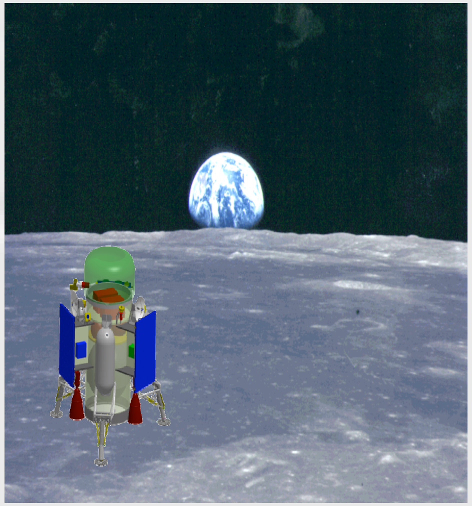
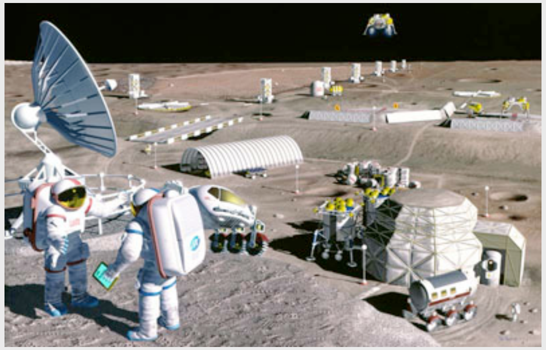
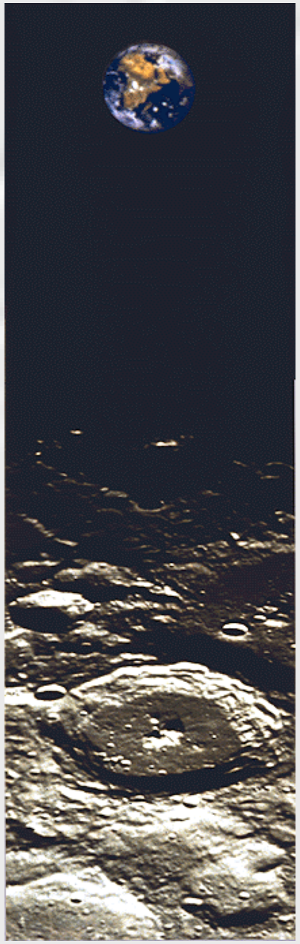
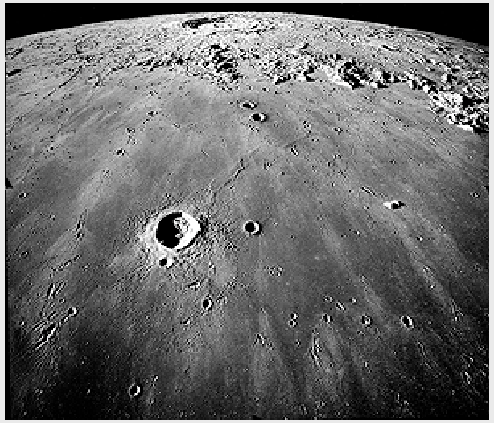








The ASI Lunar Exploration Programme

Sylvie Espinasse

Observation of the Universe Dpt.

National Programme for Moon Exploration

- In 2005, ASI Top Management proposed to the government to elaborate a National Programme for Moon Exploration and this has been approved by the Italian government in 2006 as one of the main element of the National AeroSpace Plan 2006-2008.

- Last year ASI has issued an AO to carry out 13 studies, 3 for science and 10 for technologies to elaborate the national “Vision for Moon Exploration”, 16 studies have been awarded.

- KO held in ASI on September 26th, 2006, duration 8/10 months, Roadmap available Summer 2007.

National Programme for Moon Exploration

- Moon Science and Resources + Earth Observation + Observation of the Universe

  >>> Scientific Objectives >>> Measurements >>> Requirements
- PLs: Optical Remote sensing + High Energy + In-situ sensing + Microwave

  >>> Mass, Power, Data Budget,…
- Launcher + Transfer Module + Orbiter + Descent and Landing System + High Mobility Vehicle + Robotics

  >>> Missions Scenarios
- ASI

  >>> **Roadmap**

Study of the Moon and its resources

- Phase 1
  - Critical analysis of the data available and identification of the new measurements to be performed taking into account of the new missions planned
- Phase 2
  - Analysis of the main open questions
  - Definition of the scientific themes to be further investigated
  - Definition of the measurements requirements
- Phase 3
  - Definition of an exploration strategy

