Extending the Landsat Legacy: Progress Towards an LDCM Launch

presented to the

Washington / Northern Virginia Chapter

of the

IEEE Geoscience and Remote Sensing Society

by

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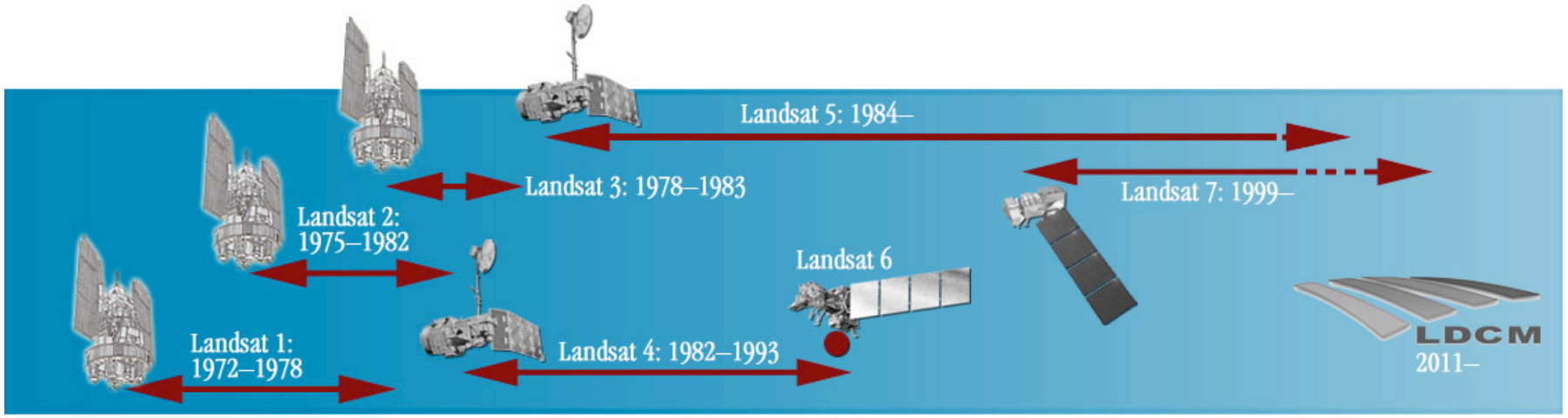
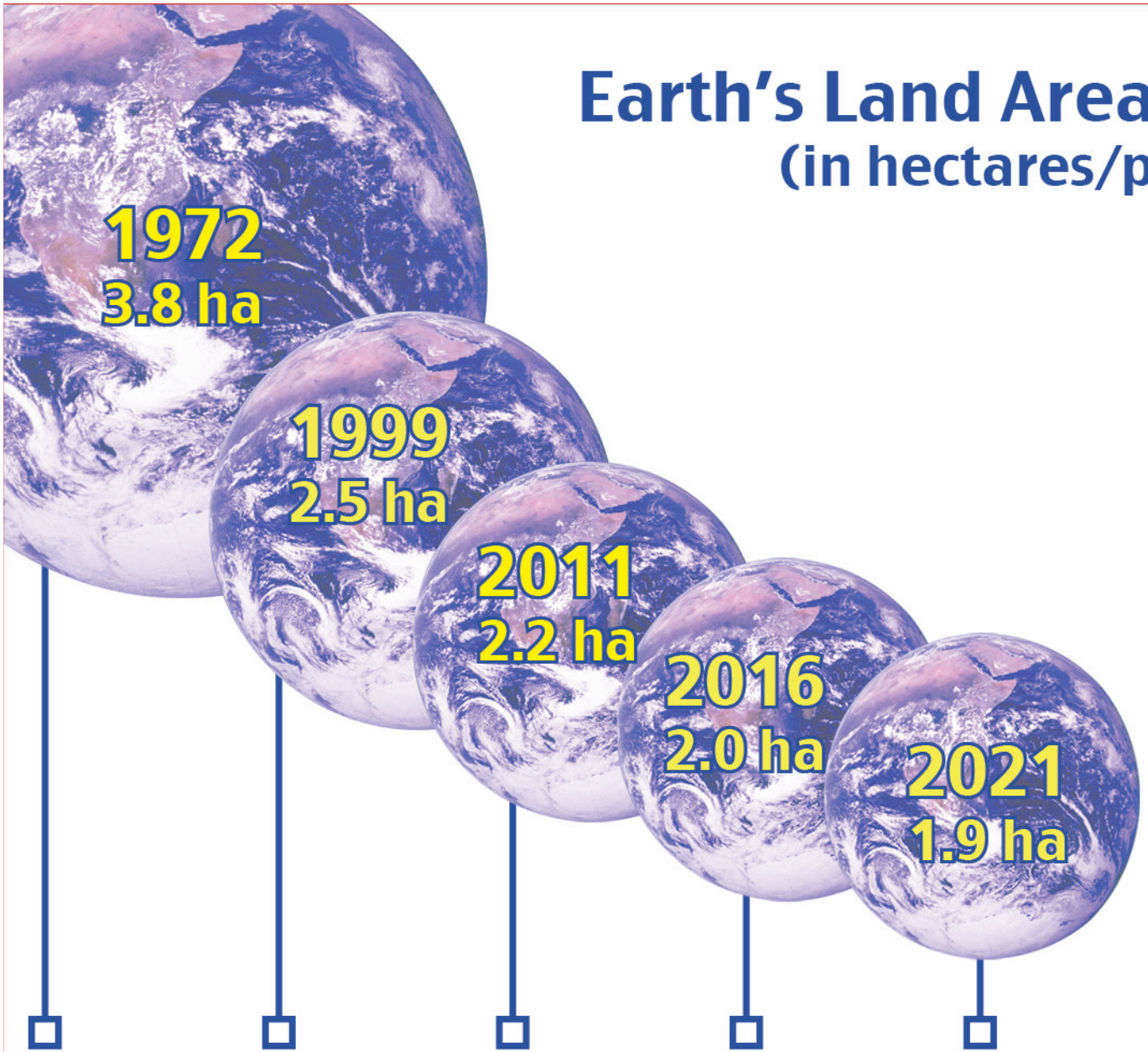
History of the Landsat Program



1970 1975 1980 1985 1990 1995 2000 2005 2010 2015

Gov't Operations | Commercial Operations | Gov't Operations

Earth's Land Area per Person
(in hectares/person)



1972	1999	2011	2016	2021
Landsat 1	Landsat 7	LDCM	LDCM	LDCM
Launch	Launch	Launch	Design Life End	End of Consumables
3.9B people	6.0B people	6.9B people	7.3B people	7.7B people

Why Build the Next One?

- **Due to increasing population land cover and land use are changing at rates unprecedented in human history with profound consequences for society**

  Food - Water - Shelter - Climate

- **No alternatives to Landsat data continuity**
  - Scale
  - Archive
  - Geographic coverage
  - Data distribution policy
  - Calibration & data quality

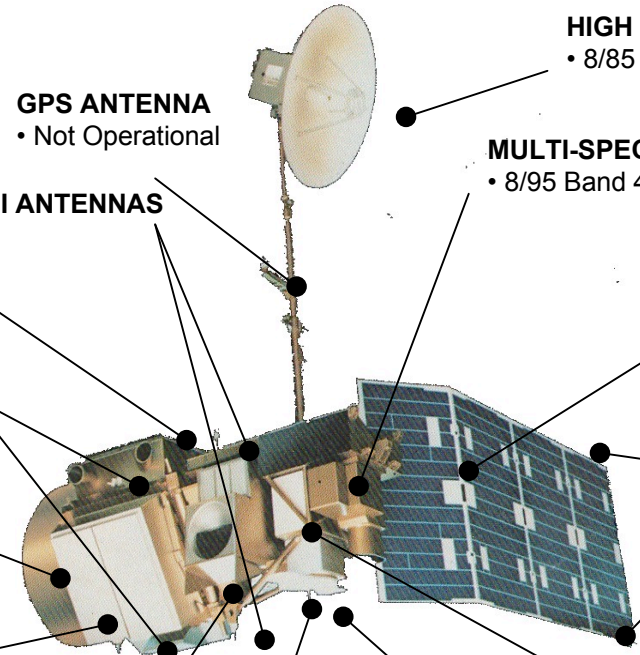
- **The need is urgent**
  - Landsat 5 and Landsat 7 are well past design lives

- **A Landsat Data Continuity Mission (LDCM) aligns directly with strategic plans for NASA, national climate change research, and international earth observations**

- **Both the Executive Office of the President and the Congress have mandated a Landsat 7 successor mission**

Landsat 5 Flight Segment

LDCM



HIGH GAIN ANTENNA
• 8/85 Transmitter A failure

GPS ANTENNA
• Not Operational

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

MULTI-SPECTRAL SCANNER
• 8/95 Band 4 failure

OMNI ANTENNAS

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

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

X-BAND ANTENNA

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

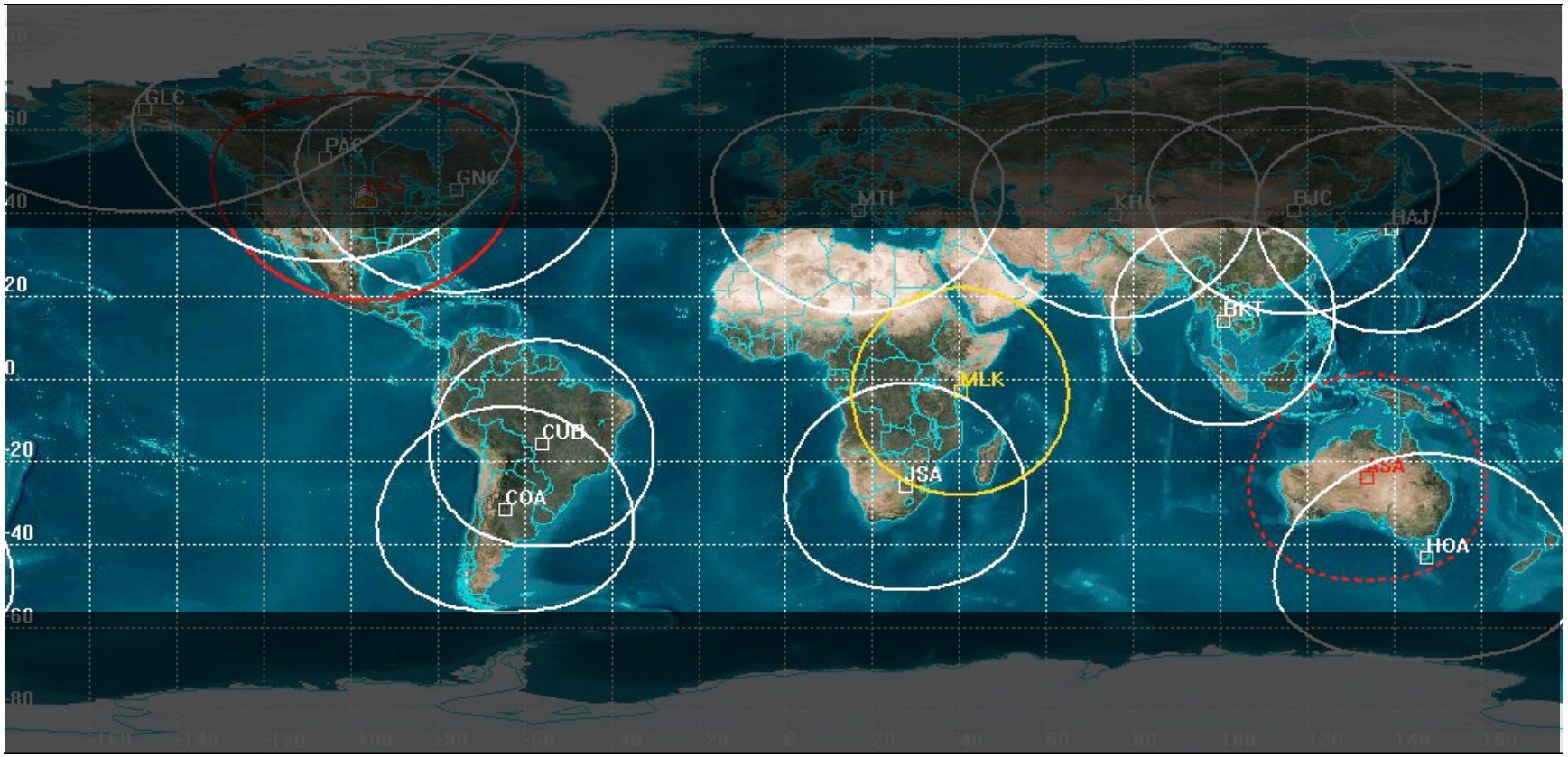
DIRECT ACCESS S-BAND
• 03/94 Side A FWD Power Sensor failure

