Mars Science Laboratory

MSL-RAD Cruise Operations Concept

AIAA Space 2012 Conference

David E Brinza, PhD
Jet Propulsion Laboratory
California Institute of Technology

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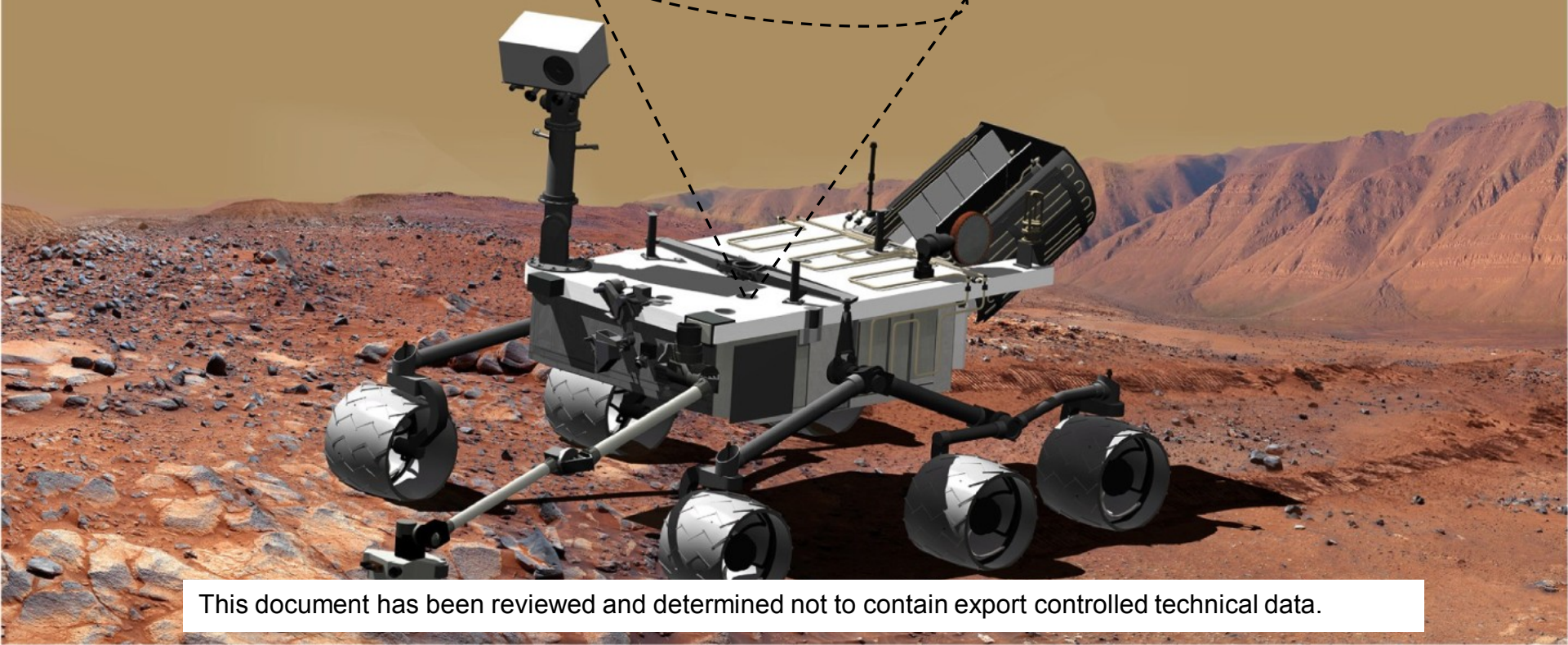

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MSL-RAD Cruise Operations Concept

- RAD Instrument Overview
  - Instrument Hardware
  - Instrument Operations
- MSL/RAD Commanding
- MSL Cruise Operations Process
  - Cruise Uplink Process
  - RAD Sequences
  - RAD Data Product Downlink Pipeline
- RAD Operations in MSL Cruise
  - Significant RAD events in Cruise
  - RAD Cruise Operating Statistics
- Conclusions and Acknowledgments

