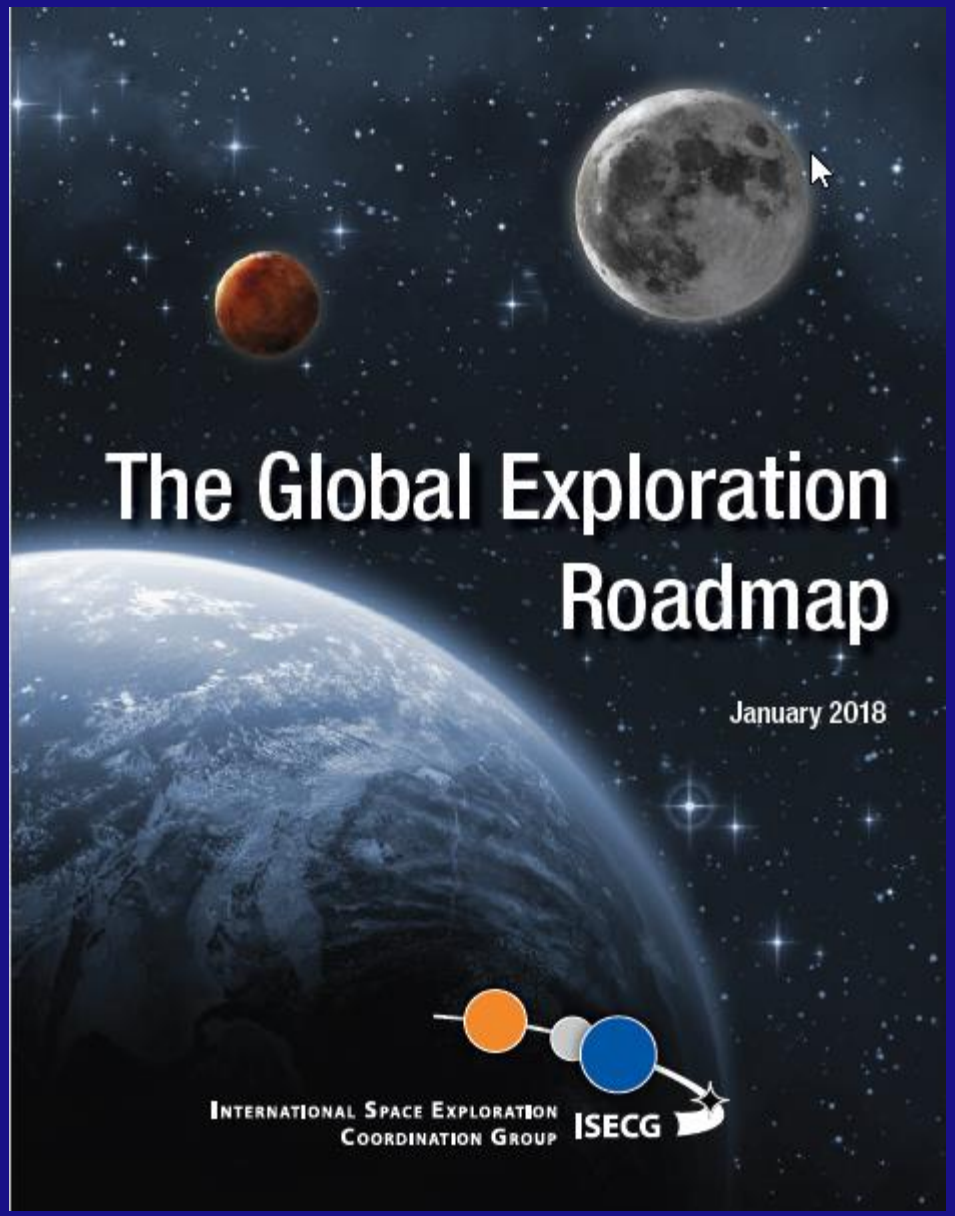
Luna program:
Toward an Italian roadmap for lunar exploration

INAF – RSN3 auditions 27-05-2021

Back to the Moon

In 2018 and 2020, the major Space Agencies in the world published the **Global Exploration Roadmap (GER)**, where their share the common intent to expand the human presence into the Solar System with the surface of Mars as driving goal and the Moon as a necessary intermediate step.



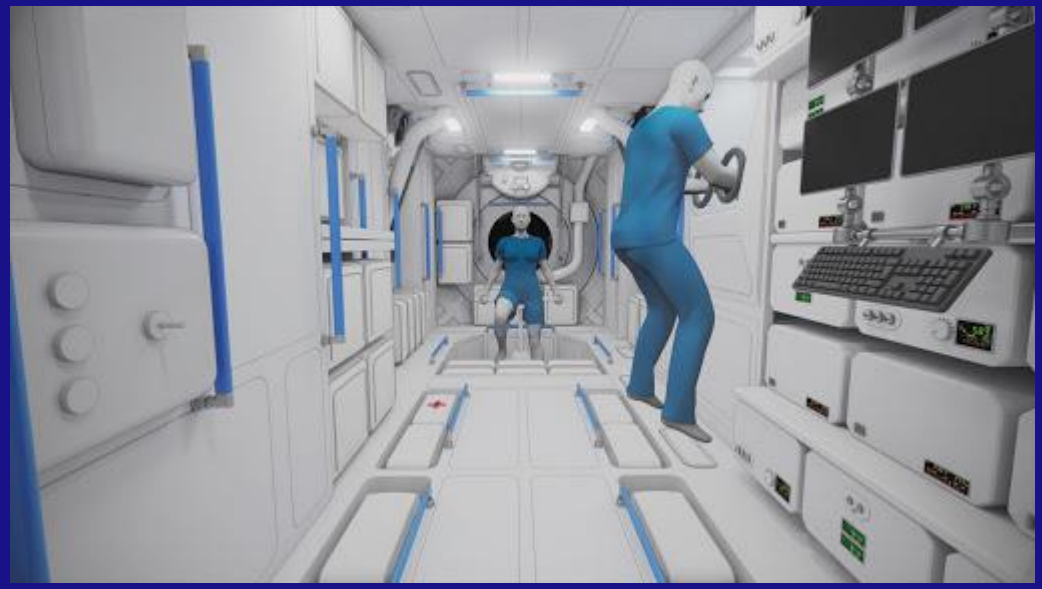
> 30 robotic missions to the Moon (from 13 Countries and from both Space Agencies and Private Companies) and 4 crewed have been already approved and are under development in 2021 - 2028 period.