Courtesy of Kristi Kline, USGS EROS

Landsat 5 Sun Angle Constraints

- **Nominal coverage at winter solstice**
  - December 21

Courtesy of Kristi Kline, USGS EROS



Breaking Landsat 5 News

- **From USGS on Tues., Jan. 20:**
  - In October 2007, the mission suffered a major anomaly with one of its two remaining batteries. At that time it wasn't certain that we'd ever be able to resume imaging operations. However, with expert handling from the L5 FOT and some external support, the mission was able to resume some imaging capability, but with a significant reduction in the ability to image a higher latitudes in the 'winter' months. With these limitations, L5 has been unable to image above the Texas state boarder during the winter months. After continuing efforts by the FOT staff, I am pleased to report that on January 19th, L5 will resume full, pre-anomaly imaging capabilities for the Northern Hemisphere ground stations. With this increased capability, we will once again be able to image full CONUS coverage year round. This improvement is also being applied to the 5 other northern ground stations currently operating

Landsat 7 Flight Segment

LDCM

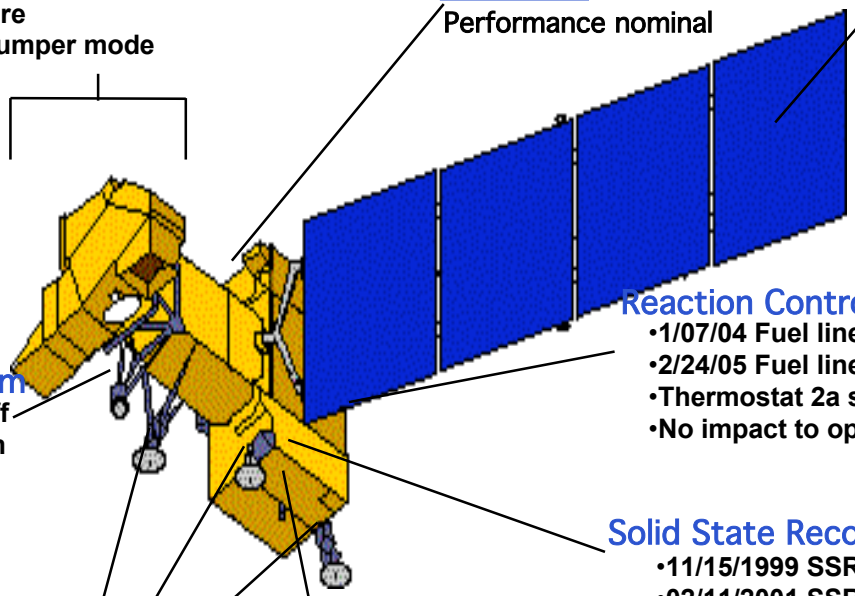
9.5 years of on-orbit operations

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

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



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

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

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

Courtesy of Kristi Kline, USGS EROS

ETM+ SLC Failure Impact

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

Multi-Decadal Archive

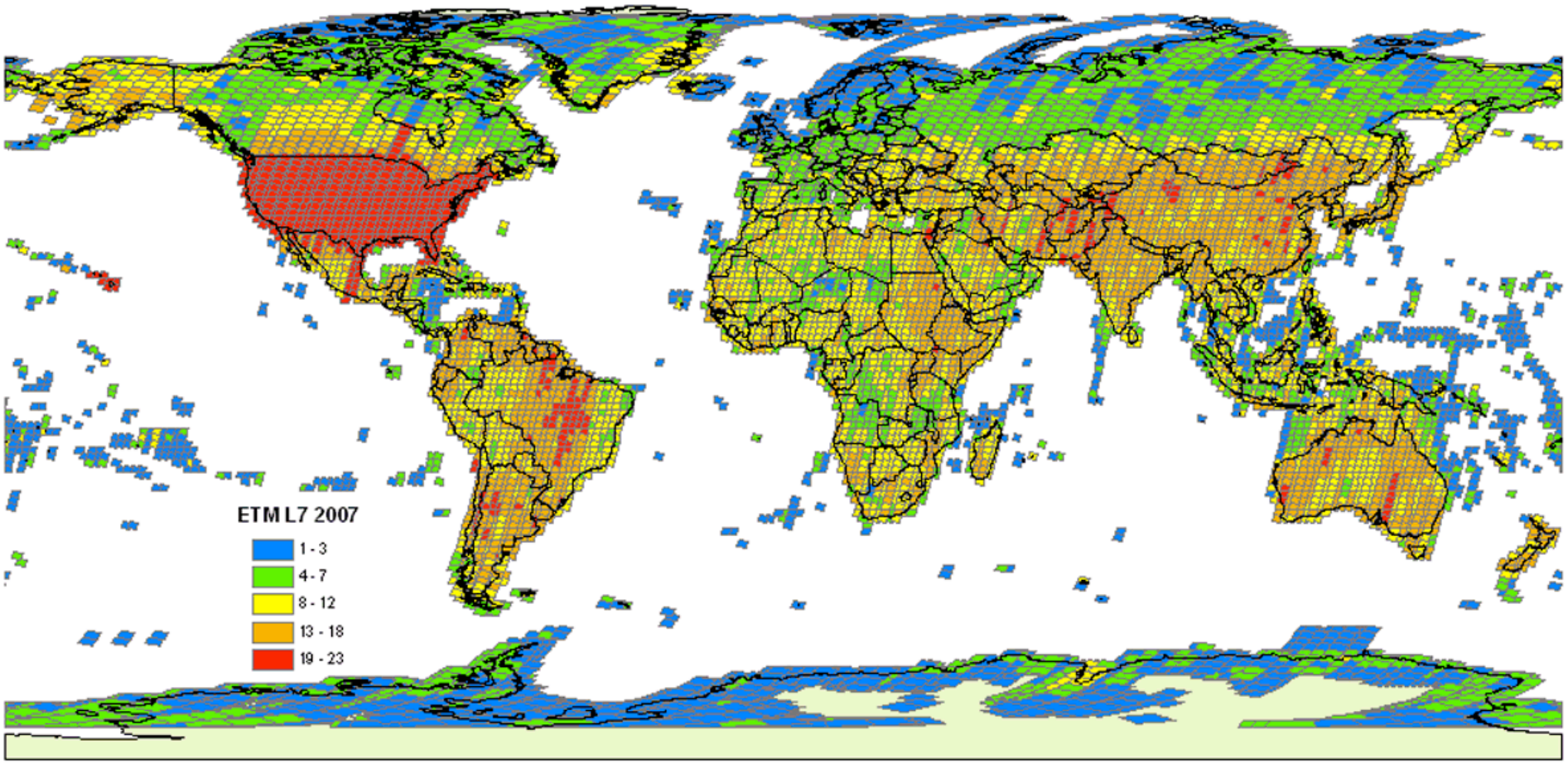
USGS operates the National Satellite Land Remote Sensing Data Archive at its EROS Center in Sioux Falls, SD

Marketable Scenes through Dec. 31, 2008:

- **ETM+: Landsat 7**
  - **892,051 scenes / 828 TB**
  - **Archive grows by 260 GB Daily**
- **TM: Landsat 4 & Landsat 5**
  - **780,191 scenes / 391 TB**
  - **Archive Grows by 40 GB Daily**
- **MSS: Landsat 1 through 5**
  - **652,173 scenes / 20 TB**
  - **20 TB of Data**

No other nation is committed to preserving a comparable record of the global land surface

ETM+ Scenes Archived in 2007



- **Landsat 7 provides systematic coverage of the global land surface on a seasonal basis via a long term acquisition plan (LTAP)**
- **No other nation's satellite system is designed or operated to achieve even annual global coverage at the Landsat scale**