Study of the Moon and its resources

- Many probes have orbited around the Moon, it has been explored by about two dozens of astronauts, 380kg of lunar samples are available in Earth laboratories but its origin, evolution and internal structure are still strongly debated.
- The Moon is still a very interesting target for Solar System key questions because it probably keeps records of the early phases of the Solar System story (planetary bodies accretion phase, impacts, heavy bombardment period, …).
- The study of the Moon and its resources is based on a critical review of the current knowledge about the Moon with the aim to identify the key measurements to be performed to answer the questions related to:
    1. the Moon origin, its evolution and internal structure
    2. the resources available
    3. interactions between the surface and the environment (exosphere)
    4. the hazards for robotic and human exploration

Study of the Moon and its resources

- Open questions:
  - What is the origin of the Moon?
  - What is the internal structure of the Moon?
  - Is it the Moon differentiated?
  - Is it the Moon geophysically active ?
  - What are the main events characterising lunar history ?
  - What is the geochemical Evolution of the Moon ?
  - What is the chemical/mineralogical composition of the Moon?
  - What is the geomorphology structure of the Moon surface?
  - What are the resources?
  - What is the interaction surface/environment?
  - What is the hazard for robotic and human exploration?

Study of the Moon and its resources

Measurements and requirements

SCIENCE THEMES	SUB THEMES	SCIENCE AND TECHNOLOGY OBJECTIVES	DETAILED SCIENCE OBJECTIVES	MEASUREMENTS	Requirements Range		Sensitivity		Coverage/resplution	
					Value	Unit	Value	Unit	Value	Unit
origin and evolution	**global composition**	**Moon global composition**	Map of Si, Al, Mg, Ca Fe, Na, O, C	X-Ray Spectra of highlands and Maria	0.5 - 20	keV	<200	eV	Global Coverage	1-10 Km at 100 Km altitude
			Map of olivines/ pyroxenes	VIS-IR Spectra of highlands and Maria	0.3 -5	?m	10	nm	Global Coverage	1-10 Km at 100 Km altitude
		Magma Ocean Model	**Mapping distribution and relative abundance of mafic mineral and plagioclase**	VIS -IR Spectra Maria	0.3 -5	?m	10	nm	Regional Coverage	1-10 Km at 100 Km altitude
		Constrain Theories of the origin of the lunar upper mantle	**sampling composition of different location of lunar maria**	VIS -IR Spectra Maria samples	0.3 -5	?m	10	nm	Local coverage	in situ
				X-Ray diffratometric analysis					Local coverage	in situ
				Raman spectra					Local coverage	in situ
		origin and evolution of Lunar Crust	**composition of different crater central peaks**	VIS-IR Spectra of central peaks	0.3 -5	?m	5	nm	Local coverage	< 100 m

Study of the Moon and its resources

Measurements and requirements

LEGENDA

KEY QUESTIONS	INFORMATION ON	KEY MEASUREMENTS	KIND OF INSTRUMENT	GLOBAL / REGIONAL SCALE	IN SITU	EXISTING MEASUREMENTS	Priorities
What is the internal structure of the Moon ?	Origin Geophysics Tectonics	Lunar Gravity field	Gravimetry Gradiometry Librations Laser/ Radar	global global global global	local	Yes but only near side Existing to be improved [illegible]	1
Is it the Moon differentiated ?	Origin Geophysics Geology Tectonism Volcanism	Lunar Gravity field Elemental composition Analysis Mineralogy	Gravimetry Gradiometry Librations Laser/ Radar Seismometry γ, x reaction VIS IR	global global global global global [illegible] global global	local/ seismometry	Yes but only near side Yes limited coverage Yes low resolution, limited number of elements Not possible in future (Chandra)	1 1 2 1/2
Is it the Moon Geophysically Active ?	Geophysics Geology Tectonics Volcanism	Lunar gravity Periodicity of crustal depth Detailed Surface structure knowledge	Gravimetry Gradiometry Librations Laser/ Radar Seismometry Imaging /altimetry	regional global /regional global /regional	local/ seismometry	Yes limited Yes limited (existing to be coverage by LRO)	1 1 2/3
What are the main events characterizing lunar history ?	Origin Evolution Differentiation Geology Chronology	Geologic map Relative dating Absolute dating	Imaging /color /stereo Crater counting	global scale global scale	local	Yes to be improved (Clementine)	2
What is the Geochemical evolution of the Moon ?	Origin Geophasis Geology Geochemistry Resources	Lunar elemental composition Geologic map Relative dating Absolute dating	x/γ reaction Imaging /color /stereo crater counting x/γ reaction radon	global / regional	in situ x,γ,n [illegible] subsurface drill	yes low resolution yes, to be improved	2 3 Share
What is the chemical / mineralogic composition of the moon ?	Origin differentiation thermal evolution surface geology mineralogy/composition resources	Lunar mineralogy	VIS - IR spectroscopy thermal spectroscopy	Global	local subsurface/Drill	not existing yet	1/2
What is the geomorphology structure of the Moon surface ?	Evolution Differentiation Geology Tectonics	Imaging (STEREO) at different phase angles Altimetry , geodesy	camera/stereo altimeters radar / interferometric laser	global/ regional global/ regional		NO (future LRO) NO	1/2 1
What are the resources ?	Average surface composition + [illegible] power generation	Water + ice detection Mineral distribution Titanium Localization of illuminated areas	VIS/IR / neutrons [illegible] Radar /sounder [illegible] [illegible] Stereo mapping γ reaction	global/ regional global/ regional global/ regional global/ regional regional	Subsurface/Drill [illegible] [illegible] Subsurface/Drill	VIS/IR [illegible] not existing not existing not existing	1/2 2 1/2 1
What is the [illegible] Exosphere ?	Surface evolution Exosphere	Exospheric measurements sodium generation	UV/Vis cameras Sodium emission ENA γ [illegible]	Global/ regional Global Global Global	local [illegible]	UV Clementine to be improved view NO ENA Yes existing (Lunar Prospector) In situ not existing	1 1/2
What is the hazard for robotic and human exploration ?	Lifetime of critical components in high radiation environment Lifetime in presence of dusty events Cratering events (micrometeoroimpacts)	Radiation flux + dose Dust measurements Meteoroid flux	Spectro /dosimeters Dust analyzer High speed camera	orbiter orbiter	in situ in situ	Dosimeters Dust analyzer Camera (high speed)	1 1 1/2

