MARS SMART LANDER

Mars Science Laboratory – Autonomy Requirements Analysis

James Crawford

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Scenario slides by:
Leslie K. Tamppari
Deputy Project Scientist

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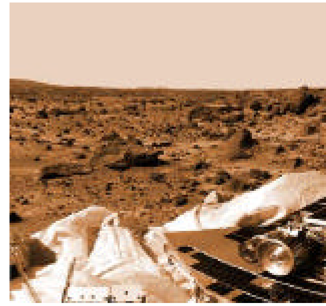
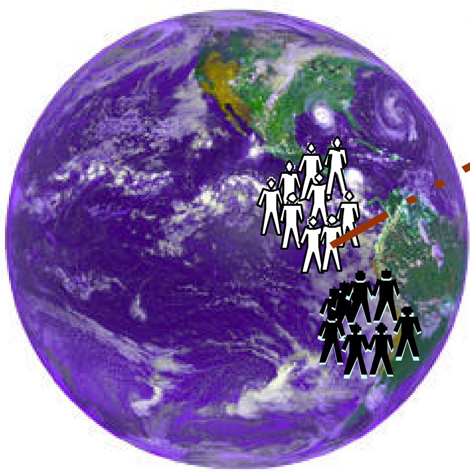
Robotic Exploration of Mars

Sojourner facts

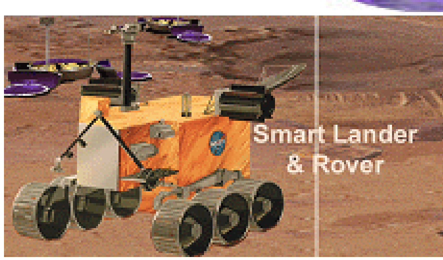
- Max distance from Lander: 12 M
- Total distance traversed 100M
- Time spent waiting: 40-75%
- 2.4 uplinks per science target
- Science cut in half during extended mission





MER – Facts

- *It takes the MER rover a day to do what a field geologist can do in about 45 seconds.* -- Steve Squyres MER 2003 PI
- Amortized cost of MER is $4 to 4.5 M per day of operation. (90 day mission)
- 240 co-located ground support scientists and engineers

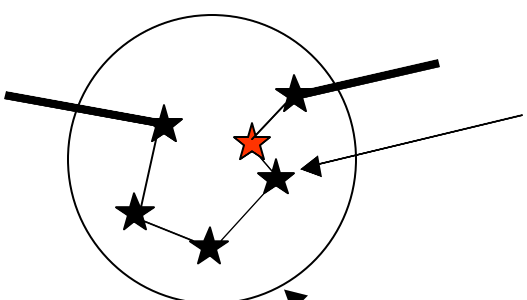


MSL Challenges

- Science Definition Team report considered Autonomy enabling to meet baseline mission requirements.
- Mission Duration 500+ days. (for nuclear option)
- Total traverse potential 30km

Mission Scenario – Each Location

- **Site location and rock/soil analysis:**
  - Once at the location, the rover performs remote science first to investigate the site and to choose the rock and soil targets. Perform 360º Pancam and mini-TES observations. Scientists use data to decide which targets to perform LIBS observations on.
  - Perform LIBS observations on up to 20 rock and soil targets. Scientists choose which 4 rock targets and 1 soil target to approach.
  - Take APXS, Moessbauer, Raman, and microscopic imaging of each rock target. Core rock target.
  - Transfer core to analysis laboratory. Examine with mass spectrometer, organics detector, microscopic imager and oxidant detector.
  - Approach and core soil target. Transfer core to analysis laboratory. Examine with mass spectrometer, organics detector, microscopic imager and assess oxidants.
  - Perform additional LIBS, mini-TES, and/or Pancam observations between targets, if time is available.



