Mars Image Products: Science Goes Operational

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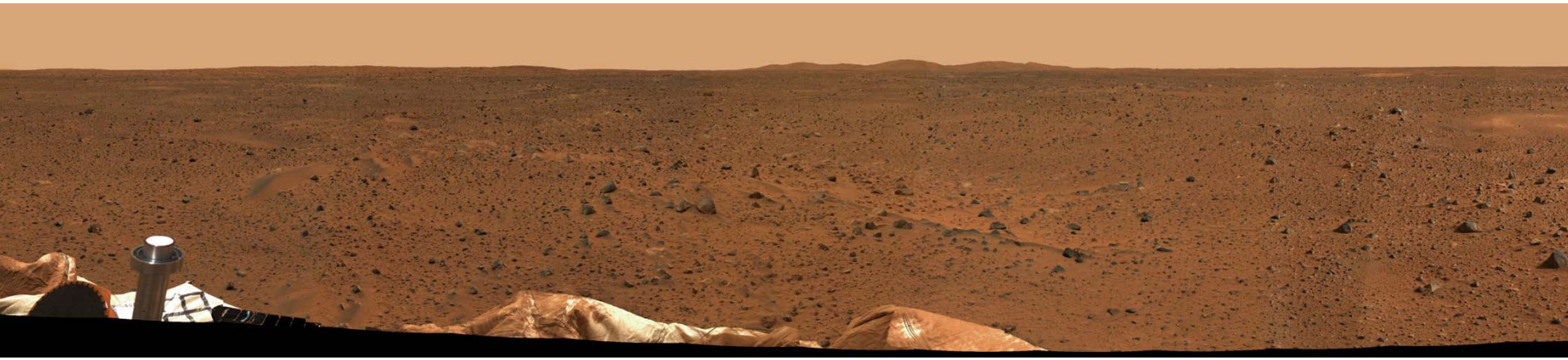
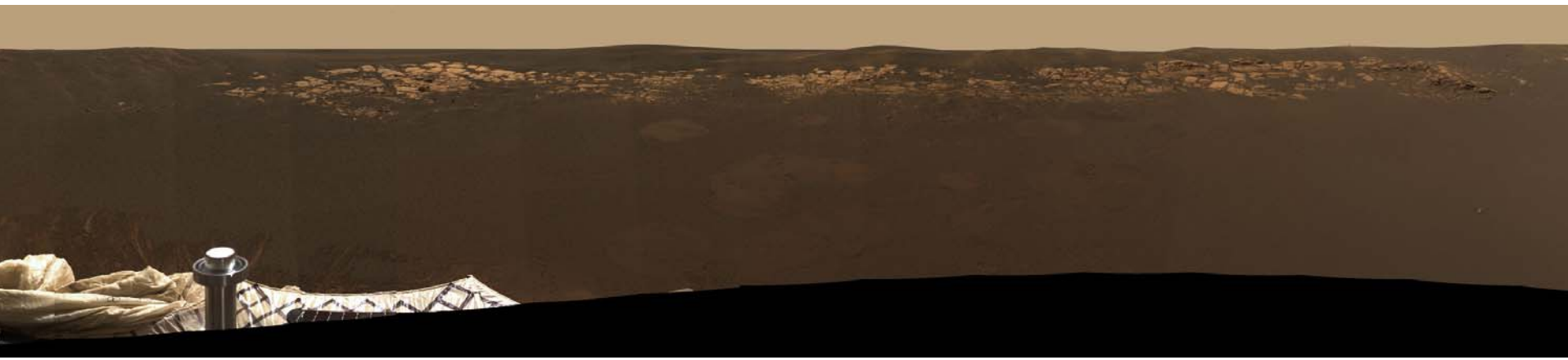
MER Mission Success Panoramas

Mars Exploration Rover





... and these are only 180 degrees

MIPL

- Multimission Image Processing Lab, at JPL
- Involved in a wide variety of missions, past, present, and future
  - Voyager, Magellan, Galileo, Mars Pathfinder, Deep Space 1, ...
  - MER, Cassini, Spitzer, Stardust, MEX
  - MRO, MSL, Deep Impact, Phoenix, ...
- Responsibilities on MER
  - Reconstruction of instrument data from telemetry (10 cameras, 4 other payloads, per rover)
  - Systematic creation of Reduced Data Records (RDRs) for images
  - Creation of special products for operations, science, and public outreach
  - In the critical path for MER operations
    - MIPL products required for planning activites for the next Sol
      - or sometimes the afternoon's activities

MIPL-Generated Products

- Single-image products
  - Original Experiment Data Record (EDR)
    - Data reconstructed from telemetry
  - Inverse Lookup Table (LUT)
    - Recover 12-bit image from 8-bit data
  - Radiometric Correction
    - Remove flat field, exposure time, and temperature effects
  - Linearization
    - Remove lens distortion; results in stereo-aligned images