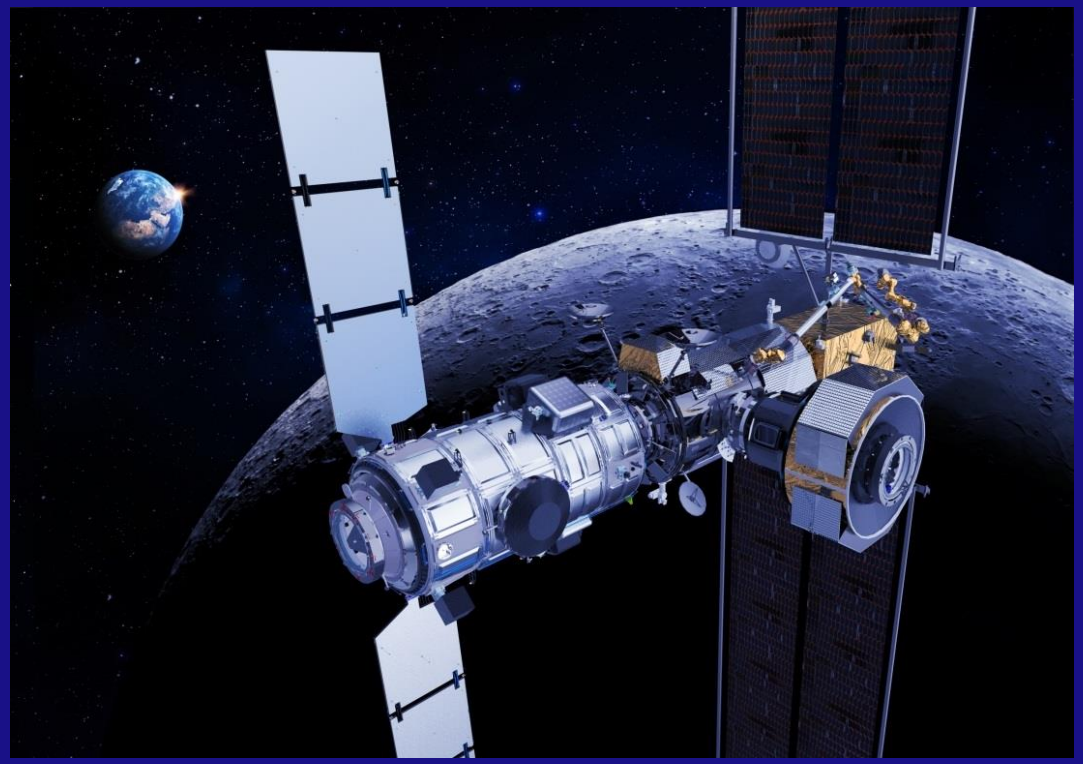
> 20 missions (robotic and crewed) have been proposed and waiting for evaluation.

Back to the Moon – the role of Italy

Italian industry is deeply involved in Artemis program:

- ESA contract to Thales for the development of two key modules for the upcoming Lunar Gateway:
  - the I-Hab, the International Habitation Module (327 M€)
  - and the ESPRIT, the communications and refueling module





- General agreement with NASA signed in Q4 2020 together with the Artemis Accords.

- ASI contract for the feasibility study of 16 project ideas both for the Moon surface and orbit (surface habitation module, communication services, pressurized elements for a laboratory basecamp and for the Gateway, transport systems for astronauts on the surface or between the Gateway and the surface, an automatic rover for the collection and transport of raw materials.

Back to the Moon: Scientific objectives

Incredible opportunity to advance in several fields of science.

Of the Moon	On the Moon	From the Moon
Bombardment	Habitability of the Earth through time	Radio astronomy
Structure from core to crust	Life in the Universe	Optical and infrared astronomy
Rock diversity and distribution	Survivability in space	Cosmic ray astronomy
Polar volatiles (e.g. ice)	Physiology and medicine	
Volcanism	Fundamental physics	
Impact processes	Space physics	
Regolith	History of the Sun and Solar System	
Atmosphere, plasma and dust	Impact rate	
Tectonics	Earth-Moon formation	

Table 2 - Science of the Moon, on the Moon, from the Moon as identified by the global scientific community and described in detail in RD3 and Annex 1.

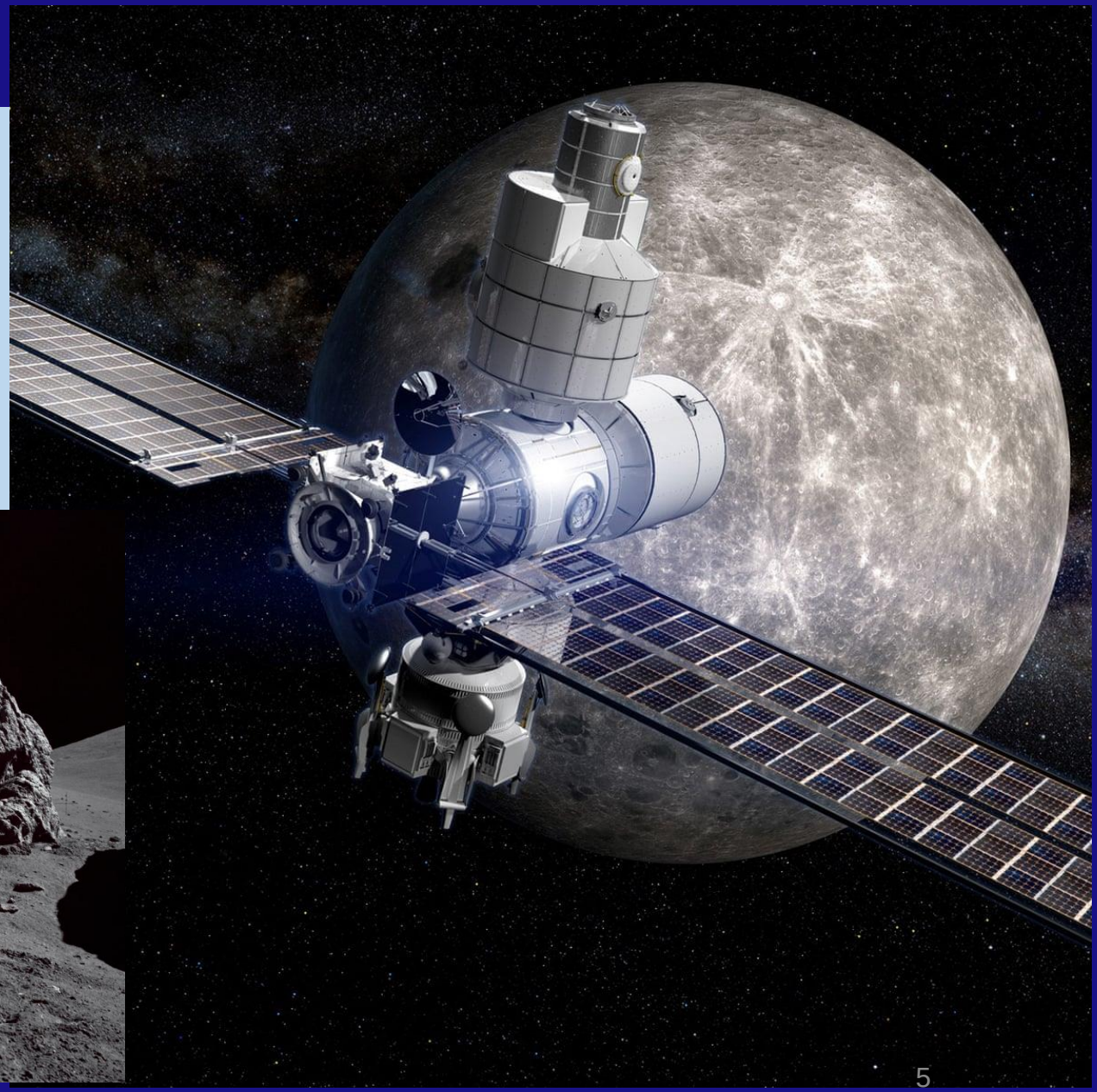
Toward an Italian roadmap for the Moon

INAF, in agreement with ASI, is coordinating the Italian lunar scientific community through the preparation of a white paper that collects the scientific interest and the relative payload that the Italian scientific community can offer in the field of lunar exploration.

