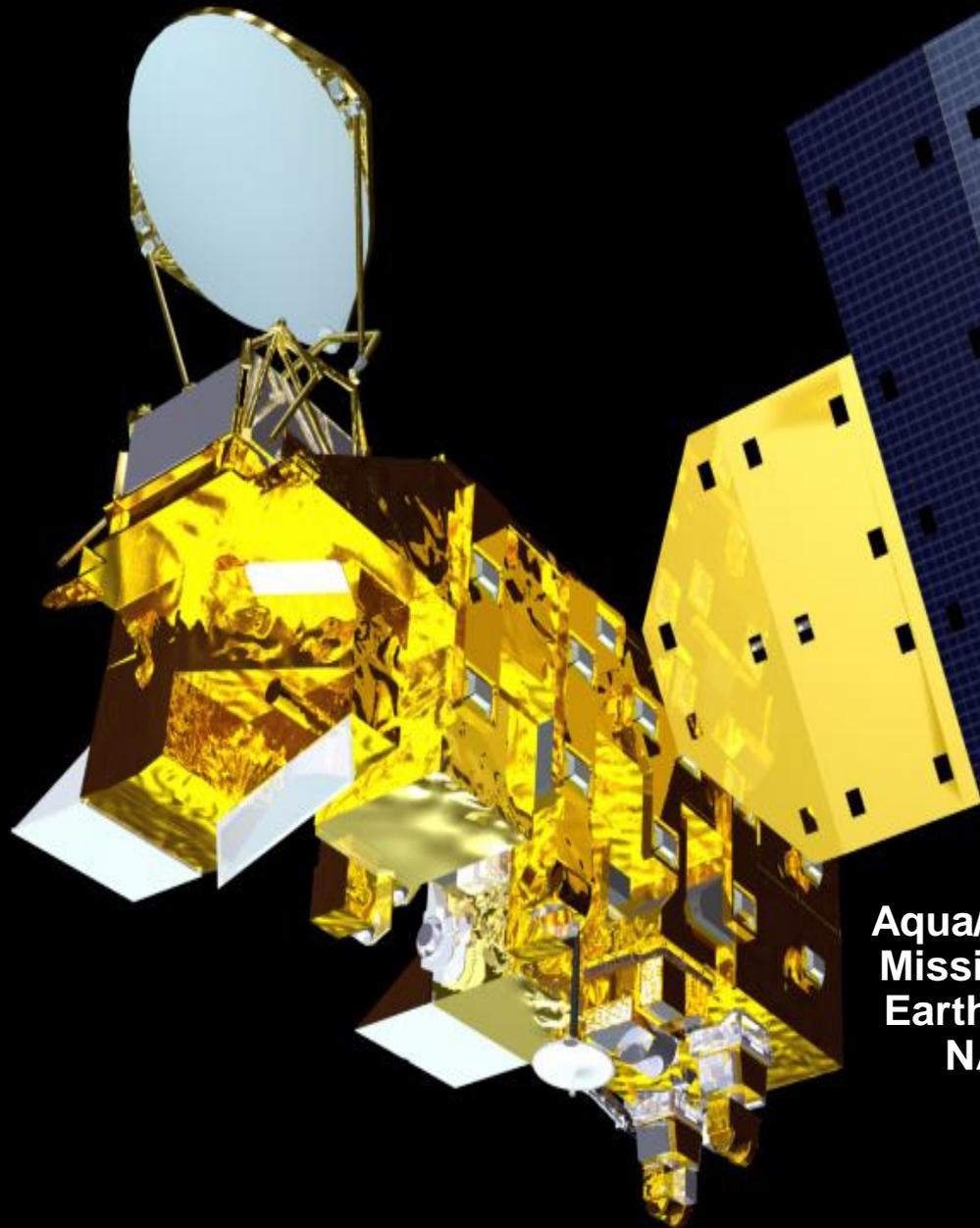


# EOS Aqua



**Mission Status  
at  
Earth Science  
Constellation  
MOWG Meeting  
Albuquerque, NM  
September 27, 2016**

**Bill Guit**

**Aqua/Aura Mission Director - Code 584/428  
Mission Validation and Operations Branch  
Earth Science Mission Operations Project  
NASA/Goddard Space Flight Center**

