MARS Science Laboratory

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Agenda

- **Project Overview**
  - Objectives
  - Cruise, Entry, Descent & Landing (CEDL)
  - Surface Operations
- **MDS Overviews**
  - State-Based Architecture
  - Systems Engineering with State Analysis
  - Integrated Software Demonstration
  - Ground Operations

Science Objectives

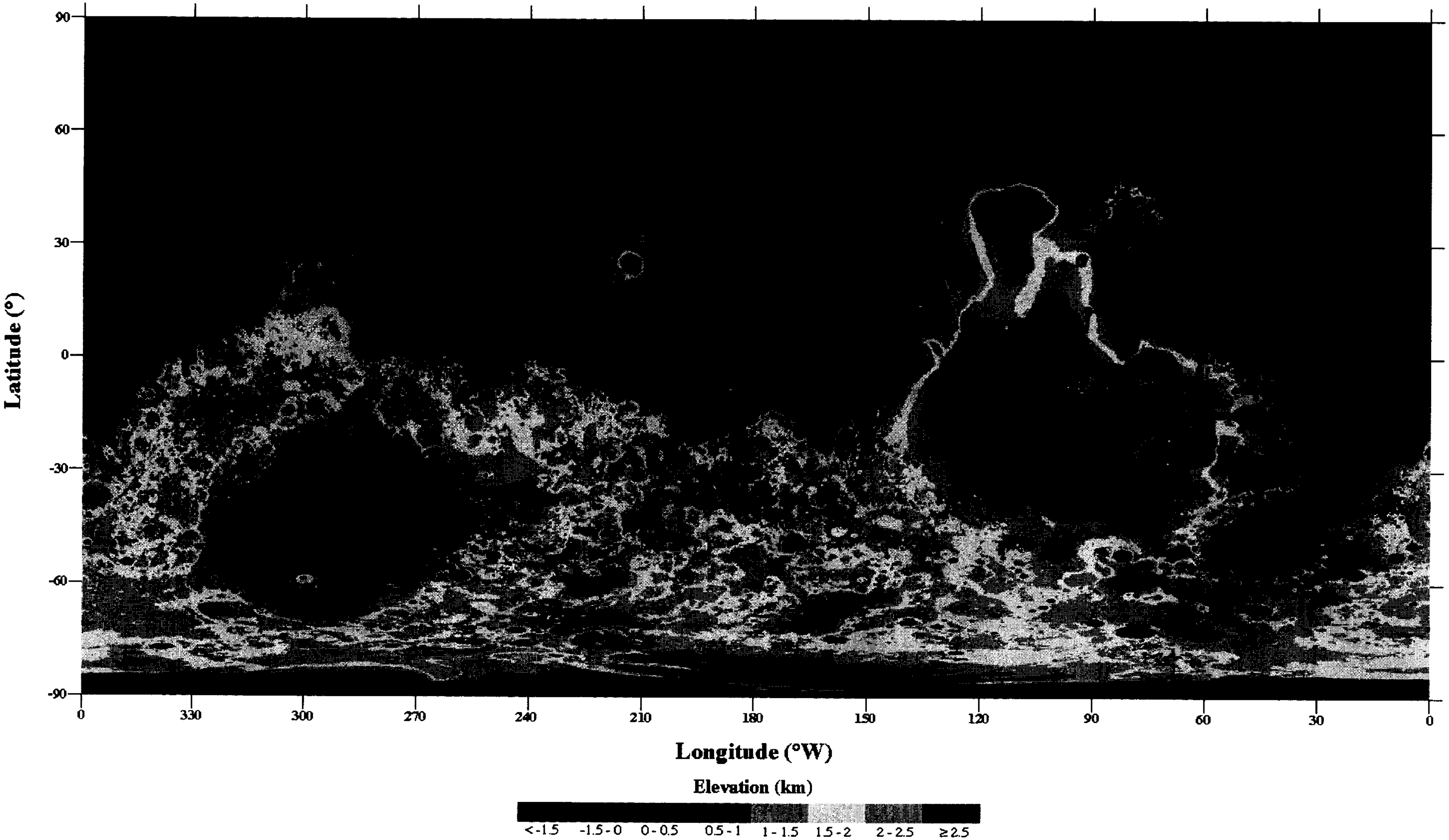
- **PSIG Science Objectives**
  - The Project System shall characterize the geology of the landing site, at different scales, so that analytic data can be interpreted in context
  - The Project System shall determine if liquid water persisted at the landing site, either on the surface or in the shallow subsurface.
  - The Project System shall assess the potential for habitability through studies of the chemistry of Martian samples, and the chemical environment in which they formed and evolved.
  - The Project System shall describe features (including textural, mineralogical and chemical) that may be possible biosignatures.

Key Requirements/Drivers

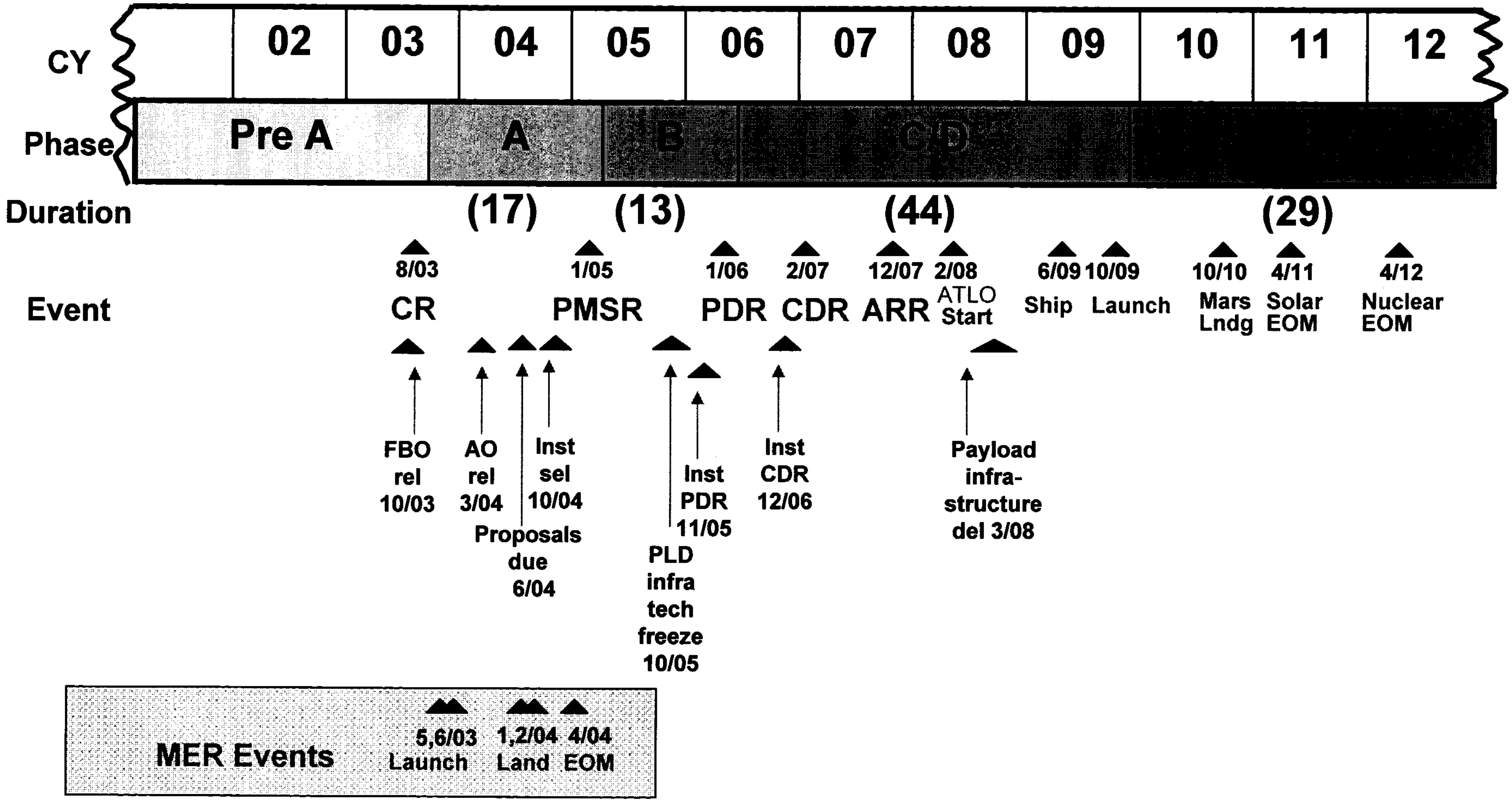
- Cost cap of $750RY (not including LV, RPS+integration (if applicable), Operations, and Contributions)
- Lifetime of 687 sols (1 Martian year) after touchdown on Mars
- Planetary Protection Category IVa or IVc
- Latitude Accessibility & Rover Operability from 60 deg S to 80 deg N
- Precision Landing: Ellipse size 10km x 5km
- Hazard Detection and Avoidance: FS shall be capable of diverting at least 100m during terminal descent to avoid a landing hazard
- Investigate at least 4 separate science locations (to increase science diversity)
- Analyze 4 samples per location
- 10m to 1km traverse distance between locations (250m as reference)

Mars Accessibility

MOLA 1/4° Gridded Topography



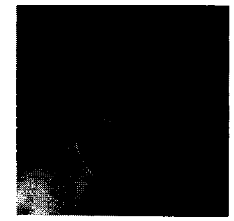
MSL Project Master Schedule

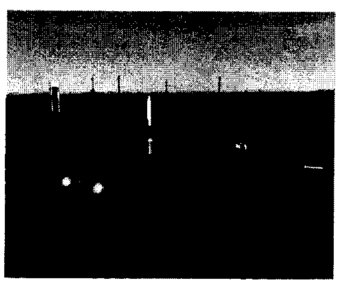


Mission Architecture

CRUISE/APPROACH
- Dumb cruise stage: uses rover avionics
- Type-I or II transfer
- 5-6 course corrections
- Optical nav for approach
- Separation @ entry – 10 min
- No carrier deflection
- Arrival Dates July – Oct 2010
- Latitude Capability 60 deg S to 83 deg N

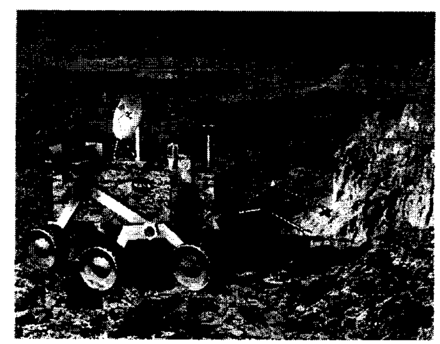
ENTRY/DESCENT/LANDING
- Guided entry, 2 parachutes and Viking Engines for descent
- Pallet or Sky-Crane landing system
- Comm provided by UHF link to orbiting asset and/or DTE X-band
- EDL data used for science
- Regional Hazard Detection & Avoidance using Phased Array Terrain Radar
- No Sun/Earth elevation constraints yet
- Arrival prohibited within +/- 30 days of solar conjunction
- Altitude Capability: <2.5km