Study of the Moon and its resources

- Traceability Matrix

KEY QUESTIONS	INFORMATIONS ON	KEY MEASUREMENTS	INSTRUMENT	GLOBAL/ REGIONAL SCALE	IN SITU	EXISTING MEASUREMENTS	Priorities
What is the internal structure of the Moon ?	**Origin Geophysics Tectonics**	**Lunar Gravity field**	**Gravimety Gradiometry Librations Laser/ Radar**	**global global global global**	**local**	**Yes but only near side Existing to be improved**	**1**

Study of the Moon and its resources

- Following the previous priorities, the scientific objectives can be achieved through ***orbital missions*** followed by ***in-situ missions.***
- In situ missions will perform ***vertical investigation*** (lander) and ***horizontal investigation*** (rover).
- But a quantum leap in the lunar exploration can be achieved only with a ***high-mobility vehicle*** because the lunar geological units are large. On a small scale, the possibility to compare different processes is low.

Study of the Moon and its resources
Orbital science

- Geophysical package: to study of the internal structure of the Moon, its differentiation and its geological history:
  - K-band
  - Gradiometers
  - Stereo-camera
  - Laser altimeter

- Geochemical package: to study the geological evolution of the Moon, the identification of the presence of water and recognition of the distribution of lunar resources:
  - Multispectral cameras
  - _, X , UV and IR spectrometers
  - radio and radar measurements

