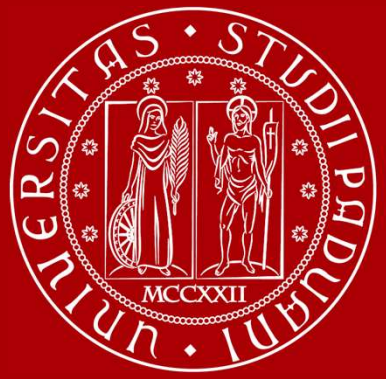


UNIVERSITÀ
DEGLI STUDI
DI PADOVA

Analysis of craters on Mars

Maddalena Faletti - 40th Cycle

Supervisor: Dr. Gabriele Cremonese

Co-Supervisor: Dr. Elena Martellato – Prof. Francesco Marzari – Dr. Angelo Zinzi

Admission to second year - 14 October 2025

Context and Goals

Scientific Context

Water on Mars:

Subsurface ice (pore-filling → excess ice) provides insights into deposition processes

→ Constraint interpretations of the paleo-climate

Impact craters:

Morphology reflects target material properties (density, strength, water content, porosity, composition)

Different resistance between ice and rock and post-formational processes → Lower depth/diameter (d/D) ratios compared to dry regolith

Craters in ice-rich substrates → Lower depth/diameter (d/D) ratios compared to dry regolith

Effect most evident in small craters, sensitive to local substrate properties

Research Programme

Objective

- Characterize Martian terraced craters and floor-fractured craters by analyzing morphology, internal structure and correlation with subsurface water ice.

Methodology

- Combine high-resolution images, DTMs and radar data
- Applies deep learning algorithm for crater detection and classification

Scientific impact

- Enhances understanding of geological processes on Mars
- Supports reconstruction of Mars' paleo-climate and ice history

Applications

- Improves planetary geology and remote sensing technique
- Base for similar studies on other planetary bodies

Support for future missions

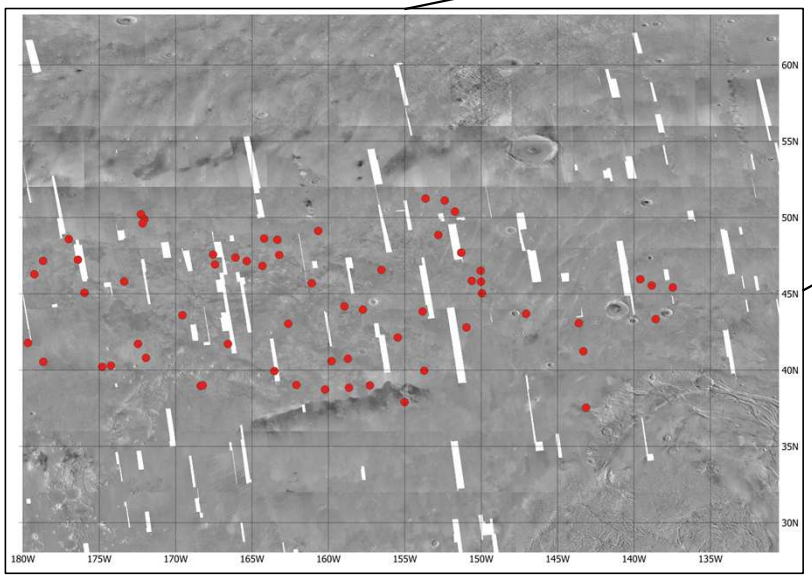
- Provides criteria for selecting landing sites and scientific targets

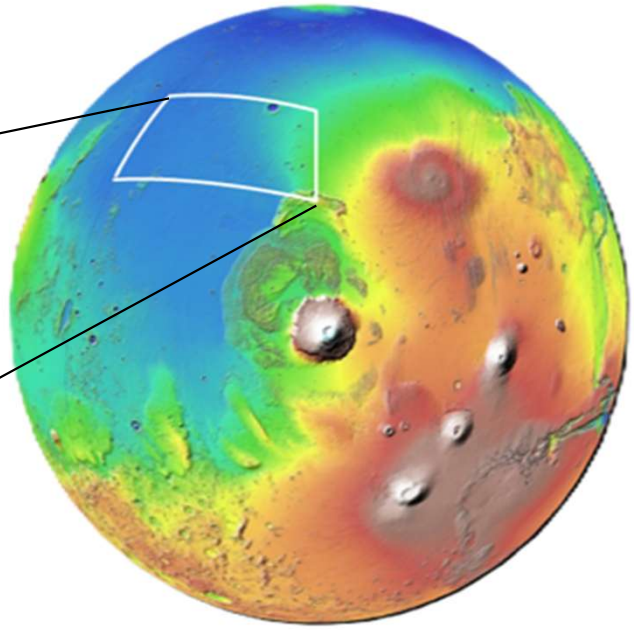
Open science commitment

- Integration into MATISSE platform
- Adoption of FAIR standards for long-term accessibility and collaboration