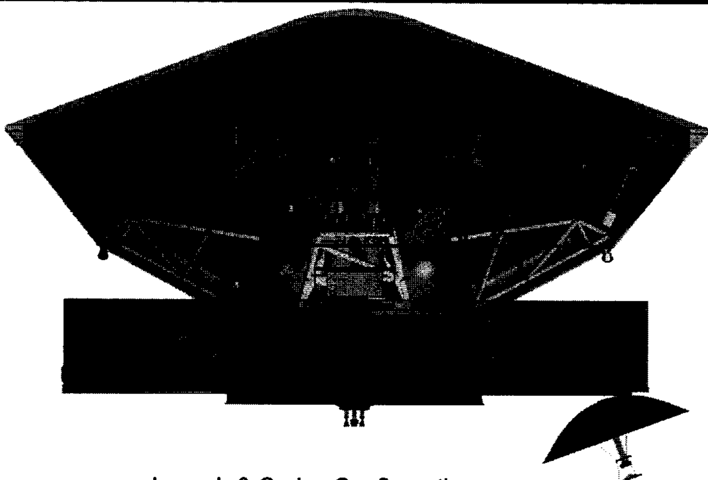


LAUNCH
- October 2009
- Delta IV/ATLAS V
- 5-m fairing

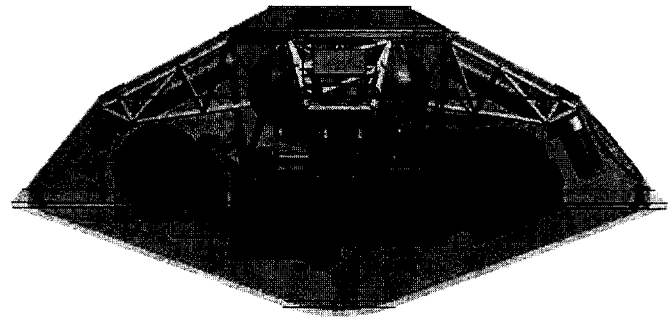
SURFACE MISSION
- 600-900 kg rover
- 500 Sol lifetime
- 3-5 km mobility
- 75 kg science payload
- Radioisotope Power Source
- Surface Avionics used for all 3 mission phases



