

Exploring small bodies and moons in the outer Solar System with SHARP

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Unveiling the Universe with SHARP: a Spectrograph Proposal for MORFEO@ELT, Palazzo Brera, 30 September 2024 to 2 October 2024



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Ministero
dell'Università
e della Ricerca

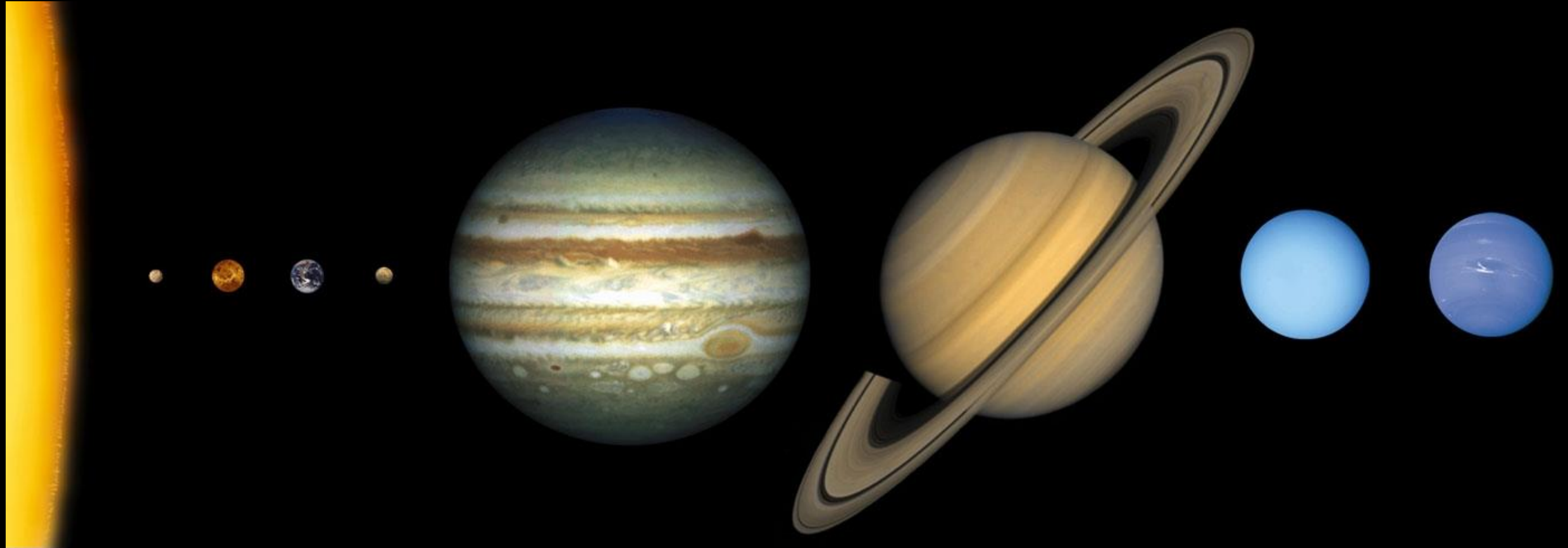


Italiadomani
PIANO NAZIONALE
DI SICUREZZA E RESILIENZA



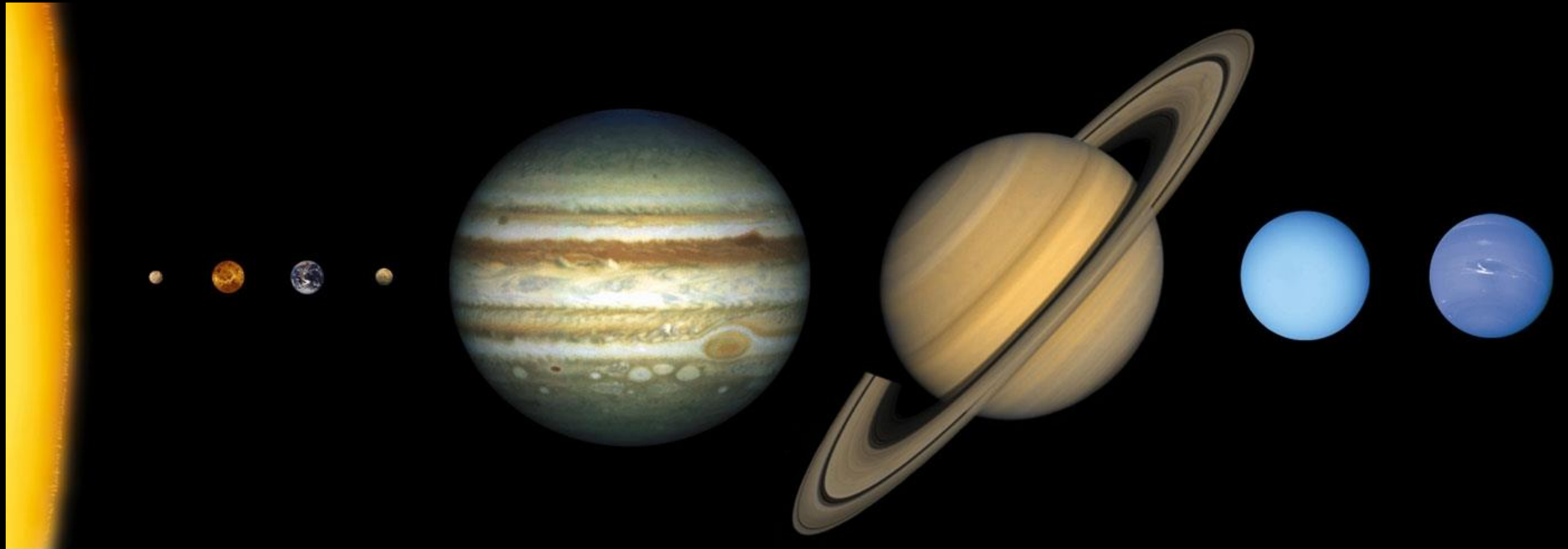
OSSERVATORIO ASTROFISICO DI ARCETRI

Common Picture of the Solar System



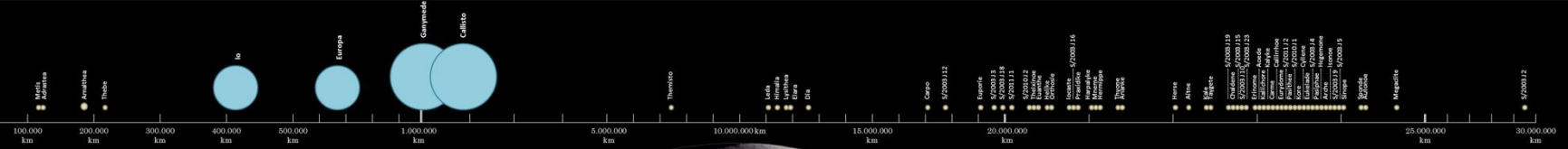
Common Picture of the Solar System

...but there is a whole different Solar System...



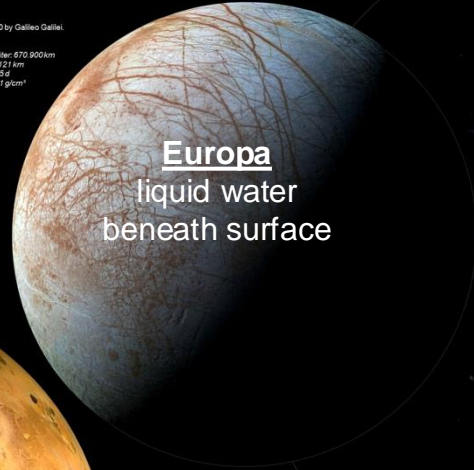
Jupiter Moons

Jupiter - 67 moons



Amalthea
Discovered in 1892 by E.E. Barnard.
PARAMETERS
Distance from Jupiter: 181,356 km
Dimensions: 250x148x128 km
Orbital Period: 11.57 h
Mean Density: 0.85 g/cm³

Europa
Discovered in 1610 by Galileo Galilei.
PARAMETERS
Distance from Jupiter: 670,900 km
Mean Diameter: 3121 km
