Ground System Architectures Workshop 2014
Landsat 8 Test as You Fly, Fly as You Test

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Introduction

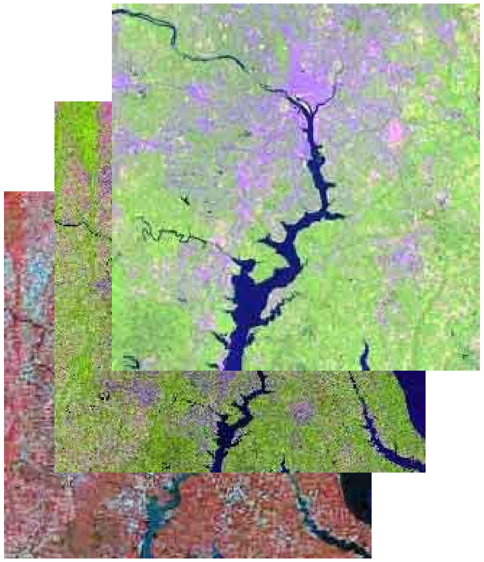
- Landsat 8 (L8) Utilized “Test as You Fly, Fly as You Test” Development Approach
- Presentation Will Provide Background on L8 Mission, Development Activities, and Significant New Technologies Flying for First Time
- Step Through Testing Activities and “Test as You Fly” Impacts
- Conclude with Lessons-Learned – Pros and Cons of “Test as You Fly” Approach

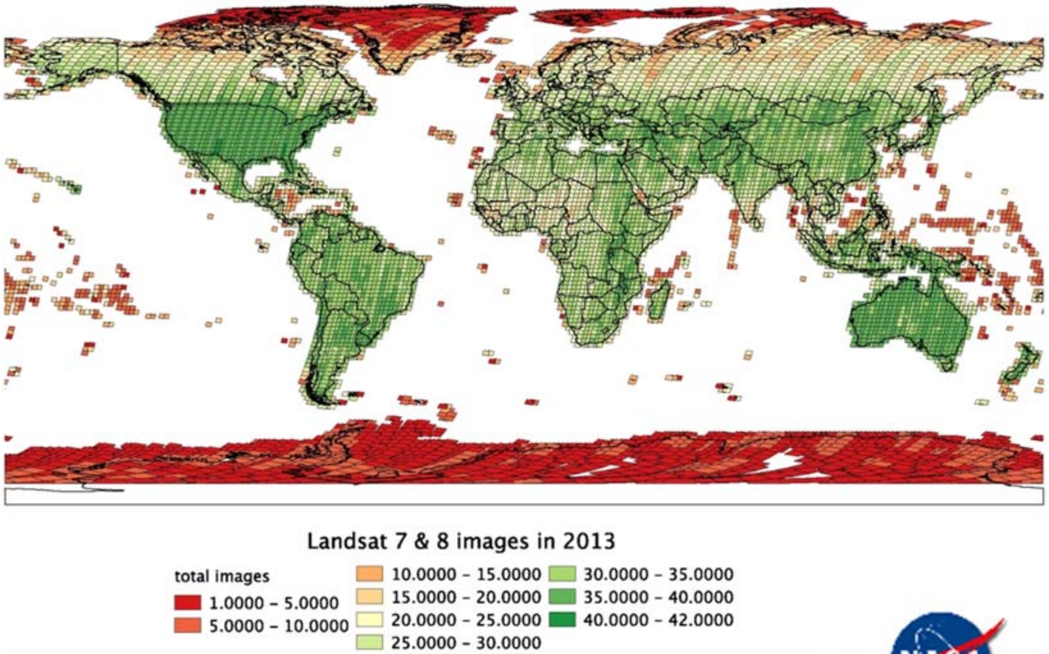
Agenda

- Introduction/Landsat Overview
- Landsat 8 Program and Development Timeline
  - Landsat Data Continuity Mission (LDCM)/Landsat 8 (L8)
  - Comm Architecture and New Technology
  - Test as You Fly, Fly as You Test Approach
- Engineering Model Testing
- RF Compatibility Testing
- Ground Readiness and Mission Readiness Testing
- Satellite Integration and Test
- Launch Readiness Testing
- On-Orbit Verification and Checkout
- Conclusion and Lessons-Learned