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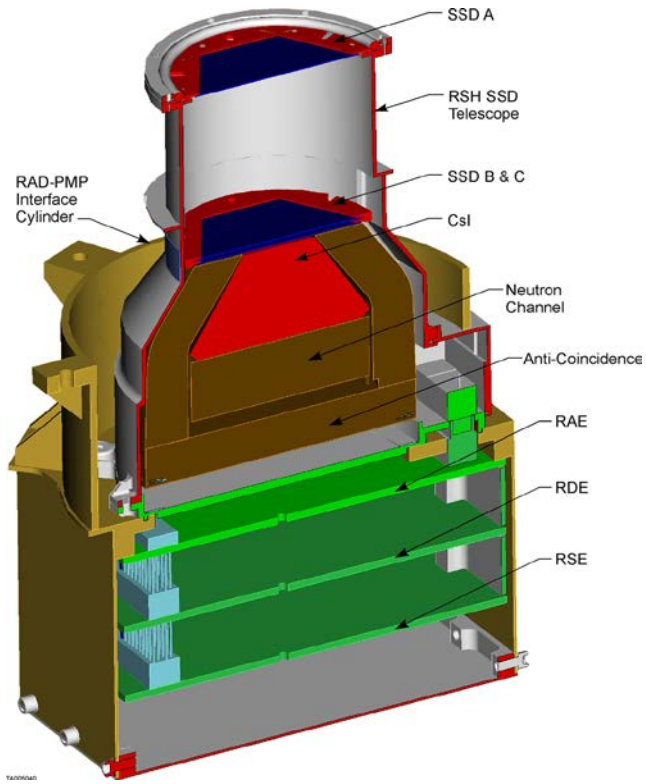
RAD Instrument Hardware

- RAD Sensor Head (RSH)
  - Solid-State Detector Telescope
    - SSD-A, SSD-B, SSD-C Si PIN-diode
  - Cesium Iodide (CsI) calorimeter
  - Bicron Scintillators
    - Neutron Channel, Anti-coincidence shell
- RAD Electronics Box (REB)
  - RAD Analog Electronics (RAE) board
    - VIRENA mixed-signal ASIC
    - Electronics for VIRENA Interface Logic FPGA
  - RAD Digital Electronics (RDE) board
    - FGPA with imbedded 8051, 2 UARTs
    - RAM, EEPROM, Flash-NVRAM (16 MByte)
  - RAD Sleep Electronics (RSE) board
    - Sleep-timer circuit (primary 28V powered)
    - Custom power supply (switched by sleep circuit)
- RAD mounted within Rover
  - Sky-facing 65° FOV through thin window



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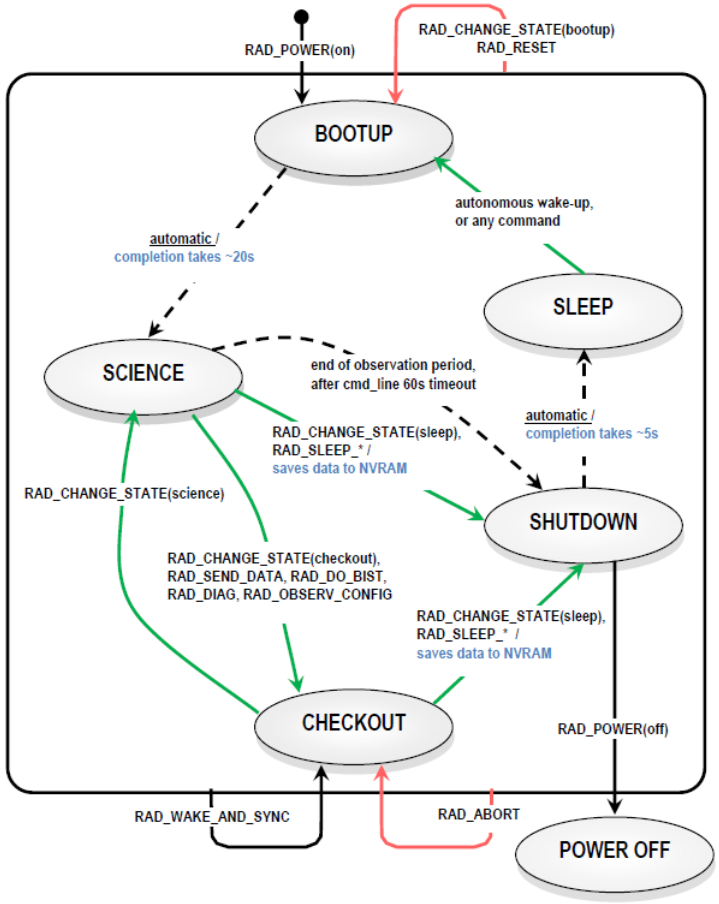
RAD Instrument Operations

