Moonbase – Third Workshop

Robotic package for Moon Surface and Subsurface resources evaluation

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1. Introduction

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In the frame of Moon exploration it is proposed a compact *Robotic Package* with the objective to support an early surface and subsurface resource characterization.

In order to exploit the availability of precursor flights, the package is conceived compact and compatible with specific launch capabilities.

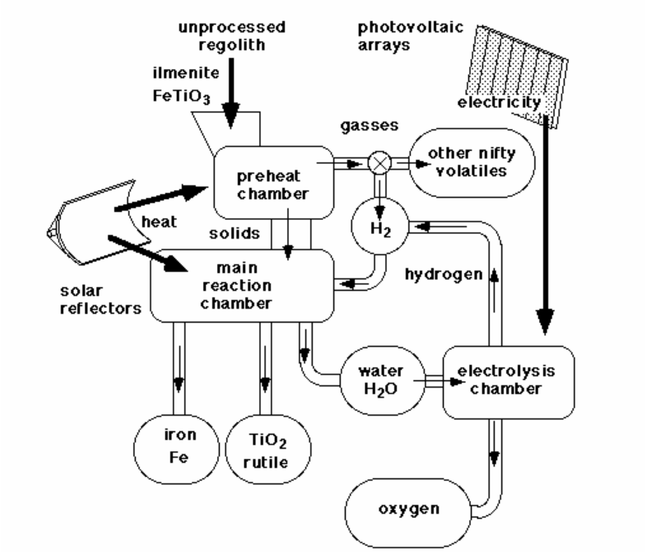
The main functional requirements considered are:

- **Collection of regolith/dust and subsurface samples aiming at oxygen extraction verification;**
- **Collection of porous subsurface samples aiming at extraction of possible water;**
- **Evaluation of local stratigraphy and subsurface compactness.**

2. Requirements

Moon regolith/dust is composed of minerals which contains oxygen in considerable quantity (like ilmenite).
***Extraction of oxygen* from these materials seems feasible (e.g. see [1], [2]) utilizing only electric power and an initial amount of hydrogen.**

The *robotic package* shall be capable to collect surface and subsurface regolith/dust samples and provide them to a test pilot plant, briefcase sized, for verification of oxygen extraction.



Example of oxygen production scheme
(Design patented by Carbotek Inc. Houston)

[1] The ARTEMIS Project, http://www.asi.org/adb/04/03/10/04/oxygen-extraction.html
[2] T. Mosher, J. Ellsworth et Al, “The Shackleton Mission: A Return to the Moon”, Utah State University

2. (cont) Requirements

The possible presence of frost (water ice) porous material could be verified with the aim to *extract liquid water* (and hydrogen /oxygen).
Frost, probably originated by precipitation of cometary volatiles [1], could be present in sunshine-deprived zones protected by upper layers of regolith.
The depth of interest is very uncertain; ref. [2] reports that frozen layers may be found at about 100 ft depth.
The issue of water presence and needed depth may be difficult to solve even by 'near' remote sensing.

The proposed *robotic package* shall be capable to collect porous frosty subsurface samples and provide them to an oven pilot plant looking for water presence.

[1] Leonard David, "Moon Water: A Trickle of Data and a Flood of Questions", http://www.space.com/scienceastronomy/060306
[2] C. Sagan, J. L. Leonard, "Extract from the book Planets", http//users.tpg.com.au/users/tps-seti/planets.html

2. (cont) Requirements

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The *knowledge of the subsurface consistency and stratigraphy (even indicative)* is important since:

- **it can support the selection of the site as candidate for future 'heavy' installations;**
- **it can give indications on the possible presence of subsurface layers (boulders or voids) of interest, prior to the completion of 'deep drilling' operations.**

The proposed *robotic package* shall be capable to derive in real time stratigraphic indications and compactness beneath and around the area to be drilled.

2. (cont) Requirements

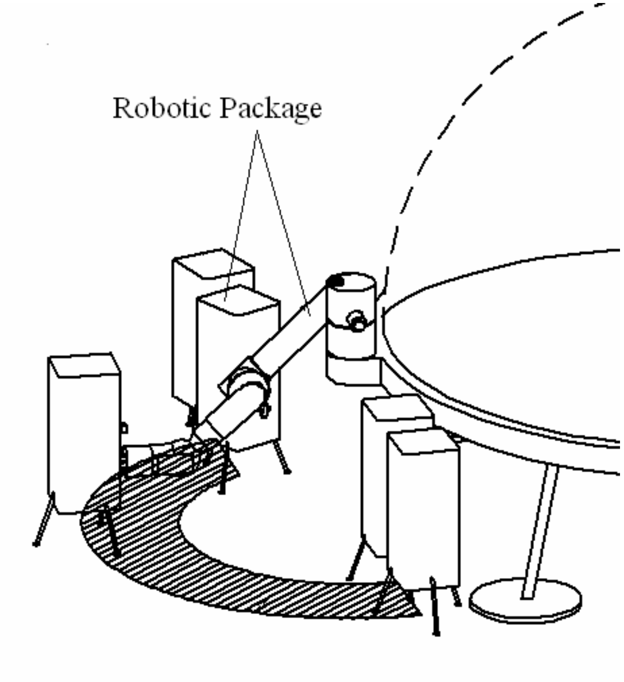
The proposed *robotic package* can be preliminary conceived taking into account the following main capabilities/features:

⇒ **Collect regolith samples (size of some cm^3) at surface and near subsurface:**
- **Depth: 0.1 m**
- **Compressive strength up to few tens of KPa**

