

Coping with complexity: Earth System Science and Extra-terrestrial Geology for planetary defense and sustainability

Diego Perugini, Maurizio Petrelli, Alessandro Pisello & Matteo Bisolfati



Petro-Volcanology Research Group (PVRG)

science

| 'saɪəns |

the intellectual and practical activity encompassing the systematic study of the structure and behaviour of the physical and natural world through observation and experiment.

geology

| dʒɪ'ɒlədʒi |

the science which deals with the physical structure and substance of the earth, their history, and the processes which act on them.

physics

| 'fɪzɪks |

the intellectual and practical activity encompassing the systematic study of the structure and behaviour of the physical and natural world through observation and experiment.

Structure of this talk:

- 1) **PVRG**: who we are and where we came from.
- 2) **Cyber-volcanology**: towards a new dimension of knowledge for risk mitigation.
- 3) **Don't look up!** Compositional mapping of planets and asteroid for Earth defence and sustainability.

PVRG: who we are and where we came from.

Now:



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Stefano Rossi
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PVRG: who we are and where we came from.

Selection of competitive Research projects since 2010

- **PRIN 2010-2011 (RU-UNIPG):** Genesis and differentiation of magmas in different geodynamic environments: petrological and geochemical characteristics of their source regions.
- **2014, ERC-Consolidator Grant:** CHRONOS - A geochemical clock to measure timescales of volcanic eruptions.
- **2014, ITN-MCA-3.01 Marie Curie actions (RU-UNIPG):** VERTIGO - Volcanic ash: field, laboratory and numerical investigations of processes during its lifecycle.
- **2019, PNRA-Antartide (RU-UNIPG):** MAGIC - Magma-Ice interaction: late Miocene ice thickness and eruption tempo in northern Victoria Land.
- **PRIN 2020 (PI):** Dynamics and timescales of volcanic plumbing systems: a multidisciplinary approach to a multifaceted problem.



PVRG: who we are and where we came from.

Our habitat is Earth System Science (ESS):

- The Earth System behaves as **a single, self-regulating system** comprised of physical, chemical, biological and human components, with **complex interactions and feedbacks between the components**.
- Global change cannot be understood in terms of a simple cause–effect paradigm. **Changes happen as multiple, complex effects that cascade through the Earth System**.
- Earth System dynamics are characterized by **critical thresholds and abrupt changes**. These changes can switch the Earth System to alternative modes of operation that may prove irreversible and less hospitable to humans and other forms of life.

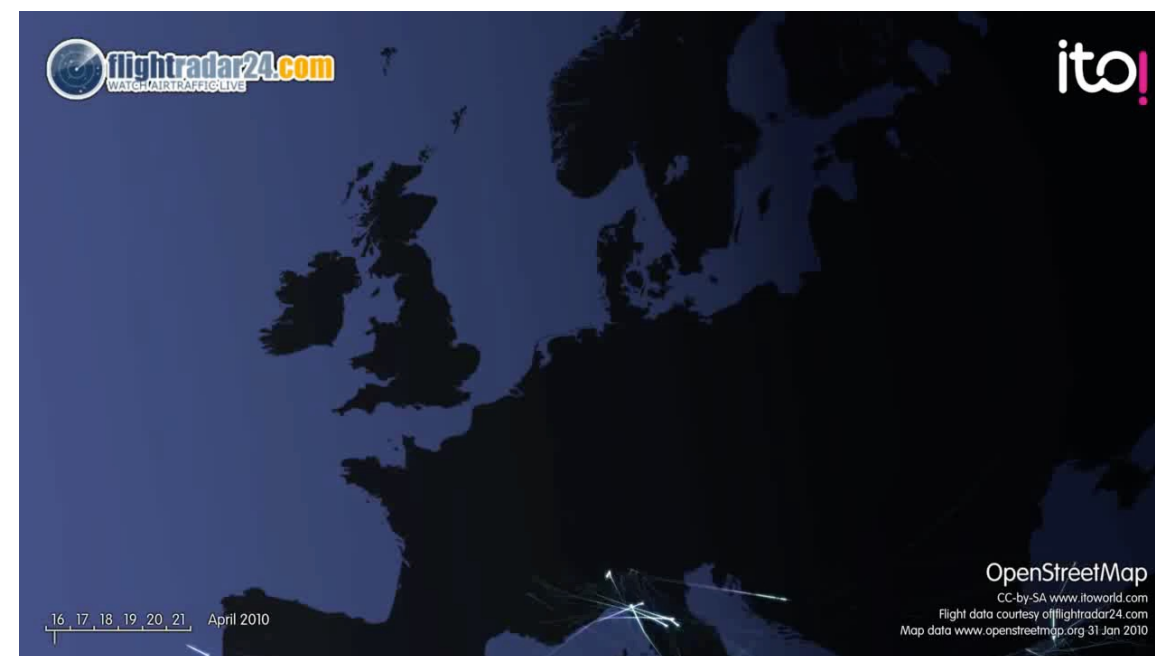
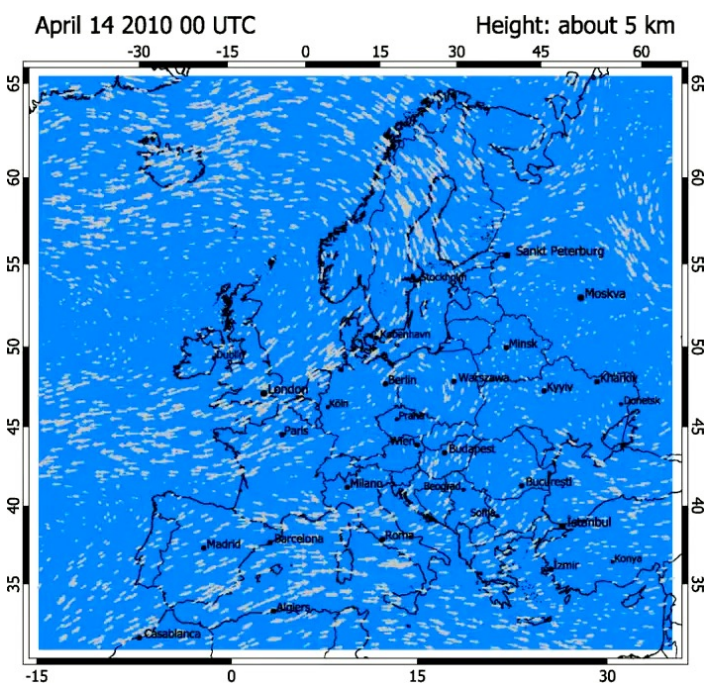




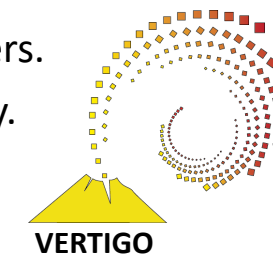
Cyber-volcanology:
towards a new dimension of knowledge
for risk mitigation.

Cyber-volcanology: towards a new dimension of knowledge for risk mitigation.