Orbital Period: 3.55 d
Mean Density: 3.01 g/cm³



Europa
liquid water
beneath surface



Io
volcanically active

Io
Discovered in 1610 by Galileo Galilei.
PARAMETERS
Distance from Jupiter: 421,700 km
Mean Diameter: 3642 km
Orbital Period: 1.76 d
Mean Density: 3.53 g/cm³

Thebe
Discovered in 1879 by S. Synnott.
PARAMETERS
Distance from Jupiter: 221,809 km
Dimensions: 116x98x84 km
Orbital Period: 15.11 h
Mean Density: 0.88 g/cm³

Himalia
Discovered in 1904 by C. D. Perrine.
PARAMETERS
Distance from Jupiter: 11,450,000 km
Mean Diameter: ca 770 km
Orbital Period: 250.96 d
Mean Density: 1.63 g/cm³



Ganymede
liquid water
beneath surface

Ganymede
Discovered in 1610 by Galileo Galilei.
PARAMETERS
Distance from Jupiter: 1,070,400 km
Mean Diameter: 5268 km
Orbital Period: 7.15 d
Mean Density: 1.93 g/cm³



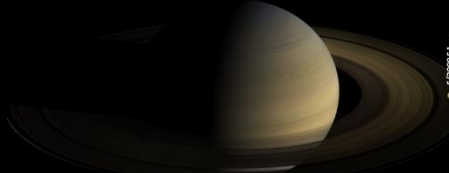
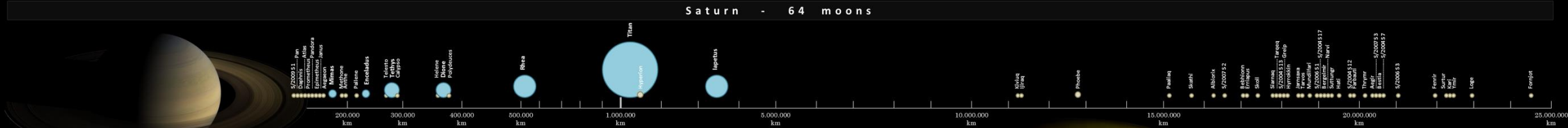
Callisto
Discovered in 1610 by Galileo Galilei.
PARAMETERS
Distance from Jupiter: 1,882,700 km
Mean Diameter: 4820 km
Orbital Period: 16.68 d
Mean Density: 1.80 g/cm³

