EXPLORATION OF MERCURY AND MARS

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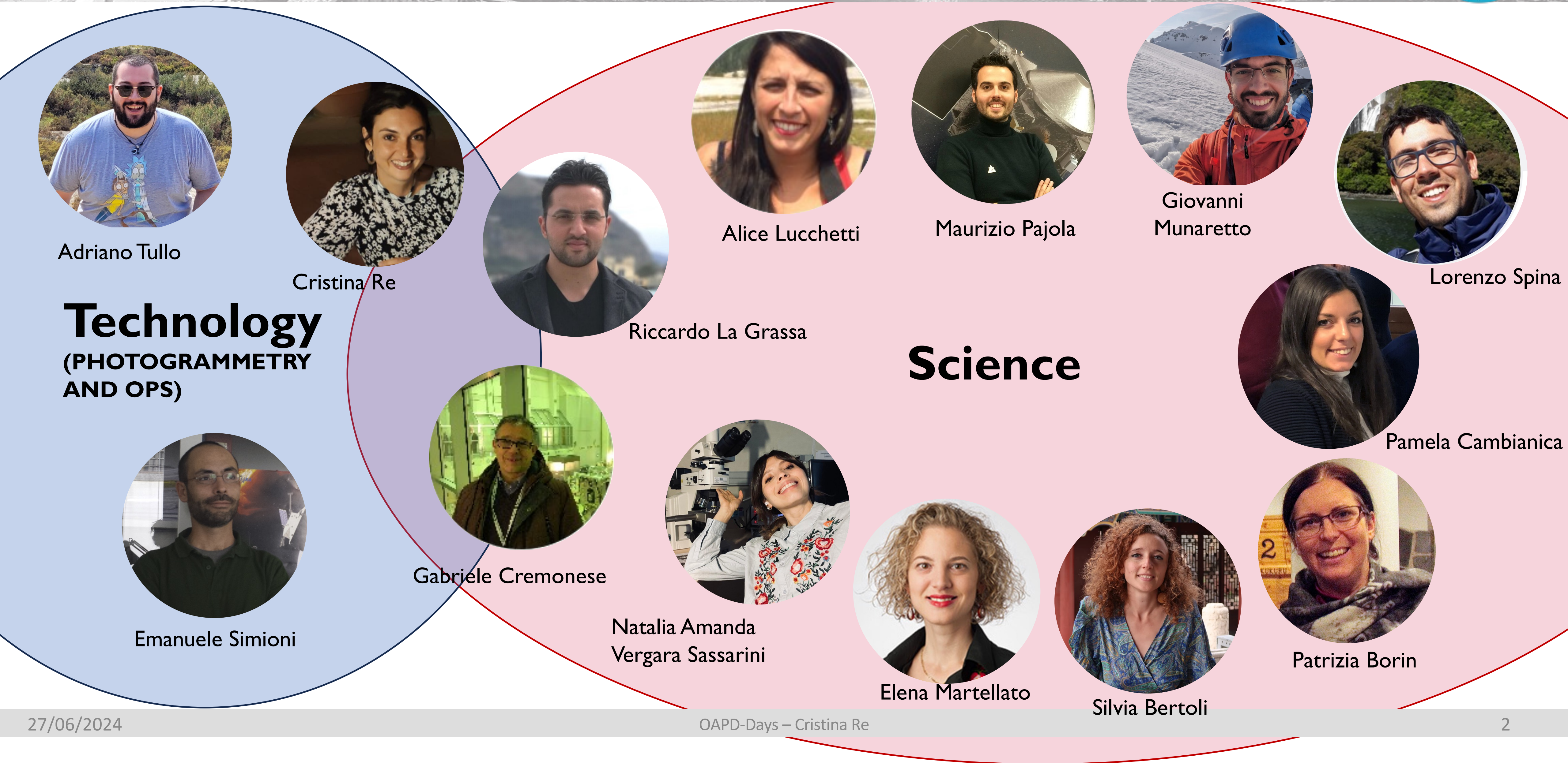
NATIONAL INSTITUTE FOR ASTROPHYSICS

RSN3/RSN5 IN OAPD FOR TERRESTRIAL PLANETS EXPLORATION

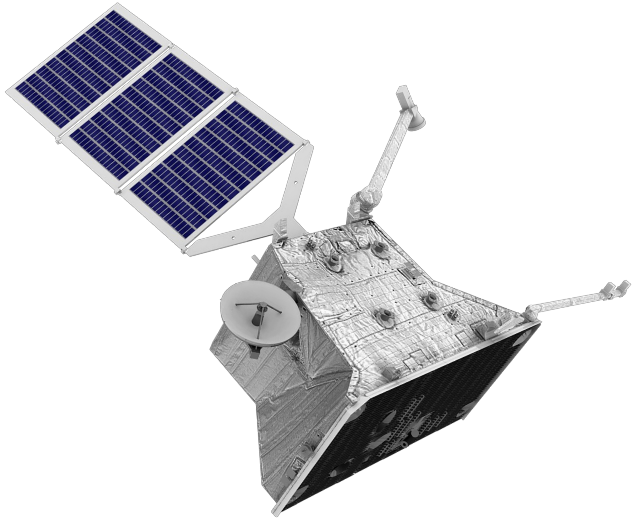


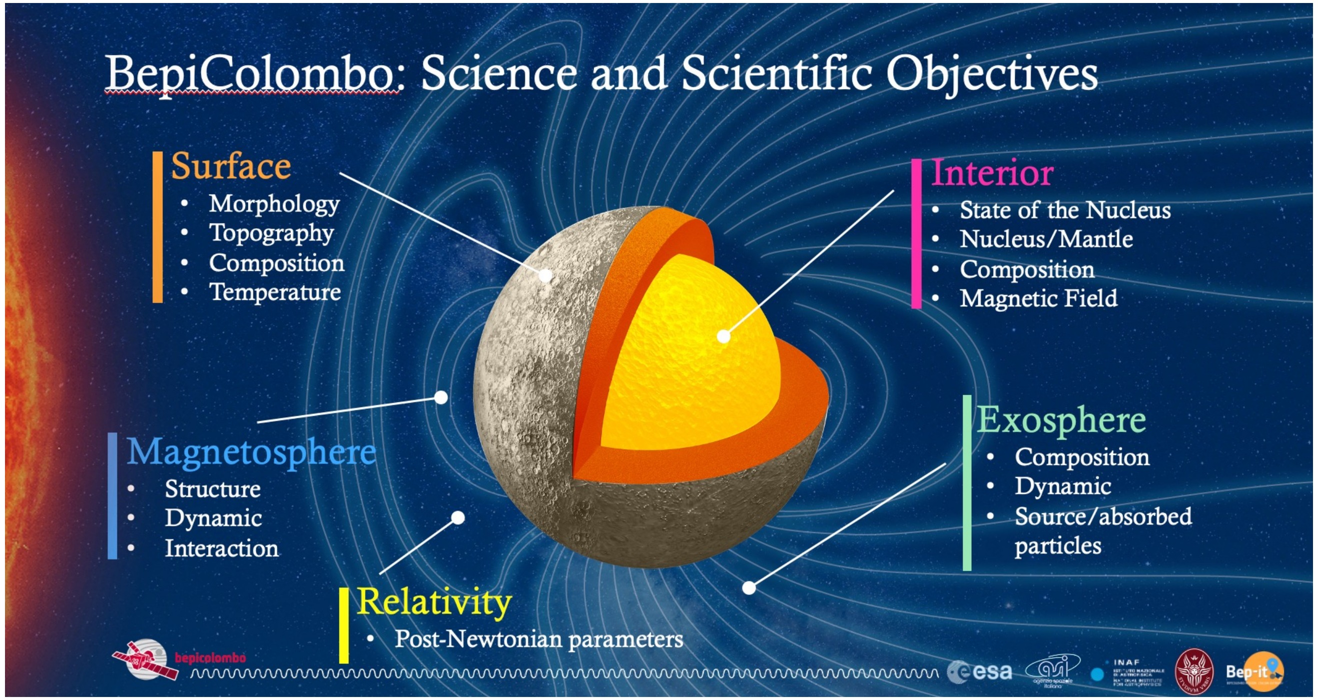
BepiColombo Mission:

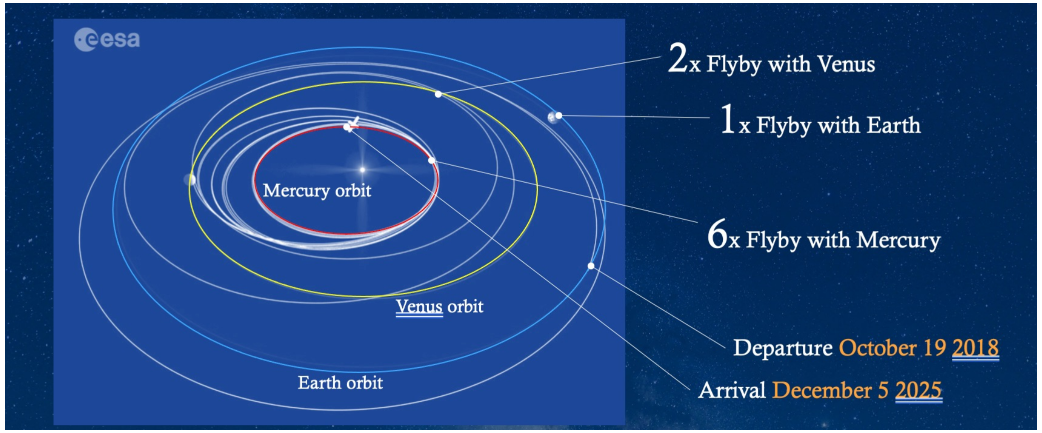
- ESA/JAXA to Mercury
- MPO: comprehensive and detailed study of the whole planet and its environment.

BC Chronology:

- October 2000: ESA select the mission within the Cosmic Vision program
- Beginning 2004 ESA deliver the Annoucement of Opportunity for selecting payload and scientific teams
- October 2009 system PDR
- Spring 2013 system CDR
- December 2014 system delta-CDR completed
- 19 October 2018 launch from Kourou
- Arrival to Mercury on December 2025







SIMBIO-SYS a REMOTE SENSING for MERCURY EXPLORATION

SIMBIO-SYS(Spectrometers and Imagers for MPO BepiColombo Integrated Observatory SYStem)

PI: Gabriele Cremonese
Co-PI: Cristina Re (STC overall responsibility)
Co-PI: Fabrizio Capaccioni (VIHI overall responsibility)
Co-PI: Pasquale Palumbo (HRIC overall responsibility)

Co-PI: Mathieu Vincendon (Main Electronics Calibration at system level)
Co-PI: Alain Doressoundiram (VIHI proximity electronics IR FPA proc. and calibration)

Sc.Coo. : Matteo Massironi (Science coordination)
TM: Carlo Bettanini (Instrument architecture Thermal structural design)

Industrial Prime: Leonardo s.p.a

CISAS G. COLOMBO

IAS orsay

LEONARDO

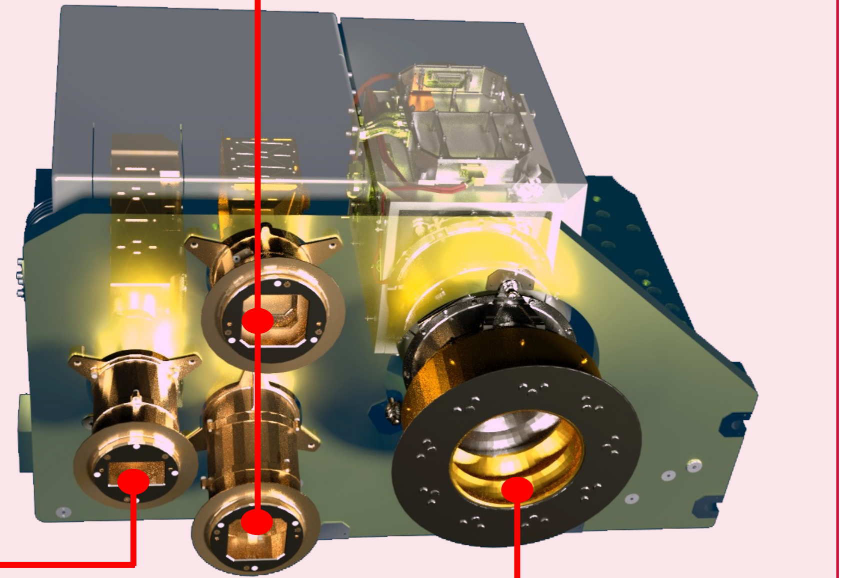
l'Observatoire de Paris | LESIA

Laboratoire d'Études Spatiales et d'Instrumentation en Astrophysique

The SIMBIO-SYS scientific team is composed by 56 Co-Investigators, 42 Associates

SIMBIO-SYS
SPECTROMETER·AND·IMAGERS FOR·MPO·BEPICOLOMBO INTEGRATED·OBSERVATORY·SYSTEM
HRIC STC STC VIHI

STC a double wide angle camera designed to image each portion of the Mercury surface from two different perspectives, providing stereo image pairs for the 3D reconstruction of the planet's surface.