This is a first step toward the definition of an Italian roadmap for lunar exploration.

Survey of laboratory facilities and scientific expertise in the Italian research institutes and universities.

>30 proposals of instrumentation have been proposed with Italian leadership



Toward an Italian roadmap for the Moon

Survey of laboratory facilities in the Italian research institutes and universities.

INAF laboratories (IAPS, OA Naples, OA Catania, OA Arcetri), University of Florence, Pavia, Perugia, Salento, Padua, University of Campania (CIRCE LAB), INGV, ENEA Frascati and Casaccia, CNR Florence, INFN (Frascati, Perugia, Florence), ASI Space Geodesy Center Matera.

SEM, IR-VIS-UV spectrometers, micro Raman, mass spectrometers (ICP-MS, LA-ICP-MS, LCMS), diffractometers, etc.

Universita' del Salento
Dipartimento di Matematica e Fisica
"Ennio De Giorgi"
Gruppo di Astrofisica

+PLUS
Planetology Laboratory University of Salento

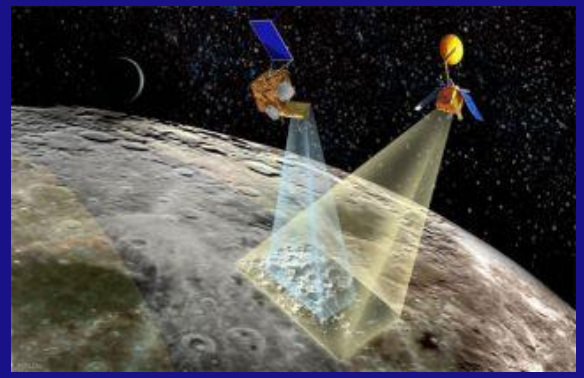
Grain size and spectroscopic (from UV to MIR) characterization of samples from lunar regolith to assess the degree of maturity (related to space weathering)

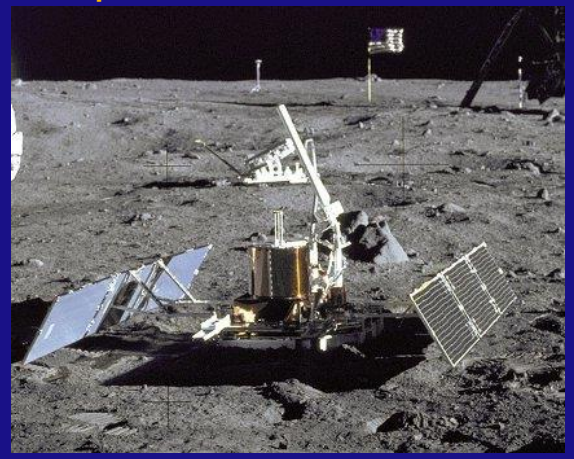
TEAM: F. Mancarella, V. Orofino, M. D'Elia (ass. INAF Sezione Universitaria Lecce), R. Politi (INAF – IAPS)

Toward an Italian roadmap for the Moon

More than 30 proposals of instrumentation were proposed with Italian leadership

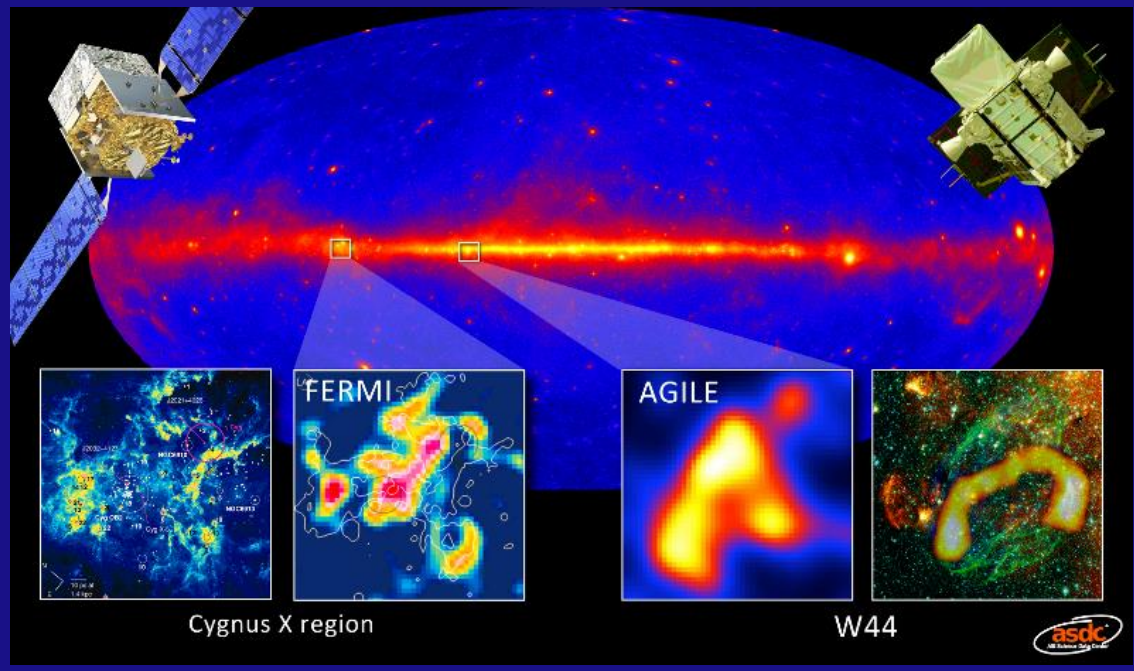
- Experiments for Cosmic-rays measurements: 3 experiments from INFN
- Seismometers: 7: 3 from INFN (also for strange quark matter detection and gravitational waves detection) + 1 Univ. "Fed. II" Naples + 1 INGV + 1 CISAS Padua + **1 from INAF**
- Experiments for High energy physics: 1 from INFN, **3 from INAF**
- Experiments for Fundamental physics: 1 from INFN
- Experiments for Heliophysics, Space weather and space physics: **2 from INAF**
- Experiments for Radio Astronomy: **1 from INAF** + 1 from University of Trieste
- Experiments for the characterisation of lunar rock diversity and distribution: **4 from INAF** + 1 from CNR + 1 from University Chieti-Pescara
- Experiments for the characterization of Atmosphere, plasma and dust; polar volatiles: 3: **2 from INAF** + 1 from CISAS Padua
- Radars: **1 from INAF** + 1 from IRSPS + 1 from Univ. Roma 3)
- ISRU: 1 from PoliMI
- Experiment for life science: **1 from INAF**
- Moving platform: **1 from INAF**