Aurastea
Discovered in 1979 by David C. Jewitt,
O. Edward Dennerhain.
PARAMETERS
Distance from Jupiter: 129,000 km
Dimensions: 20x16x14 km
Orbital Period: 7.09 h
Mean Density: 0.86 g/cm³

Metis
Discovered in 1879 by S. Synnott.
PARAMETERS
Distance from Jupiter: 128,000 km
Dimensions: 60x40x34 km
Orbital Period: 7.24 h
Mean Density: 0.86 g/cm³

Saturn Moons

Saturn - 64 moons



Mimas
Discovered in 1789 by William Herschel.

PARAMETERS
Distance from Saturn: 185,520 km
Mean Diameter: 397 km
Orbital Period: 22.6 h
Mean Density: 1.14 g/cm³

Pan
Discovered in 1980 by Voyager Team.

PARAMETERS
Distance from Saturn: 133,583 km
Mean Diameter: 23 km
Orbital Period: 13.8 h
Mean Density: 0.42 g/cm³

Daphnis
Discovered in 2005 by Cassini Team.

PARAMETERS
Distance from Saturn: 136,505 km
Mean Diameter: 7 km
Orbital Period: 14.2 h
Mean Density: 0.34 g/cm³

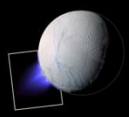
Prometheus
Discovered in 1980 by Voyager Team.

PARAMETERS
Distance from Saturn: 139,353 km
Dimensions: 142x85x62 km
Orbital Period: 16.7 h
Mean Density: 0.48 g/cm³

Pandora
Discovered in 1980 by Voyager Team.

PARAMETERS
Distance from Saturn: 141,700 km
Dimensions: 114x64x62 km
Orbital Period: 16.1 h
Mean Density: 0.49 g/cm³

Enceladus Cryogenic Vulcanism



Epimetheus
Discovered in 1966 by R. Walker.

PARAMETERS
Distance from Saturn: 151,422 km
Dimensions: 164x108x98 km
Orbital Period: 16.7 h
Mean Density: 0.64 g/cm³

Telesto
Discovered in 1980 by B. Smith, H. Reitsema, S. Larson, J. Fountain.

PARAMETERS
Distance from Saturn: 294,660 km
Dimensions: 30x26x15 km
Orbital Period: 1.88 d

Methone
Discovered in 2004 by Cassini Team.

PARAMETERS
Distance from Saturn: 194,000 km
Mean Diameter: 3 km
Orbital Period: 24 h
Mean Density: 0.31 g/cm³

Atlas
Discovered in 1980 by Voyager Team.

PARAMETERS
Distance from Saturn: 137,670 km
Dimensions: 40x20 km
Orbital Period: 14.4 h
Mean Density: 0.46 g/cm³

Janus
Discovered in 1966 by Audouin Dollfus.

PARAMETERS
Distance from Saturn: 151,422 km
Dimensions: 184x190x154 km
Orbital Period: 16.7 h
Mean Density: 0.63 g/cm³

Tethys
Discovered in 1684 by Giovanni Cassini.

PARAMETERS
Distance from Saturn: 294,619 km
Mean Diameter: 1066 km
Orbital Period: 1.88 d
Mean Density: 0.9 g/cm³



Dione
Discovered in 1684 by Giovanni Cassini.

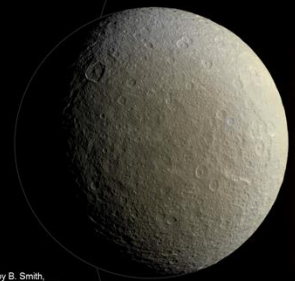
PARAMETERS
Distance from Saturn: 377,396 km
Mean Diameter: 1123 km
Orbital Period: 2.73 d
Mean Density: 1.5 g/cm³

Polydeuces
Discovered in 2004 by Cassini Team.

PARAMETERS
Distance from Saturn: 377,400 km
Mean Diameter: 3.7 km
Orbital Period: 2.73 d

Calypso
Discovered in 1980 by B. Smith, H. Reitsema, S. Larson, J. Fountain.

PARAMETERS
Distance from Saturn: 294,660 km
Dimensions: 30x23x14 km
Orbital Period: 1.88 d

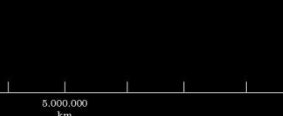


Rhea
Discovered in 1672 by Giovanni Cassini.

PARAMETERS
Distance from Saturn: 527,108 km
Mean Diameter: 1529 km
Orbital Period: 4.51 d
Mean Density: 1.23 g/cm³

Helene
Discovered in 1980 by P. Laques, J. Lecacheux.

PARAMETERS
Distance from Saturn: 377,400 km
Dimensions: 36x32x30 km
Orbital Period: 2.73 d



Iapetus
Discovered in 1671 by Giovanni Cassini.

PARAMETERS
Distance from Saturn: 3,560,820 km
Mean Diameter: 1,472 km
Orbital Period: 79.32 d
Mean Density: 1.27 g/cm³

Phoebe
Discovered in 1898 by William Pickering.