Data Distribution and Data Policy

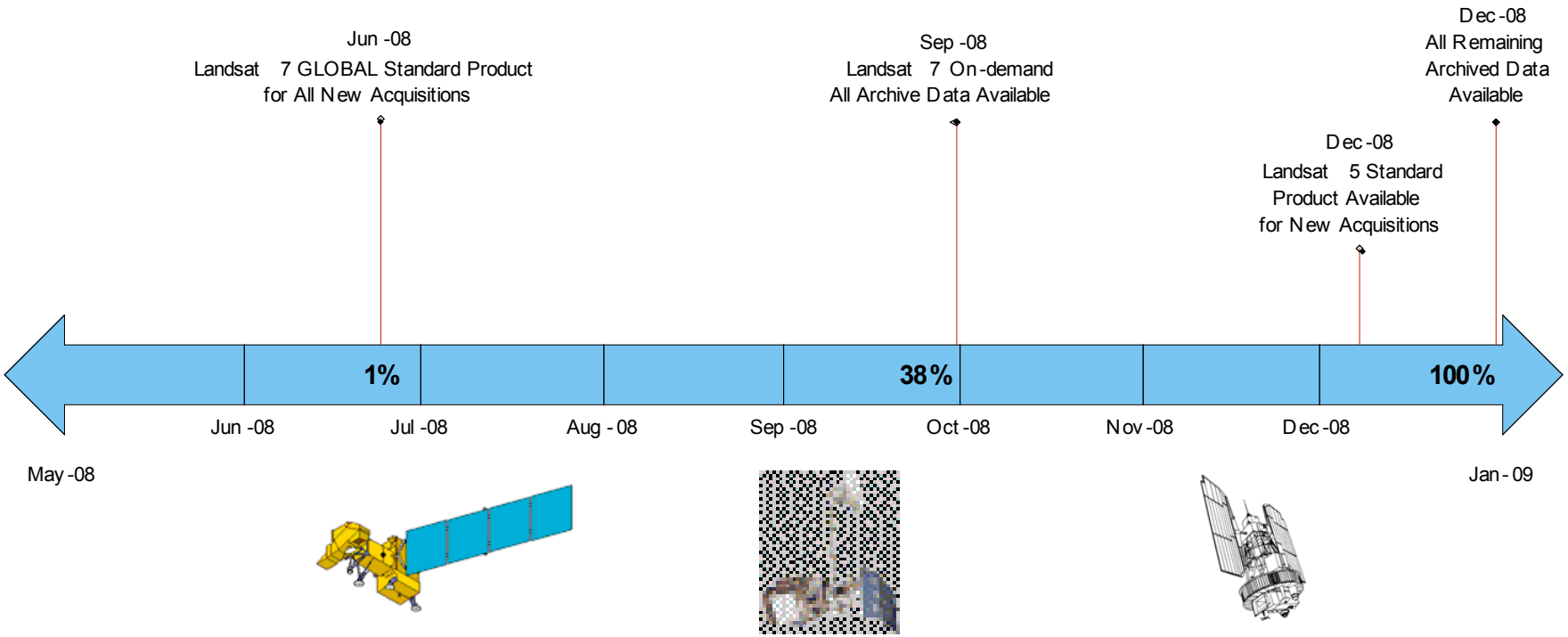
A NEW ERA

- **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

- **On April 21, 2008 the USGS released a USGS Technical Announcement stating:**
  - "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."

Landsat Data Release Schedule

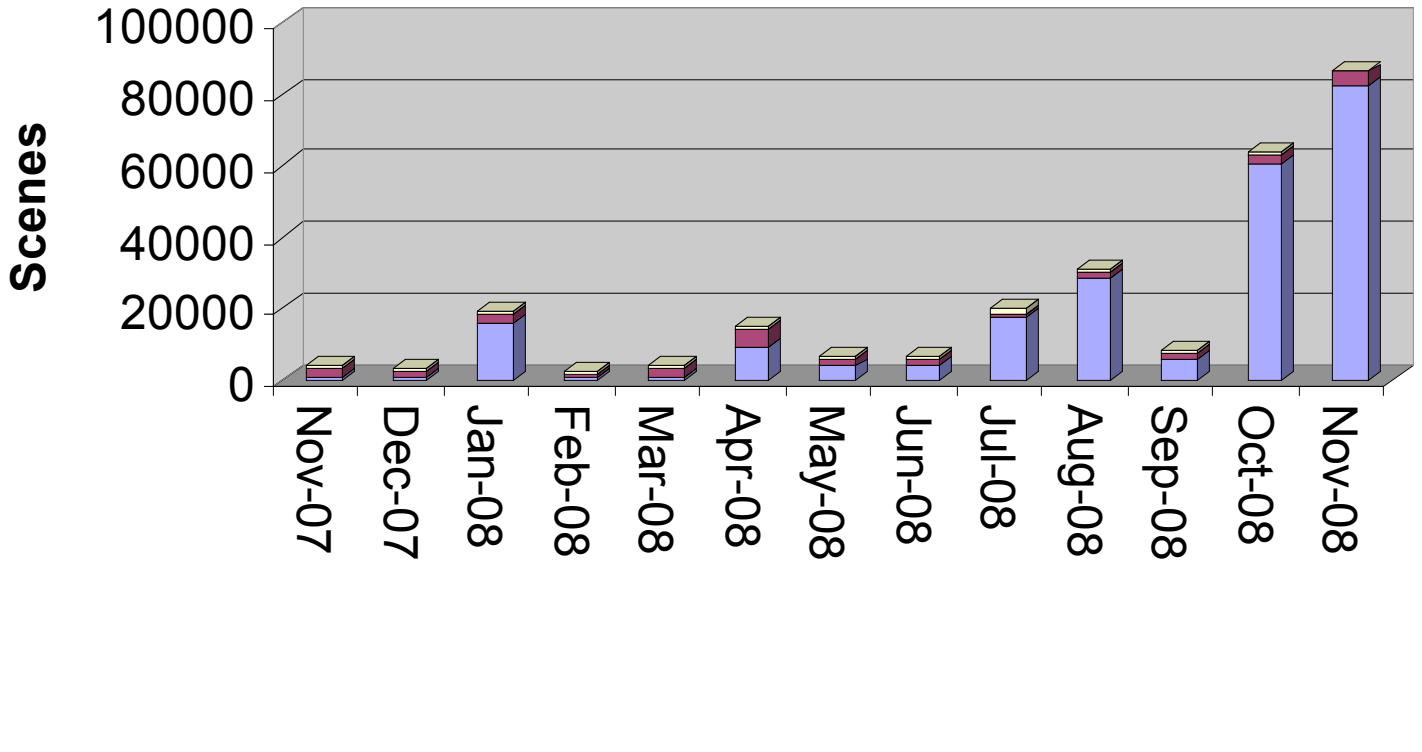
LDCM



Courtesy of Kristi Kline, USGS EROS

2008 Landsat Data Distribution

Landsat Data Distribution

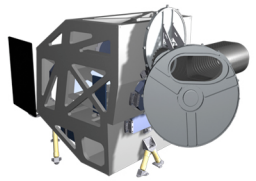


Courtesy of Kristi Kline, USGS EROS

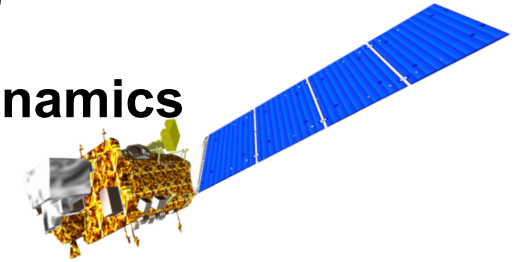
Landsat Data Continuity Mission (LDCM)

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

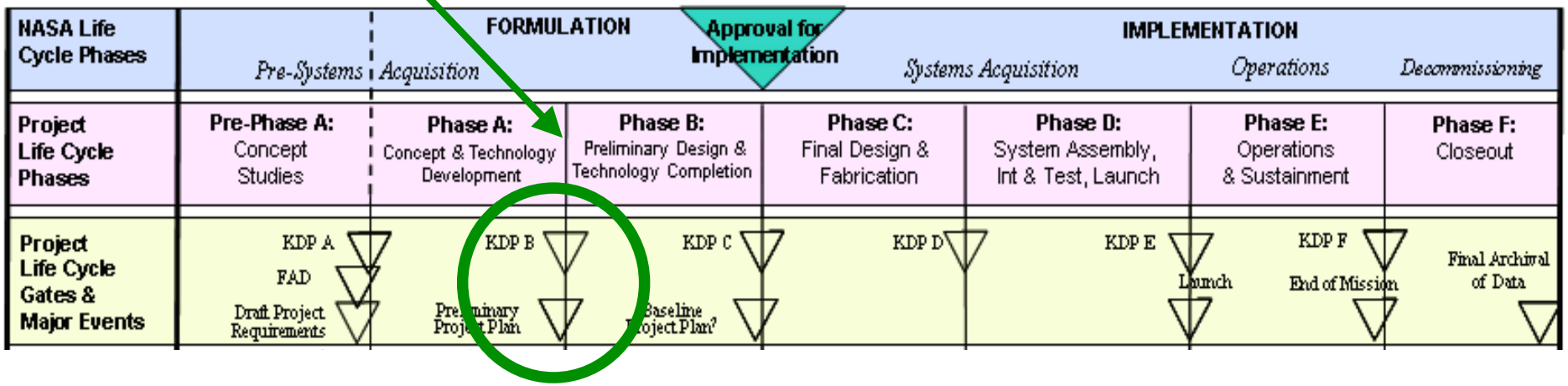


- Mission Operations Element (MOE) contract awarded to The Hammers Company in September, 2008
- Key Decision Point - B review on September 25, 2008

Programmatic Status

- **LDCM approved to proceed into Project Life Cycle Phase B**
  - Key Decision Point – B (KDP-B) Review (Initial Confirmation) conducted on September 25, 2008
    - As a NASA Category 1 Mission, LDCM requires highest level approval of the Agency Program Management Council chaired by NASA Associate Administrator, Chris Scolese, to initiate each phase of the project life cycle
    - Phase B is the system preliminary design phase following concept studies, Pre-Phase A, and concept and technology development, Phase A
    - LDCM spent **9 years** in formulation, re-formulation, Pre-Phase A, and Phase A

LDCM at KDP-B



KDP-B Process

- **In preparation for KDP-B, LDCM conducted a System Requirements Review/Mission Definition Review/Preliminary Non-Advocate Review in May 2008**
  - System Requirements Review (SRR)
    - Examines functional and performance requirements defined for the system and ensures the requirements and the selected concept will satisfy the mission
  - Mission Definition Review (MDR)
    - Examines proposed requirements, mission architecture, and flow down to all functional elements of the mission to ensure the overall concept is complete, feasible, and consistent with available resources
  - Preliminary Non Advocate Review (PNAR)
    - PNAR is conducted as part of the MDR to provide Agency management with an independent assessment of the readiness of the project to proceed to Phase B (mission executable within current cost and schedule)

- **SRR/MDR/PNAR is conducted by a Standing Review Board (SRB)**
  - Independent review panel which conducts system level reviews and follows mission for entire development life cycle
  - Role of the SRB
    - Provides expert assessment of technical and programmatic approach, risk posture, and progress against baseline
    - Advisory role to Agency
    - Makes recommendations to improve performance or reduce risk
    - Provides independent cost and schedule assessments