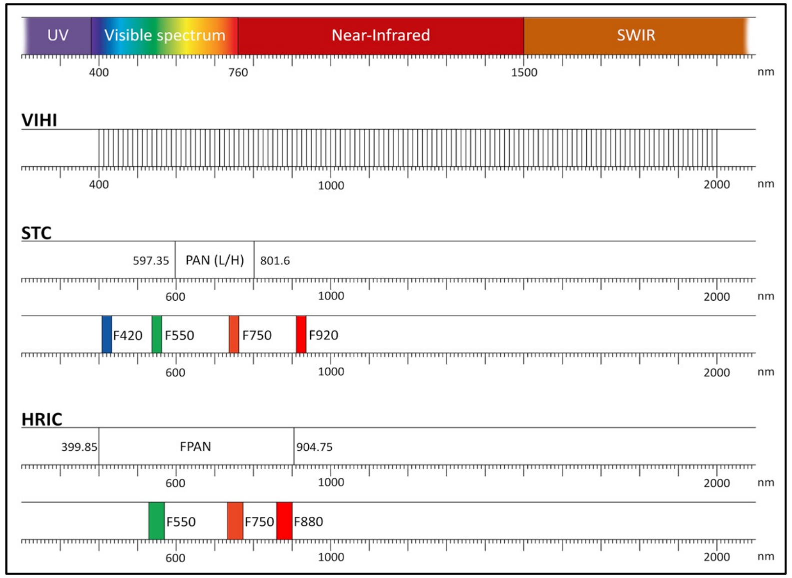


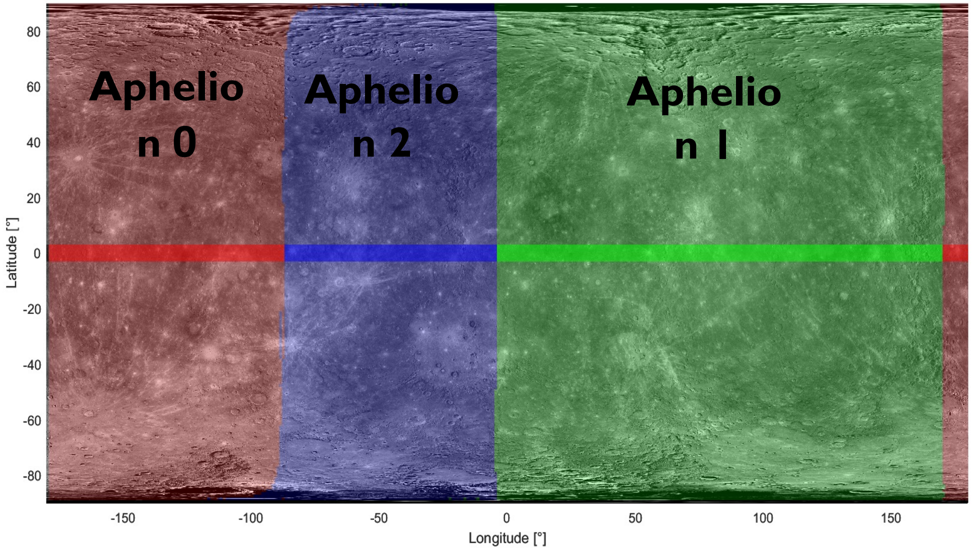
VIHI is a Vis/NIR spectrometer that will provide the hyper spectral global mapping of the surface. Its objective is to study the hermean surface composition.

HRIC is the high resolution camera. The main objective is to characterize relevant Mercury surface features at high resolution level.

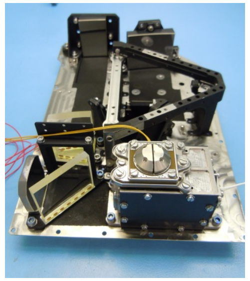
SIMBIO-SYS a REMOTE SENSING for MERCURY EXPLORATION

- **38% of the data volume** of the entire mission is allocated to SIMBIO-SYS. 980 Gbit per year (mostly data compressed by a factor 7).
- SIMBIO-SYS operations shall allow both global coverage and target-oriented observations
- All SIMBIO-SYS channels shall be able to operate in parallel to allow needed **operational flexibility**
- Co-registration and **data fusion** are enabled
- SIMBIO-SYS will provide **high-resolution images**, the **Digital Terrain Model** of the entire surface, and the **surface composition** using a wide spectral range, as for instance detecting sulphides or material derived by sulphur and carbon oxidation**, at resolutions and coverage higher than the MESSENGER mission.**
- All the data that will be acquired will allow to cover a wide range of scientific objectives, from the **surface processes** and **cartography** up to **the internal structure**, contributing to the **libration experiment**, and the **surface-exosphere** interaction.

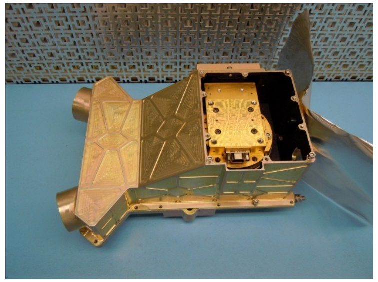




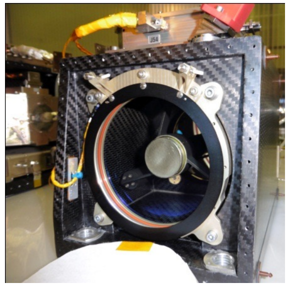
VIHI



STC



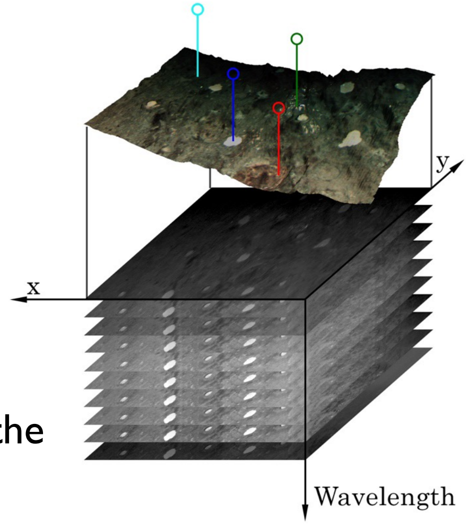
HRIC

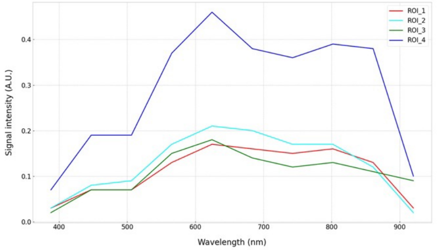


HYPSOS: HYPERSPECTRAL STEREO CAMERA

Starting from SIMBIO-SYS....

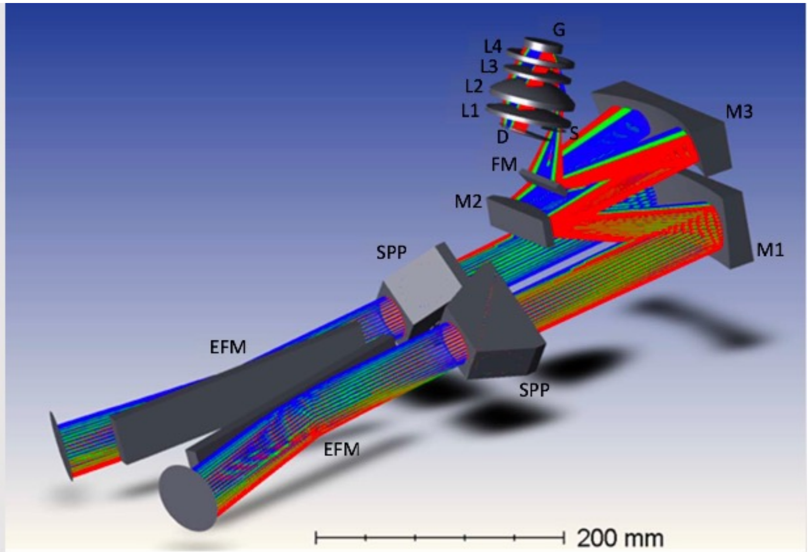
HYPSOS (HYPerspectral Stereo Observing System) combines two different approaches to studying the surface of a planet:
3D reconstruction with **hyperspectral reflectance providing stereo images at every wavelength of the visible**, with fine sampling at the spectral resolution of a spectrograph.

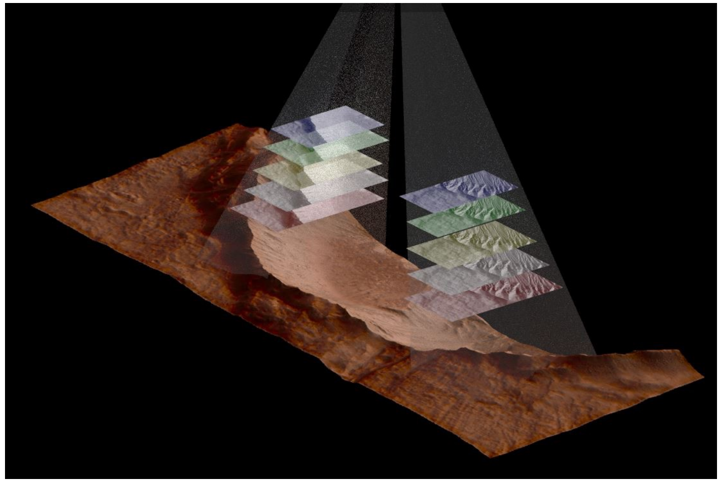




The morphology of any topographical feature will be *directly linked* to the composition of the same surface feature, through the hyperspectral data, similar to the approach by a mineralogist.

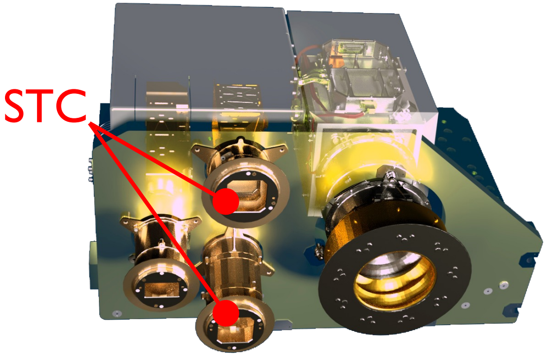
- **Patent deposited** 01/09/2016, M.Tordi (EIE), G.Naletto, G.Cremonese, C.Re
(n. 102016000097439: "DISPOSITIVO STEREOIPERSPETTRALE PERFEZIONATO")
- **ASI-INAF** Agreement n.2018-16-HH.O *Study activity for the national scientific community on Sun, Solar System and Exoplanets [KO 2020 March]*

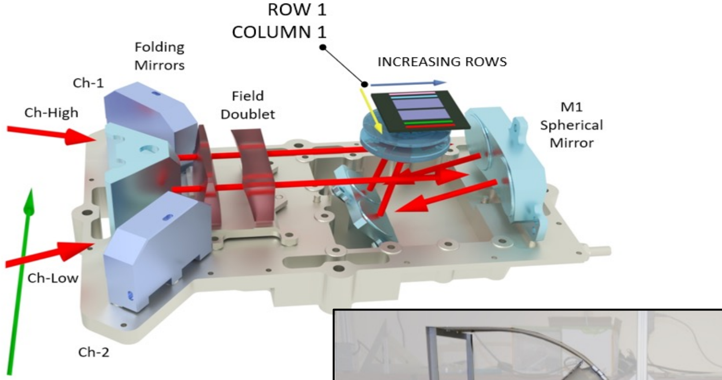


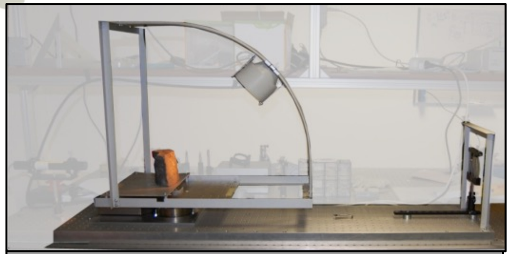


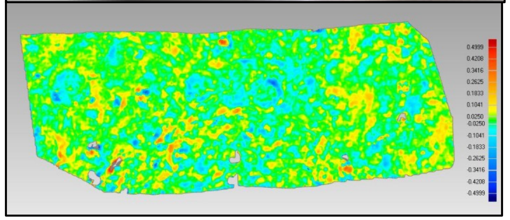
SIMBIO-SYS Stereo Channel STC:

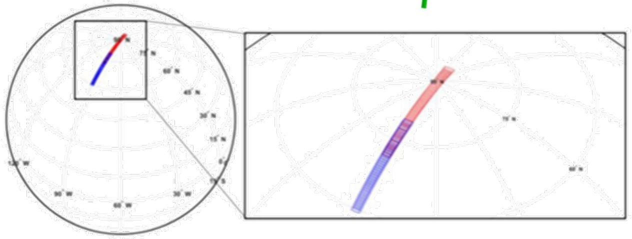
- OPTICAL DESIGN
- CALIBRATION CAMPAIGN:
  - -Radiometric Calibration
  - -Geometric Calibration
- STEREO VALIDATION
- STEREO PIPELINE
- PERFORMANCES and OPS.
- SCIENCE

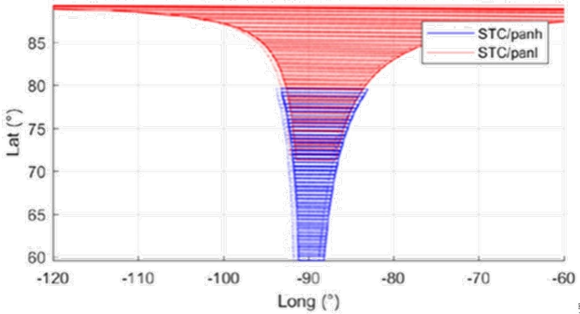


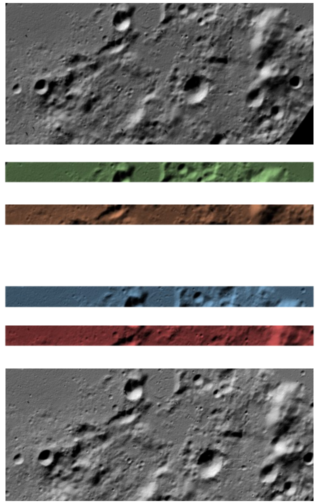


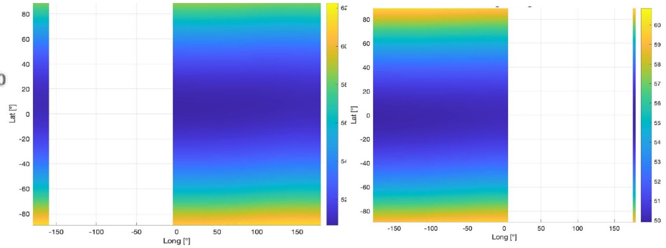






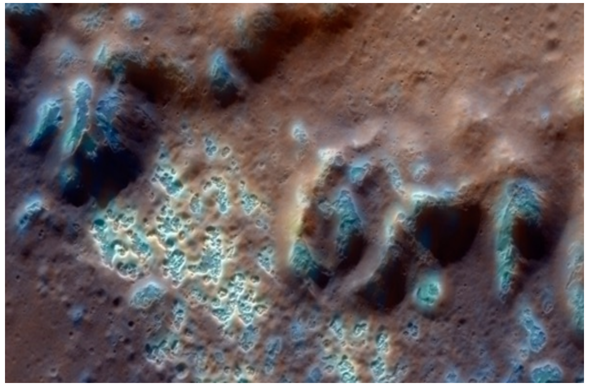


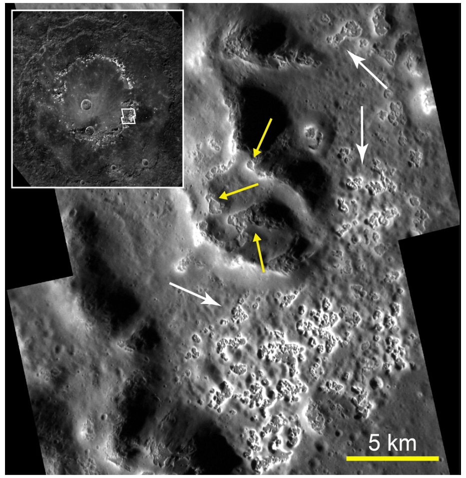




Mercury's polar *water ice deposits*, putative *pyroclastic deposits* from explosive volcanism, and *hollow* landforms are features that exhibit the complexity of the distribution of volatiles on Mercury.