Terraced Craters

- 187 craters, Diameter = 0,125 to 2 km:
  - 62: single well-defined terrace
  - 35: two distinct terraces
  - 90: presence of poorly distinguishable or difficult to interpret terraced morphologies
- High-resolution Digital Terrain Models (DTMs) from the HiRISE archive:
  - 10: terraced craters already used in Bramson et al. 2015
  - 6: terraced craters added in this work



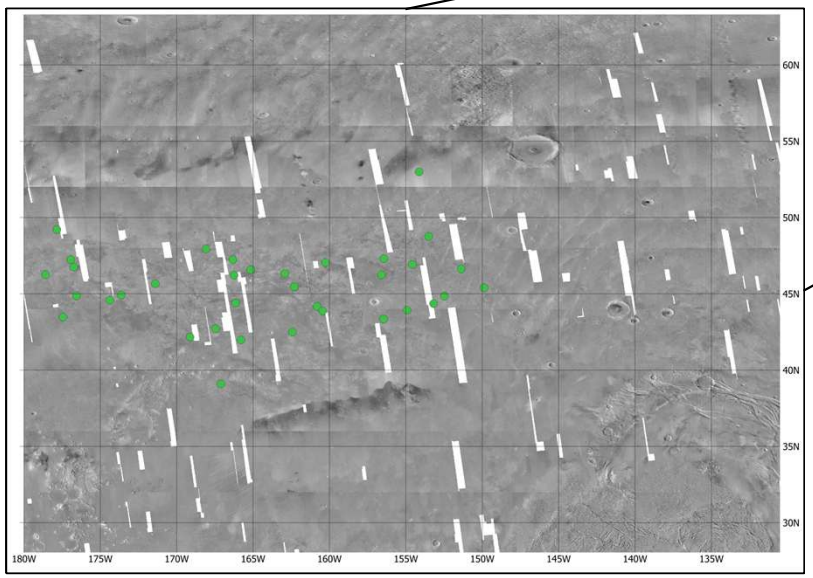


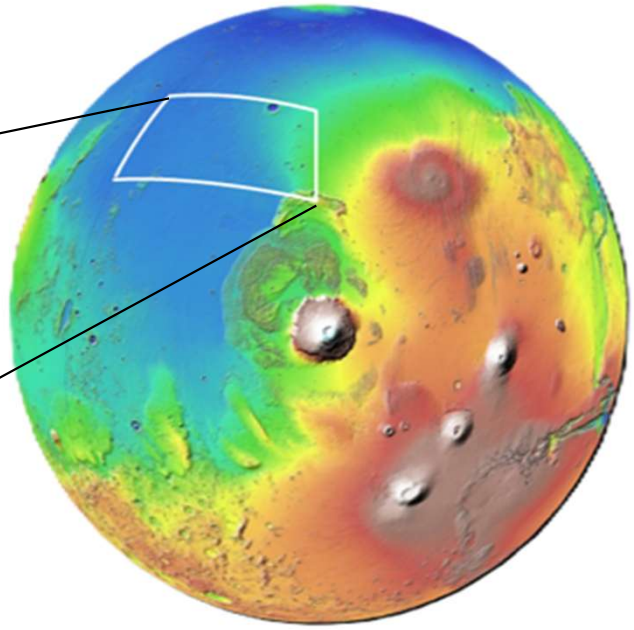
Region of the study:
Arcadia Planitia

0 5 10

Terraced Craters

- 187 craters, Diameter = 0,125 to 2 km:
  - 62: single well-defined terrace
  - 35: two distinct terraces
  - 90: presence of poorly distinguishable or difficult to interpret terraced morphologies
- High-resolution Digital Terrain Models (DTMs) from the HiRISE archive:
  - 10: terraced craters already used in Bramson et al. 2015
  - 6: terraced craters added in this work