PARAMETERS
Distance from Saturn: 12,952,000 km
Dimensions: 219x217x204 km
Orbital Period: 550.11 d
Mean Density: 1.04 g/cm³

Titan
Discovered in 1655 by Christiaan Huygens.

PARAMETERS
Distance from Saturn: 1,221,870 km
Mean Diameter: 5152 km
Orbital Period: 15.94 d
Mean Density: 1.87 g/cm³

Kiviuq
Discovered in 2000 by Brett James Gladman.

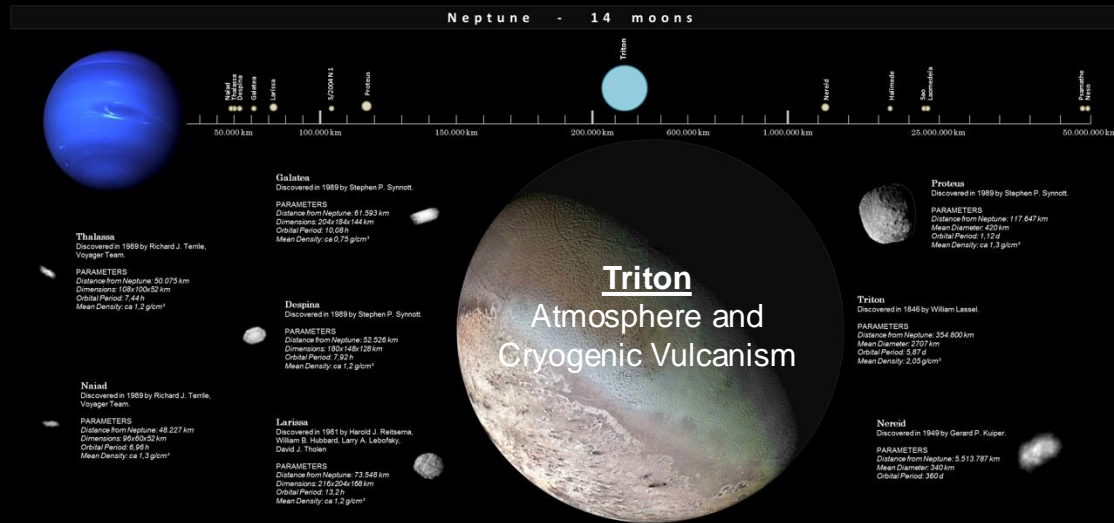
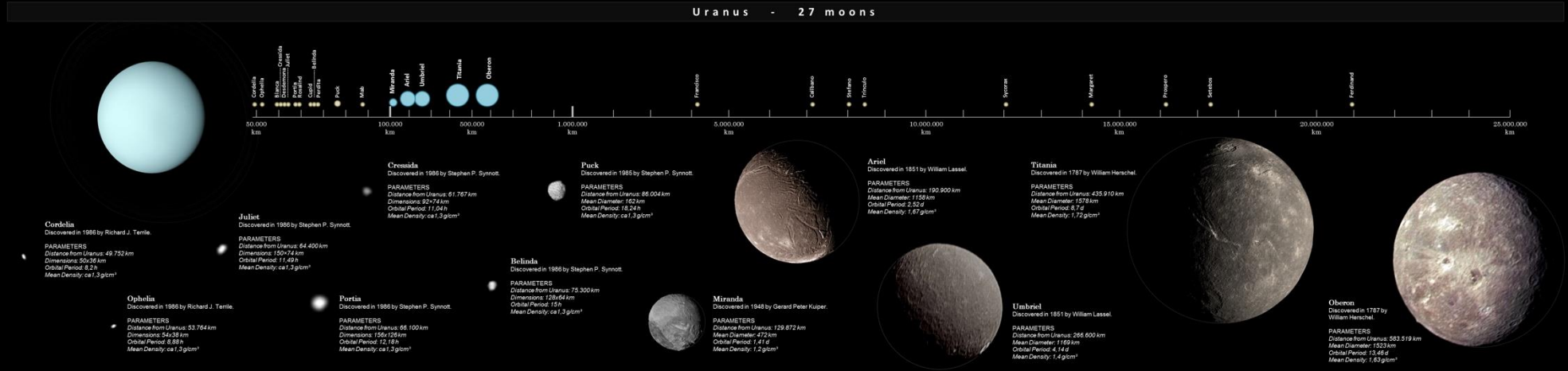
PARAMETERS
Distance from Saturn: 11,365,000 km
Mean Diameter: 16 km
Orbital Period: 449.2 d

Hyperion
Discovered in 1848 by W. C. Bond, G. P. Bond, W. Lassell.

PARAMETERS
Distance from Saturn: 1,481,100 km
Dimensions: 360x280x225 km
Orbital Period: 21.27 d
Mean Density: 0.54 g/cm³

Titan
Thick Atmosphere
(nitrogen, methane,
and hydrogen)

Uranus and Neptune Moons



Dwarf planets, Asteroids, Comets and TNOs

Several asteroids

Ceres
Discovered in 1801 by Giuseppe Piazzi.