- What is the nature of the volatile elements trapped beneath the surface, like the **hollows**?
- How are the volatiles preserved during Mercury's formation, are the volatiles delivered to Mercury at a later phase?

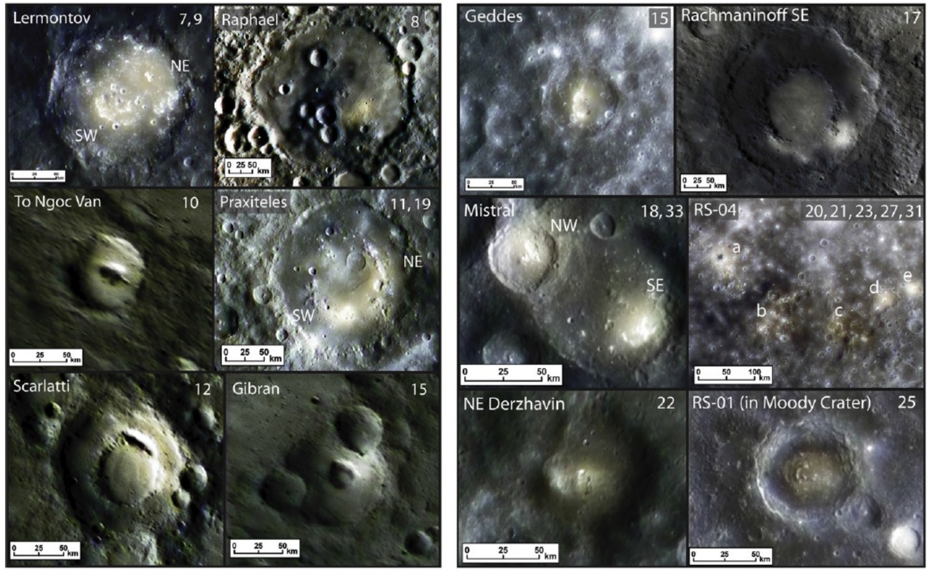




Shallow, irregular, rimless, flat-floored depressions with bright interiors and halos, often found on crater walls, rims, floors and central peak whose nature is still unknown (Blewett et al., 2011,2013).

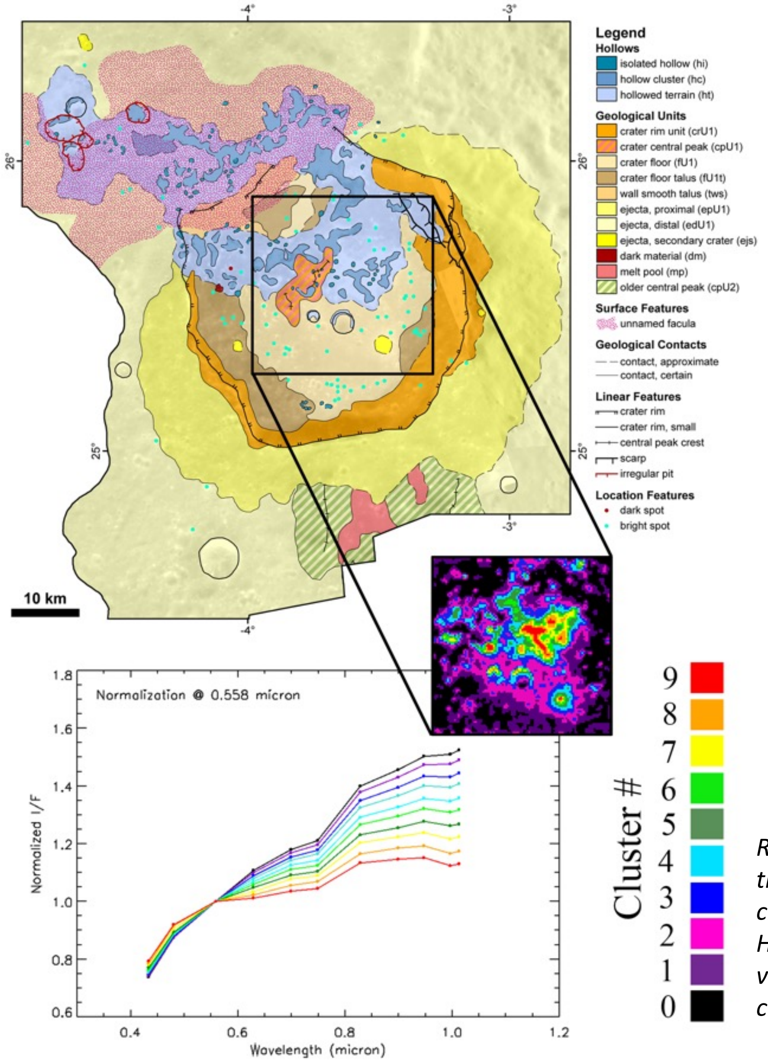
Understanding the composition of these features provides additional information on Mercury's surface characterization.

Pyroclastic and other volcanic deposits represent important sources of information about planetary structure, composition (including volatile content), stress state, and thermal history (Wilson, 2009).



Pyroclastic deposits are **explosive volcanic eruption products** formed by the fragmentation and upward propulsion of magma particles driven by the expansion of volatile species released from rising bodies of magma (e.g., Wilson and Head, 1981).

SPECTRAL CLUSTERING AND GEOMORPHOLOGICAL ANALYSIS OF HOLLOWS (Lucchetti et al.)



Result coming from the comparison between the geological map and the spectral clustering analysis for Canova crater. Hollows are here identified by a well-defined visible spectrum, which is represented by cluster #9.

SPECTRAL CLUSTERING

statistical clustering over the entire dataset based on a **K-means partitioning algorithm** developed and evaluated by Marzo et al., (2006, 2008, 2009) and makes use of the Calinski and Harabasz criterion (Calinski, T., Harabasz, J., 1974) to find the intrinsically natural number of clusters, making the **process unsupervised.**

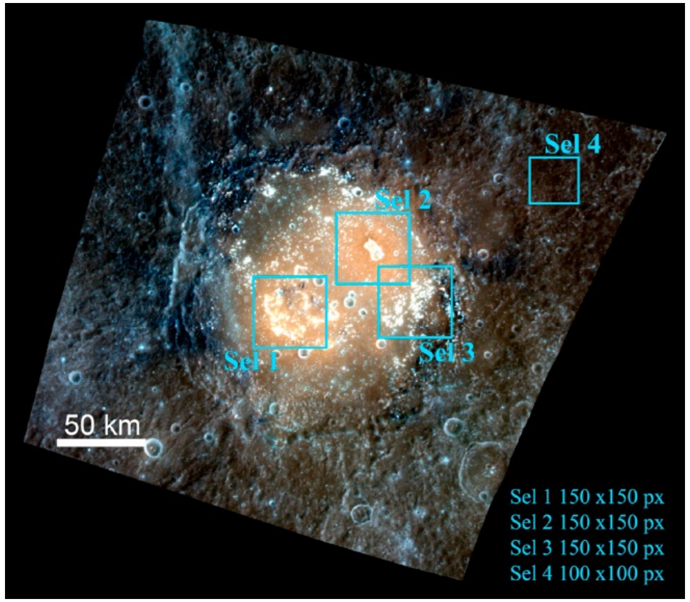
↓

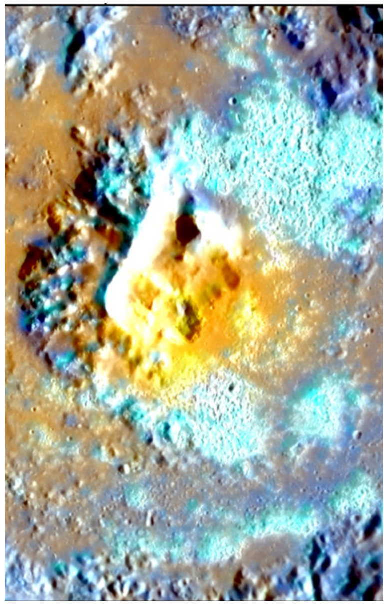
CORRELATION BETWEEN SPECTRAL UNITS AND GEOLOGICAL ONES

Comparison between spectra and geomorphological map reveals a correlation between different spectral units and geological ones. **Hollows in different craters are identified by a similar spectrum.**

Hollows are the expression of both the remnants of materials from devolatilization and bedrock forming material *(Lucchetti et al., 2018).*

CORRELATION BETWEEN HOLLOWS AND PYROCLASTIC DEPOSITS (Pajola et al. and Lucchetti et al.)



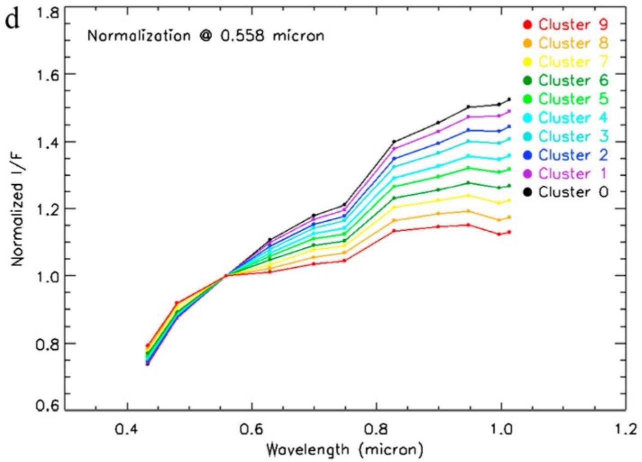


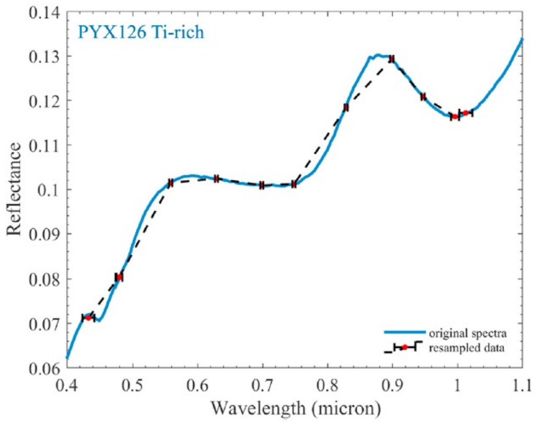
How is the correlation between <u>hollows</u> and other structures located on the surface of Mercury, such as <u>pyroclastic deposits</u>?

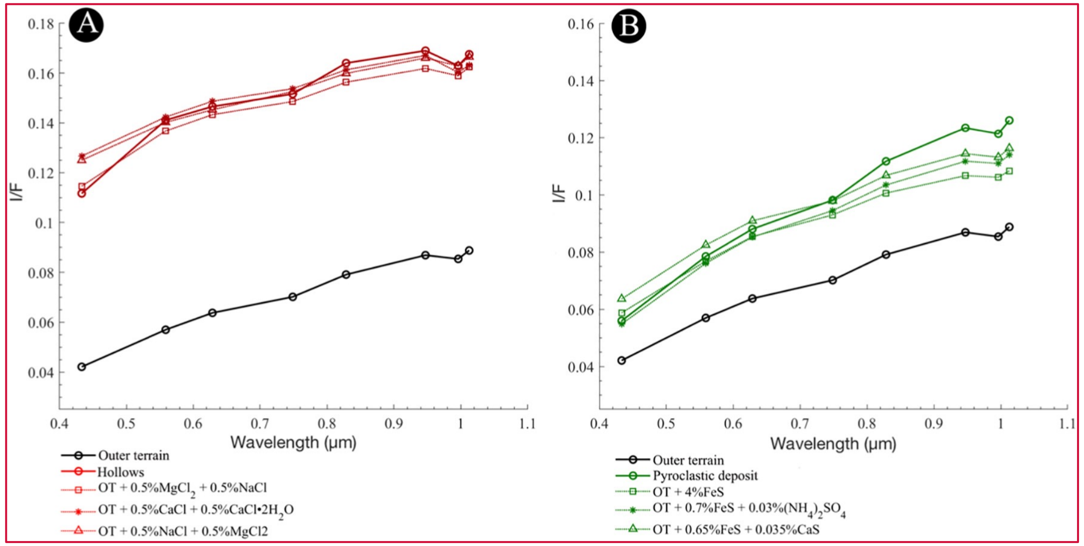
Are the Vis Spectra comparable?

Are there differences between them?

