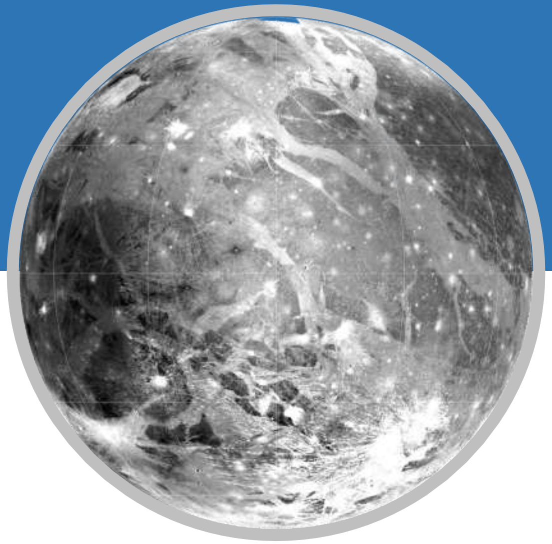
OSSERVATORIO ASTRONOMICO DI PADOVA

## Scheda INAF: Icy worlds

# Icy Moons in the Solar System: Comparative Analysis on Different Worlds

*Alice Lucchetti*



**9 Maggio 2022**

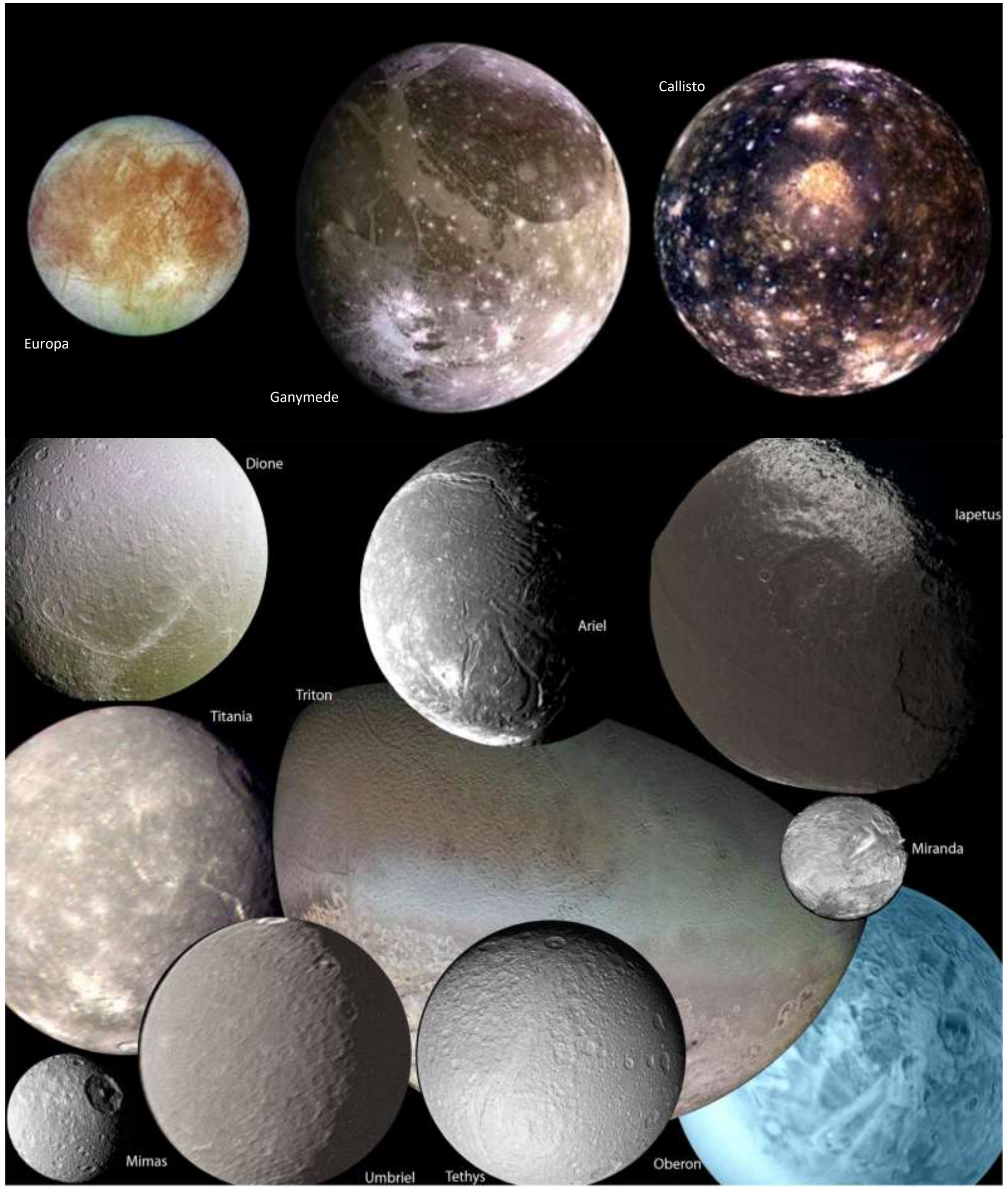
# Icy worlds | Objective

- ✓ The exploration of the icy satellites in the outer Solar System (Jovian, Saturnian, Uranian and Neptunian) shows a stunning **variety** in these **bodies'surface geology**;

- ✓ Icy satellites are interesting from an **astrobiological** perspective because they are "**ocean worlds**", hosting or possibly hosting an internal liquid ocean;

- ✓ Understanding both the geological processes that shape the icy satellites' surfaces and the link between the subsurface ocean and the surface itself is pivotal to give new insights into their current states and **geological histories** and/or **evolution**.

**The aim of this project is to make a <u>comparative analysis</u> between the icy satellites of the outer Solar System to identify the common and different geological processes affecting them.**

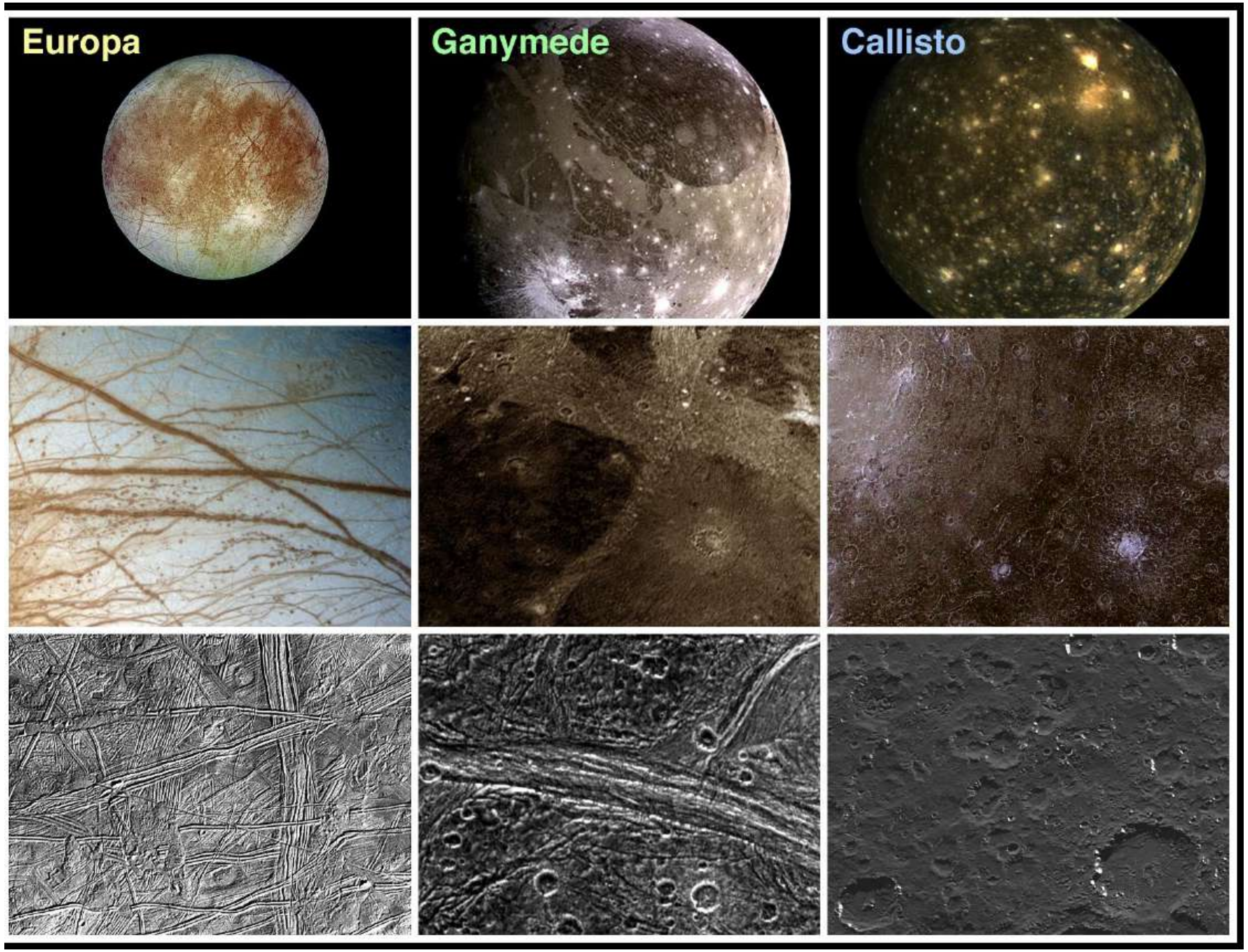


# Icy worlds|Jupiter satellites

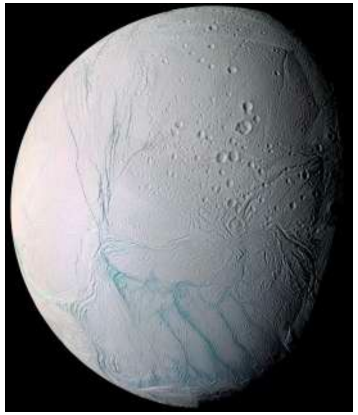
### Europa
- ✓ Internal liquid ocean (icy crust of 10-20 km)
- ✓ Resurfacing and tectonic activity
- ✓ Young age (30- 100 My)
- ✓ Cryovolcanism

### Ganymede
- ✓ Internal liquid ocean at a depth of 150 km
- ✓ Bright and dark terrains
- ✓ Lineaments: grooves and furrows
- ✓ Cryovolcanism

### Callisto
- ✓ Old and dark surface
- ✓ Surface rich of craters
- ✓ No geological activity
- ✓ Sublimation degradation process