New LDCM Launch Readiness Date

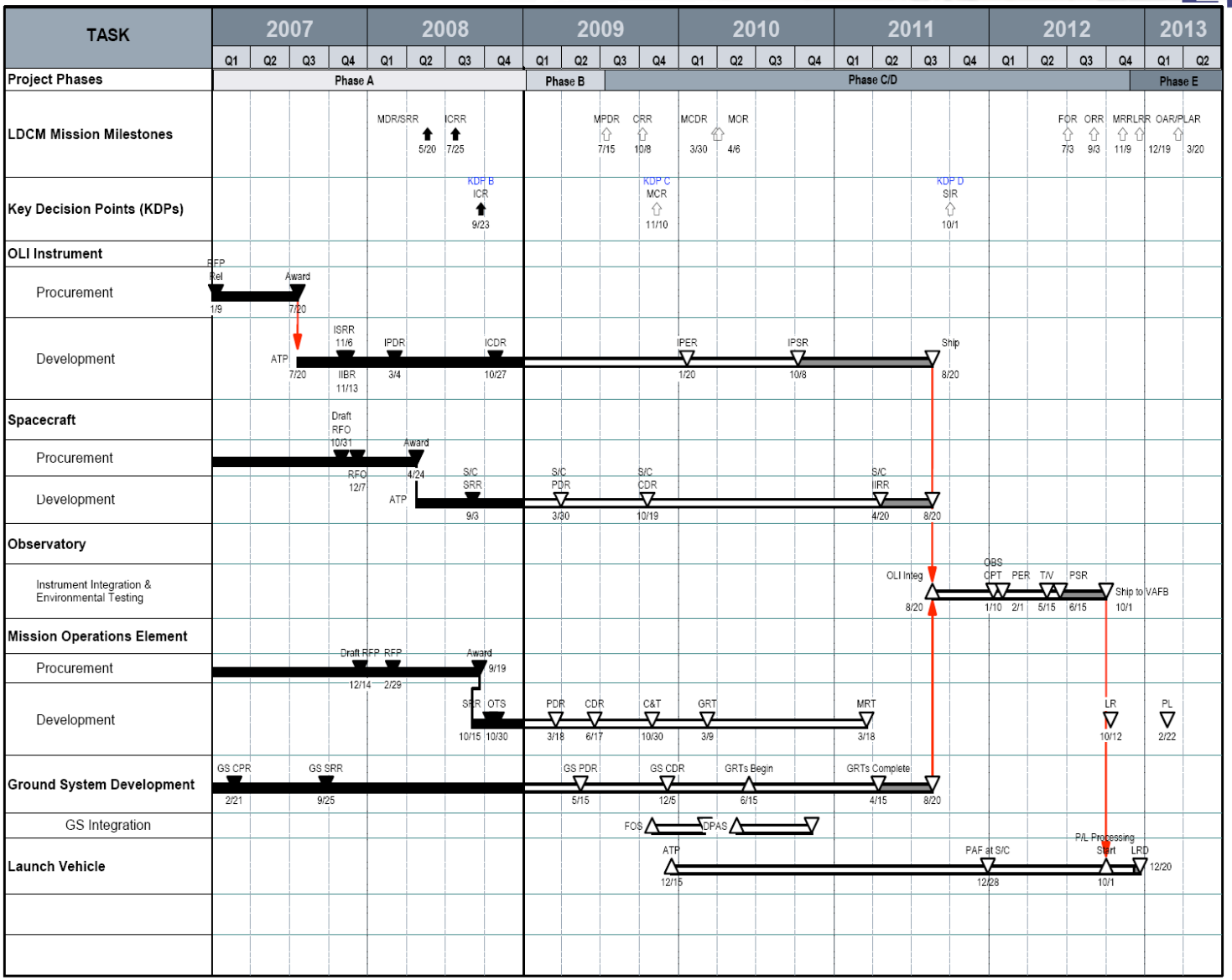
- **Major finding of SRB**
  - Original launch readiness date, July, 2011 was considered excessively aggressive and added risk to the mission
    - "The existing LDCM development schedule is not achievable. There is less than a 20% chance that the July 24, 2011 Launch Readiness Date (LRD) can be achieved."

- **Mission schedules must reflect a 70% confidence level (70% chance of making launch date)**
  - Reconciliation of numerous independent schedule assessments and project's own assessment resulted in a retargeted 70% confidence launch date for LDCM

- **Through KDP-B Process**
  - Retargeted launch date to **December, 2012**
    - Provides appropriate level of confidence
    - Approved by NASA Agency Program Management Council

Dec. 2012 LRD Schedule

LDCM



NASA/USGS Partnership

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

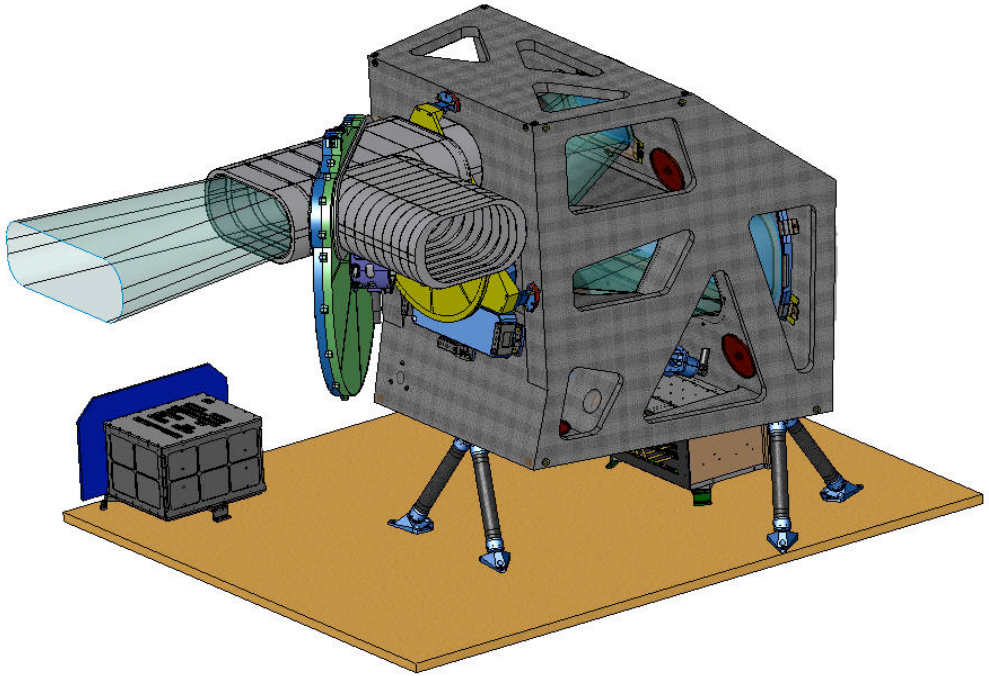
- **NASA Responsibilities**
  - Development of Space Segment, Launch Segment, and the Mission Operations Element (MOE)
  - Lead mission development as the system integrator and lead the missions systems engineering for all mission segments throughout development, on-orbit check-out, and acceptance
  - 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 MOE
  - Lead, fund, and manage the Landsat Science Team
  - Lead LDCM mission operations, after the completion of the on-orbit checkout period

Operational Land Imager (OLI)

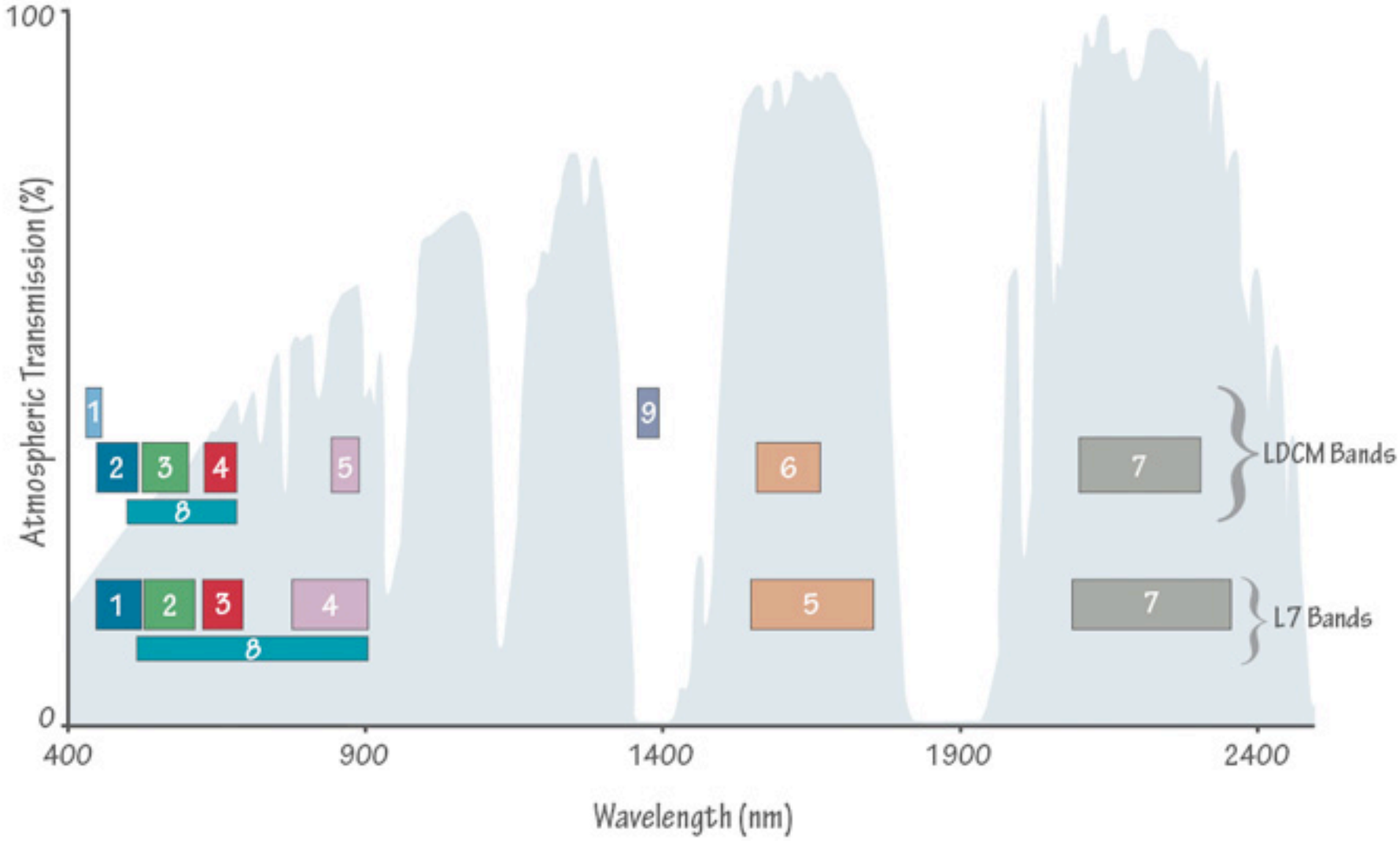
Contract awarded to Ball Aerospace Technical Corp. (BATC) July 2007
Critical Design Review Completed Oct. 2008