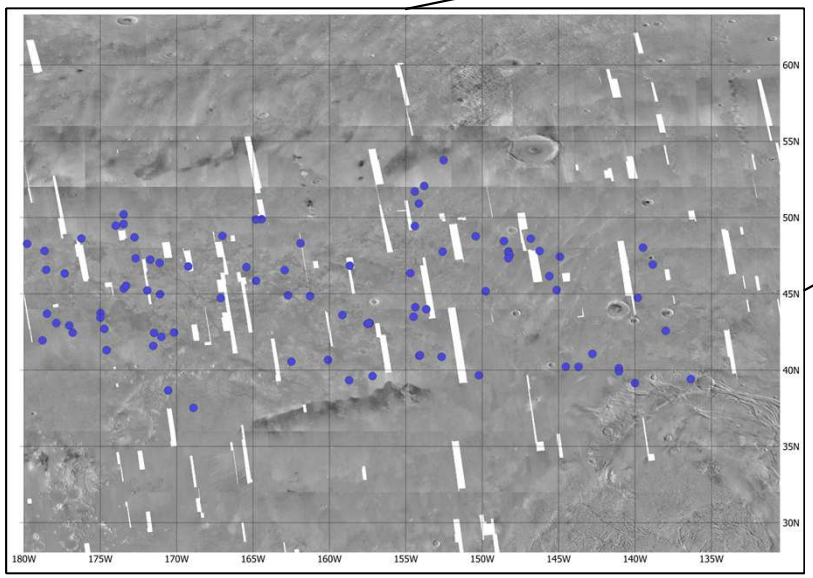


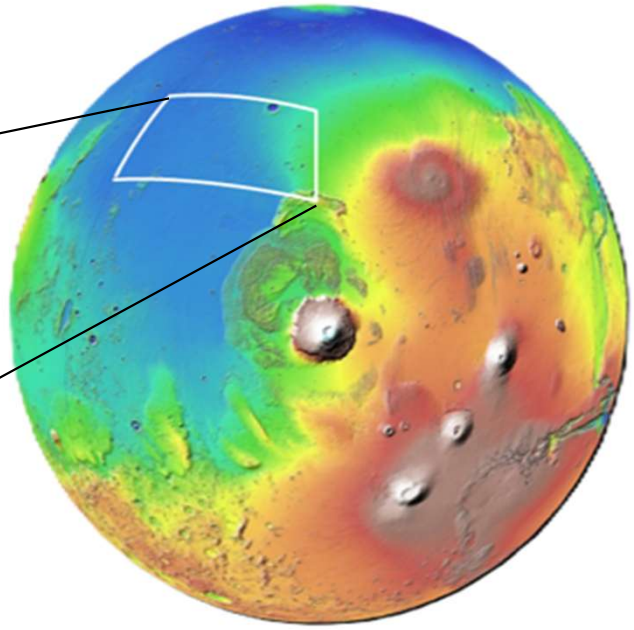
Region of the study:
Arcadia Planitia

0 5 10

Terraced Craters

- 187 craters, Diameter = 0,125 to 2 km:
  - 62: single well-defined terrace
  - 35: two distinct terraces
  - 90: presence of poorly distinguishable or difficult to interpret terraced morphologies
- High-resolution Digital Terrain Models (DTMs) from the HiRISE archive:
  - 10: terraced craters already used in Bramson et al. 2015
  - 6: terraced craters added in this work





Region of the study:
Arcadia Planitia

0 5 10

Terraced Craters

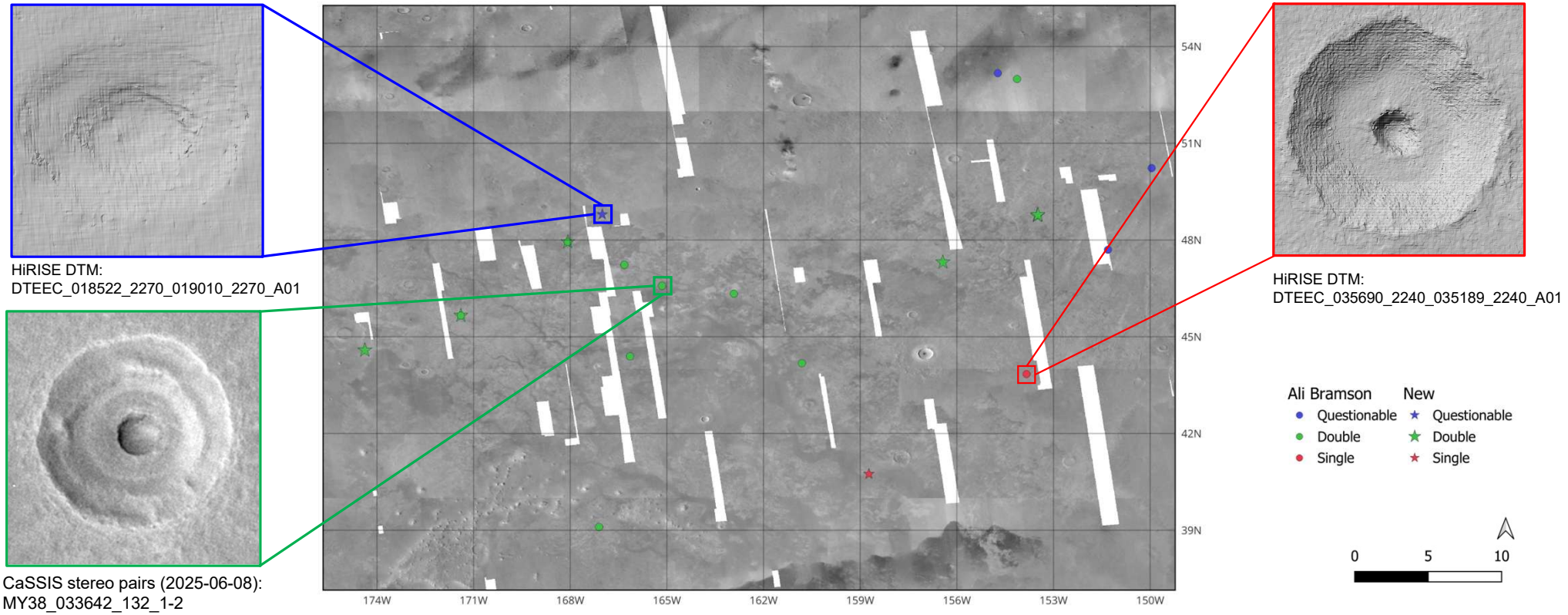


Figure 1: The central panel shows a section of the Martian surface with craters classified into three categories: questionable, double, and single, based on Bramson et al. (circle) and new DTMs (star). Colored boxes highlight representative examples: questionable crater(blue); well-defined single crater (red); double crater (green) shown in both top-down view.