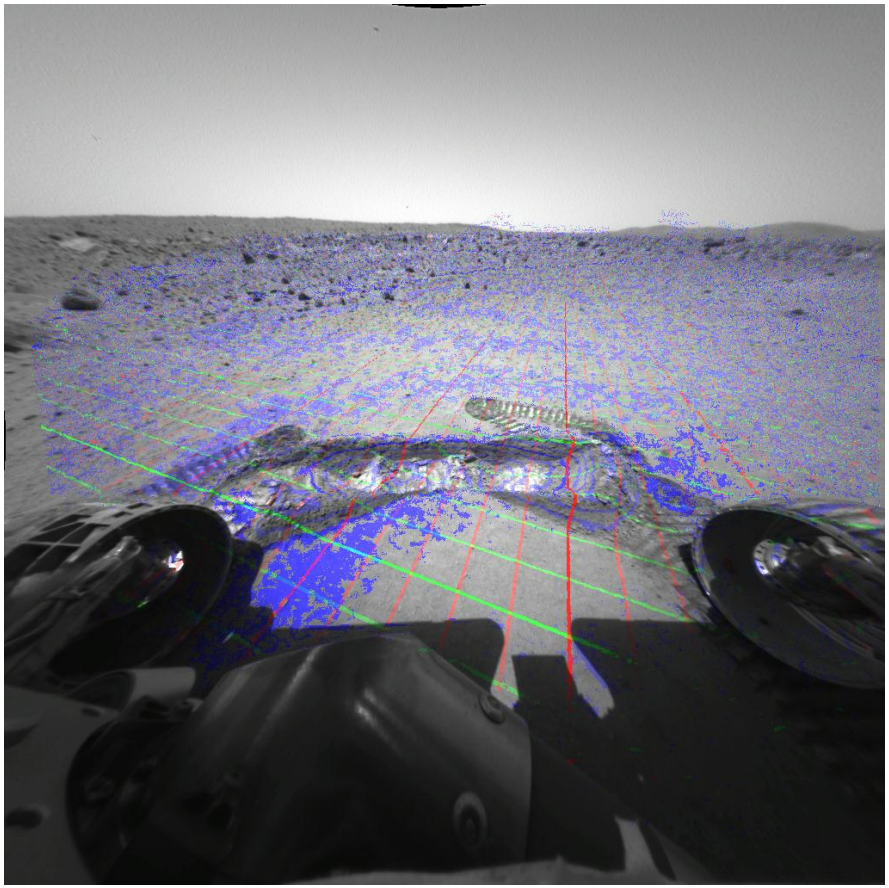
Raw EDR and Linearized Image

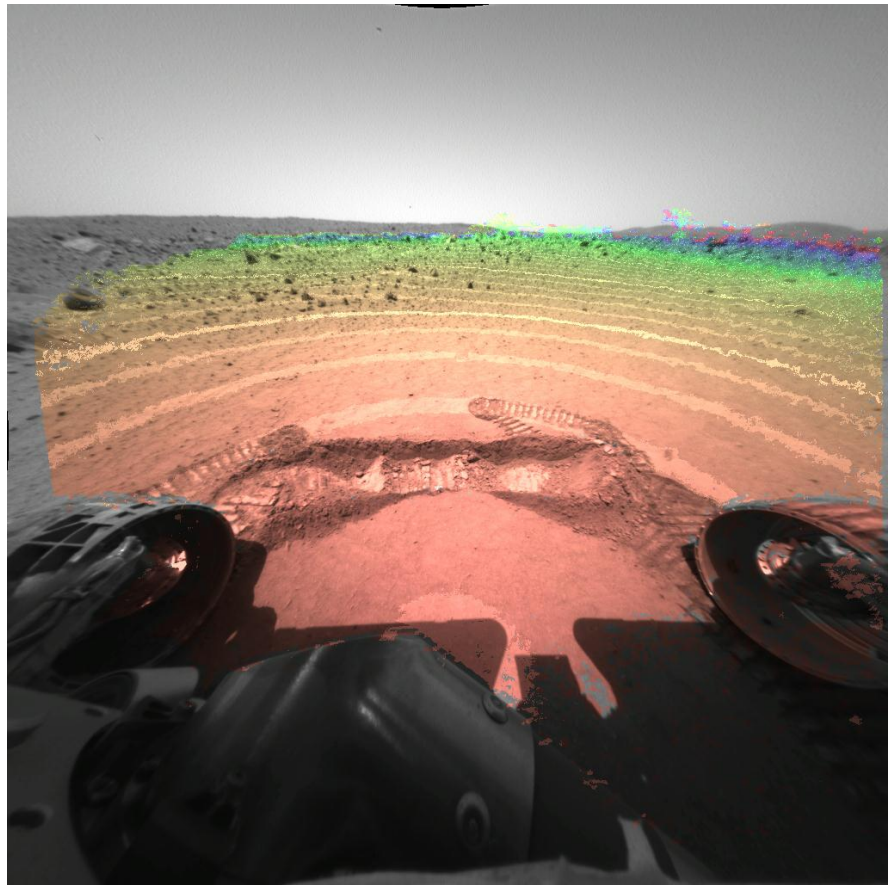
Mars Exploration Rover

MIPL-Generated Products (cont.)

- Stereo-image products
  - Disparity
    - Correlate stereo pairs to recover terrain
  - XYZ
    - Project corresponding points through camera models to find intersection
  - Range
    - Distance from the camera