⇒ **Collect subsurface frosty porous material samples (size of some cm3):**
- **Depth: meter to thirty meter range**
- **Compressive strength < 2 Mpa**

⇒ **Support the determination of the soil material compactness and provide stratigraphic indications**

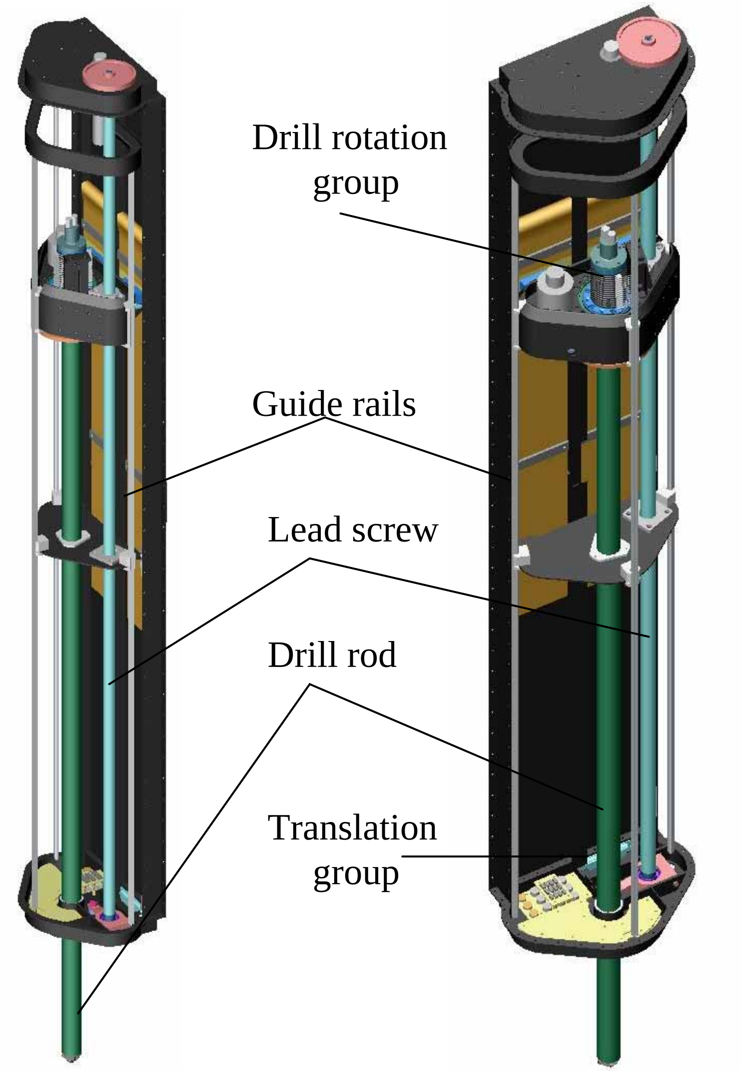
⇒ **Robotic Package main budgets (target):**
Mass 15-30 kg, Size 30-60 liters, Power 40-80 W



Schematics of Robotic Package
Drill Unit plus Positioner

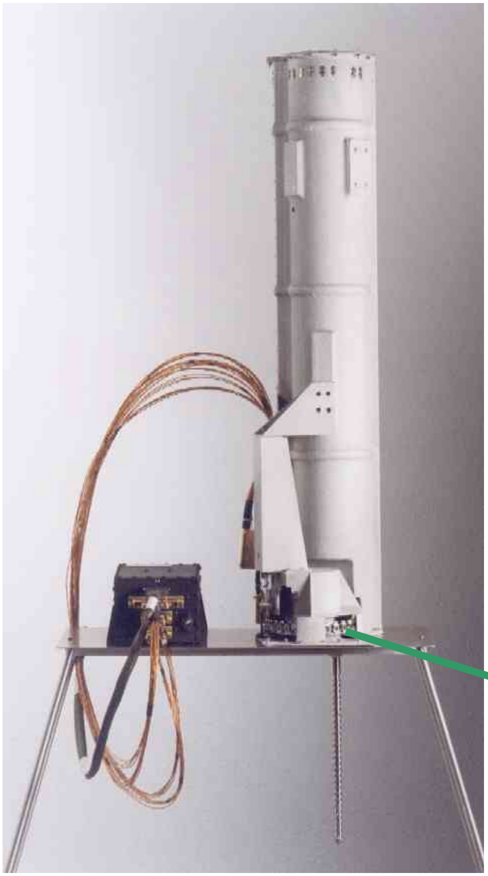
3. Sampling methods - Single stroke drilling approach

- The single rod drill uses one drill tool with sampling capability; overall drill length is sufficient for the drilling depth
- The drill length is related to the required penetration depth (typically 0.5 m)
- It basically has only two mechanisms: drill rotation and drill translation
- It is a simple but very reliable equipment



Schematics of single stroke drill
DeeDri (ASI program)

Rosetta Drill Sample and Distribution System-SD2 (ASI contract):
Technology Readiness Level (TRL) 8-9 (in flight)



Three major items:

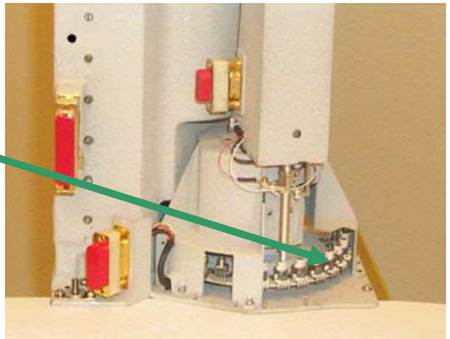
- **Drill unit (with distribution carousel)** ***Mass: 3.9 kg***
- **Electronic unit** ***Mass: 1.02 kg***
- **Harness** ***Mass: 0.5 kg***