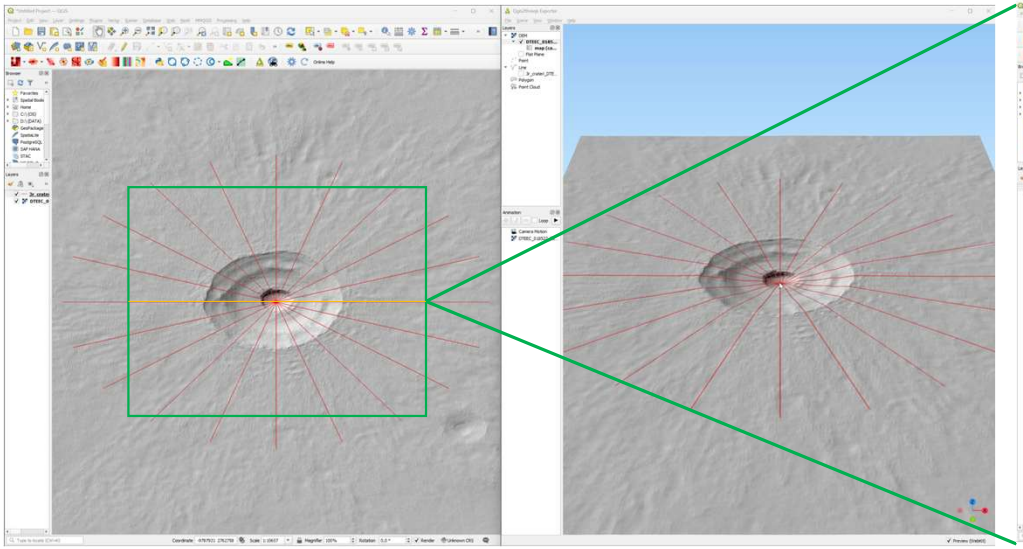
Methods

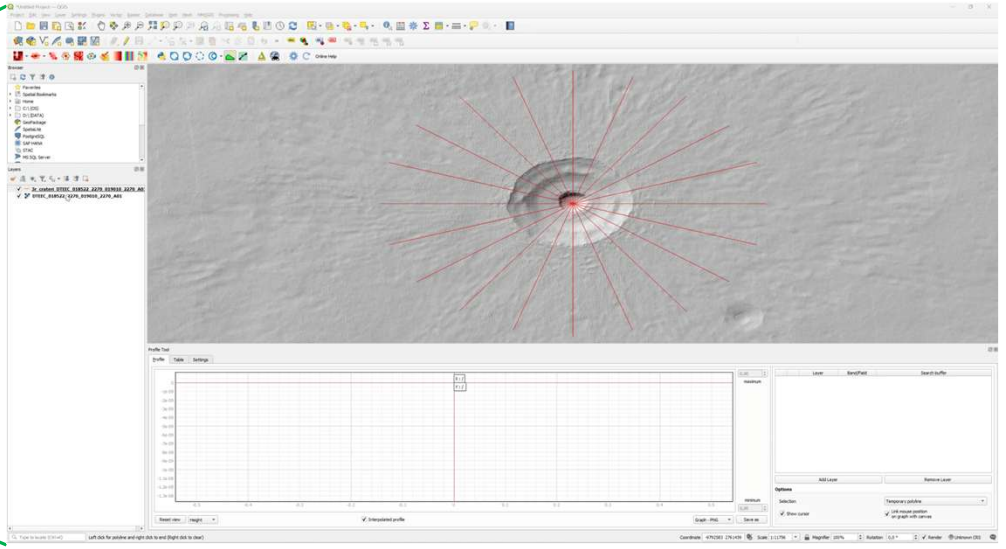
Python code → Processing in QGIS and Data analysis → Automated & repeatable workflow (extendable to future datasets)