- **Statistical clustering** over the entire dataset based on a **K-means partitioning algorithm.**
- Resampling of the spectra though MDIS WAC bandpasses
- Bands Identification and comparison





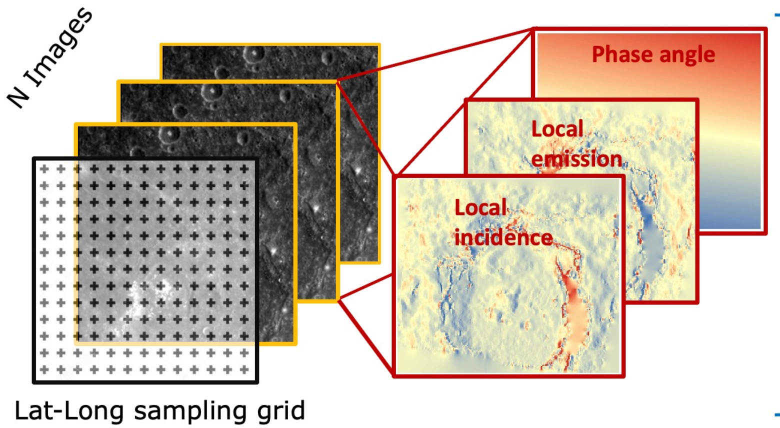


PHOTOMETRIC MODELLING (Munaretto et al.)

- Collect multiple measurements of flux under different illumination and observation directions from 8-filter MDIS/WAC observation of Hollows at Canova and Tyagaraja craters, Mercury

- Fit photometric models to the data collected in 1). As in Domingue et al., (2016) we consider the Hapke and Kasalaainen-Skhuratov models

flux → Photometric angles → Model parameters



Hapke

$$r(\theta_0,\theta,g)=\frac{\omega}{4\pi}\frac{\mu_{0e}}{(\mu_{0e}+\mu_e)}\{[1+B(g)]P(g)+H(\mu_{0e})H(\mu_e)-1\}S(\theta_0,\theta,g)$$

Kasalaainen-Skhuratov

$$KS_1=A_N e^{-\alpha\mu}\frac{2\cos i}{\cos i+\cos e},$$

$$KS_2=A_N e^{-\alpha\mu}\cos\left(\frac{\alpha}{2}\right)\cos\left[\frac{\pi}{\pi-\alpha}\left(\gamma-\frac{\alpha}{2}\right)\right]\frac{(\cos\beta)^{\alpha/(\pi-\alpha)}}{\cos\gamma},$$

$$KS_3=A_N e^{-\alpha\mu}\left[c_l\left(\frac{2\cos i}{\cos i+\cos e}\right)+(1-c_l)\cos i\right],$$

$$KS_4=A_N e^{-\alpha\mu}(\cos i)^k(\cos e)^{k-1},$$

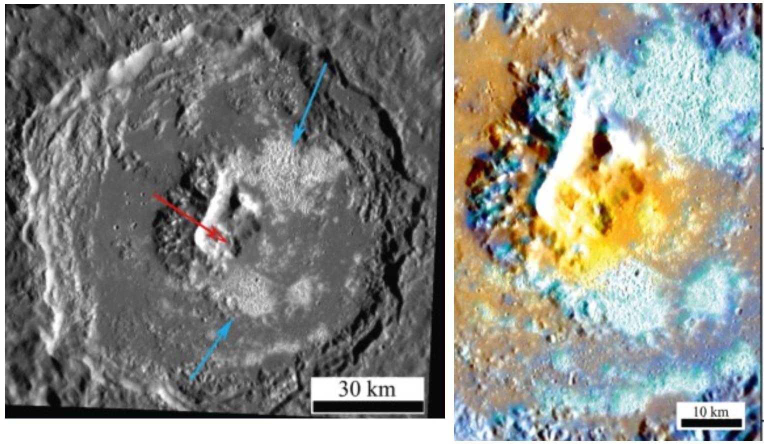
$$KS_5=A_N e^{-\alpha\mu}\cos\left(\frac{\alpha}{2}\right)\cos\left[\frac{\pi}{\pi-\alpha}\left(\gamma-\frac{\alpha}{2}\right)\right]\frac{(\cos\beta)^{\eta\alpha/(\pi-\alpha)}}{\cos\gamma}.$$

$$KS_6=A_N\frac{e^{-\mu_1\alpha}+me^{-\mu_2\alpha}}{1+m}\times\cos\left(\frac{\alpha}{2}\right)\cos\left[\frac{\pi}{\pi-\alpha}\left(\gamma-\frac{\alpha}{2}\right)\right]\frac{(\cos\beta)^{\eta\alpha/(\pi-\alpha)}}{\cos\gamma}.$$

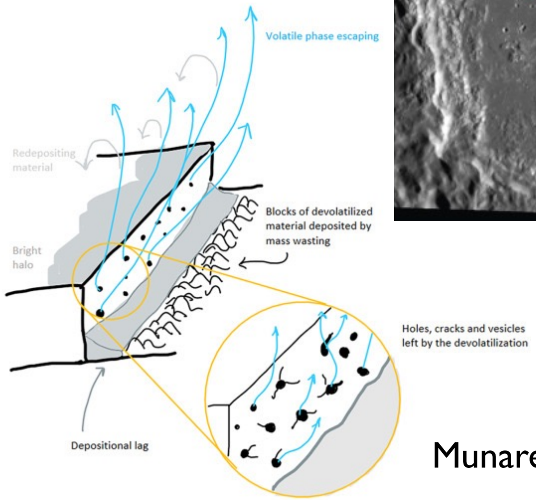
Link the observed surface brightness with parameters related to physical properties of the surface

AIMS:

- ANALYSIS OF SCATTERING PROPERTIES OF MERCURY'S SURFACE: through the analysis of photometric models for different surface features (hollows, pyroclastics, LRM, fresh rays etc …)
- SUPPORT SPECTROPHTOMETRIC ANALYSES: by estimating accurate, material specific photometric corrections
- CALIBRATION OF OBSERVED RADIANCES : comparison between observed / predicted reflectances, in prep. for SIMBIO-SYS@BepiColombo
- CHARACTERIZATION OF STC COLOR FILTERS: analyze the filters performances in distinguishing different spectral units.

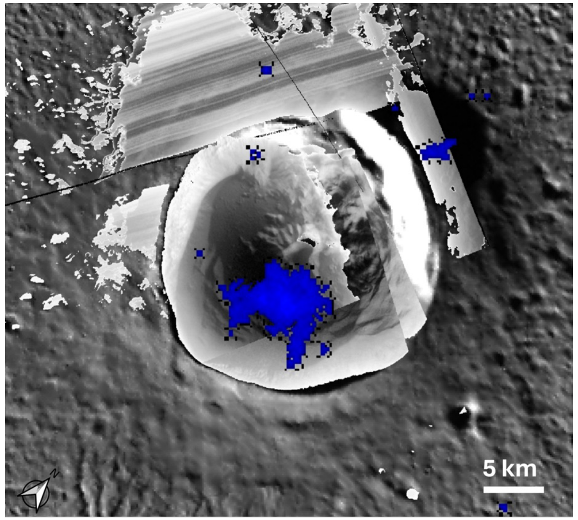


Lucchetti et al., (2021)

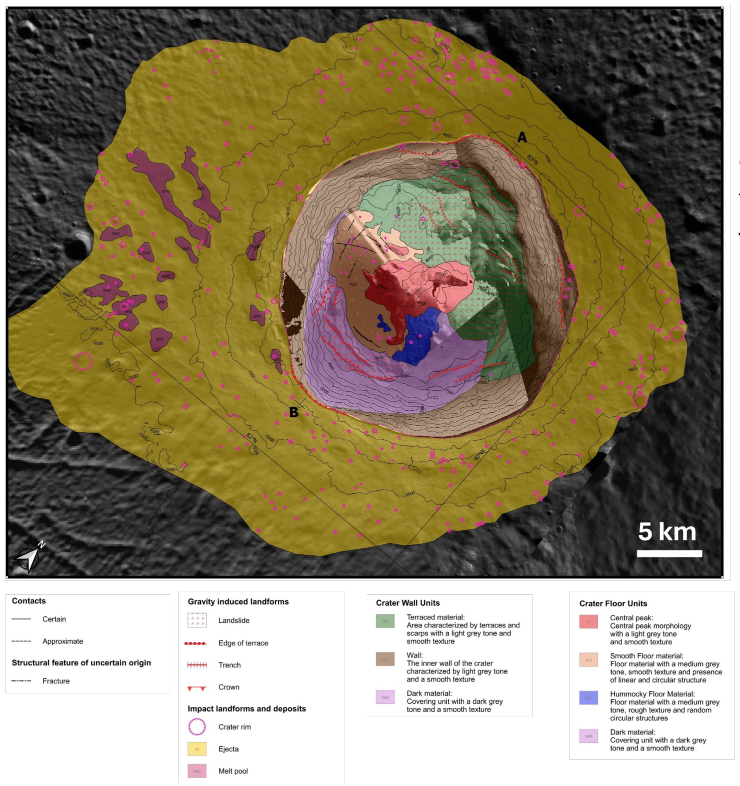


Munaretto et al., (2023)

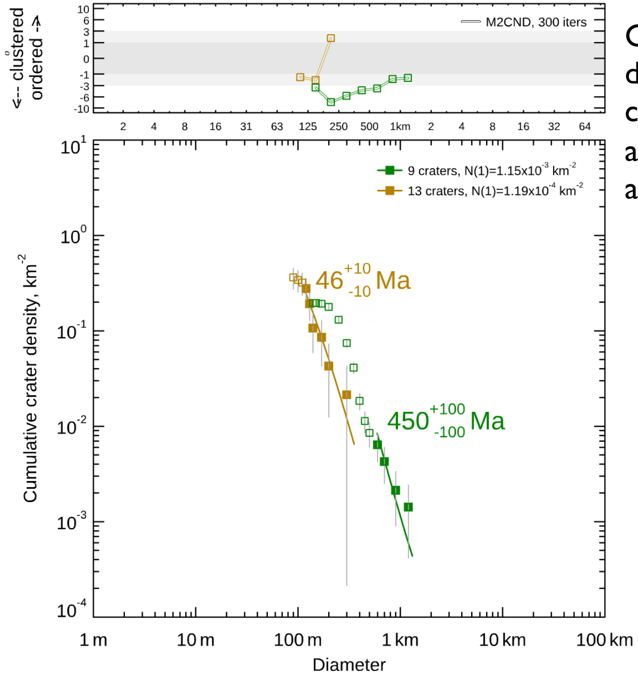
CARTOGRAPHY, AGE DETERMINATION, IMPACT AND THERMAL MODELLING OF HERMEAN POLAR CRATERS



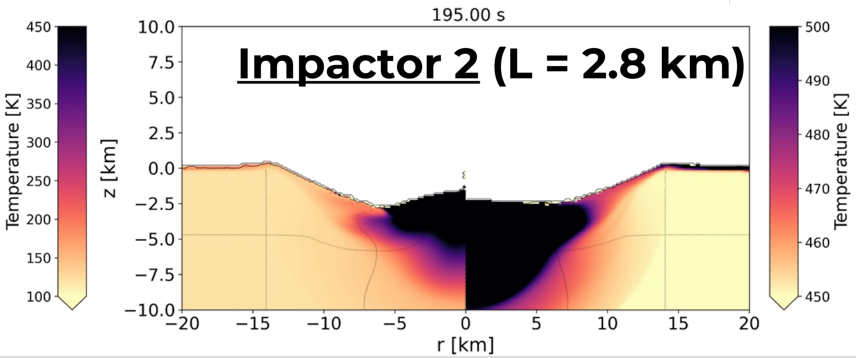
Fuller crater overlapped by the radar bright deposit (in blue).



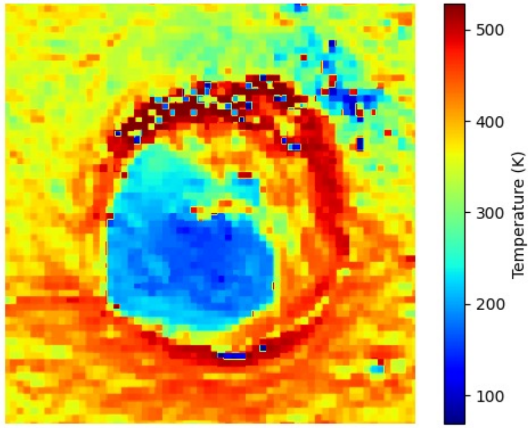
Geological map of Fuller crater taken from **Bertoli et al.**



Cumulative size frequency distribution of the crater counted in the floor (yellow) and ejecta (green) units, with age determination.