L Tamppari, D. Limonadi

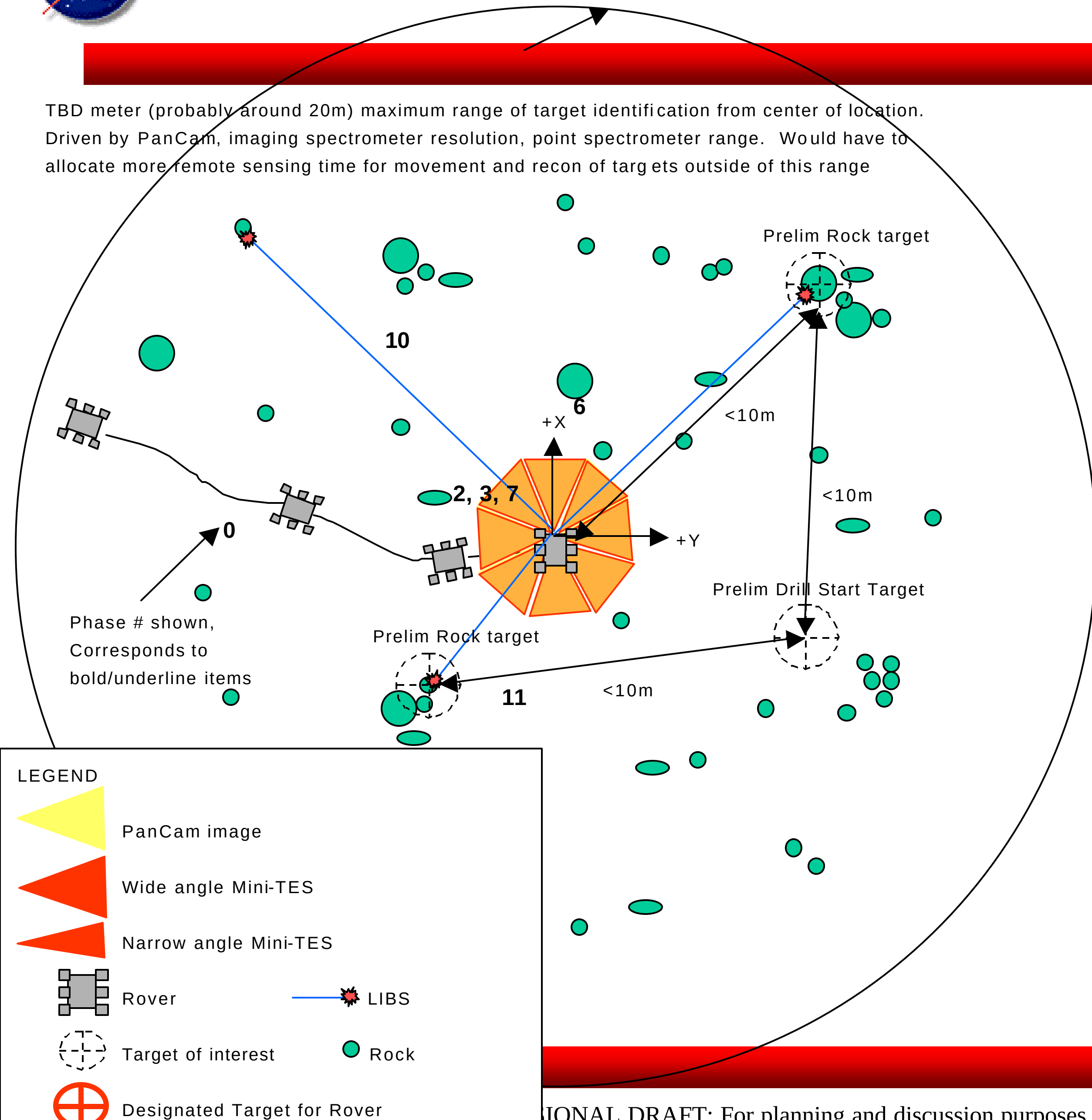
Mission Scenario – Traverse

- **Traverse:**
  - Before setting out, take 180º Pancam, mini-TES, and LIBS observations behind the rover
  - While driving, use Navcams and Hazcams to avoid obstacles and stay on course
  - While driving perform continuous GPR measurements
  - Enhancement: Take autonomous mini-TES data while driving. Use on-board spectral detection algorithm to identify important signatures. If found, stop and radio home. May also take autonomous Pancam images and playback as downlink is available.
  - At the end of a driving day, take 180º Pancam and mini-TES observations in drive direction. Send back overnight.