With the eruption of Eyjafjallajökull (14-21 April 2010) the world has been affected drastically by volcanic ash in a manner unique in history. This demonstrated the disadvantages of an industrialized world that largely relies on the “just in time”-concept.



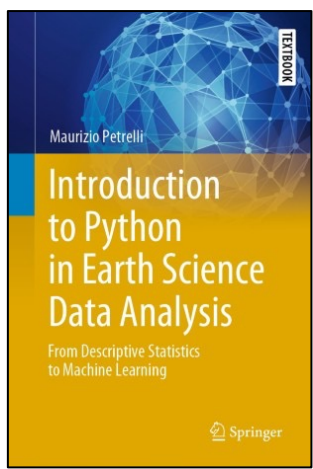
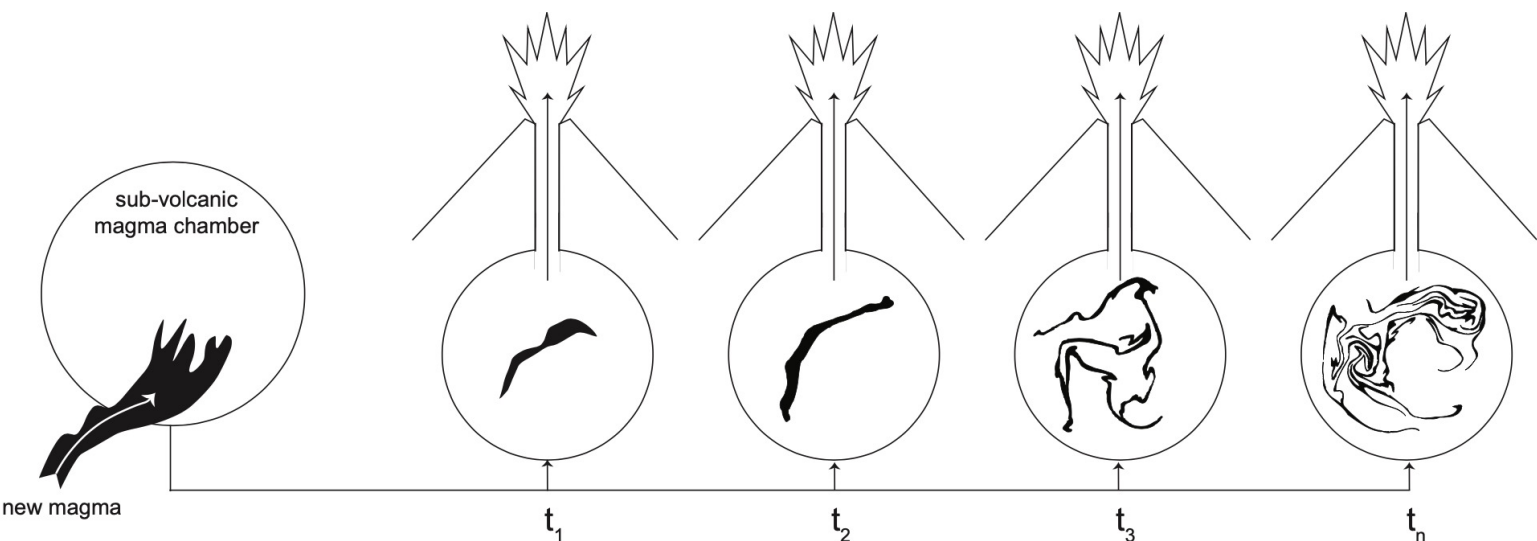
- ❖ 107,000 flights cancelled, accounting for 48% of total air traffic in **Europe**, affecting ca. 10 millions of passengers.
- ❖ Air travel and transport throughout the **world** was cancelled resulting in a loss of ca. 200 millions euros per day.
- ❖ **Kenya** and **Zambia** lose ca. 3.8 millions and 150,000 euros per day, respectively, due to undelivered flowers.
- ❖ The **Netherlands** was unable to supply orchids for the start of the May wedding market in North America.
- ❖ In **Japan** Nissan suspended the production of three models because of disruption of supply of parts.



Cyber-volcanology: towards a new dimension of knowledge for risk mitigation.

The mixing of magmas is associated with more than 90% of volcanic eruption on Earth.

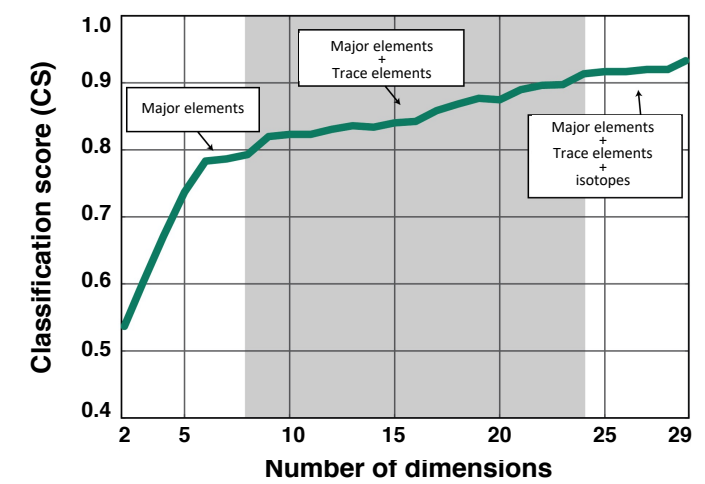
Volcano	VEI	Year (AD)	Country	Magma A	Magma B	Ref.
Askja	5	1875	Iceland	basalt	rhyolite	a
Pinatubo	6	1991	Philippines	basalt	dacite	b
Soufriere Hills	3	1995	Montserrat (UK)	basalt	andesite	c
Vesuvius	5	79	Italy	basanite	phonolite	d
Krakatau	6	1883	Java (Indonesia)	basalt	rhyolite	e
Eyjafjall	3	2010	Iceland	basalt	dacite	f
Lassen Peak	3	1915	California (USA)	basalt-andesite	dacite	g
St. Helens	5	1980	Washington (USA)	basalt	dacite	h
El Chichon	5	1982	Mexico	basalt	trachyte	i
Gallungung	5	1822	Java (Indonesia)	basalt	basalt-andesite	j
Santa Maria	6	1902	Guatemala	basalt	dacite	k
Ksudach	5	1907	Kamchatka (Russia)	andesite	rhyodacite	l
Tambora	7	1815	(Indonesia)	basalt	trachy-andesite	m
Novarupta	6	1912	Alaska (USA)	andesite	rhyolite	n
Fuego de Colima	5	1913	Mexico	basaltic-andesite	andesite	o
Bezymianny	5	1956	Kamchatka (Russia)	basaltic-andesite	dacite	p
Agung	5	1963	Bali (Indonesia)	basalt	andesite	q
Cerro-Hudson	5	1991	Chile	basalt	trachy-andesite	r



