Status of Landsat 5, Landsat 7, and the Landsat Data Continuity Mission

Spring Land Cover / Land Use Change Science Team Meeting
April 22, 2010
Bethesda, Maryland

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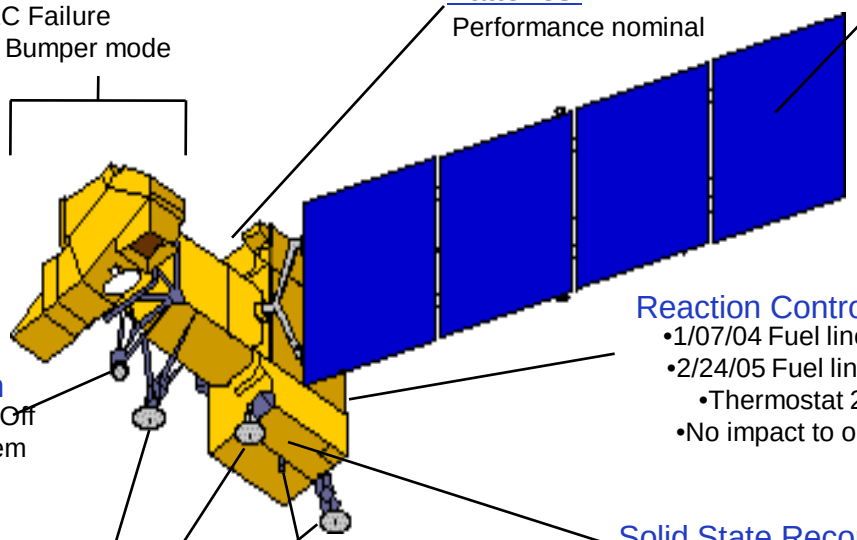
Landsat 7 Status



Electrical Power System

Batteries:
Performance nominal

Solar array:
- 5/14/2002 Circuit #14 Failure
- 5/16/2005 Circuit # 1 Failure
- 14 circuits remain operating
- No impact to ops

Enhanced Thematic Mapper +
- 5/31/2003 SLC Failure
- 4/01/2007 SAM -> Bumper mode

Attitude Control System
- 05/05/2004 Gyro 3 Shut Off
- Singe gyro control system in development

Reaction Control System
- 1/07/04 Fuel line #4 thermostat #1a failure.
- 2/24/05 Fuel line #4 thermostat #1b failure
- Thermostat 2a shows signs of failure
- No impact to ops; extended plan in place

Solid State Recorder
- 11/15/1999 SSR PWA #23 Loss
- 02/11/2001 SSR PWA #12 Loss
- 12/07/2005 SSR PWA #02 Loss
- 08/02/2006 SSR PWA #13 Loss
- 03/28/2008 SSR PWA #22 Loss
- Each PWA is ≈4% loss of launch capacity
- Boards are likely recoverable
- 09/03/2006 SSR PWA #23 Recovered

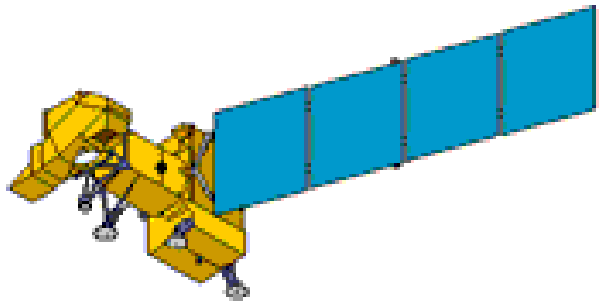
X-band System
Performance nominal

S-band System
Performance nominal

Landsat 7 Status

Landsat 7 - 6 years beyond design life

- 1999 Launch
- Spacecraft
  - Gyro 3 Failure (Shut down May 5, 2004)
    - Working additional improvements for software gyro
  - Other Spacecraft Issues (non-critical)
    - Solid State Recorder – 4 memory boards
    - Electrical Power Subsystem – shunt #14 and shunt #6
    - Fuel Line Thermostat
- ETM+
  - **Scan Line Corrector Failure (May 31, 2003)**
  - Bumper Mode Operations (April 1, 2007)
  - Collecting over 300 scenes per day
- Fuel
  - Current estimate indicates fuel sufficient for operations out to 2017