- RAD is designed for autonomous operations
  - No commanding required for making science observations
  - RAD can operate with rover computer asleep
  - Data transfer to rover computer (once daily)
  - Instrument configuration can be changed (infrequently)
- RAD is a state machine with six states:
  - POWER OFF (no 28V power, no activity)
  - BOOTUP (< 30 sec)
    - Load code image from selected EEPROM into RAM
    - Perform Solar Event Pre-Obs
  - SCIENCE (observation period)
    - Capture detector events
    - Process event counts, histograms
  - SHUTDOWN (<10 sec)
    - Compress, prioritize events
    - Store science packet and operating parameters
    - Initiate SLEEP
  - SLEEP
    - Low-power countdown timer circuit
    - Wake-up upon command activity or timer expiration
  - CHECKOUT
    - Commanded state for further rover communications



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RAD Commanding on MSL

- RAD has a very simple ops strategy
  - Operate RAD every day, as much as possible
    - GCR radiation is always present
    - Solar Particle Events (SPEs) are unpredictable
  - Regular RAD observations execute autonomously
    - RAD automatically detects Solar Events to change observations
    - RAD operates even when the rover computer is asleep
  - RAD_GetData (sequenced activity) is performed on regular basis

Key RAD Commands on MSL

Command Name	Description
RAD_POWER	Controls 28VDC power to RAD instrument
RAD_WAKE_AND_SYNC	Halts RAD cadence for commanding
RAD_DIAG	Transfers engineering status to rover computer
RAD_SEND_DATA	Transfers all science observations since prior instance
RAD_SLEEP_FOR_TIME	Restarts observation cadence after commanding
RAD_OBSERV_CONFIG	Changes RAD observation/sleep cadence
RAD_MEM_LOAD_TABLE	Updates internal event processing parameters

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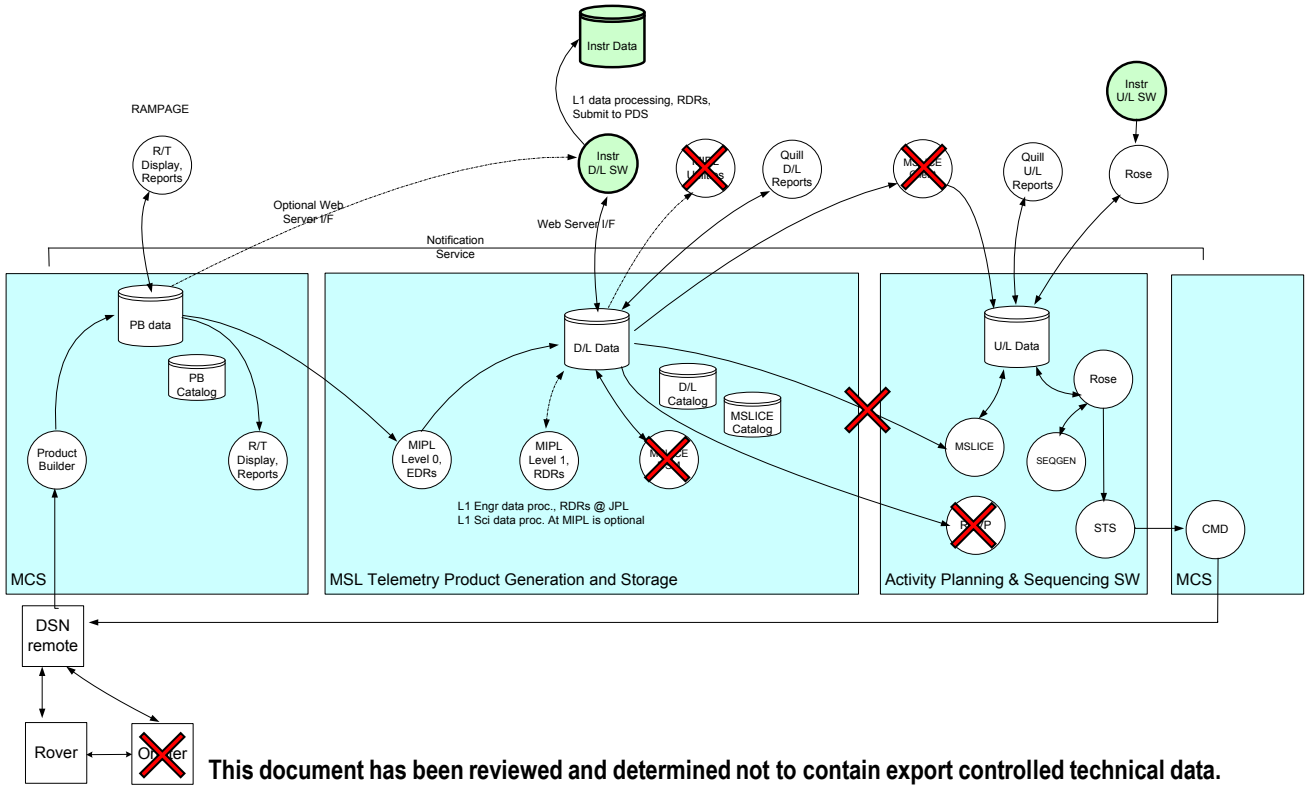
MSL Mission Operations System (Cruise)