**[William.J.Guit@nasa.gov](mailto:William.J.Guit@nasa.gov)**



# Topics



- **Mission Summary**
- **Spacecraft Subsystems Summary**
- **Recent & Planned Activities**
- **Inclination Adjust Maneuvers**
  - Spring 2017 DRAFT Calendar
  - Long-Term Plan (in EOS Flight Dynamics Presentation)
- **Propellant Usage & Lifetime Estimate**
- **Mission Summary**
- **Additional Slides:**
  - Orbit Maintenance Maneuvers
  - Conjunction Assessment High Interest Events
  - Ground Track Error & Mean Local Time History
  - Spacecraft Orbital Parameters Trends & Predictions



# EOS Aqua Mission Summary

(Updates since April 2016 Meeting in Boulder, CO)



- **05/04/02: Launch**
  - 6-Year Design Life
- **12/02/08: End of Prime Mission Review**
- **03/03/15: Senior Review Proposal #5**
  - Reliability Estimates thru 2022
  - Consumables through 2021
- **06/22/15: 2015 Mission Extension Senior Review Proposal Panel Report**
  - #1 Ranked Earth Science Mission
  - Mission extension through FY19
- **12/08/15: End of AMSR-E Operations**
- **01/27/16: ESMO Annual Review #9**
- **05/04/16: Aqua 14-Year Anniversary**

National Aeronautics and Space Administration

# Aqua

## Senior Review Proposal

Dr. Claire L. Parkinson, Aqua Project Scientist  
NASA Goddard Space Flight Center

Dr. Lazaros Oreopoulos, Aqua Deputy Project Scientist  
NASA Goddard Space Flight Center

Dr. Joao Teixeira, AIRS/AMSU/HSB Science Team Leader  
NASA Jet Propulsion Laboratory

Dr. Roy Spencer, AMSR-E Science Team Leader  
University of Alabama in Huntsville

Dr. Norman G. Loeb, CERES Science Team Leader  
NASA Langley Research Center

Dr. Michael D. King, MODIS Science Team Leader  
University of Colorado

Wynn Watson, Earth Science Mission Operations  
NASA Goddard Space Flight Center

Submitted to NASA Headquarters, March 3, 2015



# Aqua Spacecraft Subsystems

**All subsystems configured to primary hardware**

**Changes since April 2016 MOWG are in blue**



- **Command & Data Handling (CDH) – Nominal**
  - Solid State Recorder (SSR) – only holds 2 orbits of data
  - *SSR Ops Error Anomaly (12/2/07) – fully recovered 1/28/09*
- **Communications (COMM) – Nominal**
- **Electrical Power System (EPS) – Nominal**
  - *Array Regulator Electronics (ARE) 4A (9/8/04 – self-recovered)*
    - » *Re-occurred 1/11/10 and 7/18/13 (2 strings)*
  - *ARE-6C (3/1/13) – post-anomaly investigation indicated 10/20/11 also*
    - » *Numerous power drops since 10/20/11 with last on 11/04/15 (6 strings)*
  - *ARE-1C (11/8/10 – 1 string) & ARE-3A (2/14/12 – 1 string) and ARE-4C (4/26/15 – 3 strings)*
  - ***NEW: ARE-5C power drop on 5/3/16, partial recovery on 6/27/16 (1 string)***
  - ***Summary: Estimated that Aqua has lost 14 strings of solar cells out of a total of 132 strings***
    - » ***Aqua continues to have significant power margin where the life limiting item is fuel***
  - *Battery Cell Anomaly (9/2/05)*
  - *Solar Panel #8 Thermistor #6 Failure (8/3/09)*
  - *Solar Array Offset (Reported 11/17/09, Corrected 6/29/10)*
- **Flight Software (FSW) – Nominal**
- **Guidance, Navigation & Control (GN&C) – Nominal**
- **Propulsion (PROP) – Nominal**
  - *Dual Thruster Module (DTM-2) Heater Anomaly (9/8/07)*
- **Thermal Control System (TCS) – Nominal**



# Recent Activities

(April 2016 – September 2016)