Luna 10 - Gamma-Moon – PI: Fabio Fuschino (OAS Bologna)

- Next generation instrument, following AGILE and FERMI
- Gamma-ray astrophysical instrument to be installed on the surface of the Moon.
- The energy range covers both X-ray and gamma-ray bands that can only be studied in space, well above the screen of the Earth atmosphere.
- Possibility of a large collecting area, much bigger, in principle, than any instrument placed in free-space.
- It is composed by a tracker based on Plastic scintillating fibres and Thungsten converter layers and a calorimeter with several sensitive planes using the lunar regolith as a converter.



Luna 12 – Planetary HERMES – PI: Fabrizio Fiore (OA Trieste)

X-ray & gamma ray spectroscopy of planetary surfaces

- **Chemical composition of planets' and asteroids' surfaces**

- Fe-L, Fe-K, Al-K, Mg-K, Si-K complexes and S-Ka, S-Kb fluorescent lines. Gamma-ray lines of the same elements but also those with high atomic number, inaccessible to X-rays.

- Miniaturized instrument can be hosted by nano-micro-sats
  - few keV - few MeV energy band
  - 50-100cm^2 collecting area
  - ~4% resolution @6keV & 600 keV

- Unique feature: Fluorescent X-ray spectroscopy and gamma-ray spectroscopy of nuclear lines complement each other in a single instrument

- Proposed for TASTE mission (PI J. Brucato)

- Proposal for a Moon application under construction (ESA framework, in coll. with Skylabs (SI) and POLIMI

fabrizio.fiore@inaf.it

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

POLITECNICO MILANO 1863

XOOM

X-ray enhanced Observatory Orbiting the Moon

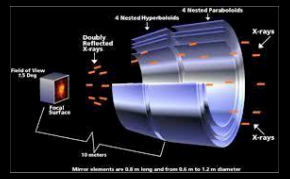
Refractive telescope in X band

PI: Marta Civitani – OABrera

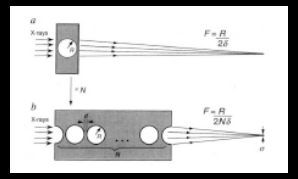
Feasibility study for a new Hard X-ray mission concept based on refractive lenses:

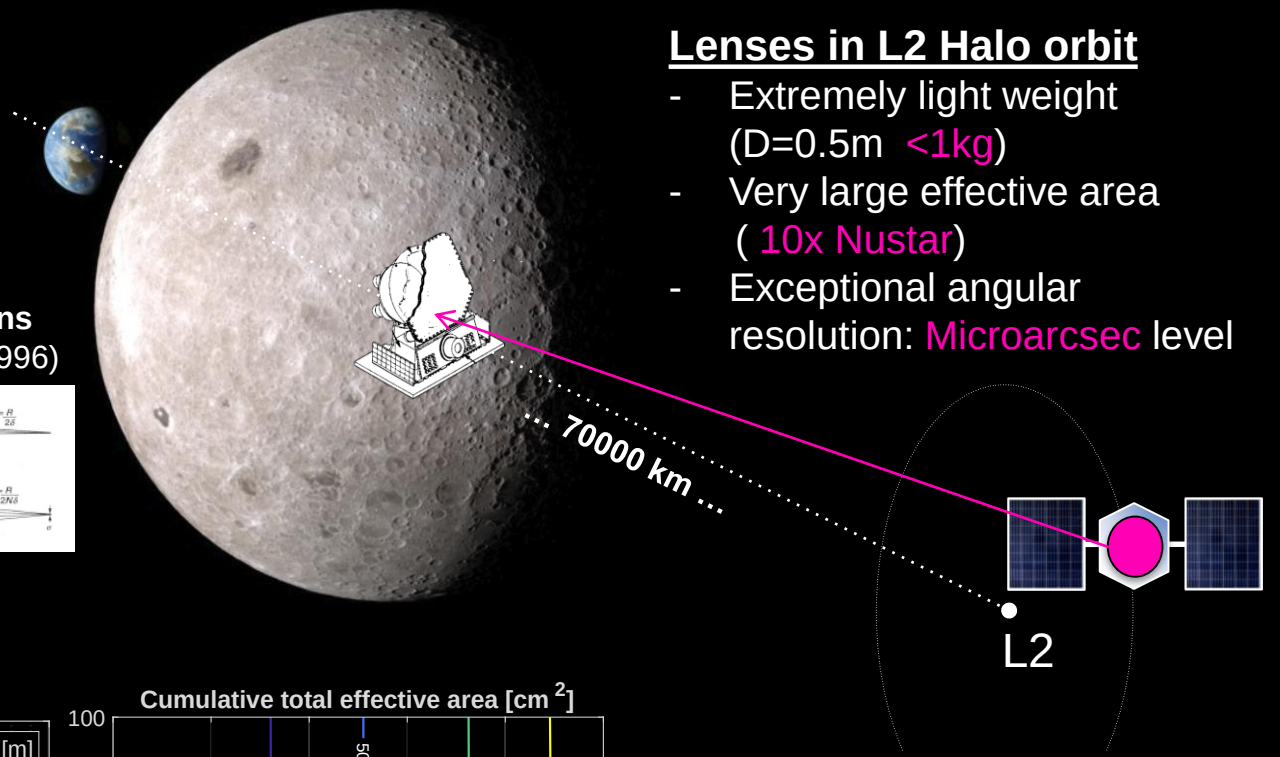
- → **very long focal length**
- → **exploit moon gravity for ensure stability to the fractionated architecture**