# Icy worlds | Saturnian satellites



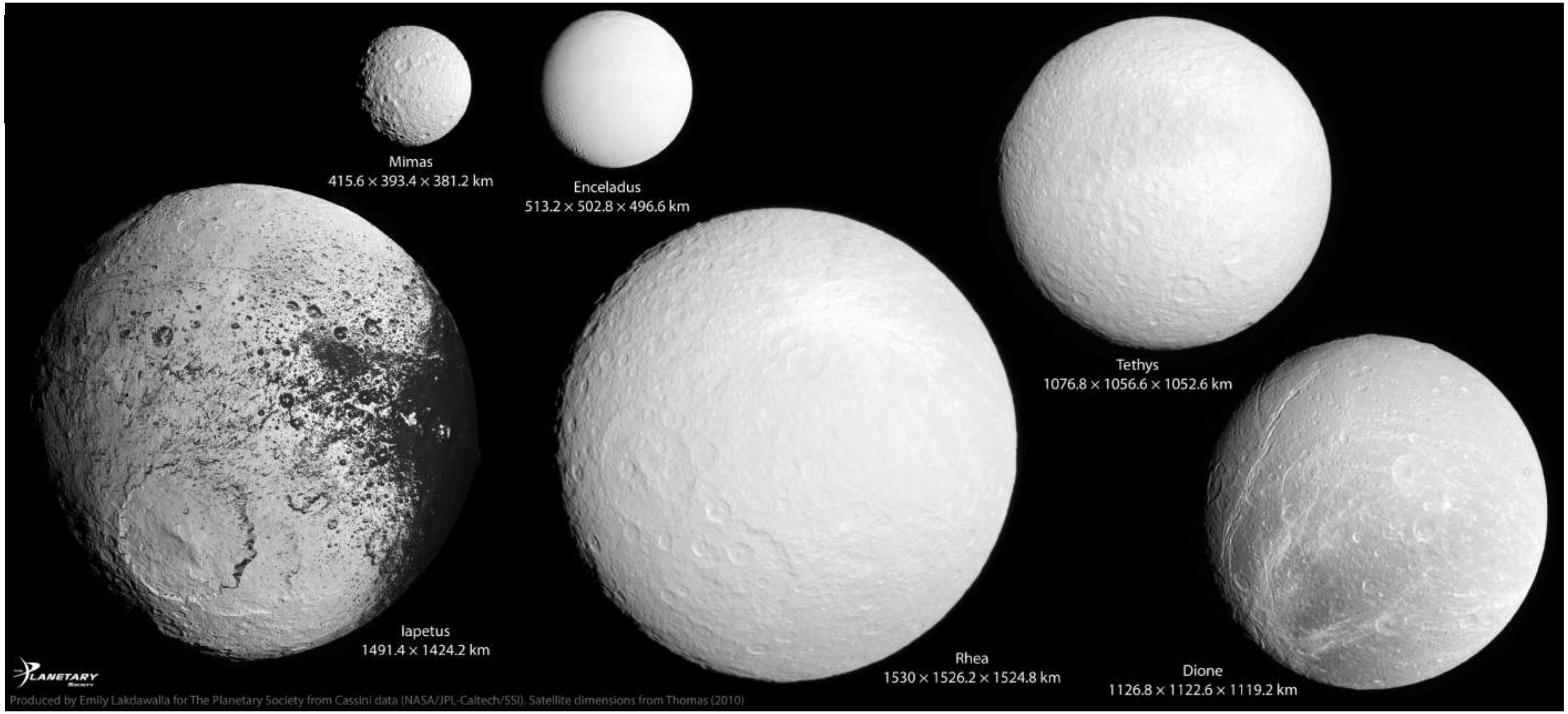
**6 medium-size moons (300 — 1500 km in diameter)**

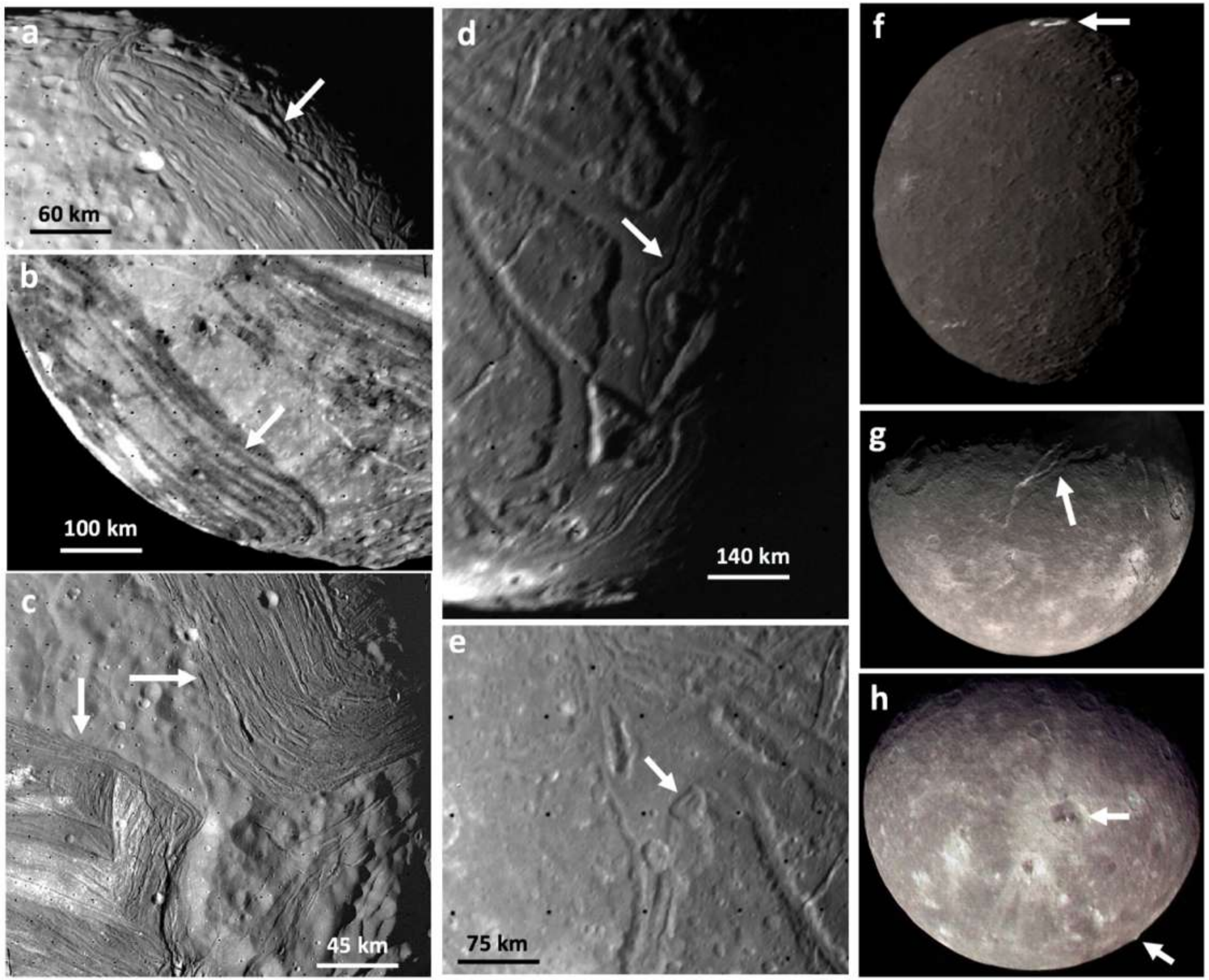
## Enceladus

- ✓ Geologically active → plumes
- ✓ Internal liquid ocean
- ✓ Dichotomy between southern hemisphere (fractured) and northern hemisphere (craters)

## Mimas, Tethys, Dione, Rhea and Iapetus

- ✓ Impact craters, fractures and presence of material whose origin is still enigmatic.
- ✓ Tectonic systems (arcuate fracures on Thetys, old fractures on Mimas and extensional fractures on Dione and Rhea).
- ✓ Smooth plains on Tethys and Dione suggest past cryovolcanism






Images from Voyager 2

**5 moons (200 — 800 km in diameter)**

**Miranda, Ariel, Umbriel, Titania and Oberon**

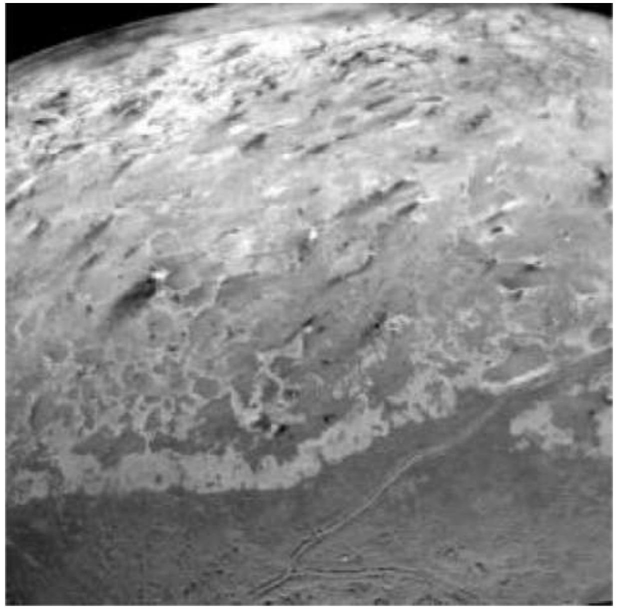
White arrows highlight:

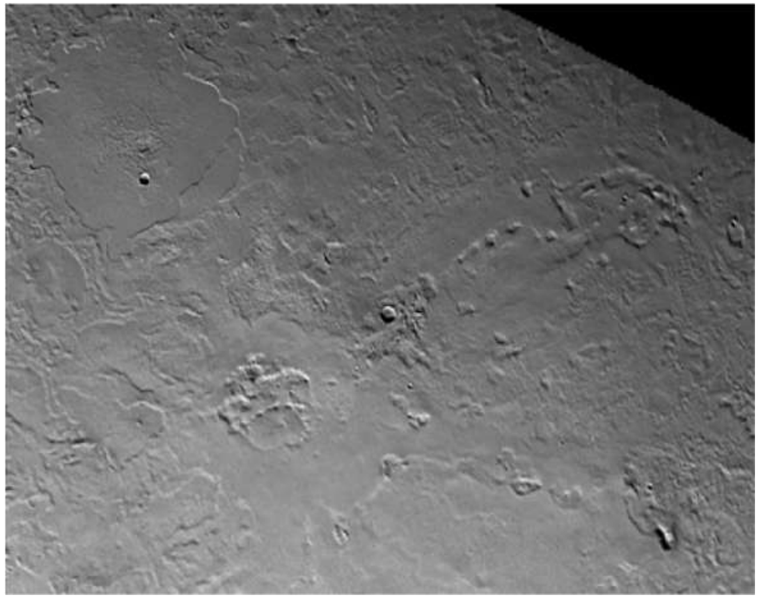
(a) ridges on Miranda, which possibly have a cryovolcanic and tectonic origin;
(b) Arden Corona on Miranda with high and low albedo banding along large tectonic faults;
(c) Inverness (bottom left) and Elsinore (top right) Coronae on Miranda that exhibit ridges and grooves. Between these two coronae are examples of craters that have been mantled by an unknown source of regolith;
(d) large chasmata with medial grooves on Ariel;
(e) an impact crater on Ariel, possibly infilled by cryolava;
(f) the bright floor of Wunda crater on Umbriel;
(g) the large Messina Chasmata on Titania;
(h) the smooth floor of Hamlet crater and an 11 km tall 'limb mountain' on Oberon.