Detail Location – Location Recon Phase

Mars Smart Lander

TBD meter (probably around 20m) maximum range of target identification from center of location. Driven by PanCam, imaging spectrometer resolution, point spectrometer range. Would have to allocate more remote sensing time for movement and recon of targets outside of this range



0) Rover finishes traverse into location

Sol 1

1) Rover start sol at desired location

2) **Take 360 degree panorama with Pancam (probably at least B&W and 1 color)**

3) **Start 360 panorama with thermal emission spectrometer**

4) Downlink data to Earth with UHF and DTE

5) Ground starts figuring out which targets are interesting enough for point spectrometer (LIBS) follow up

6) **PanCam data is used to create new coordinate frame for location specific activities**

Sol 2

7) Finish 360 panorama with thermal emission spectrometer

8) Finish sending data to Earth with DTE and UHF

Sol 3 & 4

9) Ground uplinks point spectrometer (LIBS) targets to rover (possibly via feature designation, not local coordinate frame)

10) **Rover hits targets with LIBS and returns data to Earth**

11) **Scientists finish preliminary pick of 4 rock targets and drill hole within location (shown with cross-hairs in figure)**

D. Limonadi

Detail Location – Rock Analysis

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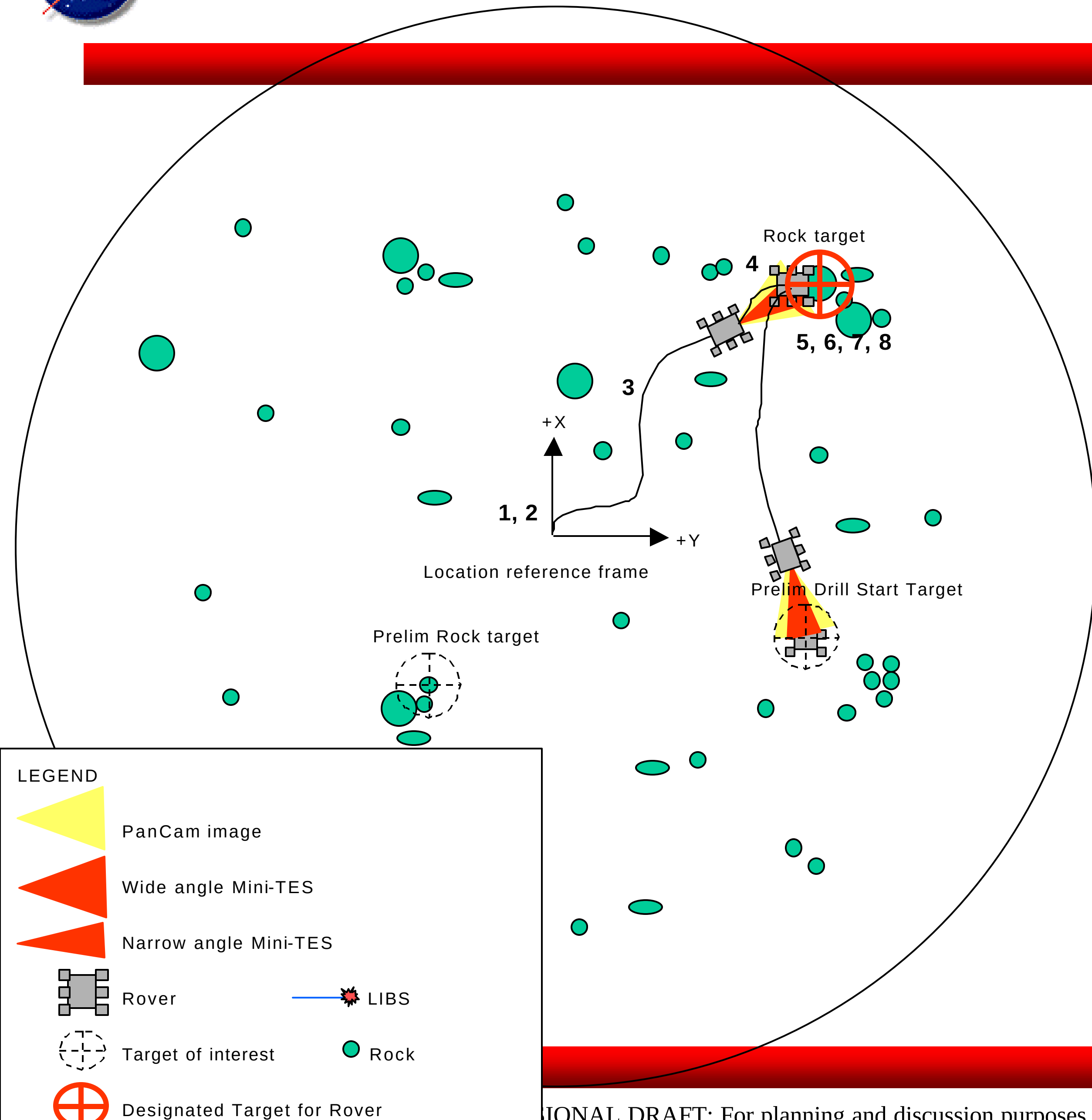