PARAMETERS
Class: C
Distance from Sun: 2.76 AU
Mean Diameter: 952.4 km
Orbital Period: 4.6 y
Rotational Period: 9.07 h
Mean Density: 2.16 g/cm³

4 Vesta
Discovered in 1807 by Heinrich W. Olbers.

PARAMETERS
Class: V
Distance from Sun: 2.36 AU
Dimensions: 578×560×458 km
Orbital Period: 3.33 y
Rotational Period: 5.34 h
Mean Density: 3.4 g/cm³

2 Pallas
Discovered in 1802 by Heinrich W. Olbers.

PARAMETERS
Class: B
Distance from Sun: 2.77 AU
Dimensions: 533×110×118 km
Orbital Period: 4.62 y
Rotational Period: 7.81 h
Mean Density: 3.4 g/cm³

3 Aten discovered in 1964 by Karl Lennert Hansen.

PARAMETERS
Class: E
Distance from Sun: 2.67 AU
Dimensions: 330×267×200 km
Orbital Period: 4.36 y
Rotational Period: 2.1 h
Mean Density: 1.9 g/cm³

243 Ida
Discovered in 1864 by Johann Palisa.

PARAMETERS
Class: S
Distance from Sun: 2.86 AU
Dimensions: 59.8×23.4×18.6 km
Orbital Period: 4.85 y
Rotational Period: 4.43 h
Mean Density: 2.6 g/cm³

433 Eros
Discovered in 1898 by Carl Gustav Witt.

PARAMETERS
Class: S
Distance from Sun: 1.5 AU
Dimensions: 34.4×11.5×11.2 km
Orbital Period: 1.76 y
Rotational Period: 5.47 h
Mean Density: 2.67 g/cm³

951 Gaspra
Discovered in 1916 by Grigori N. Zhukovskiy.

PARAMETERS
Class: S
Distance from Sun: 2.71 AU
Dimensions: 18.2×12.5×8.8 km
Orbital Period: 3.29 y
Rotational Period: 7.4 h
Mean Density: 2.7 g/cm³ (assumed)

21 Lutetia
Discovered in 1852 by Hermann M. S. Goldschmidt.

PARAMETERS
Class: M
Distance from Sun: 2.13 AU
Dimensions: 71×121×79 km
Orbital Period: 3.8 y
Rotational Period: 5.16 h
Mean Density: 3.4 g/cm³

253 Mathilde
Discovered in 1987 by Johann Palisa.

PARAMETERS
Class: C
Distance from Sun: 2.64 AU
Dimensions: 66×45×46 km
Orbital Period: 4.3 y
Rotational Period: 17.4 d
Mean Density: 1.3 g/cm³

Pluto - 5 moons

Pluto
Discovered in 1930 by Clyde W. Tombaugh.

PARAMETERS
Distance from Sun: 39.48 AU
Mean Diameter: 2370 km
Orbital Period: 247.68 y
Mean Density: 1.86 g/cm³

Charon
Discovered in 1978 by James W. Christy.

PARAMETERS
Distance from Pluto: 17,536 km
Mean Diameter: 1208 km
Orbital Period: 2.73 d
Mean Density: 1.65 g/cm³

Nix
Discovered in 2005 by Hubble Space Telescope.

PARAMETERS
Distance from Pluto: 48,694 km
Dimensions: 41×36×24 km
Orbital Period: 24.85 d

Nyx
Discovered in 2005 by Hubble Space Telescope.

PARAMETERS
Distance from Pluto: 64,738 km
Dimensions: 30×23 km
Orbital Period: 2.73 d

Kerberos
Discovered in 2005 by Hubble Space Telescope.

Hydra
Discovered in 2005 by Hubble Space Telescope.

PARAMETERS
Distance from Pluto: 64,738 km
Dimensions: 30×23 km
Orbital Period: 2.73 d

Dysnomia

Eris

Sedna

Namaka

Makemake

2007 OR₁₀

Hi'iaka

Haumea

Weywot

Quaoar

Some Periodic Comets

81P/Wild
Discovered in 1978 by Paul Wild.

PARAMETERS
Aphelion: 5.3 AU
Perihelion: 1.59 AU
Dimensions: 5x4x3 km
Orbital Period: 6.4 y
Mean Density: 0.6 g/cm³

103P/Hartley
Discovered in 1966 by Malcolm Hartley.

PARAMETERS
Aphelion: 3.87 AU
Perihelion: 1.05 AU
Dimensions: 1.6x1.2 km
Orbital Period: 6.46 y

19P/Borrelly
Discovered in 1904 by Alphonse Louis Nicolas Borrelly.

PARAMETERS
Aphelion: 5.93 AU
Perihelion: 1.35 AU
Dimensions: 8x4 km
Orbital Period: 6.8 y
Mean Density: 0.5 g/cm³

Tempel 1
Discovered in 1867 by Wilhelm Tempel.