DTM

DTEEC_018522_2270_019010_2270_A01

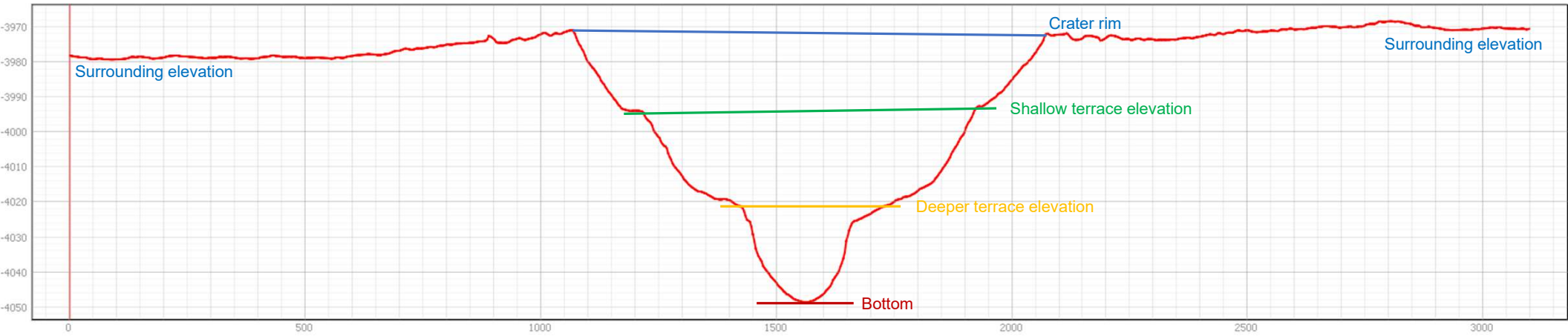
Elevation profile





Methods

Morphological analysis



Diameter (m)	711.69
Radius (m)	355.84
3*radius (m)	1067.53
Latitude (N)	46.58
Longitude (E)	-165.15

Surrounding Elevation (m)	-3975.48
Crater rim (m)	-3971.37
Shallow Terrace Elevation (m)	-3991.91
Deeper Terrace Elevation (m)	-4017.58
Bottom Elevation (m)	-4051.05
Shallow Terrace Depth (m)	-16.43
Deeper Terrace Depth (m)	-42.09
Bottom Pit Depth (m)	-75.57
Depth (m)	79.68

Surrounding Dip (°)	0.346
Shallow terrace dip (°)	5.636
Deeper terrace dip (°)	4.312

d/D	0.1120
Error d/D	0.0023

Preliminary Results

- **Comparison with Bramson et al. 2015:**
  - Good agreement for surrounding dip
  - Discrepancies in terrace slopes → different interpretations of terrace boundaries and larger number of diameters sampled per crater
  - Differences more evident in questionable terraced craters, where morphology is harder to interpret

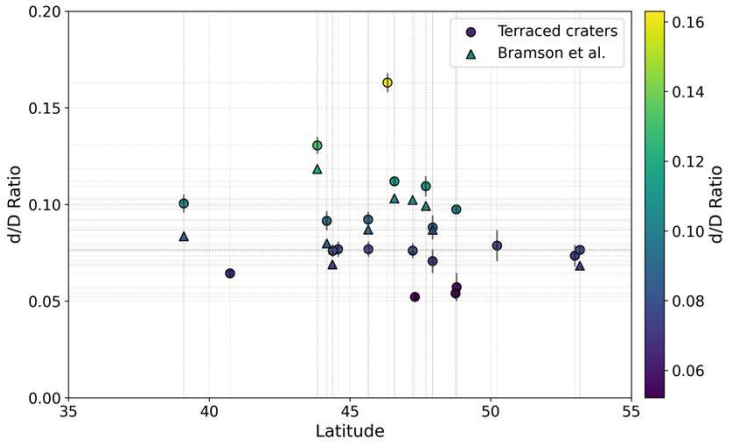


Figure 2: d/D ratios as a function of latitude. Comparison between terraced craters from this study (circles) and data from Bramson et al. (triangles).

- **0.064 ± 0.002 < d/D < 0.112 ± 0.002**
- Same DTMs → different values between this project and Bramson et al. → different interpretations of terrace boundaries and a larger number of diameters sampled per crater
- Simple craters show higher d/D ratios at comparable latitudes → subsurface ice reduces target strength during impact
- Variations in terrace slopes and terrace elevations → may indicate stratified, ice-rich deposits in Arcadia Planitia

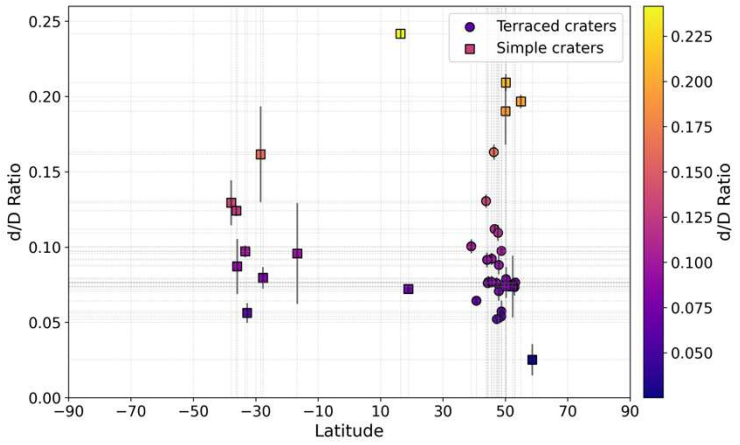
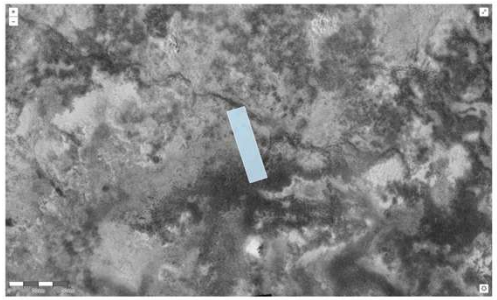


Figure 3: d/D ratios as a function of latitude. Comparison between terraced craters from this study (circles) and simple craters (squares).