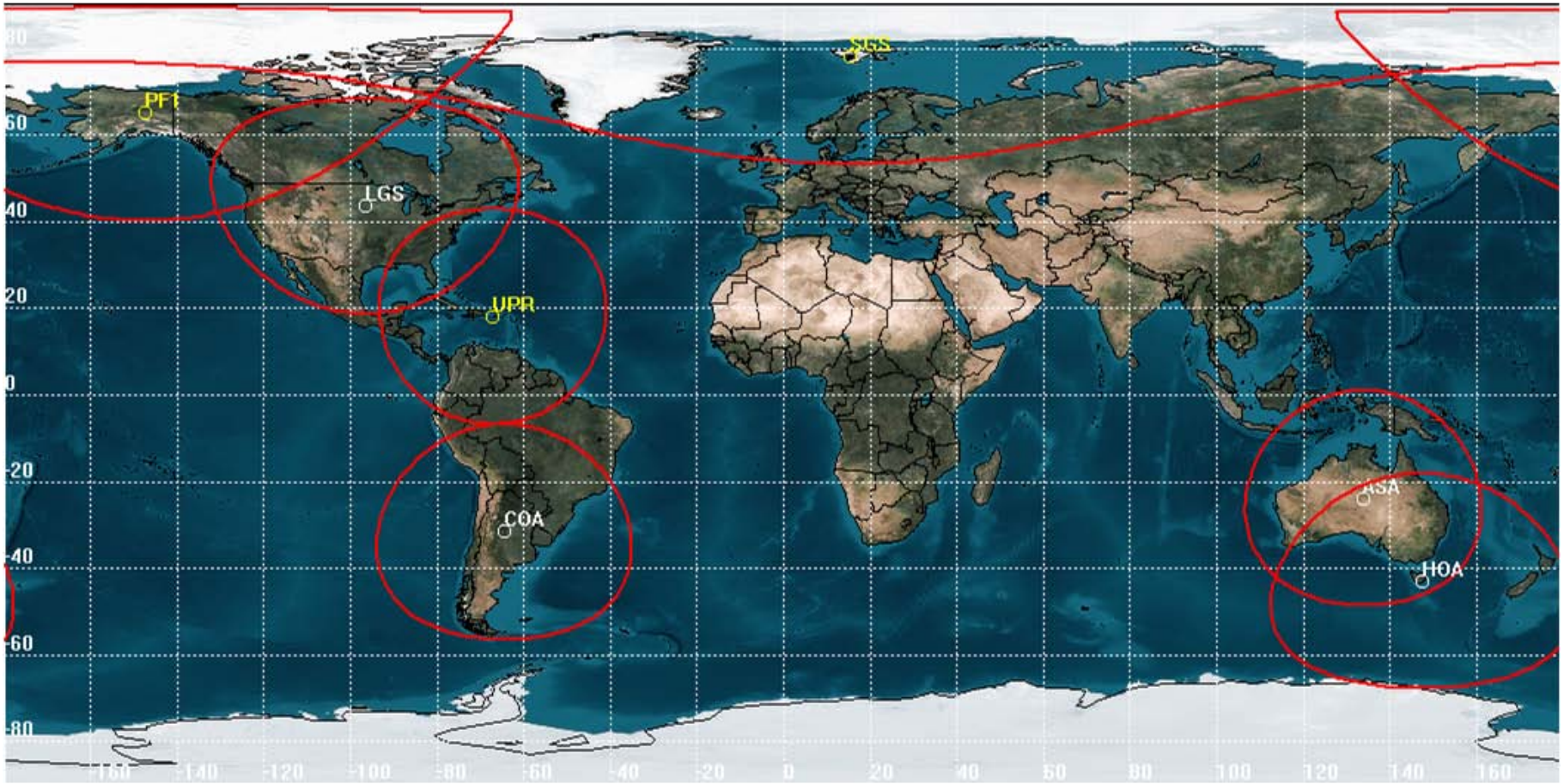


ETM+ SLC Failure Impact

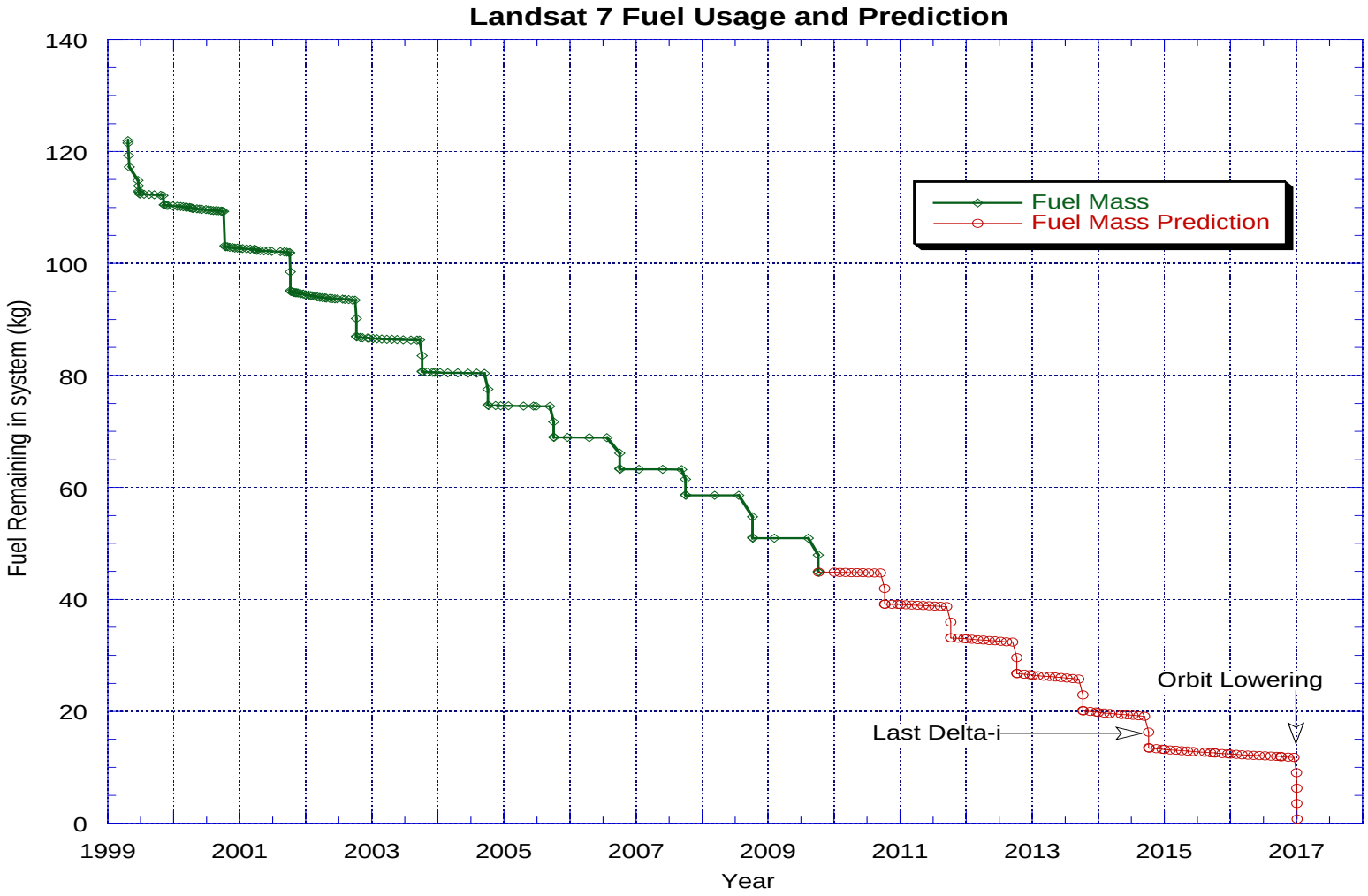
Note that the images show partial scenes, from the western edge through the scene center.

Landsat 7 Reception Network

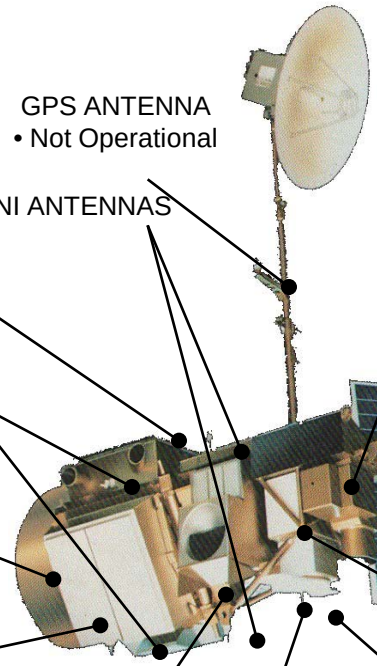
- US Network: LGS, PF1, PF2, ASA
- Backup Network: SGS
- IGS Network: UPR, COA, HOA



Landsat 7 Fuel Usage



Landsat 5 Status



HIGH GAIN ANTENNA
• 8/85 Transmitter A failure

GPS ANTENNA
• Not Operational

COMM & DATA HANDLING MODULE
• Located back side of s/c

OMNI ANTENNAS

MULTI-SPECTRAL SCANNER
• 8/95 Band 4 failure

ACS MODULE
• 07/03 FHST#1 Degradation
• Skew wheel tack anomaly 10/92
• 11/92 Earth Sensor 1 failure
• 02/02 Earth Sensor 2 failure
• Intermittent operations possible

SOLAR ARRAY DRIVE / PANELS
• 01/05 Primary Solar Array Drive failure
• Nominal Solar array panel degradation (12/04)
• 11/05 Redundant Solar Array Drive Malfunction

COARSE SUN SENSORS

PROPULSION MODULE
• 3/84 Primary Thruster D failure

POWER MODULE
• 05/04 Battery 1 failure / Removed from power circuits
• 10/07 1 of 22 Cells fails on Battery #2

X-BAND ANTENNA

WIDEBAND COMM. MODULE
• 07/88 Ku-band TWTA Prime failure (OCP)
• 07/92 Ku-band TWTA Redundant failure (OCP)
• 08/87 X-band TWTA Prime failure (OCP)
• 03/06 X-band TWTA Redundant Anomaly

THEMATIC MAPPER
• 10/94 Power Supply 1 stuck switch
• 06/02 TM switched to bumper mode

DIRECT ACCESS S-BAND
• 03/94 Side A FWD Power Sensor failure

Landsat 5 Lifetime Estimate

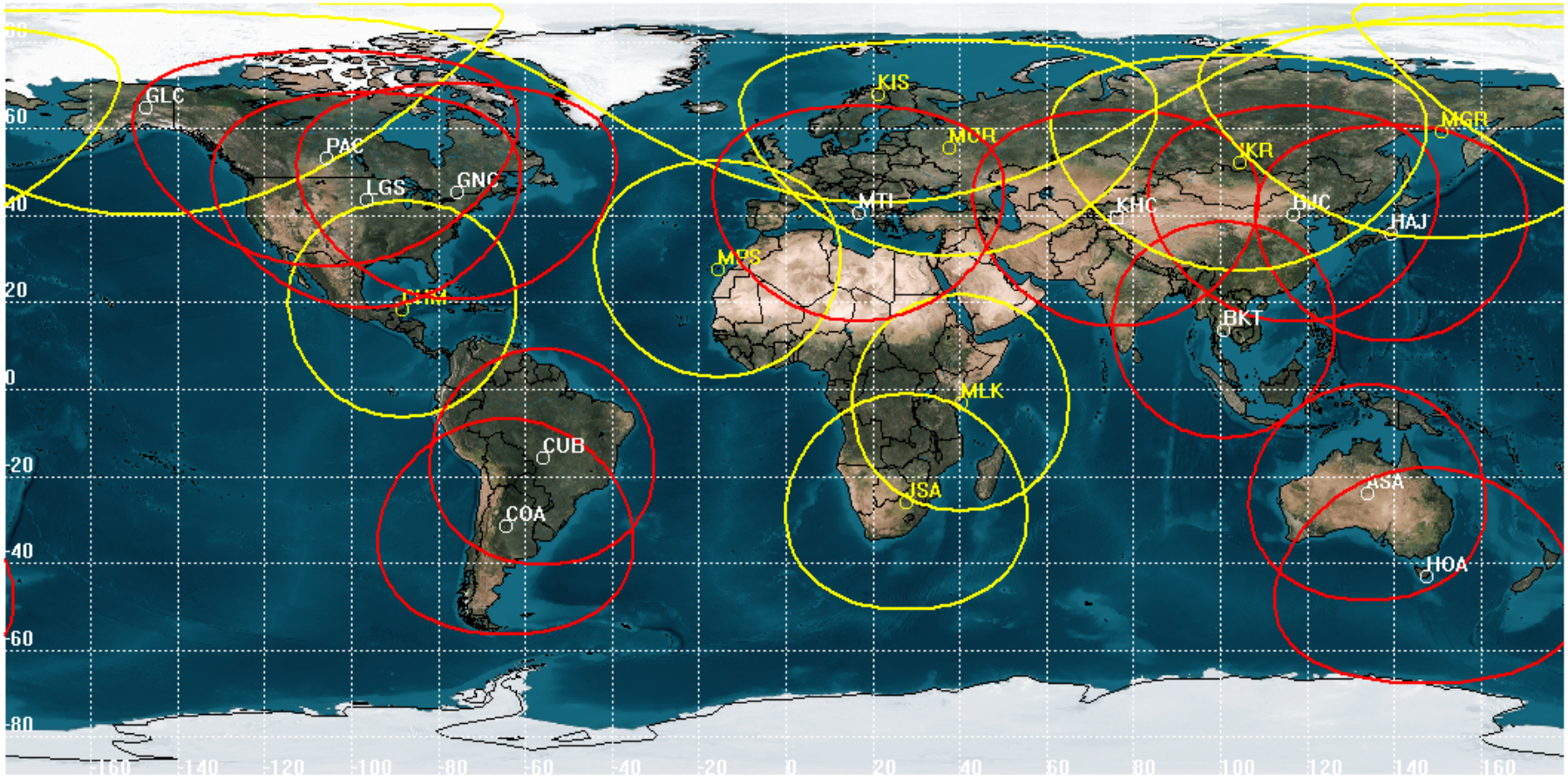
Resource	Relevant Data	Conclusion
Expendable (Propellant)	Fuel usage history monitored closely	Sufficient fuel to maintain current orbit to late 2013 within mission specifications
Expendable (Electric Power)	Solar array margin significantly above current energy storage capacity	Solar Array performing well with sufficient margin to continue operations through 2014
Life Limited (Battery)	Battery 3 operating nominally; actually improved after attitude anomaly reconditioning. Battery 2 at reduced capacity and used primarily as contingency power source	Aerospace review of battery performance sees no signs of imminent failure for either remaining battery
Life Limited (TWTAs)	Primary TWTA being monitored. Life expectancy from 8 months to 3 years	Mission will be operated until component failure then decommissioned
Configuration (redundancy)	26 years into the mission, many redundancies have been exercised.	Operational workarounds have been successfully instituted where necessary to maintain mission operations.