PARAMETERS
Aphelion: 4.73 AU
Perihelion: 1.5 AU
Dimensions: 7.6x4.9 km
Orbital Period: 5.32 y
Mean Density: 0.62 g/cm³

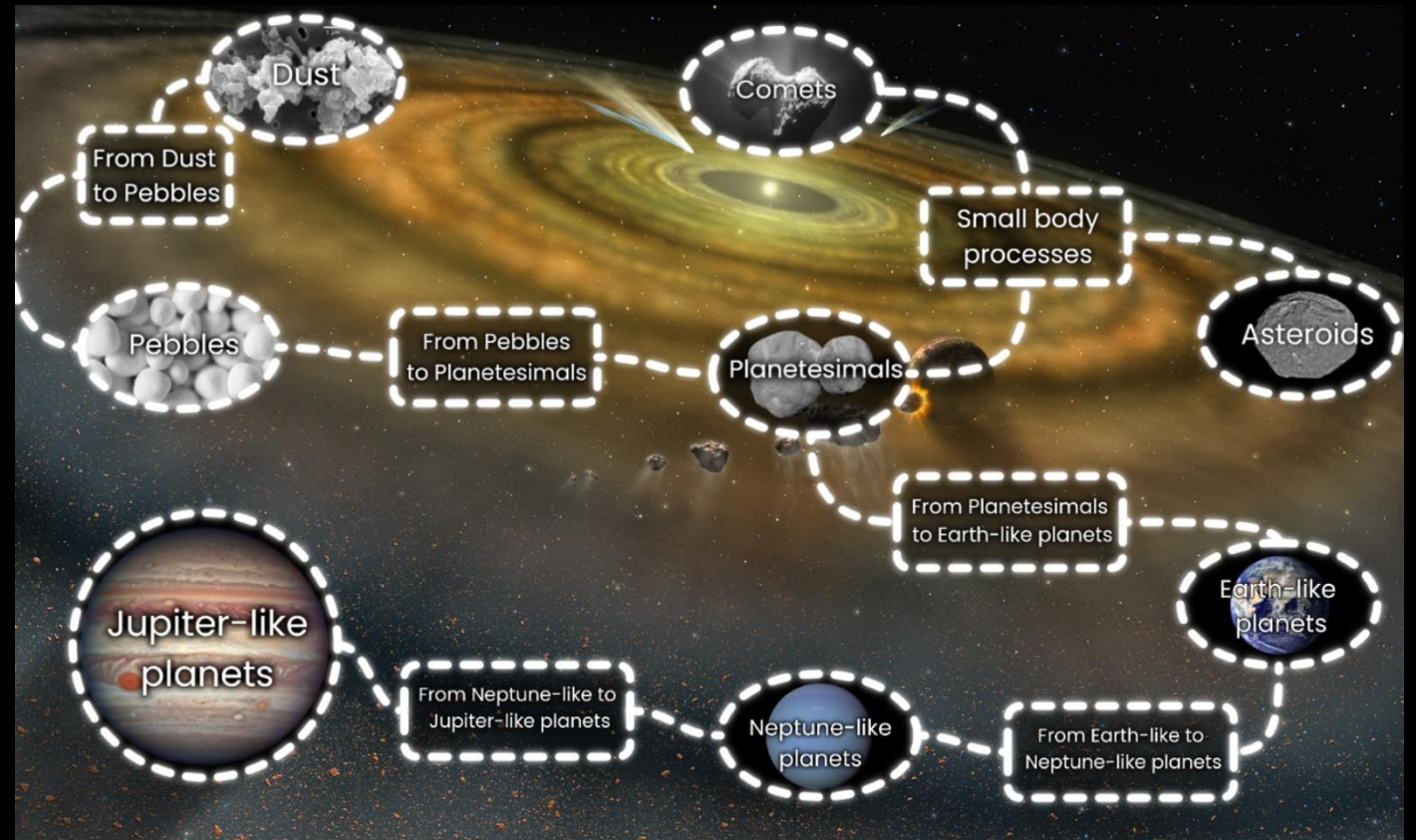
67P/Churyumov-Gerasimenko
Discovered in 1969 by Klim Ivanovitch Churyumov, Svetlana Ivanovna Gerasimenko.

PARAMETERS
Aphelion: 5.88 AU
Perihelion: 1.24 AU
Dimensions: 4.1x3.3x1.8 km
Orbital Period: 6.44 y
Mean Density: 0.47 g/cm³

On the importance of studying small bodies

A - Origins of the Solar System

- Among the least altered bodies from the solar system formation
- Expected to preserve during time material from the protosolar nebula and our proto-planetary disk
- Reveal key clues about our origins