Sampling capability: some tens of mm^3 (each collection)
100 MPa soil hardness (capability)

Stroke > 500 mm

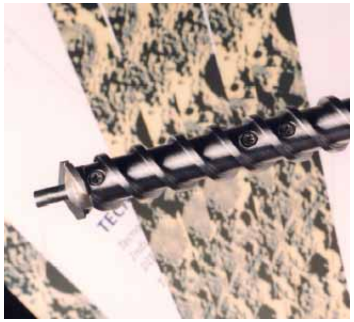
Operational temperature: -150°C to +40°C

Detail on Carousel



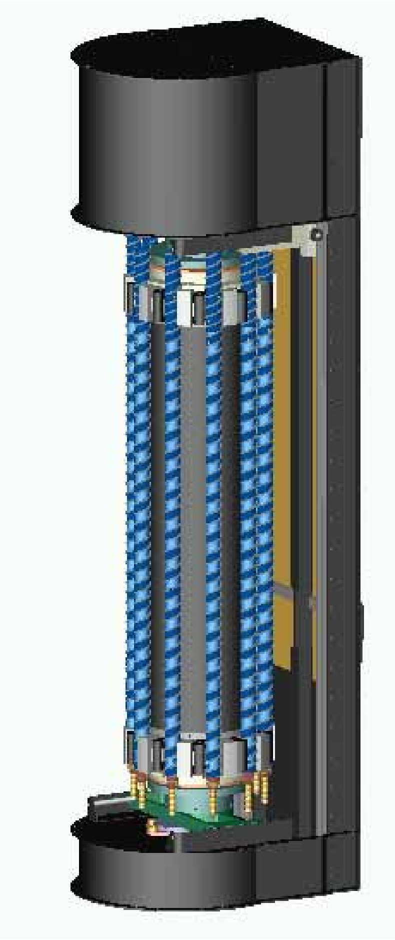
Drilling Rod (drilling mode)

Drilling Rod (sampling mode)



3. (cont) Sampling methods - Multiple stroke drilling approach

- **The multi rod drill uses a drill tool with sampling capability and a number of extension rods which are "added" to obtain the required drilling depth**
- **The number of rods and their length depends on the available volume for accommodation**
- **The extension rods are assembled and disassembled during operations**



Schematics of multiple stroke drill
DeeDri (ASI program)

3. (cont) Sampling methods - Multi stroke drill heritage

DeeDri technology development (ASI contract) : Study plus Breadboard (B/B) TRL 4

Three major items:

- **Drill rod with shutters**
- **Corers**
- **Extension rods**

Sampling capability: some cm^3 each collection

Drill rod with shutters (drilling and coring configuration, collected sample)

Extension rods

Corer (drilling and coring configuration, collected sample)

3. (cont) Sampling methods - Multi stroke drill heritage (cont.)

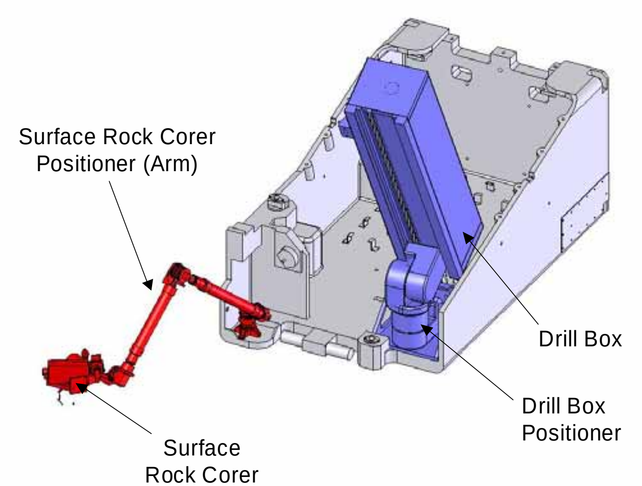
Exomars development program (ESA contract) : Study plus B/B (running program)
TRL 4-5 by mid 2007

Four major items:

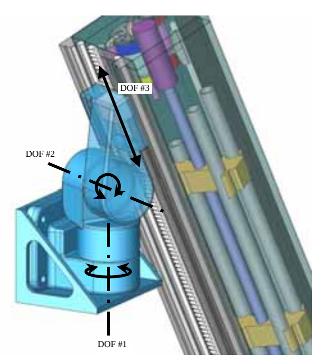
- **Drill box (sampling depth capability 2 m)** ***Mass: 7 kg***
- **Drill Box Positioner**
- **Sample Processing and Distribution System (SPDS)**
- **Electronics**

Sampling capability: some cm^3 each collection

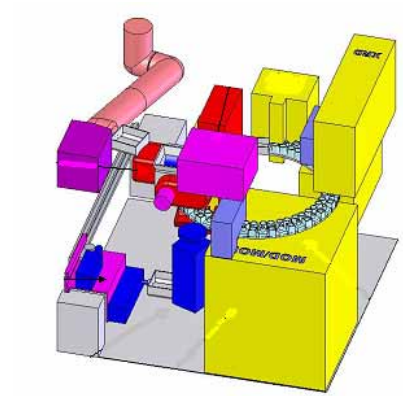
100 MPa soil hardness (capability)