- **9 CARA High Interest Orbital Debris Events (HIEs):** See chart 18
  - 2 that required significant action
  - 2 RMM/DAMs PLANNED – 2 SELF-MITIGATED – 0 EXECUTED
  - 0 Planned routine DMUMs postponed/replanned and/or rescheduled
- **2 Spacecraft Bus Anomalies:**
  - 05/03/2016: ARE-5C Power Drop Anomaly – partial recovery on 6/27
  - 07/08/2016: Transponder Interface Electronics (TIE) Clock Reboot Anomaly
- **0 Instrument Anomalies**
- **8 Spacecraft Delta-V Maneuvers:**
  - **4 Routine Drag Make-Up Maneuvers (DMUMs):** All without yaw slews
    - » 2016: 05/25 (#107), 06/29 (#108), 07/21 (#109) and 08/25 (#110)
  - **4 Inclination Adjust Maneuvers (IAMs):**
    - » 2016: 3/9 (#48), 3/16 (#49), 4/6 (#50) and 4/21 (#51)
  - **0 Debris Avoidance Maneuvers (DAM):**
- **5 Instrument Calibration Maneuvers: Monthly MODIS Lunar Calibrations**



# Planned Activities



- **October 2016: Drag Make Up Maneuver (DMUM) # 112**
- **November 2016: Updated Decommissioning Plan**
- **December 2016: Updated Reliability & Lifetime Estimates**
- ----- 2017 -----
- **January 2017: Flight Operations Annual Review (#10)**
- **January 2017: Updated End of Mission Plan**
- **February 2017: Extended Mission Senior Review Proposal #6**
- **Spring 2017: A-Train Science Symposium (4/18-20/2017 – Pasadena, CA)**
- **Spring 2017: Annual Inclination Adjust Maneuvers (DRAFT SCHEDULE)**
  - 3/1/2017 (#52), 3/8/2017 (#53), 3/22/2017 (#54) & 3/29/2017 (#55) – Backup 4/5
- **Spring 2017: Earth Science Constellation(ESC)/A-Train MOWG**
  - Update propellant budget, decommissioning analysis, reliability predictions,...
- **Long-Term Plans**
  - Continue to improve Debris Avoidance Maneuver (DAM) responsiveness
  - Automation of Routine Operations
  - Possible Re-fueling Mission



# Collision Risk Management Process Improvements

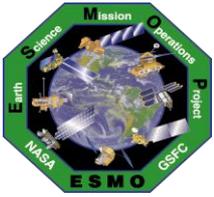


**In response to the constantly increasing number of predicted close approaches with orbital debris and operational satellites (High Interest Events – HIEs – see slides 18 & 19) and anticipated updates to the DOD’s Space Fence and size of the Space Catalog (20K → 200-270K)**

**ESMO is developing new ground system capabilities to autonomously identify and develop maneuver options to assist in Debris Avoidance Maneuver (DAM) planning (fully-automated end-to-end 24x7)**

**Collision Risk Management System (CRMS) capabilities include:**

- **Automated debris avoidance maneuver planning process**
- **User defined collision risk thresholds**
- **Maneuver optimization to address multiple conjunctions with secondary object conjunctions**