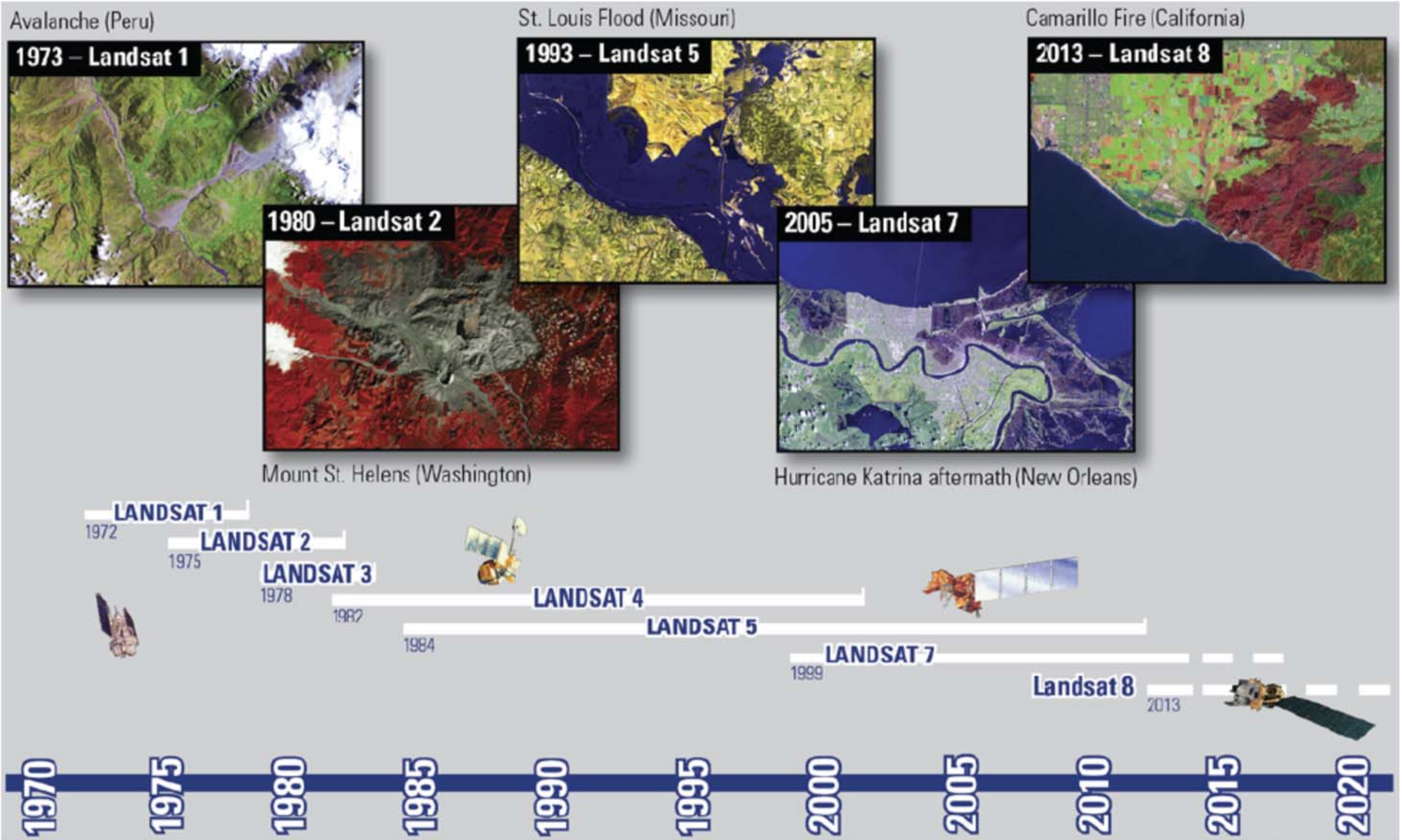
Landsat Mission Overview

- Long-Term Operational Moderate-Resolution Land Imaging Program
- Extensive Continuous Historical Record of Observations
- Key Data Source for Global Change Research and Regional Studies
- Large Commercial Applications and User Base
- Large Well-Developed International Cooperator (IC) Network
- Satellites Developed by NASA and Operated by USGS
- LDCM/L8 Recently Launched in February 2013 and Declared Operational at the end of May 2013





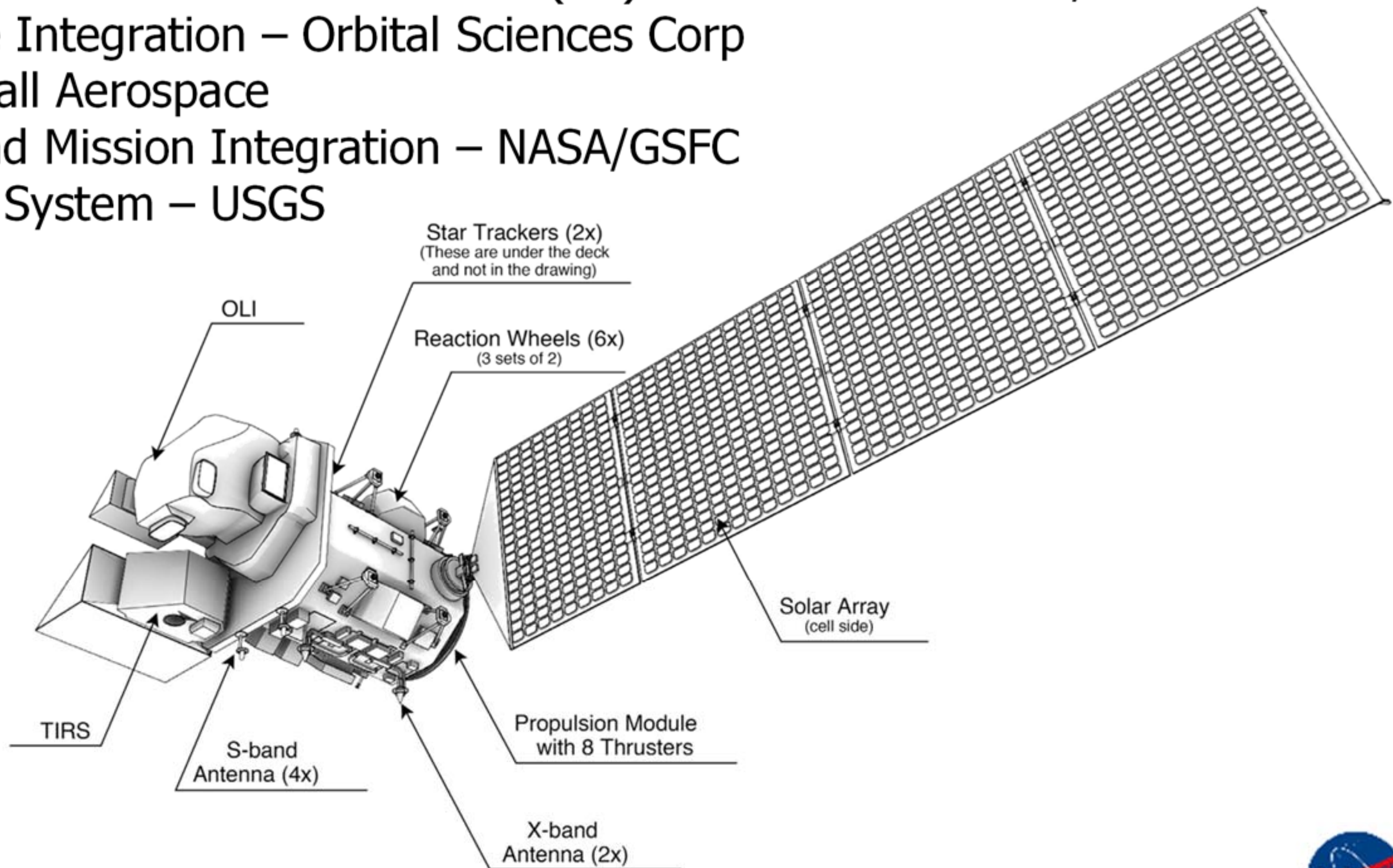
Landsat Mission Overview, cont.