# Icy worlds | Neptune satellite

**Triton** surface is:

- ✓ Young → Average surface age ~50 Ma, possibly <10 Ma;
- ✓ Dynamic → Resurfacing via volcanic, tectonic, and sublimation processes; endogenic and exogenic;
- ✓ Diverse → Several geological units, some appear unique;
- ✓ Plumes → Found on volatile-rich south polar terrain and Interpreted to result from sublimation-driven explosive venting of dark material from beneath transparent ice.



South polar terrain


Smooth plains


Cantaloupe terrain

# Icy worlds | Outstanding open questions

Which are the geological processes that modelled or are still modelling the surfaces of icy satellites? Are they still active?

Are they hosting or have hosted internal liquid ocean? Which are the astrobiological implications?

Which is the composition of icy satellites in the outer SS? How much does it differ between bodies?

Which is the correlation between geology, composition and the surrounding environment?

Which is the role of the tectonic resurfacing or cryovolcanism?

How common are the geological features, such as landslides, boulders, fractures, cryovolcanic regions on the different icy satellites?

Which is the link between the surface and the subsurface?

Are the icy satellites experienced a common evolution history?

# Icy worlds | Multidisciplinary analysis

Icy bodies are extremely geologically complex and witness the presence of different processes that act on the outer objects of the Solar System

**Comparative analysis through a multidisciplinary approach to advance the knowledge of the icy worlds of the outer Solar System**

Geomorphological analysis

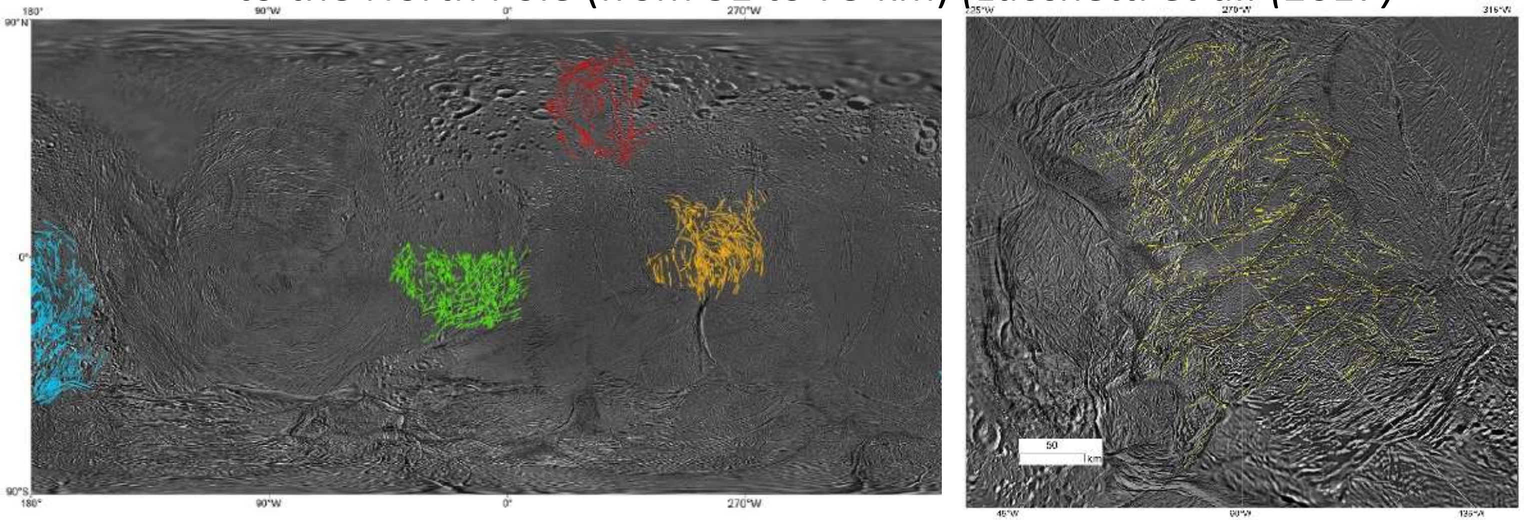
Compositional analysis

3D analysis
(both geological and DTM analysis)

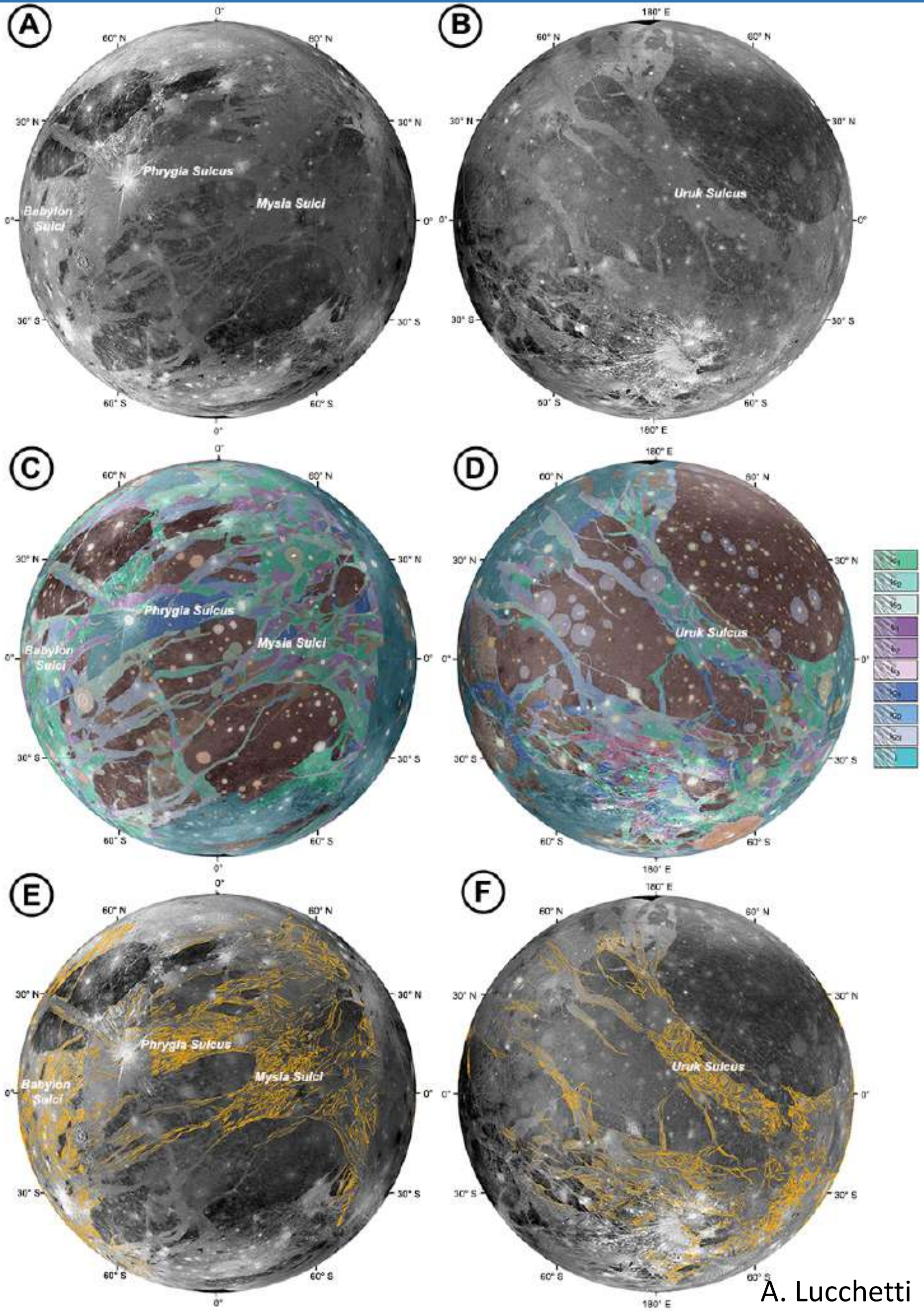
# Icy worlds | Fractal analysis

Determine the **DEPTH OF FRACTURE PENETRATION IN ICY CRUST** by performing a fractures **self-similar clustering** and **length distribution** analysis

**Enceladus**: Brittle ice shell thickness increases from the South to the North Pole (from 31 to 75 km) *(Lucchetti et al. (2017)*