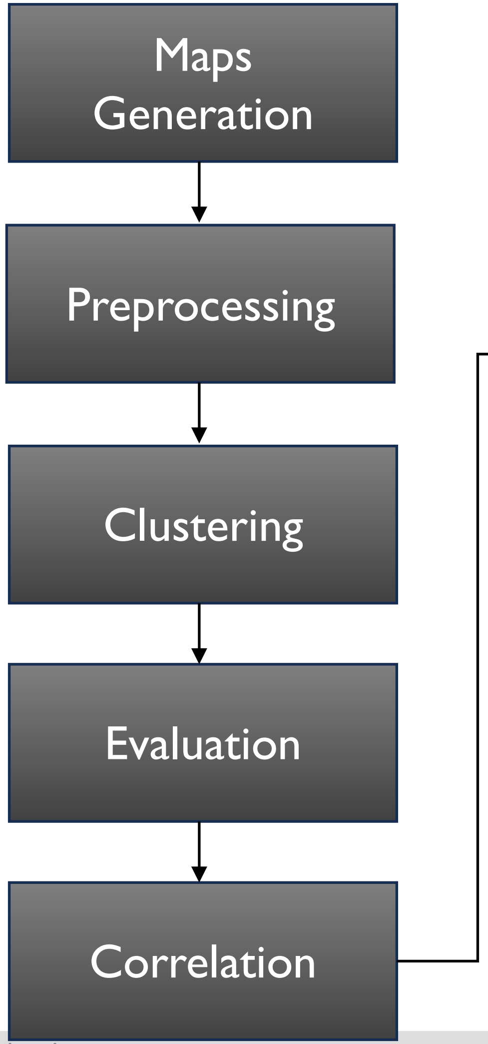


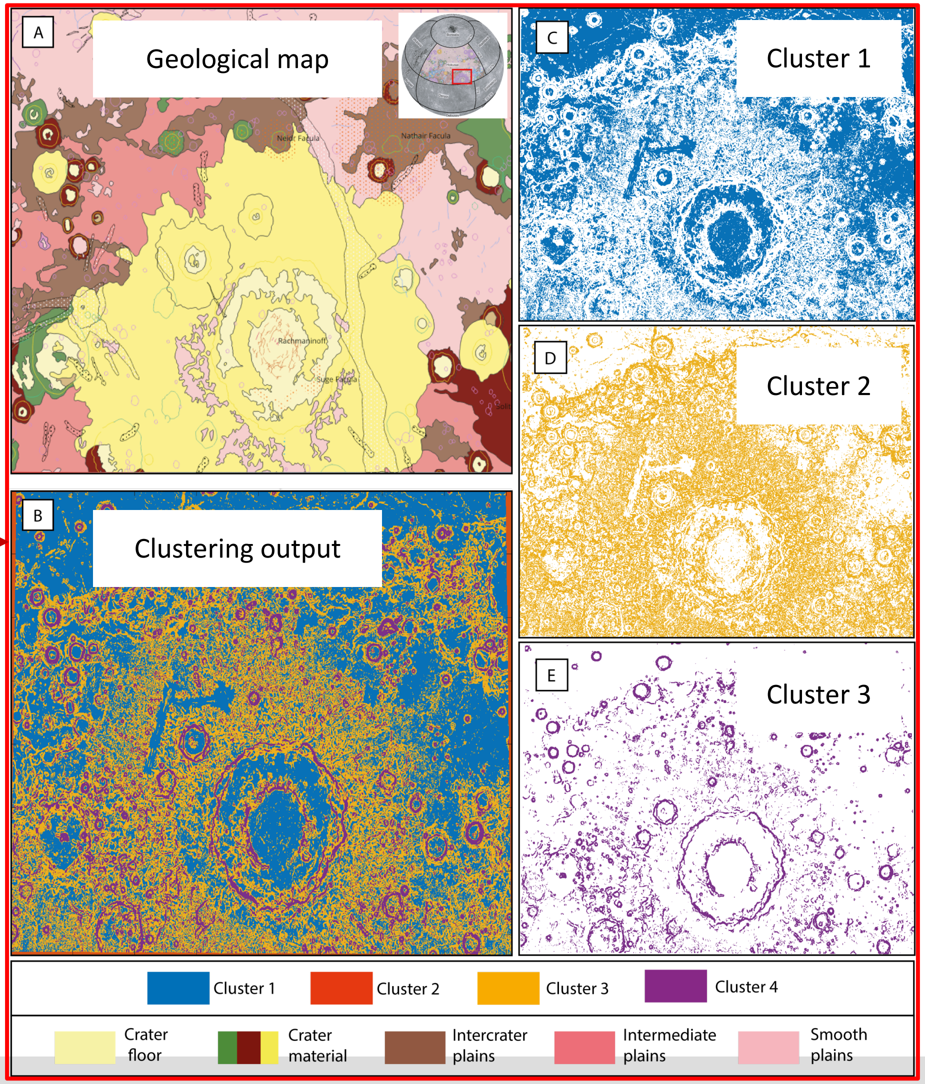
Impact numerical modelling **(Martellato et al.)**



Thermal modelling **(Cambianica et al.)**

CAN UNSUPERVISED LEARNING AID THE GENERATION OF (explorative) GEOLOGICAL MAPS?



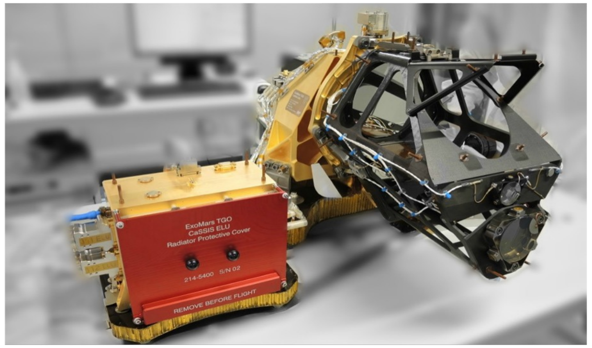


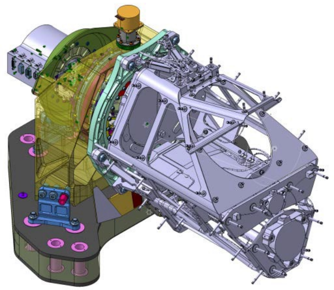
Example of a Gaussian Mixture clustering algorithm applied to the ruggedness map (TRI) of Rachmaninoff Basin (H05) area.

INVOLVMENT IN SCIENTIFIC PROJECTS: MARS

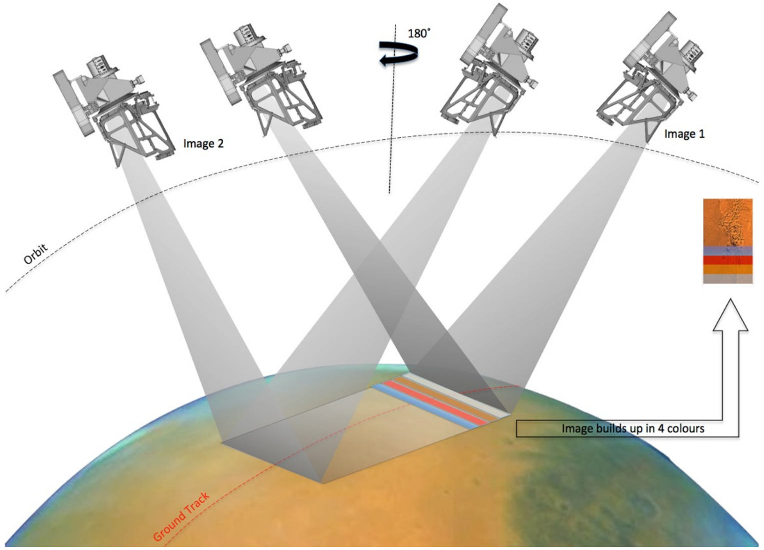
ExoMars:

- ESA/Roscomos to Mars (conception 2011, launch 2016, scientific mission 2018)
- Trace Gas Orbiter (TGO)
- CaSSIS (Colour and Stereo Surface Imaging System)
  - PI: Nicolas Thomas
  - Co-PIship: Gabriele Cremonese
  - OAPD-Team Responsible for DTM archiving and generation



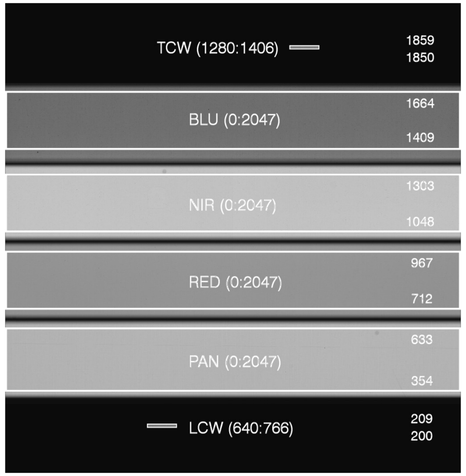


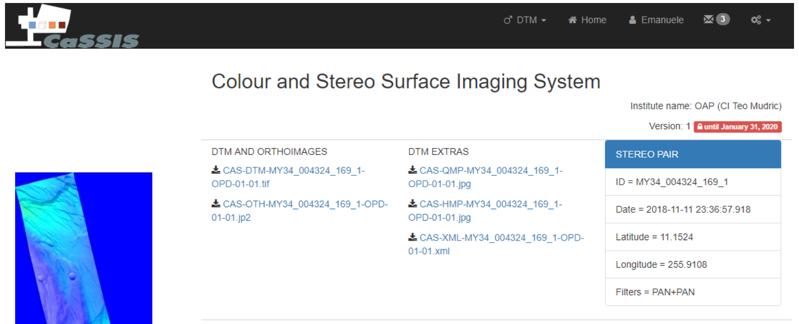
- Key concept is the rotation mechanism to produce stereo pair
- Four colour filter bands oriented with their longer dimension perpendicular to the ground-track direction
- Framelets with a repetition rate syncronized to the ground track velocity
- Overlap between successive framelets to allow accurate mosaicking

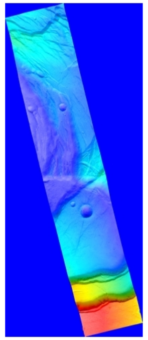


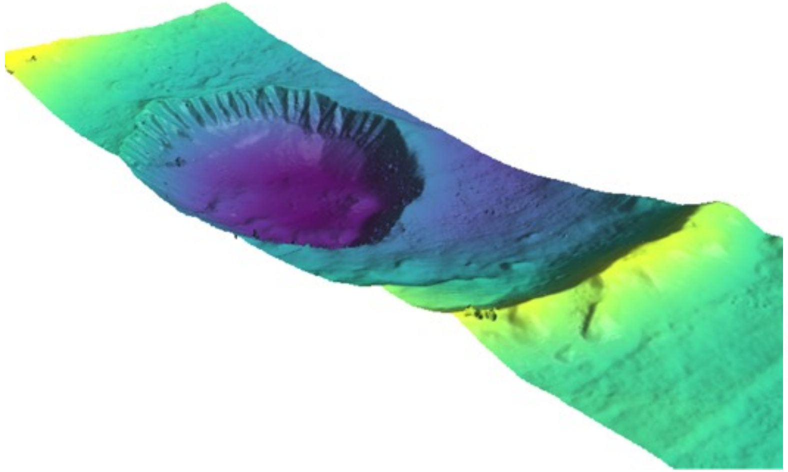
CaSSIS:

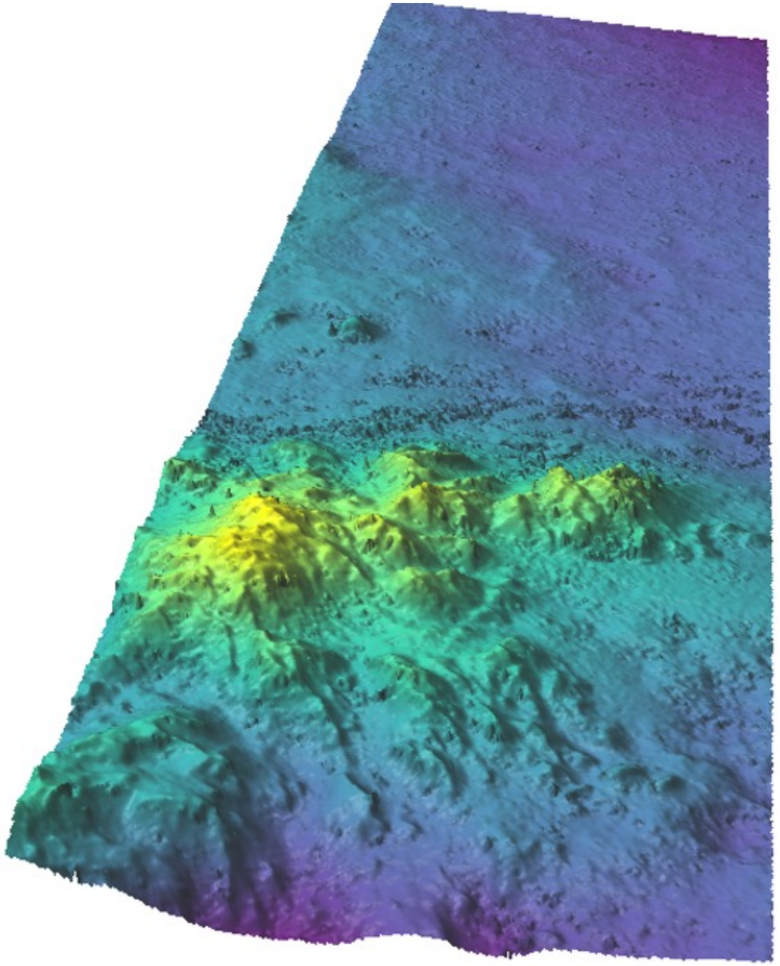
- DETECTOR, the focal plane system is a spare from SIMBIO-SYS
- Contribution in CALIBRATION CAMPAIGN
- DTM generation
- STEREO PRODUCT REPOSITORY (web-based)
- CaSSIS Stereo Data ingestion in ASI-MATISSE
- SCIENCE





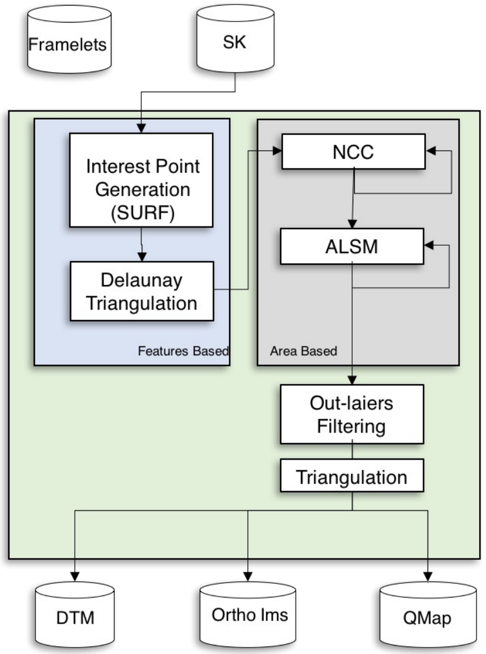


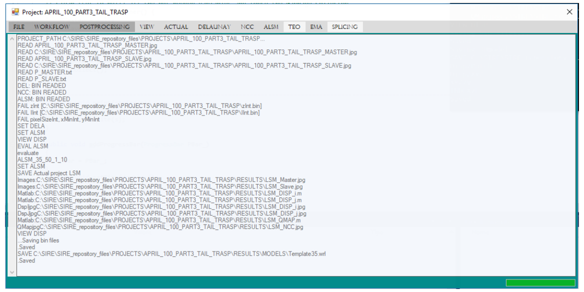


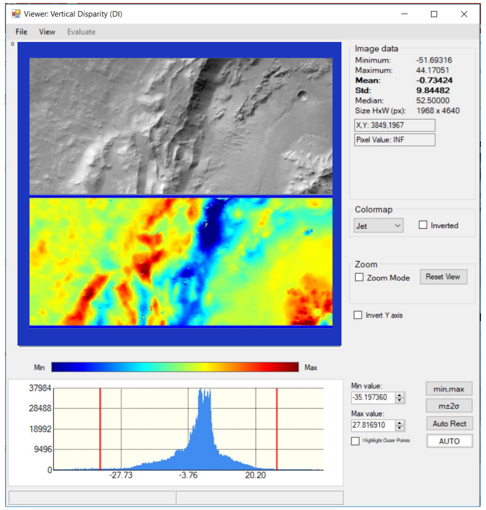


STEREO PROCESSING PIPELINE

Novel photogrammetric pipeline (CaSSIS Reader + 3DPD) for the processing of the stereo images of **CaSSIS** (a starting point for the future procedures that will be applied to Stereo Camera **STC** for the BepiColombo mission to Mercury) (Simioni et al. 2021, Re et al, 2022)