XYZ and Range images

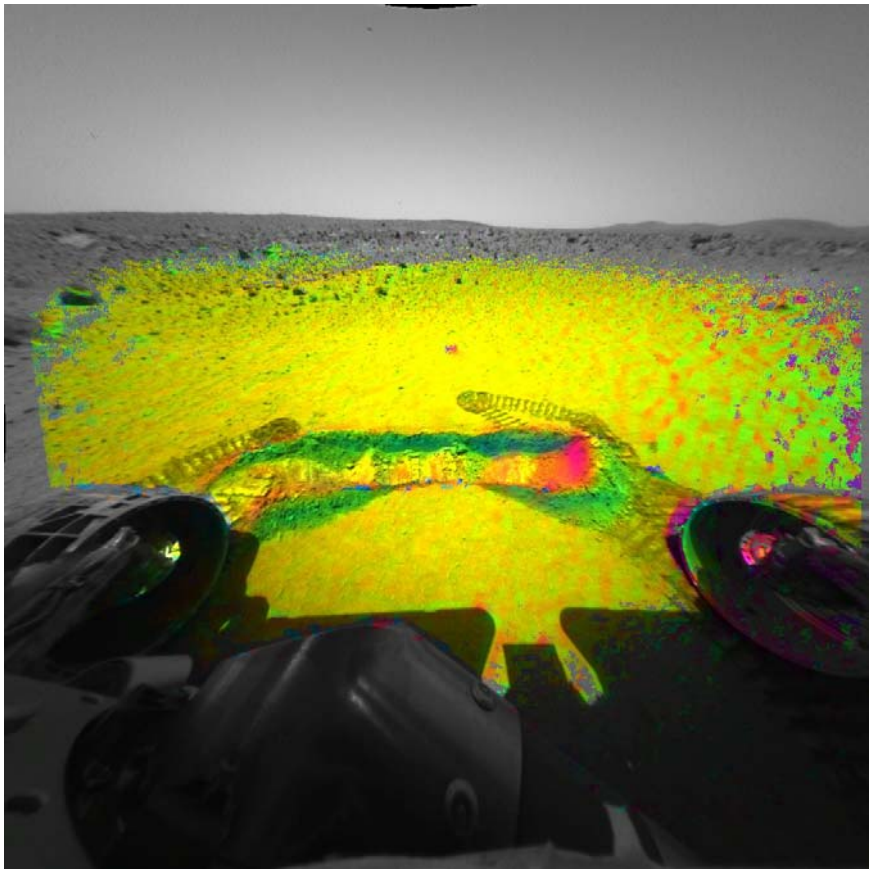


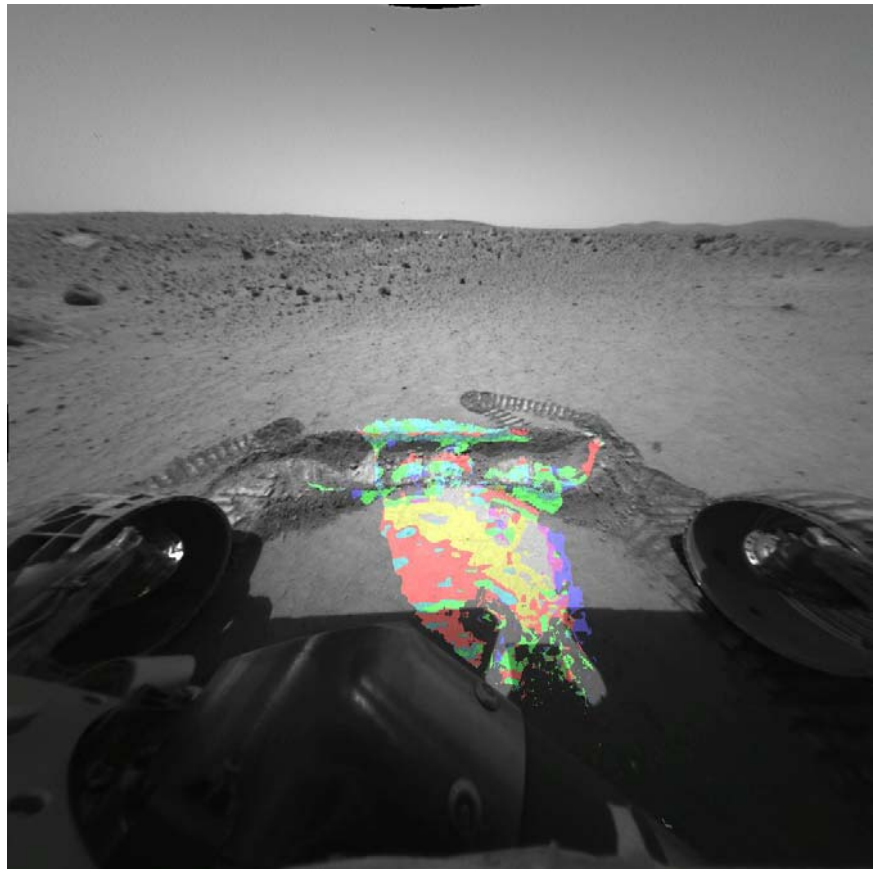


MIPL-Generated Products (cont.)

- Stereo-image products (cont.)
  - Terrain Wedge
    - 3-D representation of surface as triangular mesh
  - Surface Normal
    - Find local slope from XYZ data
  - IDD Reachability
    - Determine points the arm instruments can reach
  - Surface Roughness
    - Determine safety for RAT tool