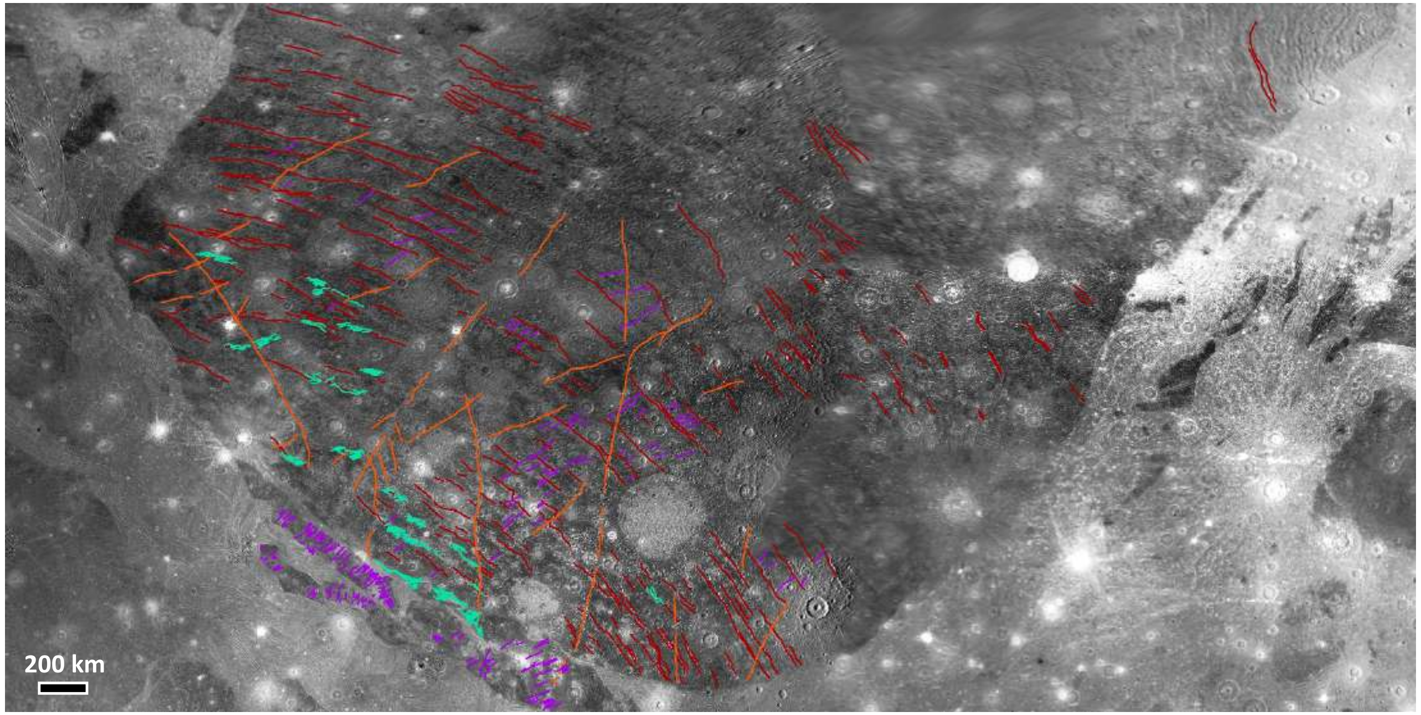

**Ganymede**: The presence of **icy solid crust with thickness of 100-130 km along the equatorial belt** of Ganymede (Lucchetti et al., 2021) which is in agreement with previous measurements (from 80 to 150 km, Schenk et al., (2002); Kivelson et al., 2002; Saur et al., 2015).





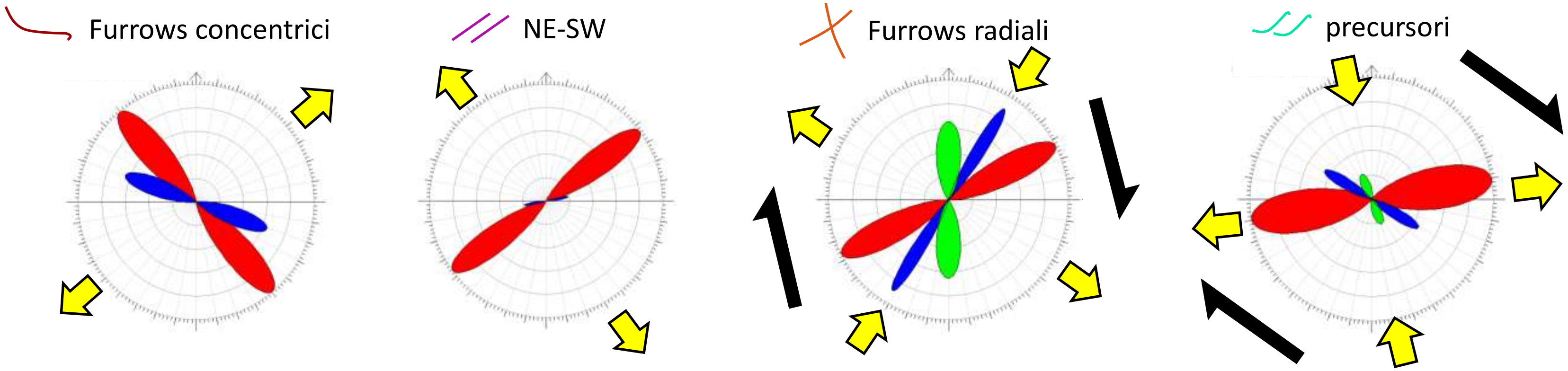

A. Lucchetti

# Icy worlds | Analysis of geological features

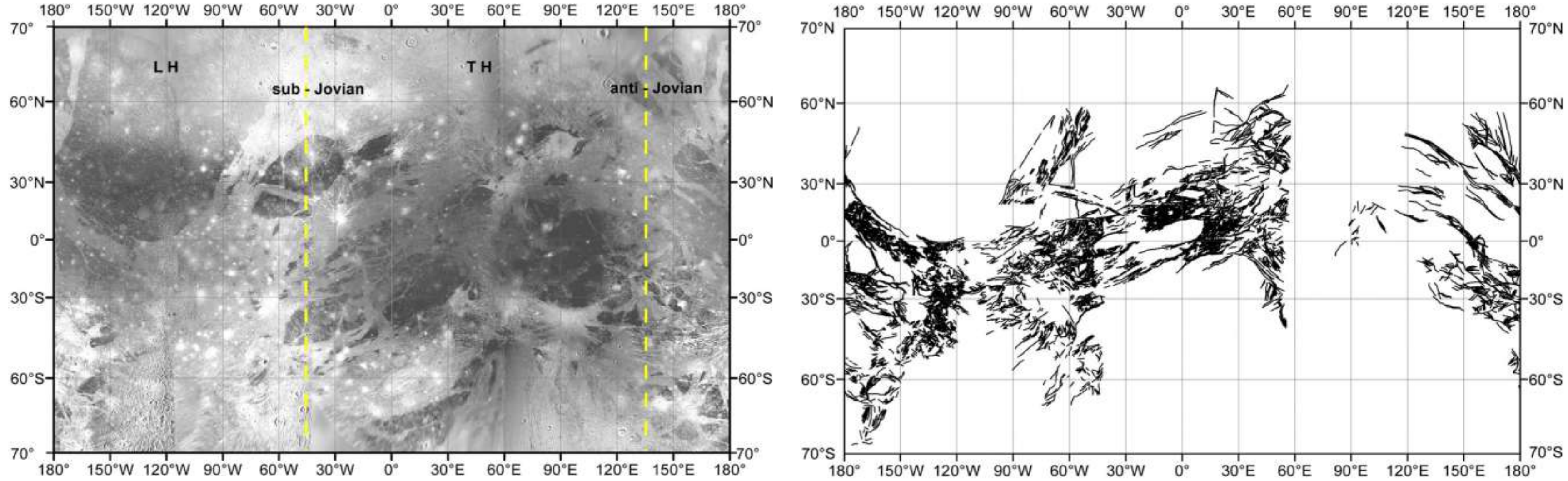



Analysis of **FRACTURES** to provide a structural analysis and an evolutive tectonic model for the region under study

Structural geological mapping of **Ganymede** Galileo regio

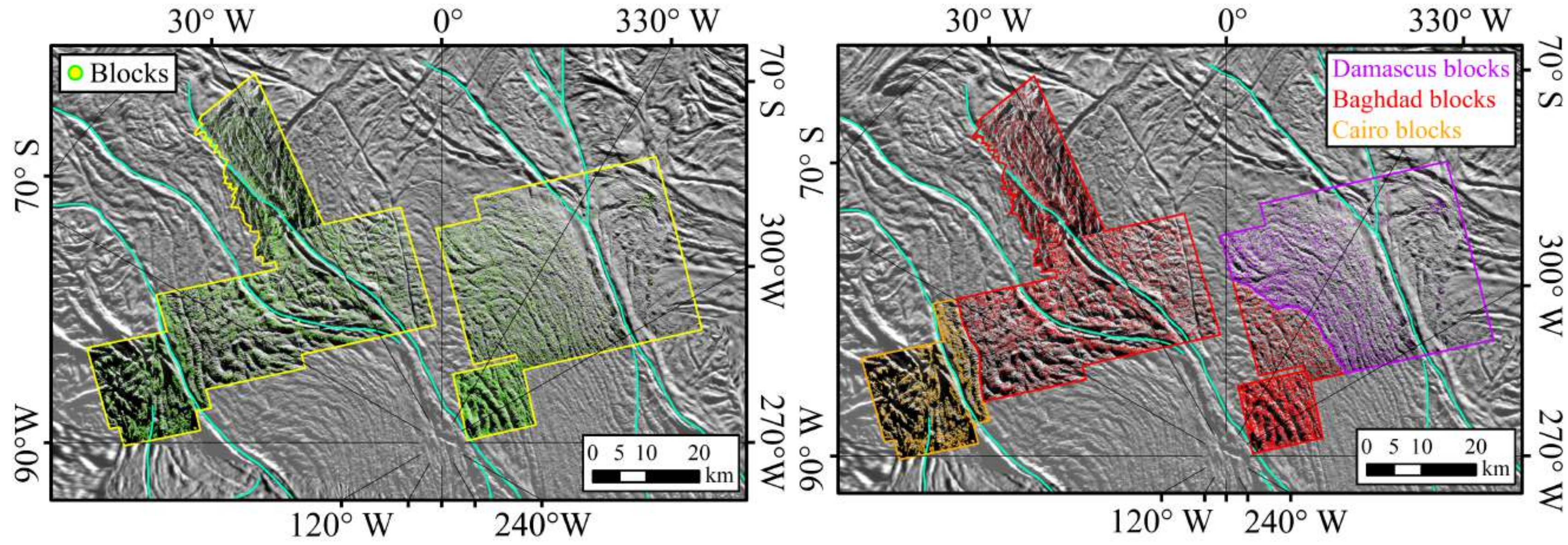



Azimuthal analysis of fractures systems and determination of stress fields (Rossi et al., submitted)




Structural geology of **Ganymede regional groove systems** (60°N–60°S)