Landsat 8 Next-Generation Satellite

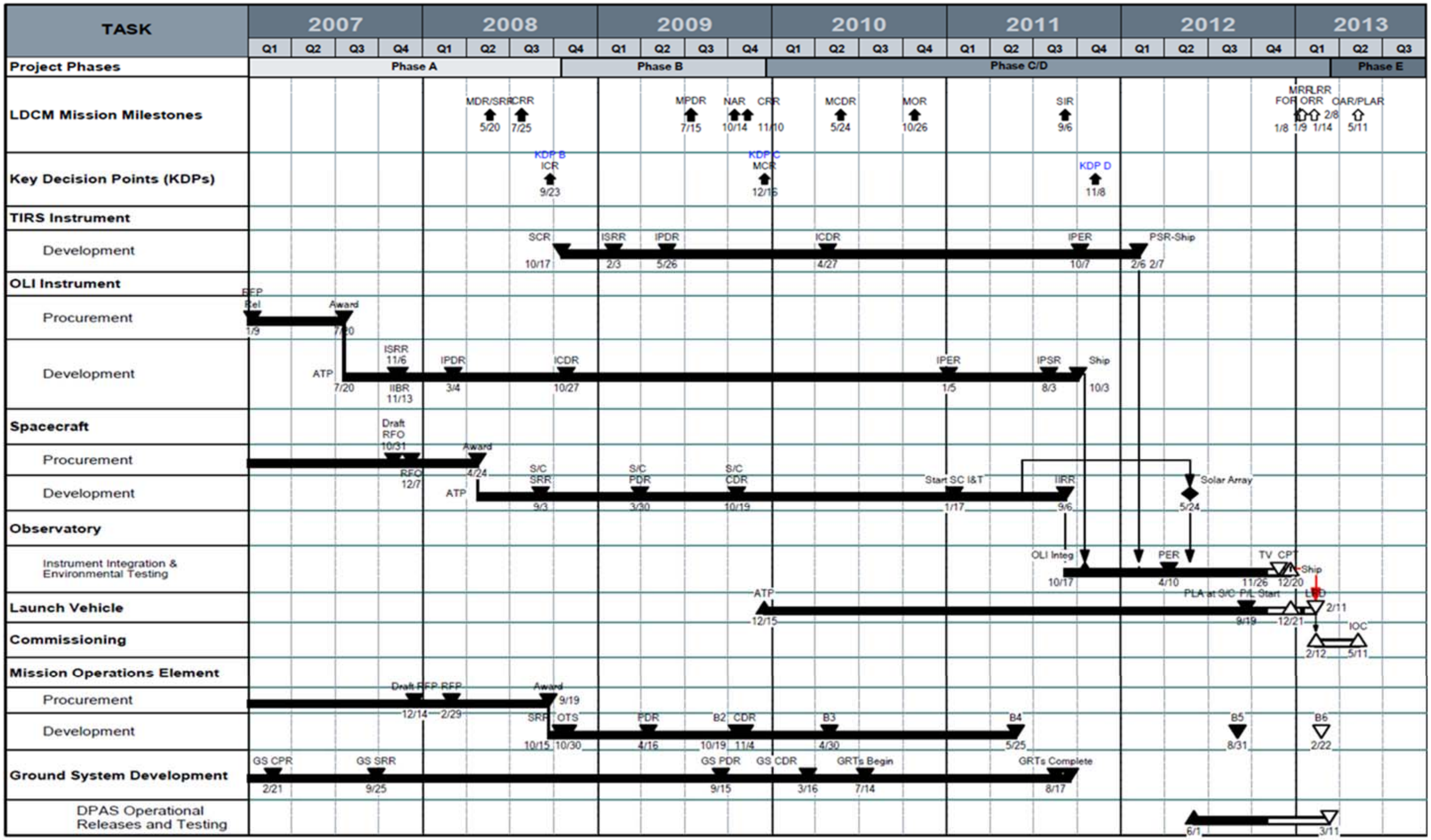
LDCM

- Landsat Data Continuity Mission (LDCM) Initiated to Develop Next-Generation Landsat Satellite
  - Operational Land Imager (OLI) is Primary Sensor
  - Thermal Infrared Sensor (TIRS) Added Later
- LDCM Implemented as Landsat 8 (L8) Dedicated Mission/Satellite
  - Satellite Integration – Orbital Sciences Corp
  - OLI – Ball Aerospace
  - TIRS and Mission Integration – NASA/GSFC
  - Ground System – USGS