Surface Normal and Reachability

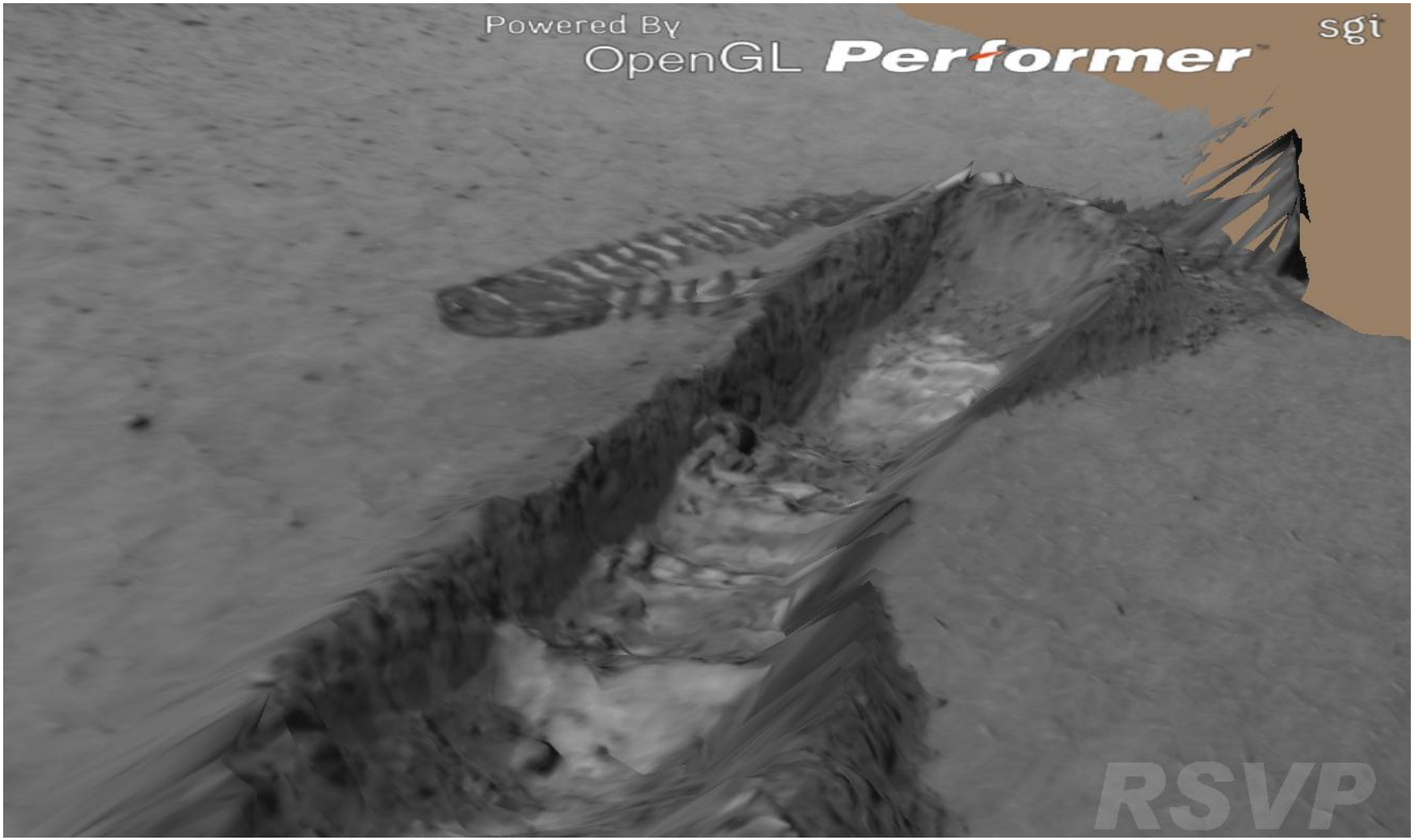




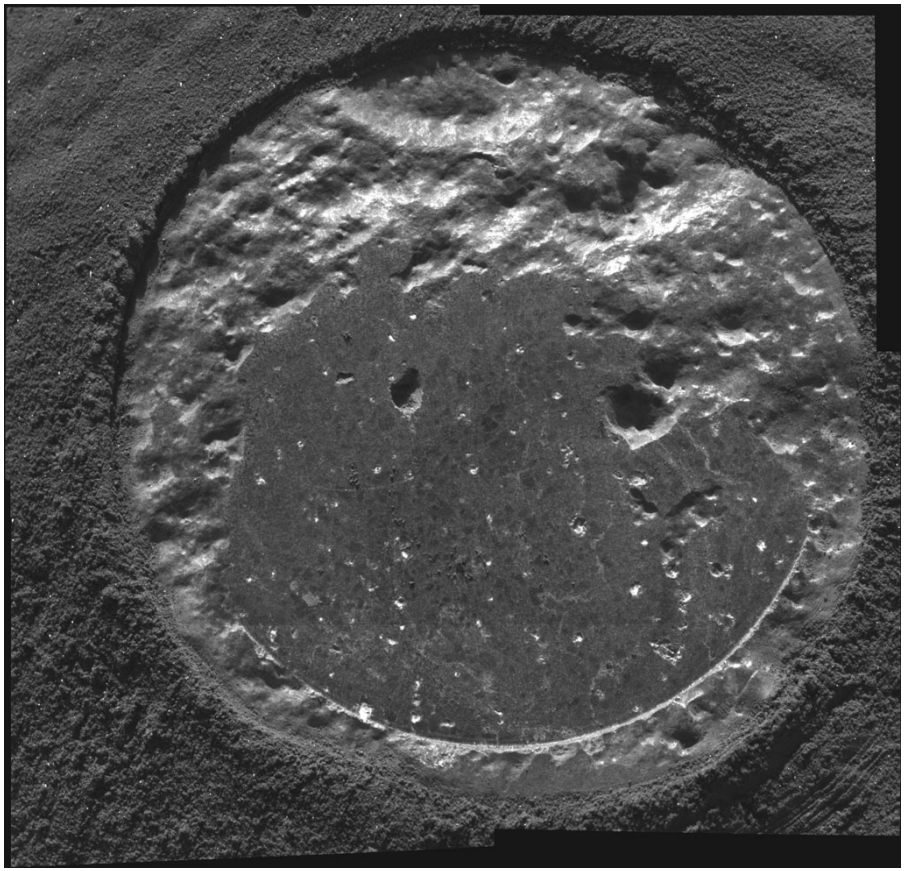
MIPL-Generated Products (cont.)