Grazing incidence



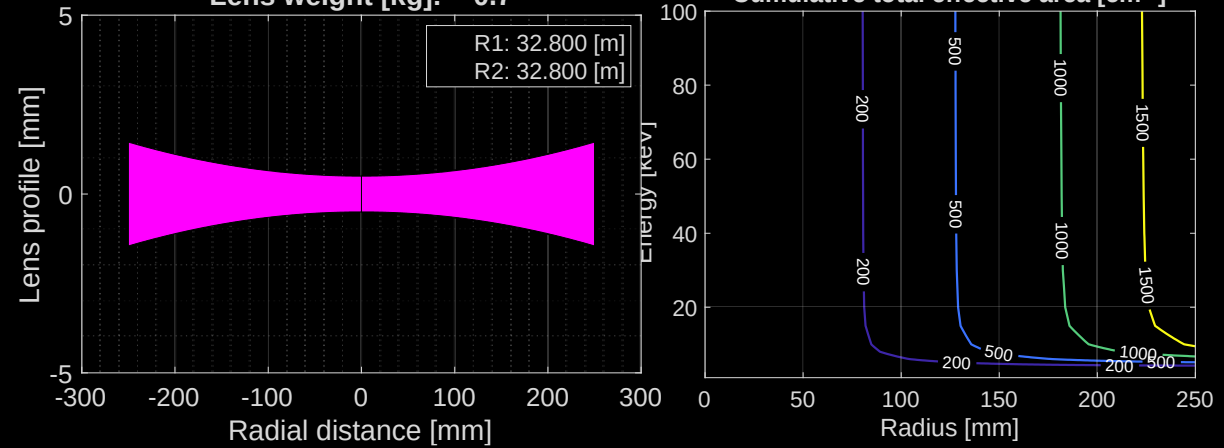
Refractive lens (A. Snigirev, 1996)





Lenses in L2 Halo orbit

- Extremely light weight (D=0.5m <1kg)
- Very large effective area (10x Nustar)
- Exceptional angular resolution: Microarcsec level

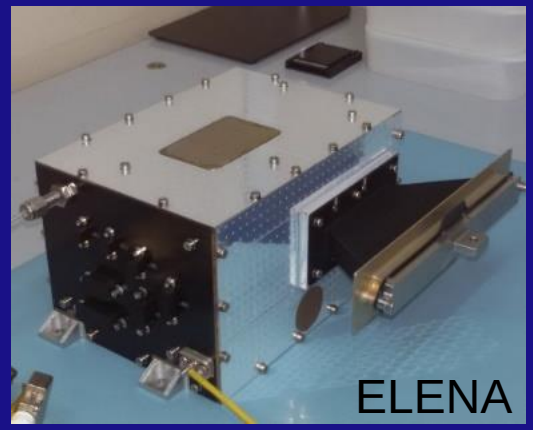


Detectors on moon

- **Large pixel size (2mm)**
- **Large area (>100 m for FOV 1”)**
- **PostProcessing/Image reconstruction**
- **Constrains on pointing**

Heliophysics and space physics: SELENE: A Lunar Orbiting Coronagraph and In-situ Solar Wind Monitor (PI: Silvano Fineschi – OA Torino)

Space weather: **Luna-3 ALENA: Analyser for Lunar Energetic Neutral Atoms**
PI/coordinator: Anna Milillo (IAPS)


ELENA

ALENA is an ENA imager (heritage BepiColombo/ELENA) optimized for a mission (small satellite or cubestat) to the Moon.

The lunar surface is directly exposed to solar wind or Earth's magnetospheric plasma.

When solar wind hits the surface, a fraction of it is reflected as protons and as Energetic Neutral Atoms (ENA).

The Moon possesses magnetic anomalies that create mini-magnetospheres, where the solar wind is deflected. The local protection of the surface from the solar wind radiation inside the mini-magnetospheres could make these sites preferred for future lunar colonization.

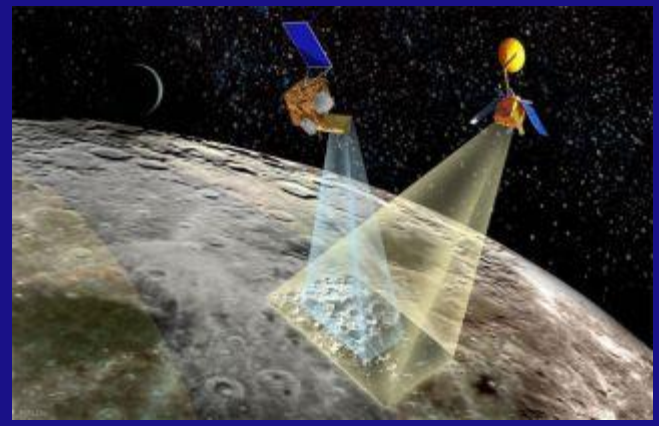
The detection of ENA emitted from the surface will allow the investigation of the interaction of the solar wind with the mini-magnetospheres.

Participation to 3 payload proposals for lunar missions.

MOSS: subsurface sounding radar - PI: Roberto Orosei (OAS Bologna)

MOSS is a subsurface sounding radar based on the design of SHARAD for Mars Reconnaissance orbiter.

It transmits a 10 MHz bandwidth pulse centered at 20 MHz. Its penetration and resolution characteristics make it particularly well suited for the study of the upper few hundred meters of the Lunar subsurface and for the detection and mapping of subsurface voids such as lava tubes



MIRDOMS: Radio interferometer – PI/coordinator: Gianfranco Brunetti (IRA – Bologna)

Radio interferometer, consisting of several detectors (antennas) mounted on rovers positioned on the hidden face of the Moon.

They will make it possible to produce, for the first time, high-resolution radio images of the sky at frequencies below 20 MHz (essentially unexplored area of the electromagnetic spectrum).

Luna-4 LUIS: Lunar Infrared Spectrometer – PI: Giancarlo Bellucci (IAPS)

- LUIS is a Fourier spectrometer for prospecting of lunar resources and surface science from orbiter, addressed by the characterization of the lunar surface composition in the 2-100 μm spectral.
- The spectral range allows to study also the water ice abundance possibly present either in polar regions or in low Sun illuminated areas.
- Heritage from ExoMars MIMA instrument.
- A study funded by ASI-INAF for the instrument optimization is in progress.

Parameter	Value	Note
Spectral range	2860-5000 cm^{-1} (1.8-3.5 μm)	CFG #1a
	2000-5550 cm^{-1} (1.8-5.0 μm)	CFG #1b
	100-2000 cm^{-1} (5 - 100 μm)	CFG #2
Spectral resolution (cm^{-1})	10	Un-apodised interferogram
FOV (mrad)	5.5x5.5	
Optical aperture (cm)	10	
Telescope	Three mirrors anastigmatic	
F#	2	
Measurement time (sec)	1	0.5 sec integ + 0.5 sec scan reversal
SNR	>100	@ 3 μm (at 80° incidence angle)
	>100	@ 10 μm (T = 270K)
NESR (Wm^{-2} sr^{-1} cm)	1E-6	@ 3.0 μm
NESR (Wm^{-2} sr^{-1} cm)	3E-4	@ 10 μm
NEDT (K)	1.5	Tsurf = 100 K
MOPD (cm)	+/- 0.05	Double sided interferogram
Digitalization	16 bits	
Beam splitter material	Synthetic diamond	Coated
Operating T range	-30 to +35 °C	
Storage T range	-50 to +40 °C	
Data volume	17 Kbit	For each measurement
Data volume (1 orbit)	16 Mbyte	Un-compressed
Detector CFG#1a-b (cm)	0.1x0.1	PbS/PbSe
Detector CFG#2 (cm)	0.1x0.1	DTLAGS pyroelectric
Mass (Kg)	10	
Dimensions (cm)	20x20x20	
Power (Watt)	10	

Luna-9 MINISPEC "Moon IN-situ Imaging SPECtrometer " – PI: Federico Tosi (IAPS)

- Imaging spectrometer operating on the surface → characterization of surface mineralogy at spatial scales (centimeters to meters) inaccessible even from low lunar orbit (LLO).
- Valid support for astronauts for a rapid reconnaissance of the surface composition down to scales of centimeters.
- Spectral range 0.4 and 3.0 μm. Characterisation of samples in terms of level of hydration, content of volatile compounds, degree of space weathering, etc.