Landsat 5 Status

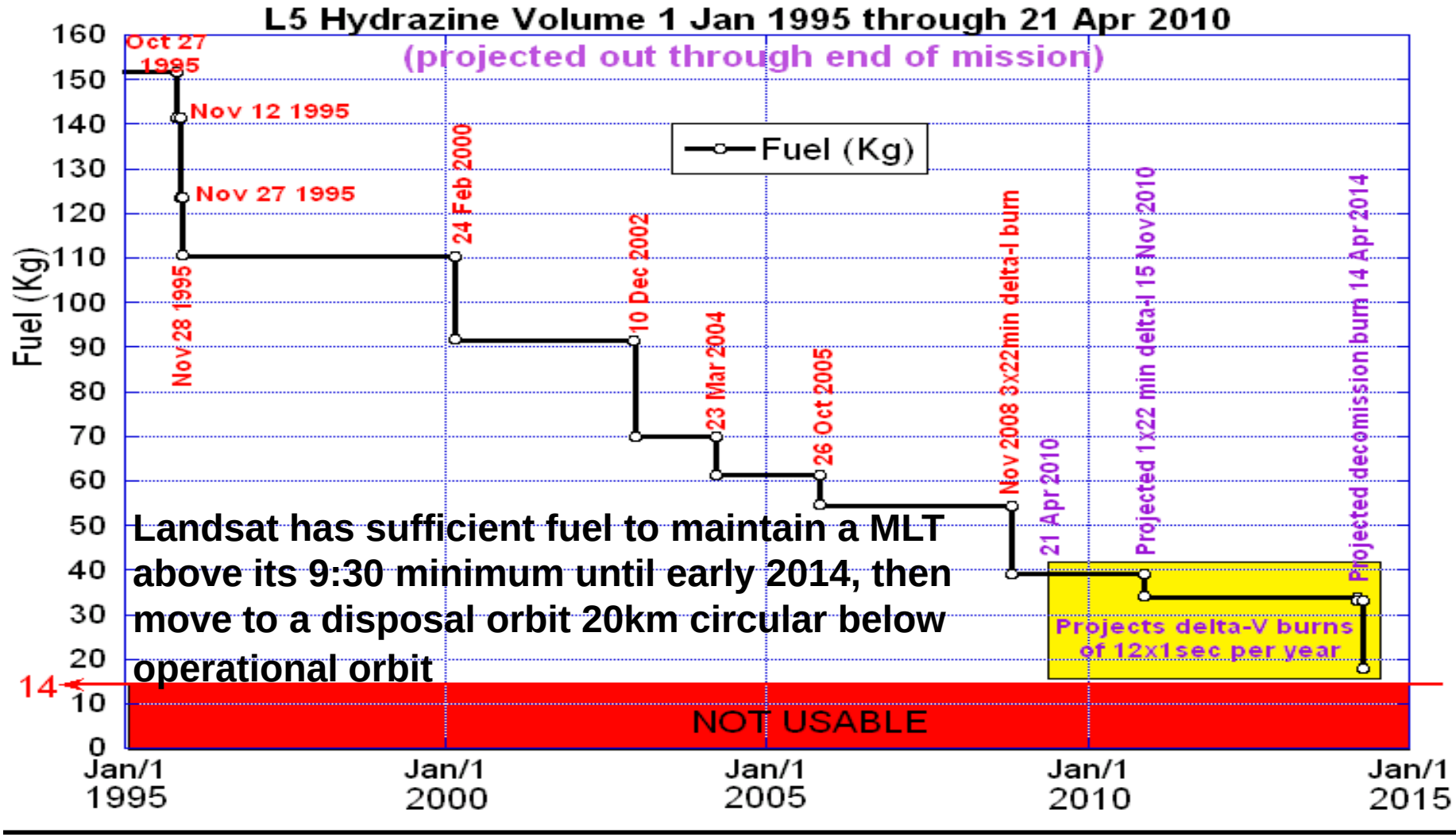
➢Landsat 5 - 23 years beyond design life

- 1984 Launch
- Spacecraft
  - Battery 2 Anomaly (On-going) – Oct 2007
  - Star Tracker Issue – June 2007
  - Solar Array Drive
    - Fixed array operations – Aug 2006
  - **Current Travelling Wave Tube Amplifier (TWTA) problems**
- TM
  - Functioning normally in bumper-mode
  - Collecting about 190 scenes per day
- Fuel
  - Current estimates indicate fuel sufficient to maintain operations through 2013

Landsat-5 Reception Network



Landsat 5 Fuel Usage:
Actual & Predicted



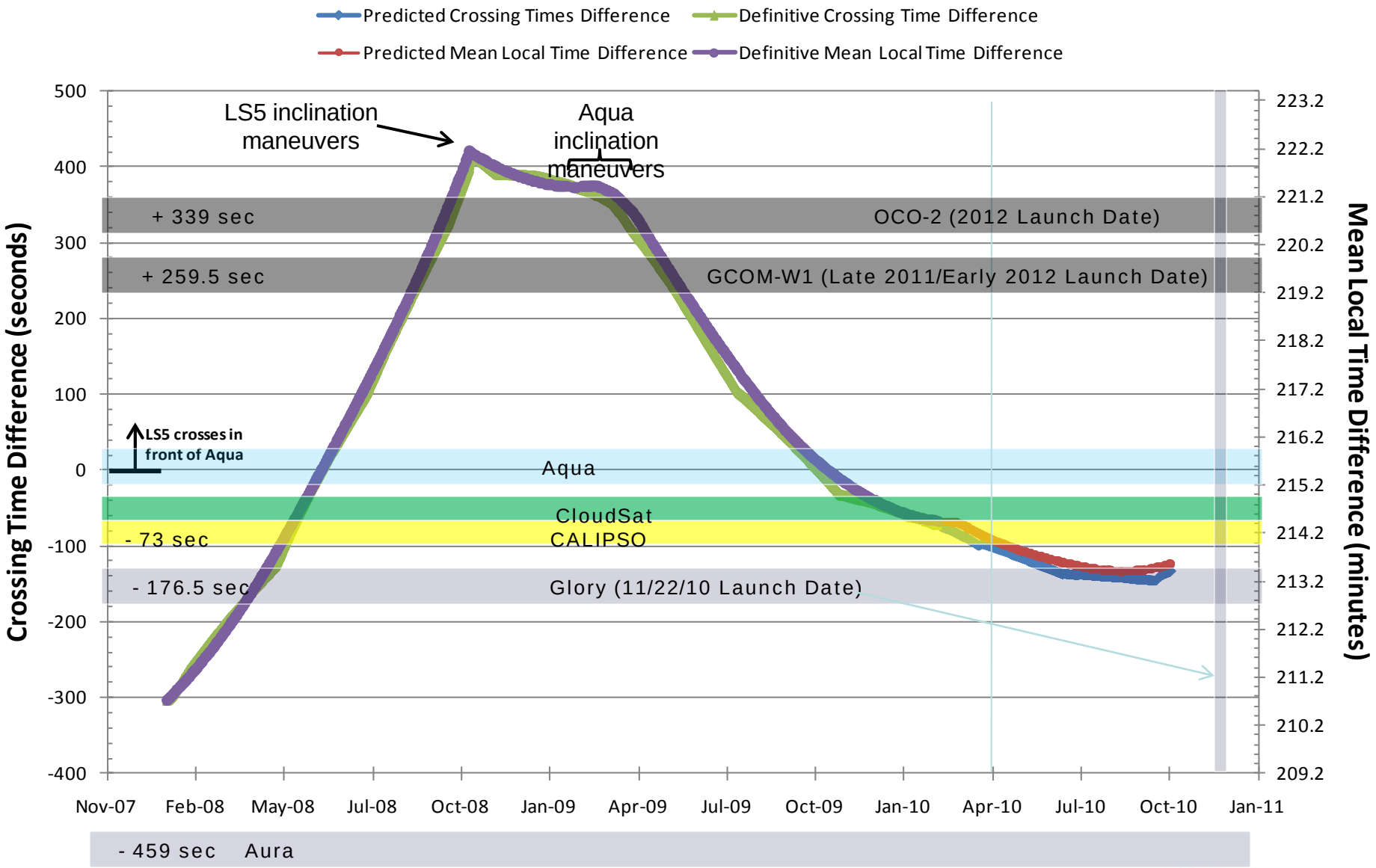
Landsat 5 TWTA Status

- **Transverse Wave Tube Amplifier (TWTA) necessary to transmit TM data through Landsat 5 X-band antenna**
  - Landsat 5 carries two TWTA's, a primary and a redundant
- **TWTA Failures**
  - *Primary X-band TWTA Failed – October 1987*
  - *Redundant TWTA Failed – December 2009*
  - *Primary TWTA Recovered – January 2010*
- **Primary TWTA began to degrade soon after 2010 recovery**
  - Helix current is diagnostic of remaining life
  - Current increase trended towards failure in three to eight months
- **TM duty cycle reduced to 50% to extend TWTA life**
  - Current increase began to plateau
  - Resulting trend indicates TWTA lifetime could extend out to three years
  - USGS accepted Science Team priorities for TM data collection