- 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

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

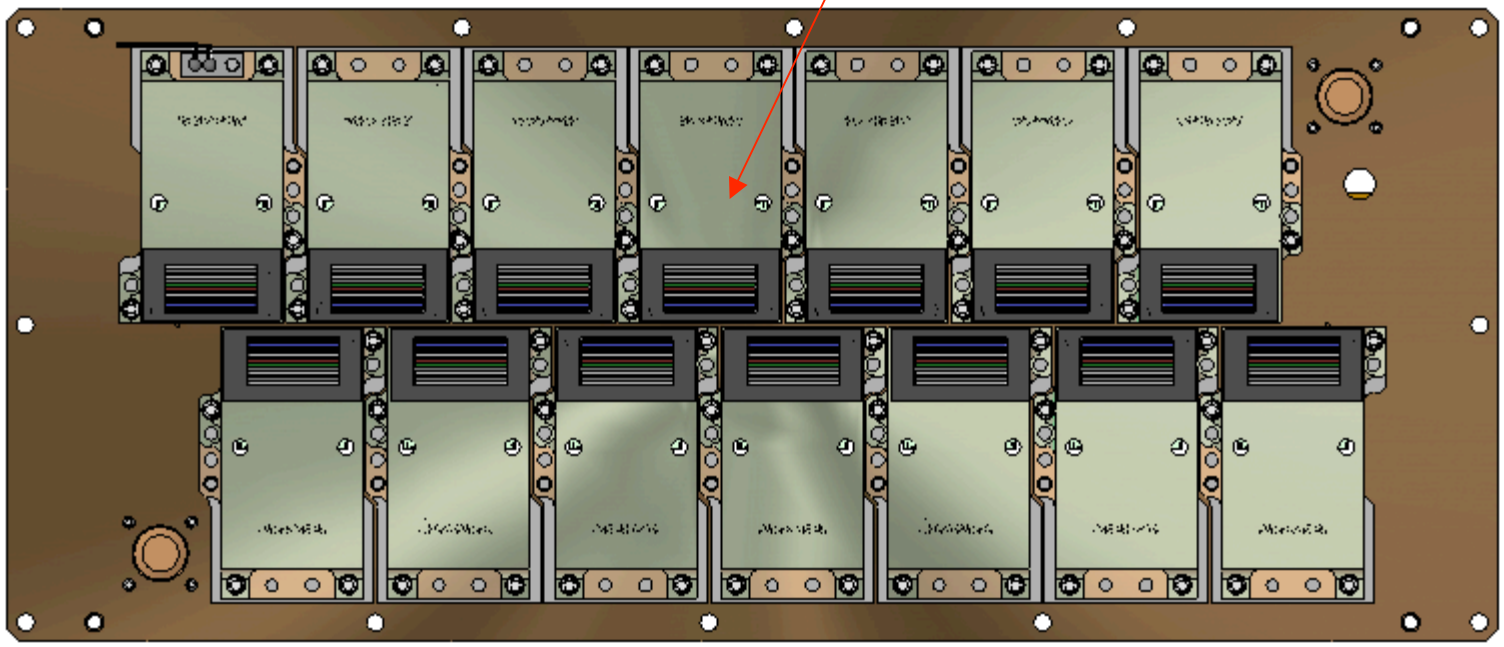
- Studies by the Earth Observer-1 (EO-1) Science Team consistently found that Advanced Land Imager (ALI) data offered improved ability to classify images, detect land cover change, and map environmental features and conditions relative to ETM+ data

Focal Plane Consists of 14 Modules

- **Each Module contains Silicon and HgCdTe detectors mounted on a single readout chip (ROIC)**
  - **Spectral Filters above the detectors provide separation into bands**

Focal Plane Module (FPM)

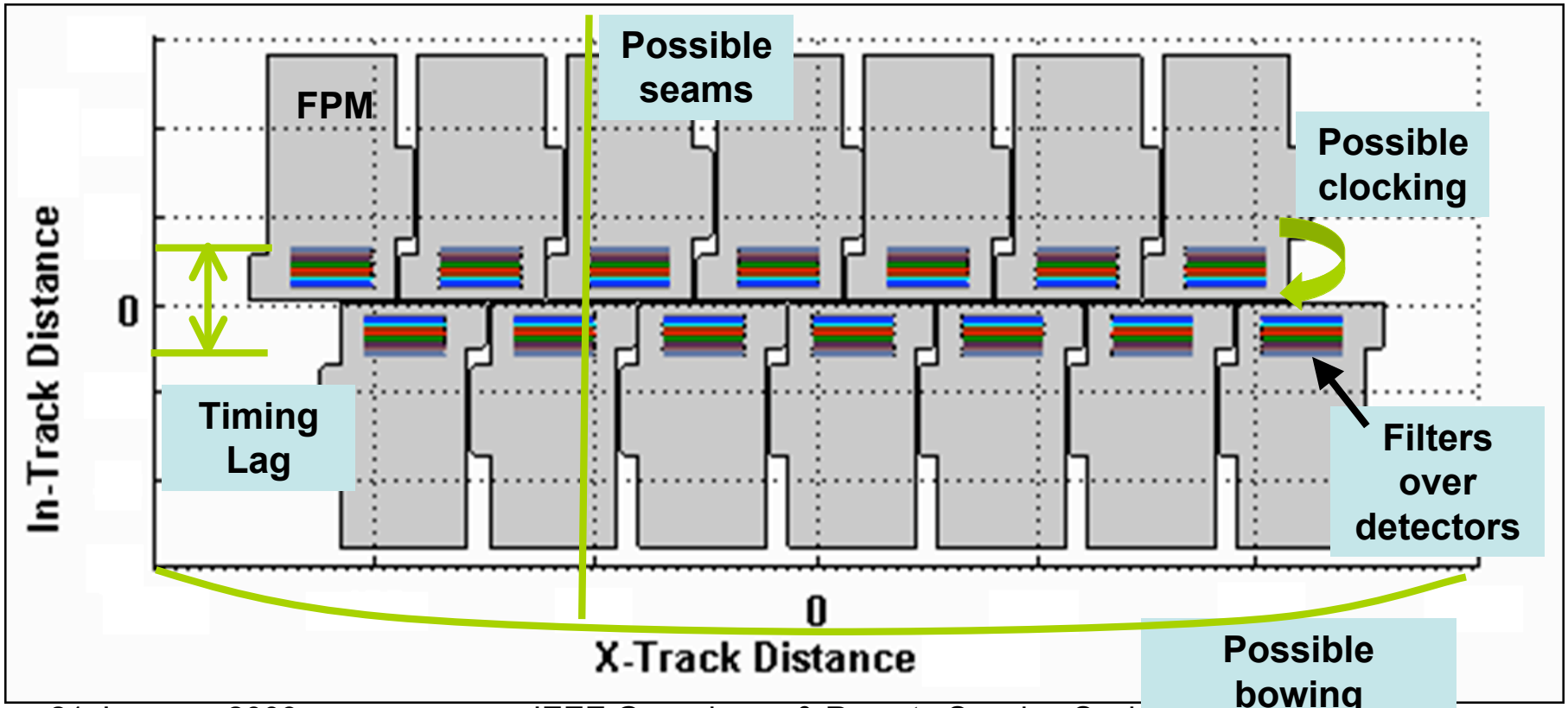
Courtesy of BATC



Focal Plane Module Uniformity

- **Need filters and detector responses to be 'the same' (<0.5%) for all 14 FPMs**
- **Need precise alignment to eliminate clocking or other errors (will be known prelaunch)**
  - Eliminate seams and bowing effects

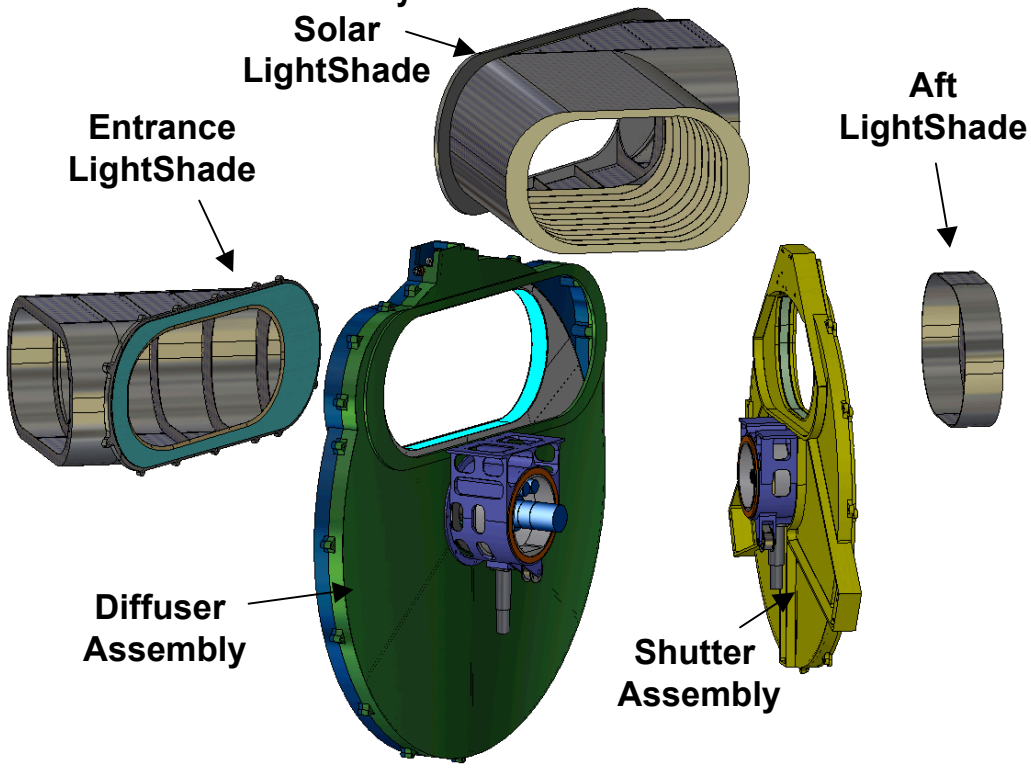
Courtesy of BATC



Calibration Detailed Design Complete

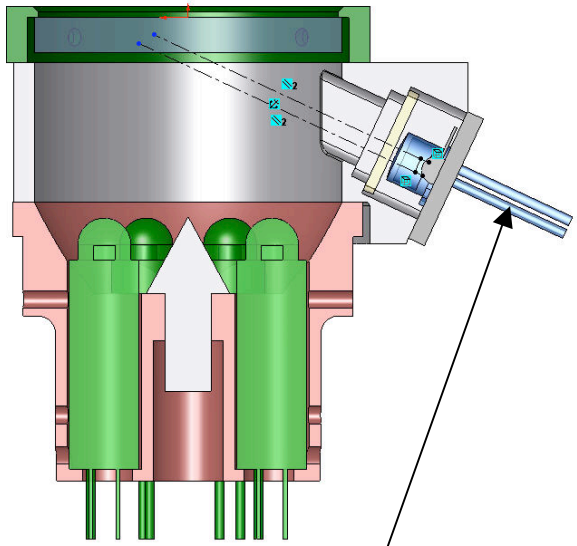
Courtesy of BATC

- **Calibration Subassembly Consists of Five Subassemblies**
  - 3 LightShade Assemblies
  - 1 Diffuser Assembly
  - 1 Shutter Assembly