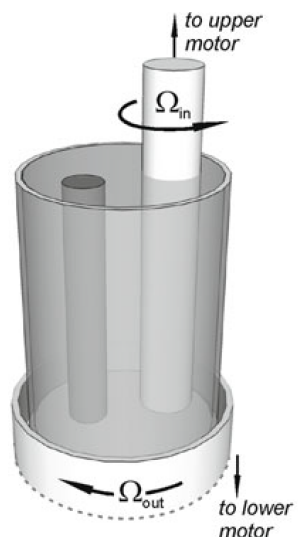
Major elements
 SiO_2 , TiO_2 ,
 Al_2O_3 , Fe_2O_3 , CaO ,
 MgO , Na_2O , K_2O

Trace Elements
 Sr, Ba, Rb, Zr, Nb,
 La, Ce, Nd, Hf, Sm,
 Gd, Y, Yb, Lu, Ta,
 Th

Isotopes
 $^{206}\text{Pb}/^{204}\text{Pb}$,
 $^{207}\text{Pb}/^{204}\text{Pb}$,
 $^{208}\text{Pb}/^{204}\text{Pb}$,
 $^{87}\text{Sr}/^{86}\text{Sr}$,
 $^{143}\text{Nd}/^{144}\text{Nd}$

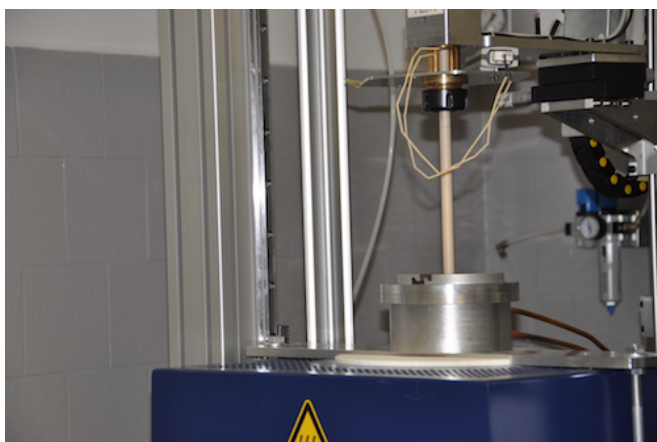
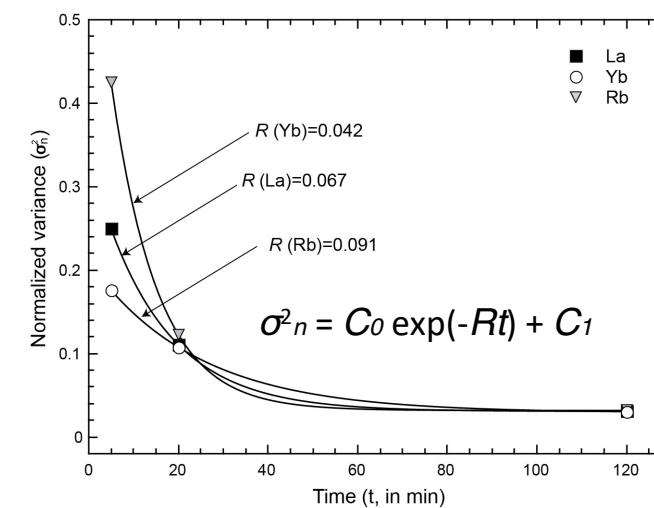
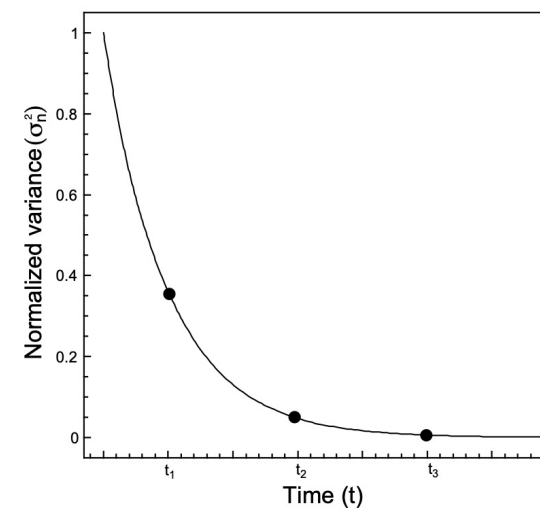
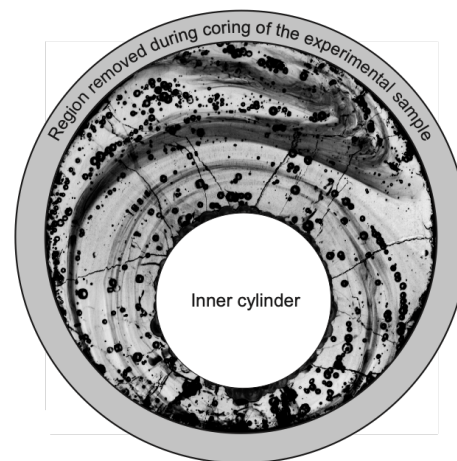
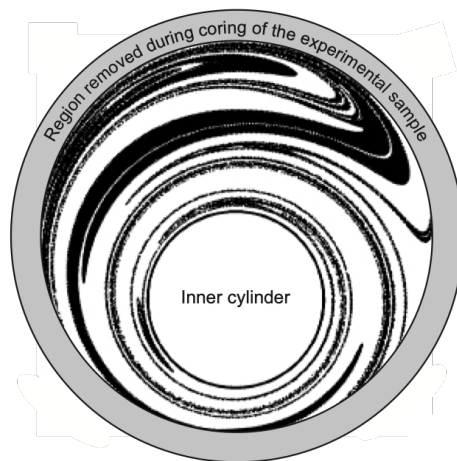
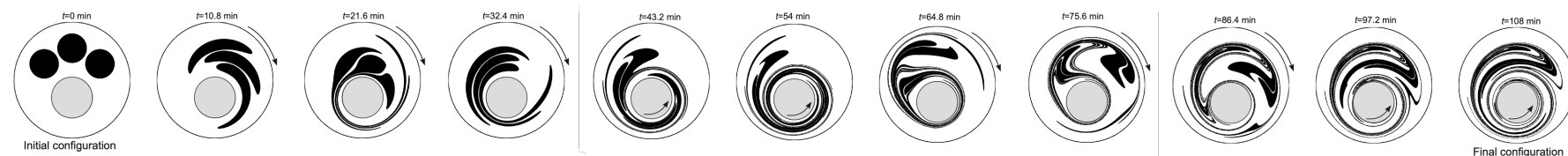


Cyber-volcanology: towards a new dimension of knowledge for risk mitigation.