Landsat 8 Development Timeline

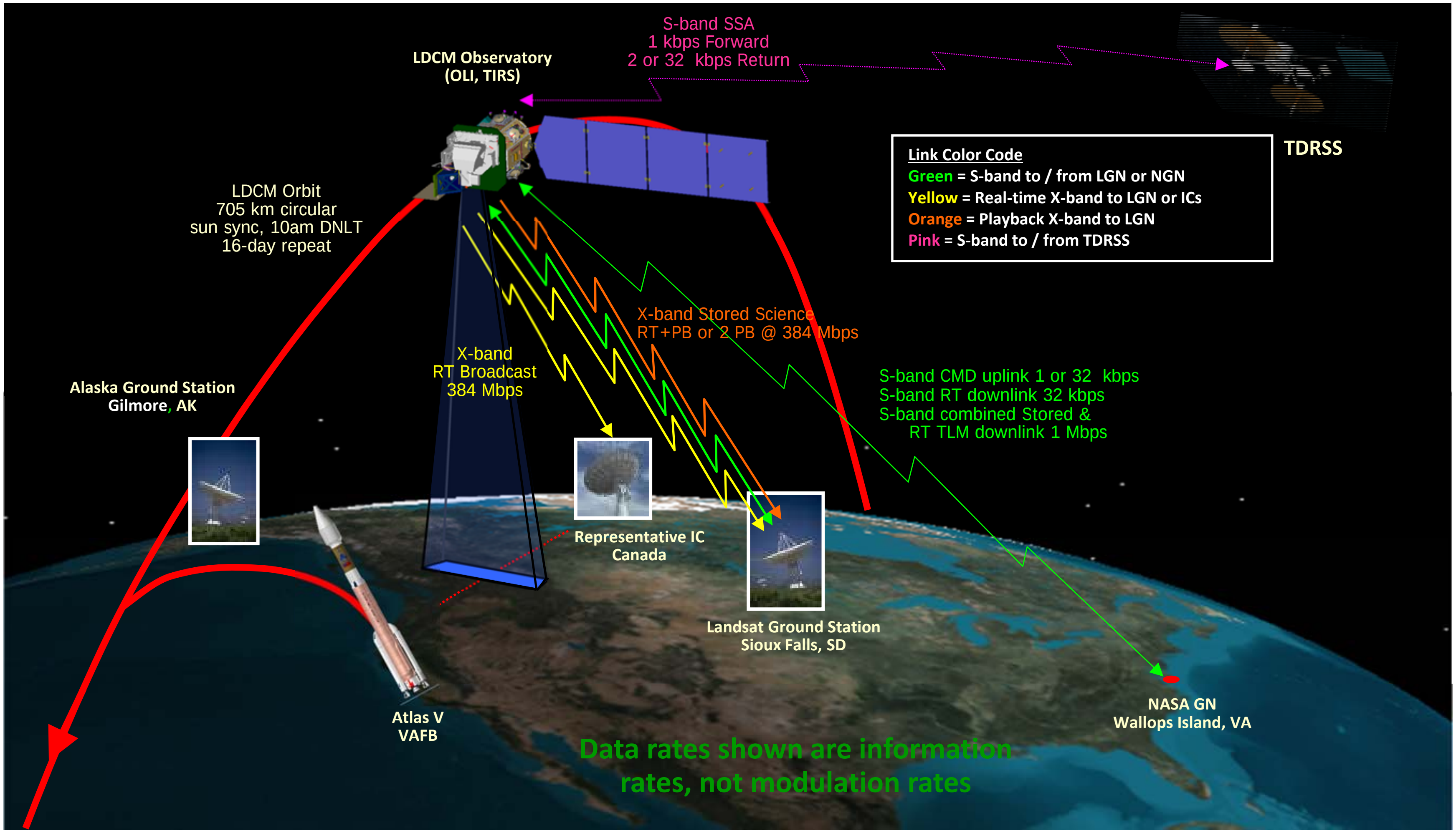
LDCM



USGS

NASA

Landsat 8 Comm Architecture



X-Band RF Characteristics

Frequency	8200.5 MHz
OLI Data Rate (not including 1.55:1 compression)	261 MBits/sec
TIRS Data Rate (uncompressed)	26 MBits/sec
Science Data (Mission) Data Rate (prior to LDPC)	384.000 MBits/sec (Includes Fill)
Forward Error Correction (FEC) Type (achieves 1x10E-12 bit error rate)	7/8 Rate LDPC Reference: CCSDS 131.1-O-2
Rate to Modulator (includes LDPC overhead)	440.825 MSymbols/sec
Filtered Bandwidth	374,850 kHz
Polarization	Left-Hand Circularly Polarized (LHCP)
Modulation	OQPSK
Effective Isotropic Radiated Power (EIRP) (peak power density observed in direction of max antenna gain)	20.5 dBWi (Earth-Coverage Antenna)
Required Eb/No to meet BER of 1x10E-12	14.0 dB
Demodulator Loss (allowed)	4.3 dB loss
Nadir Margin (Worst Case)	3.1 dB
Noise Specification – Minimum G/T at 5 degrees elevation	31 dB/K
Design Link Availability	97%

New Landsat 8 Comm Technology

- Required to Support Increased Data Rates and Link Requirements
- CCSDS File Delivery Protocol (CFDP)
  - Allows for Data Management like Files on a PC
  - File Delivery Con Ops of Deletion After Successful Ground Reception
- Next-Generation Solid State Recorder
- Low-Density Parity Check (LDPC) Forward Error Correction (FEC)
  - First Implementation on Flight Program
  - Much More Efficient Than Rate-1/2 Convolutional Coding and Rate-7/8 Reed-Solomon (LDPC is Rate-7/8)
- 10^{-12} Bit-Error Rate on X-Band Space-to-Ground Link
- Variable Rice Compression for Mission (Image) Data
  - First ASIC Flight Implementation
- Asymmetrical Filtering to Meet DSN and ITU Bandwidth Restrictions
- Improved X-Band TWT Amplifier Implementation and Switch-less Redundant Architecture
  - RF Hybrids Used Instead of RF Switches for Improved Reliability