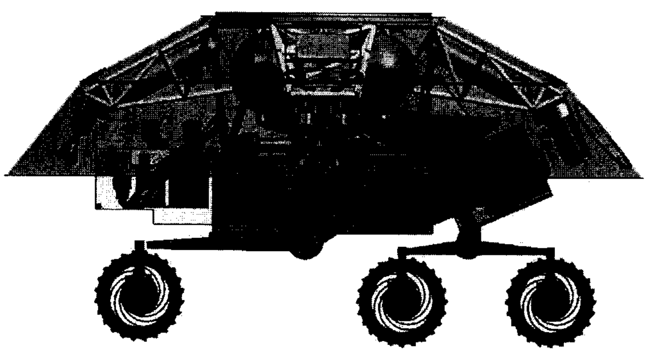
Configuration By Phase



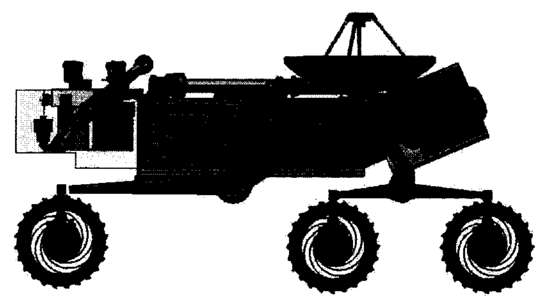
Launch & Cruise Configuration



Entry Configuration

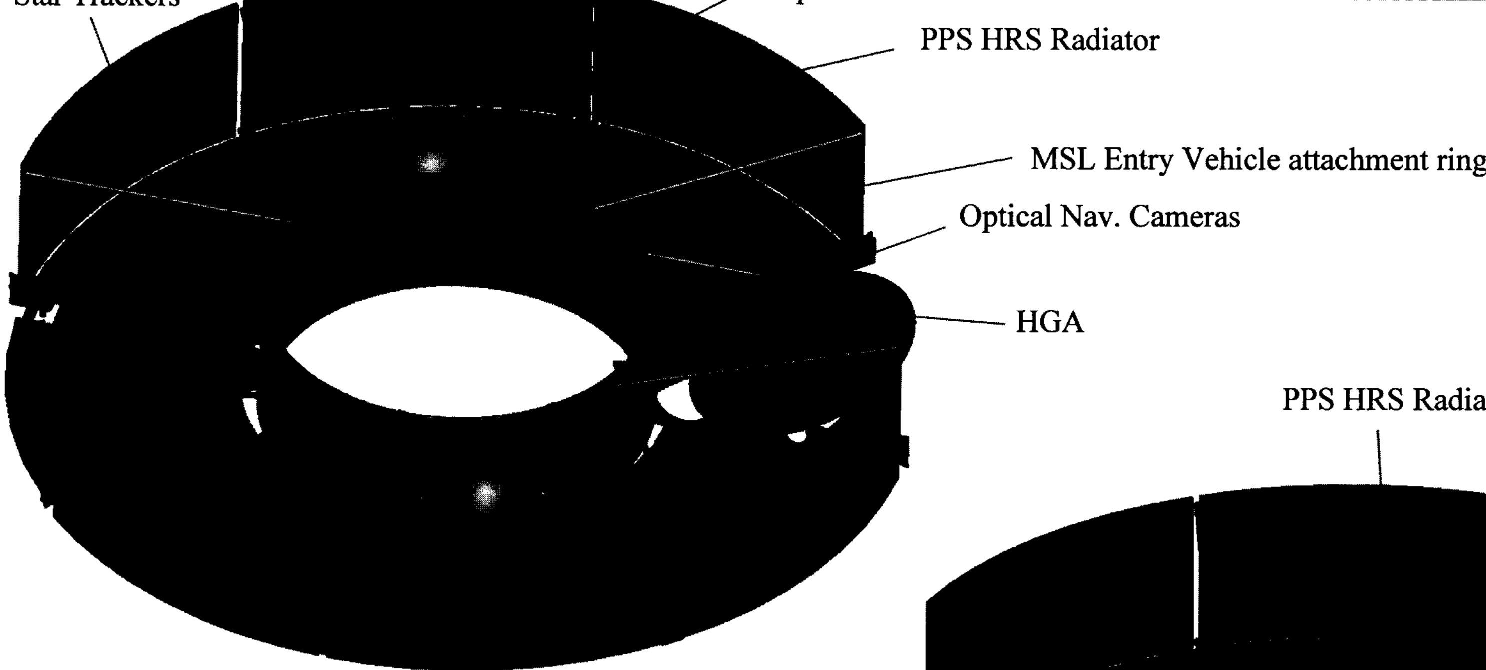


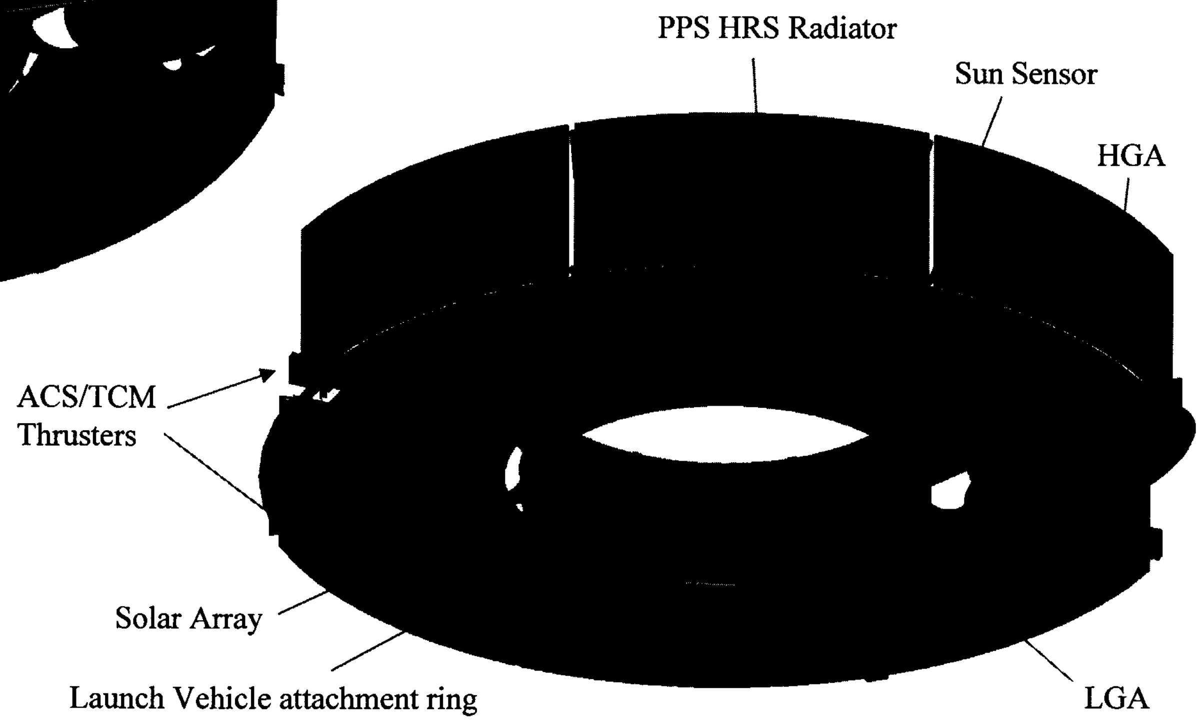
Descent and Landing Configuration



Landed Configuration

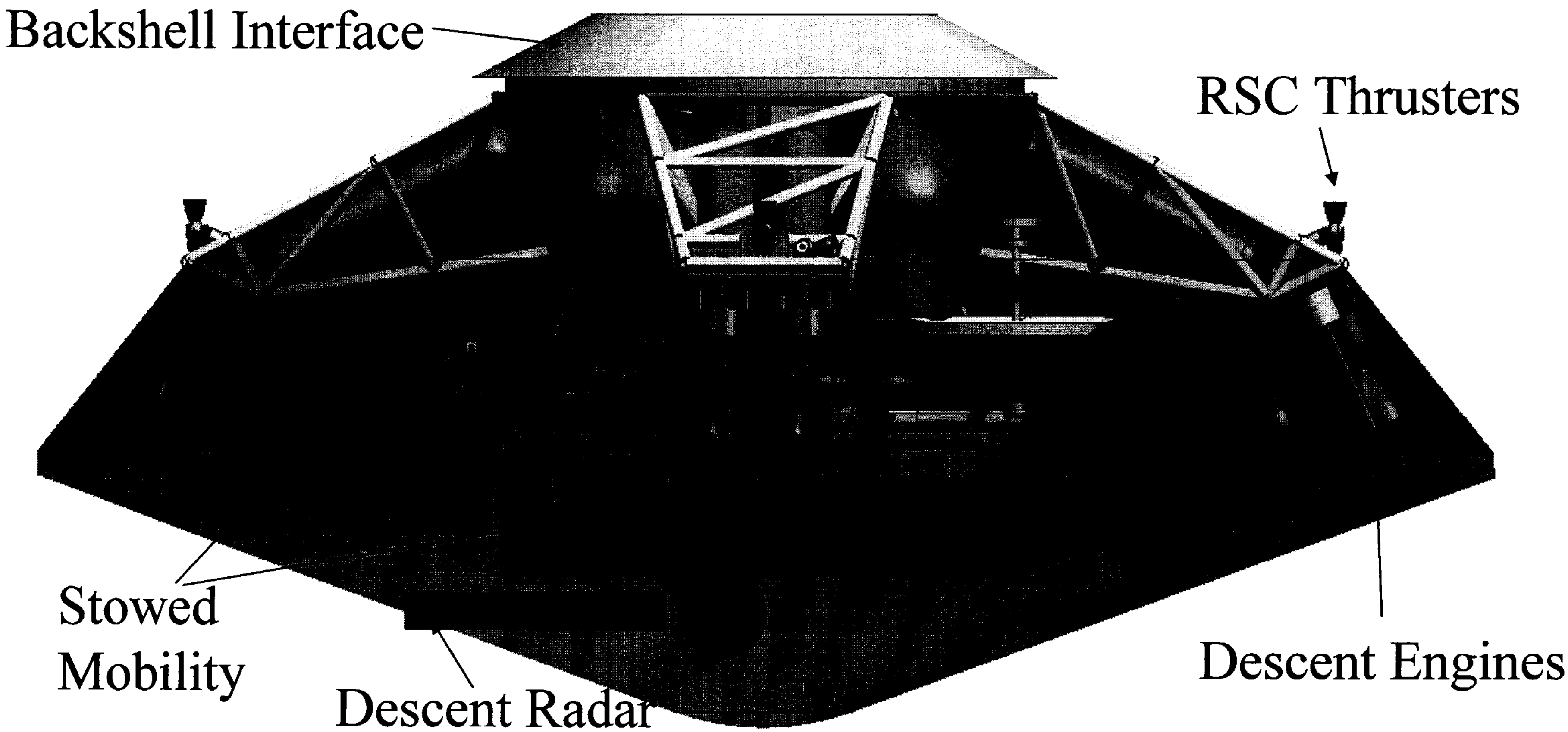
Cruise Configuration





MSL Carrier Configuration

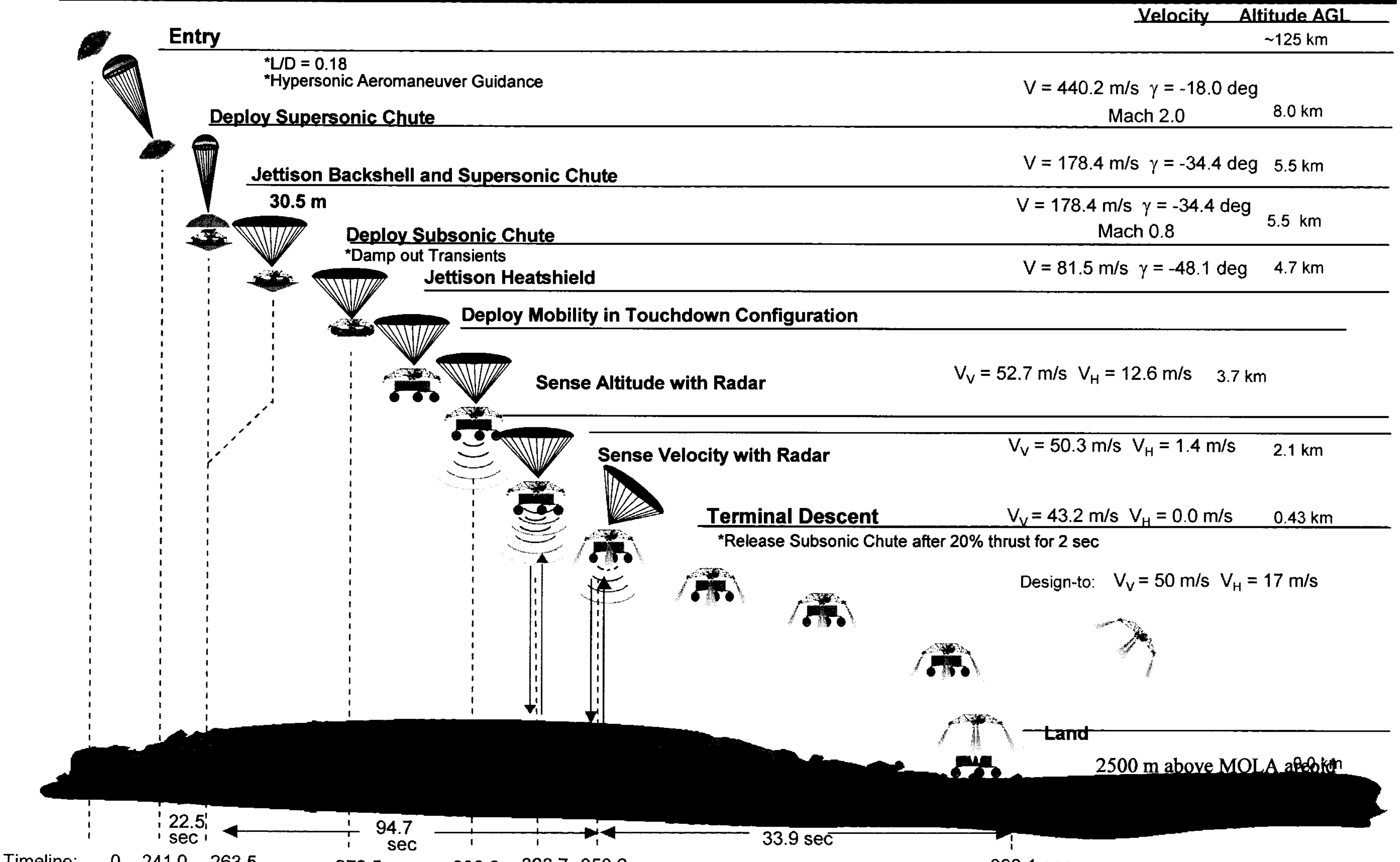
Entry Configuration (SkyCrane)



Shaded region shows the entry Envelope… not the Backshell

PRE-DECISIONAL DRAFT; For planning and discussion purposes only

Timeline, Nominal [Needs Revision]



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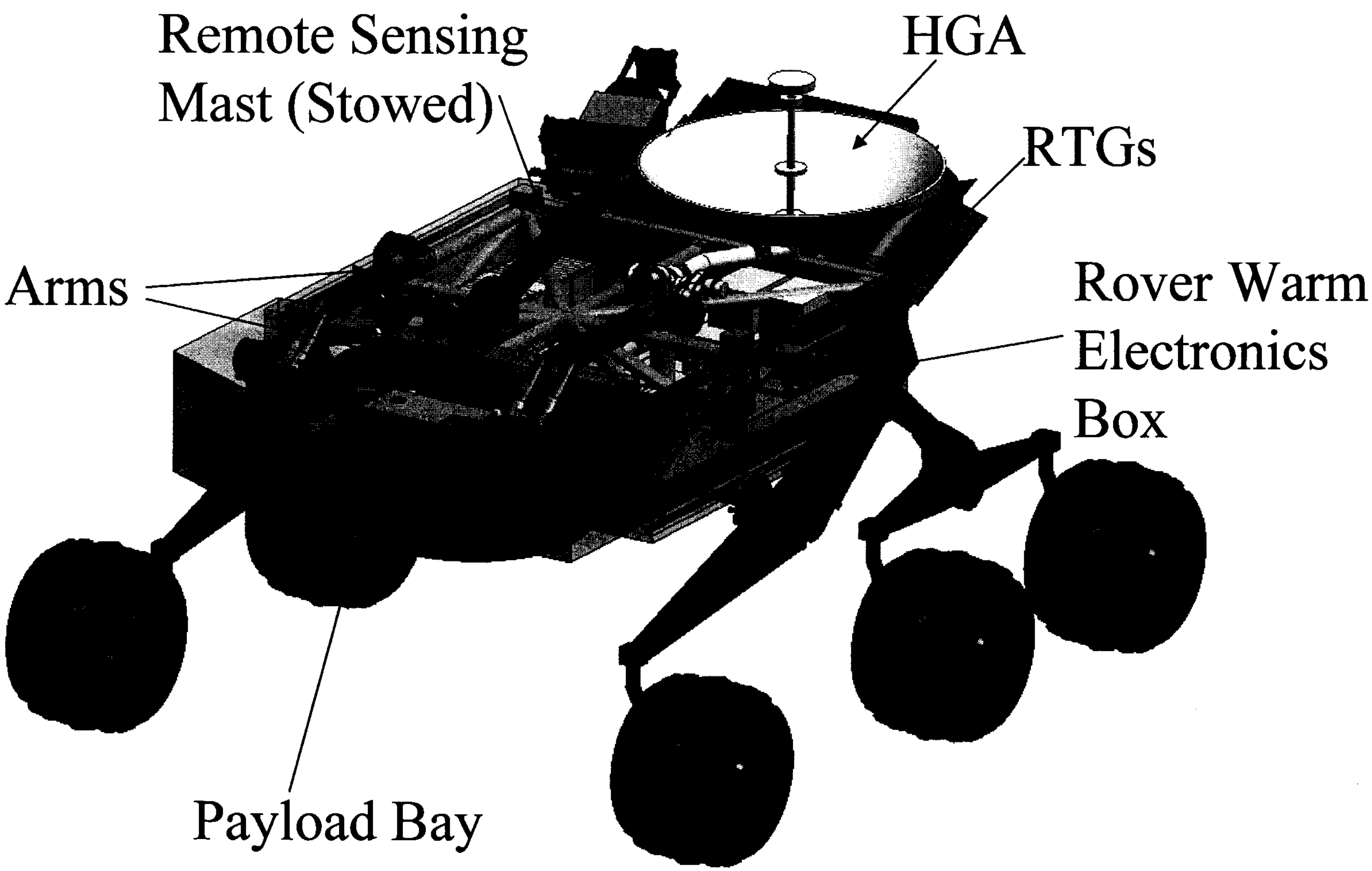
Rover Configuration



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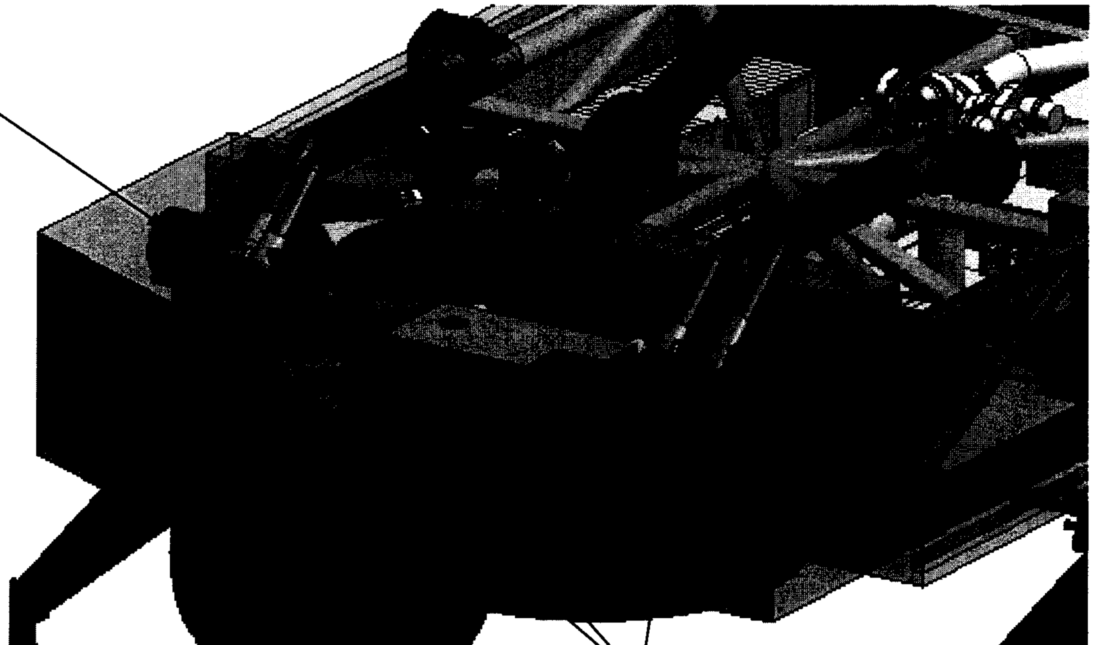
Payload Bay