Experimental parameters

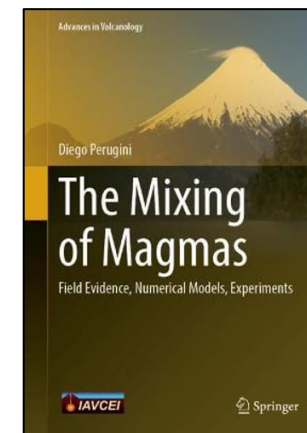
- R_{out} → radius of the outer cylinder
- Ω_{out} → angular velocity of the outer cylinder
- R_{in} → radius of the inner cylinder
- Ω_{in} → angular velocity of the inner cylinder
- δ → distance between the centers of the inner and outer cylinders
- r → radius of liquid B blob



COMMA@unipg – ChaOtic Magma Mixing Apparatus

Mixing-to-eruption time

- Phlegrean Fields – O (30 min)
- Vesuvius – O (2-4 hours)
- Island of Vulcano – O (10-30 hours)
- Azores – O (20-40 hours)



Cyber-volcanology: towards a new dimension of knowledge for risk mitigation.

OUR VISION: developing new methods that will cut the Gordian knot of the presently intractable problem of volcanic eruption forecasting. The main aim is to develop novel approaches based on the use of an “ecosystem” of multiple, heterogeneous, new generation robots permanently “living” on active volcanic systems and monitoring the geophysical and geochemical processes in real-time with the support of remote sensing.



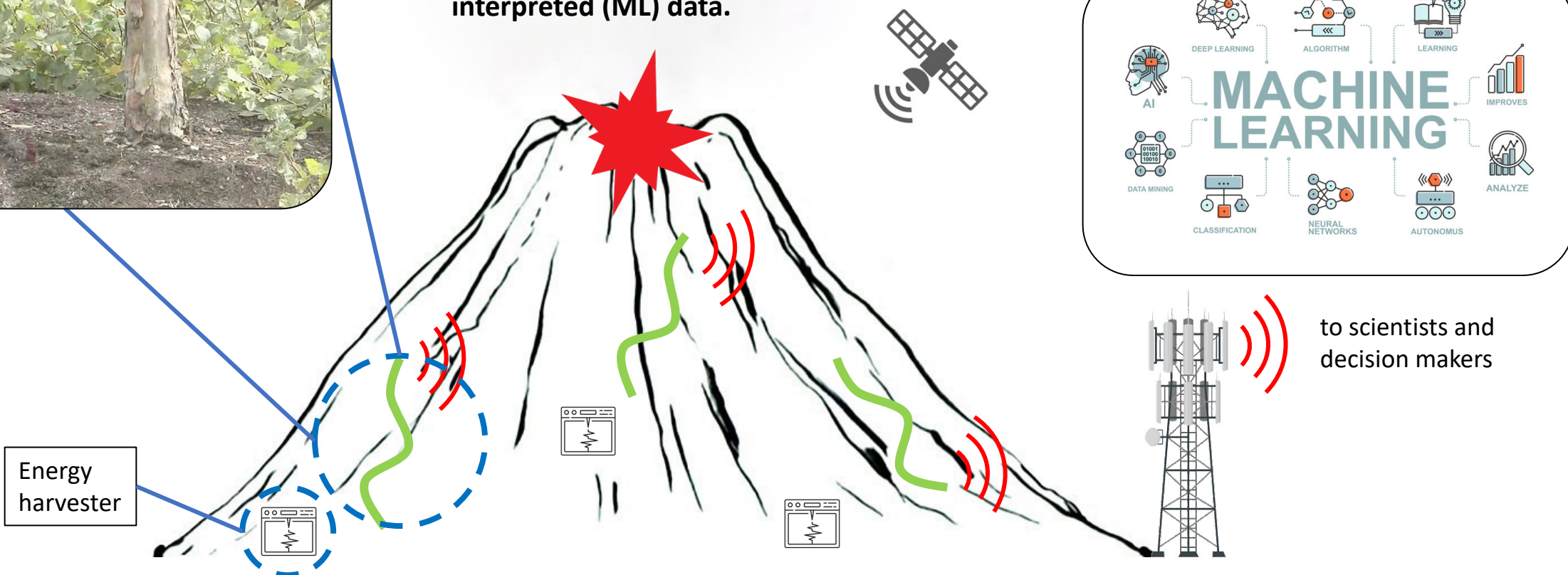
Cyber-volcanology: towards a new dimension of knowledge for risk mitigation.

An ecosystem of multiple, heterogeneous, new generation robots permanently “living” on active volcanic systems.

- **Permanent monitoring of the entire volcanic system.**
- **Continuous transmission of raw and semi-interpreted (ML) data.**