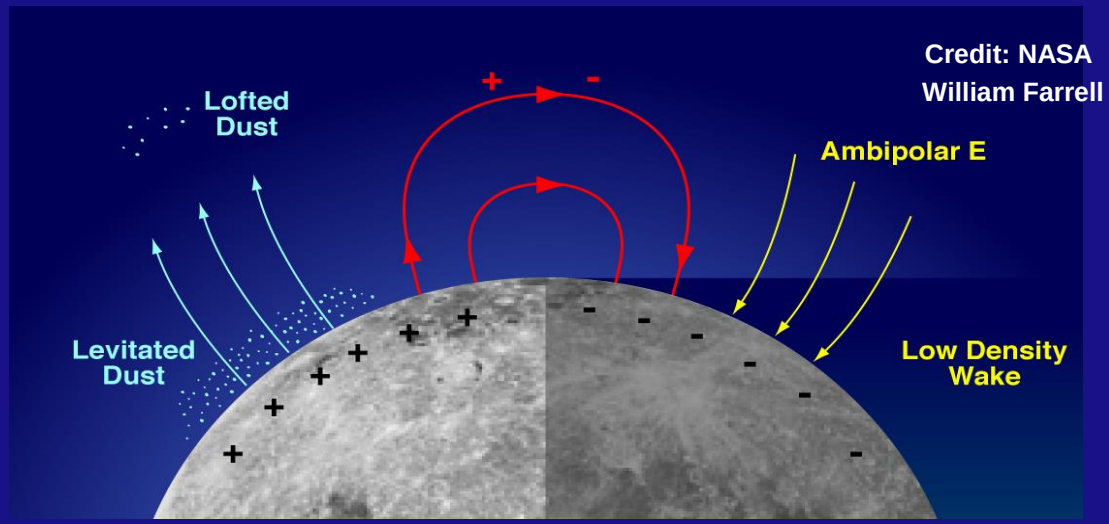
Luna-2 MOVIDA (Moon Volatile Investigator and Dust Analyser) – PI: Ernesto Palomba (IAPS)

Dust detector based on micro-oscillators device.

Able to measure volatiles' abundance (e.g., water, hydroxile) in grain dusty material and to characterise the dust charging and levitation processes.

It will measure the dust grain mass and charge.

Since the charge-to-mass ratio depends on the grain size, it is possible to infer information also on the granulometry.



Dust detector – PI: Fabio Cozzolino (OA Naples)

Dust detector based on PVDF technology.

It is constituted by a PVDF detector and a metallic grid.

It will measure mass, speed, electrical charge of dust in lunar environment.

Astrobio lab-on-chip – PI: John Robert Brucato (OA Arcetri)

Life Science Astrobio lab-on-chip: chip for the identification and assessment of organic compounds at parts-per-billion sensitivity from samples extracted from the surface of the Moon.

Extraction and analysis methods based on immuno- and enzimatic-assays → Several advantages in terms of minimizing the degradation of target analytes, maintaining original molecular information, and enabling the analysis of non-volatile and large organic molecules directly in the aqueous phase.
Ability to detect large water-soluble organic molecules that would be difficult/impossible to detect in the gas-phase.

Luna-1 Lunar Ants – PI: Francesca Esposito (OA Naples)

Group of micro-rovers for lunar exploration, with reduced weight, size (300 x 200 x 100 cm3) and cost, working in swarm logic.

Planning missions considered too risky for a conventional rover, guaranteeing a greater probability of success (e.g. in case of loss of a unit it is possible to reschedule the tasks of the others in order to achieve the expected results) and a greater flexibility in mission planning, with the ability to modify mission objectives during operations.

The micro-rovers can be equipped with various miniature sensors, selectable according to the scientific purpose of the mission (eg HR cameras, H2O detectors, dust sensors).

ISA-MS Seismometer for Moon Missions – INAF coordinator: Roberto Peron (IAPS)

Seismometer to be deployed in several selected locations on the lunar surface making a network of seismometers to achieve the following key goals:
1) determine crust structure and composition; 2) constrain the composition of the mantle, characterize the layering of the mantle; 3) determine, or constrain, the size of the lunar core, its composition and its state (liquid or solid); 4) characterize and investigate the seismicity of the Moon; characterize the local properties of the landing sites.

Direct heritage from ISA-Bepi Colombo

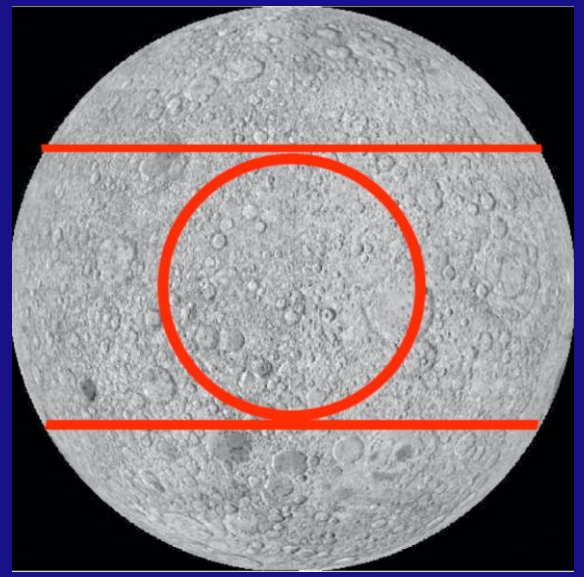
Luna-6 Far Side – INAF coordinator: Emilio Molinari (OA Cagliari)

A working group, ITA+CH, lead INAF, for a proposal to the UN concerning the protection of the far side of the Moon from light+EM pollution.