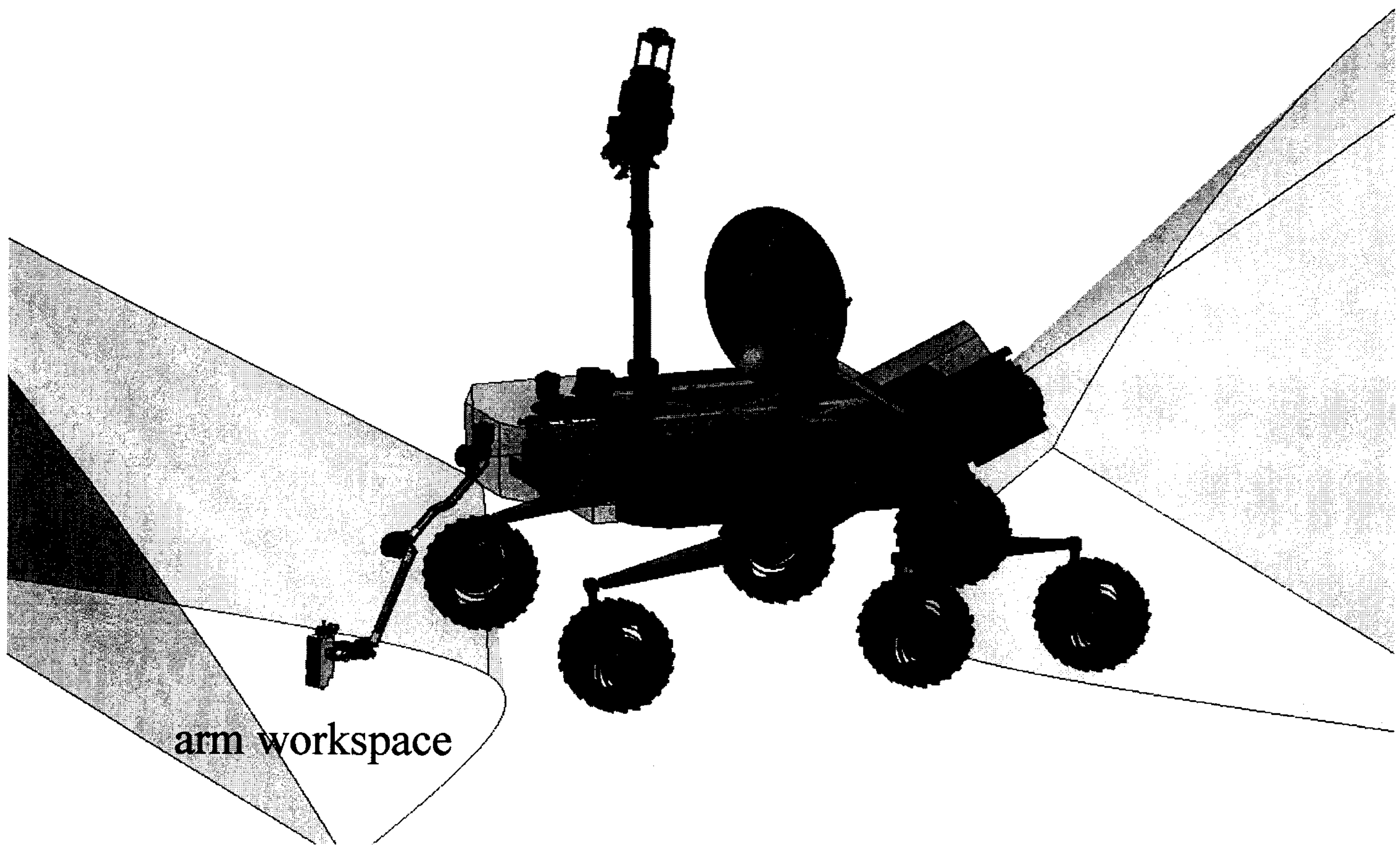
Arm with Mini-Corer



Sample Processing Unit

Analytical Instruments

MSL Rover Configuration - Preliminary



Arm workspace is defined by the Hazcam pair overlapping field of view. Hazcams are mounted ~1.0 m above the ground, 10 cm apart, oriented 30 degrees down from the rover plane, 120 degree field of view

Strawman Payload

PSIG Strawman Payload Instruments and Infrastructure

Analytical Lab (Sample Inlets)
- 3-4 instruments

Contact Suite (arm mounted)
- 2-3 instruments

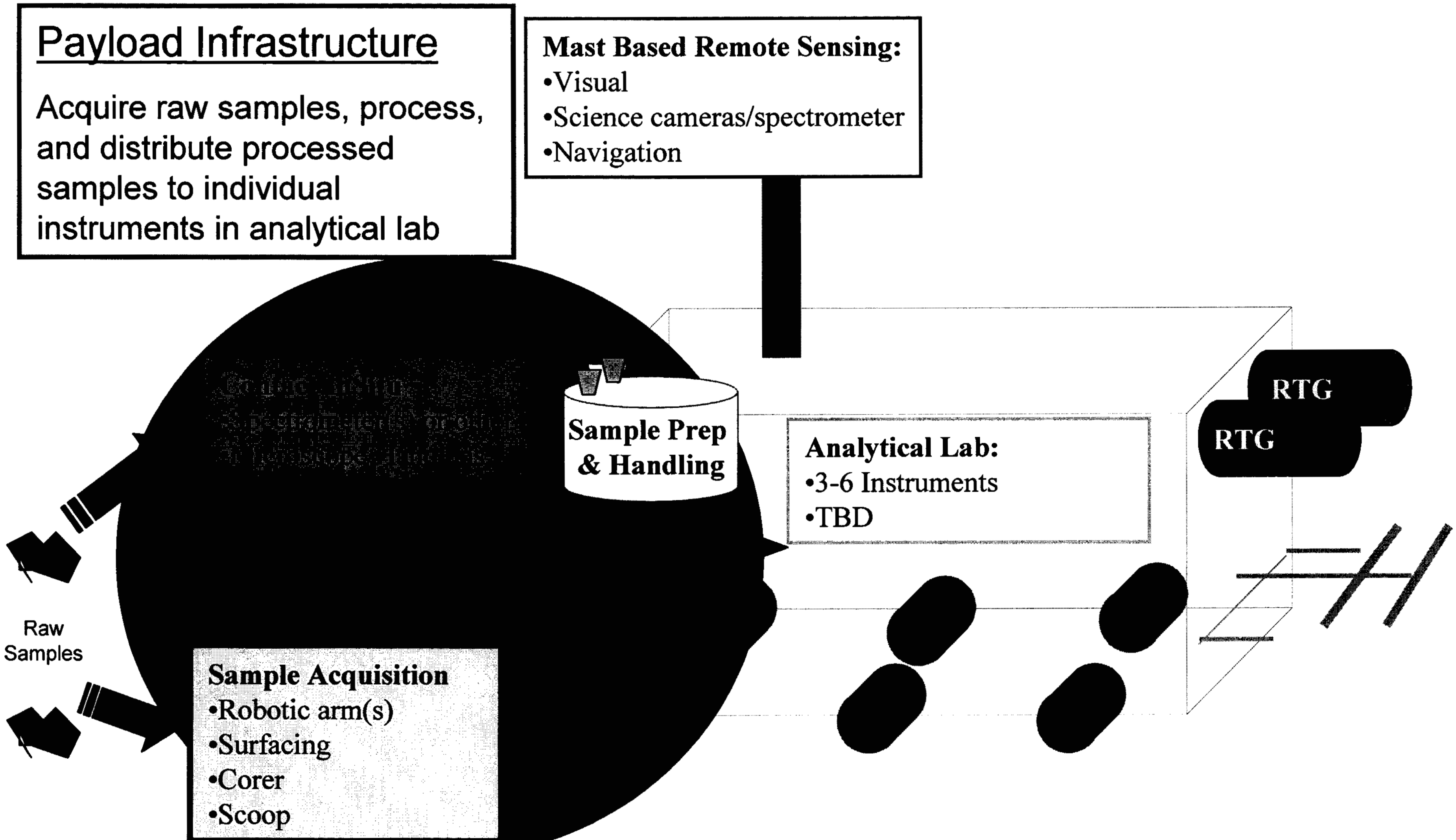
Mast Mounted Instruments
- Science cameras
- Spectrometer

PSIG Strawman Payload Infrastructure Elements
- **Primary Arm – 5 DOF**
  - **Surface Abrasion Tool**
  - **Corer**
  - *Science contact instrument*
- **Secondary Arm – 5 DOF**
  - **Scoop**
  - *Science contact instrument*
- **Sample Processing and Distribution**

RFI elements

Mast Instrument Elevation Platform
- NavCam
- *Science cameras*
- *Spectrometer*
- UHF antenna
- Fish Eye Camera

Context Sketch – PSIG Strawman Payload



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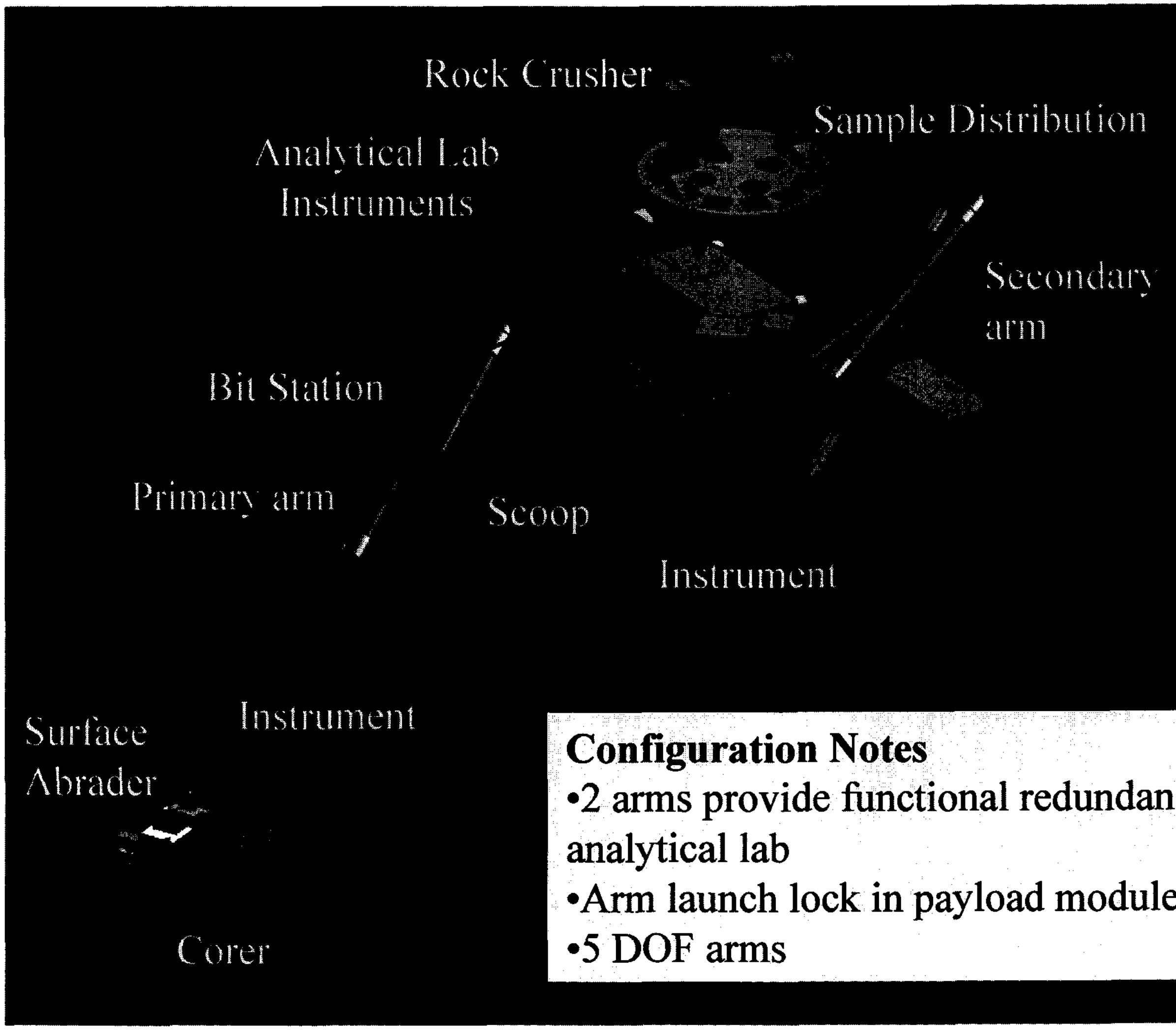
Strawman Configuration



Configuration Notes
- 2 arms provide functional redundancy for sample delivery to the analytical lab
- Arm launch lock in payload module
- 5 DOF arms

Payload Infrastructure Key Attributes *Preliminary*

- **Control and processing can be either centralized or distributed.**
- **Path planning to prevent collisions with rover and terrain.**

  The arm activities include path planning for arm placement to sample acquisition sites and to points on the payload module for evaluation or start of processing
- **Automated arm activities within the defined workspace**
- **Control and limit contact forces between tools and instruments and the terrain.**

  Sensors are required to monitor the contact forces during instrument observations and during sample acquisition.
- **Capability to evaluate samples with the arm mounted (contact suite) instruments in up to four states**

  1) at target identification, 2) after surface abrasion, 3) after coring, and 4) after processing.
- **Capability to terminate the sample evaluation at different stages.**

  Keep the ability to dispose of the sample at any point of the evaluation and processing sequence if the sample is determined to be of little interest.