On the importance of studying small bodies

A - Origins of the Solar System

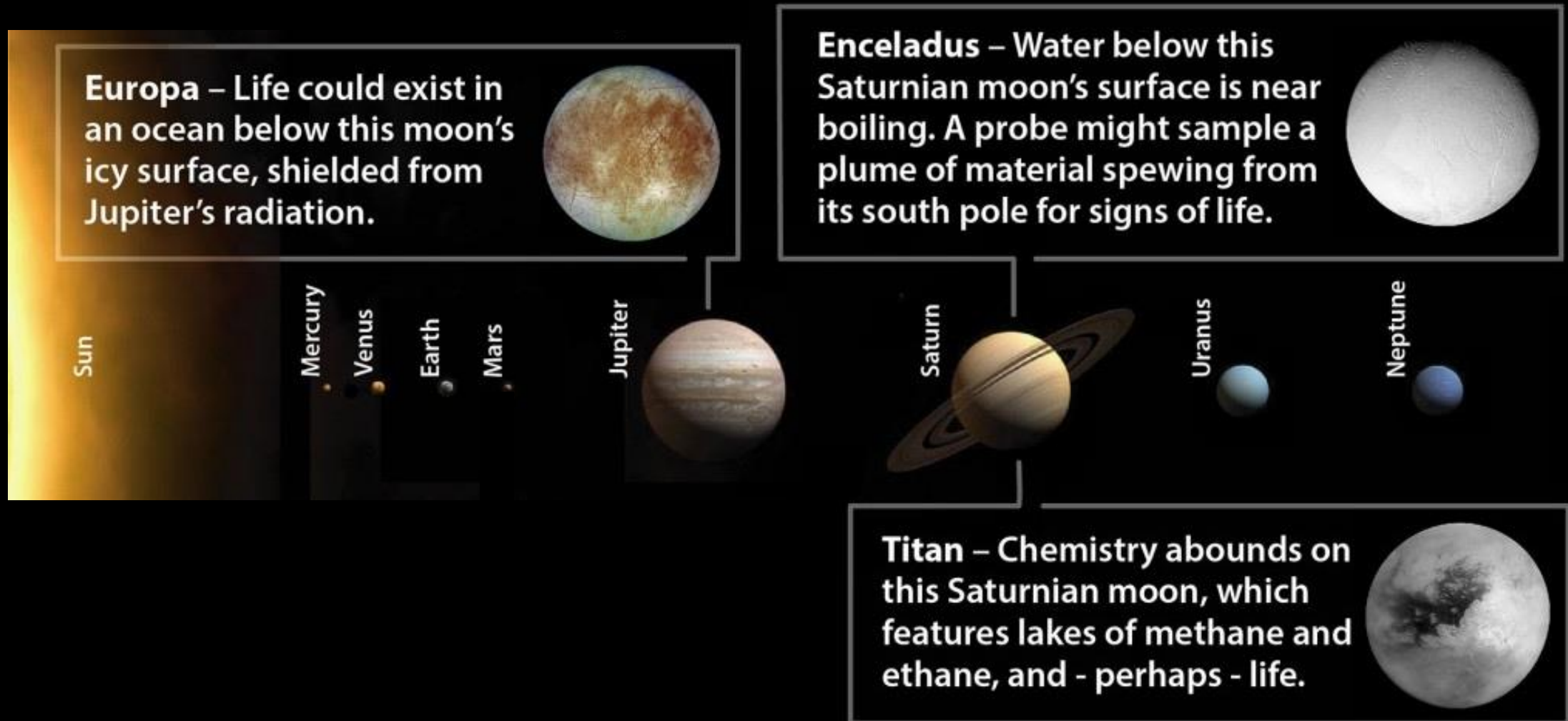
- Among the least altered bodies from the solar system formation
- Expected to preserve during time material from the protosolar nebula and our proto-planetary disk
- Reveal key clues about our origins

B - Origins of life on our planet

- Earth formed in a water-poor region
- Comets and other water-enriched bodies may have delivered essential species to our planet



Moons as Habitable Worlds



SHARP + MORPHEO @ ELT

Spectral and Spatial investigation with unprecedented details of the composition of small bodies/moons surfaces and atmospheres

SHARP + MORPHEO @ ELT

Spectral and Spatial investigation with unprecedented details of the composition of small bodies/moons surfaces and atmospheres

Simultaneous spatial measurements of active comets to understand their physics and chemistry



*Comet NEOWISE - Photograph by JUAN CARLOS CASADO,
SCIENCE PHOTO LIBRARY*

SHARP + MORPHEO @ ELT

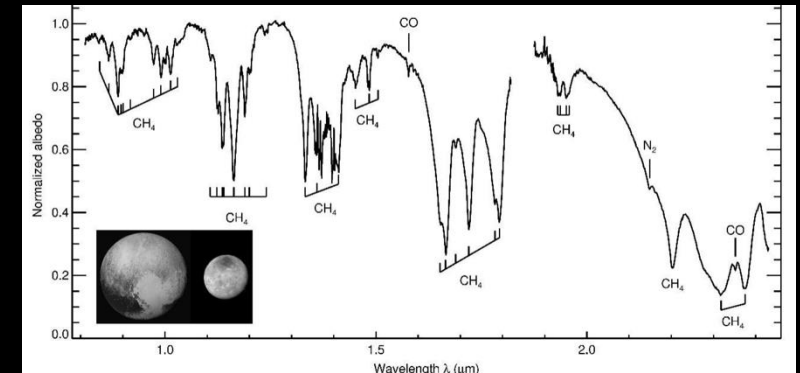
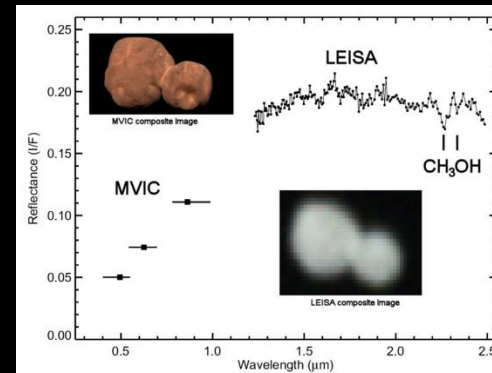
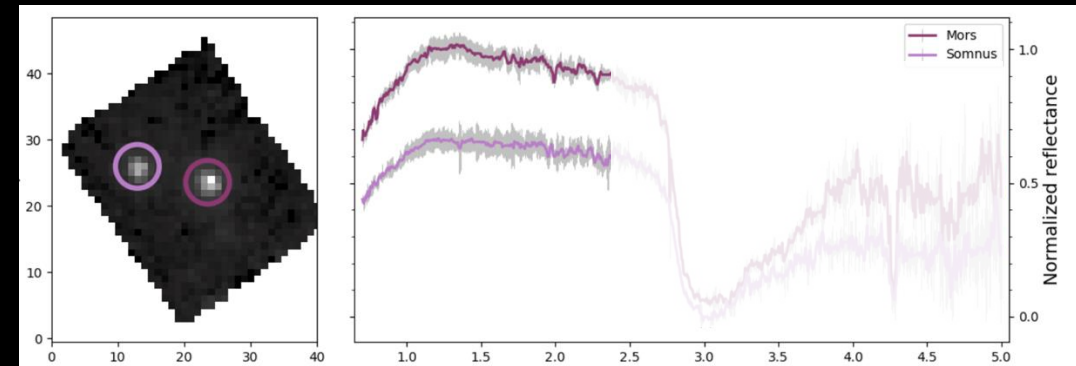
Spectral and **Spatial** investigation with unprecedented details of the composition of small bodies/moons surfaces and atmospheres