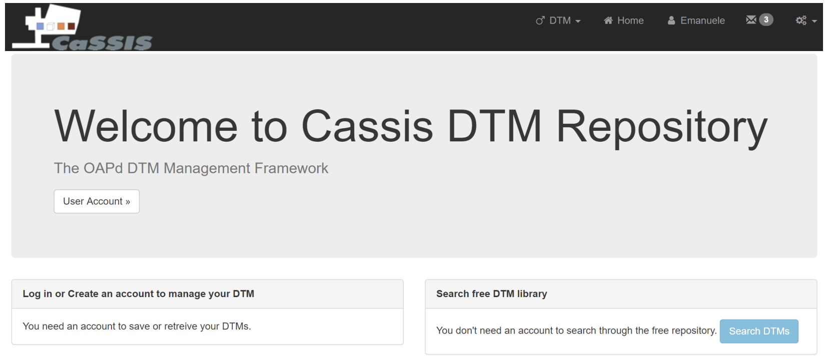
CaSSIS Repository hosted @ OAPD and accessible to the public via a dedicated web-page ([http://cassis.oapd.inaf.it/)](http://cassis.oapd.inaf.it/).

It provides the ability of on-line visualization and download of the stereo products that are delivered periodically after their validation.

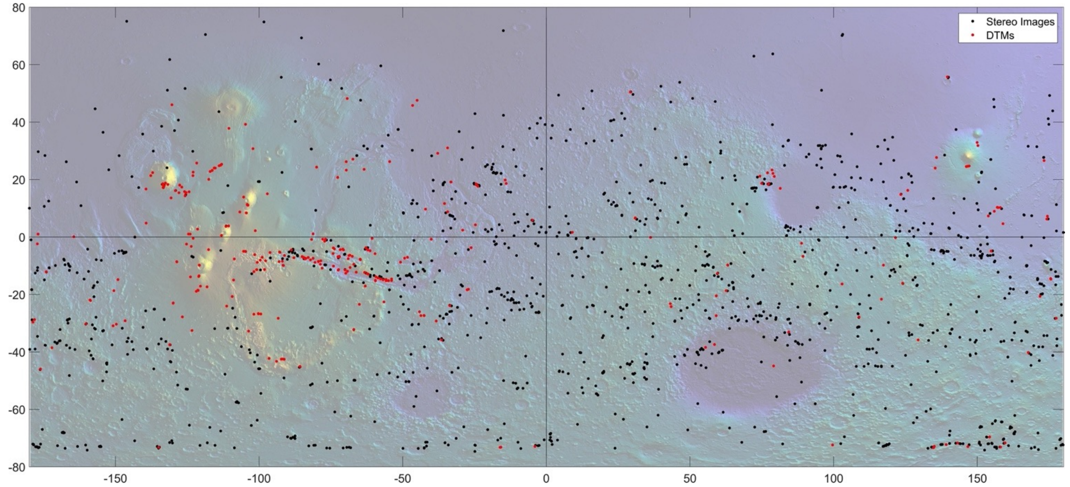
CaSSIS Repository nowadays hosts:

<u>1800 products linked to DTMs</u>

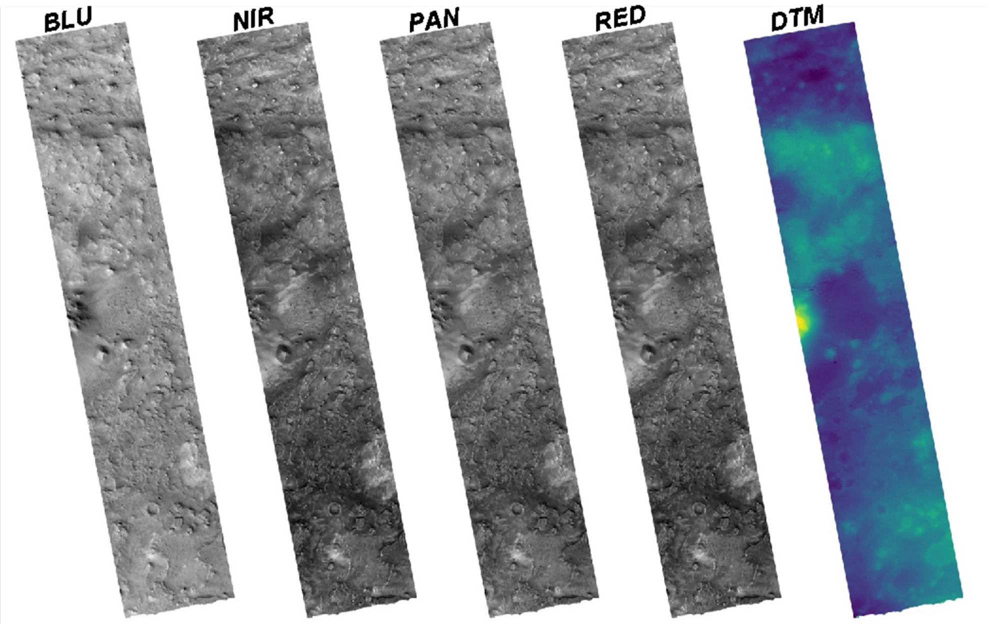
<u>435 Anaglyphs</u>

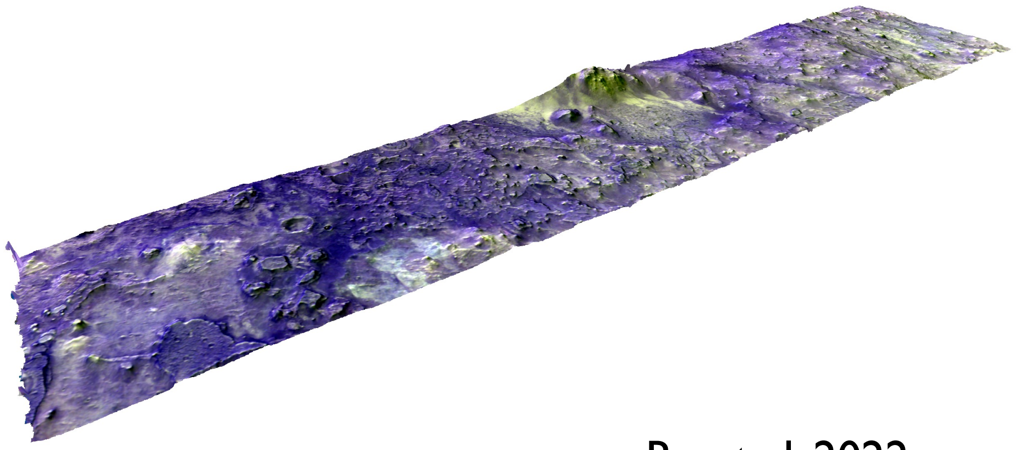


STEREO PRODUCTS @ OAPD



2100 stereo couples---400 DTM

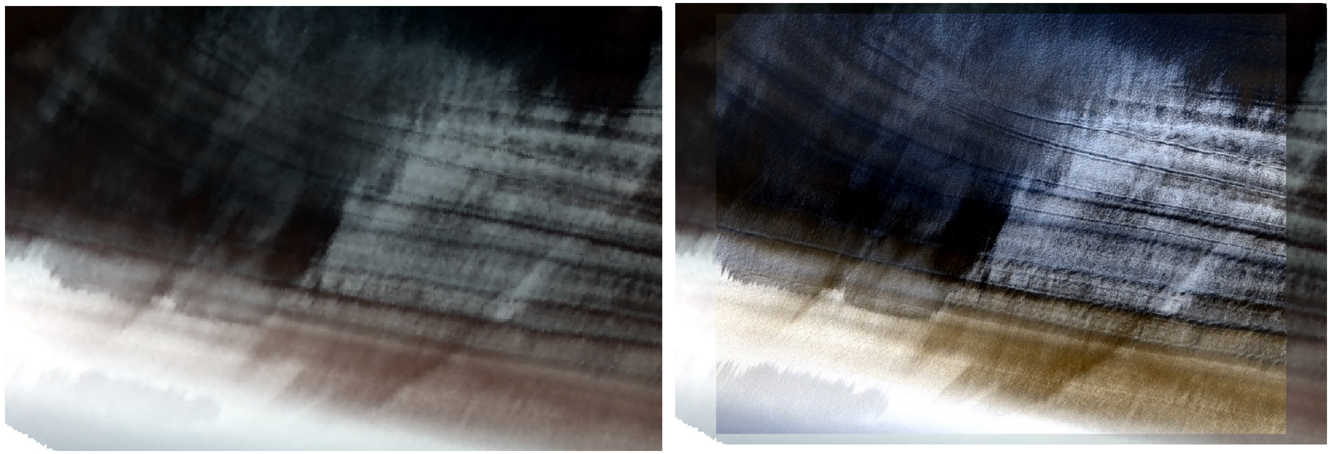


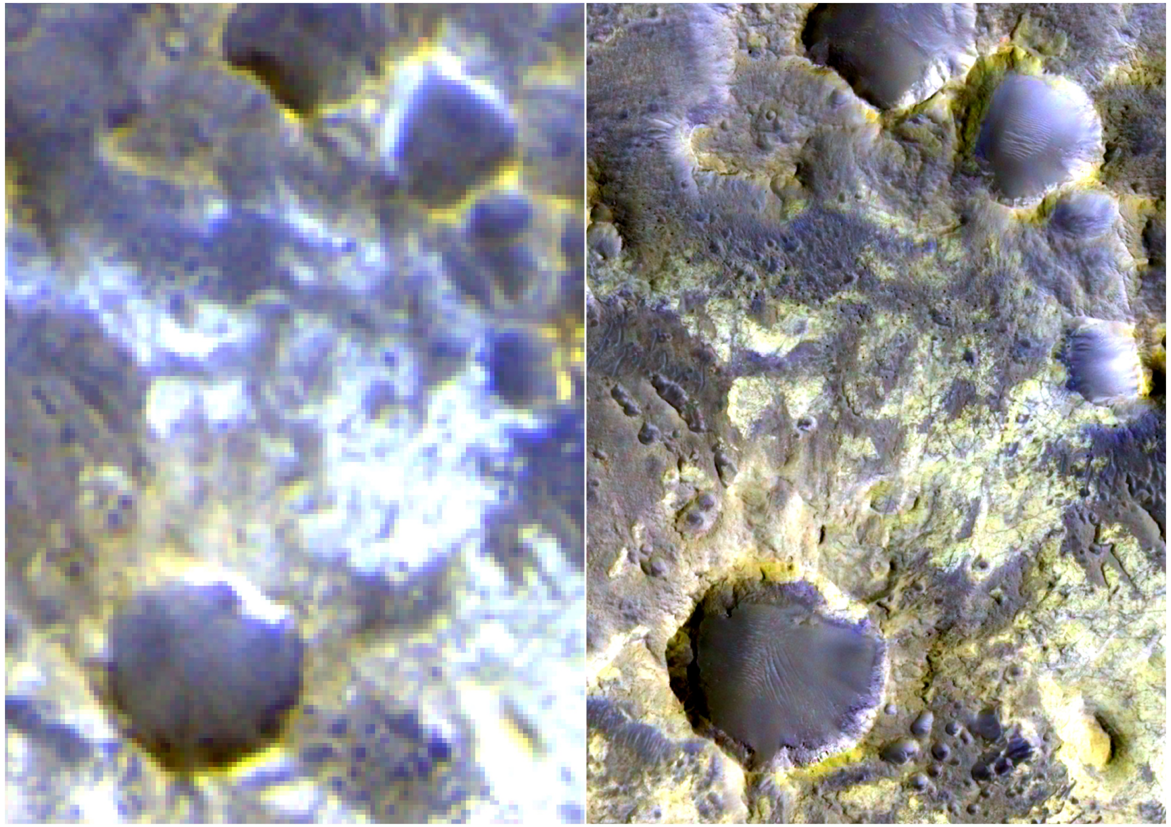


Re et al, 2022

DATA FUSION WITH PANSHARPENING (Tullo et al.)

Pansharpening represents a family of data fusion and radiometric transformation techniques that aim to merge lower-resolution multispectral data with a high-resolution panchromatic base image. Different techniques have been in continuous development for almost forty years since the inception of his theory.