*(Rossi et al., 2018)*

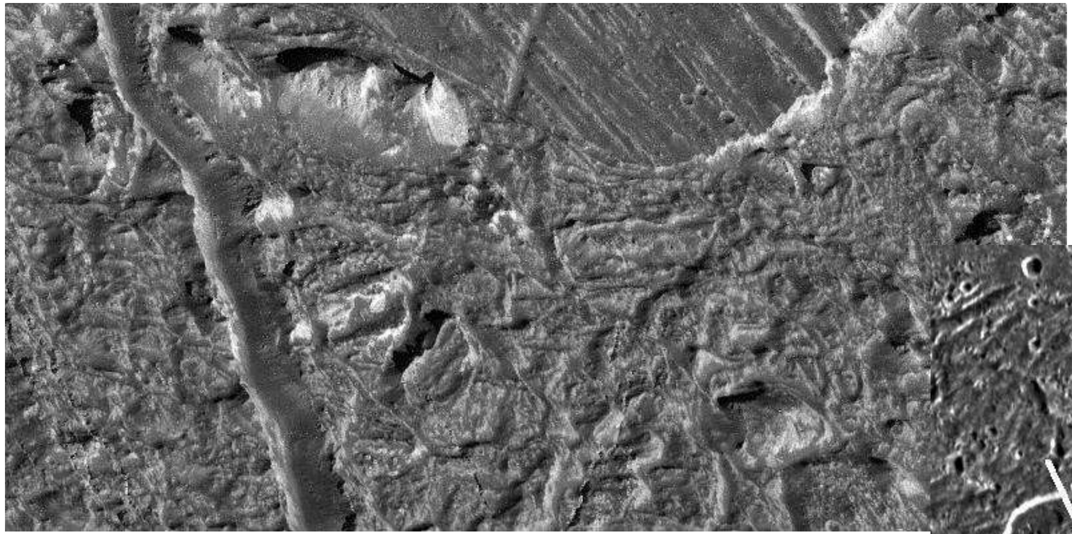



**BOULDERS** Size Frequency Distribution in the Tiger Stripes area (**Enceladus**)

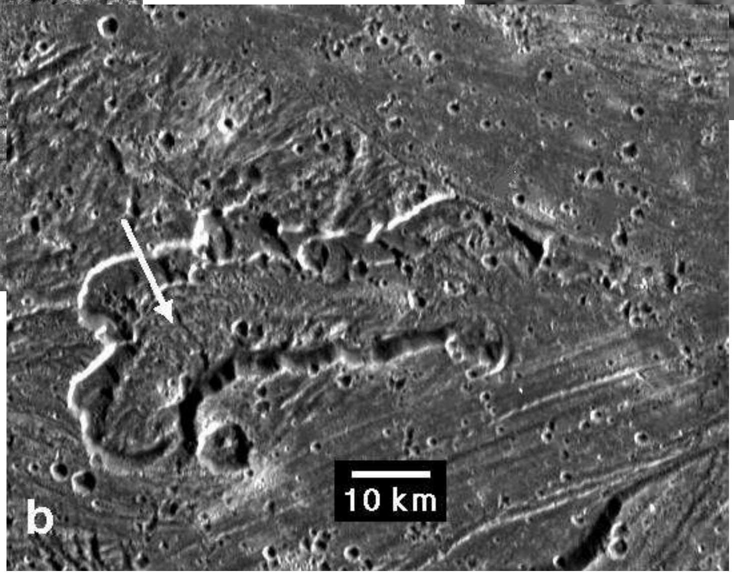
Different processes concur in the formation and evolution of such blocks, in particular sublimation and cryovolcanic ejection mechanisms, as previously hypothesized by Martens et al., (2015).

*Pajola et al., (2021)*

Mapping and model the formation of features that could be generated by **CRYOVOLCANIC PROCESS or DIAPIRISM.**



Chaos terrain on Europa

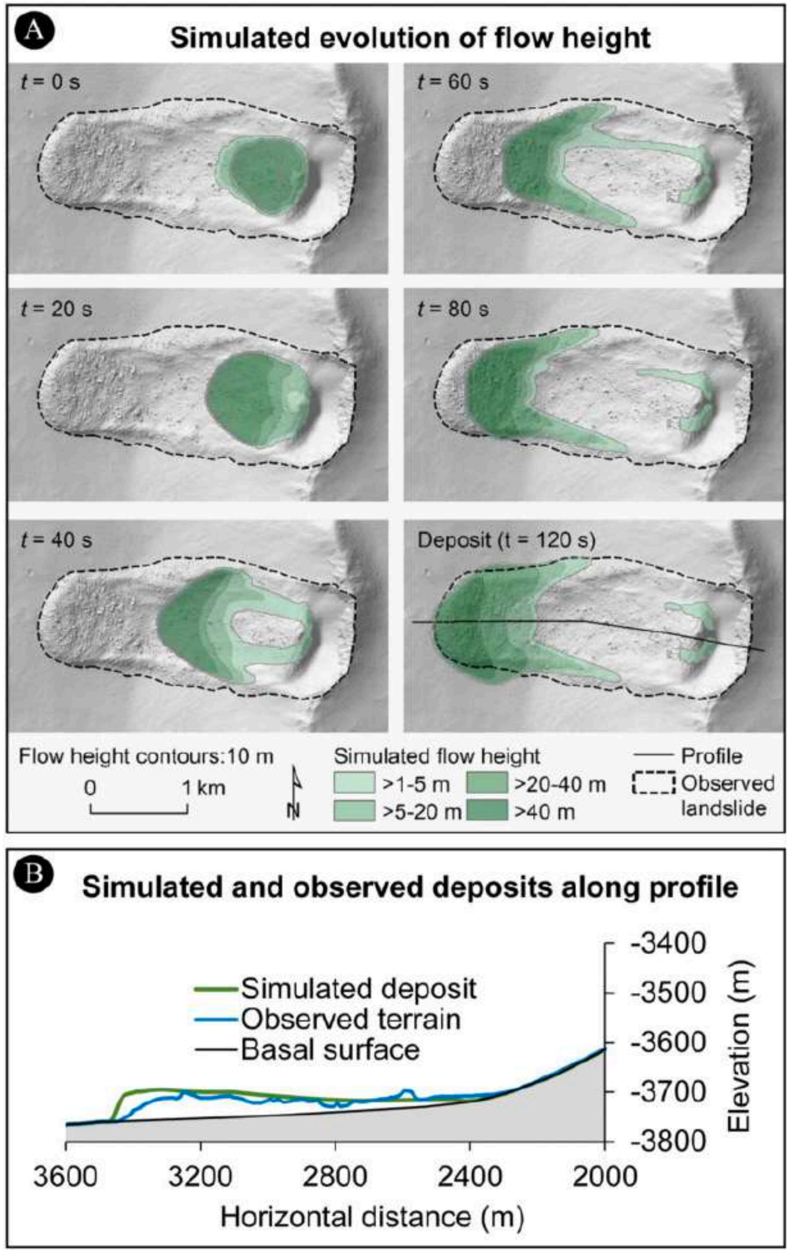



Caldera on Ganymede

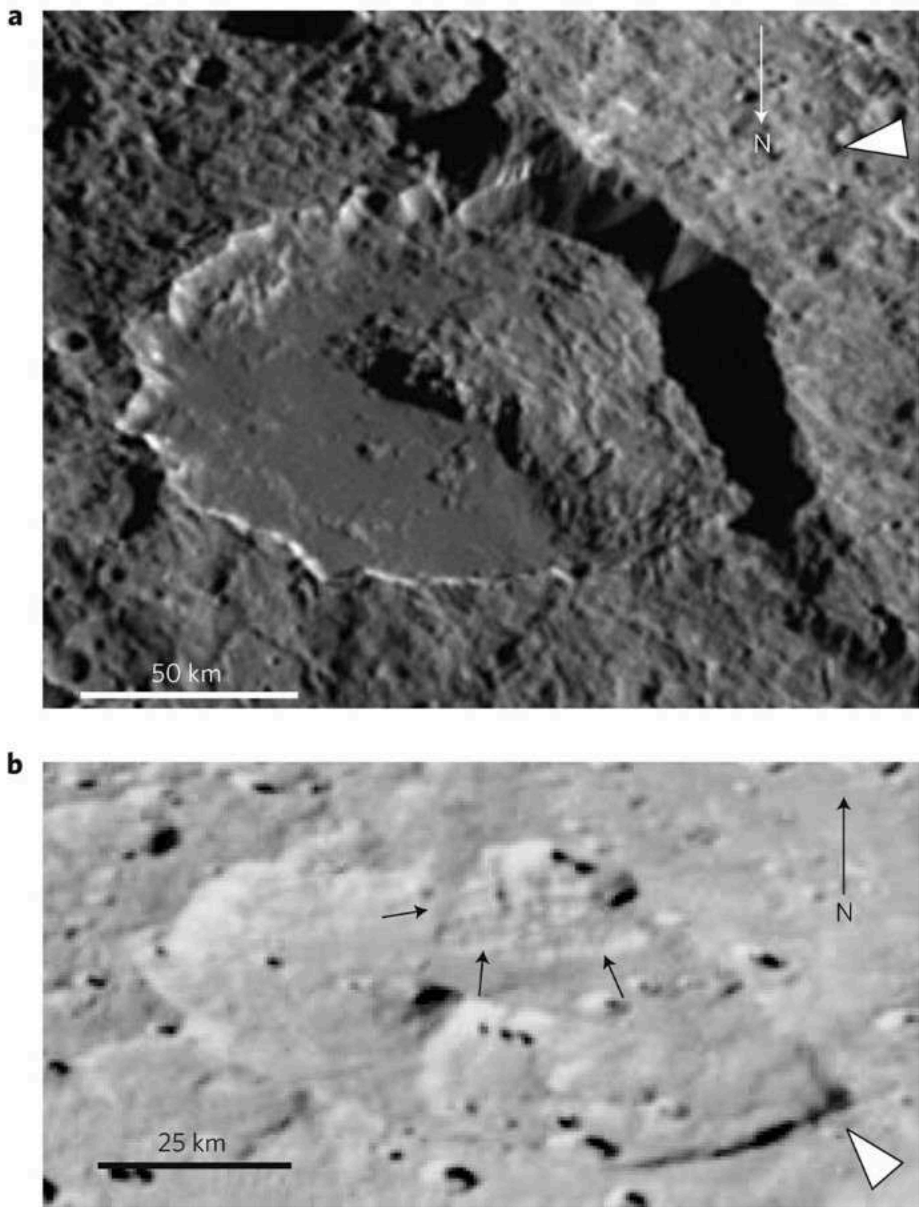
Cantaloupe terrain on Triton

Analyse the different geological processes affecting the surfaces, such as **LANDSLIDES**

Adapt different terrestrial modelling software (r.avaFlow, etc..) to model landslides on the surface of icy satellites




Pajola et al., (2021)