# DRAFT Spring 2017 Aqua/Aura Inclination Adjust Plan



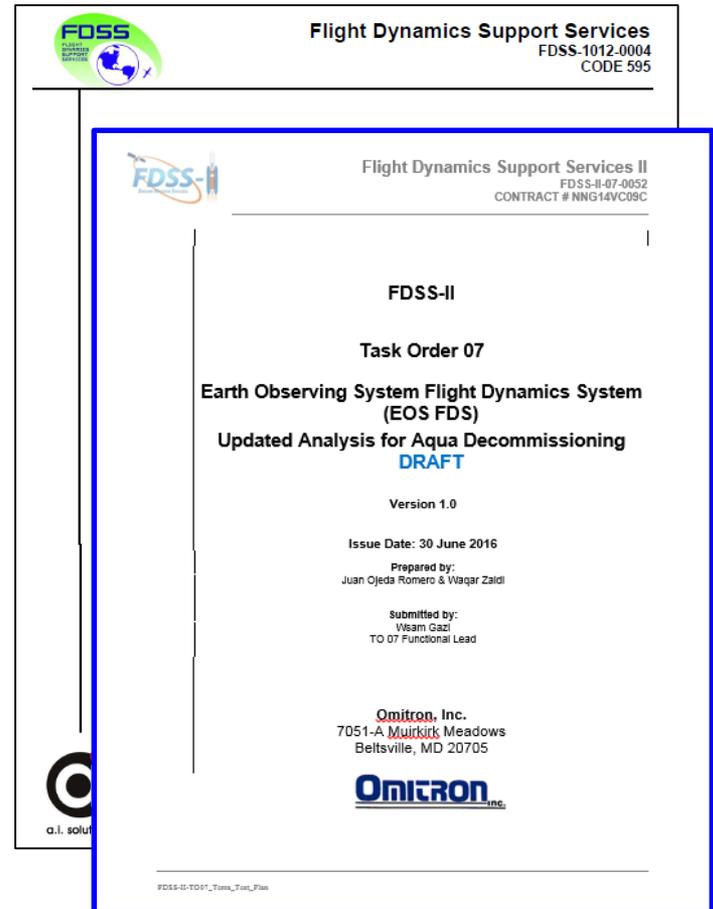
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
19 Feb	20	21	22	23	24	25
26	27	28	1 March Aqua IAM #52	2 Aura IAM #49	3	4
5	6	7	8 Aqua IAM #53	9 Aura IAM #50	10	11
12	13	14	15 Spring Break	16 Spring Break	17	18
19	20	21	22 Aqua IAM #54	23 Aura IAM #51	24	25
26	27	28	29 Aqua IAM #55	30 Aura IAM #52	31	1 April
2	3	4	5 Aqua Backup	6 Aura Backup	7	8
9	10	11	12	13	14	15
16 Easter	17	18	19	20	21	22
<b>A-Train Science Symposium in Pasadena, CA</b>						



# Aqua Propellant Usage (September 2016)



- **2006: Initial Aqua lifetime fuel analysis**
- **2008: Detailed Aqua & Aura lifetime analyses**
  - Presented to A-Train MOWG and at Aqua End of Prime Mission Review in December 2008
- **September 2012: Initial Aqua Decommissioning Plan**
  - Updated Lifetime Estimates
- **August 29, 2013: Updated Decommissioning Plan**
  - Updated definitive fuel usage and predicted solar flux levels
    - Updated propellant estimates for IAMs & DMUMs
  - Updated Constellation Exit Plan
    - Safely exiting the Afternoon Constellation requires that Aqua's final apogee be at least two kilometers below the minimum perigee of the other constellation members (692 km target)
    - Perform orbit lowering maneuvers centered at apogee and perigee (pairs of maneuvers)
- **September 30, 2014: Updated Decommissioning Plan**
  - Updated definitive fuel usage and predicted solar flux levels
    - Updated propellant trends for IAMs & DMUMs
- **Annual updates provided each September**
  - Final produced 60 days before start of decommissioning
- **September 2015 Update was delayed to allow additional time to evaluate long-term plan and decommissioning maneuvers**
- **September 2016: Investigating retrograde maneuver options**