Landsat 5 / A-Train Conjunctions

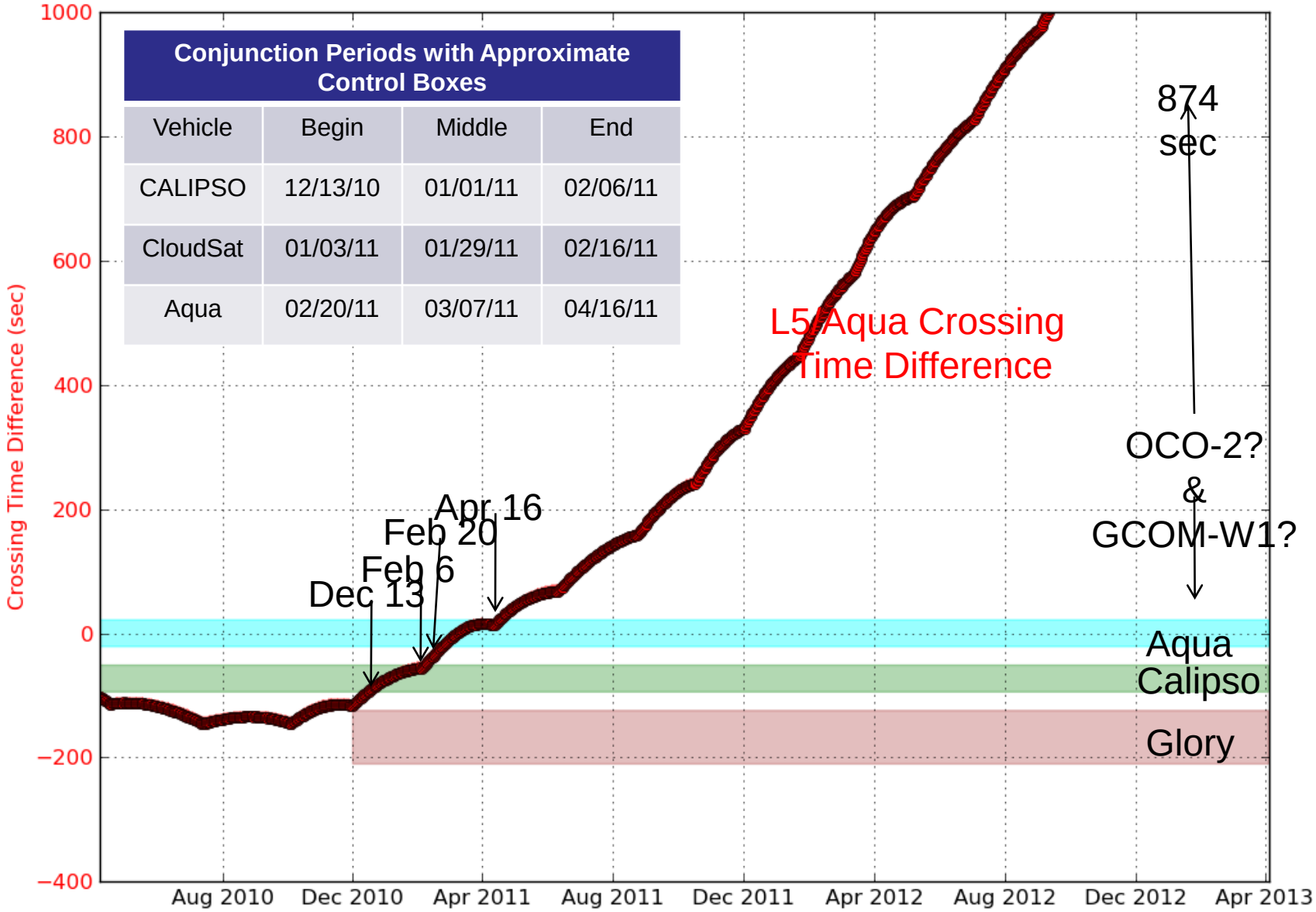
- **Landsat 5 and A-Train satellite orbits cross at the poles**
  - Satellites all in nominal 705 km orbits
- **PROBLEM: Existing JSpOC conjunction assessment process missed conjunction between L-5 and A-Train prior to 2010**
  - Software logic fault led to failure to predict and report conjunctions
  - Software has been fixed
  - A-Train operators, coordinated by ESMO, and the Landsat 5 operators were unaware of pre-2010 conjunctions
- **ESMO organized meeting at NASA GSFC yesterday and today to resolve issues**
  - Glory launch into A-train in November, 2010 increases complexity
  - Future missions, e.g., LDCM, must be operated to avoid conjunctions

Aqua Orbit Crossing and Mean Local Time Differences Relative to Landsat 5



L5-Aqua Time Separation at Crossings

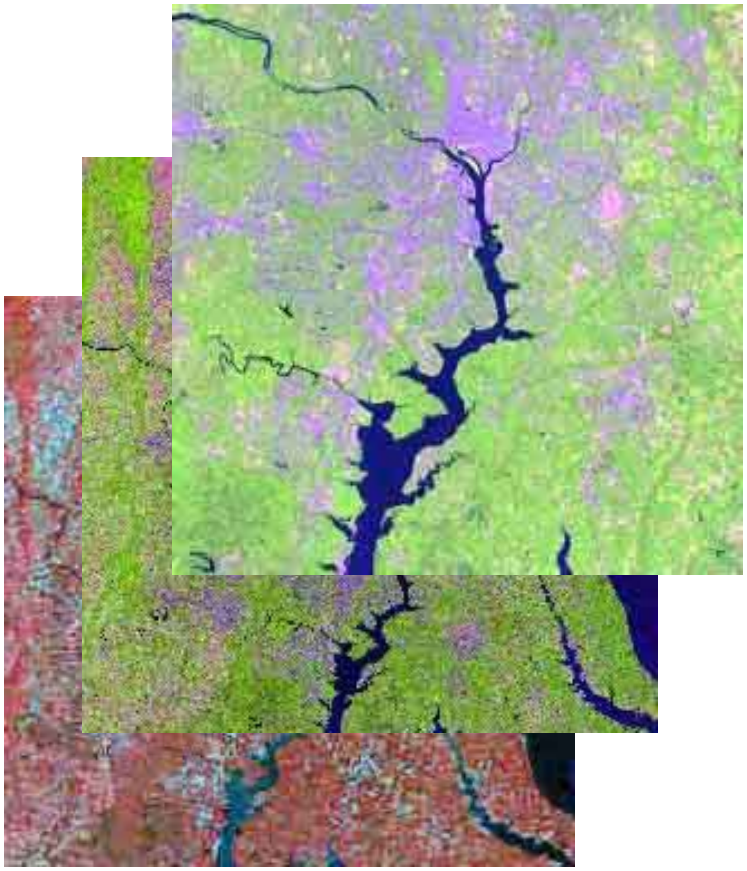
Conjunction Periods with Approximate Control Boxes			
Vehicle	Begin	Middle	End
CALIPSO	12/13/10	01/01/11	02/06/11
CloudSat	01/03/11	01/29/11	02/16/11
Aqua	02/20/11	03/07/11	04/16/11



U.S. Landsat Data Archive Status

- **Data are archived and distributed by USGS EROS Center, Sioux Falls, SD**
  - **Over 2 million scenes in the archive**
  - **Products are provided for free on request to the public via the internet**

- **As of November 30, 2009**
- **ETM+: Landsat 7**
  - 990,735 scenes
  - 920 TB RCC & L0Ra Data
  - Archive grows by 260 GB Daily
- **TM: Landsat 4 & Landsat 5**
  - 843,787 scenes
  - 211 TB of L0Ra Data
  - Archive Grows by 40 GB Daily
- **MSS: Landsat 1 through 5**
  - 652,088 scenes
  - 19 TB of Data



A New Era for Landsat Data Users

- **USGS EROS has historically distributed Landsat data products to the general public on a non-discriminatory basis at the "cost of fulfilling a user request (COFUR)"**
  - $600 per Landsat 7 ETM+ scene

- **April 21, 2008 USGS Technical Announcement:**
  - "By February 2009, any Landsat archive scene selected by a user will be processed, at **no charge**, automatically to a standard product recipe and staged for electronic retrieval."