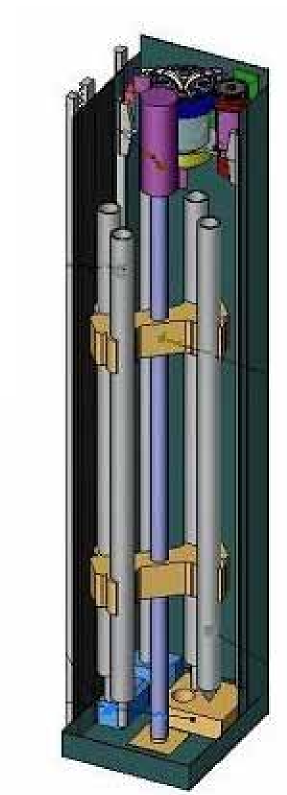
Schematics of integrated Drill Box and Positioner (from Exomars Phase A)



Drill Box Positioner (schematics only)



SPDS (schematics only)

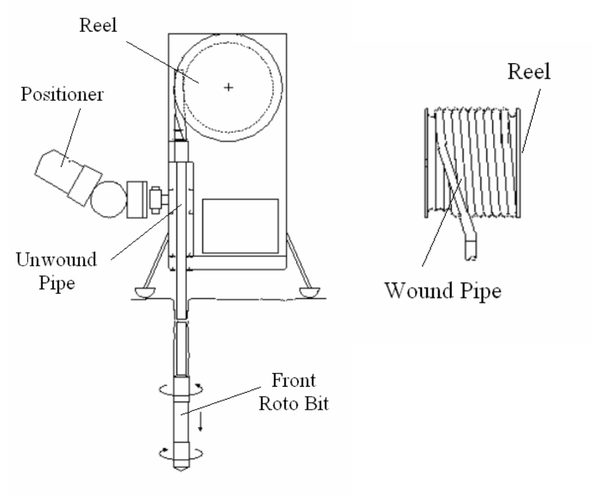


Drill Box (schematics only)

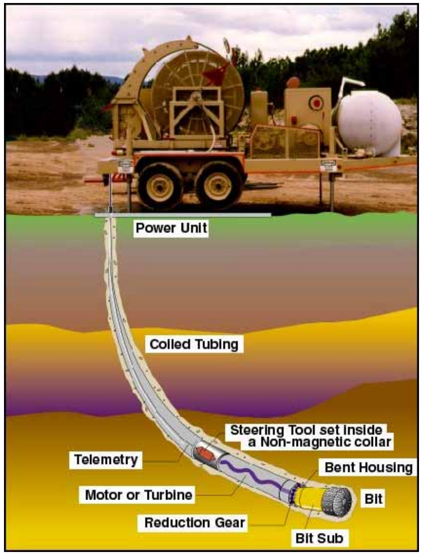
3. (cont) Sampling methods - Coiled Tube Drilling approach

Coiled Tube Drilling (CTD) has an excavating head mounted at the end tip of a flexible guiding tube.

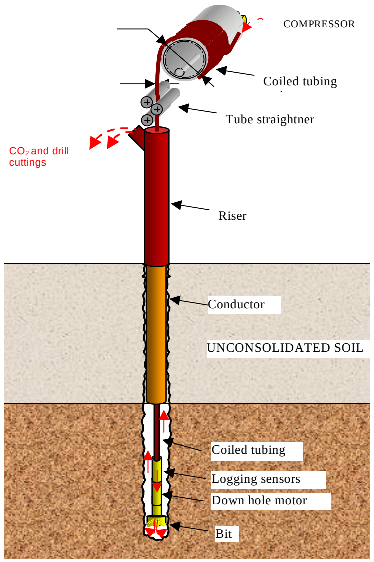
- **the tube can support the transmission of pushing force from the surface unit to the drilling head;**
- **possibility to implement sample collection downhole;**
- **deployable probes can be used to conduct down-hole scientific experiments.**



Schematics of CTD for Moon



Example of CTD developed by Los Alamos Laboratory



Example of CTD for Mars DeeDri (ASI program)

Example of performances for Moon:

- Penetration depth: 30m in regolith

- Sample size: several cm3

- Mass: 10-15 kg (excluding depl. device)