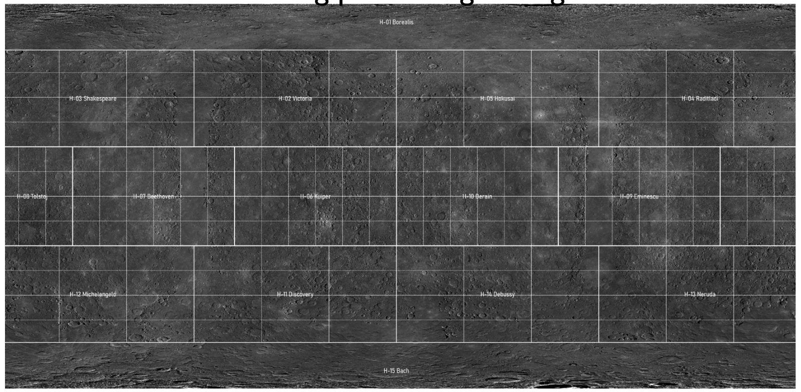
16x resolution increase obtained with **Pansharpening** from 4.5 m/px the original CaSSIS resolution (to the left) to 0.25 m/px, using a modified MMSE algorithm

PHOTOGRAMMETRIC ACTIVITIES

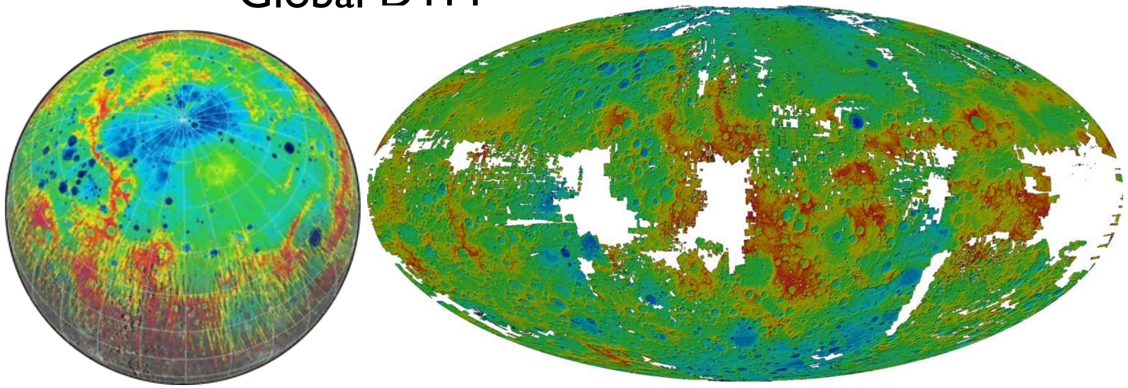
OAPD as World Reference for **PLANETARY PHOTOGRAMMETRY**

- High competences in 3D reconstruction from stereo processing:
  We are leaders for Digital Terrain Models from CaSSIS stereo pairs thanks to our stereo pipeline (3DPD SW).
- We design the first push-frame stereo camera (STC) and we are developing the entire photogrammetric data processing of the complete stereo image coverage of Mercury.
  - **MOSAICKING** tool
  - **BUNDLE ADJUSTMENT** tool for **CO-REGISTRATION**
  - **DTM, ORTHOIMAGE** generation, **PANSHARPENED** images
- We will process:
  # STC STEREO PAIRS for GM: 518 acq. for orbit, 373 k for GM
- STC stereo products:
  - BEST SPATIAL RESOLUTION: ~40 m (at the end of the extended period)
  - WORSE SPATIAL RESOLUTION: ~ 225 m (first aphelion at Poles)
  - VERTICAL ACCURACY (Mission Requirements): 80 m

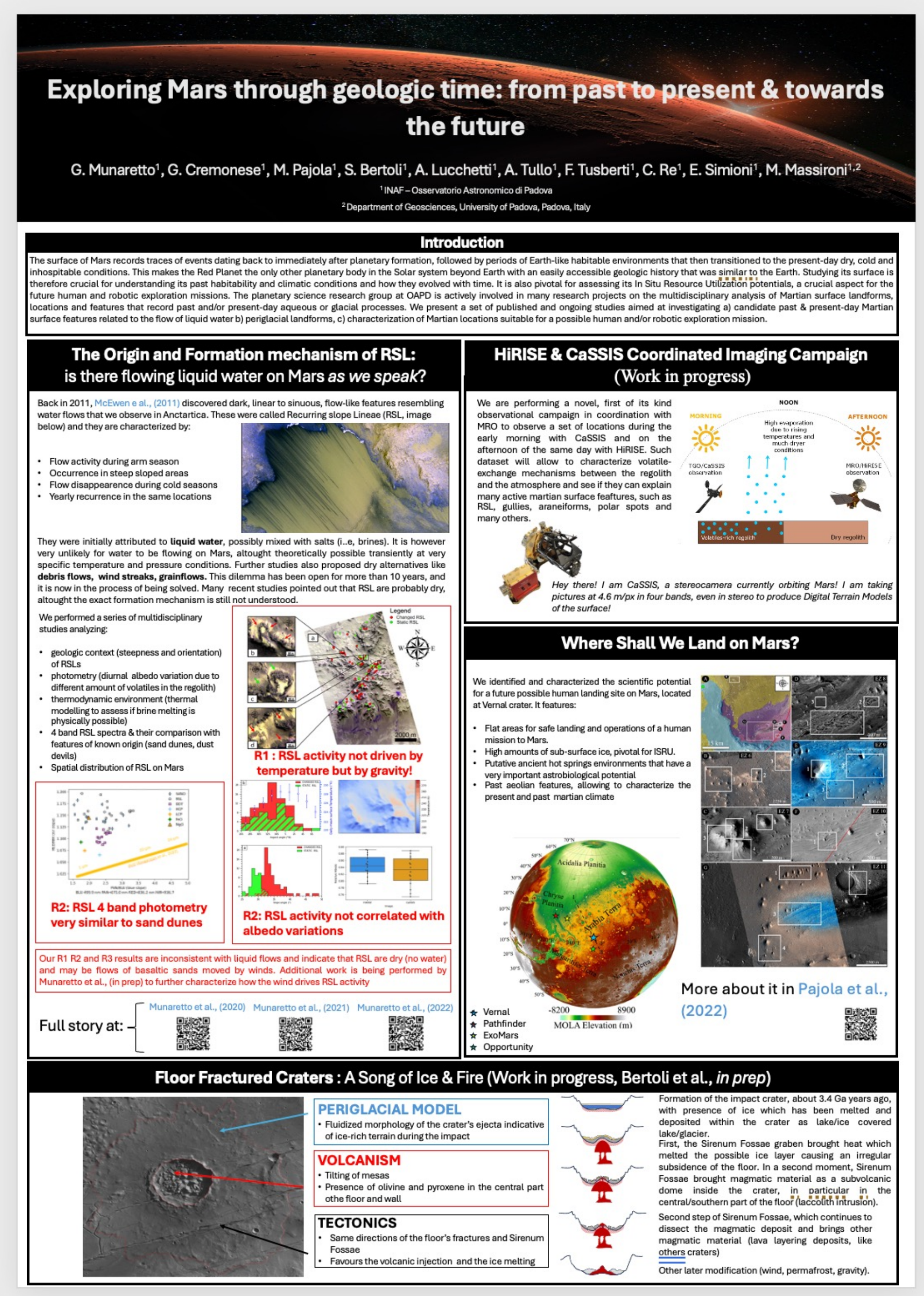
Mosaicking processing management



Global DTM



SCIENCE ON MARS



Exploring Mars through geologic time: from past to present & towards the future

G. Munaretto[1], G. Cremonese[1], M. Pajola[1], S. Bertoli[1], A. Lucchetti[1], A. Tullo[1], F. Tusberti[1], C. Re[1], E. Simioni[1], M. Massironi[1,2]

[1] INAF – Osservatorio Astronomico di Padova

[2] Department of Geosciences, University of Padova, Padova, Italy

Introduction

The surface of Mars records traces of events dating back to immediately after planetary formation, followed by periods of Earth-like habitable environments that then transitioned to the present-day dry, cold and inhospitable conditions. This makes the Red Planet the only other planetary body in the Solar system beyond Earth with an easily accessible geologic history that was similar to the Earth. Studying its surface is therefore crucial for understanding its past habitability and climatic conditions and how they evolved with time. It is also pivotal for assessing its In Situ Resource Utilization potentials, a crucial aspect for the future human and robotic exploration missions. The planetary science research group at OAPD is actively involved in many research projects on the multidisciplinary analysis of Martian surface landforms, locations and features that record past and/or present-day aqueous or glacial processes. We present a set of published and ongoing studies aimed at investigating a) candidate past & present-day Martian surface features related to the flow of liquid water b) periglacial landforms, c) characterization of Martian locations suitable for a possible human and/or robotic exploration mission.

The Origin and Formation mechanism of RSL: is there flowing liquid water on Mars *as we speak*?

Back in 2011, McEwen e al., (2011) discovered dark, linear to sinuous, flow-like features resembling water flows that we observe in Anctartica. These were called Recurring slope Lineae (RSL, image below) and they are characterized by:

- Flow activity during arm season
- Occurrence in steep sloped areas
- Flow disappearence during cold seasons
- Yearly recurrence in the same locations

They were initially attributed to **liquid water**, possibly mixed with salts (i..e, brines). It is however very unlikely for water to be flowing on Mars, altought theoretically possible transiently at very specific temperature and pressure conditions. Further studies also proposed dry alternatives like **debris flows, wind streaks, grainflows.** This dilemma has been open for more than 10 years, and it is now in the process of being solved. Many recent studies pointed out that RSL are probably dry, altought the exact formation mechanism is still not understood.

We performed a series of multidisciplinary studies analyzing:

- geologic context (steepness and orientation) of RSLs
- photometry (diurnal albedo variation due to different amount of volatiles in the regolith)
- thermodynamic environment (thermal modelling to assess if brine melting is physically possible)
- 4 band RSL spectra & their comparison with features of known origin (sand dunes, dust devils)
- Spatial distribution of RSL on Mars

R1 : RSL activity not driven by temperature but by gravity!

R2: RSL 4 band photometry very similar to sand dunes

R2: RSL activity not correlated with albedo variations

Our R1 R2 and R3 results are inconsistent with liquid flows and indicate that RSL are dry (no water) and may be flows of basaltic sands moved by winds. Additional work is being performed by Munaretto et al., (in prep) to further characterize how the wind drives RSL activity

Full story at: Munaretto et al., (2020) Munaretto et al., (2021) Munaretto et al., (2022)

HiRISE & CaSSIS Coordinated Imaging Campaign (Work in progress)

We are performing a novel, first of its kind observational campaign in coordination with MRO to observe a set of locations during the early morning with CaSSIS and on the afternoon of the same day with HiRISE. Such dataset will allow to characterize volatile-exchange mechanisms between the regolith and the atmosphere and see if they can explain many active martian surface feaftures, such as RSL, gullies, araneiforms, polar spots and many others.

Hey there! I am CaSSIS, a stereocamera currently orbiting Mars! I am taking pictures at 4.6 m/px in four bands, even in stereo to produce Digital Terrain Models of the surface!

Where Shall We Land on Mars?

We identified and characterized the scientific potential for a future possible human landing site on Mars, located at Vernal crater. It features:

- Flat areas for safe landing and operations of a human mission to Mars.
- High amounts of sub-surface ice, pivotal for ISRU.
- Putative ancient hot springs environments that have a very important astrobiological potential
- Past aeolian features, allowing to characterize the present and past martian climate

More about it in Pajola et al., (2022)

Floor Fractured Craters : A Song of Ice & Fire (Work in progress, Bertoli et al., *in prep*)

PERIGLACIAL MODEL
- Fluidized morphology of the crater's ejecta indicative of ice-rich terrain during the impact

VOLCANISM
- Tilting of mesas
- Presence of olivine and pyroxene in the central part othe floor and wall

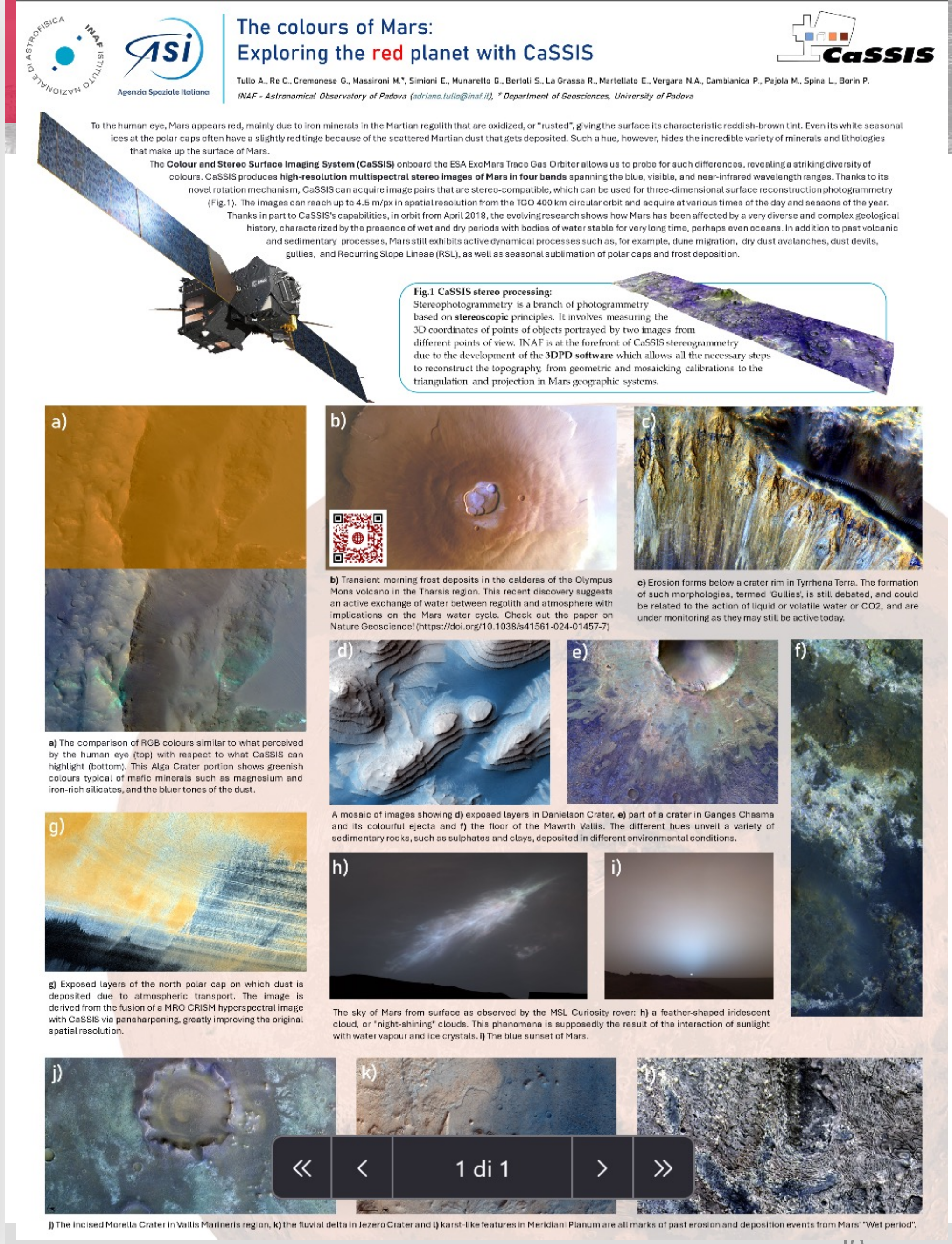
TECTONICS
- Same directions of the floor's fractures and Sirenum Fossae
- Favours the volcanic injection and the ice melting

Formation of the impact crater, about 3.4 Ga years ago, with presence of ice which has been melted and deposited within the crater as lake/ice covered lake/glacier.