Exploded View of Calibration Subassembly

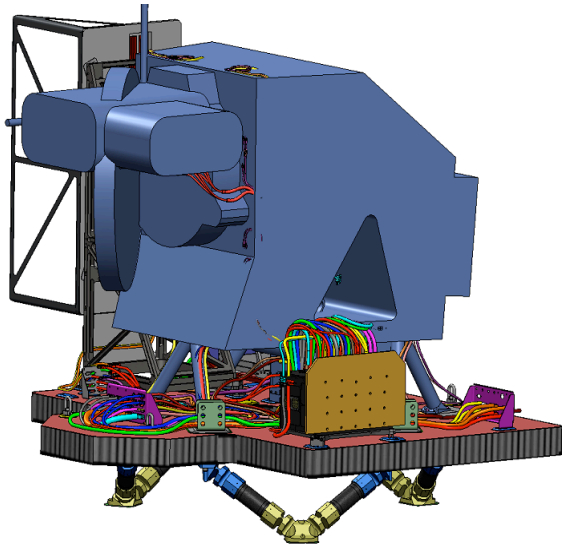
- **Stim Lamp Assemblies redesigned to increase emitted light and optimize monitoring diode position**



Diodes view diffuser instead of housing wall
No direct view of any lamps

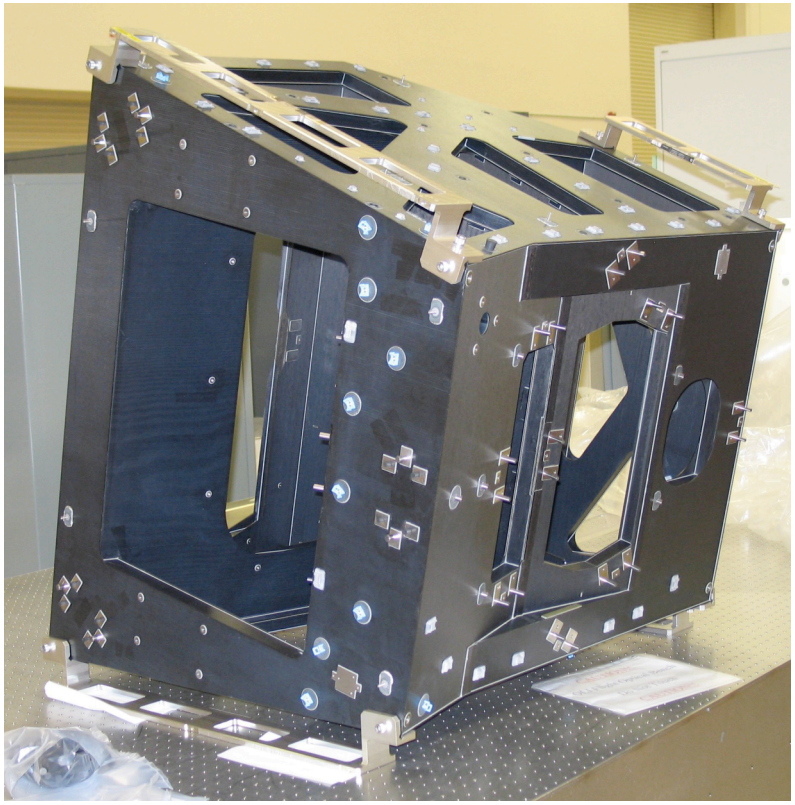
OLI Status

- **OLI Critical Design Review (CDR) successfully conducted Oct. 27-30**
- **Flight Hardware**
  - Optical Bench completed and delivered to BATC
  - All flight optics completed and delivered to BATC
  - All 14 flight butcher block filters delivered to BATC
  - All 14 EDU focal plane modules completed
  - EDU Instrument Support Electronics box completed
  - EDU Focal Plane Electronics in box-level testing

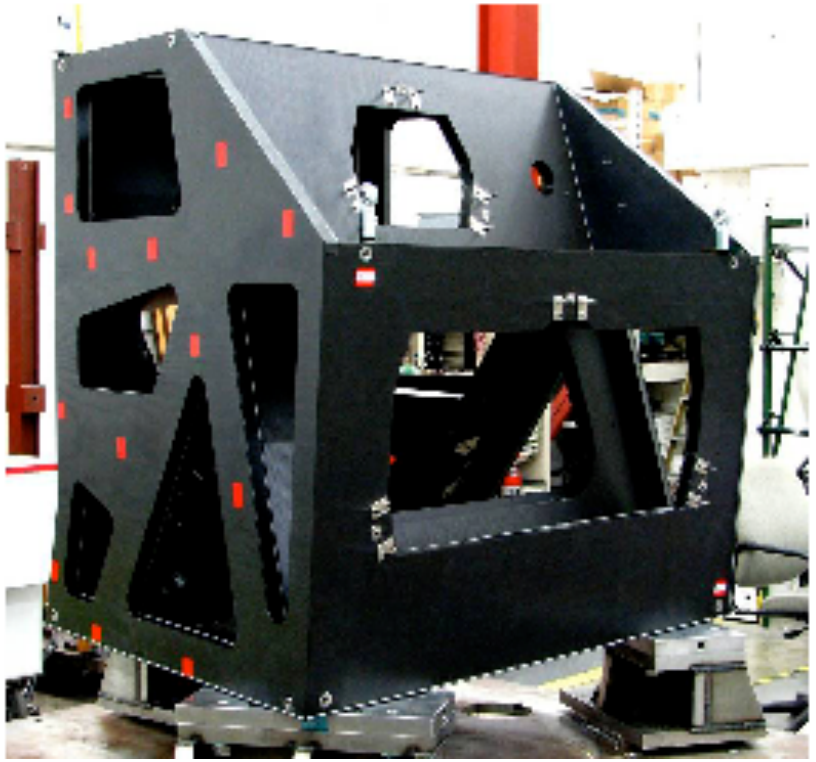


- **New OLI Baseplate**
  - Baseplate helps 'buffer' the maturity gap between the observatory elements
    - Limits impacts to OLI interface from either changes in spacecraft or TIRS designs
      - Either the baseplate itself and/or the thermal control subsystem (radiator sizes, blanket designs, etc.)
    - Allows work to keep moving on the telescope, the electronics box designs, the focal plane, etc.
    - Allows OLI to shipped to GD as a whole unit and break down after testing
  - Baseplate (as proposed) will delay OLI delivery from late Oct. 2010 to mid-Dec. 2010