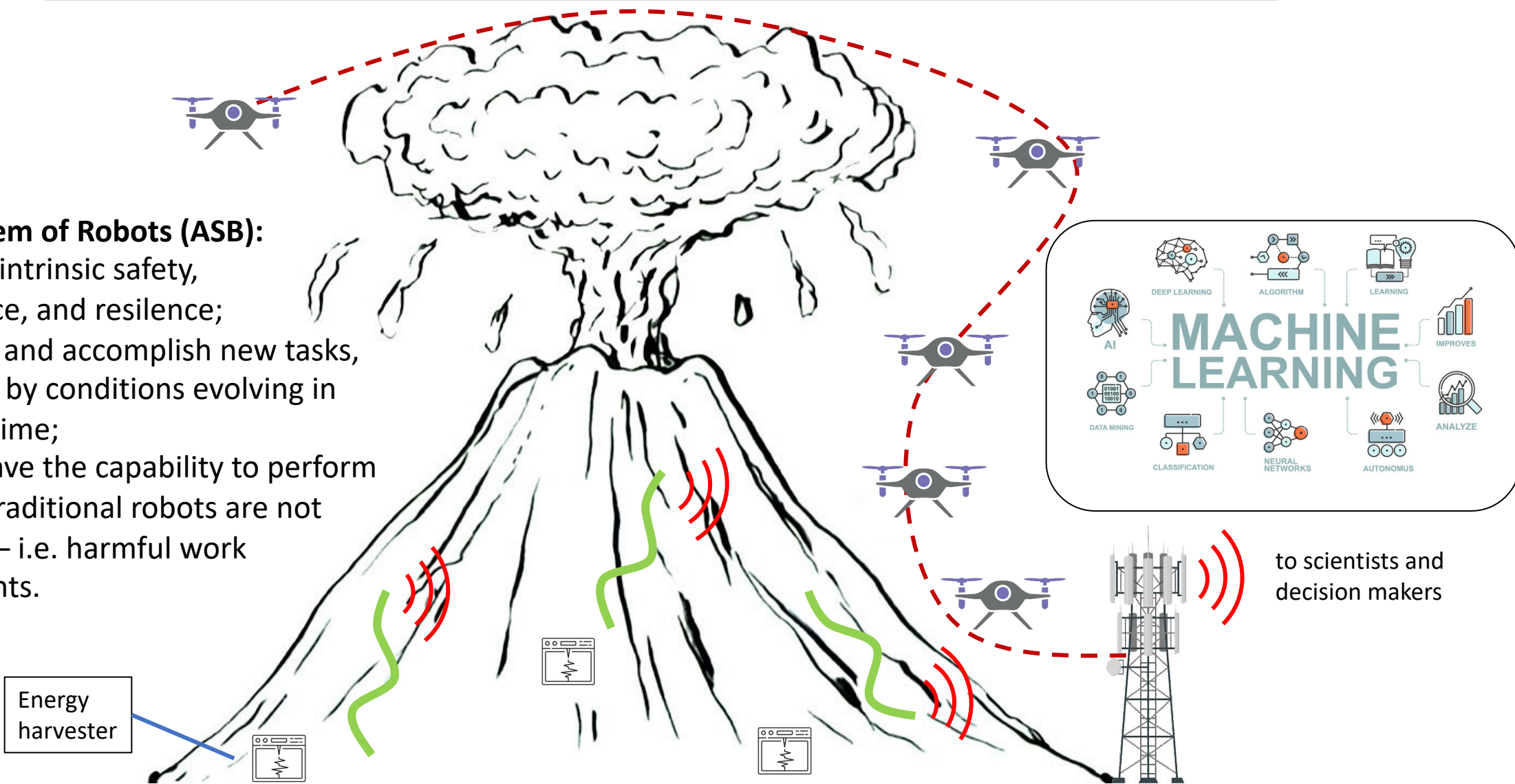
Energy harvester



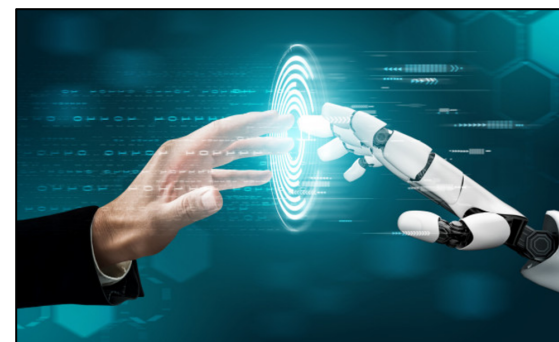
Cyber-volcanology: towards a new dimension of knowledge for risk mitigation.

Adaptive System of Robots (ASB):

- It will have intrinsic safety, performance, and resilience;
- It will learn and accomplish new tasks, as required by conditions evolving in space and time;
- It should have the capability to perform tasks that traditional robots are not capable of – i.e. harmful work environments.



Cyber-volcanology: towards a new dimension of knowledge for risk mitigation.



Area 01 Scienze matematiche e informatiche

- AI
- Big Data
- Num. modeling
- ...

Area 02 Scienze fisiche

- Muon tomogr.
- New sensors
- Energy harvesting
- ...

Area 03 Scienze chimiche

- Spectral and chemical analysis
- Air pollution
- Water pollution
- ...

Area 04 Scienze della Terra

- Petrology & Mineralogy
- Geochemistry
- Volcanology
- ...

Area 05 Scienze biologiche

- Evolution of life
- Ecosystem' disruption after eruption
- ...

Area 06 Scienze mediche

- Medical geology
- Toxic enmissions and impact on health
- ...

Area 07 Scienze agrarie e veterinarie

- Fertilizers
- Soil pollution
- Crop failure
- Animal deseases
- ...

Area 08 Ingegneria civile e architettura

- New building materials
- Structural resilience
- ...

Area 09 Ingegneria industriale e dell'informazione

- Robotics
- Remote sensing
- Cubesat integration
- ...

Area 10 Scienze dell'antichità, letterarie e storiche

- Ancient concepts of volcanoes
- Mythology of volcanic eruptions
- ...

Area 11 Scienze storiche, filos., pedagog., e psicol.

- Life and death and psychology of disasters
- Religion
- ...

Area 12 Scienze giuridiche

- New legal framework for robots on varried enviroments
- ...

Area 13 Scienze economiche e statistiche

- Economic losses due to eruptions
- Air traffic disruption
- ...

Area 14 Scienze politiche e sociali

- Relations with stakeholders and decision makers
- Geopolitics
- ...

Cyber-volcanology: towards a new dimension of knowledge for risk mitigation.**Ambiti del PTSR interessati:**

- Energy Harvesting
- Geologia relativa e assoluta
- Struttura dell'interno della Terra e geodinamica
- Geoinformatica
- Earth system and global changes
- Data science e infrastrutture per big data
- Scienze e tecnologie per lo spazio
- Crisi complesse e previsione del rischio

Azioni di ateneo and clusters Horizon Europe:

- Sicurezza civile per la società
- Clima, energia e mobilità
- Digitale, industria e spazio
- Salute

PNRR:

- Rischi naturali e antropici
- Innovazione tecnologica

Collaborazioni esistenti:

- UNIPG:
 - Dipartimento di Ingegneria
 - Dipartimento di Matematica
 - Dipartimento di Scienze Farmaceutiche
- Italy:
 - INGV
 - Dipartimento di informatica, bioingegneria, robotica e ingegneria dei sistemi (UNIGE)
 - IIT
 - Eagleprojects s.r.l.
 - (...)
- World:
 - University of Munich
 - Institut de Physique du Globe de Paris
 - University of Geneva
 - McGill University
 - (...)