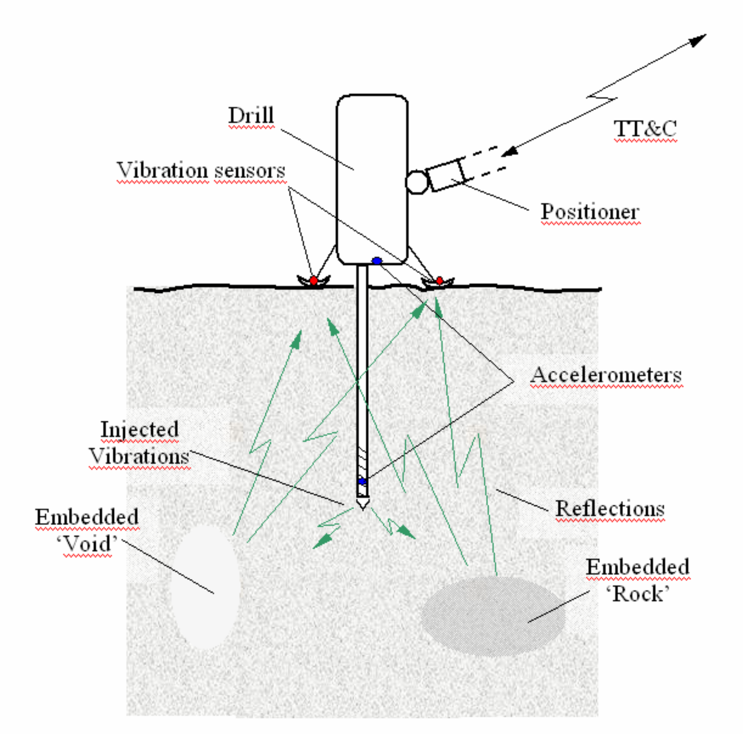
4 - 5 kg of electronics

- Length: 600-700 mm

Subsurface stratigraphic determination can be attempted by utilizing the approach of 'Seismic Reflection' based on the propagation, reflection, measurement and analysis of seismic waves through the media.

The method SEISBIT®, jointly developed by OGS (Trieste) and ENI, allows to determine 3D geophysics characteristics beneath and around the drill bit exploiting the vibrations produced by the bit itself and by measuring and analysing the delays and intensity of the direct and reflected waves at appropriate locations.

The method, patented for earth applications, is certainly worth being evaluated to verify its suitability and adaptability in the frame of a Moon scenario.



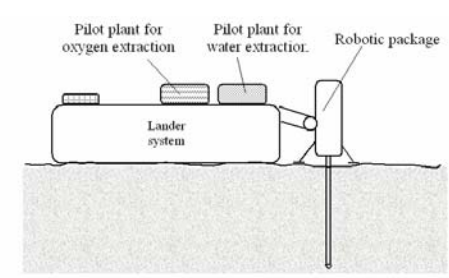
Schematics of SEISBIT® method Adapted for Moon scenario

OGS Istituto Nazionale di Oceanografia e Geofisica Sperimentale – Trieste
ENI Ente Nazionale Idrocarburi

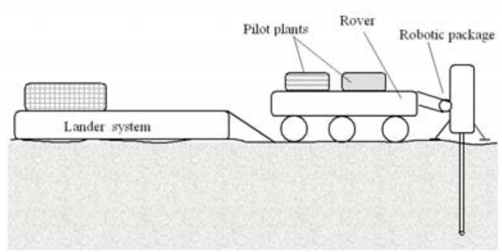
5.1 Possible scenarios

Possible operative scenarios on the Moon can be different depending upon overall mission strategy, launch resources, moon landed H/W budgets

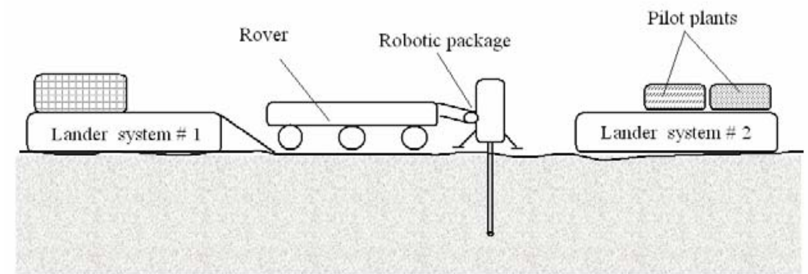
Some examples:



- **One launch**
- **Low mass P/L**



- **One launch**
- **Extended mass P/L**



- **Two launches**
- **One Extended mass P/L for Robotic package on Rover**
- **One Low mass P/L for Pilot Plants**

Each of the scenarios will present specific demands and criticalities in several areas like: power generation and distribution, telecomunication links, operation coordination and interactive teleoperation from ground.

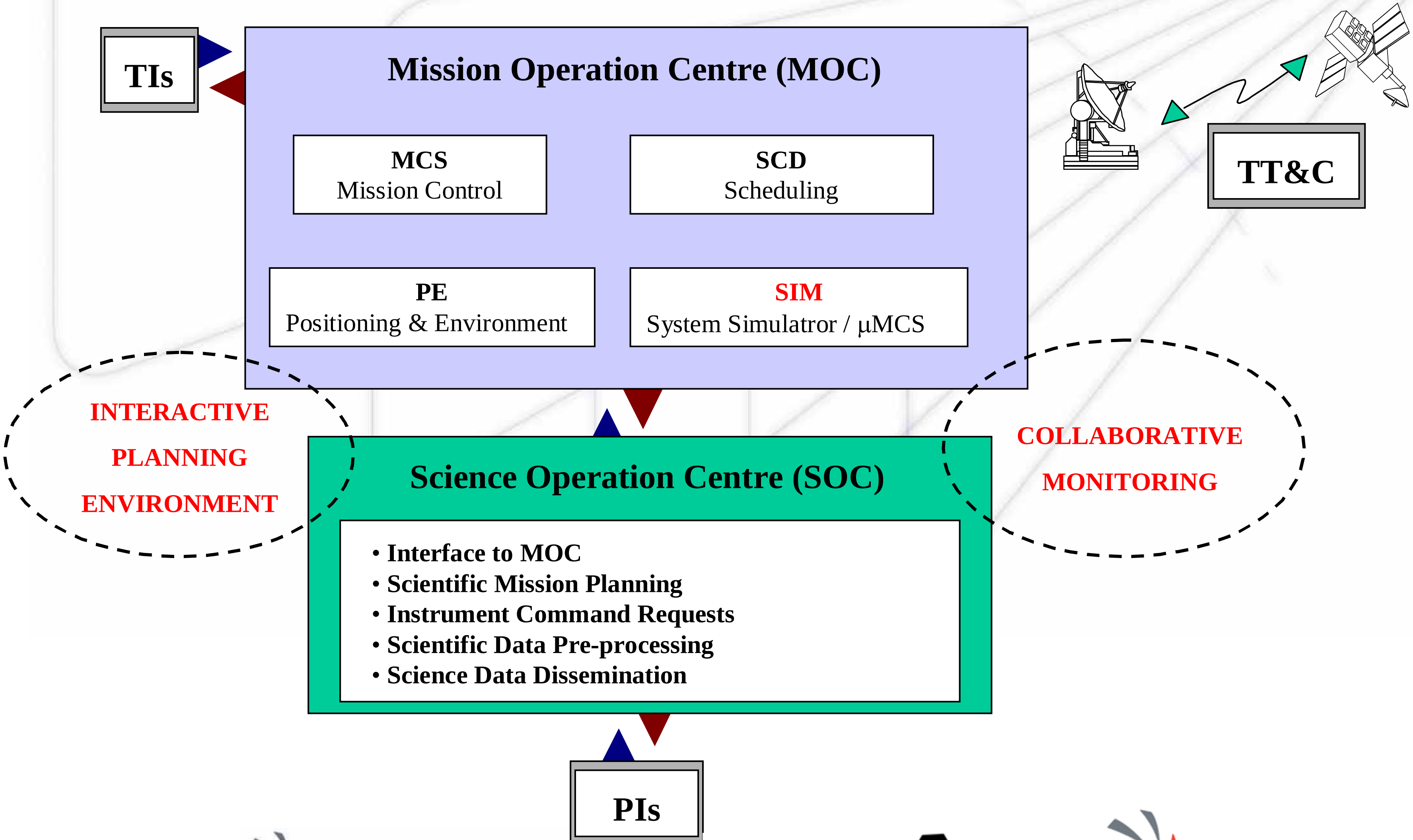
5.2 Interactive teleoperation from ground