- MSL Cruise Operations utilized portions of the MSL Ground Data System
  - MSL GDS designed to support Curiosity surface tactical operations
    - Surface-only elements are crossed out
    - MSL/RAD data was not automatically fed back into MSLICE tool
  - RAD sequences manually generated in MSLICE
  - RAD Experiment Data Records received via File Exchange Interface



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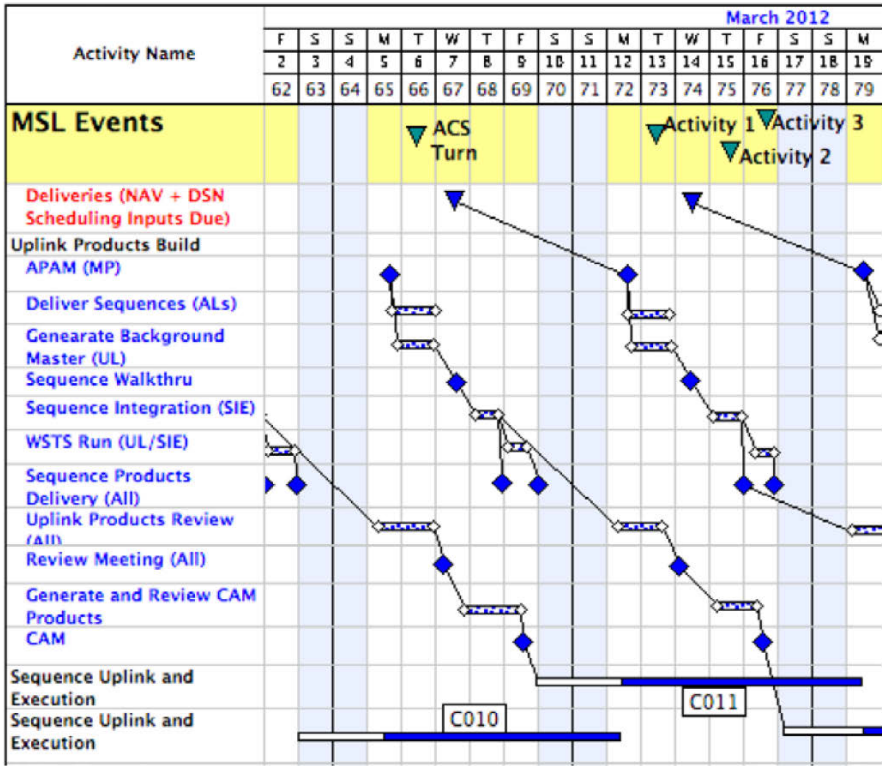
MSL Cruise Operations Uplink Process