- **Data distribution rate increased by a factor of 45**
  - EROS began distributing free Landsat data on Oct. 01, 2008
  - Previous annual maximum distribution was 25,000 scenes in 2001
  - EROS distributed 1,145,704 scenes in FY09, resulting in a 45x increase in data distribution

- **LDCM will be the first Landsat satellite launched into this new era of free Landsat data**

LDCM Milestones

- OSTP directed NASA and USGS to implement the LDCM as a "free-flyer" satellite in Dec., 2005
- NASA and USGS signed Final Implementation Agreement in April, 2007
- Operational Land Imager (OLI) contract was awarded to Ball Aerospace Technology Corporation in July, 2007
- Atlas V launch vehicle was selected in Oct. 2007
- Spacecraft contract was awarded to General Dynamics Advanced Information Systems in April, 2008
- Mission Operations Element (MOE) contract awarded to The Hammers Company in September, 2008
- Thermal InfraRed Sensor (TIRS) development started in July, 2008

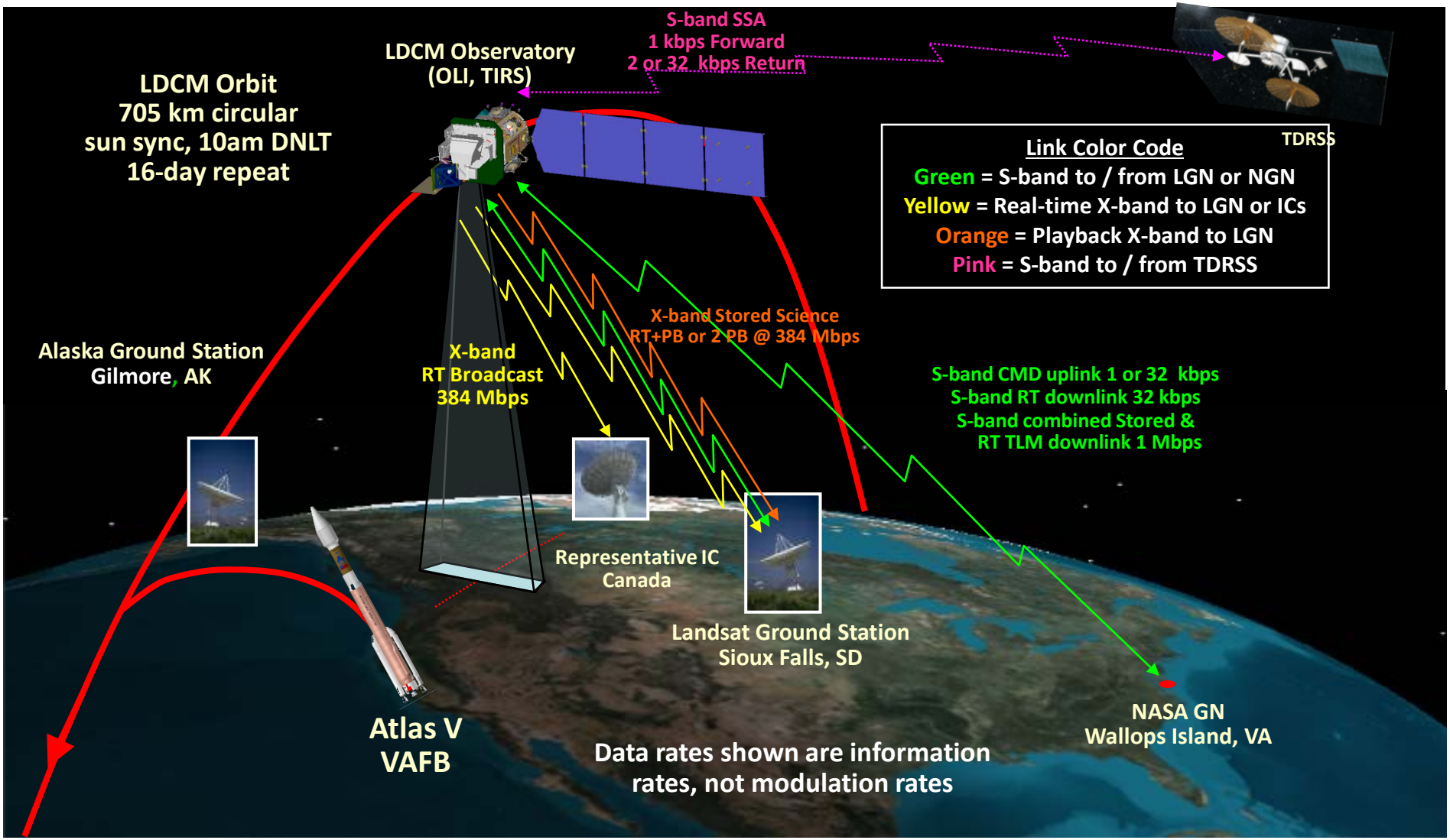
NASA/USGS Partnership

- **The NASA Associate Administrator and the USGS Associate Director of Geography, signed a "Final Implementation Agreement" for LDCM in April 2007**

- **NASA Responsibilities**
  - Development of Space Segment, Launch Segment, and the Mission Operations Element (MOE)
  - Lead mission development as the system integrator and lead the missions systems engineering for all mission segments throughout development, on-orbit check-out, and acceptance
  - Accountable for mission success through on-orbit check-out and acceptance across all mission segments

- **USGS Responsibilities**
  - Development of the Ground System (comprised of the Flight Operations and Data Processing and Archive Segments), excluding procurement of the Mission Operations Element (MOE)
  - Lead, fund, and manage the Landsat Science Team
  - Lead LDCM mission operations, after the completion of the on-orbit checkout period

LDCM System

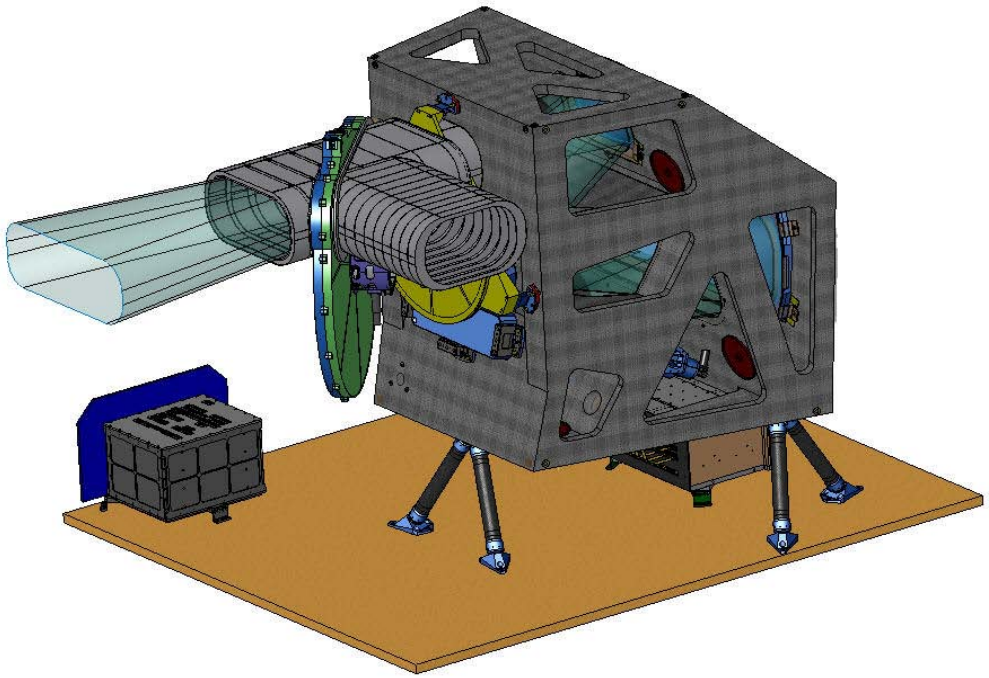

LDCM Orbit
705 km circular
sun sync, 10am DNLT
16-day repeat
LDCM Observatory
(OLI, TIRS)
S-band SSA
1 kbps Forward
2 or 32 kbps Return
TDRSS
Link Color Code
Green = S-band to / from LGN or NGN
Yellow = Real-time X-band to LGN or ICs
Orange = Playback X-band to LGN
Pink = S-band to / from TDRSS
X-band Stored Science
RT+PB or 2 PB @ 384 Mbps
Alaska Ground Station
Gilmore, AK
X-band
RT Broadcast
384 Mbps
S-band CMD uplink 1 or 32 kbps
S-band RT downlink 32 kbps
S-band combined Stored &
RT TLM downlink 1 Mbps
Representative IC
Canada
Landsat Ground Station
Sioux Falls, SD
NASA GN
Wallops Island, VA
Atlas V
VAFB
Data rates shown are information
rates, not modulation rates

Operational Land Imager (OLI)