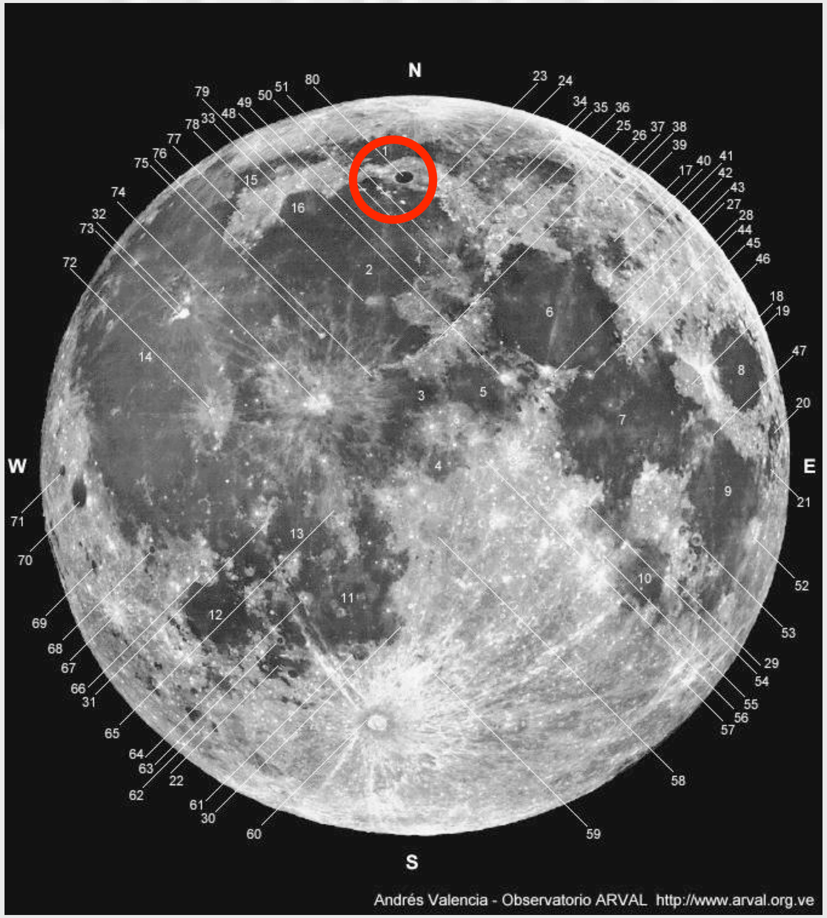
Study of the Moon and its resources

- Possible scenario
  - Mission duration → 9 months
  - Possible payload → 50 Kg
  - Reference orbit → 100 Km circular
  - Possible further orbit→ 50 Km circular
  - Second orbiter → elliptical orbit

Study of the Moon and its resources
In situ science

- In situ science from a landed platform:
  - Ops in one point >>> importance of the selection of the landing site (high precision landing)
- In situ science from a mobile platform:
  - The rover shall be able to travel for a distance larger than the landing ellipse error

Study of the Moon and its resources



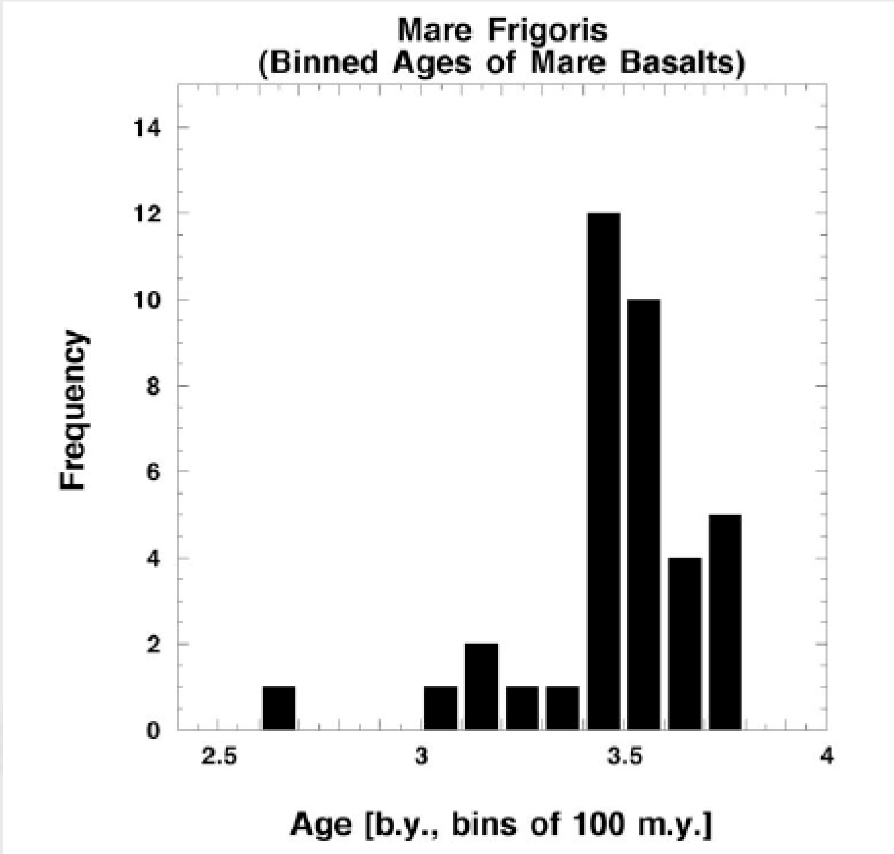


Fig. 1: Distribution of basalt ages in Mare Frigoris

Study of the Moon and its resources
In situ science

- Lander package:
  - **Interior of the Moon**
    - High-temporal resolution seismometer
    - GPR
    - Drill + NIR Spectrometer, micro-sounder)
    - Laser retroreflector
  - **Geology**
    - Cameras (stereo)
    - High-temporal resolution cameras (impact events)
    - High resolution NIR
  - **Geochemistry**
    - Microscopy polarimetry VIS/IR
    - Raman / LIBS - LIF
    - Neutron spectrometer
    - IR Spectrometer (5 – 20 μm)
    - Spectrometer/gamma/X
    - _ backscattering Spectrometer X Diffractometer
  - **Environment**
    - Dust analyzer

Study of the Moon and its resources
In situ science

- Rover package:
  - **Geology**
    - Cameras (stereo)
    - High-temporal resolution cameras (impact events)
    - High Resolution NIR
    - GPR
  - **Geochemistry**
    - Microscopy polarimetry VIS/IR
    - Raman / LIBS
    - Neutron spectrometer
    - IR Spectrometer (5 – 20 μm)
    - Spectrometer /gamma/X
  - **Environment**
    - Dust Detector
    - Dosimeter

- The rover shall be able to survive in shaded areas, inside of the craters, in order to sample and analyse potential cold traps.
- The duration of both, lander and rover operations shall be more then one lunar month.