Main Bench Assembly Completed



Side View of Bench

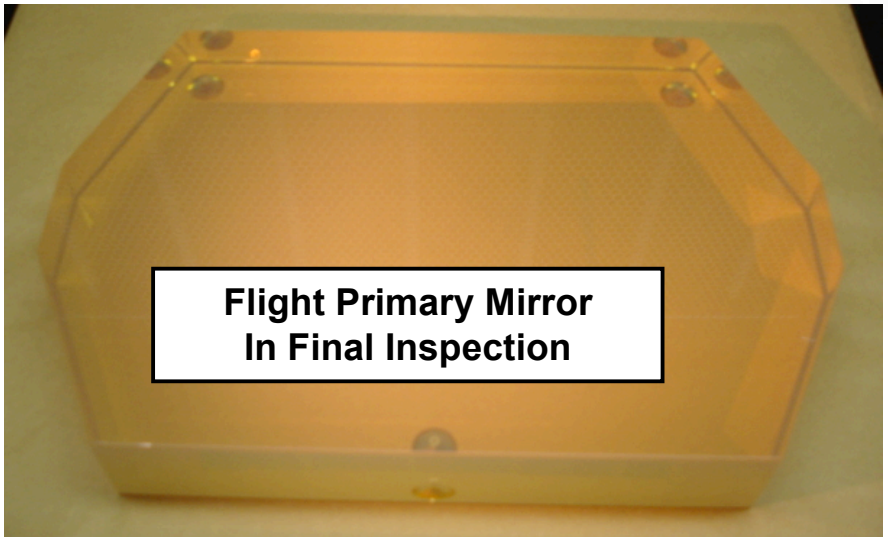


Back View of Bench

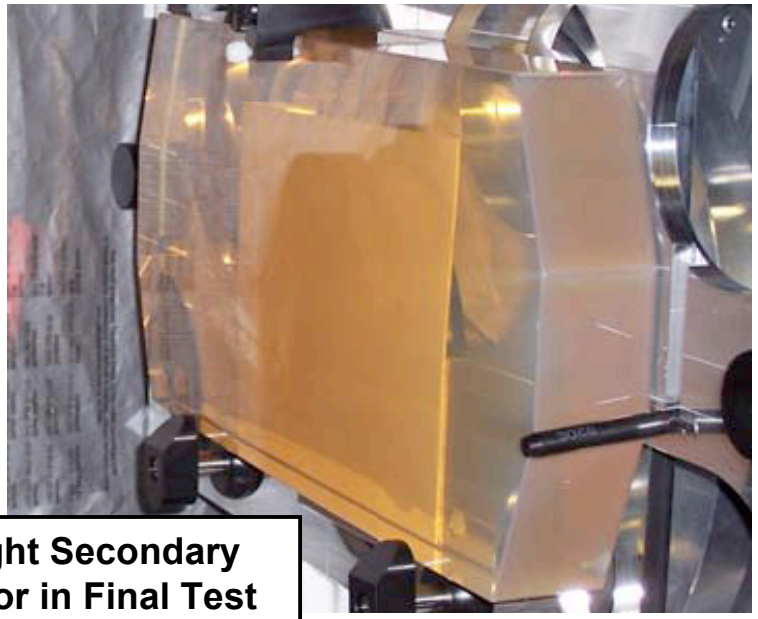
Courtesy of BATC

Optical Fabrication Complete

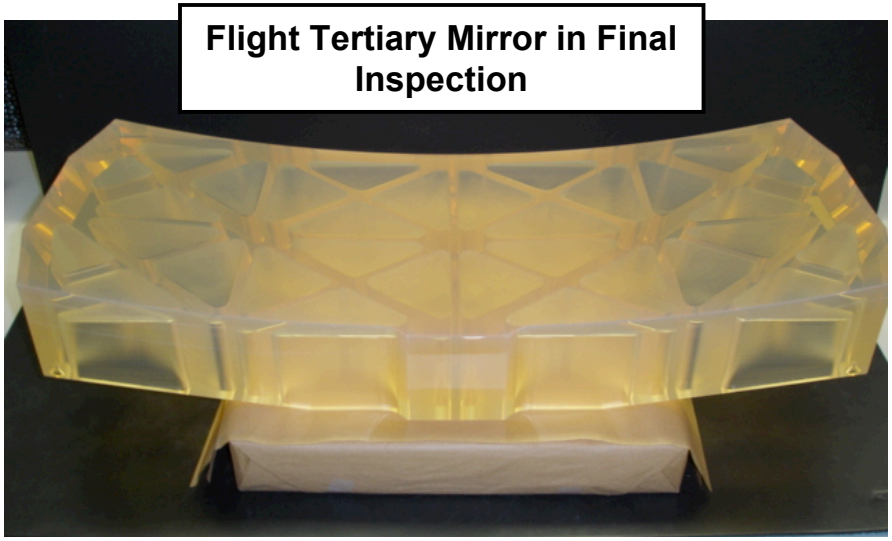
LDCM



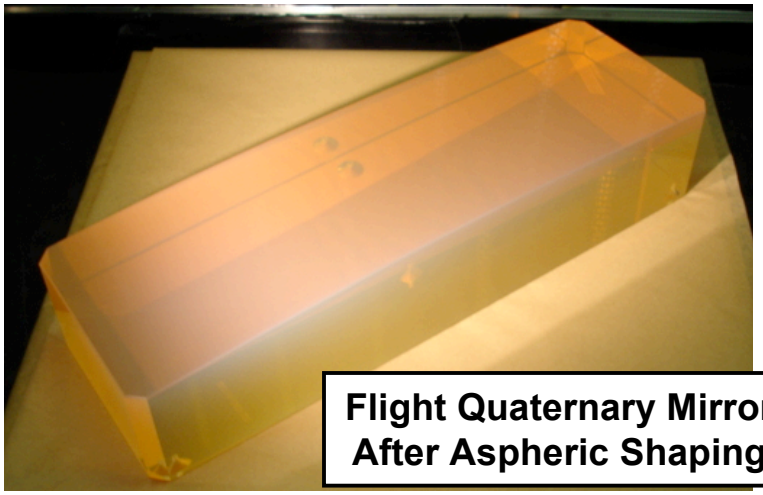
Flight Primary Mirror
In Final Inspection



Flight Secondary
Mirror in Final Test



Flight Tertiary Mirror in Final
Inspection

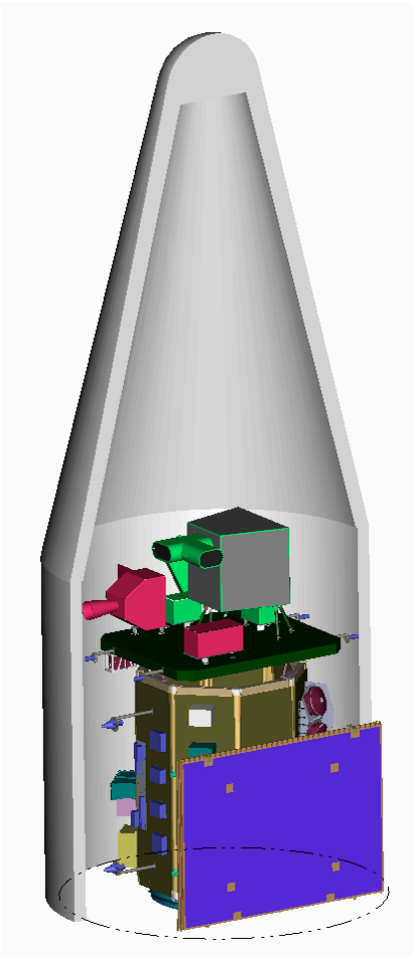


Flight Quaternary Mirror
After Aspheric Shaping

Courtesy of BATC

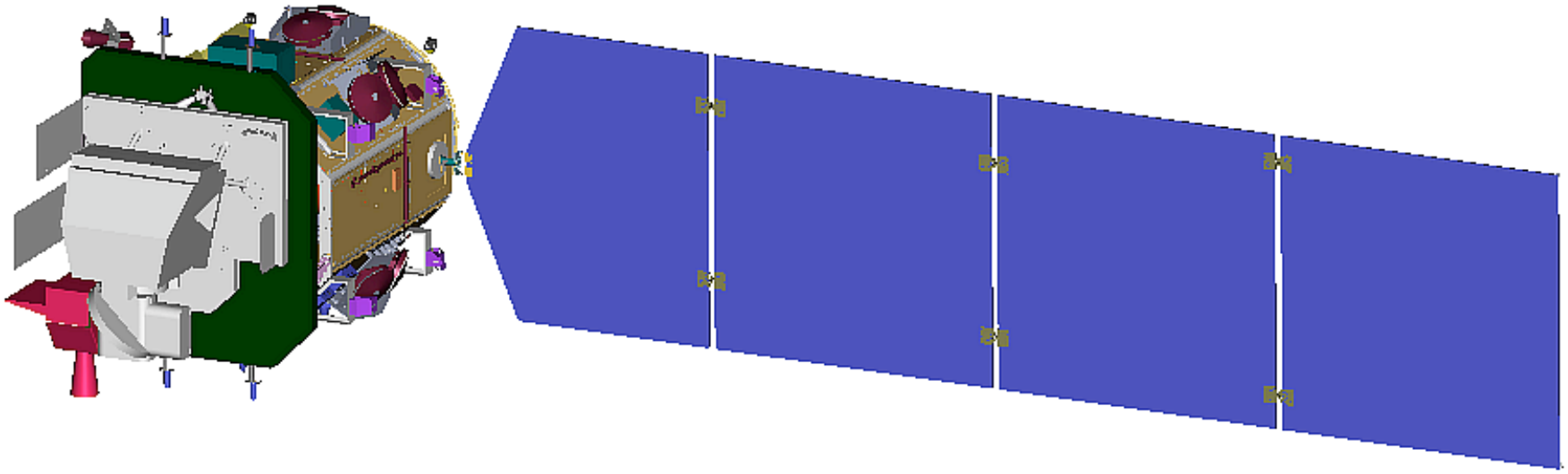
Launch Vehicle

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



Courtesy of GDAIS

LDCM Spacecraft

LDCM

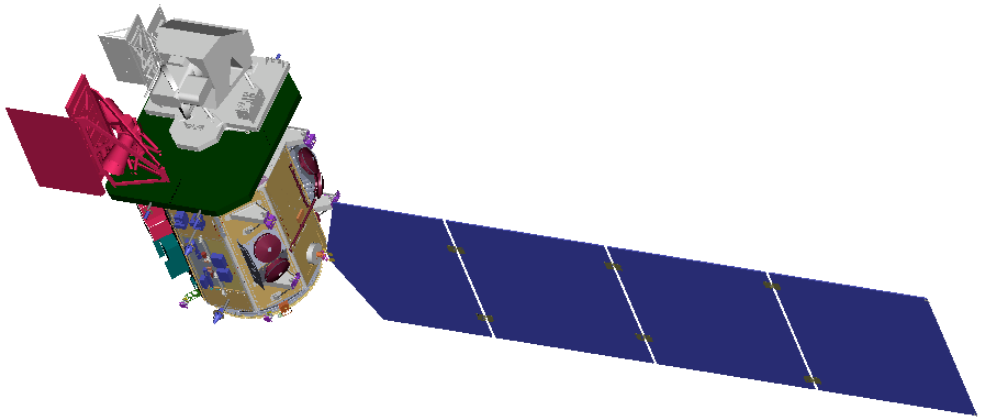
COMMUNICATIONS
- *S-band to GN/LGN: 1, 32kbps uplink: and 2k,16k, 32k, or 1 Mbps downlink*
- *Omni antennas*
- *TDRSS - SA: 1 kbps return and 2 or 32 Kbps forward*
- *X-band: 384 Mbps science data*

PROPULSION
- *Hydrazine blow-down propulsion module*
- *Eight 22N Redundant Thrusters*

GUIDANCE, NAVIGATION & CONTROL
- *2 of 3 star trackers active*
- *High precision IRU*
- *Honeywell reaction wheels*
- *SADA with damper*
- *3-axis stabilized*
- *Zero momentum biased*

THERMAL CONTROL
- *Passive with heaters*
- *Constant conductance heat pipes (if needed)*

STRUCTURE
- *Aluminum primary structure*
- *Externally mounted components*
- *Clear instrument FOVs*
- *Clear instrument radiative paths*



ELECTRICAL POWER
- *Single wing single axis articulated GaAs solar array provides 4300 W at EOL*
- *125 amp-hour NiH_2 battery*
- *Unregulated 22 V - 36 V power bus*
- *Two power distribution boxes*

COMMAND & DATA HANDLING
- *cPCI architecture; RAD750 CPU*
- *3.1 Tbit (BOL) solid state recorder*
- *265 Mbps peak OLI data transfer*
- *26.2 Mbps peak TIRS data transfer*
- *High rate PB at 384 Mbps*

Courtesy of GDAIS

S/C Status

- **System Requirements Review (SRR) held Sept. 3-4, 2008**
  - 4 Deficiencies:
    - Requirements Flow Down
    - Open requirements
    - Instrument Interfaces
    - Fault Management
  - GSFC and GD worked together to ensure all SRR deficiencies adequately addressed
    - Major areas of concentration included instrument interfaces (both OLI and TIRS) and resolution of open requirements
- **Delta SRR was successfully conducted on Dec. 17th**
- **Working towards PDR at end of March**

Additional Instruments?

- **The spacecraft contract with General Dynamics required that the spacecraft be "scarred" for two additional instruments**
  - **Total Solar Irradiance Sensor (TSIS)**
    - In May 2008, NOAA announced that TSIS is back on NPOESS
    - TSIS no longer an option for LDCM
  - **Thermal Infrared Sensor (TIRS)**
    - Based on continued Congressional and community interest, the LDCM Project is ensuring that a TIRS instrument could still be included on LDCM *(more a little later in this talk)*

Mission Operations Element (MOE)

- **NASA awarded The Hammers Company a contract in Sept., 2008 to build the MOE per a reimbursable agreement with USGS**
- **Provides the primary means to control and monitor the spacecraft**
  - Mission planning and scheduling
  - Command and control
  - Monitoring and analysis
  - Flight dynamics
  - Onboard memory management
- **The MOE will be installed in the Mission Operation Centers (MOC's)**
  - Launch MOC will be located at Goddard
- **MOE System Requirements Review (SRR) successfully conducted in Nov.**
- **1st instance of the MOE delivered to GSFC in Nov.**
  - Off-The-Shelf version

Thermal Infrared Sensor (TIRS)

- **NASA Authorization Act of 2008 signed into law Oct. 15, 2008**
  - SEC. 205. LANDSAT THERMAL INFRARED DATA CONTINUITY.
  - (a) Plan- In view of the importance of Landsat thermal infrared data for both scientific research and water management applications, the Administrator shall prepare a plan for ensuring the continuity of Landsat thermal infrared data or its equivalent, … As part of the plan, the Administrator shall provide an option for developing a thermal infrared sensor at minimum cost to be flown on the Landsat Data Continuity Mission with minimum delay to the schedule of the Landsat Data Continuity Mission.
- **The proposed American Recovery and Reinvestment Bill of 2009 includes:**
  - NASA: $600 million, including $400 million to put more scientists to work doing climate change research, including Earth science research recommended by the National Academies, satellite sensors that measure solar radiation critical to understanding climate change, **and a thermal infrared sensor to the Landsat Continuing Mapper** necessary for water management, particularly in the western states;

TIRS Status

- **Current LDCM baseline design, as approved by NASA Program Management Council, includes only OLI as a single-sensor payload**
- **Based on NASA Program Management Council Direction, the LDCM project at GSFC is ensuring that:**
  - Development of the LDCM spacecraft will not preclude the accommodation of a thermal instrument
  - Accommodation of a thermal instrument does not impact the performance of the Operational Land Imager
- **In parallel with LDCM mission development, thermal instrument and technology risk reduction activities are being pursued**
  - For example, cryogenically-cooled detector technologies are now being evaluated including quantum well infrared photodiodes (QWIP's)

TIRS Status

- **A Phase A Study was initiated July 1, 2008.**
  - The Purpose of this study was to proactively investigate the implementation of a Thermal Infrared Sensor for LDCM and provide risk mitigation to the Dec. 2012 LRD.
    - Evaluate / Allocate LDCM requirements.
    - Create a feasible concept design.
    - Assess the programmatic implementation including the scheudle and early procurements needed prior to PDR.
    - Begin the instrument development activities.