The basic functions of a Mission Operations Center (MOC) in closed-loop interaction with a Science Operations Center (SOC) are taken as a starting point

Innovative solutions for enhancing the robustness and interactiveness of the system are then proposed:

- **independent system simulator (including μ*MCS*)**
- **advanced planning**
- **collaborative monitoring**
- **enhanced control centre functionalities to support multi-control for collaborative robots operations**

5.2 (cont) teleoperation basic architecture



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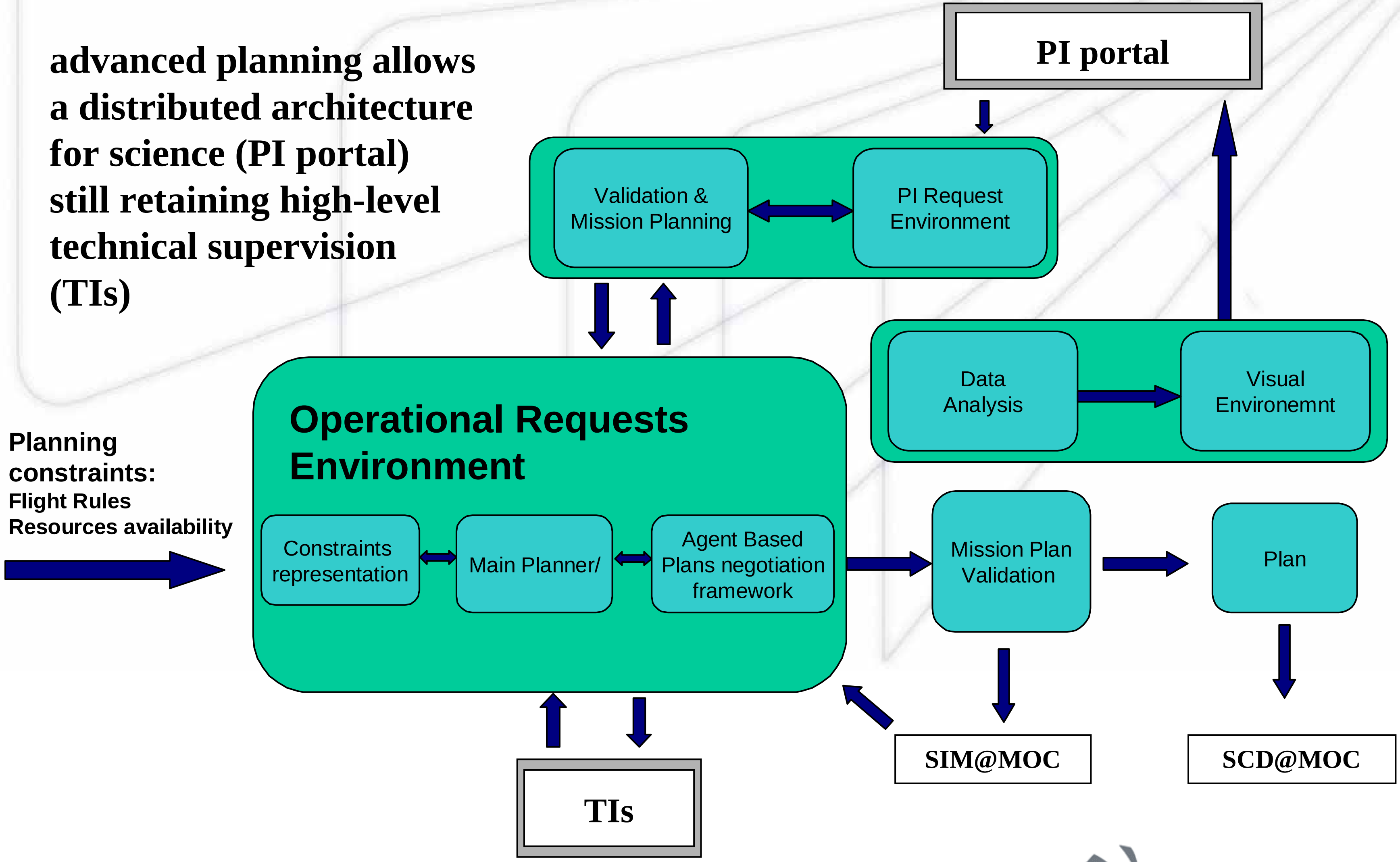
advanced planning allows a distributed architecture for science (PI portal) still retaining high-level technical supervision (TIs)