Simultaneous spatial measurements of active comets to understand their physics and chemistry



Comet NEOWISE - Photograph by JUAN CARLOS CASADO, SCIENCE PHOTO LIBRARY

Surface investigation of Dwarf Planets and TNOs searching for icy signatures

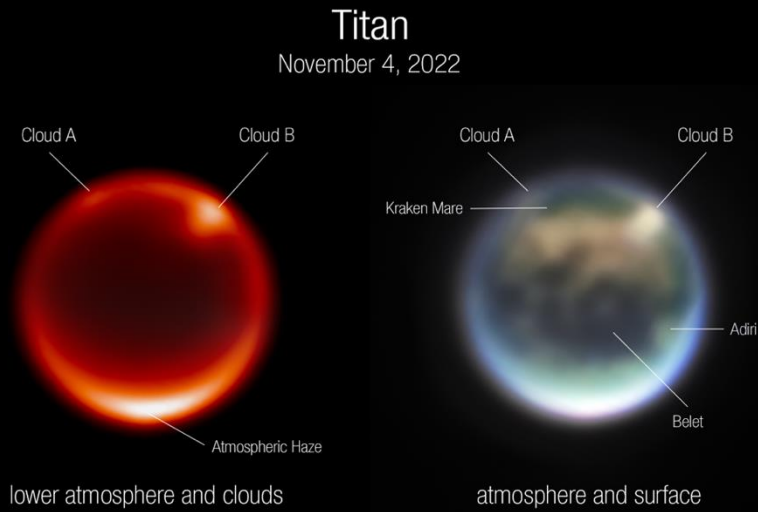


Top: A. C. Souza-Feliciano et al, 2024; Bottom: Dale P. Cruikshank et al., 2020

SHARP + MORPHEO @ ELT

Spectral and **Spatial** investigation with unprecedented details of the composition of small bodies/moons surfaces and atmospheres

Spectral imaging to determine structure and composition of moons' atmospheres



SHARP + MORPHEO @ ELT

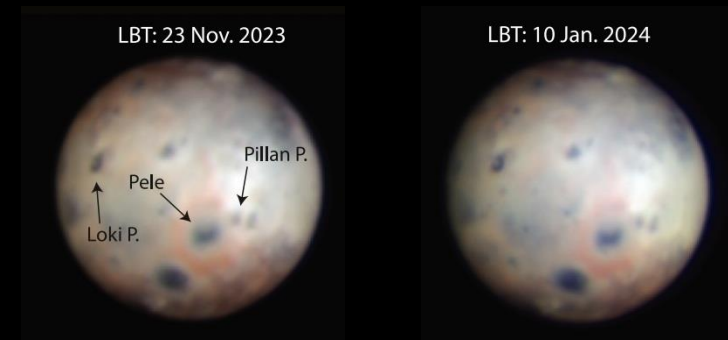
Spectral and **Spatial** investigation with unprecedented details of the composition of small bodies/moons surfaces and atmospheres

Spectral imaging to determine structure and composition of moons' atmospheres



Titan as observed by NIRCAM-JWST

Spectral imaging to monitor volcanic (and cryogenic) activity of “active” moons



SHARK-VIS detection image of Io, Conrad, Al et al., 2024

SHARP + MORPHEO @ ELT

- Knowing and understanding the chemistry and physics of small bodies and moons of the Solar System is fundamental to understand the origins and evolution of our planetary system
- These bodies are also of astrobiological interest, since they may have involved in the past delivery of water and organics in the inner solar system and/or are nowadays in conditions that may favour the development of life
- Instruments such as SHARP + MORFEO @ELT applied in this context can allow the deep spatial and spectral study of these bodies with unprecedented details

Thank you very much for your attention! 😊