRSO Launch to Mars
MOM-2 Launch to Mars

2021

Mar: OSIRIS-REx Dep Bennu
Juno EOM
ExoMars Rover EDL Mars
Lucy Launch to Jupiter-Trojans
Luna 26 Orbiter Launch

2022+

[Chinese Asteroid FB] Launch
Europa Clipper Launch to Jupiter
JUICE Launch to Jupiter
Luna 27 Lander Launch
Psyche Launch to Psyche
EM-2 Launch to Cislunar Space (2023)
OSIRIS-REx EDL Earth (2023)
MMX Launch to Mars (2024)
Bepi-Colombo OI Mercury (2025)
JUICE EDL Jupiter (2032)

FB: Flyby; OI: Orbit Insertion; App: Approach; Dep: Departure; Imp: Impact
EDL: Entry, Descent and Landing; SL: Soft Landing; EOM: End of Mission