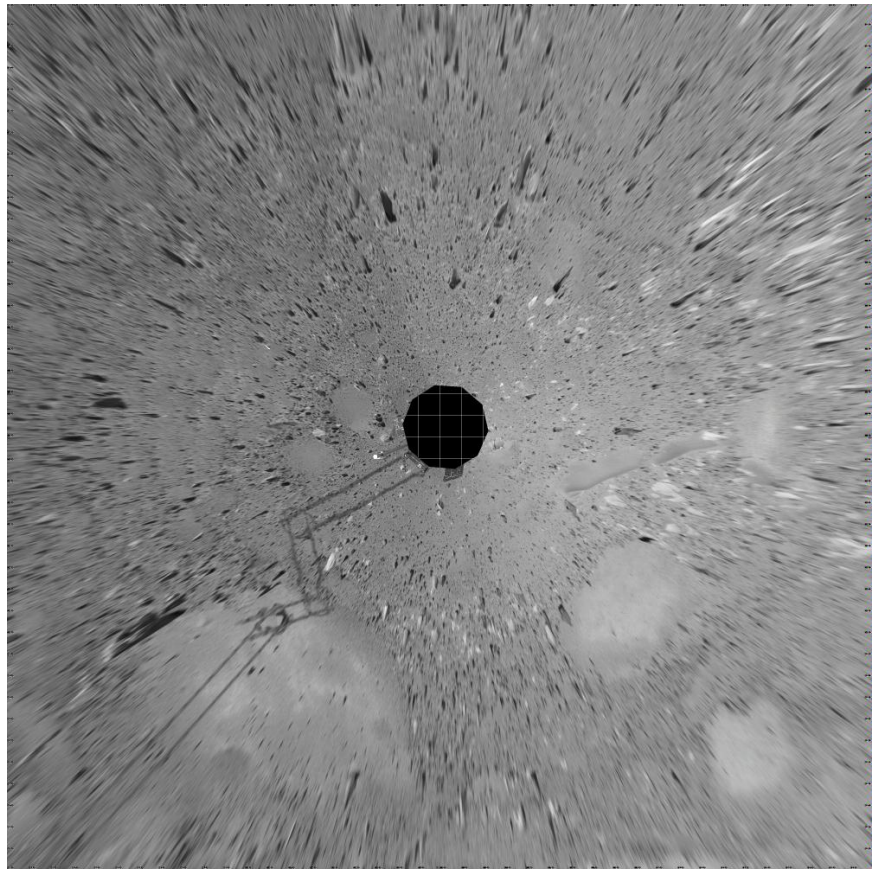
- Multiple-image products
  - Terrain Mesh
    - Combine multiple wedges into a large-scale 3-D terrain
  - Mosaics
    - Combine multiple images into a larger image
    - Includes pointing correction to reduce geometric seams (special products)
    - Five projections:
      - Cylindrical, Polar, Vertical, Perspective, Cylindrical-Perspective

Terrain Mesh



Mosaics, Small and Large Scale





Software History

- Core image processing system (VICAR) has evolved since 1960's
- RDR generation software originally developed for Mars Pathfinder (MPF)
  - Primarily mosaics, XYZ, and radiometric correction
- MPF software intended mostly for science use
  - Correlation took an hour for 256x256 image
  - Mosaic pointing correction cumbersome
  - Specific to MPF
- Software suite rewritten for Mars Polar Lander (MPL)
  - Reusable, mission-independent design
  - Rudimentary pipeline for systematic product generation
- Significant upgrades for MER as products moved into operations
  - Correlation now 3-4 minutes for 1024x1024 images
  - Much better pointing correction
  - Many new types of products
  - Robust pipeline

Software Design Overview

- RDR-generation programs (except wedge/mesh)
- Application programs are multimission
  - No mission-specific code
- All mission-specific code encapsulated into a library
  - C++ class library
  - Base classes provide common interfaces and services
    - Camera model, pointing, coordinate systems, file metadata access, etc.
  - Mission-specific subclasses implement differing functionality
    - Less than 15% of total code base for all 6 missions

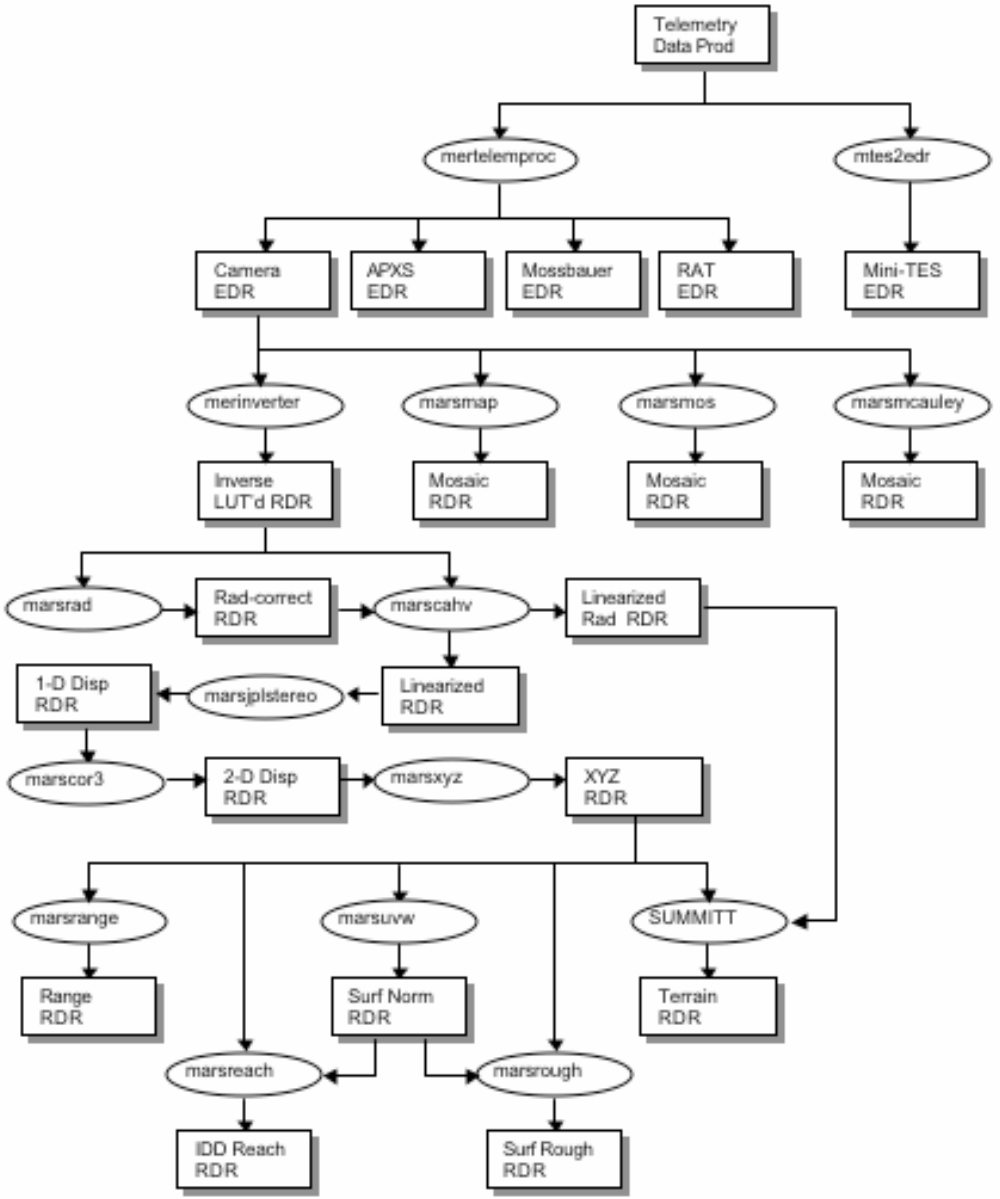
Software Design (cont.)