Contract awarded to Ball Aerospace Technical Corp. (BATC) July 2007

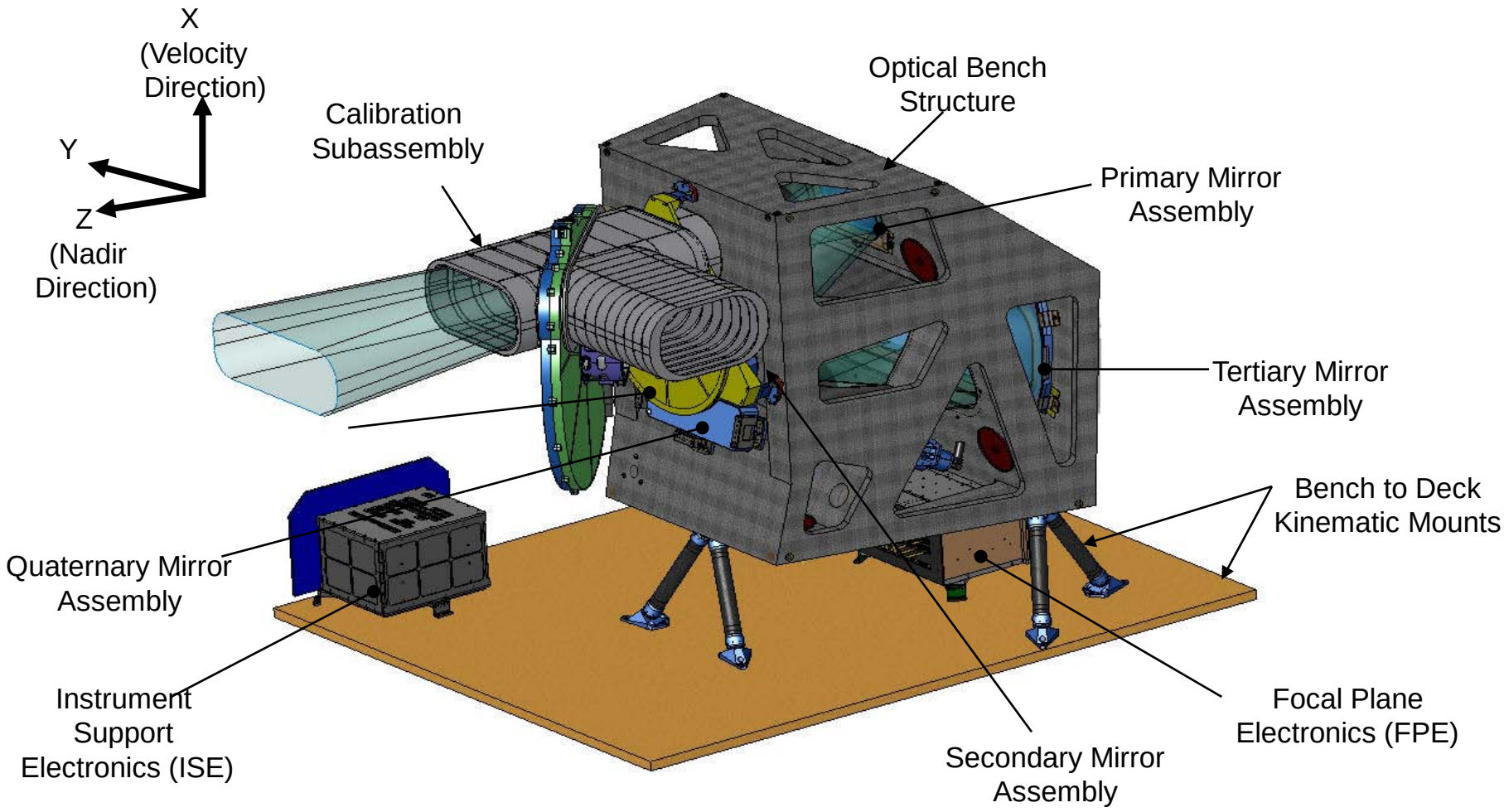
Critical Design Review Completed Oct. 2008

- Pushbroom VIS/SWIR sensor
- Four-mirror telescope with front aperture stop
- FPA consisting of 14 sensor chip assemblies, passively cooled
- Aperture 135 mm
- F number 6.4
- 36 um / 18 um detectors (MS / Pan)



Courtesy of BATC

OPERATIONAL LAND IMAGER

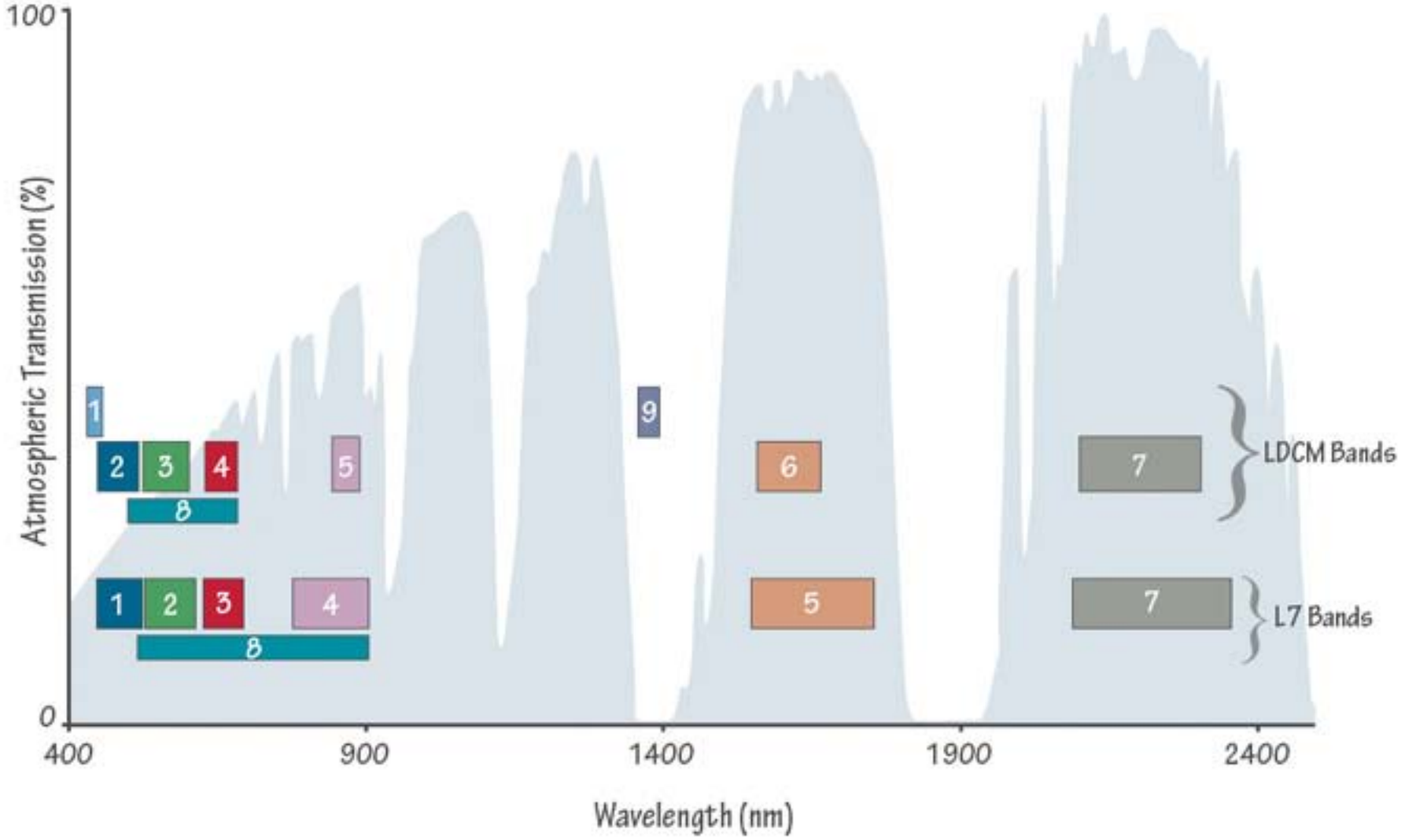


Key Spectral Requirements – Spectral Bands

L7 ETM+ Bands			LDCM OLI Band Requirements			
			30 m Coastal/Aerosol	0.433 - 0.453	**(2)**	**Band 1**
Band 1	**30 m Blue**	0.450 - 0.515	**30 m Blue**	0.450 - 0.515		**Band 2**
Band 2	**30 m Green**	0.525 - 0.605	**30 m Green**	0.525 - 0.600		**Band 3**
Band 3	**30 m Red**	0.630 - 0.690	**30 m Red**	0.630 - 0.680		**Band 4**
Band 4	**30 m Near-IR**	0.775 - 0.900	**30 m Near-IR**	0.845 - 0.885		**Band 5**
Band 5	**30 m SWIR-1**	1.550 - 1.750	**30 m SWIR-1**	1.560 - 1.660		**Band 6**
Band 6	**60 m LWIR**	10.00 - 12.50	**N/A**		**(3)**	
Band 7	**30 m SWIR-2**	2.090 - 2.350	**30 m SWIR-2**	2.100 - 2.300		**Band 7**
Band 8	**15 m Pan**	0.520 - 0.900	**15 m Pan**	0.500 - 0.680		**Band 8**
			30 m Cirrus	1.360 - 1.390	**(1)**	**Band 9**

- **Explanation of Differences**
  1) Cirrus Band added in 2001 to detect cirrus contamination in other channels
  2) Coastal Band added in 2001 at request of ocean color investigators requiring higher resolution of coastal waters relative to MODIS and SEAWifs
  3) LWIR data to be collected by Thermal InfraRed Sensor (TIRS)
  4) Bandwidth refinements made in all bands to avoid atmospheric absorption features
     1) Enabled by higher SNR which is, in turn, enabled by push-broom instrument architecture

OLI Spectral Bands



System Enhancements

Signal-to-Noise Ratios (SNR)

	$L_{typical}$ SNR			L_{High} SNR		
Band	**ETM+ Performance**	**EO-1 ALI Performance (1)**	**OLI Requirements (2)**	**ETM+ Performance**	**EO-1 ALI Performance (1)**	**OLI Requirements (2)**
Coastal Aerosol	N/A	150	130	N/A	340	290
Blue	40	190	130	140	540	360
Green	40	210	100	190	830	390
Red	30	210	90	140	810	340
NIR	35	170	90	250	880	460
SWIR 1	35	200	100	190	1080	540
SWIR 2	30	240	100	140	950	510
Pan	16	190	80	90	550	230
Cirrus	N/A	N/A	50 (3)	N/A	N/A	N/A

- Studies by the Earth Observer-1 (EO-1) Science Team consistently found that Advanced Land Imager (ALI) data offered improved ability to classify images, detect land cover change, and map environmental features and conditions relative to ETM+ data