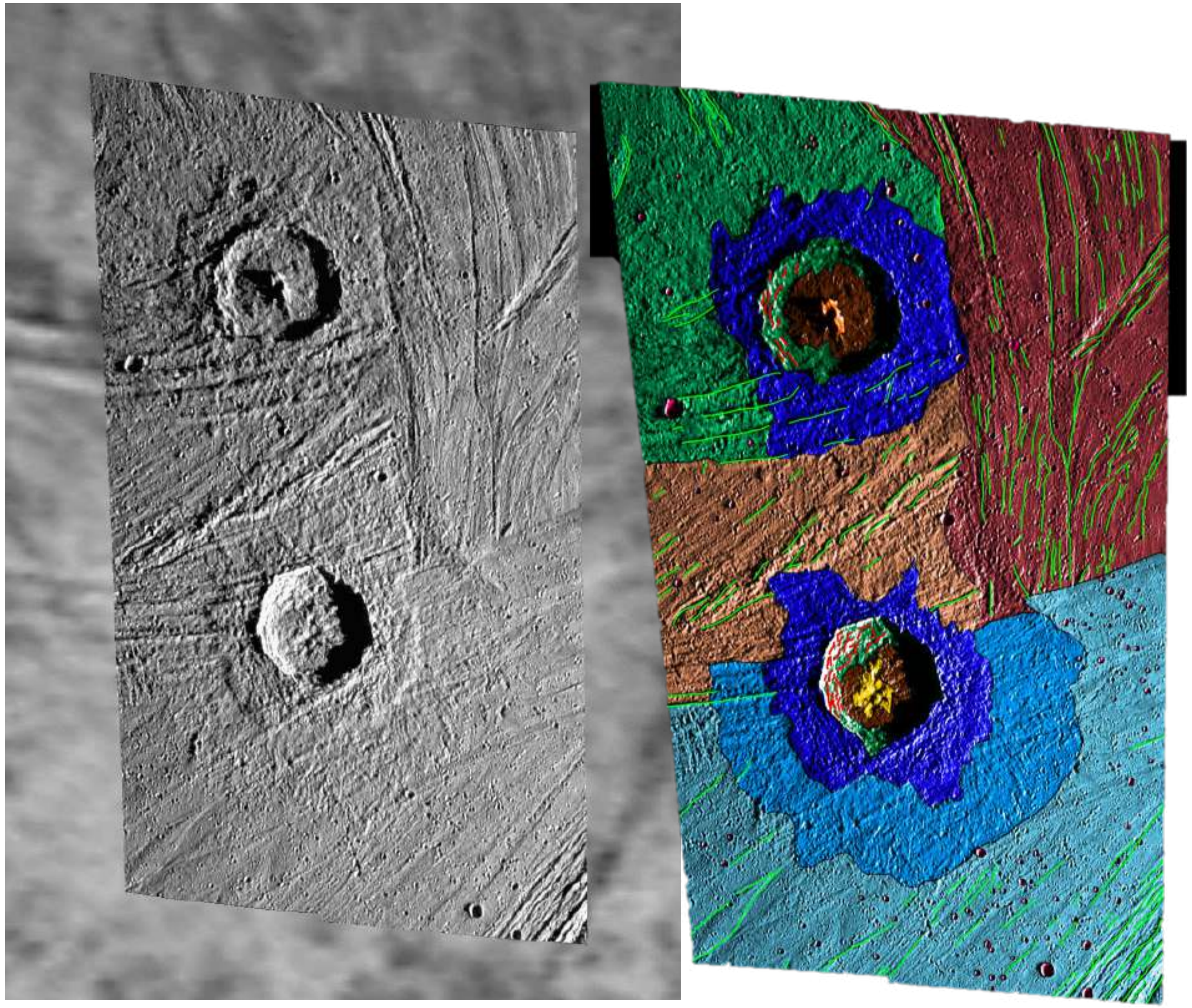

Iapetus



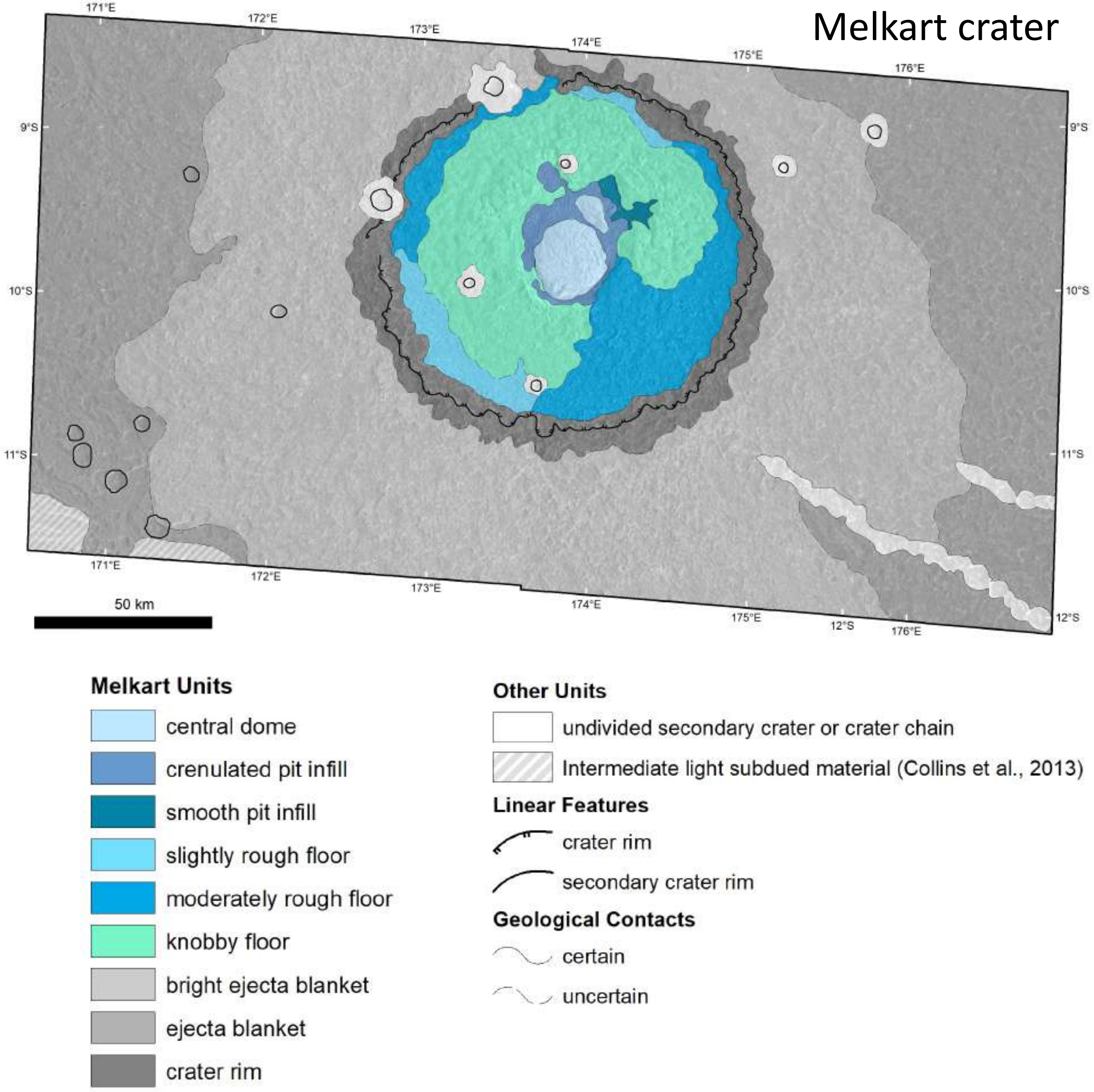
A. Lucchetti

# Icy worlds | Geological maps

## Ganymede: Gula and Achelous craters



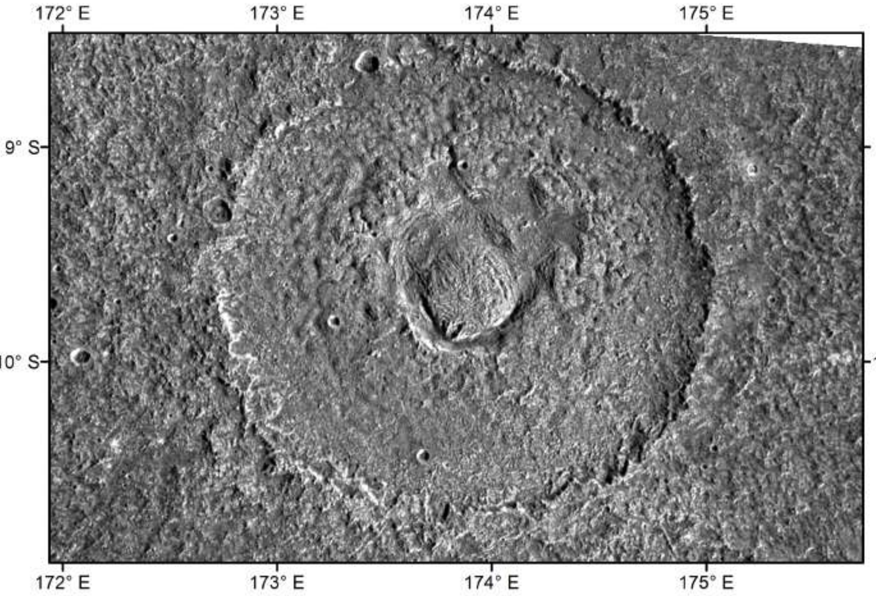
## Melkart crater

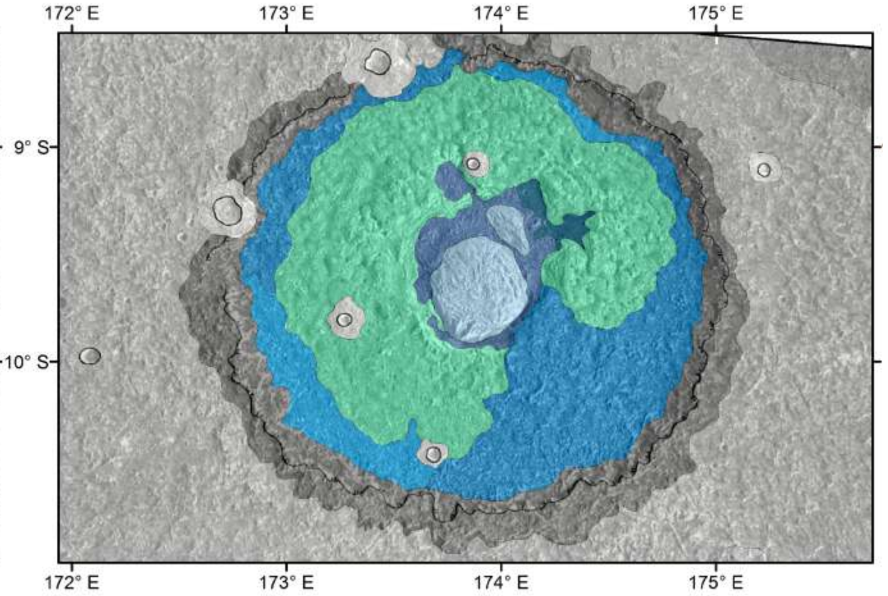




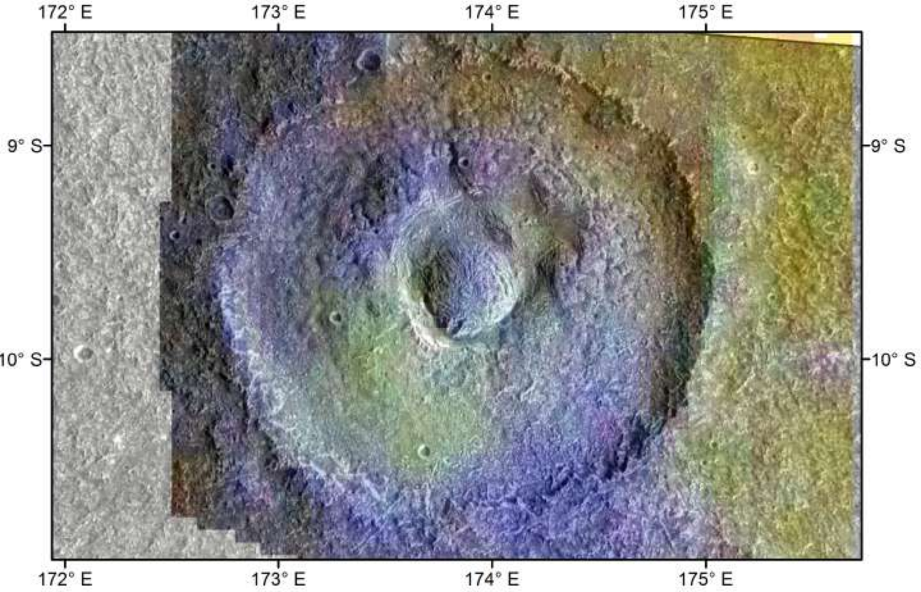