CaSSIS Observations

7–14 June → 4 stereo pairs → 5 terraced craters



▾ Geometry

Latitude	46.6149°
Longitude	194.805°
Emission	13.5°
Incidence	24.0°
Phase	35.0°
LST	12.9h
N Azimuth	270.0°
SubSolar Azimuth	120.6°

▾ Image Windows

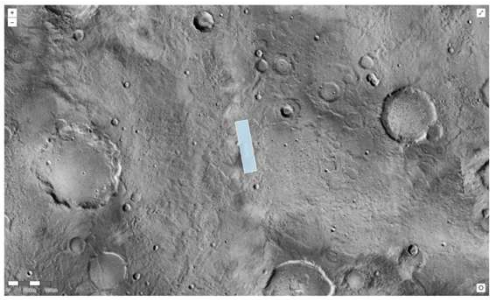
Window	Type	Binning	Compression	Range
1	PAN	1	0.0 JPEG-LS	192,354-1855,634
2	NIR	1	0.0 JPEG-LS	192,1048-1855,1304
3	BLU	1	0.0 JPEG-LS	192,1409-1855,1665

▾ Timing

Imaging Duration	11.54 s
ReferenceTime	2025-06-08T10:06:56.744
Setup Duration	15.0 s

MY38_033642_132_1

14–21 June → 1 stereo pairs → 2 floor-fractured craters



▾ Geometry

Latitude	20.7074°
Longitude	44.9637°
Emission	10.2°
Incidence	4.4°
Phase	14.5°
LST	11.9h
N Azimuth	270.0°
SubSolar Azimuth	294.8°

▾ Image Windows

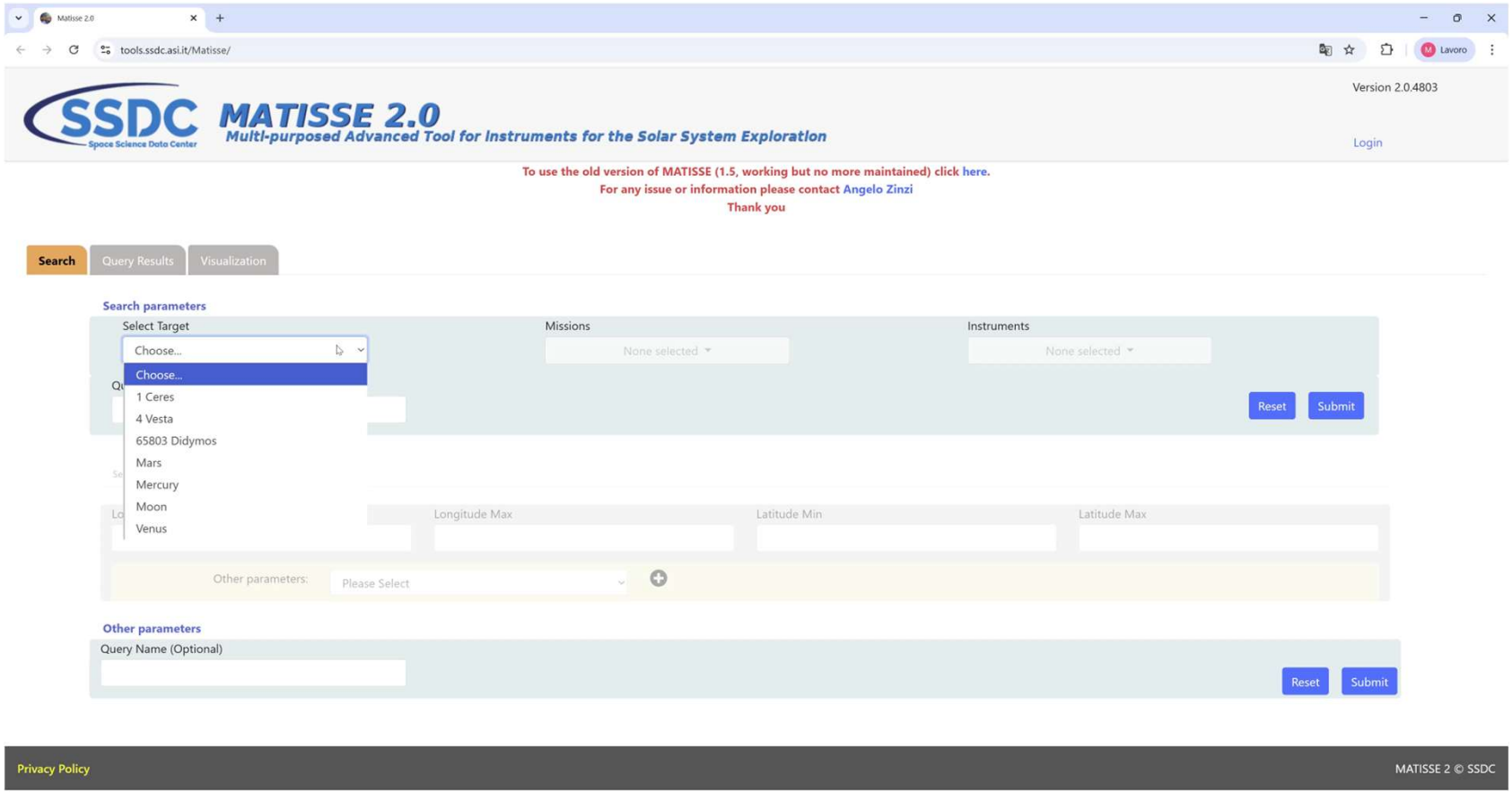
Window	Type	Binning	Compression	Range
1	PAN	1	0.0 JPEG-LS	192,354-1855,634
2	RED	1	0.0 JPEG-LS	192,712-1855,968
3	BLU	1	0.0 JPEG-LS	192,1409-1855,1665