Rock Analysis

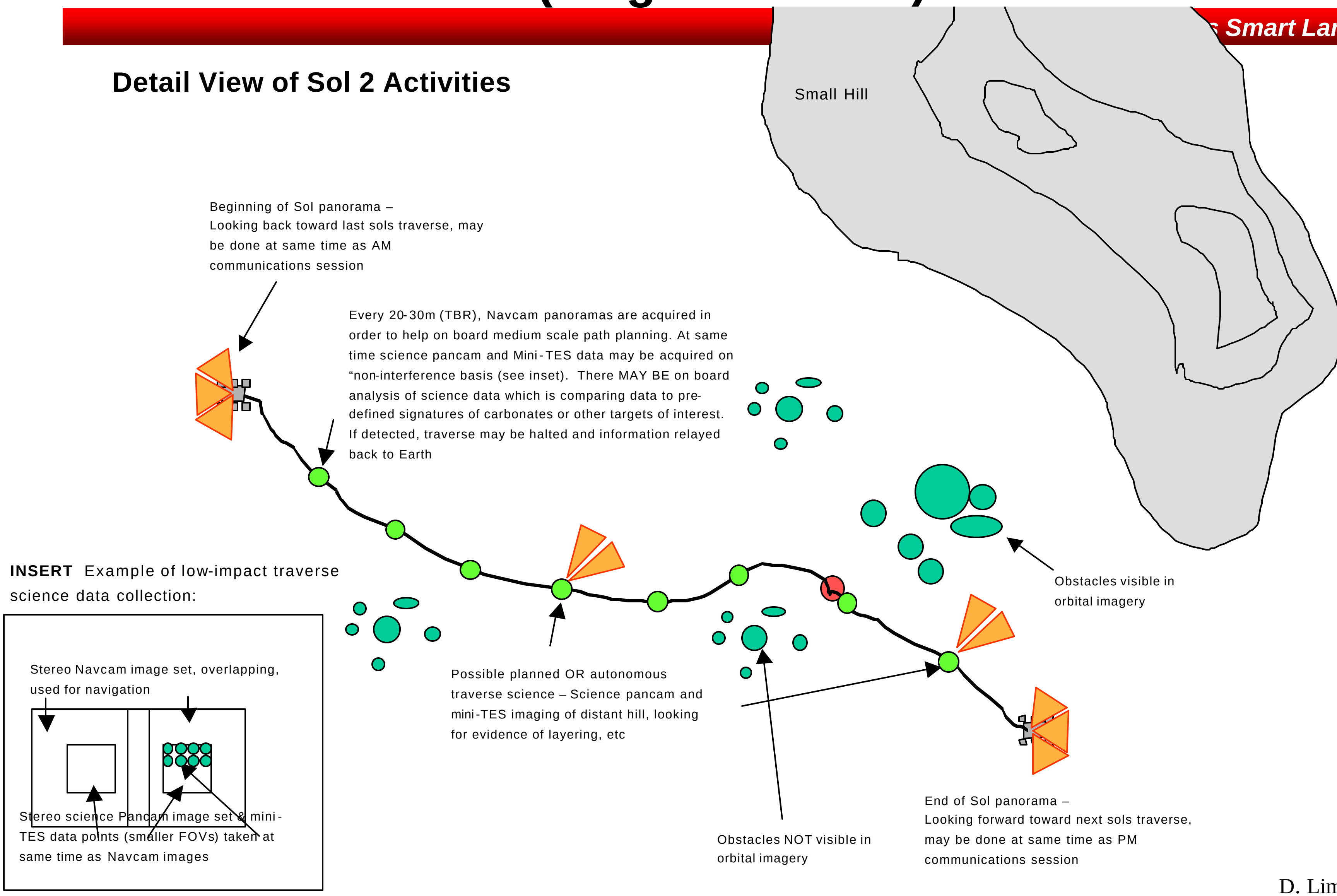
3 sols for mini-core only

4-4.5 sols for contact science <u>and</u> mini-core

1) Rover starts from recon site. Recon site local coordinate frame is used as reference throughout location exploration (TBR)
2) 1st target is designated via command uplink from initial location. Step 3-7 should be done autonomously by rover, but key decision of mix of contact science and whether or not mini-core will be acquired will be designated by the ground, or involve ground in the loop.
3) Approach rock target from <10m distance. At some point close to target, stop, take focused full color PanCam and Mini-TES scan of target rock, from the final approach angle to the designated sample point
4) Complete final approach to target
5) If part of sequence, deploy contact sensors, spend roughly 24 hours collecting data (due to integration time of APXS and Mossbauer)
6) If rock is still deemed "interesting enough", deploy mini-corer onto designated point, acquire sample with corer, place into sample transfer system
7) Prepare sample, transfer to analysis instruments
8) Time, energy, and downlink bandwidth permitting, do parallel remote sensing science of general location and next target with PanCam, scanning IR spectrometer, and LIBS
9) Once analysis of sample is complete, ground designates new target and move on (repeat above if rock, see other figure for drilling)

Traverse Operations (single-sol view)

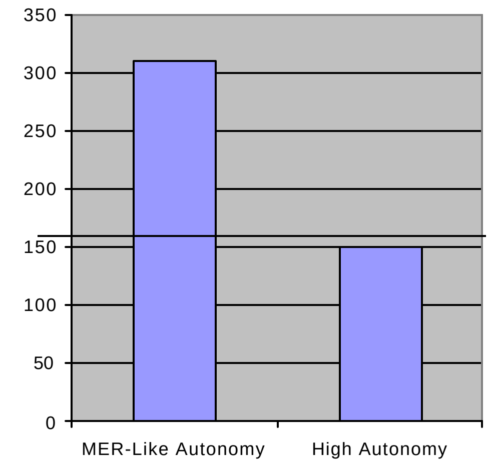