OLI Status

OLI Status

- **Flight Telescope Completed**
  - Alignment
  - Thermal Vacuum
  - Vibration
- **Engineering Development Unit (EDU) Focal Plane Array Testing Completed**
  - Integration and alignment into flight telescope completed
  - Electrical integration to telescope starting
- **Stray Light Test Successfully Completed**
- **Instrument Baseplate Delivered**
- **Flight Software successfully completed Qualification Testing**
- **Thermal Control System Thermal Balance Test successfully completed**
- **Flight Focal Plane Electronics vibration successfully completed**
- **Algorithm Development Progressing**
  - Many portions of code completed in preparation for EDU Risk Reduction Testing

A Thermal InfraRed Sensor (TIRS) for the LDCM

- **A Phase A TIRS study was initiated by HQ at NASA Goddard Space Flight Center (GSFC) on July 1, 2008.**
  - The goal was to develop an instrument concept and implementation approach that would not delay the planned December 2012 launch of LDCM.
- **The Systems Concept Review was successfully completed on October 17th, 2008**
- **A TIRS System Requirements Review was successfully completed on February 2-3, 2009.**
- **A TIRS Preliminary Design Review was successfully conducted May 27-28, 2009**
- **TIRS was included in the baseline LDCM design for the mission preliminary design review in July, 2009**
- **The TIRS critical design review is scheduled for April 27-29, 2010**

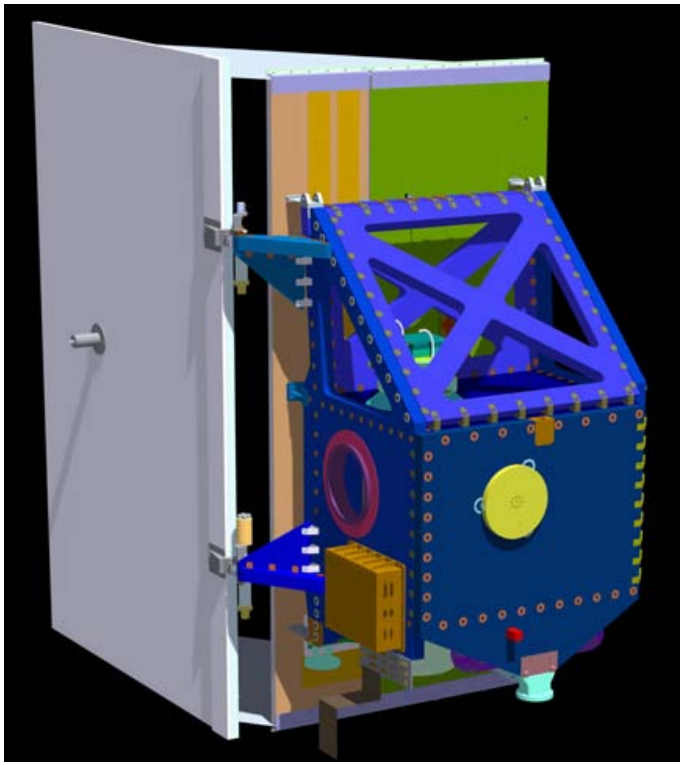
LDCM Thermal Requirements

Band	Center Wavelength (micrometers)	Spatial Resolution At Nadir (m)	NEΔT Requirements	
			At $T_{Typical}$	At T_{High}
Thermal 1	10.8	120	0.4 K	0.35 K
Thermal 2	12.0	120	0.4 K	0.35 K

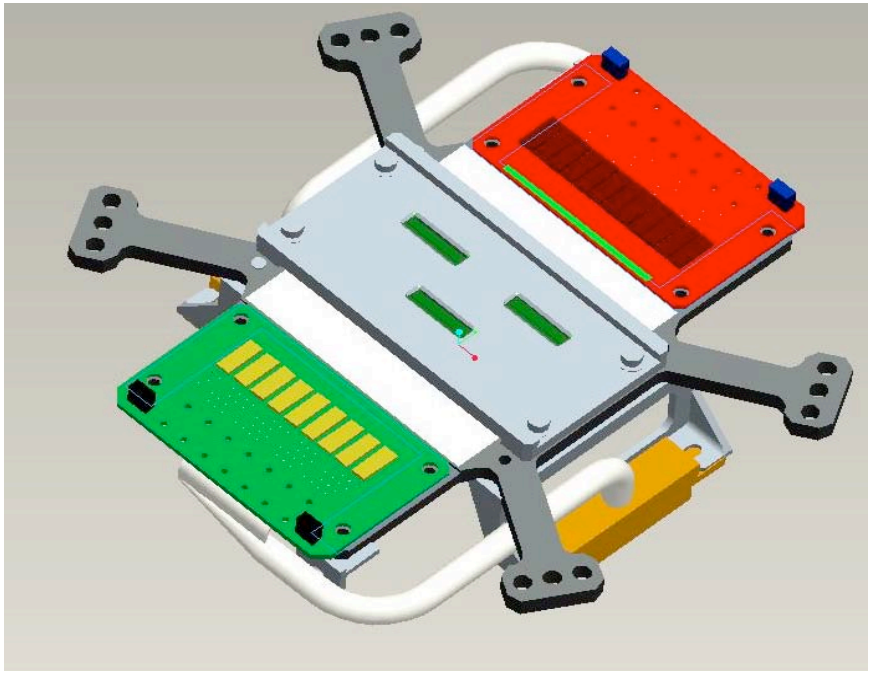
- 120 m resolution was felt to be sufficient to resolve most center-pivot irrigation fields in U.S. West - typically 400 to 800 m in diameter
- Landsat satellites provide 16 day repeat imaging -- sufficient for water consumption estimation
- Landsat 4 & 5 TM's provided 120 m thermal images for a single thermal band
- Landsat 7 ETM+ provided 60 m thermal images for a single thermal band
- A two band instrument will enable atmospheric correction so that more accurate surface temperatures can be derived.

TIRS Overview

- 2 channel (10.8 and 12 um) thermal imaging instrument
- Quantum Well Infrared Photodiodes (QWIP) / FPA built in-house at Goddard
- <120 m Ground Sample Distance (100 m nominal)
- 185 km ground swath (15° field of view)
- Operating cadence: 70 frames per second
- Pushbroom design with a precision scene select mirror to select between calibration sources
- Two full aperture calibration sources: onboard variable temp black body and space view
- Passively cooled telescope assembly operating at 180K
- Actively cooled (cryocooler) FPA operating at 43K
- 3 Year Design Life, Class C Instrument

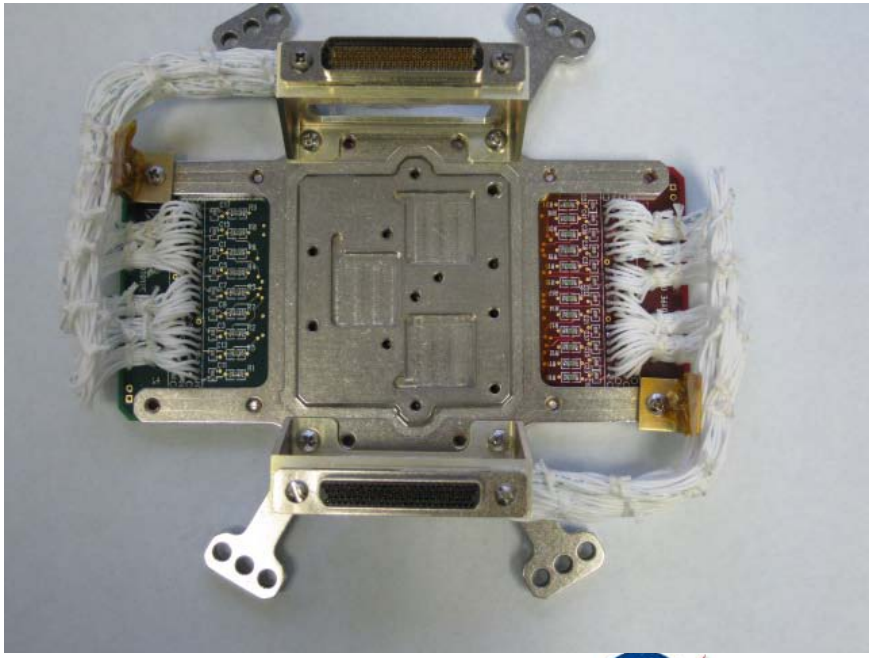


Pathfinder Focal Plane Assembly (FPA)