Test as You Fly, Fly as You Test

- Test as You Fly, Fly as You Test Development Approach
  - "Bake In" Compatibility During Development
  - Reduces Surprises on Orbit
- Development Implications
  - Ground System Needs to be Ready (Tested/Certified) Before Flight H/W to Support Testing
  - Reduces Time Available for Ground System Development
  - Need Flexibility in Accommodating Changes in Flight H/W Development
- Test Implications
  - Need to Have Additional Ground System H/W Available to Dedicate to S/C Testing
  - Also Need Ground System Staff to Support S/C Test Activities
  - S/C Development Effort Needs to Accommodate Testing with Ground System, Either Integrated or as Additional Testing

Engineering Model Testing

- Early Test of New Technologies and Demonstration of Ability to Meet BER
  - First Flight Usage for LDPC
  - Provide Time to Address any Performance Shortfalls
- Engineering Model of RF Comm and Data Handling Subsystems Connected to Ops Demod and Down Converter
- Secondary Objective to Demonstrate Data Flow Ops Using Simulated Mission Data
- Conducted in June 2010 in Orbital I&T Lab

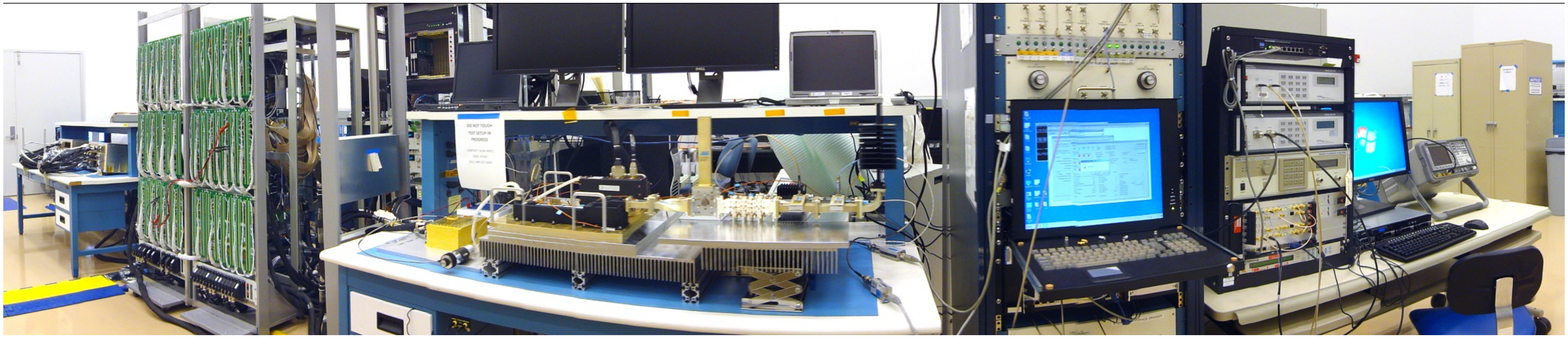
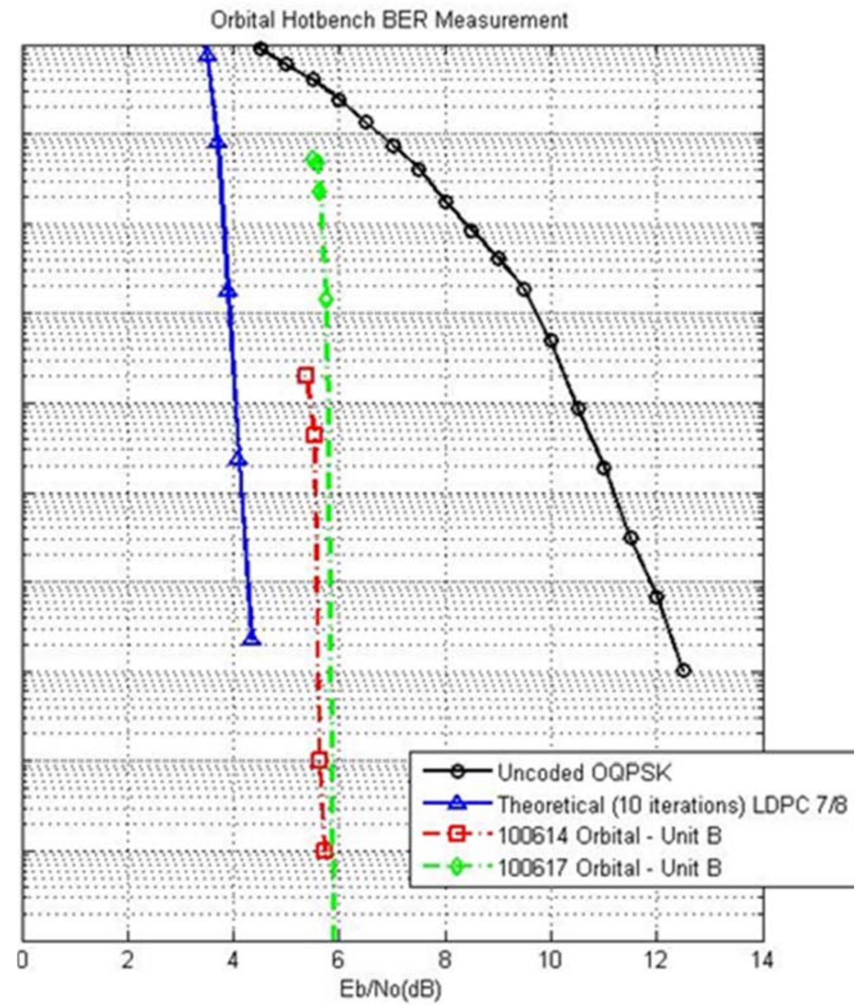