Earth Observation from the Moon

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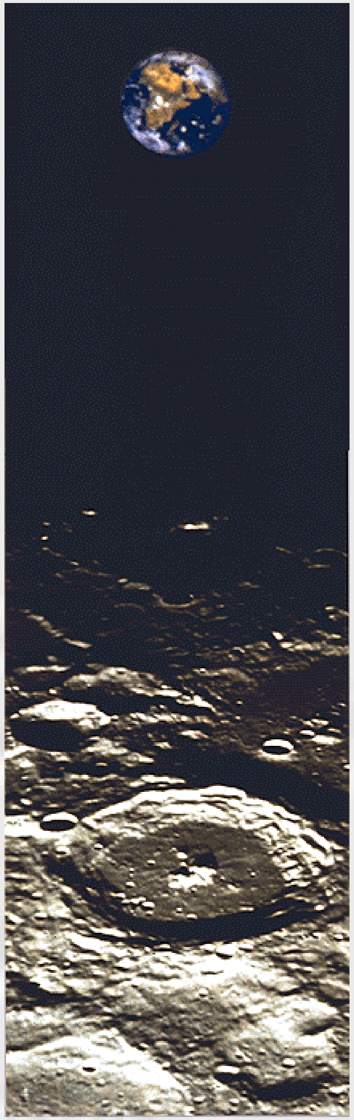
- **This study is taking into account the characteristics of the Lunar environment:**
  - a global view of the Earth, providing a full disk view (sunlit half the time)
  - the capability to observe continuously the Earth disk for long periods
  - the possibility to increase the integration time
  - day-night observations of the same area (relevant for vegetation fluorescence monitoring)
  - varying views of the Earth
  - the opportunity to monitor the evolution of large spatial scale phenomena with larger FoVs than those offered by a constellation of satellites



Earth Observation from the Moon

- the possibility to observe the same area at high picture rate, for long periods allowing the characterization of rapidly varying, large scale phenomena
- the reduction of influence of intermittent clouds
- the possibility to deploy larger, more complex instrumentation

- **But:**
  - thermal conditions (night/day variations; terminal crossing)
  - power supply during night
  - dust as a radiation absorber and damaging element for mechanisms
  - no magnetic field >>> cosmic rays
  - resolution (distance)
  - … and … transportation, installation, maintenance …

Earth Observation from the Moon

- Analysis of the science that can be done only from the Moon or in a better way than that allowed from a satellite or a constellation of satellites, in particular:
  - phenomena and processes acting at global spatial scale and with a high variability both in space and time:
    - simultaneous observation of different point of the Earth to explore spatial correlation over wide areas (vegetation, oceans)
    - phenomena requiring continuous observation of the same area for a certain interval of time (weather systems)
    - global (or very large area) observation because of their impact on large areas (ozone distribution)
  - phenomena not well localized in space and with slow frequency that can benefit from a continuous monitoring of large areas such as meteoroids impacts

Earth Observation from the Moon
Main Objectives

1. Earth atmosphere: monitoring weather systems, clouds (radiative, chemical and physical properties), aerosols and gases (atmospheric chemistry at global and local scale)
2. Oceans:
   a. Physical oceanography: mapping of marine currents; ocean circulation; oceanic front identification; Optical Oceanography, water masses characterization, Sea-ice melting and formation
   b. Marine ecosystem studies: pollution monitoring, coastal waters, marine biology
3. Vegetation monitoring: global climate change; terrestrial carbon cycle; resource management and sustainability, desertification, photosynthesis efficiency, fires
4. Earth radiation budget: Sun spectral variations monitoring, SPEs, Earth monitoring, climatology, Earth-Sun interaction, Space Weather
5. Definition of a selenocentric reference system

Earth Observation from the Moon Priorities

WP's	Detailed Science Objectives	priority
WP 1100 - 1200 Atm. Observation	Aerosols Optical Properties	2
	Trace gases content (O_3,NO_x,SO_2,CO,…)	1
	Radiative & Microphysical properties - Cloud amount in terms of Cloud Optical Thickness - Particle size in terms of efficient radius - Cloud liquid and ice water content - Precipitation rate - Cloud liquid and ice water content - Temperature Humidity profile	2
	Tropical cyclones, tornadoes, weather fronts and depression	3