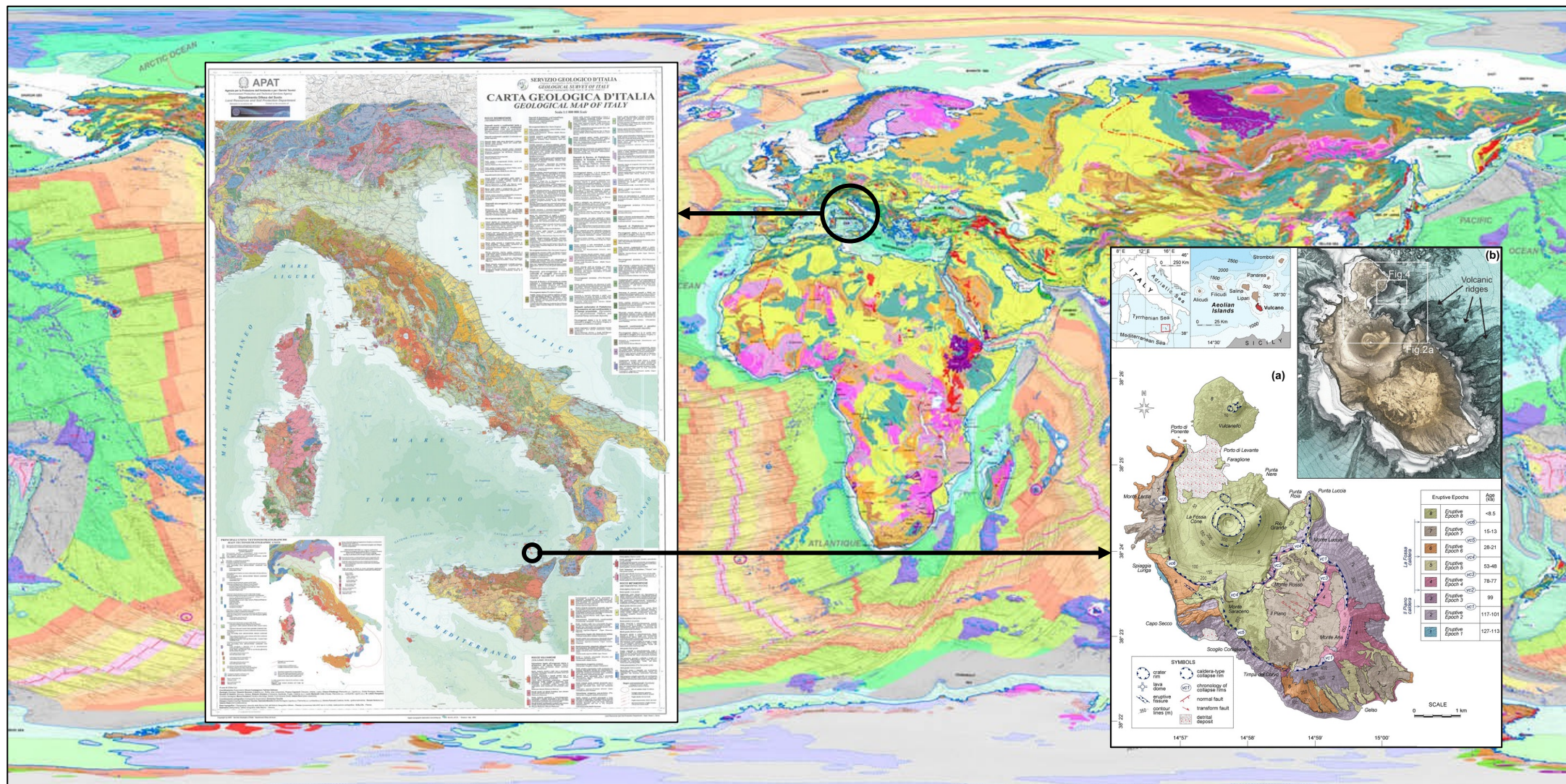




Don't look up! Compositional mapping of planets and asteroids for Earth defence and sustainability.

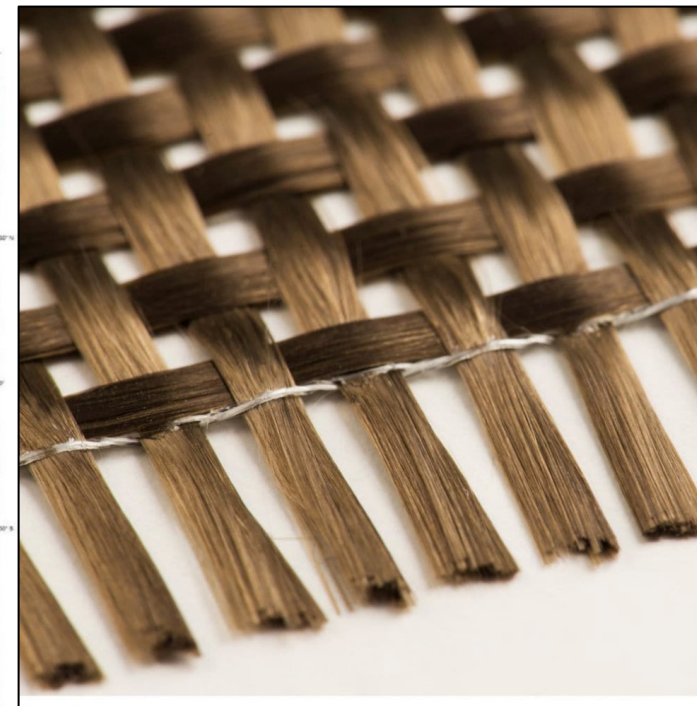
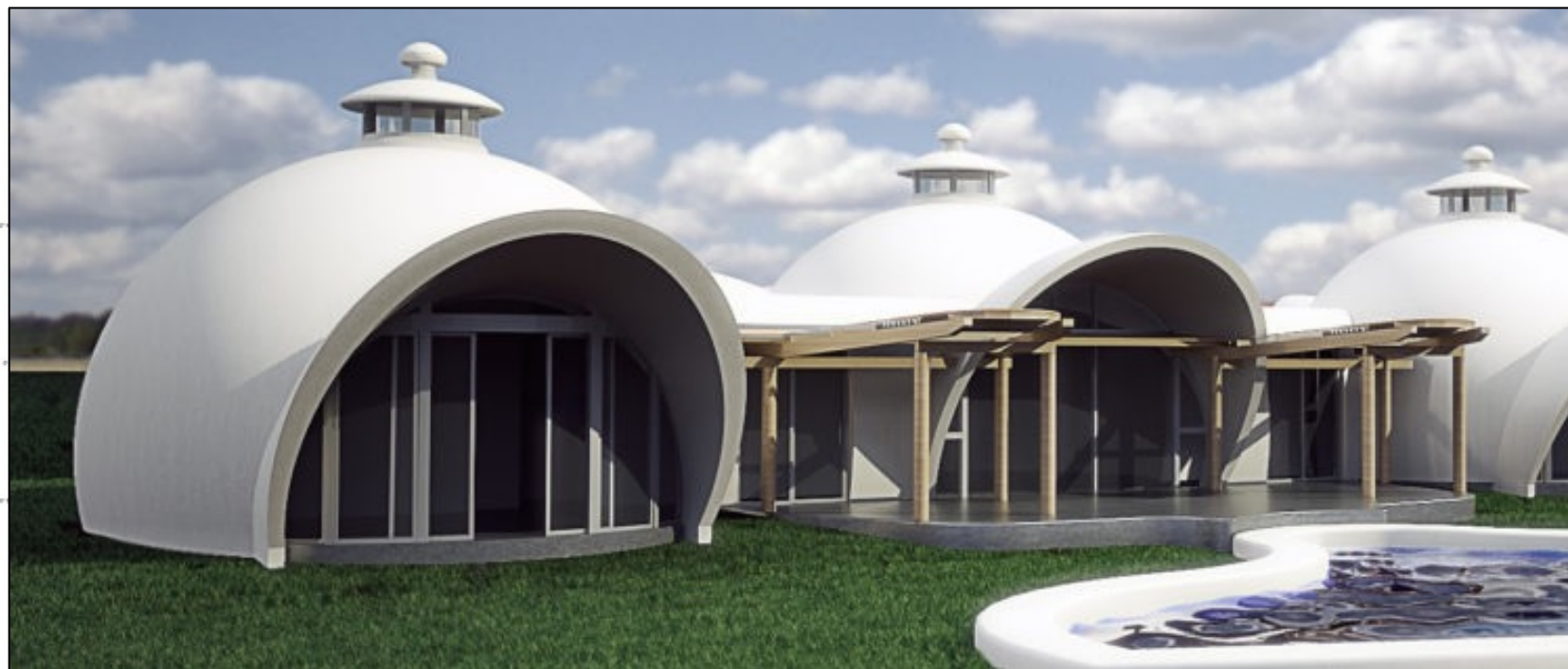


Don't look up! Compositional mapping of planets and asteroids for Earth defence and sustainability.



The Geological Map in Mercator projection of the World where the Polar Regions are hyper-deformed.

Don't look up! Compositional mapping of planets and asteroids for Earth defence and sustainability.