Detail View of Sol 2 Activities

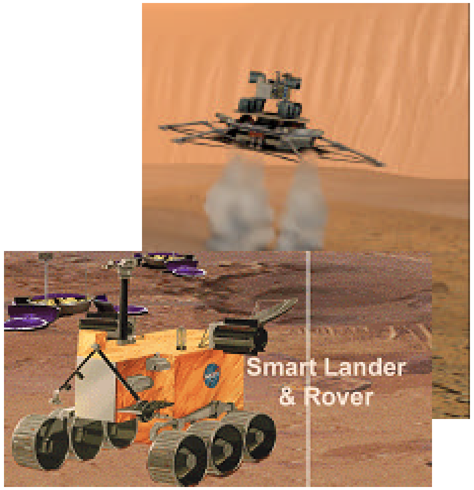


D. Limonadi

Mission needs:

- Science Definition Team found autonomy as limiting factor for power rich scenarios.
- Conservative assessment shows 50% decrease in required mission duration for equivalent science.
- Increase autonomy is critical to satisfy baseline requirements.
- Distributed ground ops on Earth time critical especially for nuclear option.





Key Requirements

- Long Traverse
- Approach and Instrument Placement
- Onboard Planning, Resource Management and Fault Protection
- Traverse and In-situ Science
- Ground System and Mission Operations

MSL Needs – Intelligent sensing and reflexive behavior

- **Single cycle instrument placement**
  - Visual servo
  - 3D scan and target analysis
  - Arm motion
- **Long traverse**
  - Localization and navigation
  - Obstacle avoidance
- **Safe landing**
  - Hazard detection and avoidance

MSL Needs – Planning and execution

- **Science planning**
  - Mixed initiative planning
  - Rapid optimization
  - Science trades
  - Probabilistic evaluation

- **Robust execution**
  - Concurrent execution
  - Resource management
  - Contingent execution
  - Limited onboard replanning under time constraints

- **“Science alarm”**

MSL Needs – Fault protection

- **Science diagnosis**
  - Sanity check on observations
- **Execution monitoring**
  - E.g., detection of wheel slippage
- **Fault recovery**
  - E.g., recovery from “minor” faults in instrument placement