Example Sample Acquisition, Processing, and Distribution Scenario

Identified Target

↓

Contact Suite Placement, in situ
Place secondary arm
Contact suite evaluation
Stow secondary arm
Place primary arm
Contact suite evaluation
Science Decision Point
Surface Abrasion
Contact suite evaluation
Stow primary arm
Place secondary arm
Contact suite evaluation
Science Decision Point

→

Sample Acquisition - Coring
Stow secondary arm
Place primary arm
Core Acquistion
Transfer core to triage area
Contact suite evaluation
Stow primary arm
Place secondary arm
Contact suite evaluation
Stow secondary arm
Science Decision Point

→

Sample Processing and Distribution
Deliver sample to rock crusher
Process sample
Particles >1 mm released to observation bin
Place primary arm
Contact suite evaluation
Stow primary arm
Place secondary arm
Contact suite evaluation
Science Decision Point
Stow secondary arm
Sample delivery to Instrument 1
Science Decision Point
Sample delivery to Instrument 2
Science Decision Point
•
•

Infrastructure Maintenance

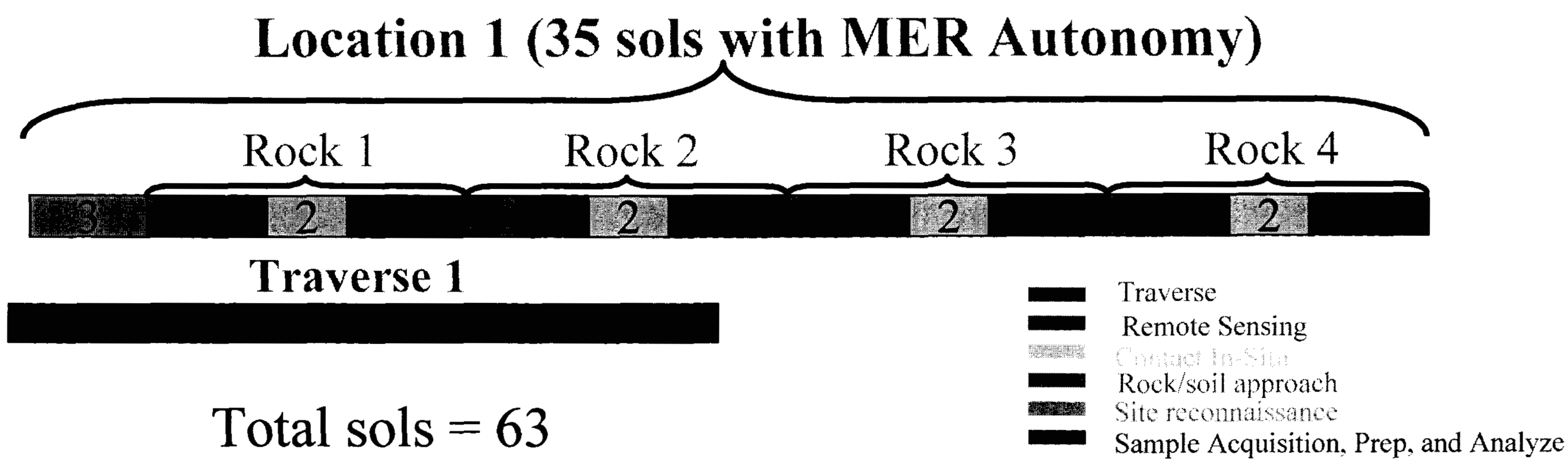
Bit Changeout

Clean Surface abrasion device teeth

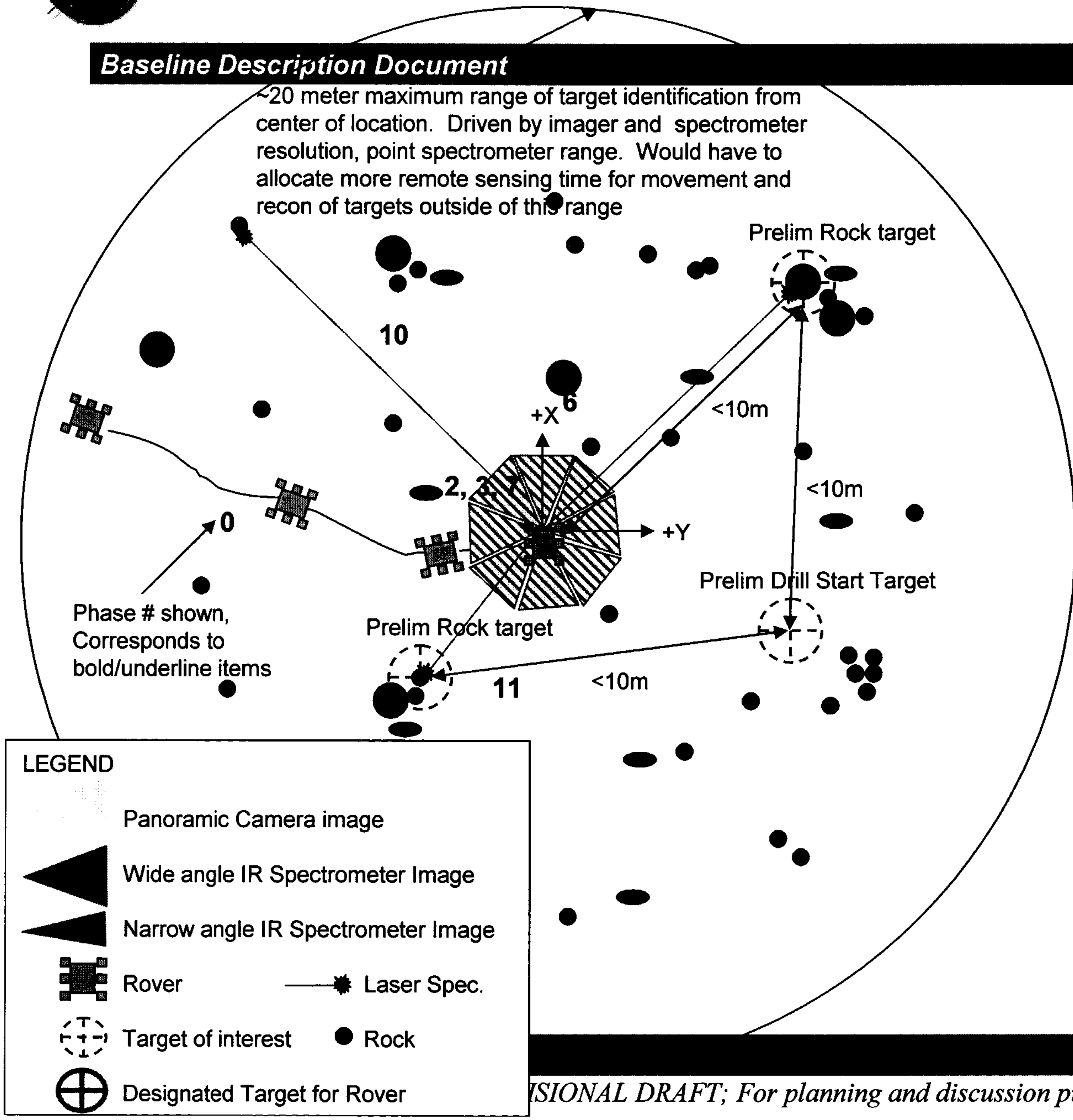
Close/Open dust covers

Surface Scenario Overview

- **Egress and Rover Checkout (approx 5 sols)**
- **Site 1 (Landing Site)**
  - Site Reconnaissance (2-3 sols)
  - Rock/soil analysis (8 sols per sample, 4 samples per location)
- **Traverse (10 - 1000 m) (at least 50m/sol)**
- **Repeat Location 1 activities for 4 locations**



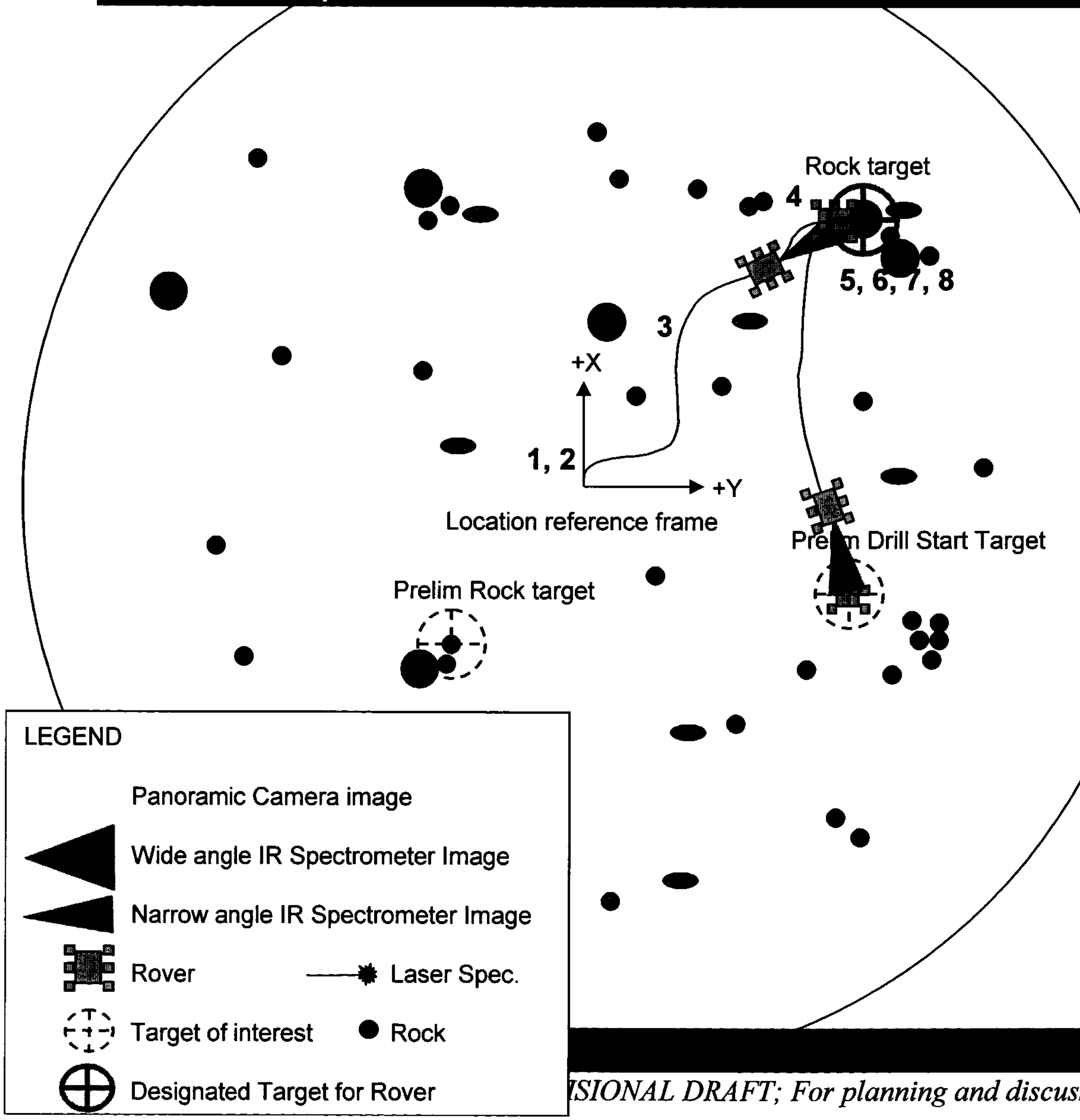
Site Reconnaissance Scenario



- **Once at the location, the rover performs remote observations to first investigate the site and choose specific rock and soil targets.**
  - 360deg color-visual image
  - 360deg IR image
  - 2-4 sols
- **Scientists on the ground will choose which rock and soil targets to perform detailed observations on**