A. Lucchetti

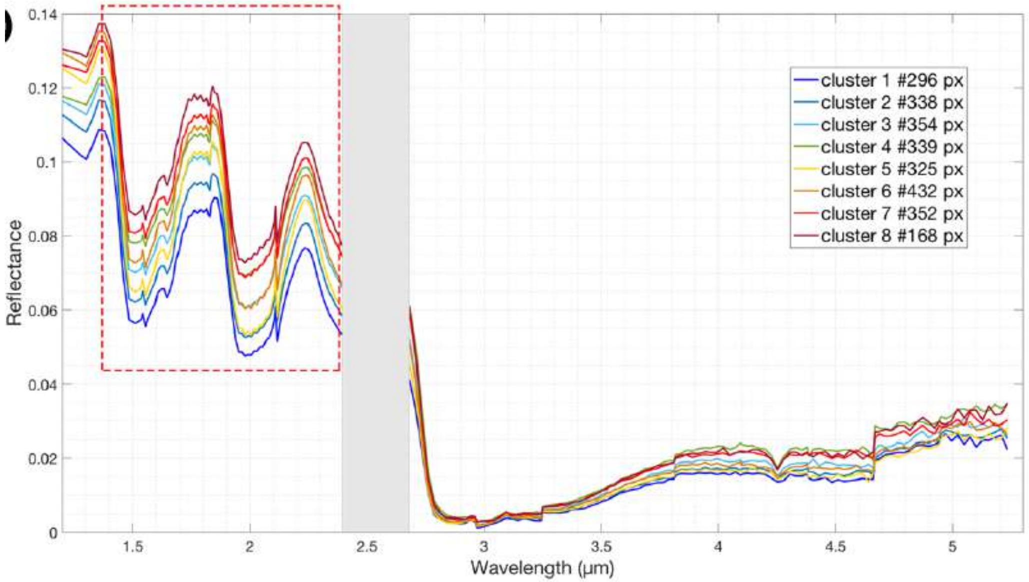
# Icy worlds | Compositional analysis



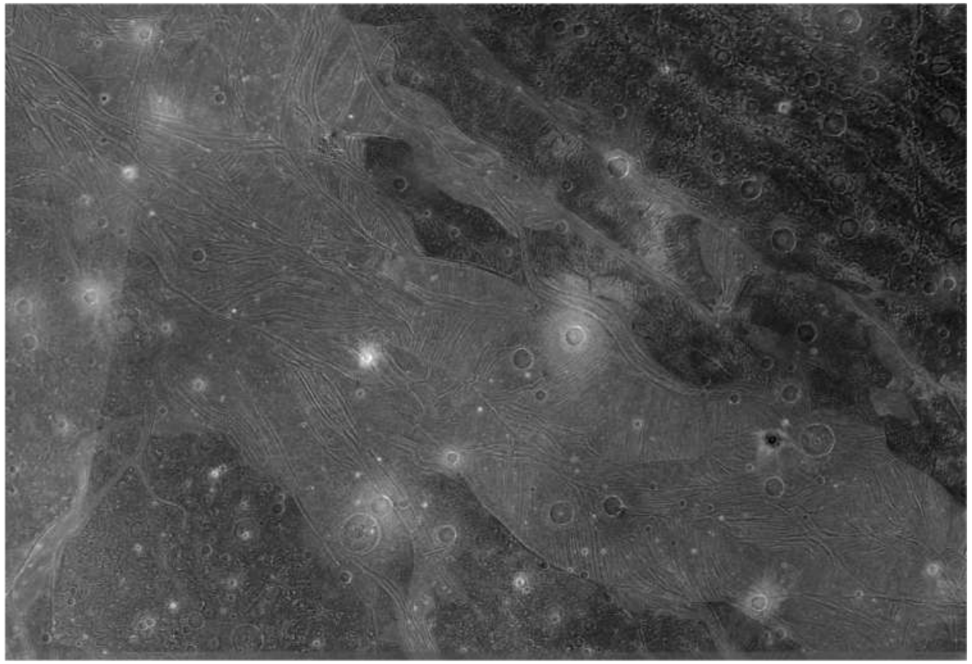



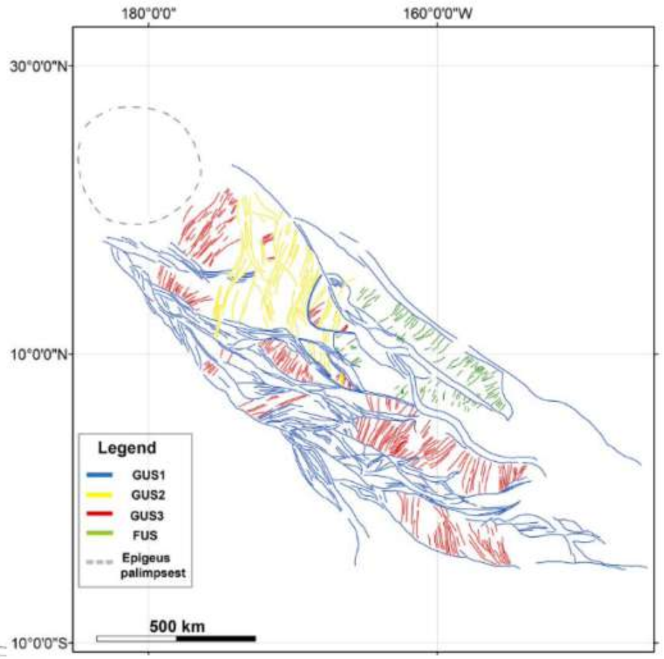

Determine the amount of crystalline and amorphous ice through **spectral clustering and spectral modelling analysis**