- Library is easily adaptable to new missions
  - MPF, MPL, MER, FIDO development rover, Mars '01 testbed, generic mission
  - Adaptation time 2 days to 2 months for new missions
    - Compare to 3 years to write original code
  - Total MER development took much longer due to addition of new capabilities
- Cost savings via reuse allows resources to be invested in new capabilities

Operational Pipeline

- We typically receive 50-350 images per day, per mission
- Managing the production of up to 12 products per image requires automation
- “merpipe” is a Bourne shell script that manages the execution of all applications (in parallel)
- Each RDR type has a processing queue which is populated by upstream processes
- Processing can vary based on instrument and specifics of the data
- Pipeline also handles generation of meshes and systematic mosaics

Pipeline Flow Diagram



Pipeline vs. Database

- No database is used for pipeline file management
  - Project requirement
- “Smart” directory structure called OSS (Operational Storage Server) is used to manage files
- Avoids single point of failure
- Script-level tools easier to develop than database code
- Provides transparency across the Project
  - Can find data in other teams’ directories easily
- Facilitates parallel development across many teams due to simple interface
  - Less constrained than a structured database
- Heritage from MPF and MPL

Operational Users of MIPL Products

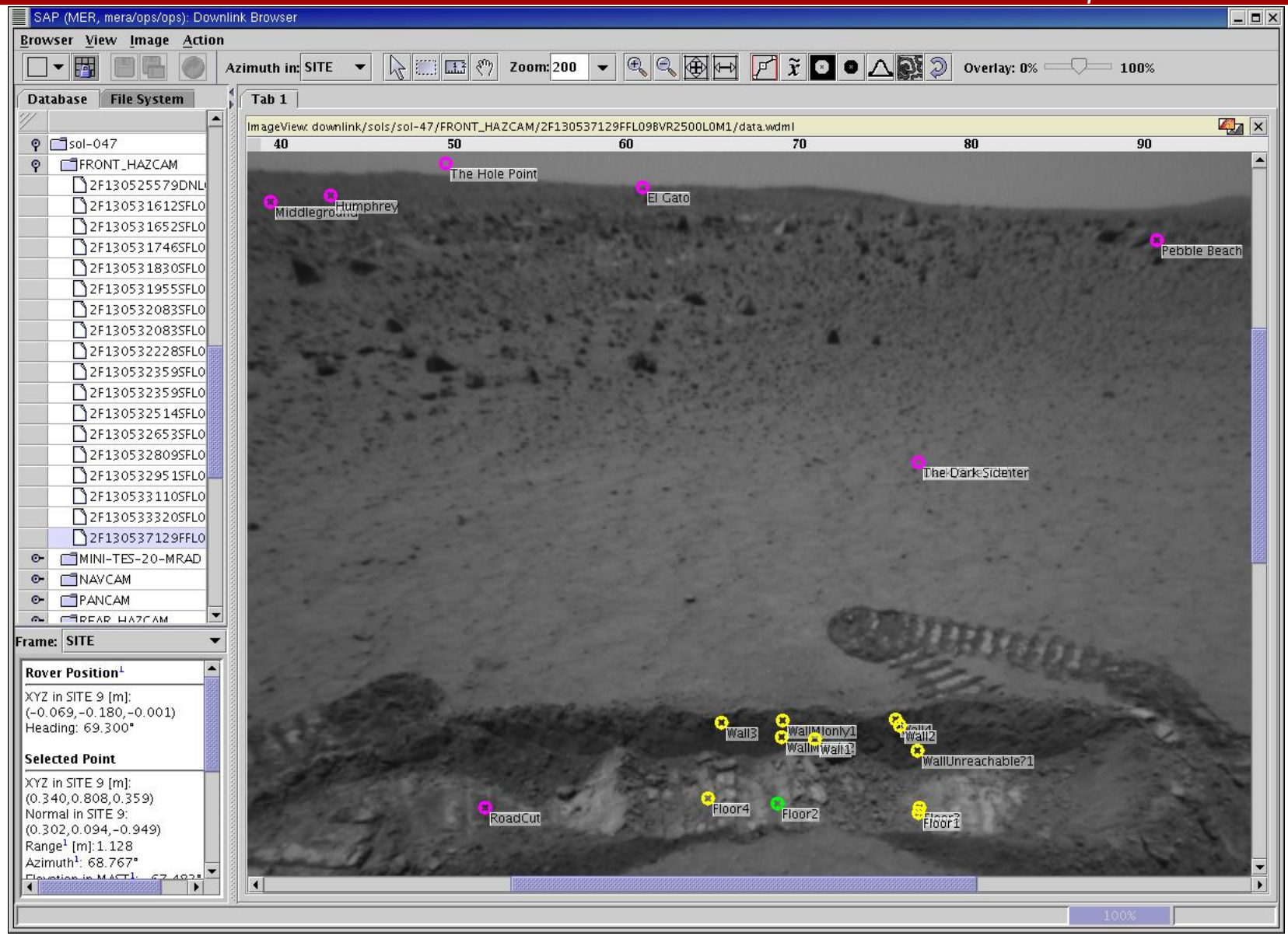
- Science Planners
  - Mostly use SAP - Science Activity Planner
  - Visualize the data and plan the day-to-day observations
    - Use radiometrically-corrected images for viewing
    - Use range data to define targets for observations
    - Use wedges to visualize terrain
    - Use IDD reachability et al to determine if arm can be used
- Rover Planners (drivers)
  - Mostly use RSVP - Rover Sequencing and Visualization Planner
  - Generate detailed commands
    - Use meshes to plan traverses (drives) and IDD (arm) moves
    - Use stereo images to verify terrain