Earth Observation from the Moon
Priorities

WP's	Detailed Science Objectives	priority
WP 1300 Ocean observation	Sea Surface Temperature (SST) mapping	2
	Ocean optical properties; ocean colour; water quality	1
	Coverage, temperature of ice sheets and caps; floating oceanic ice	3
	Phytoplankton, phytobenthos, pollutants, Dissolved Organic Matter (DOM), Harmful Algal Blooming (HAB); primary production by marine phytoplankton	2
	water quality; suspended matter; DOM; pollutants; eutrophication processes;	2
	Oil slicks type and thickness; pollutants; wastewaters; silt runoff	3
WP 1400 Vegetation monitoring	Photosynthesis efficiency	3
	Light use efficiency	1
	Wet biomass-WBM, dry biomass-DBM, leaf area index-LAI, and plant height-PLNTHT	3
	Cover type and extent; desertification	2
	Anthropogenic impact; human-induced changes; global crop area	2
	Major ecosystem estimate	2
	Crop inventories; extensive subsistence agriculture	3
	Carotenoids, chlorophyll a, chlorophyll b; xantophylls; anthocyans.	1
	Water content; N uptake	2

Earth Observation from the Moon Priorities

WP's	Detailed Science Objectives	priority
WP 1500 Earth radiation budget	Total Solar Irradiance	2
	Solar Luminosity Oscillation Imaging	3
	XUV radiance variability	3
	EUV radiance variability	1
	UV radiance variability	1
	Visible radiance variability	2
	Near-IR radiance variability	1
	EUV Scattering	2
	UV Backscattering	2
	Visible Band Reflection	2
	Near IR Emission	2
	Thermal IR Emission	2
WP 3200 Georeferencing image	Selenocentric fixed system definition and materialization	1
	Connecting Selenocentric fixed and Earth Fixed systems	1
	Gravity	3
	Geodynamics	2
	Lunar Science and Selenophysics	2

Earth Observation from the Moon Priorities

WP's	Detailed Science Objectives	priority
WP 2200 Earth SAR remote sensing	Land	2
	Internal water and glaciers	3
	Ocean	2
	Risk	1
	Vegetation and Forestry	3

Ocean Observation

Measurement method	VIS-NIR reflectance imaging				VIS-IR reflectance imaging	IR radiometric imaging	
Spectral range	380-1060 nm				0.4 - 2.5 ?m	10-12 ?m; 3.5-4 ?m	10-12 mm:
Spectral resolution	2nm				20 - 40 nm VIS 20 - 60 nm IR	10-12 ?m: < 0.5 ?m 3.5-4 ?m: < 0 .1 ?m	< 0.5 mm
Sensitivity	NEdR: < 2%				NEdR: < 2%	NEdT: <0.05 K	NEdT: <0.05 K
Science objective	- Optical oceanography - Water masses characterisation, - Mapping of marine currents; - Ocean circulation; - Oceanic front identification	Marine biology; Fisheries science	Coastal waters and other optically - complex waters	Pollution monitoring	Sea-ice melting and formation	Mapping of marine currents; Ocean circulation; Oceanic front identification Climate change	Sea-ice melting and formatio n
Coverage	Global	Global	Coastal areas	Global / selected areas	Polar regions	Global	Polar regions
Spatial resolution	1x1 km^2 on coastal waters 5x5 km^2 open/ocean waters	1x1km^2 coastal waters 5x5 km^2 ocean waters	1x1km^2	1x1km^2	1x1 km2, (< 4x4 km 2 acceptable)	1x1 km2 coastal waters 5x5 km2 ocean waters	1x1 km2, (< 4x4 km2 acceptable)
Temporal resolution	1 h	1 - 24 h programmable	1 - 24 h programmable	global: daily regional: 1 h	1 h	1 h	1 h
Continuity	annual/seasonal	annual/ seasonal	annual/ seas onal	acute pollution events	annual/seasonal	annual/seasonal	annual/seasonal
Priority	**1**	**1**	**2**	**2**	**2**	**2**	**2**