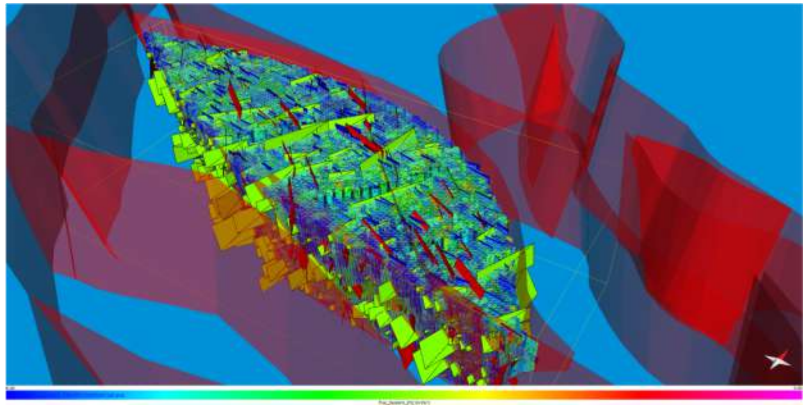


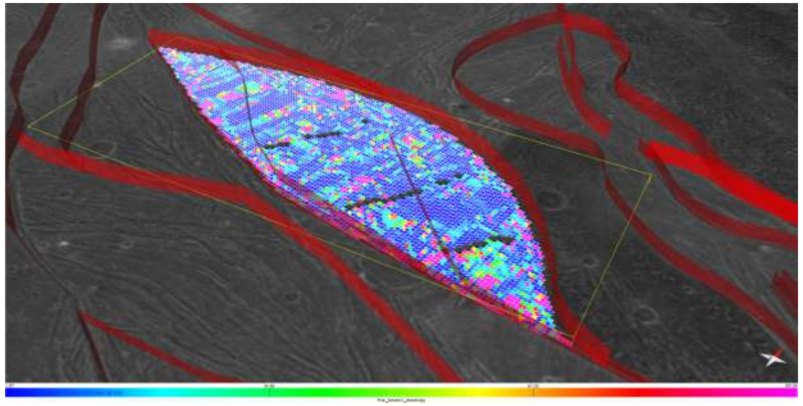



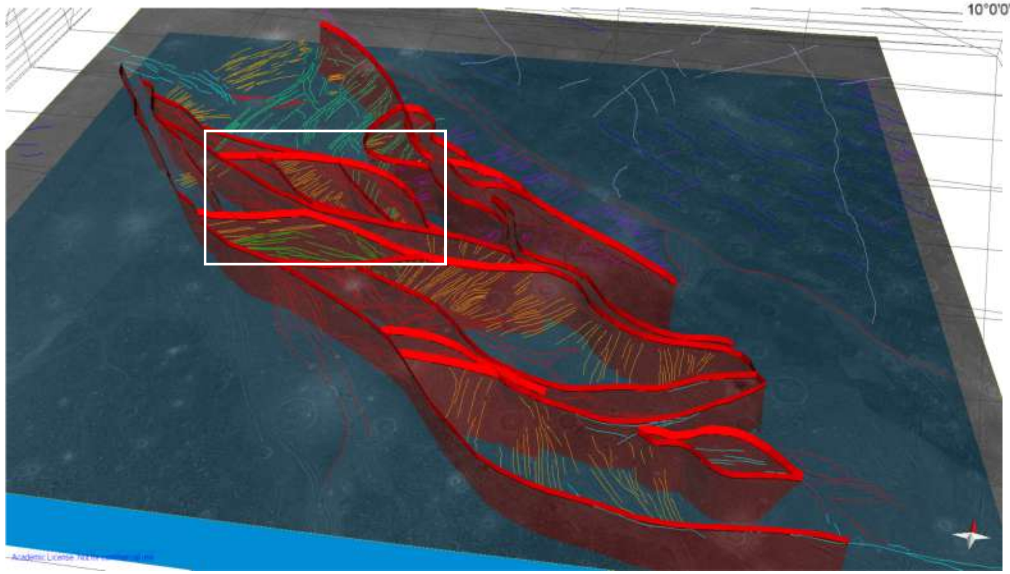
# Icy worlds|3D geological modelling







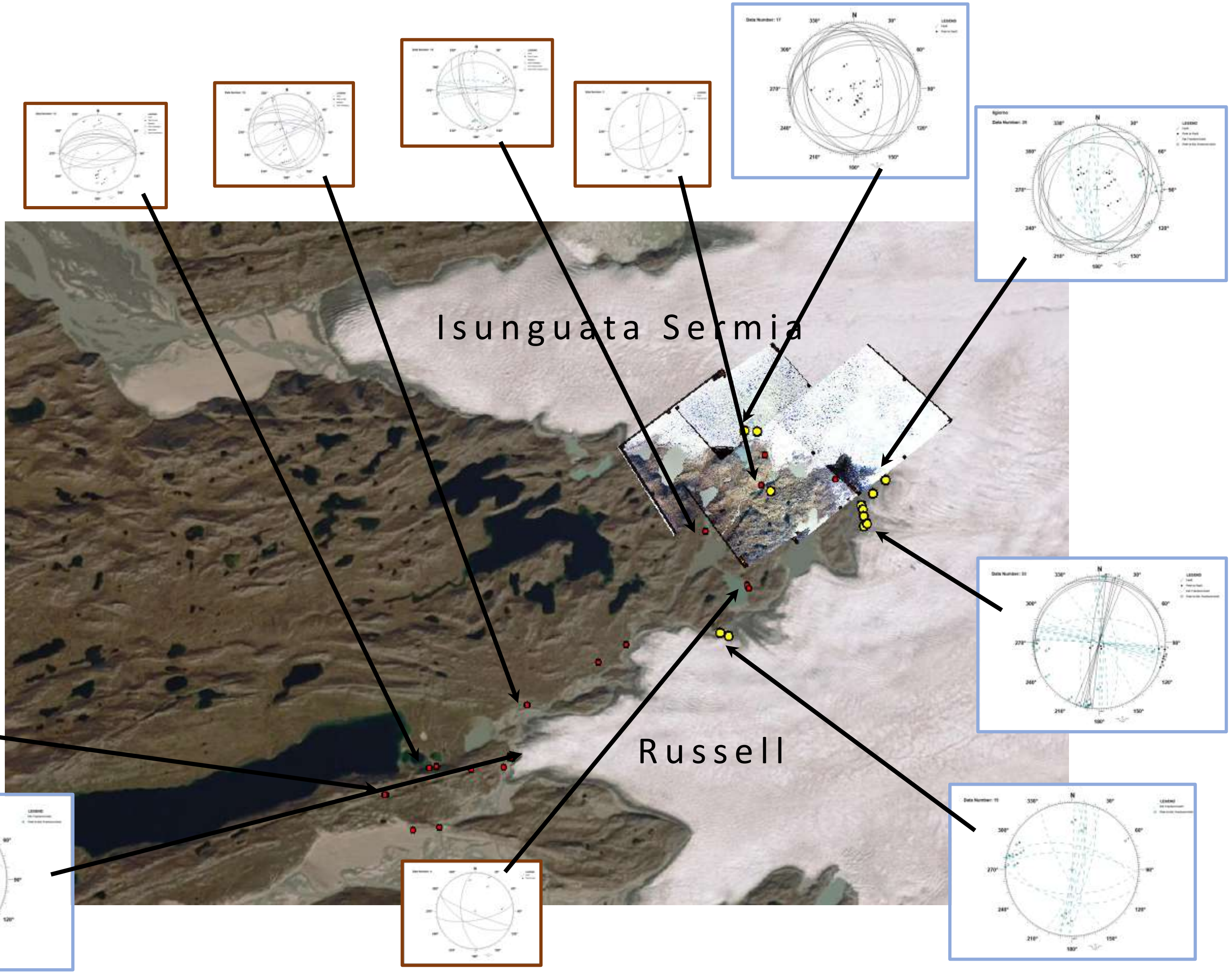


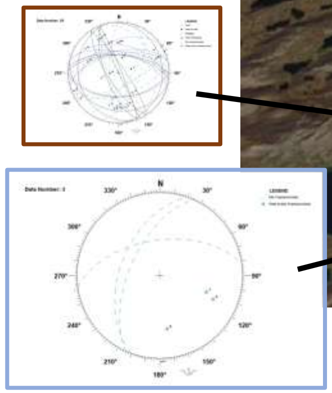
*Move software*

**3D geological model** of surface regions to determine the behavior of the evolution of the body
*(Pozzobon et al., in preparation)*

## Terrestrial analogues: Russell and Isunguata Sermita, Groenlandia


Study area



# Icy worlds | Team

| # | Nome | E-mail | Struttura | TI | Qualifica | Ruolo nel Progetto | Impegnate (2022/23/24) |
|---|---|---|---|---|---|---|---|
| 1 | alice.lucchetti | alice.lucchetti@inaf.it | O.A. PADOVA | Y | RICERCATORE | Responsabile - PI | [0.3, 0.3, 0.3] |
| 2 | costanza.rossi | costanza.rossi@inaf.it | O.A. PADOVA | N | ASSEGNISTA | Co-I, analisi geologica | [0.8, 0.8, 0.8] |
| 3 | maurizio.pajola | maurizio.pajola@inaf.it | O.A. PADOVA | Y | RICERCATORE | Co-I, analisi spettrofotometrica | [0.0, 0.0, 0.0] |
| 4 | riccardo.pozzobon | riccardo.pozzobon@unipd.it | O.A. PADOVA | N | ASSEGNISTA | Co-I, analisi morfologica e modellistica 3D | [0.4, 0.4, 0.4] |
| 5 | luca.penasa | luca.penasa@inaf.it | O.A. PADOVA | N | BORSISTA | Co-I, analisi morfologica e modellistica 3D | [0.5, 0.5, 0.5] |
| 6 | gabriele.cremonese | gabriele.cremonese@oapd.inaf.it | O.A. PADOVA | Y | PRIMO TECNOLOGO | Co-I | [0.0, 0.0, 0.0] |
| 7 | pamela.cambianica | pamela.cambianica@inaf.it | O.A. PADOVA | N | ASSEGNISTA | Co-I, analisi dati | [0.0, 0.0, 0.0] |
| 8 | giovanni.munaretto | giovanni.munaretto@inaf.it | O.A. PADOVA | N | ASSEGNISTA | Co-I, analisi spettrofotometrica | [0.0, 0.0, 0.0] |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | matteo.massironi | matteo.massironi@unipd.it | Dipartimento di Geoscienze, Università degli Studi di Padova | Y | professore ordinario | Co-I | [0.1, 0.1, 0.1] |
| 2 | silvia.bertoli | silvia.bertoli.3@phd.unipd.it | CISAS, University' di Padova | N | Dottoranda | Co-I | [0.0, 0.0, 0.0] |

**Institutions involved:**

- ✓ INAF – OAPD (3 staff, 5 postdoc)
- ✓ University of Padova (1 staff, 1 PhD student)

# Icy worlds | Results

## ✓ Refereed Publications

- Lucchetti, A., Pozzobon, R., Mazzarini, F., Cremonese, G., Massroni, M. (2017). Brittle ice shell thickness of Enceladus from fractures distributionanalysis. Icarus, Volume 297, p. 252-264. DOI: 10.1016/j.icarus.2017.07.009
- C. Rossi, P. Cianfarra, F. Salvini, G. Mitri, M. Massé, 2018. Evidence of transpressional tectonics on the Uruk Sulcus region, Ganymede.Tectonophysics, 749, 72-87. https://doi.org/10.1016/j.tecto.2018.10.026
- C. Rossi, P. Cianfarra, F. Salvini, 2019. Structural Geology of Ganymede Groove Systems (60°N-60°S). Journal of Maps, 1-11.https://doi.org/10.1080/17445647.2019.1685605
- Rossi, C., Cianfarra, P., Salvini, F., Bourgeois, O., & Tobie, G. (2020). Tectonics of Enceladus' South Pole: Block rotation of the Tiger Stripes.Journal of Geophysical Research: Planets, 125(12), e2020JE006471 https://doi.org/10.1029/2020JE006471
- Lucchetti, A., Rossi, C., Mazzarini, F., Pajola, M., Pozzobon, R., Massironi, M., & Cremonese, G. (2021). Equatorial grooves distribution on Ganymede: Length and self-similar clustering analysis. Planetary and Space Science, 195, 105140. https://doi.org/10.1016/j.pss.2020.105140
- Pajola, M., Lucchetti, A., Senter, L., & Cremonese, G. (2021). Blocks Size Frequency Distribution in the Enceladus Tiger Stripes Area: Implicationson Their Formative Processes. Universe, 7(4), 82. https://doi.org/10.3390/universe7040082.

## ✓ Conference proceedings

## ✓ International collaborations

# Icy worlds | Future workflow

**Research activity (Ricerca di Base) with a long term (> 10 years) vision research**

↓

The **interest in studying icy satellites is strongly increasing as testified by future space missions and space agencies recommendations**:

- ✓ ESA JUICE mission
- ✓ NASA Europa Clipper mission
- ✓ ESA Voyage 2050, science theme is Moons of the Icy Giants
- ✓ NASA Decadal Survey, Flagship mission: Uranus orbiter and atmospheric probe, New Frontiers recommendations: Enceladus multiple flyby mission, Triton mission.

# Icy worlds|Funds, critical aspects and leadership

## Funds

There are no ad hoc funding for such activity

*- a few research activities are being developed also under other projects, while one minigrant has been submitted to the recent INAF call (PI: A. Lucchetti)*

## Critical Aspects:

- ✓ It is necessary to develop ad hoc tools for the analysis of past space mission data
- ✓ Difficulty in treating and elaborating old space mission data, such as the production of DTMs

*Solid State Imaging (SSI) e Near Infrared Mapping Spectrometer (NIMS) (Galileo mission) - Imaging Science Subsystem (ISS) e Visual and Infrared Mapping Spectrometer (VIMS) (Cassini mission) - Imaging Science Subsystem(ISS) (Voyager mission) - Long Range Reconnaissance Imager (LORRI) (new Horizons mission),*

- ✓ Part of the team is involved in other projects or is paid on other projects, hence, it will be necessary to enlarge the team.
- ✓ Limited budget

## Leadership:

- ✓ All presented analysis can be well-developed and carried out by the team

# Thank you

*alice.Lucchetti@inaf.it*