Operational Users of MIPL Products

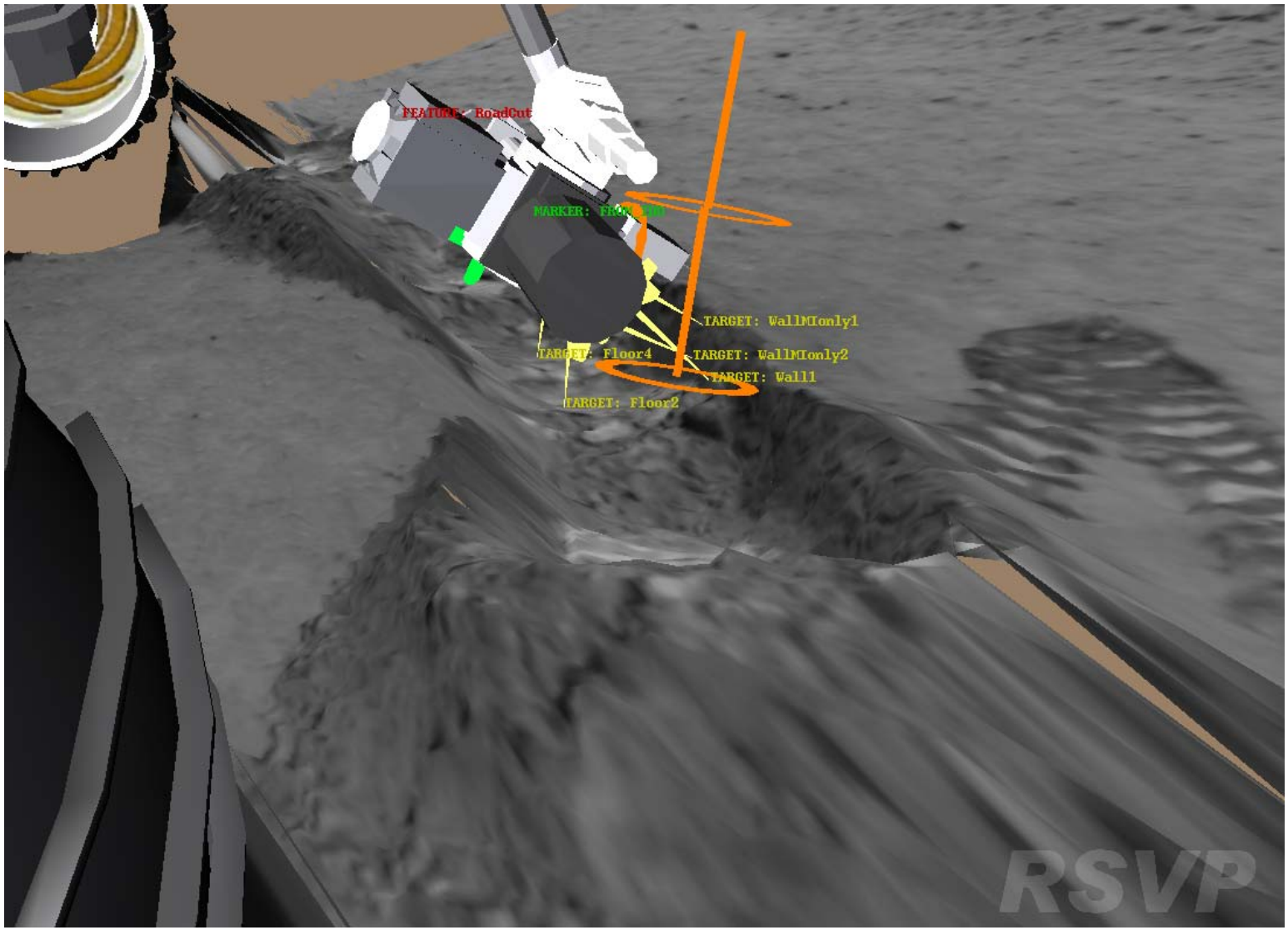
- Mobility Analysts
  - Use SAP, RSVP, and many other tools
  - Determine what the rover actually did vs. what it was supposed to do
    - Health and safety monitoring of arm and mobility elements
    - Fault diagnostics and recovery
    - Use meshes, wedges, and XYZ's to visualize and quantify terrain
- Long-term planners
  - Use mosaics and terrain meshes to help plan
  - Decide what the rover will be doing in several days or weeks

SAP screen shot

Mars Exploration Rover



RSVP screen shot



Other Users of MIPL Products

- Scientists still use the products too, for analysis
  - SAP used extensively for visualization of data
  - Data imported into users' own SW
  - Trench analysis (XYZ and normal)
  - Photometrically corrected image production
- Public Information (PIO) use
  - Many special products for press release
    - Created using same software, with some extra interactive tools
  - Raw images pushed to Web via pipeline
  - Images pushed to Museum Alliance
  - Images also used by Maestro (public version of SAP)

Operational Experiences: Does it Work?