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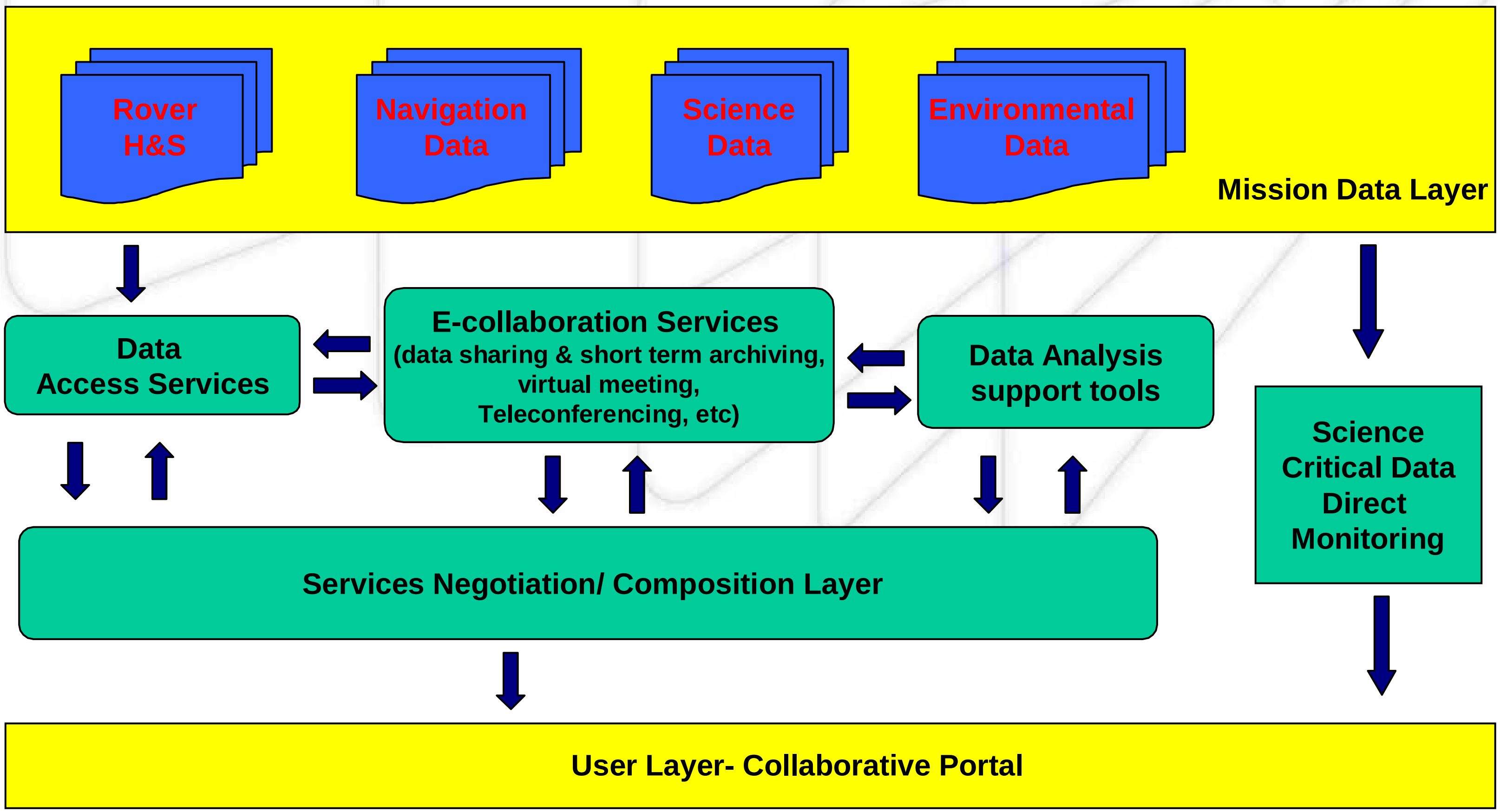
collaborative monitoring enhances the capability of the system of monitoring different robotic agents



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5.3 Ground Segment

In the wider context of a Moon Base scenario, two major aspects will characterize operations:

- **Autonomous operations system**
- **Distributed operations system**

In this respect the following main concepts are already addressed in the present Ground Segment and Operations design for the International Space Station:

- **Network of technical and scientific competences**
- **Multi-Robotic Packages Mission Control**
- **Growth Capability to support the mission scenarios evolution**

5.3 (contd.) Ground Segment

Autonomous operations system

In support to complex operative scenarios in order to reduce the constraints due to latency and/or communication.

A primary objective is to enabling the Robotic Package to appropriately respond to unexpected problems and to take advantage of unanticipated opportunities.