D. Limonadi

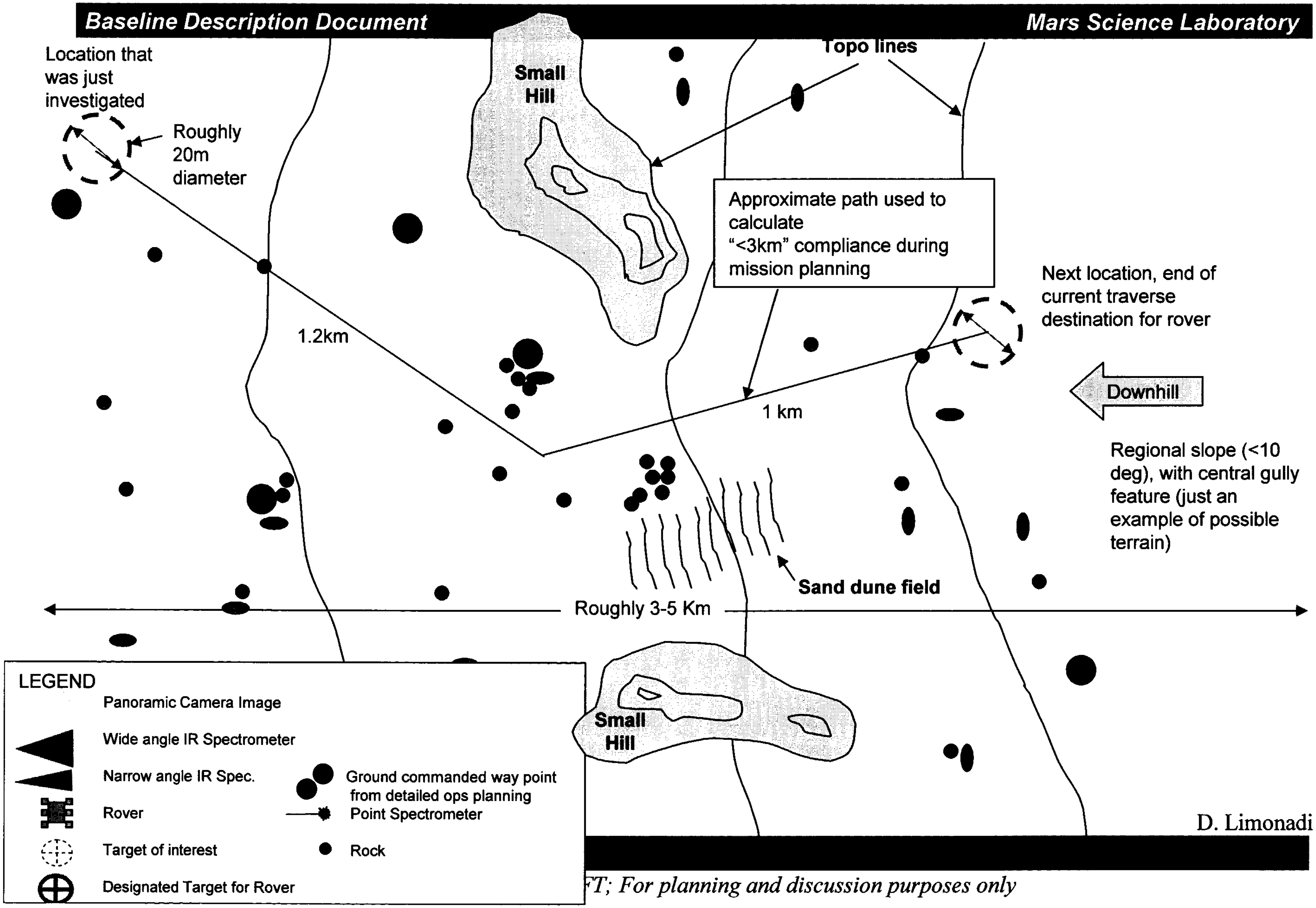
Rock Analysis Scenario
up to 4-7 sols per rock, 4 rocks per site



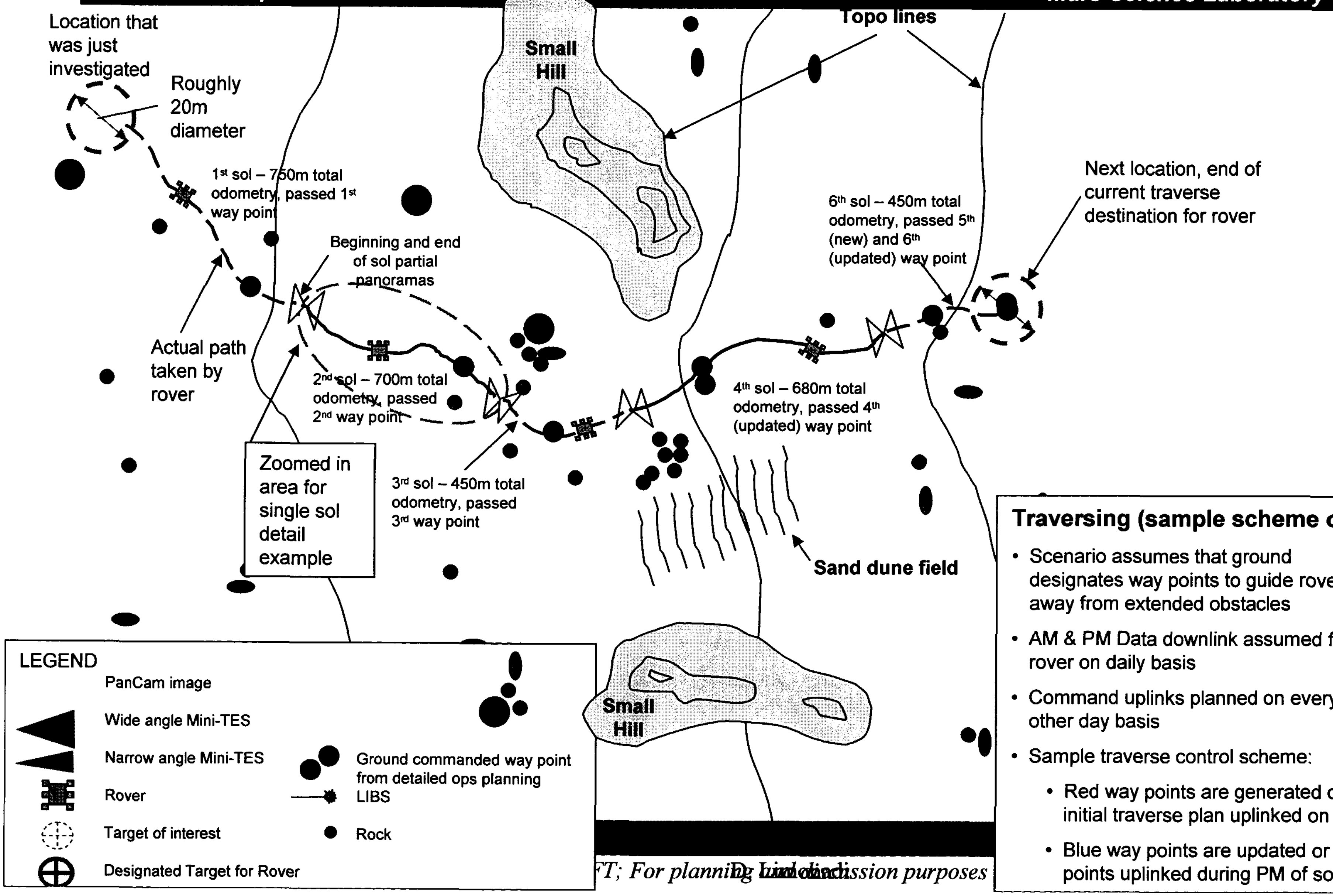
Rock Analysis

0) **SOL 1:** Rover starts from recon site. Recon site local coordinate frame is used as reference throughout location exploration (TBR)
1) 1st target is designated via command uplink from initial location.
2) Approach rock target from 10-15m distance. At some point close to target, stop, take focused full color PanCam and IR Spectrometer scan of target rock, from the final approach angle to the designated sample point
3) Complete final approach to target (could take up to 3 sols for total approach, depends on autonomy)
4) Remove weathering layer with RAT or similar tool. Take a close up IR Image and 3-color visual image.
5) **SOL 2:** Take Raman Spectrometer and Microscope Image of target
6) Core Rock Target (1/2 sample, ~5cm); Transfer to SPAH.
7) Examine with Raman Spec and Microscope.
8) Crush core sample, deliver to Lab Instruments.
9) **SOL 3:** Ground decision point: analyze with GCMS or dump
10) **SOL 4:** Ground decision point: analyze with XRF or dump
11) Daily background observations
12) Repeat sols 2-4 for 2nd half of core sample

Traverse Scenario (1)

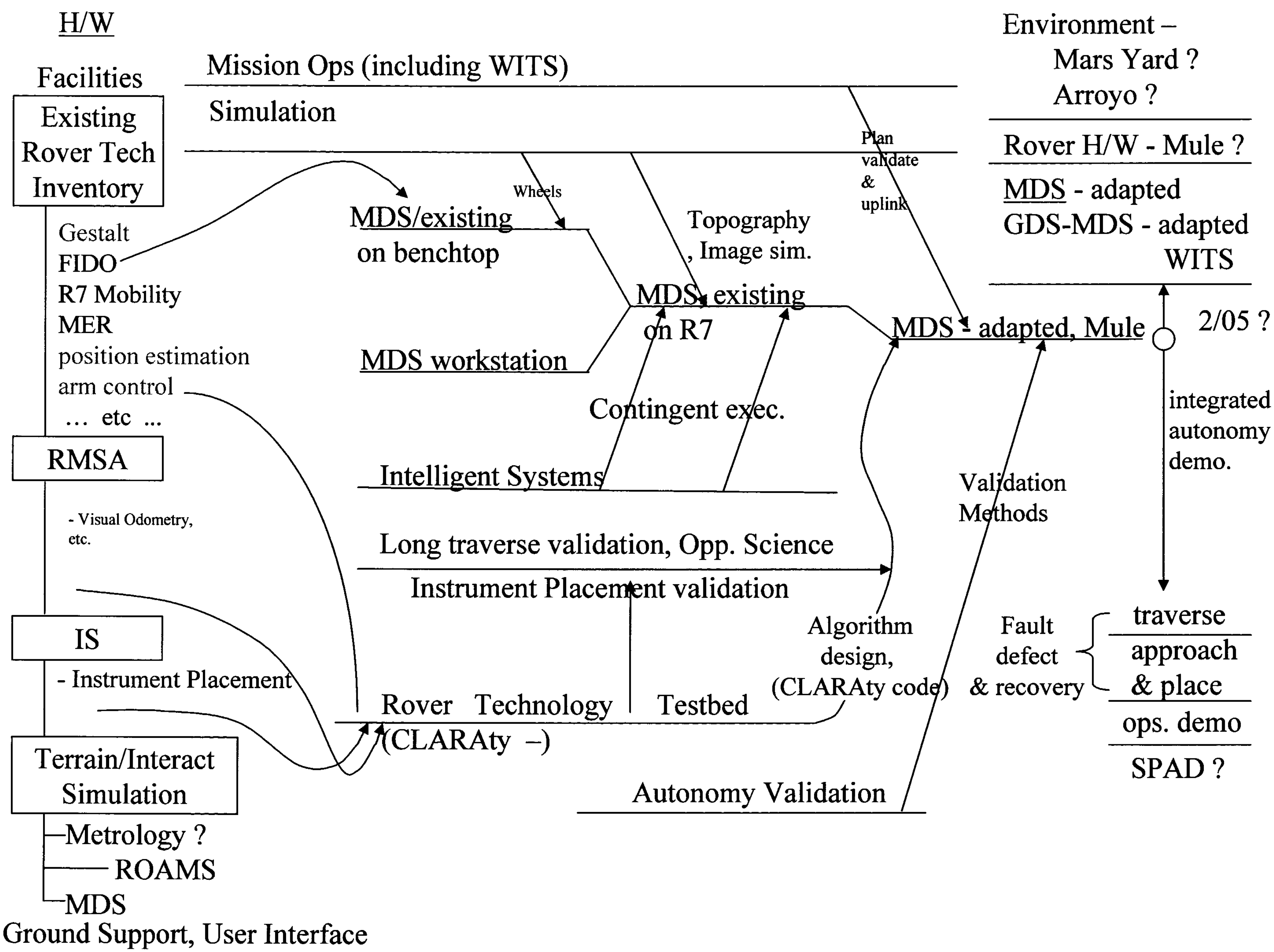


Traverse Scenario (2)