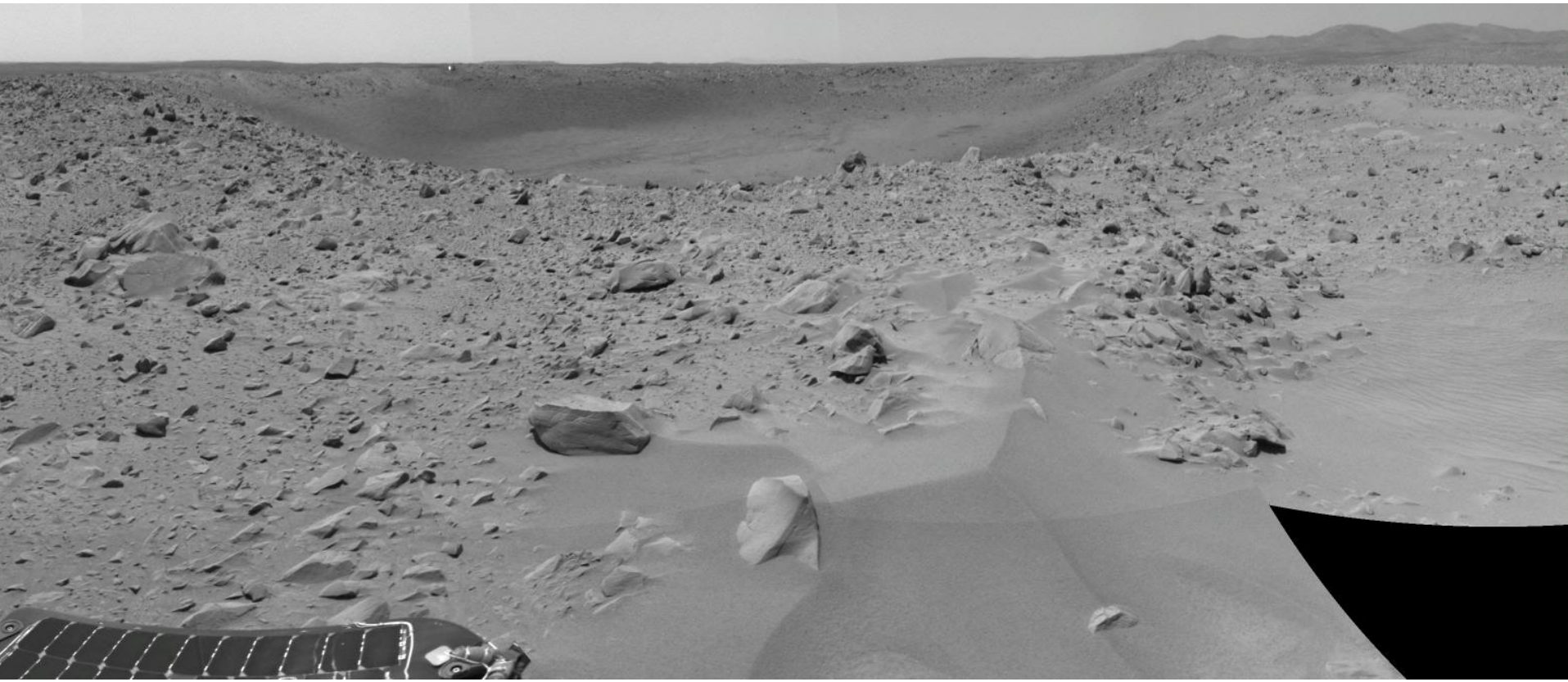
- Operations have been a huge success so far
  - Very few major problems
  - No “Lost Sols” due to MIPL, as of this writing
- Where it works well
  - Modular approach to software
    - Have been able to adapt several programs to surprises provided by Mars quickly and easily
    - Able to add new product types to adapt to operational needs
  - Loose coupling of pipeline
    - Individual processes can be restarted without affecting rest of pipeline
    - Easy to inject special products into middle of pipeline
    - Allows parallel processing of incoming streams
  - Inheritance from prior missions
    - Huge cost savings
    - Allows us to concentrate on new features rather than fixing old ones
  - Automation allows MIPL to meet its stringent processing time requirements

Does it Work? (cont.)

- Problem Areas
  - Legacy code makes consistent error reporting and logging a challenge
  - Loose coupling approach requires monitoring of many more processes
  - More parallelism for CPU-intensive processes would be helpful
  - Some hardware issues have plagued us
- OSS file structure vs. database
  - It works, but the jury is still out to some extent
  - Freedom from database facilitates running private pipes outside of OSS
    - Often necessary for special products or time-critical processing
  - Files occasionally get “stuck” in queues and require manual intervention
  - OSS structure itself is cumbersome
    - Over a million directories (!) for about a dozen test and ops OSS trees
  - Monitoring of process status is a bit difficult
  - Finding other teams’ data is easy without requiring specialized query tools
- In the final analysis...
  - Our customers are happy

Does it Work? (cont.)

- Judge for yourself



Questions

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