▾ Timing

Imaging Duration	10.8 s
ReferenceTime	2025-06-17T00:37:00.483
Setup Duration	15.0 s

MY38_033747_160_2

MATISSE


tools.ssdc.asi.it/Matisse/
Version 2.0.4803
SSDC
Space Science Data Center
MATISSE 2.0
Multi-purposed Advanced Tool for Instruments for the Solar System Exploration
Login
To use the old version of MATISSE (1.5, working but no more maintained) click here.
For any issue or information please contact Angelo Zinzi
Thank you
Search
Query Results
Visualization
Search parameters
Select Target
Missions
Instruments
Choose...
None selected
None selected
Choose...
1 Ceres
4 Vesta
65803 Didymos
Mars
Mercury
Moon
Venus
Reset
Submit
Longitude Max
Latitude Min
Latitude Max
Other parameters:
Please Select
Other parameters
Query Name (Optional)
Reset
Submit
Privacy Policy
MATISSE 2 © SSDC

Deep Learning Algorithm

- **CTX**
  - Global coverage
  - Suitable for large craters
  - Limited: Small craters are less visible
- **Datasets**
  - Terraced craters
  - Negative examples (simple craters)
- **Training & Testing of 2 detectors**

Dataset & Training

Preliminary results

- **Detector 2**
  - Very good performance
  - Almost all terraced craters detected
  - Very few errors
- **Test set often too optimistic**
- **Human validation always required**

Future Work

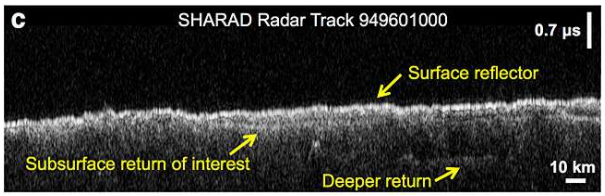
Terraced craters

- Generation of additional DTMs
- Refine morphology and d/D analyses
- Test robustness of current results

Floor-fractured craters

- Same workflow used for terraced craters

Extend the analysis to the use of radar data



Bramson et al. (2015)

Future catalogues via Deep learning algorithm

- Terraced craters
- Floor-fractured craters

Statistical analysis & age determination

Provide stronger constraints on subsurface ice distribution

Activities

CONFERENCE:

- XX Congresso Nazionale di Scienze Planetarie, 3-7 febbraio 2025, Pescara, Italy
- **Faletti, M.**; Cremonese, G.; Martellato, E.; Tullo, A.; Bertoli, S.; Munaretto, G.; Marzari, F.; and Zinzi, A., *Analysis of terraced craters in Arcadia Planitia,* EPSC,DPS. Helsinki sept.2025, EPSC-DPS2025-729, session TP3, poster presentation.
- Bertoli, S.; Massironi, M.; Salvatore, M.C.; Baroni, C.; Baschetti, B.; Tullo, A.; Munaretto, G.; Martellato, E., Cremonese, G.; Pajola, M.; Hauber, E.; and **Faletti, M.**, *Geological history of a Floor-Fractured Crater in Gorgonum Chaos, Terra Sirenum, Mars,* EPSC,DPS. Helsinki sept.2025, EPSC-DPS2025-1494, session TP1, abstract, oral presentation.
- La Grassa, R.; Re, C.; Martellato, E.; Tullo, A.; Bertoli, S.; Galluzzi, V.; Giacomini, L.; Vergara Sassarini, N.A.; Cremonese, G.; **Faletti, M.**; *Mercury Global Crater Catalog using Multimodal Deep Learning for Crater Detection and Morphometric Analysis,* EPSC,DPS. Helsinki sept.2025, EPSC-DPS2025-1625, session MITM5, poster presentation.