Do we have any chance to provide detailed compositional maps of planets and asteroids?

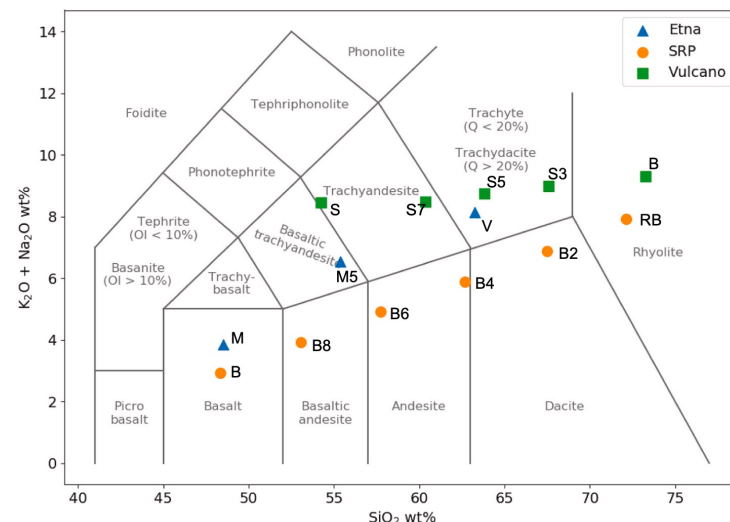
Why do we need this information?

- Gain new knowledge on our solar system and planetary differentiation.
- Evaluate the mining potential of PM and REE which are essential for technology.
- Evaluate the presence of "materials" to be used for future extraterrestrial habitats.
- Evaluate the risk an impact of an asteroid would pose if crashing on Earth.

Don't look up! Compositional mapping of planets and asteroids for Earth defence and sustainability.



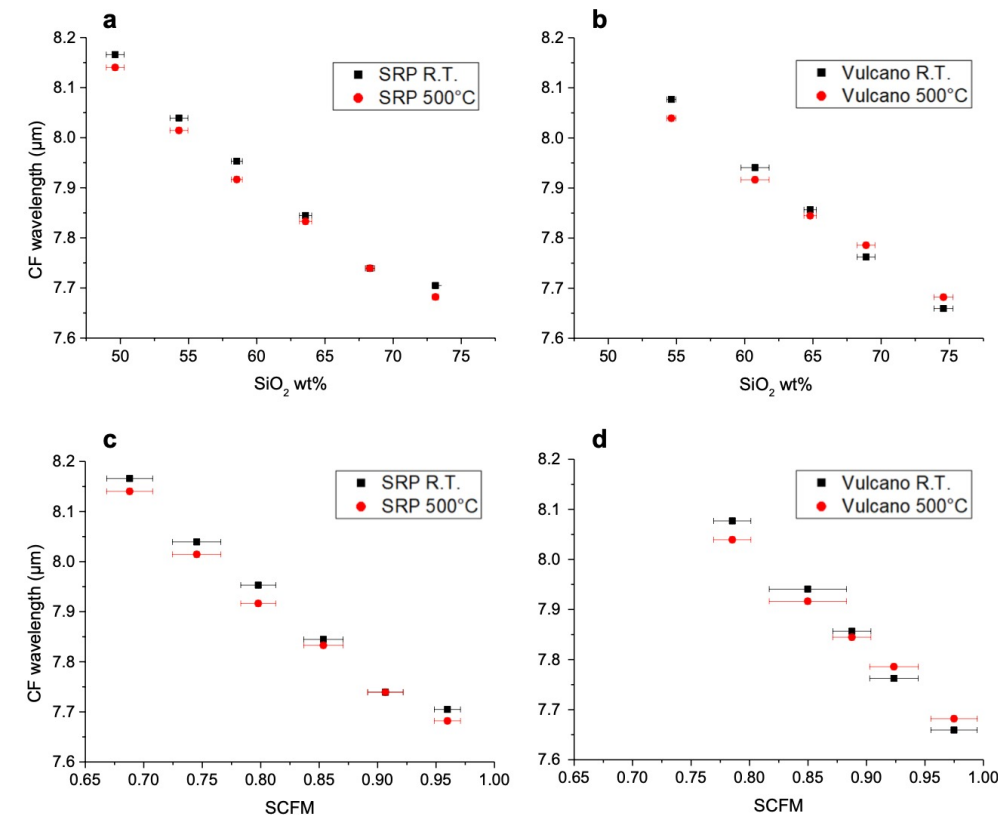
Rock synthesis and spectral analysis



Not that bad ...

- We can produce any magmatic rock virtually cropping out on extraterrestrial planets and asteroids.
- We can derive empirical relationships between composition and spectral features.
- We can infer with precision the composition of the rocks starting from spectral analysis.

So what?

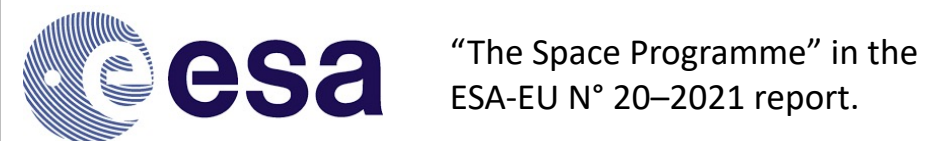
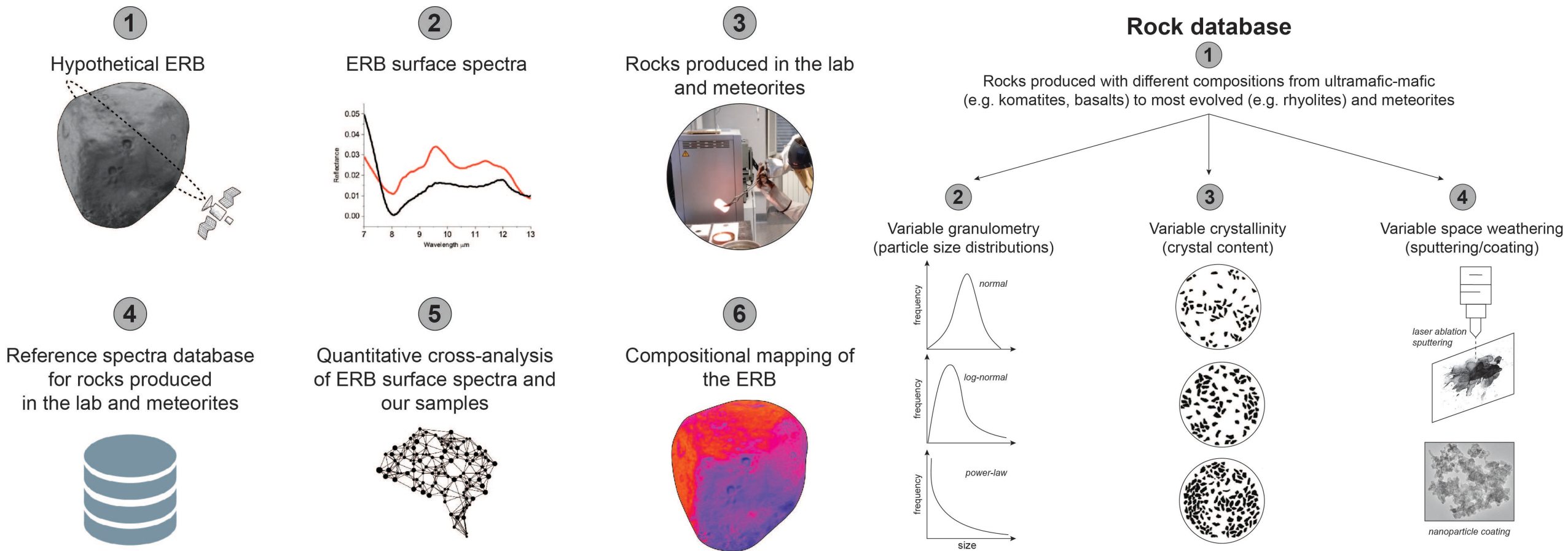