Fully assembled FPA
Front side

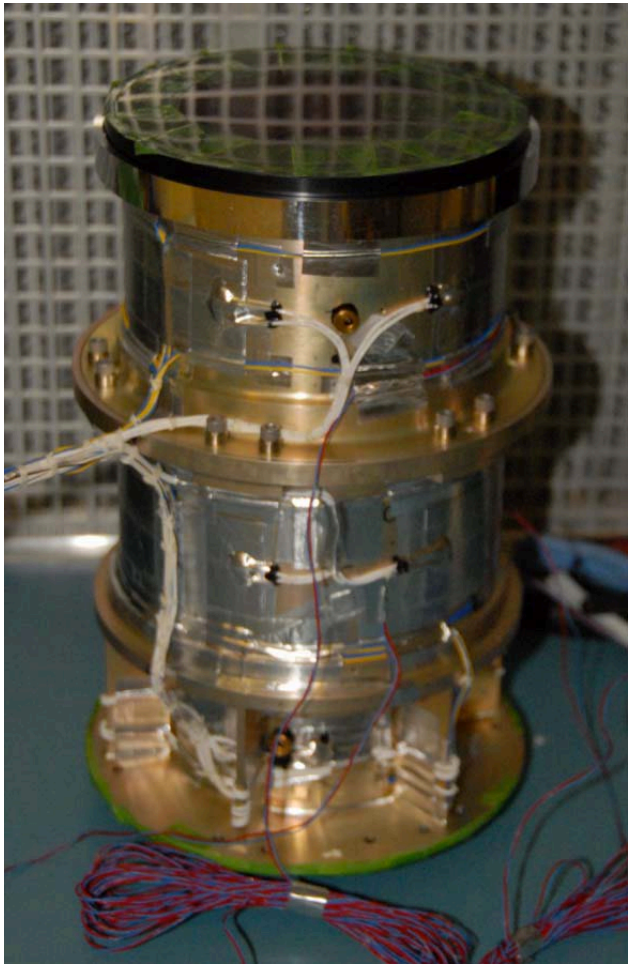
- Pathfinder FPA testing conducted to demonstrate flight readiness of the design
  - Vibration
  - Radiation
  - Thermal Cycling



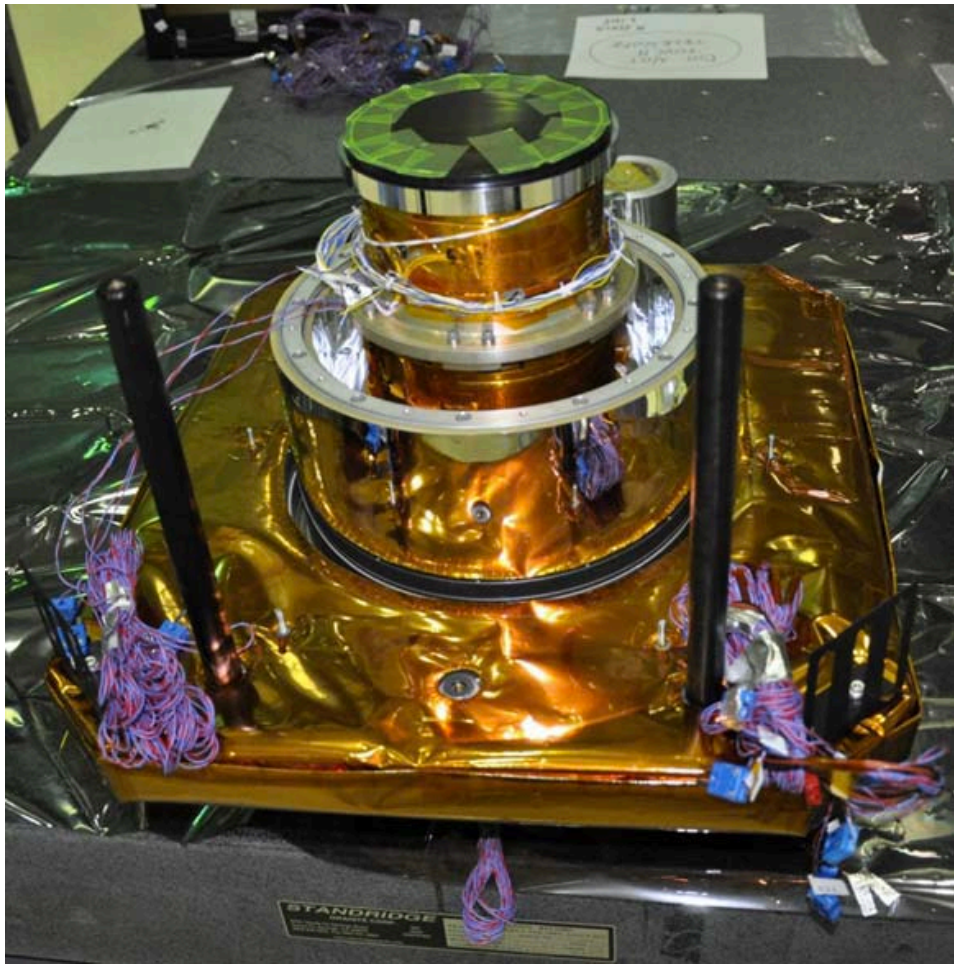
TIRS Status

- **Focal Plane Array**
  - Successfully completed its Technical Readiness Level-6 testing
    - Radiation on the ROICs / QWIPs
    - 40 thermal cycles on the FPA
    - Vibration on the FPA
  - Flight Detectors have been selected
- **Engineering Model FPE completed and in test**
  - Image has been produced through the ROIC using the FPE Engineering Model
- **TIRS Functional Performance Model in testing**
  - Significant risk reducer for TIRS.
    - Includes Engineering Model telescope and FPA
  - Initial testing validates design
    - Focus testing
    - Scattering
- **Scene Select Mechanism**
  - Pathfinder scene select mirror completed through fabrication and anodization
  - Electronics breadboard is operating and demonstrating the required stability

TIRS Functional Performance Model



Telescope



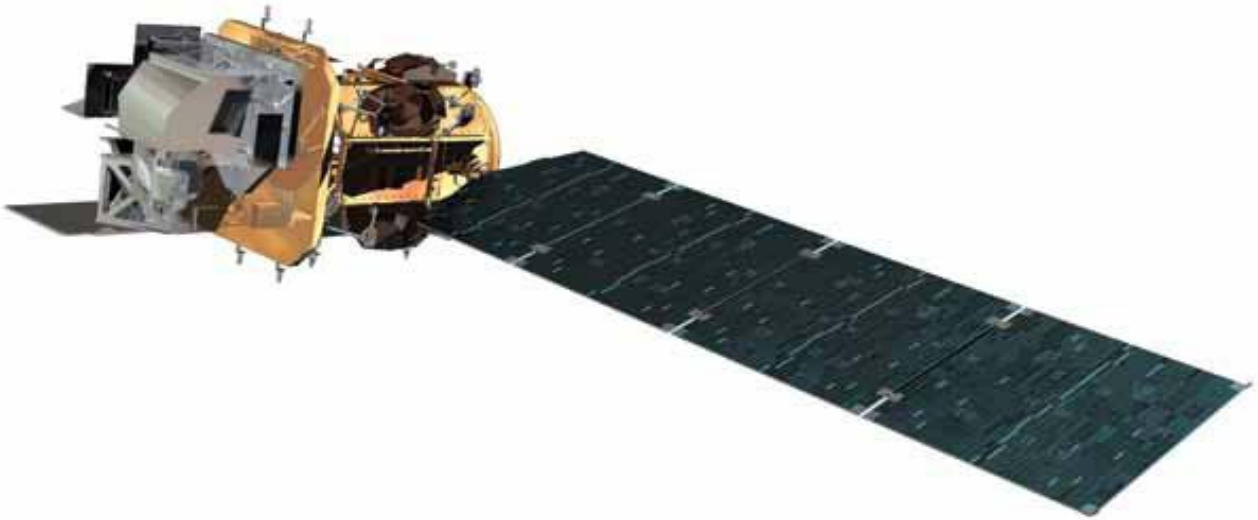
Completed Functional Performance Module

Launch Vehicle

In September 2007, the Atlas V 401 launch vehicle was selected for LDCM by the Kennedy Space Center.

LDCM Spacecraft

- **Contract awarded to General Dynamics Advanced Information Systems (GDAIS) in April 2008**
  - Critical design review completed October, 2009
- **Orbital Sciences Corporation (OSC) completed acquisition of GDAIS spacecraft manufacturing division by April 02, 2010**



Courtesy of OSC

Spacecraft Status

- All Engineering Model boxes complete and tested
- Flight harness in fabrication
- Engineering Model solar array deployed
- Low Density Parity Chip ASIC completed qualtest
- Successful X-band demonstration (with GSFC ground equipment)
- Successful S-band demonstration
- Spacecraft structure assembly is underway

Ground System

- **The LDCM ground system is in development under the management of the USGS Earth Resources Observation and Science (EROS) Center in Sioux Falls, SD**
- **The ground system will schedule the collection of 400 coincident OLI/TIRS scenes per day**
  - Data collection will be scheduled on the basis of a Long Term Acquisition Plan (LTAP) modeled on the Landsat 7 LTAP to achieve seasonal coverage of the global land surface
  - USGS EROS will capture and archive all 400 scenes
    - OLI/TIRS data will also be directly transmitted from the spacecraft to international ground stations
  - Level 1 data products distributed at no cost to users consistent with current data policy
    - Orthorectified, terrain corrected images for all OLI and TIRS spectral bands
    - Level 0 data (essentially raw data) will also be distributed on request
- **Ground System Critical Design Review held March 16 – 18 in Sioux Falls, SD**

Take Away Message

- **The NASA Agency Management Council confirmed that the LDCM is ready for the final design and fabrication phase of mission development following a Dec. 16, 2009 review. The confirmed LDCM payload now includes TIRS in addition to the OLI with development managed towards a target Dec., 2012 launch date.**
  - Mission Critical Design Review scheduled for May 25 – 27, 2010
- **Summary**
  - BATC is building an Operational Land Imager (OLI)
  - NASA GSFC is building a Thermal InfraRed Sensor (TIRS)
  - OSC is building the LDCM spacecraft
  - An Atlas V will launch the LDCM observatory
  - USGS will operate the observatory and will collect, archive and distribute LDCM data
    - LDCM data products will merge the OLI and TIRS data
    - LDCM data products will be distributed for free