Vegetation Monitoring

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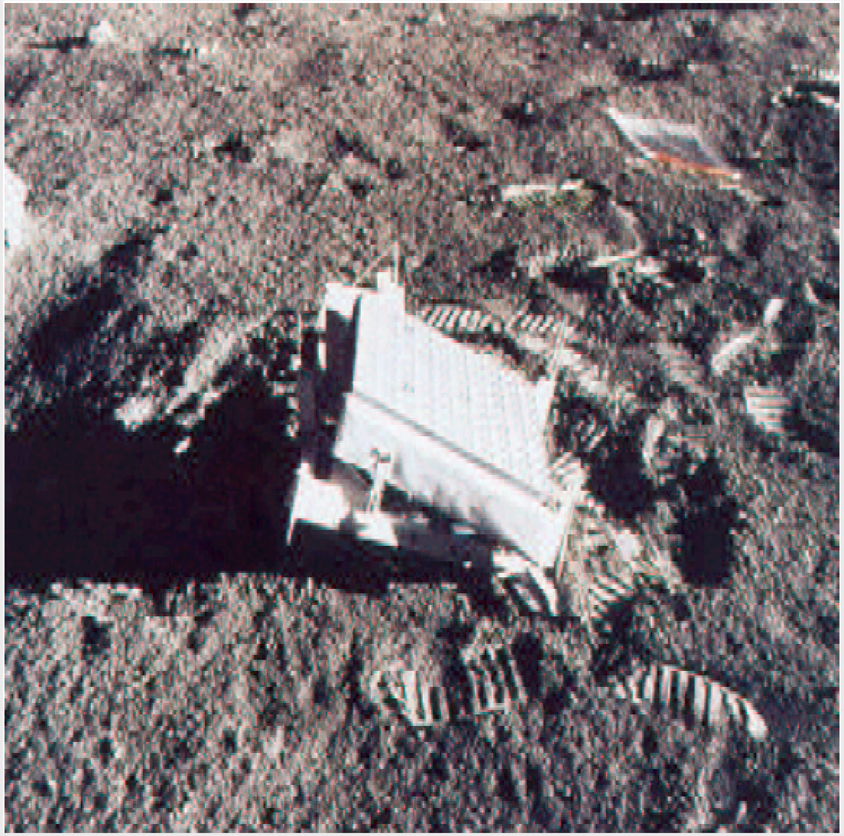
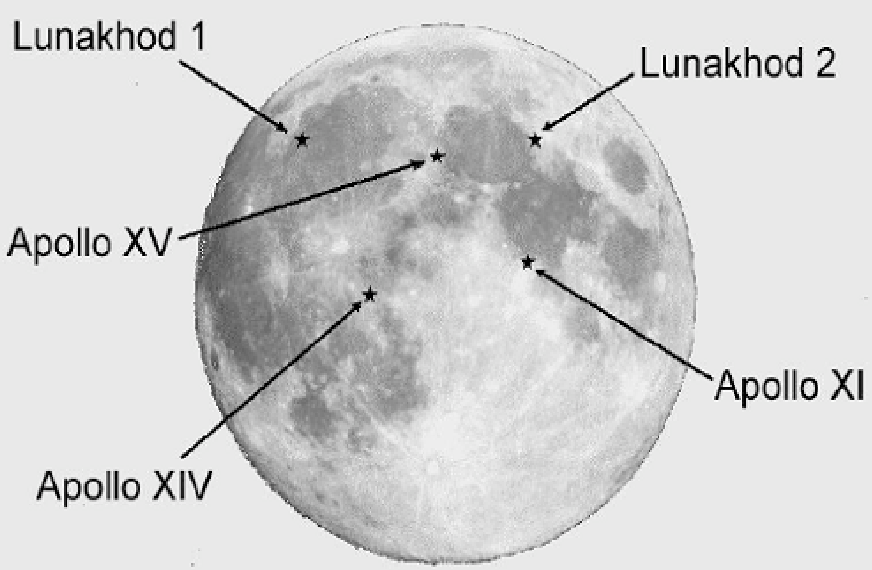
Measurement method	**VIS - NIR - SWIR reflectance imaging**						**Pigment fluorescence detection in the Fraunhofer lines**	
Spectral range	400-2500 nm						Selected Fraunhofer lines (possibly four spectral lines at about 760nm, 687 nm, 656 nm, 486 nm)	
Spectral resolution	2nm VIS 20 nm IR						According to the selected line width; typically, at least 20 channels inside the line	
Sensitivity / resolution	12 bit						<1 $mW/m^2/nm$	
Science sub themes	Global change		Resource management; sustainability				Global change	Resource management; sustainability
Science objective	Global land cover	- Carbon cycle - Net primary production	Pigment content	- Natural vegetation classification; -Forestry management; - Land use	Precision farming; Crop type; Species identification	Disaster management	Carbon cycle; net primary production	Crop and vegetation stress - early warning, Precision farming
Coverage / spatial resolution	Global / regional	Global / regional $<1x1km^2$	Global / regional	Global / regional	Global / regional $<1x1km^2$ programmable	Regional $<1x1km^2$	Global / regional $<1x1km^2$	Global / regional $<1x1km^2$ programmable
Temporal resolution	Daily	Daily	Daily	Daily	Daily	1h	Daily/ 1h	Daily/ 1h
Continuity	annual/seasonal	annual/ seasonal	annual/ seasonal	annual/ seasonal	annual/ seasonal	Short term follow up	annual/ seasonal	annual/ seasonal
Priority	2	1	1	2	1	2	2	2