Photo Courtesy Orbital

Engineering Model Test Results

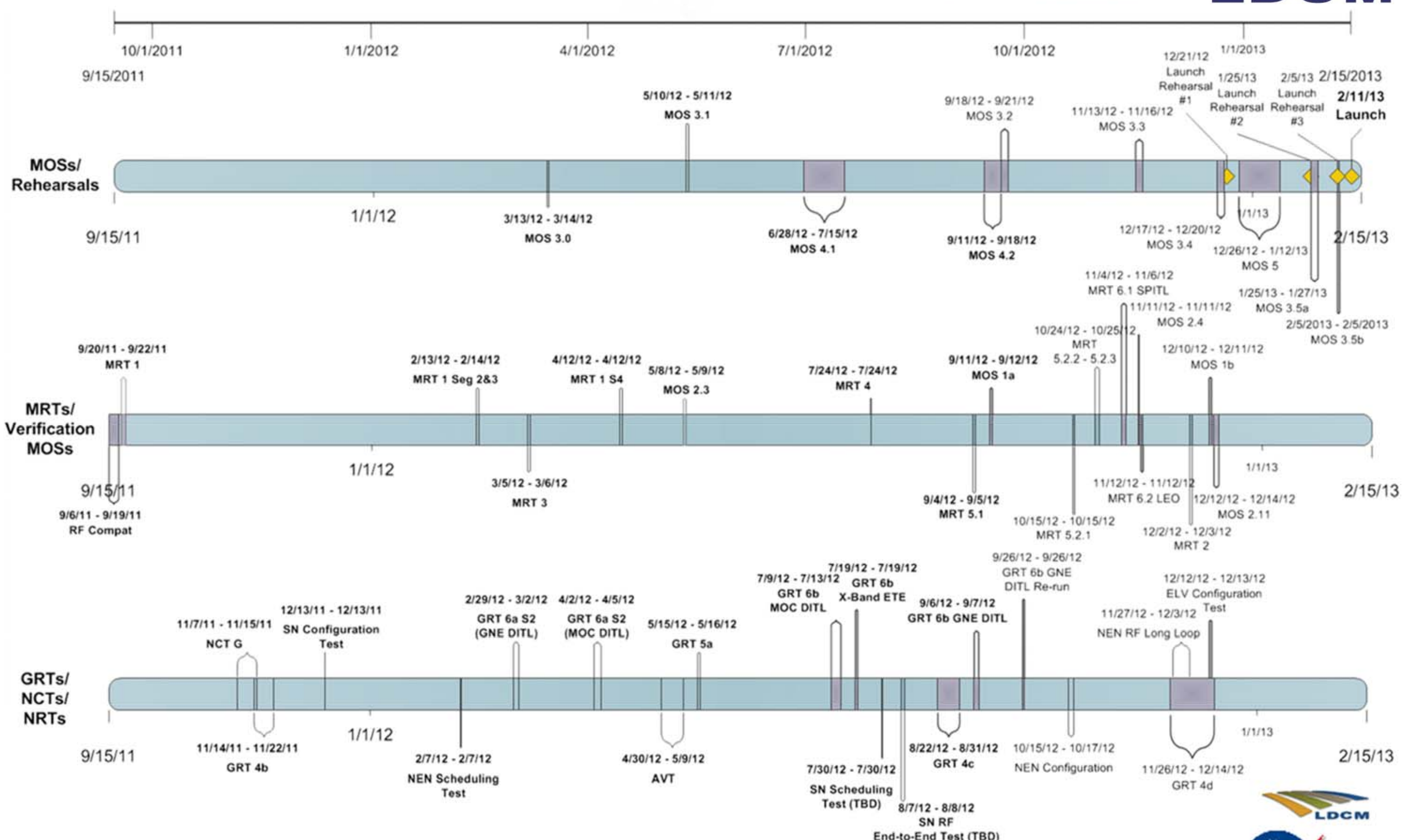
- Demonstrated Compatibility Between Ops Demod and EM Flight H/W
- Demonstrated Required Level of Performance is Achievable
  - Demonstrated Performance at Better Than 10^{-13} BER
  - System is Stable and Error-Free Over 10-15 min Period of a Pass
- Identified Some Further Work Needed in CFDP Processing Modules of Demod
  - Also Learned a Few Things About How Test Data Were Constructed that Would be Useful Later...