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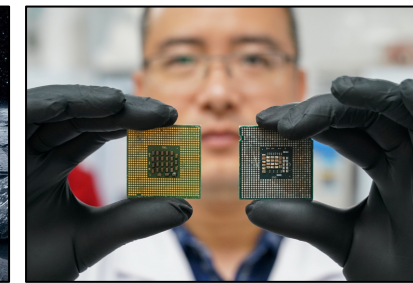
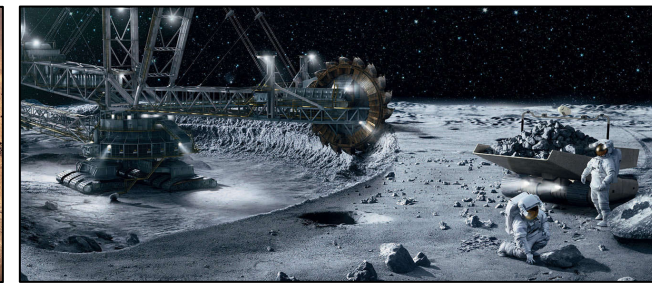
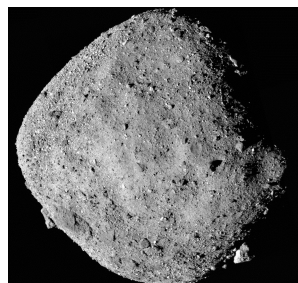
OUR VISION: developing a new method to face the complex issue of mapping the composition of planets and asteroids to mitigate the issue of shortage of industrially relevant chemical elements. These maps will have an immense value, ensuring the supply of these elements for the development of innovative technologies and fuelling a new economy in space in favour of a more sustainable planet. Compositional maps will also aid in the context of Earth defense considering the risk an asteroidal impact will pose for our planet.



Don't look up! Compositional mapping of planets and asteroids for Earth defence and sustainability.



Don't look up! Compositional mapping of planets and asteroids for Earth defence and sustainability.



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- Catalysis
- Cosmochemistry
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- Structural geology
- ...

Area 05 Scienze biologiche

- Evolution of life
- Ecosystem' disruption after impact
- ...

Area 06 Scienze mediche

- precious metals (e.g. aural and retinal implants) + cancer T. (Pt)
- ...

Area 07 Scienze agrarie e veterinarie

- Fertilizers (NH_4OH , NH_3)
- Selenium: plant growth regulator, antioxidant,...

Area 08 Ingegneria civile e architettura

- New building materials
- Earth sustainability
- ...

Area 09 Ingegneria industriale e dell'informazione

- semiconductors
- Construction
- catalytic converters
- ...

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- Ancient concepts of asteroids
- extraterrestrial belief
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- Religion
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- New legal framework
- Space mining regulation
- ...

Area 13 Scienze economiche e statistiche

- Capital assets and infrastructure
- New business model canvas
- ...

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PNRR - ASI - ESA:

- Spazio
- Agenda Asi 2021-2023
- Agenda ESA 2022-2024

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 - POLIMI
 - Eagleprojects s.r.l.
 - (...)
- World:
 - DLR
 - University of Berlin
 - The French Aerospace Lab-ONERA
 - Arizona State University
 - (...)



Don't look up! Compositional mapping of planets and asteroids for Earth defence and sustainability.

THE SPACE MINING COMPANY



SIMONE VANTINI
Chief of data science



DIEGO PERUGINI
Chief of HT lab and spectra

*A team from
another
planet!*



ALESSANDRA MENAFOGLIO
Data science



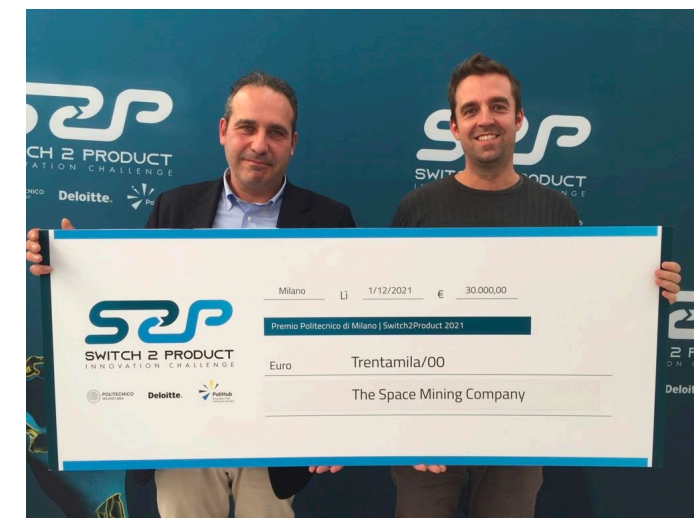
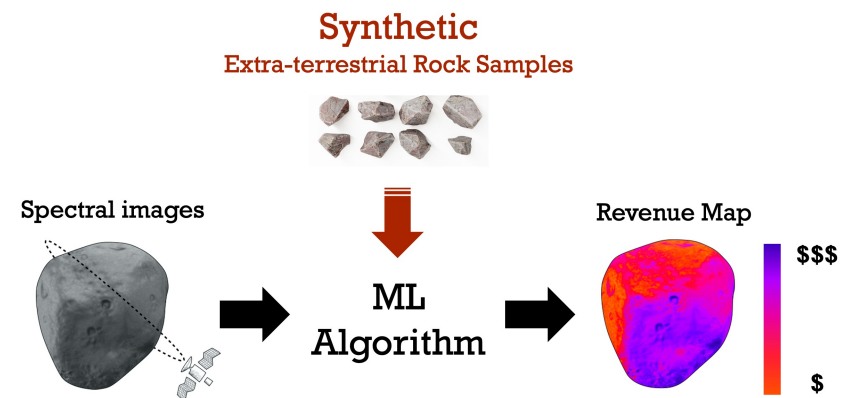
ALESSANDRO PISELLO
HT lab and spectra



MARA BERNARDI
Data science



MAURIZIO PETRELLI
HT lab and spectra





Petro-Volcanology Research Group (PVRG)