The system shall run with limited communication with ground. It shall be able to create command sequence or plan to achieve the main goal based on received science and engineering goals, flight rules respecting relevant constraints.

Distributed Operations

A collaborative environment system supports the distributed operation architecture and make available science and engineering data to the distributed centers, allowing them to participate in a joint planning and scheduling activity.

- ***Make downlink data available to the remote scientists and engineers.***
- ***Allow scientists to interactively share targets designation.***
- ***Facilitate the sharing of plan files that contain scientific observations.***
- ***Dynamically create indexing metadata of available data products.***
- ***Allow Interactive Planning and Scheduling***
- ***Allow distributed advanced simulation***
- ***Support teleoperations activities***
- ***Guarantee operational security, reliability and robustness.***

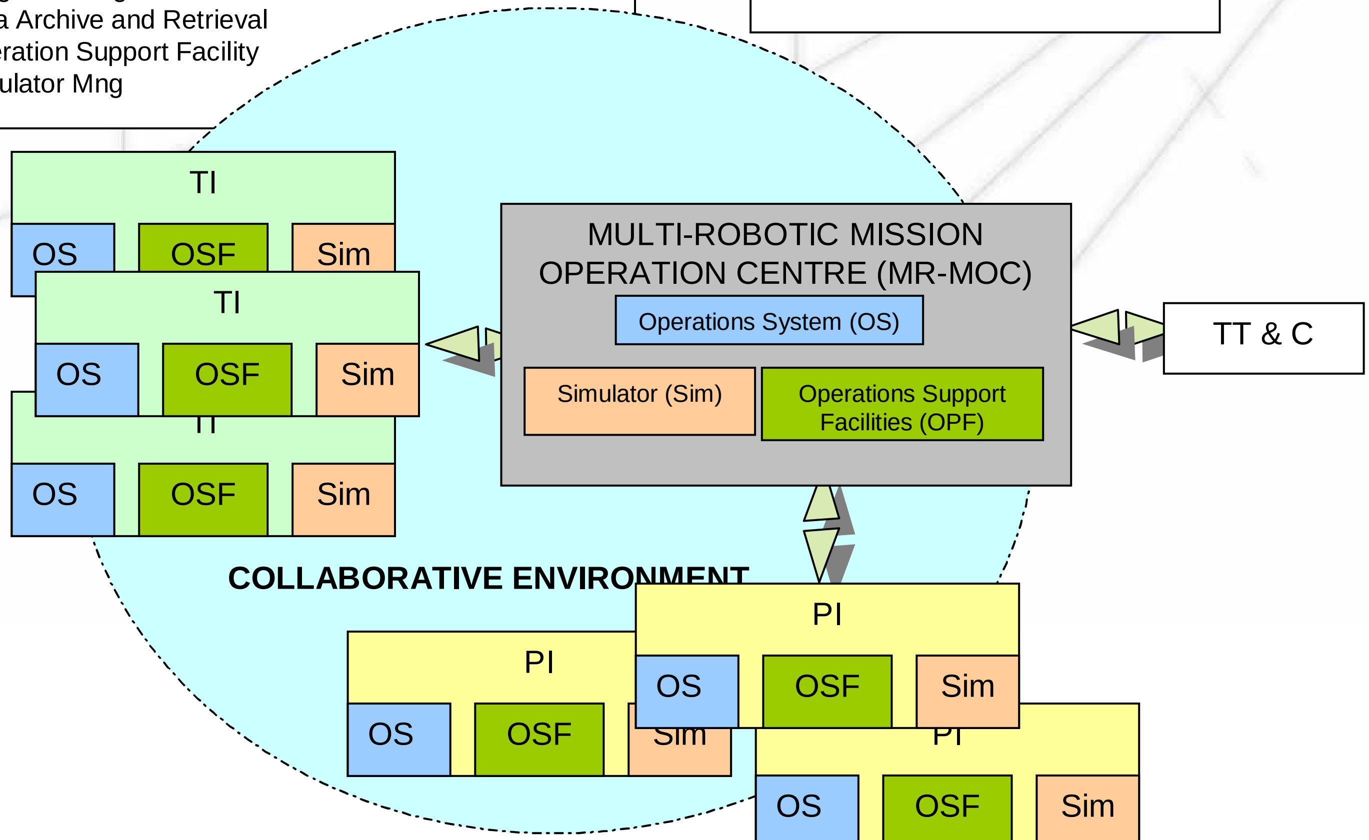
5.3 (contd.) Ground Segment: overall scenario

Operation System / OS

- TM Acquisition and Processing
- System Telemetry data assessment
- Science Data Assessment
- Activity Planning
- Command Generation, Simulation and Validation
- Images Management
- Data Archive and Retrieval
- Operation Support Facility
- Simulator Mng

Operation Support Facilities /OSF

- Voice Loops
- Multimedia System
- Chit/Anomalies tracking System
- Consol Log
- Procedures and processes
- Mission Data Base



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The Italian Gateway to ISS

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6. Conclusions

The utilization of a Robotic Package for Moon surface and subsurface evaluation certainly constitutes a very important element in support to the Moon exploration scenario.

Several technologies are involved in the Robotic package; the major issues are related to deep drill front end, sample recovery from depth, sample transfer to pilot plants, power and timing optimisation, interactive teleoperation and control.

To our opinion it is very important to identify a Design and Development Plan on the basic technologies necessary to the Robotic Package in order to timely perform the necessary verifications duly tuned with the overall mission schedule.