RF Compat Testing

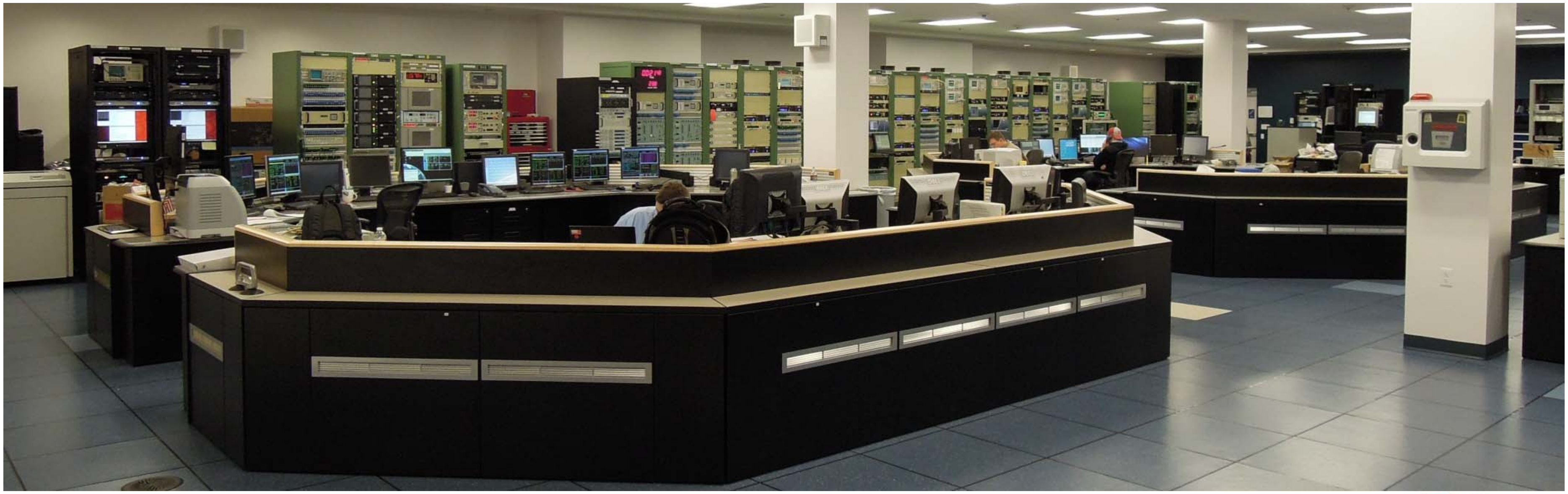
- Standard NASA RF Compat Process and Test Procedure
  - NASA Responsible for S-Band (NEN/SN)
  - USGS Responsible for X-Band (LGN - Landsat Ground Network Stations)
- Tailored to Bring Ground Station Equipment to S/C Facility for Testing
  - Stations Were Already Operational
  - “Test as You Fly”
  - Some Equipment Also Used for S/C I&T
- Combination of Flight and EM S/C H/W Used for Test, but Representative of Full Flight Configuration
- Testing Done in Combination with Mission Readiness Test to Take Advantage of Equipment Onsite

LDCM Readiness Test Schedule



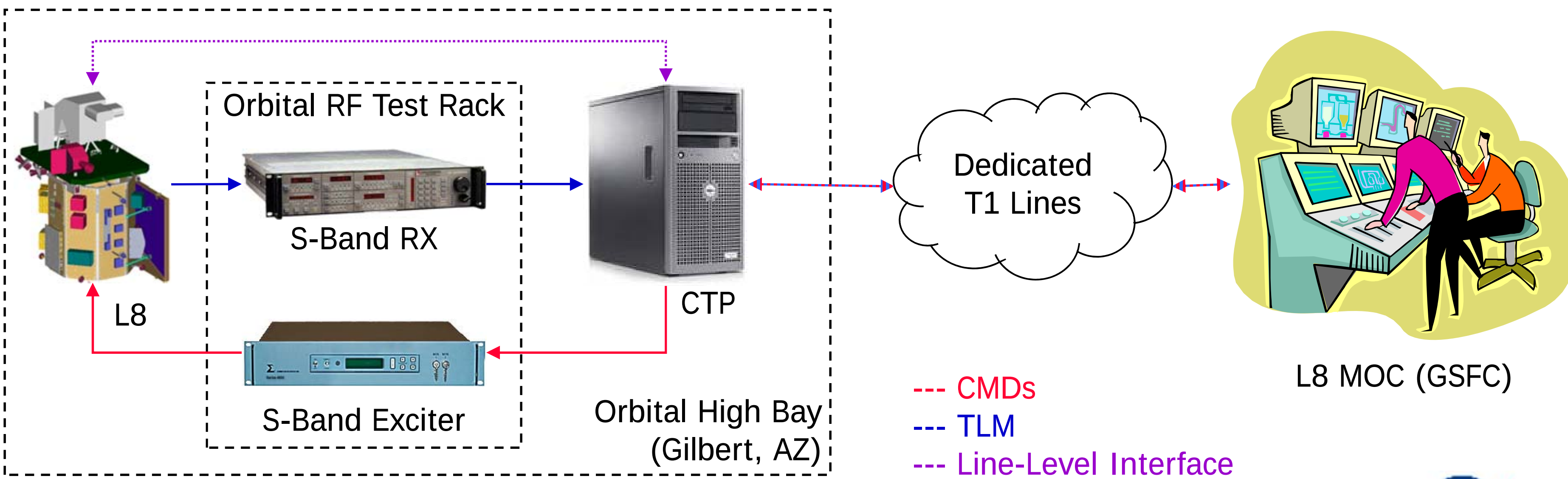
Ground Readiness Testing (GRT)

- Verify Ground System Meets Requirements and Ready for Use in S/C Test
- Planned for Completion before S/C Testing Started
  - Needed to Make Changes to Accommodate S/C Design/Implementation
  - Data Processing Testing Deferred to Later in Schedule
- Some Testing Used S/C EM H/W – "Test as You Fly"
- Needed to Re-Plan/Re-Phase Testing Schedule as Program Evolved



Mission Readiness Testing (MRT)

- End-to-End Testing with S/C and Ground System
- Ideally was Planned to Reflect Normal Ops Scenarios, But Changed in Order to Exercise All Functionality
  - Every CMD Sent to S/C at Least Once
  - Start with Simple Test Sequences and Work Up to Full Day-/Week-in-the-Life
- MOC Interfaced to S/C Using Ops CMD and TLM Processor (CTP) and RF Interface Rack, or Line-Level Interface from CTP to S/C



Mission Operations Simulations (MOS)

- Focus on Normal Ops Scenarios, Work Through Ops Procedures
- Stress Testing at Normal Ops Level Capacity/Data Flow
- Interleaved with S/C Test Activities
- Test Data Derived from S/C Testing and High-Fidelity S/C Simulator Located at MOC

Satellite Integration and Test

- Orbital Astro-RT TLM and CMD System Used for I&T and Pre-Launch Satellite Testing
  - MOC System Used for MRTs
  - Orbital RF Rack Used for I&T, MRT 2-6, and pre-launch Testing
- “Hallway Ground Station” (HGS) Implemented to Support S/C Testing Activities
  - Initially Planned Just to Have Demod Running in Parallel with S/C Testing to Capture Copy of Test Data for Archival and Anomaly Investigations in Ops
  - Evolved from X-Band Test Rack left at Orbital after RF Compat Testing
  - Added Server Running Subset of Ingest and Data Processing S/W
  - Enhanced Over Course of Testing to Perform Near-Real-Time Data Processing from RF to L1 Product

Satellite Integration and Test (Cont.)