Traversing (sample scheme only)

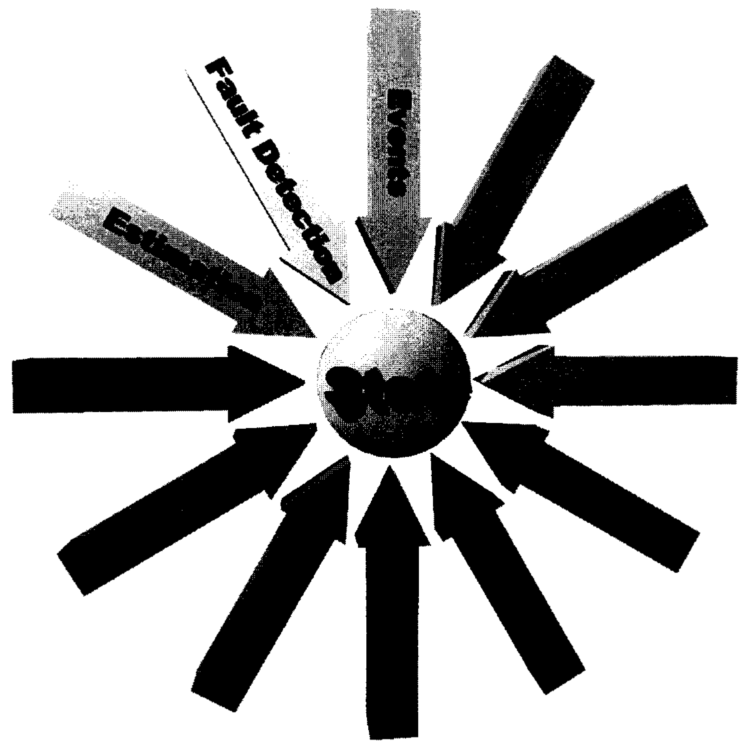
- Scenario assumes that ground designates way points to guide rover away from extended obstacles
- AM & PM Data downlink assumed from rover on daily basis
- Command uplinks planned on every other day basis
- Sample traverse control scheme:
  - Red way points are generated during initial traverse plan uplinked on Sol 1
  - Blue way points are updated or new points uplinked during PM of sol 3



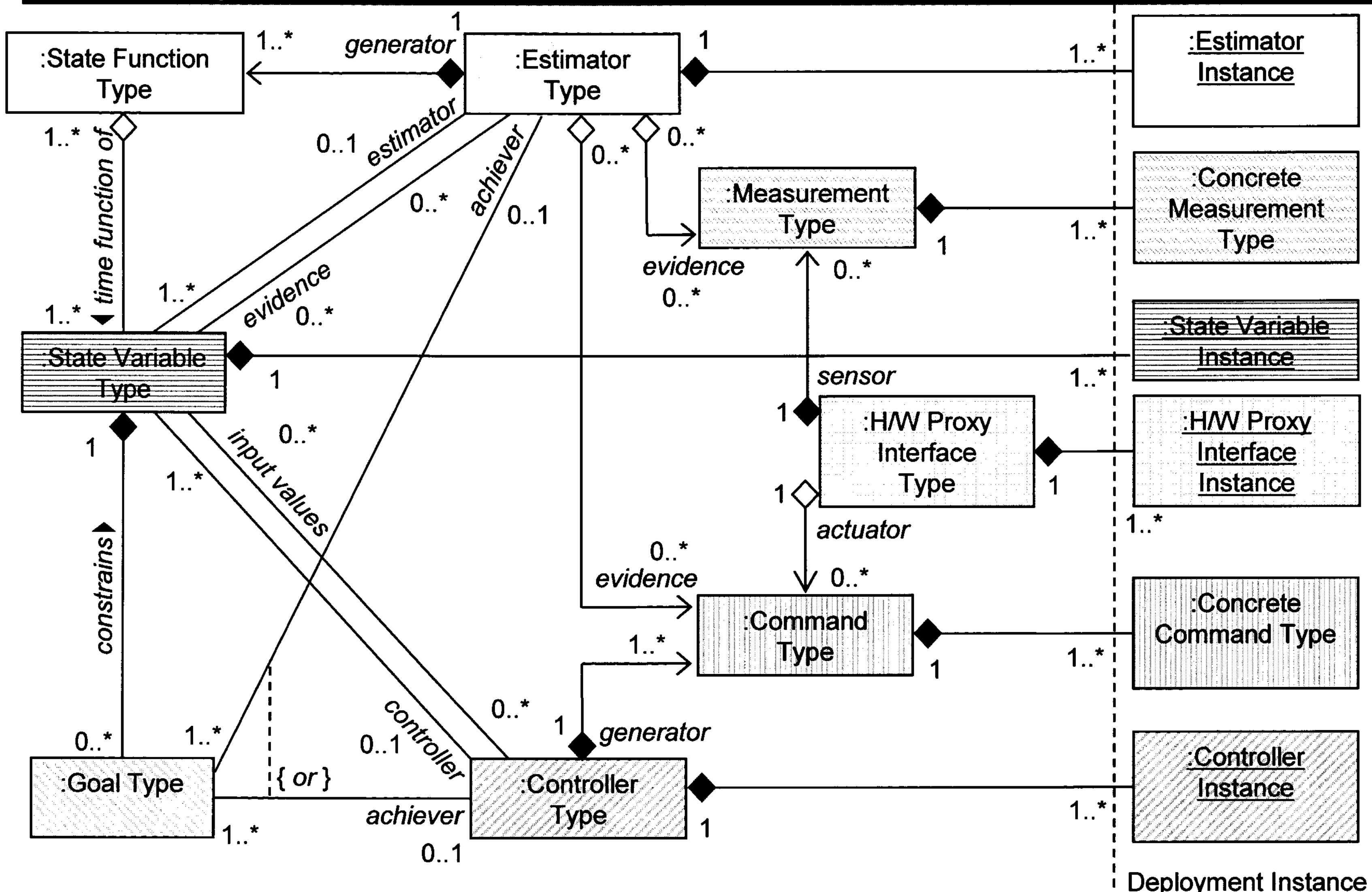
H/W
Facilities
Existing Rover Tech Inventory
Gestalt
FIDO
R7 Mobility
MER
position estimation
arm control
… etc ...
RMSA
- Visual Odometry, etc.
IS
- Instrument Placement
Terrain/Interact Simulation
Metrology ?
ROAMS
MDS
Ground Support, User Interface
Mission Ops (including WITS)
Simulation
Wheels
MDS/existing on benchtop
MDS workstation
Topography, Image sim.
MDS, existing on R7
Plan validate & uplink
MDS - adapted, Mule
Contingent exec.
Intelligent Systems
Long traverse validation, Opp. Science
Instrument Placement validation
Rover Technology Testbed (CLARAty –)
Algorithm design, (CLARAty code)
Validation Methods
Autonomy Validation
Environment –
Mars Yard ?
Arroyo ?
Rover H/W - Mule ?
MDS - adapted
GDS-MDS - adapted
WITS
2/05 ?
integrated autonomy demo.
Fault defect & recovery
traverse
approach & place
ops. demo
SPAD ?

State is Central

- **A** system **comprises project assets in the context of some external environment that influences them**
- **The function of mission software is to monitor and control a system to meet operators' intents**
- **MDS manages all essential aspects of this function via** state
  - Knowledge of the system, including its environment, is represented over time in **state variables**
  - The behavior of the system is represented by **models** of this state
  - Interaction with the system is achieved via modeled relationships between state and interface data (**measurements** and **commands**), as mediated by **hardware proxies**
  - Information is reported, stored, and transported as **histories** of state, measurements, and commands
  - Operators' intent, including flight rules and constraints, are expressed as **goals** on system states



State Analysis UML Diagram



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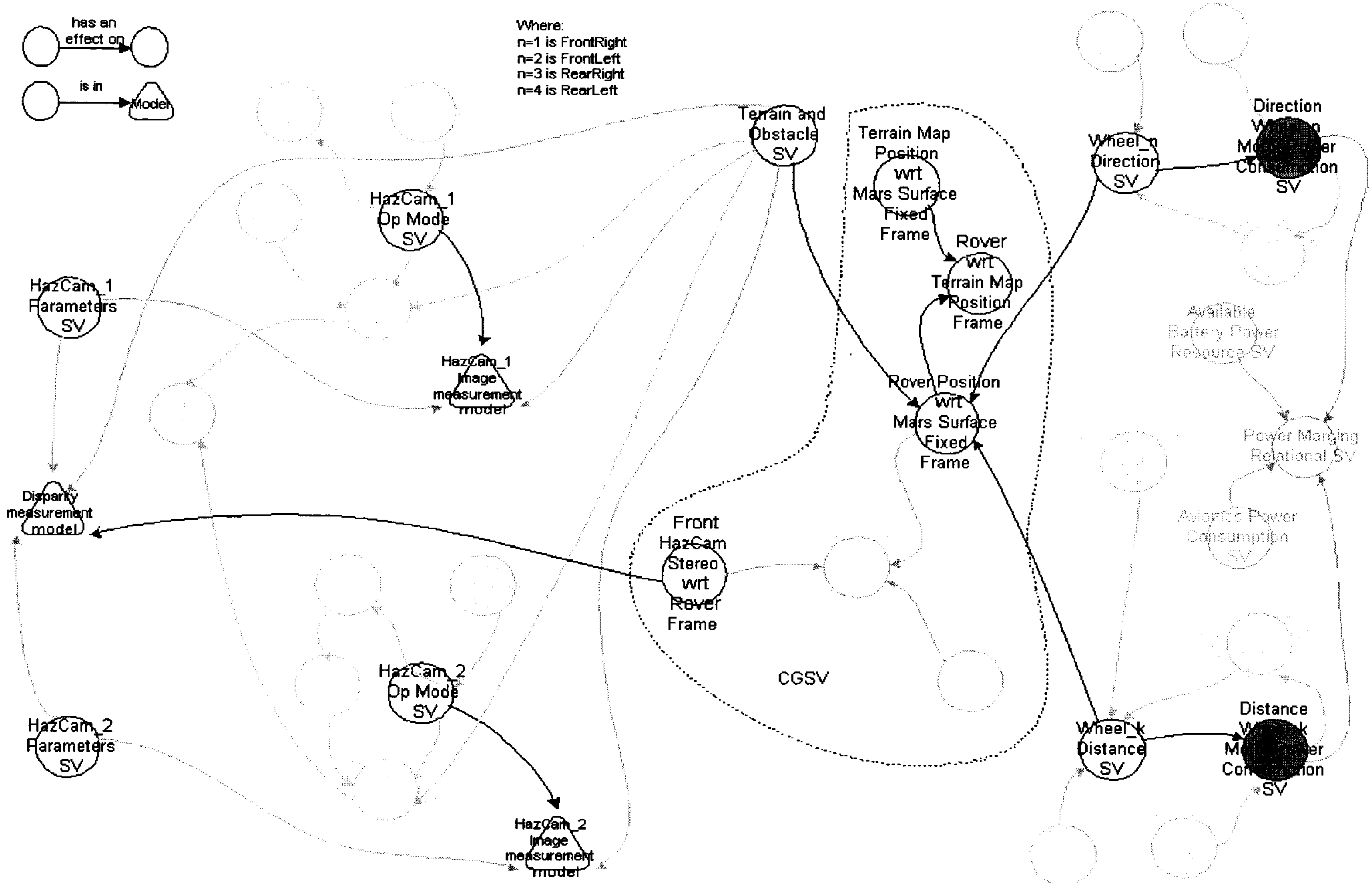
Example of State Effects Model