- **Concept design developed, meets or exceeds the TIRS performance requirements.**
  - System Concept Review held October 17, 2008
    - Independent Review of the current TIRS concept.

TIRS Status

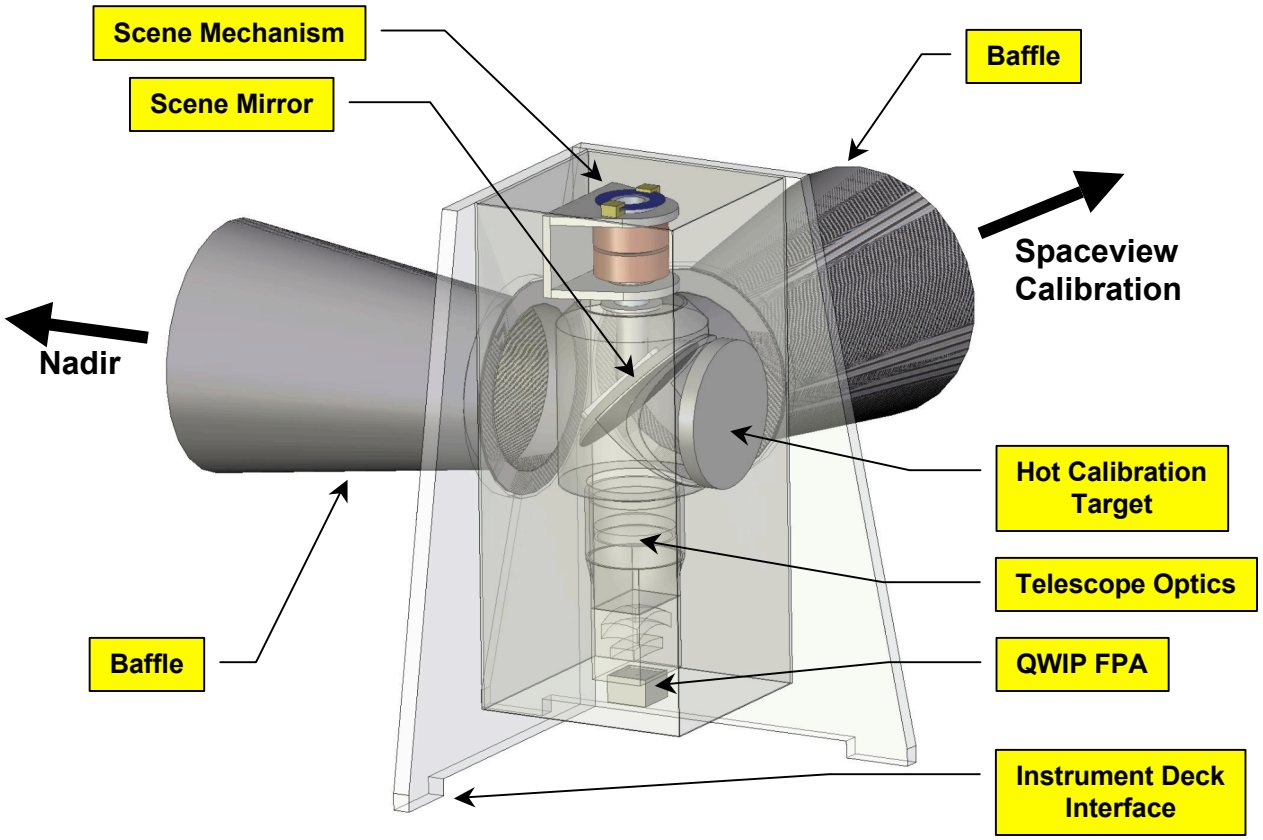
- **Development of Quantum Well Infrared Photodetector (QWIP)**
  - ROICs successfully completed both Proton and Gamma Radiation tests.

- **TIRS Instrument implementation targets LDCM launch date of December, 2012.**
  - Instrument delivery planned for December 2011, allowing 10 mos. integration and test at the spacecraft vendor.
  - Current instrument development schedule is detailed for each subsystem and instrument I&T and meets the required delivery date.

- **System Requirements Review scheduled for February 2 and 3rd, 2009**
  - Review all Level 4 and driving level 5 requirements and traceability to Level 3.
  - Review updated concept and system performance against requirements.

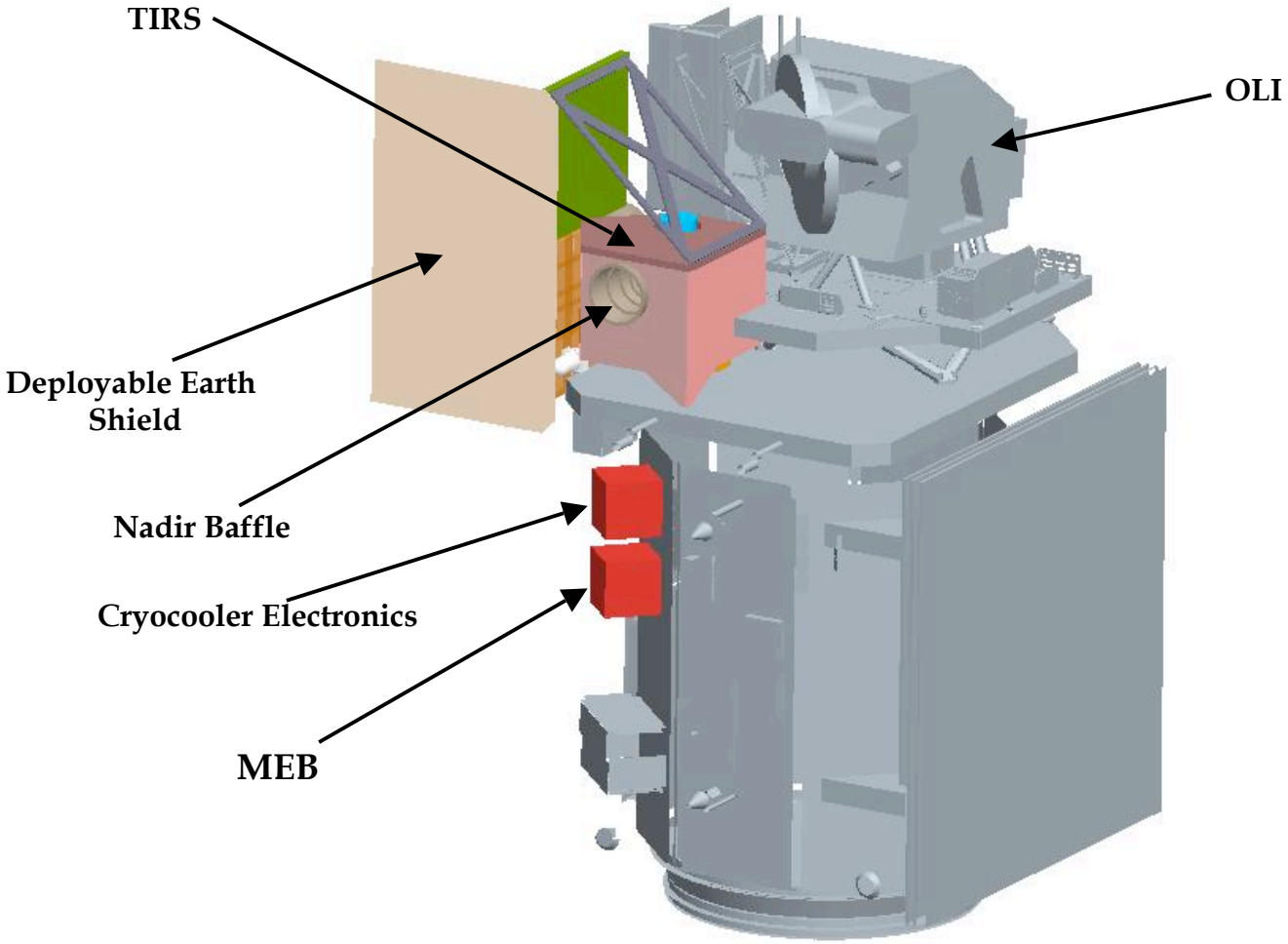
- **TIRS PDR scheduled for May 2009**

TIRS Instrument Diagram



TIRS Optical Sensor Unit

Spacecraft View



TIRS Decision

- **Congressional interest in TIRS remains high**
  - Development of the LDCM spacecraft will not preclude the accommodation of a TIRS instrument
  - Accommodation of TIRS does not impact the performance of the Operational Land Imager
- **Project proceeding down path as if TIRS will be there**
  - Directed by Agency PMC at KDP-B to proceed at risk
- **Management of the TIRS instrument currently under purview of LDCM**
  - TIRS team is fully integrated into LDCM team
- **Resolution is expected from the final FY09 appropriations language**
  - Hopefully this spring

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	0.4K	0.35K
Thermal 2	12.0	120	0.4K	0.35K

- 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.

Summary

- **Good progress towards implementation of the LDCM as a free-flyer - Program has advanced to Phase B**
  - Ball Aerospace Technology Corporation is building the OLI
    - OLI Critical Design Review successfully conducted in Oct., 2008
  - Atlas V launch vehicle was selected in Oct., 2007
  - General Dynamics Advanced Information Systems awarded spacecraft contact in April, 2008
  - Mission Operations Element contract awarded to The Hammers Company in Sept., 2008
  - Ground system development underway at USGS EROS
- **Launch readiness date rescheduled from July, 2011 to December, 2012**
- **Decision to add a TIRS to the LDCM payload is expected following final FY09 NASA appropriations bill**