- MSL Cruise Operations 2-week planning cycle (overlapping)
  - Activities are designed prior to the Activity Plan Approval Meeting (APAM)
    - Cruise Activity Design document is reviewed and approved
  - Sequences are reviewed at Sequence Walkthrough Meeting
    - Delivery to Sequence Integration Engineer (SIE)
    - Work Station Test Set (WSTS) used for sequence verification
  - Uplink product generation, approval and execution
    - Sequences
    - On-console procedures
      - Contingency procedures



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RAD Cruise Sequences

- RAD required only a few sequences to support Cruise Ops
  - Turn RAD on or off
  - Transfer RAD science data to rover for downlink
    - RAD_GetData was often executed from the Master Sequence
  - Modify RAD configuration and internal parameters for event processing
  - Handle data transfers over weekends when no Master Sequence is on-board
  - Configure RAD for initial surface operations

Key RAD Sequences for MSL Cruise

Command Name	Description
RAD_TurnOn	Power-on RAD, get engineering status, start science ops
RAD_TurnOff	Get RAD science data, then power RAD off
RAD_GetData	Get RAD science data and resume science ops
RAD_TableUpdate	Change RAD internal configuration, parameters
RAD_Weekend_GetData	Wait 36 hours, then execute RAD_GetData
RAD_End_of_Cruise	Run RAD_GetData, change to surface configuration and turn RAD off

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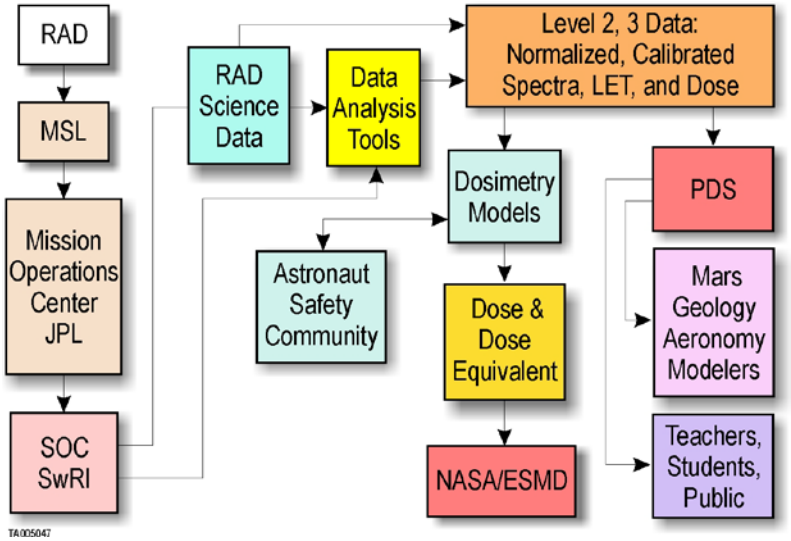
RAD Data Product Downlink Pipeline

- End-to-end RAD data pipeline
  - Raw Data Packets from RAD to Earth
    - RAD to MSL Rover Computer
    - Deep Space Network communications
    - JPL Mission Operations
  - RAD Experiment Data Records (EDR)
    - Raw data packets converted to EDRs with Day-of-Year (DOY) boundaries
    - EDRs are transferred via File Exchange Interface to RAD Science Operations Center
  - RAD Science Team website
    - Store DOY records in database
    - Detect missing packets
    - Plotting and query tools
  - Planetary Data System archival
    - RAD EDRs and Reduced Data Records
    - Archive per PDS standards
    - Six months after landing



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RAD Operations in MSL Cruise

- No Project-level requirements for ANY cruise science
  - Science requirements focussed on surface operations only
  - Cruise plan included basic checkout of science instruments
- RAD cruise operations on “reasonable effort” basis
  - Resource availability was key
    - Flight software to support RAD operations
    - Power, downlink bandwidth
    - Operations team workload
  - Minimal intrusion on critical operations
- MSL Cruise operations team support
  - Training of RAD Activity Lead
  - Review and approval of cruise activities
  - Sequence Integration and Delivery
  - Uplink products, downlink assessment