MSL Needs – Agent architectures and distributed autonomy

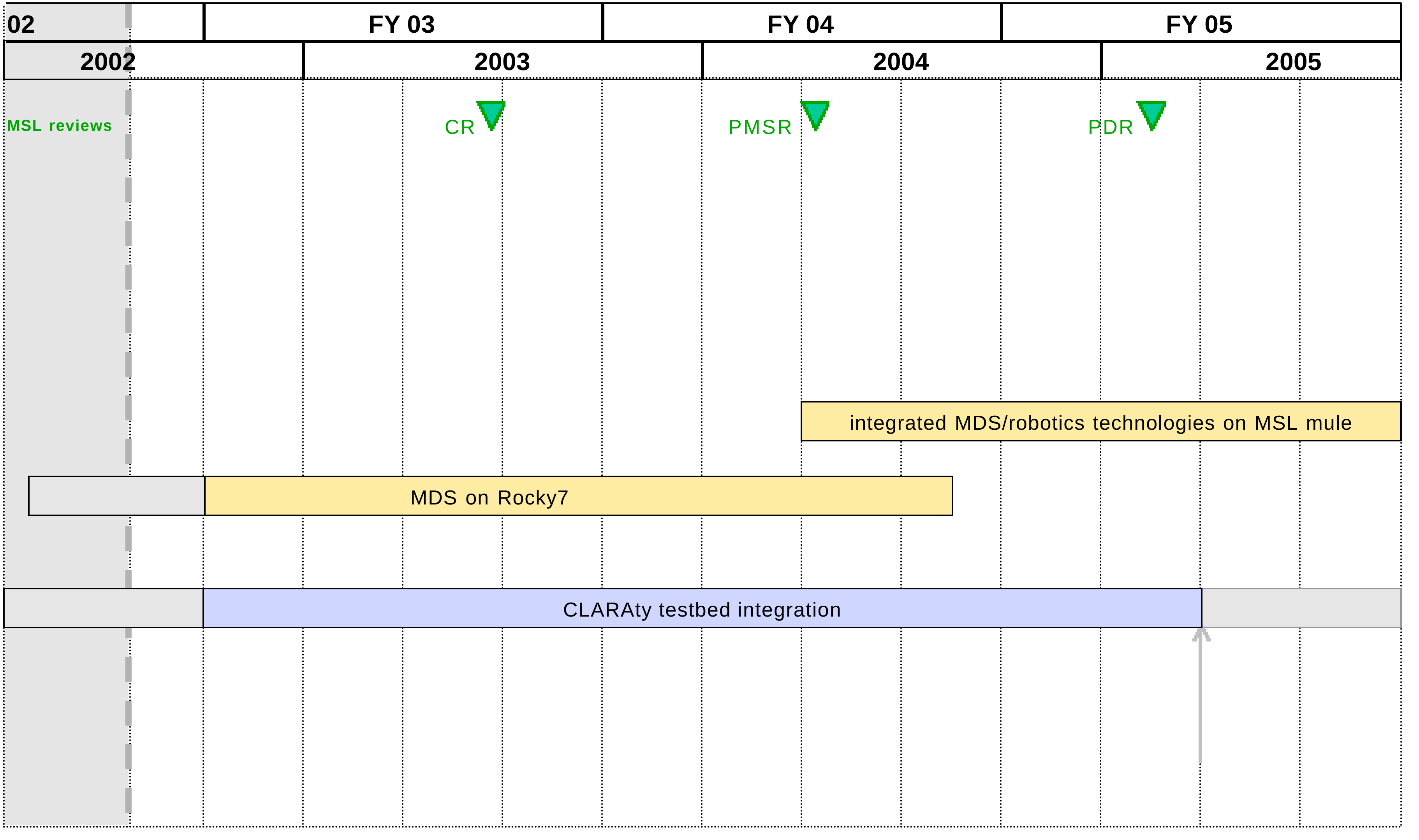
- **System design – especially flight software**
  - MDS is a major part of MSL software design
  - Goals, elaborators, estimators, controllers, etc.

MSL Needs – Software engineering and Validation

- **Validation and verification of autonomy software**
  - "Safety kernel"
  - System decomposition for validation
  - Combined utilization of formal verification and testing
  - Combined utilization of simulation and field tests

Critical limiting factor for deployment

Draft MSL Technology Schedules



Summary

- **2005 demonstration critical for adoption of autonomy in MSL**

- **Not seen as a gate for individual technologies**

- **Most important needs:**
  - Single cycle instrument placement
  - Long traverse
  - Robust execution
  - Maintainable ground processes