First, the Sirenum Fossae graben brought heat which melted the possible ice layer causing an irregular subsidence of the floor. In a second moment, Sirenum Fossae brought magmatic material as a subvolcanic dome inside the crater, in particular in the central/southern part of the floor (laccolith intrusion).

Second step of Sirenum Fossae, which continues to dissect the magmatic deposit and brings other magmatic material (lava layering deposits, like others craters)

Other later modification (wind, permafrost, gravity).



The colours of Mars: Exploring the red planet with CaSSIS

Tullo A., Re C., Cremonese G., Massironi M.*, Simioni E., Munaretto G., Bertoli S., La Grassa R., Martellato E., Vergara N.A., Cambianica P., Pajola M., Spina L., Borin P.

*INAF - Astronomical Observatory of Padova (adriano.tullo@inaf.it), * Department of Geosciences, University of Padova*

To the human eye, Mars appears red, mainly due to iron minerals in the Martian regolith that are oxidized, or "rusted", giving the surface its characteristic reddish-brown tint. Even its white seasonal ices at the polar caps often have a slightly red tinge because of the scattered Martian dust that gets deposited. Such a hue, however, hides the incredible variety of minerals and lithologies that make up the surface of Mars.

The **Colour and Stereo Surface Imaging System (CaSSIS)** onboard the ESA ExoMars Trace Gas Orbiter allows us to probe for such differences, revealing a striking diversity of colours. CaSSIS produces **high-resolution multispectral stereo images of Mars in four bands** spanning the blue, visible, and near-infrared wavelength ranges. Thanks to its novel rotation mechanism, CaSSIS can acquire image pairs that are stereo-compatible, which can be used for three-dimensional surface reconstruction photogrammetry (Fig.1). The images can reach up to 4.5 m/px in spatial resolution from the TGO 400 km circular orbit and acquire at various times of the day and seasons of the year.

Thanks in part to CaSSIS's capabilities, in orbit from April 2018, the evolving research shows how Mars has been affected by a very diverse and complex geological history, characterized by the presence of wet and dry periods with bodies of water stable for very long time, perhaps even oceans. In addition to past volcanic and sedimentary processes, Mars still exhibits active dynamical processes such as, for example, dune migration, dry dust avalanches, dust devils, gullies, and Recurring Slope Lineae (RSL), as well as seasonal sublimation of polar caps and frost deposition.

Fig.1 CaSSIS stereo processing: Stereophotogrammetry is a branch of photogrammetry based on **stereoscopic** principles. It involves measuring the 3D coordinates of points of objects portrayed by two images from different points of view. INAF is at the forefront of CaSSIS stereogrammetry due to the development of the **3DPD software** which allows all the necessary steps to reconstruct the topography, from geometric and mosaicking calibrations to the triangulation and projection in Mars geographic systems.

a) The comparison of RGB colours similar to what perceived by the human eye (top) with respect to what CaSSIS can highlight (bottom). This Alga Crater portion shows greenish colours typical of mafic minerals such as magnesium and iron-rich silicates, and the bluer tones of the dust.

b) Transient morning frost deposits in the calderas of the Olympus Mons volcano in the Tharsis region. This recent discovery suggests an active exchange of water between regolith and atmosphere with implications on the Mars water cycle. Check out the paper on Nature Geoscience! (https://doi.org/10.1038/s41561-024-01457-7)

c) Erosion forms below a crater rim in Tyrrhena Terra. The formation of such morphologies, termed 'Gullies', is still debated, and could be related to the action of liquid or volatile water or CO2, and are under monitoring as they may still be active today.

A mosaic of images showing **d)** exposed layers in Danielson Crater, **e)** part of a crater in Ganges Chasma and its colourful ejecta and **f)** the floor of the Mawrth Vallis. The different hues unveil a variety of sedimentary rocks, such as sulphates and clays, deposited in different environmental conditions.

g) Exposed layers of the north polar cap on which dust is deposited due to atmospheric transport. The image is derived from the fusion of a MRO CRISM hyperspectral image with CaSSIS via pansharpening, greatly improving the original spatial resolution.

The sky of Mars from surface as observed by the MSL Curiosity rover: **h)** a feather-shaped iridescent cloud, or "night-shining" clouds. This phenomena is supposedly the result of the interaction of sunlight with water vapour and ice crystals. **i)** The blue sunset of Mars.

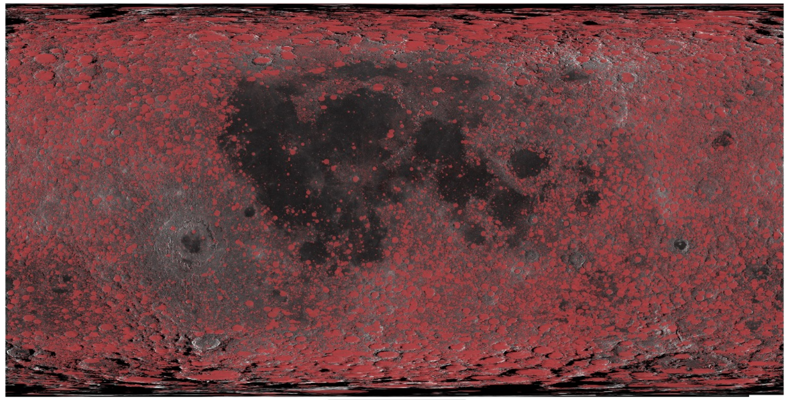
j) The incised Morella Crater in Vallis Marineris region, **k)** the fluvial delta in Jezero Crater and **l)** karst-like features in Meridiani Planum are all marks of past erosion and deposition events from Mars' "Wet period".

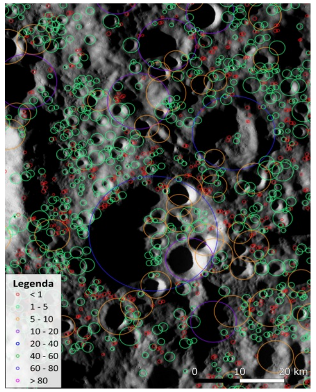
1 di 1

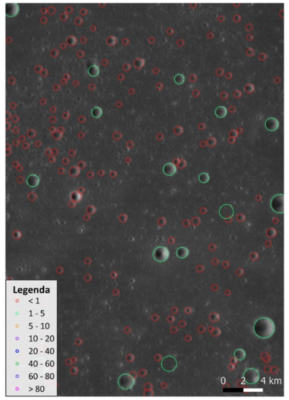
ARTIFICIAL INTELLIGENCE/DEEP LEARNING

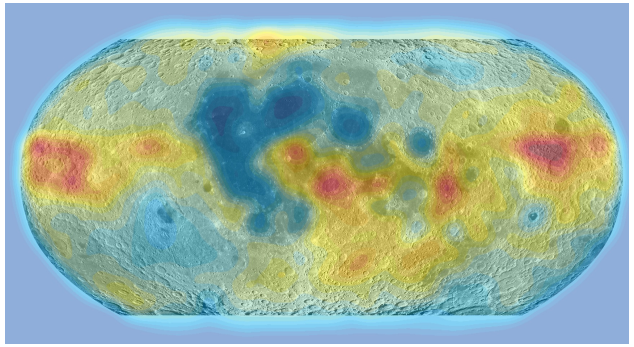
- Feature Detection (Crater Catalogues – Moon, Mercury, Ceres)
- Image Enhancement (Super Resolution)
- Image Classification/Segmentation/Clustering
- DTM generation (monoscopic)
- Hyperspectral compressor

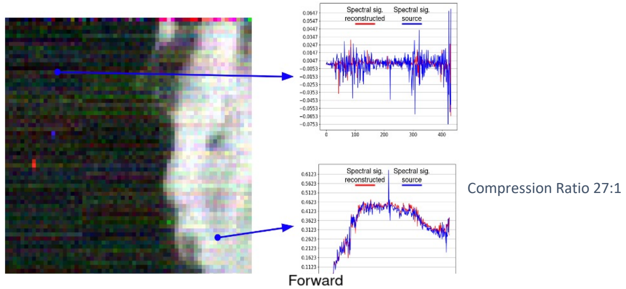
ARTIFICIAL INTELLIGENCE/DEEP LEARNING (Riccardo La Grassa et al.)

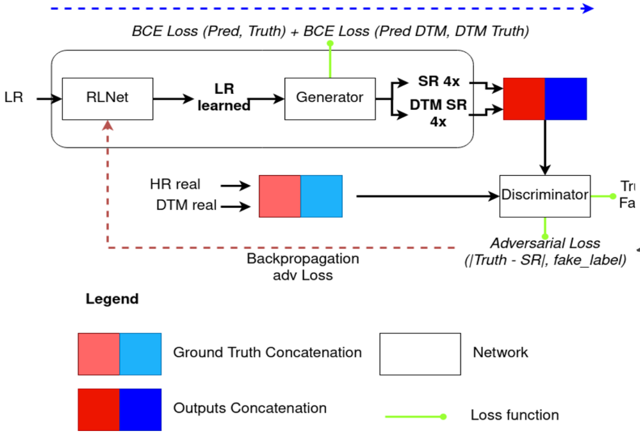


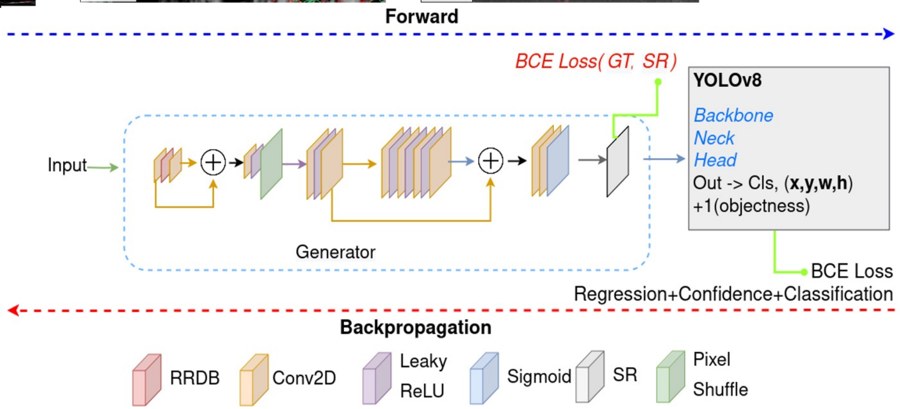


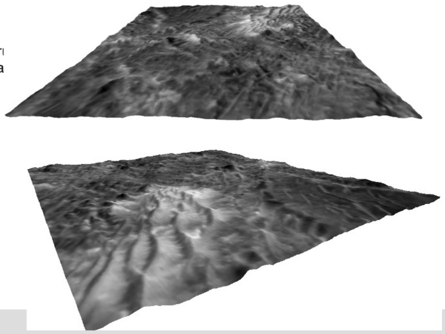


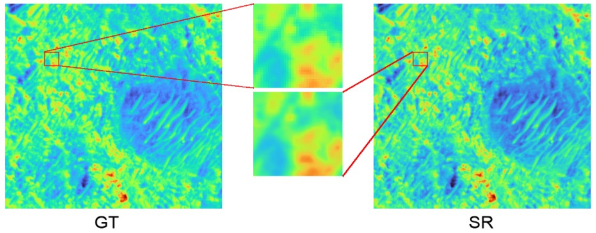


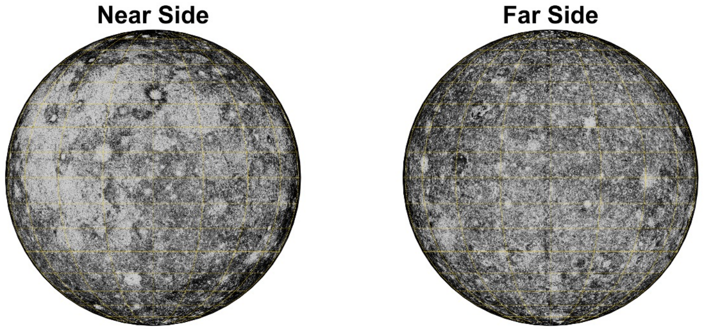


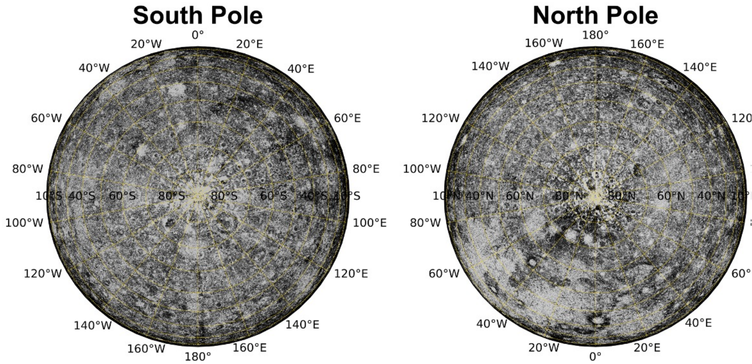












Thanks for your attention!