# Remaining Fuel Estimate

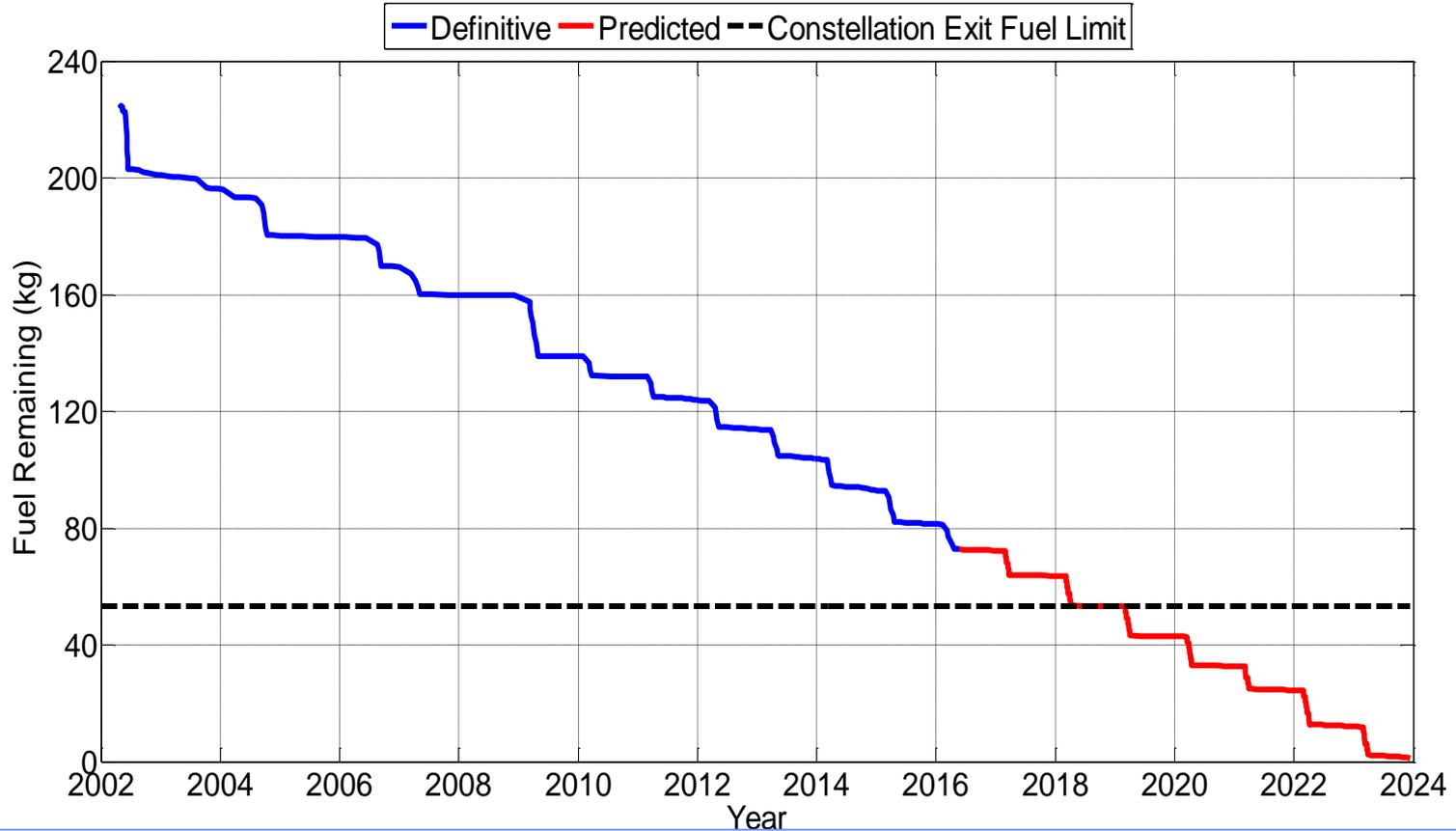
## (September 2016)



- Long-term orbit simulations were run for Aqua through 2023
  - Used mean nominal Schatten solar flux predictions
  - Estimated the frequency of drag make-up maneuvers (DMUMs) to maintain Aqua's WRS-2 ground track requirements
  - Estimated the required number of annual inclination maneuvers (IAMs) for Aqua to maintain it's mean local time (MLT) requirement
  - Did not include potential debris avoidance maneuvers
  - Utilized FreeFlyer 6.7.2 which incorporated the solid earth tide model allowing greater accuracy for long term predictions of inclination, beta angle, and mean local time
- Lifetime predictions for Aqua show that the spacecraft will have sufficient fuel to maintain its current orbit within the Afternoon Constellation through **early 2019** and possibly beyond
- Analyses are updated annually by EOS Flight Dynamics Team
  - **Currently investigating various retrograde maneuver options and inclination/mean local time options to extend the potential lifetime**



# Fuel Usage: Actual & Predicted (September 2016)



Dotted line (53.2 kg) is residual fuel needed to exit the constellation (which is now estimated to be about 13 kg higher than 2015 estimate due to higher thruster duty cycles and less efficient burns) plus 10 kg propellant buffer (under review)