Rocky7 Increment-12 Wheel Motor Power Allocation

State Effects Model

See URL for elaboration guidelines https://mds-lib.jpl.nasa.gov/mds-lib/dscgi/ds.py/Get/File-8077/SEM_to_Elaboration_Guidelines.jpg



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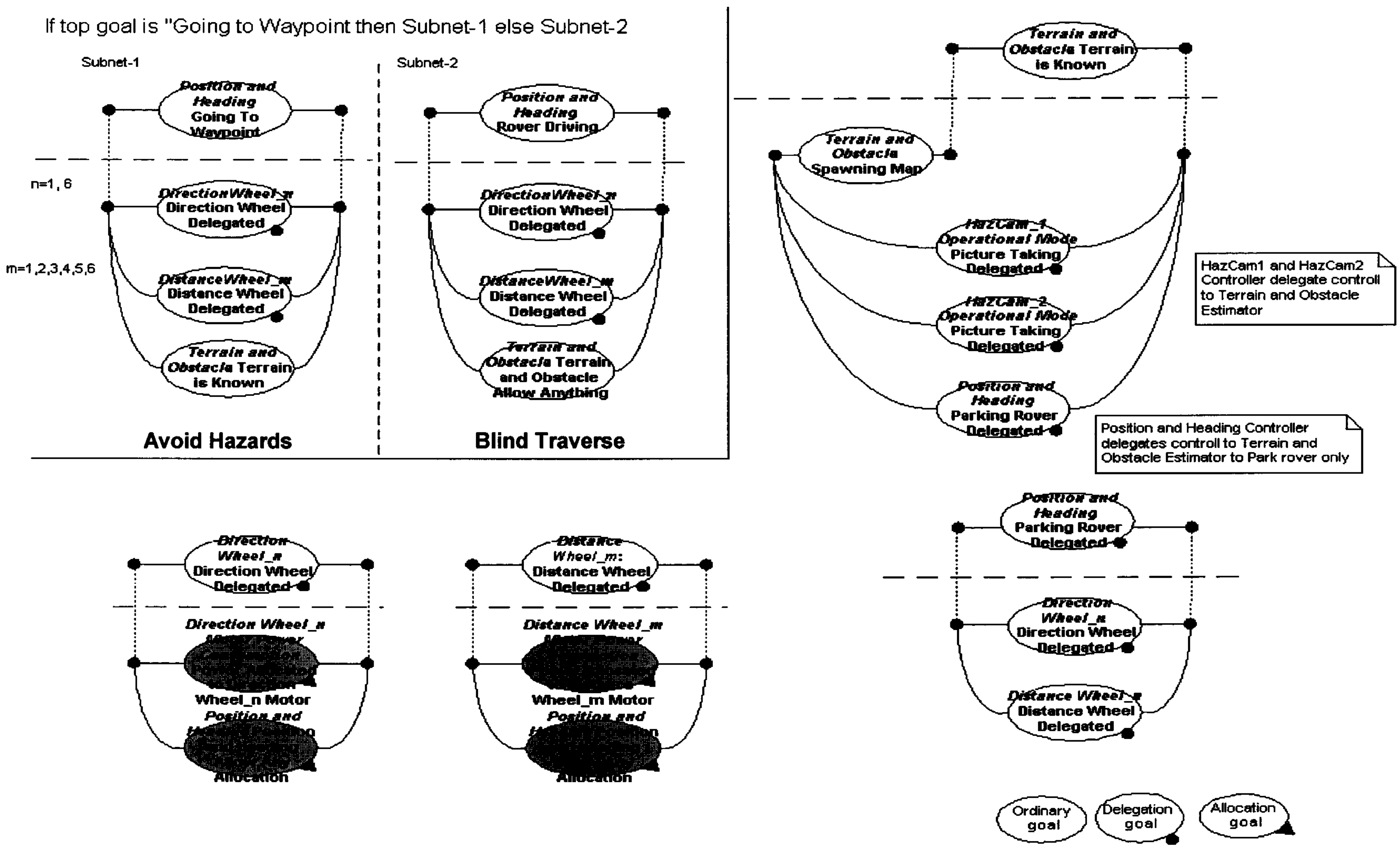
Example of Goal Elaboration

Rock7 Increment-12 Wheel motor power allocation



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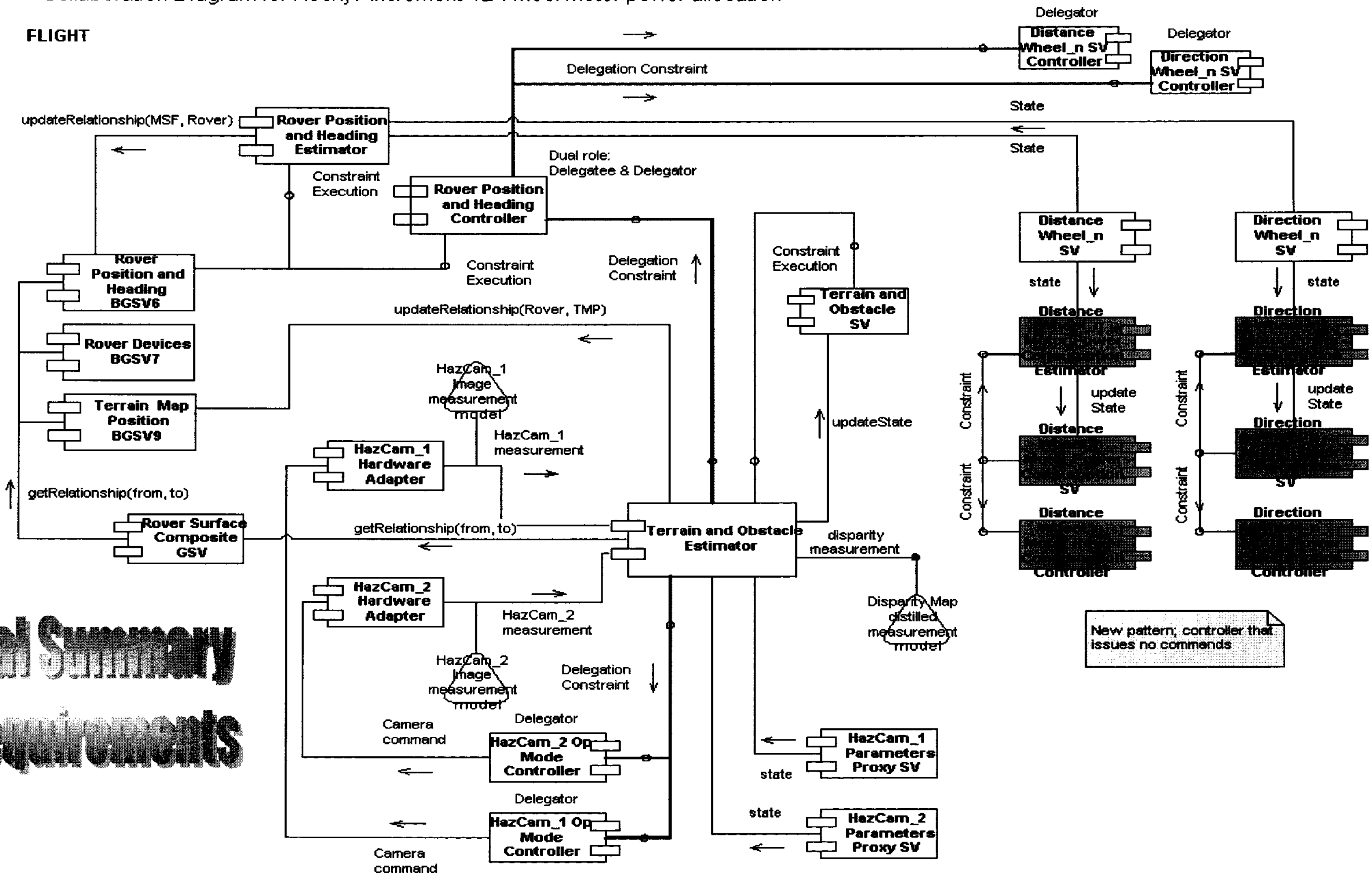
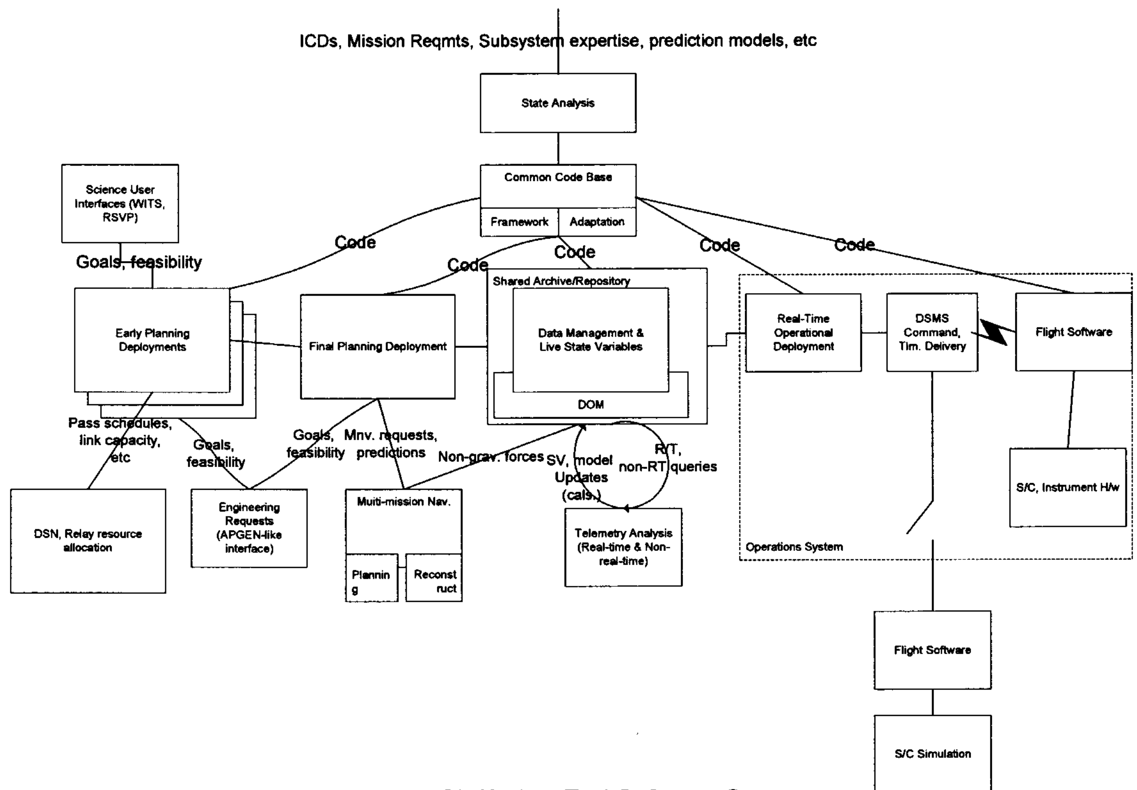
Example of Collaboration Diagram

Collaboration Diagram for Rocky7 Increment-12 Wheel motor power allocation



Visual Summary of Requirements

GDS Overview & Context



MSL End-to-End Software System

See GDS Software Guidelines, Description of GDS Diagram for narrative

MDS Collaborations

- Sun - Real-Time Java Collaboration
- USC - Student adaptation of MDS
- Ames/IS - High Dependability Computation - S/W Validation & Reliability
- (Possible) JHU/APL - Operator Visualization of Goal Nets
- Ames/IS - Drummond - Autonomous re-elaboration & scheduling
- MIT (Ingham) - Model-Based Fault Detection and Analysis