Lunar fixed reference frame as a pre-requisite for georeferencing images and for Moon exploration





MoonLIGHT:
MOON LASER INSTRUMENTATION FOR GENERAL RELATIVITY HIGH-ACCURACY TESTS

C. Cantone, *S. Dell'Agnello**, G. O. Delle Monache, M. Garattini, N. Intaglietta***
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R. Vittori
Italian Air Force, Rome, ITALY

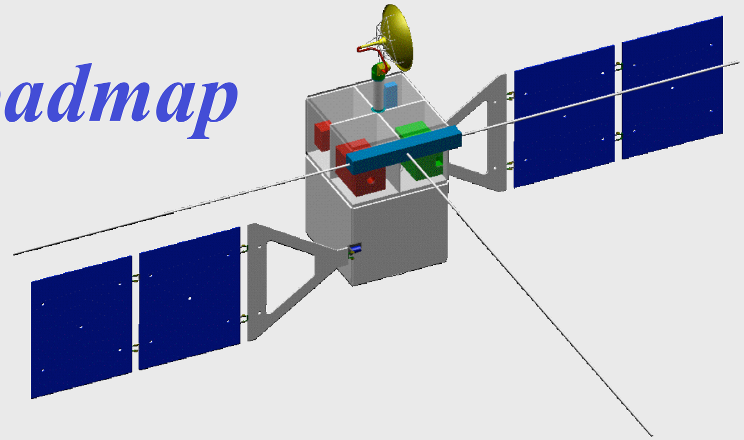
- From the abstract …….
  - a proposal (to NASA) for improving by a factor 1000 or more the accuracy of the current Lunar Laser Ranging (LLR) experiment (performed in the last 37 years using the retro-reflector arrays deployed on the Moon by the Apollo 11, 14 and 15 missions). Achieving such an improvement requires a modified thermal, optical and mechanical design of the retro-reflector array and detailed experimental tests. The new experiment will allow a rich program of accurate tests of General Relativity already with current laser ranging systems. This accuracy will get better and better as the performance of laser technologies improve over the next few decades, like they did relentlessly since the '60s.

Lunar Laser Ranging Experiment

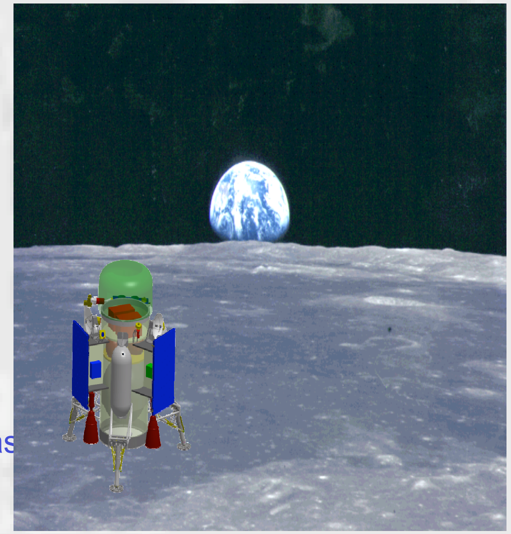
1. Establishment of a selenocentric reference system tied with the Earth fixed one which is needed for Earth images taken from the Moon georeferentiation (Earth observation, Moon exploration/navigation)
2. General relativity high-accuracy tests (Equivalence Principle) (Observation of the Universe)
3. Moon librations, Moon internal structure, tides, Moon geophysics (Moon study)

>>> looking in more details and with all the 3 communities what could be done.

… towards the roadmap



- Scientific objectives identification: completed.
- Analysis of the measurements requirements by the technological studies: on-going to define P/Ls and related TRL
- Missions scenarios within current "boundary conditions": on-going
  - **VEGA launcher** + transfer module with electric propulsion
  - First **launch in 2011-2012**
  - Orbiter carrying 100 kg of scientific P/L in polar orbit 100 km x 100 km or 100 km x 20.000 km (1.061 / 606 days cruise)
  - Descent and Landing Module delivering 90-110kg of P/L at the Lunar surface (14 days P/L support for Power and TLC)
  - Robotics capabilities
  - SEP with 2-3 years cruise
- Analysis with other launcher
- Roadmap elaboration: starting now



ASI Approach

- The Roadmap will be essentially science driven and based mainly on national capabilities.
- The Programme will be open to international collaborations based on synergies and common objectives with other national/international programmes including a mission to the Moon in the Aurora framework.