PAPER PUBLISHED:

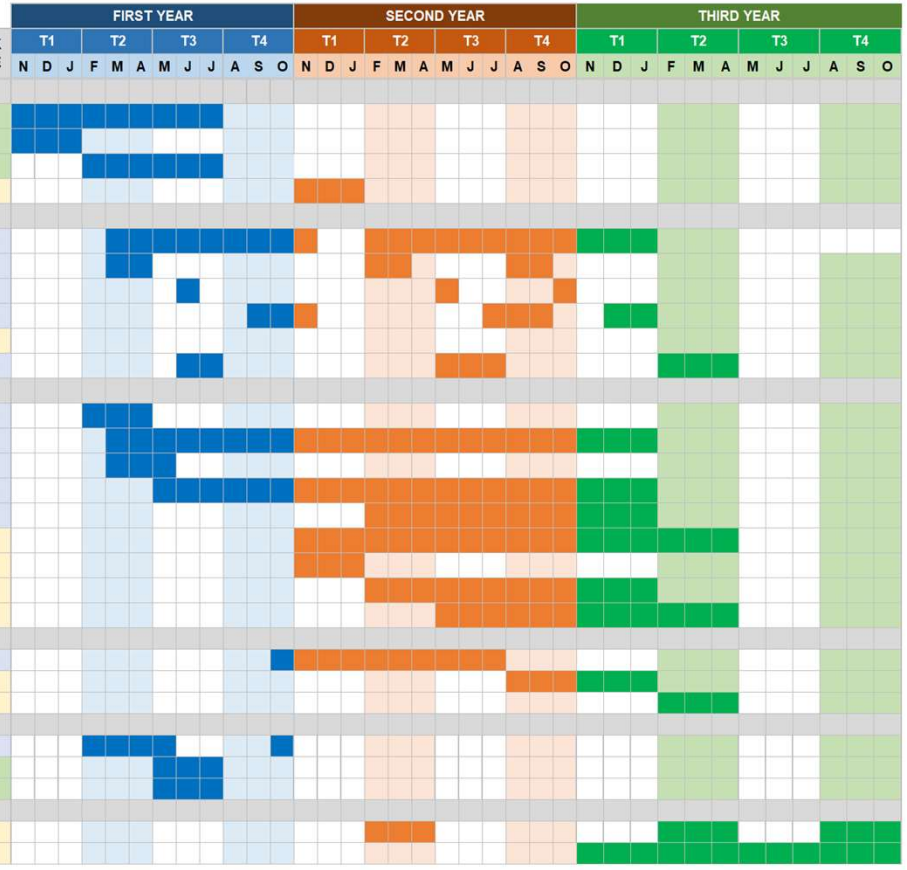
- La Grassa, R.; Re, C.; Martellato, E.; Tullo, A.; Bertoli, S.; Cremonese, G.; Vergara Sassarini, N.A.; **Faletti, M.**; Galluzzi, V.; Giacomini, L. *From the Moon to Mercury: Release of Global Crater Catalogs Using Multimodal Deep Learning for Crater Detection and Morphometric Analysis*. Remote Sens. **2025**, 17, 3287. https://doi.org/10.3390/rs17193287

SCHOOLS:

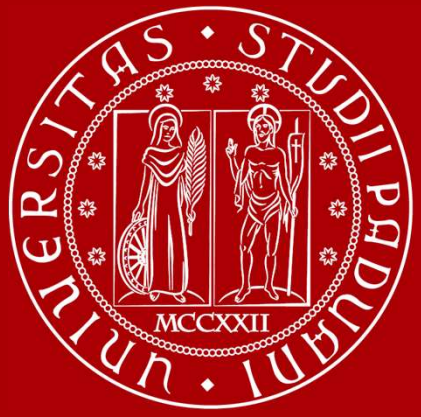
- GMAP Planetary Geological Mapping Winter School, 10-14 February 2025, Online
- CARE-ON, 13 February 2025, Online
- INAF PhD School – From the solar system to high redshift galaxies, 26-31May 2025, Asiago

Gantt Chart

WBS NUMBER	TASK TITLE	% OF TASK COMPLETE
1	**Study of literature and instruments operating on Mars**	
1.1	Literature review	Completed
1.2	Study of the instruments (CaSSIS and MARSIS)	Completed
1.3	Study of tools (MATISSE, GIS)	Completed
1.4	Study of tools forn analyze radar data	Next year
2	**Planning of instruments and tool**	
2.1	Planning CaSSIS	In progress
2.1.1	Observational planning	In progress
2.1.2	Data collection	In progress
2.1.3	First analysis of the collected images	In progress
2.2	Planning MARSIS	Next year
2.3	MATISSE: data entry	In progress
3	**Data acquisition and analysis**	
3.1	Selection of craters	In progress
3.2	Analysis of terraced craters	In progress
3.2.1	Identification of craters and data already present in the HiRISE and CaSSIS archives	In progress
3.2.2	Morphological analysis using QGIS and Python	In progress
3.2.3	Working with radar data	In progress
3.3	Analysis of floor-fractured craters	Next year
3.3.1	Identification of craters and data already present in the HiRISE and CaSSIS archives	Next year
3.3.2	Morphological analysis using QGIS and Python	Next year
3.3.3	Working with radar data	Next year
4	**Statistica analysis**	
4.1	Search for terraced craters across the entire surface of Mars to expand the catalogue and its analysis	In progress
4.2	Analysis of data for both morphologies	Next year
4.2.1	Age determination	Next year
5	**Educational activities**	
5.1	Interdisciplinary STMS courses	In progress
5.2	Extended seminars	Completed
5.3	Short seminars	Completed
6	**Reporting, pubblication and thesis**	
6.1	Publications	Next year
6.1	Thesis writing	Next year



Thanks for the attention



UNIVERSITÀ
DEGLI STUDI
DI PADOVA