The Protected Antipode Circle (PAC), with 30° radius,, including 80km ø Dedalus crater

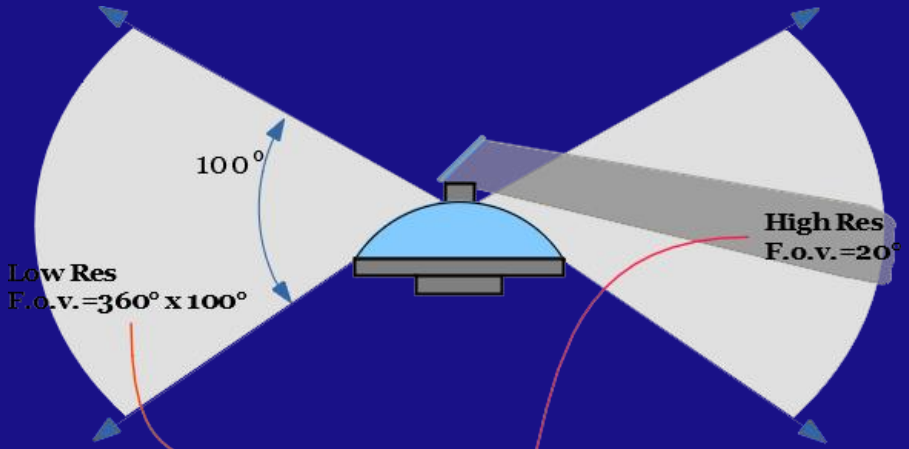
Switch off Lunar GPS satellite when over the PAC

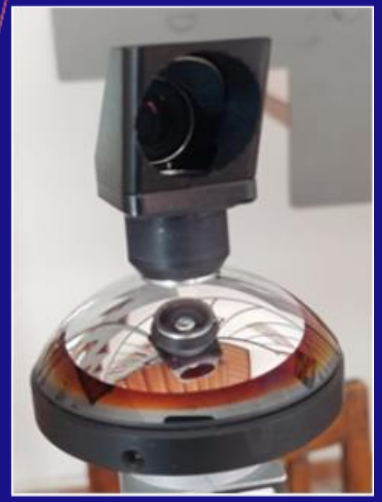
Vantage point for astronomy (visual and radio), SETI, planetary protection (NEOs)



Team: C.Maccone, P.Caraveo, E.Molinari, F-Malerba, S.DiPippo, M.E.DeMaestri, L.Derosa, D.Kubler, N.Ambrosetti, C.Grimaldi, M.Rasetti, B.Valerio, C.Firrone, S.Pluchino, W.Riva, G.Bassani

Luna 11 – Bifocal Panoramic Lens – PI: Claudio Pernechele (OA Padova)





The BPL, due to its double functionality in a compact fashion, results especially useful for space applications.

In the framework of the lunar exploration, an “immersive camera”, mounting four PANCAMs, has been selected by ESA to be used in exploring the lunar caves (Daedalus project).

The camera is able to acquire an immersive image of the cave (Fov=4π) and, simultaneously, four scientific (coloured) images with higher resolution and Fov=20°.

The PANCAM is based on a novel (and patented) Bifocal Panoramic Lens (BPL) which is able to acquire, simultaneously, a panoramic image (360°x100°) and an higher resolution one.

Luna-7 HYPerspectral Stereo Observing System – PI: Gabriele Cremonese (OA Padova)

The main objective of HYPSOS is to merge the 3D spatial information with the hyperspectral information. Starting from the experience of SIMBIO-SYS (STC and VIHI channels), HYPSOS has an optical design representing a stereo camera + a spectrometer, that is a single instrument providing stereo pair for each spectral sampling of the spectrometer. Then 4D data will be generated, as each pixel of the DTM will have the spectral information.

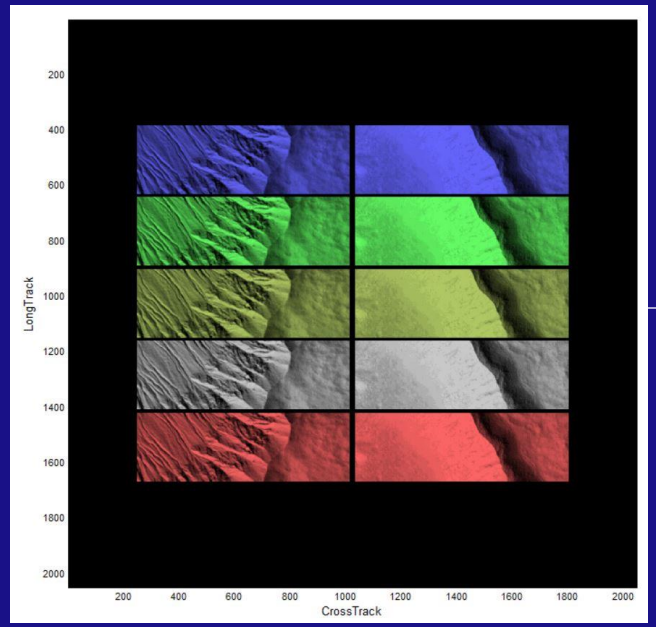
The project consists in:

- Optical design optimization
- Realization bredboard on optical bench
- Acquisition stereo pairs
- Generation HyperDTM

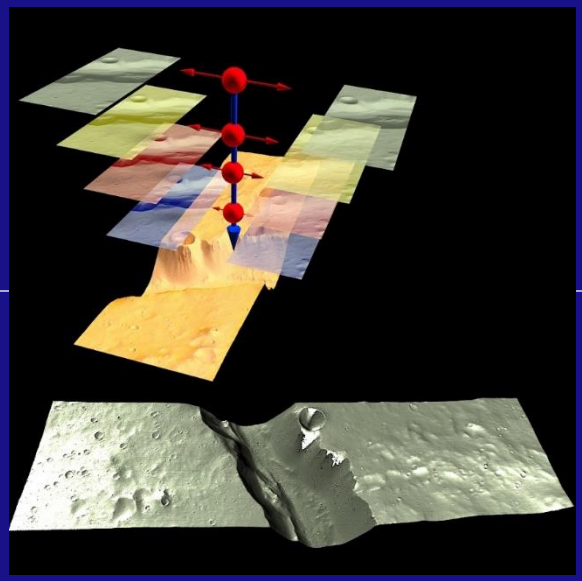
FTE 2021 = 2,2

Funds 2020-2022 = 250 keuro
Funds INAF = 103 keuro

Agreement ASI-INAF,
bando Sole, Sistema Solare ed Esopianeti



The stereo pairs in the focal plane. Each color corresponds at the same surface region observed at different wavelength



Each depth may correspond to different Composition as emphasized by different stereo pair