- Standard Test Suite Developed and Reused at Various Stages of Testing
  - Subsystem-Specific Tests
  - Functional End-to-End Test Cases (CPTs and LPTs)
- Orbital Astro-RT T&C System Used to Control S/C and Run Test Procs
- LabView Scripts Used for Test Equipment Status and Control
- NASA and USGS Test Equipment Connected in Parallel
  - Listen Line to Relay TLM Back to MOC
  - Demod and Capture System for X-Band Data, Some S-Band Equipment Also
  - Mostly Manual Operation

S/C Environmental Testing

- Electromagnetic Interference (EMI)
  - Functional and Data Flow Tests to Look for Interference
  - S-/X-Band Free-Space Link to S/C
  - Extensive X-Band Data Testing to Assess Potential EMI on Instruments
- Shock/Vibration/Acoustics
  - Instruments Tested, But Not X-Band Data Flows
- Thermal/Vacuum (TV)
  - Same Suite of Functional and Data Flow Tests Run During Ambient I&T Repeated During Thermal Cycling
  - Extended X-Band Operation Demonstrated at Hot/Cold Temps
- Onsite Support by MOC and Ground System Development Staff

End-to-End Functional Testing

- Test Procedures Designed with "Test as You Fly" in Mind
  - Demonstrates Operational Scenarios with Instruments Collecting Simulated Data, S/C Processing and Downlinking Data, and Test Equipment Receiving/Processing Data (Like Ops)
  - Also Demonstrates Scheduling of Instrument Operations on S/C in Addition to Real-time Commanding
- Comprehensive Performance Tests (CPT)
  - Executed End-to-End Operational Scenario
  - Multiple Instrument and S/C Modes Tested
  - Derived from Design Reference Case (DRC-16) for Scenario Covering All Functions Used in Operations
  - Ran Multiple Times at Each Stage of S/C Testing
  - Both A- and B-Sides of Instruments and S/C
- Limited Performance Tests (LPT)
  - Abbreviated Subset of CPTs
  - End-to-End Data Flows

Launch Readiness Testing

- Launch Site Testing
- Tailored Set of Integrated S/C Tests
- Testing After Final Assembly and Integration with Launch Vehicle
- All Satellite Testing Repeated using Orbital RF Test Rack and USGS Hallway Ground Station
- No Testing with MOC

On-Orbit Verification/Commissioning

- On-Orbit Checkout Went Very Smoothly
- Issues Quickly Addressed Some Ground Station Problems in Areas That Weren't Tested Before Launch
  - Development Team Onsite at Gilmore Creek Helped to Quickly Resolve Problems
  - Many Issues Were Expected as Items That Would be Tuned with S/C On-Orbit
  - Some Issues Due to Less-Than-Robust Configuration Management/Control
- Was Able to Quickly Ramp-Up to Beyond Normal Imaging Schedule
  - System Designed for 400 Scenes/Day, Able to Demonstrate Routine Acquisition of 550-600 Scenes/Day

Conclusions and Lessons-Learned

- Development
  - Ground System Required to be Ready and Tested While S/C and Instruments Still in Development Incurs Rework Penalty for Updates
  - Assumptions Made in Ground System Design Before S/C and Instruments Detailed Design are Complete
  - Get Early Experience with Equipment, Plenty of Time to Find/Fix Bugs
  - Need to Have Capabilities for Internal Generation of Test Data
  - Ops-Like Equipment Available for S/C and Instrument Test
- Integration and Test
  - Good Understanding of Equipment for Testing Due to Early Access, Streamlines Test Development and Ops (Since Not Learning to Use New Equipment at Same Time)
  - HGS and Ops/Dev Staff Support Invaluable for Quick Resolution of Test Anomalies, Also Provide Additional Resources to Work Issues
  - Ops Staff Gain Detailed Knowledge (Understanding) of S/C and Instrument by Supporting Test
  - Fixes from Testing Easily Transferred to Ops Environment
  - Also Need to Test System for Ops-Like Throughput in Addition to Requirements Verification Testing

Conclusions and Lessons-Learned, cont.

- Mission Readiness/Ops
  - Robust Test Data/Simulation Available from Internal Equipment Testing
  - Can Run Into Issues with Resources Needed for both Mission Testing and Ops Readiness
  - Successes with S/C Testing Can Lead to Complacency and Assumptions that Ops Will Not Have Any Issues
  - Difficult to Provide All Ops Staff with Opportunities to Work Satellite Testing
  - CM Very Important to Maintain “Tested” Configurations Until Launch
- General
  - Need to Invest Early in Equipment, Harder to Take Advantage of Technology Improvements Available Later in Program (i.e. – Faster Computers, Bigger/Cheaper Storage, New/Better Products, etc.)
  - Need to Plan for Technology Advances from Start (i.e. – Only Procure First String for Testing, Plan for Later Buys to Size System for Ops...)
  - May Run Into Issues with Equipment Refresh Scheduling (Close to Launch and/or Ops Transition)
  - Can Also Use New Equipment to Support Current Ops Missions in Addition to Development Activities

Acknowledgments

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