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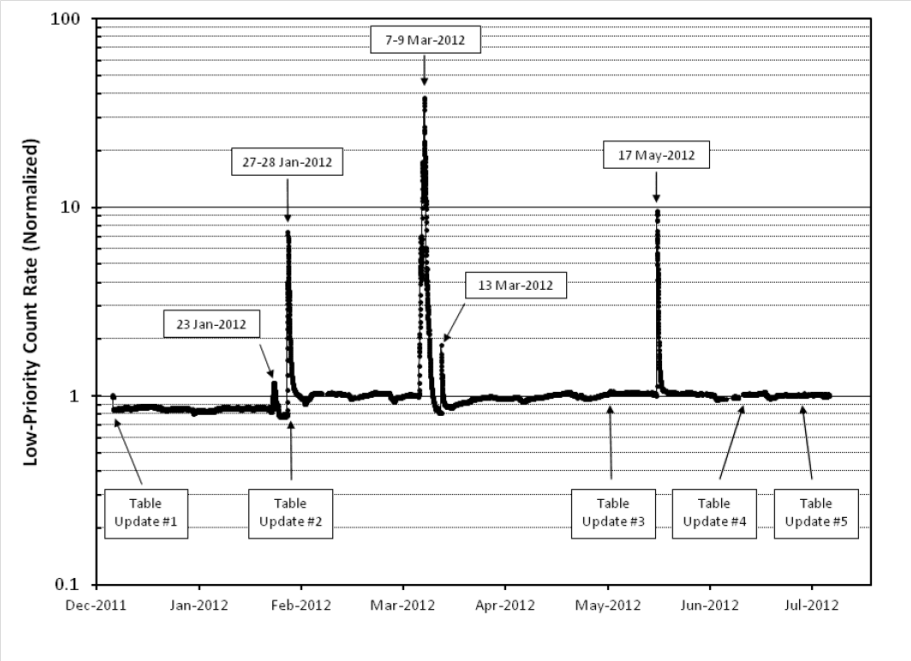
Key RAD Events during MSL Cruise

- RAD Operations Timeline
  - Initial Turn-on: 6 Dec 2011
    - Operate 2 hours with pre-launch parameters
    - Modify configuration for initial cruise
  - RAD off for critical mission events
    - Trajectory Correction Maneuvers
    - Flight Software Updates
    - Key subsystem checkouts
  - RAD Table Updates
    - Adjust RAD parameters based on observations (5 total during cruise)
    - Adjust cadence to reduce data volume as downlink rate decreased
  - Five Solar Particle Events observed
    - Pair of events in late-January, RAD TableUpdate #2 coincident with event
    - Extreme Solar Event on 7-9 March with a minor event a few days later
    - Significant solar event on May 17



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RAD Cruise Operations Statistics

- Operations from Dec 6, 2011 to July 14, 2012
  - Nearly 5,000 hours operating time (95% coverage)
  - “Outages” only for critical mission events
  - No Solar Events missed
- RAD instrument statistics
  - Over 15,000 Science Observations received
  - Approximately 250 Mbytes downlinked and processed
  - Instrument power switch cycled 30 times
- RAD Activities on MSL
  - 240 RAD_GetData sequence executions
    - 55 data transfers on the B-side flight computer
  - 5 RAD_TableUpdate executions

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Conclusion and Acknowledgements

- RAD cruise operations were very successful
  - Science data collected is valuable for future human interplanetary missions
- Success was due to efforts many team members:
  - Flight Software: M. Schoppers, Y. Brenman, C. Williams
  - Mission Operations: C. Baker, J. Biehl, Z. N. Cox, B. Ferdowsi, P. Hwang, D. Oh, G. Yang, A. Amador (Mission Manager)
  - System Test: B. Pavri, A. Scodary, N. Warner, A. Thompson
- Programmatic Support
  - Work was carried out at JPL/Caltech under NASA prime contract
  - RAD development supported by NASA Human Exploration and Operations Mission Directorate, Advanced Exploration Systems
  - RAD Sensor Head developed at Christian-Albrechts University in Kiel, Germany under DLR Space Administration grant 50QM0501

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