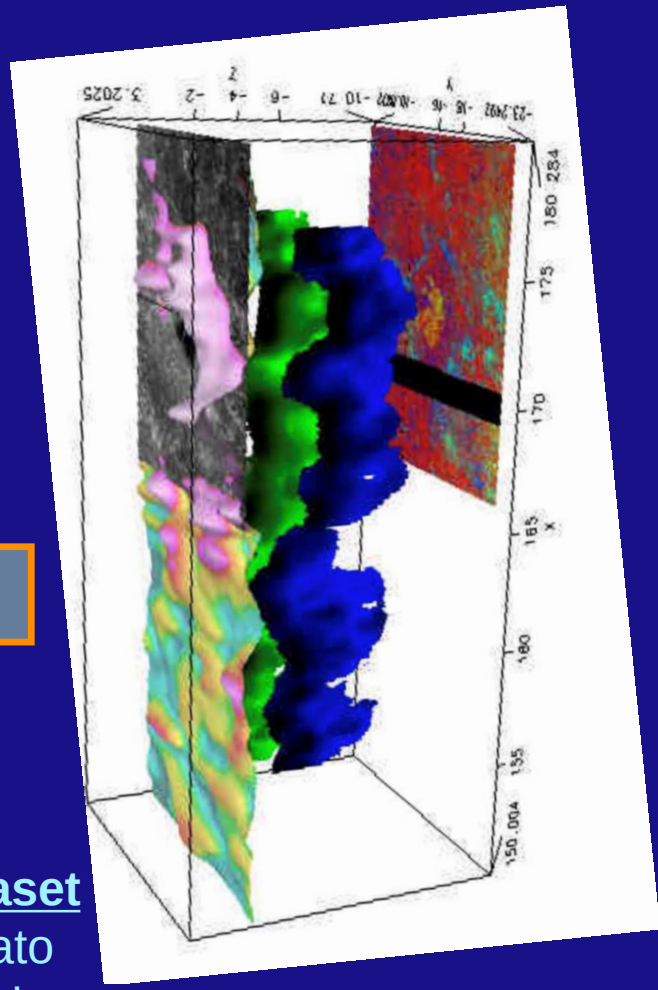
Realization of a slightly modified version of the optical design to be used for a cubesat

G.Cremonese et al., SIMBIO-SYS: scientific cameras and spectrometer for the BepiColombo mission, 2020, SSR, 216, 75.
M.Tordi et al., HYPSOS: a HYPerspectral Stereo Observing System for Solar System exploration, 2020, SPIE, 114437C-1
Patent on the concept of HYPSOS, 2016, n.102016000097439. Inventors are: G.Cremonese, G.Naletto, C.Re, M.Tordi (EIE)

Luna-8: "Moon multisEnsor and LabOratory Data analYsis (MELODY)"

Coordinatore scientifico nazionale: **Federico Tosi (INAF-IAPS)**

- Progetto **PRIN INAF (RIC) selezionato il 10/11/2020**.
- Finanziato con **167 k€**.
- Iniziato il **01/03/2021**, durata biennale.
- Enti coinvolti: **INAF (IAPS, IRA)**, **UniPD**, **UniRomaTre**, **UniFI**, **UniTrieste**.
- Leadership INAF: **Sì**.
- Impegno complessivo: **10.8 FTE** (di cui 5.4 INAF).



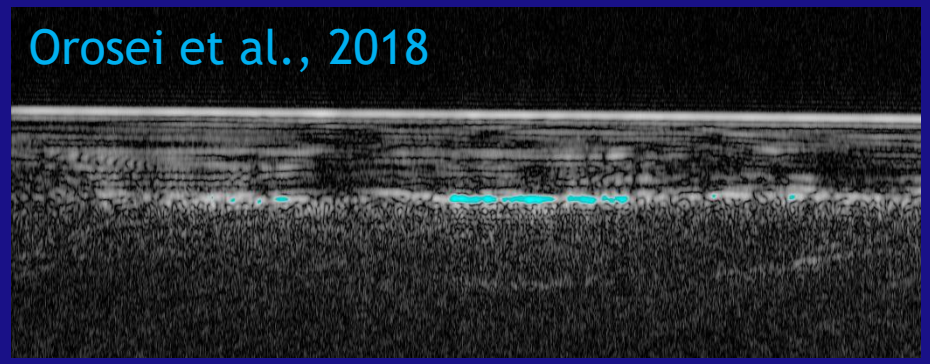
MELODY WP1: Scienza di superficie – Analisi dati multisensore

Con **MELODY** effettueremo un'**analisi innovativa di dati lunari pubblicamente disponibili**, relativi a: **colori, geochimica, mineralogia, topografia** e **gravimetria**. Per **tre regioni di interesse**, scelte in modo strategico, **combineremo questi dati in un unico dataset "aggregato"** al fine di evidenziare **unità omogenee** in cui potrebbero emergere **correlazioni** interessanti tra **superficie e sottosuperficie**.

Esempio di **dataset aggregato**, creato combinando assieme **più dataset di natura diversa**.

Luna-8: "Moon multisEnsor and LabOratory Data analYsis (MELODY)"

MELODY WP2: Geofisica sottosuperficiale e supporto di laboratorio



Simulazione dello scattering radar lunare e confronto con set di dati disponibili pubblicamente. Correlazioni tra radargrammi.

EPP-Lab all'Università Roma Tre

Angelantoni ® climatic chamber (100 – 450 K)

Caratterizzazione di laboratorio delle proprietà elettromagnetiche di analoghi di suolo lunare a supporto dell'analisi dei dati radar.

SLAB_REFL@IAPS: Spettroscopia di riflettanza bidirezionale nell'intervallo 0.35-2.5 µm

MELODY WP3: Analisi mineralogica e geochimica di meteoriti lunari

Laboratori "Filippo Olmi" dell'Università di Firenze

Thermo Scientific™ Triton Plus - Multicollector Thermal Ionization Mass Spectrometer (TIMS)

Team & Funds

Leadership

INAF (Francesca Esposito OA Naples) is coordinating the activity at national level.

Team members

Team members are related to all the projects in the "daughter cards"

INAF team members: **67** → 54 TI, 13 non-staff

INAF Associates team members: 23

FTE

Reported FTE are related just to the 3 funded projects:

- Total INAF FTE: 9.6
- Total INAF TI FTE: 9.0
- Total (all partners) FTE: 18.0

Almost no funds associated with R&D activities related to collected INAF proposals.

3 funded projects:

- **MELODY**: Moon multisEnsor and LabOratory Data analYsis (PI Federico Tosi) → PRIN INAF 2020: 167 keuro
- **HYPSOS**: Hyperspectral Stereo Observing System → ASI 2020-2022 (Attività di studio per Sole, Sistema Solare ed Esopianeti) 250 keuro
- **BPL** (Bifocal Panoramic Lens) → UE 2016 + 2020 ESA + 2021 INAF (progetti covid-19): 400 keuro (estimated), 70 keuro to INAF

Consolidated funds 2021: 167 (MELODY) + 30 keuro (BPL) + 83 keuro (HYPSOS) = 280 keuro

Status, Planning & Critical issues

White paper & Italian Moon roadmap

Status

- Nov 2020 – April 2021: First survey (3 calls) among Italian Research Institutes and Universities completed
  - 34 project ideas for new space instrumentation collected – instrument cards
  - 17 laboratory groups with interest, expertise and instrumentation available for the analysis of lunar samples
- March 2021: Sharing of proposals table with ASI and beginning of programmatic path

Planning

- White paper document to be completed within the Summer
- Possibility of annual (TBC) updates
- Start of definition of an Italian Moon roadmap in agreement with ASI
- Organization of dedicated workshops (date to be defined)

Critical issues

- There is currently no dedicated line of funding @ASI or @INAF for R&D devoted to the development of low TRL scientific space HW for lunar missions
- Recent new ASI configuration: changes in main actors – difficulties in identifying a POC