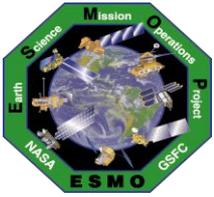


# Debris Assessment Software

## (September 2016)



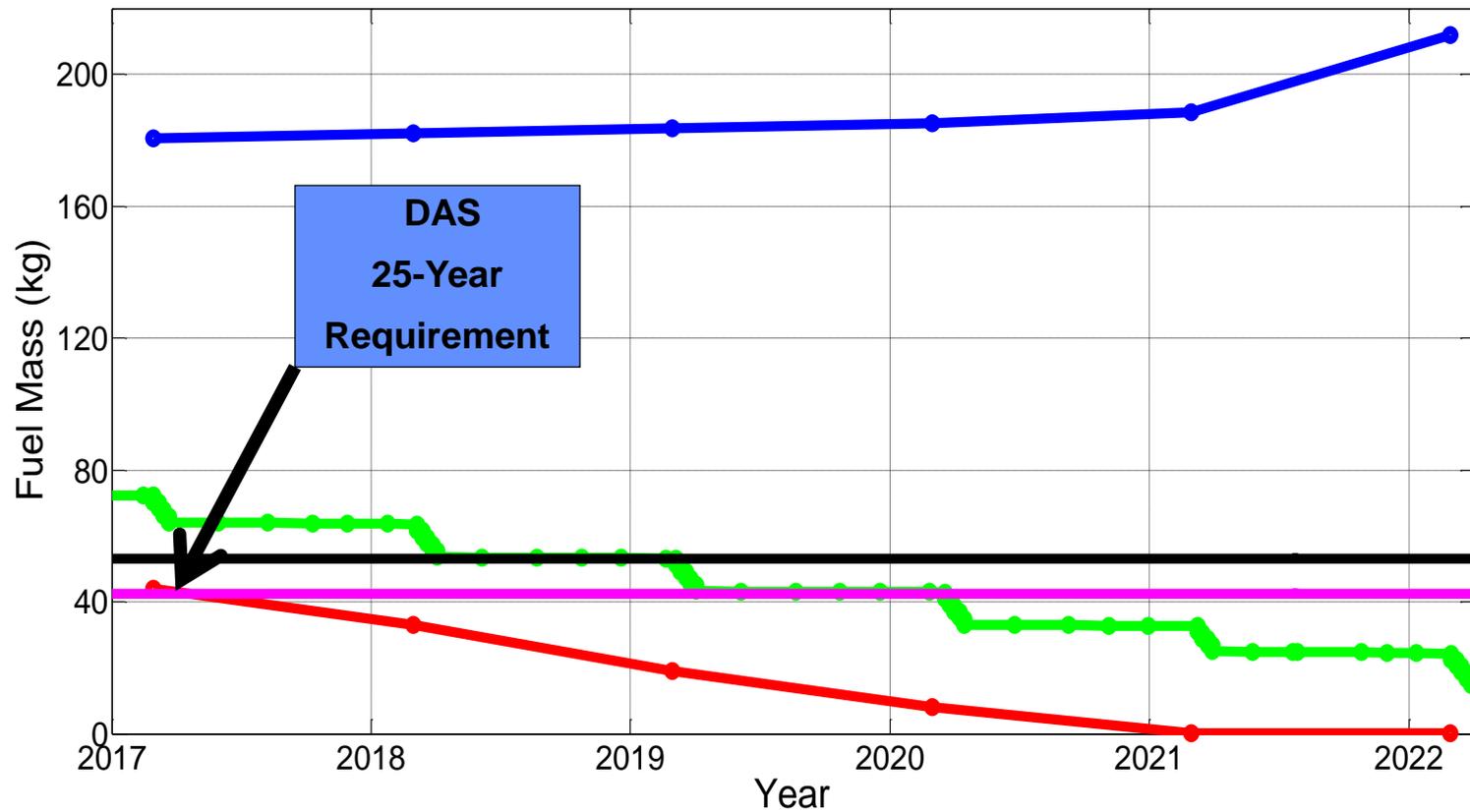
- **The Debris Assessment Software (DAS) was created by the Orbital Debris Office in Johnson Space Center and is the Agency standard for end of mission life analyses and lifetime estimations (Current Version 2.0.2)**
- **DAS requires several inputs describing the spacecraft's mission:**
  - **Start apogee (~692 km, at constellation exit)**
  - **Spacecraft dry mass (2864.6 kg) – includes 10 kg fuel buffer (TBC)**
  - **Tumbling Area (61.85 m<sup>2</sup>)**
  - **Ballistic coefficient (0.02159 m<sup>2</sup>/kg) – measured as Tumbling Area/Dry Mass**
  - **Start inclination (98.2°)**
  - **Launch date (05/04/2002)**
- **In turn, DAS outputs:**
  - **If the mission is compliant with NASA requirements for limiting orbital debris**
  - **A recommended apogee and perigee that will allow the spacecraft to reenter within a specific period and satisfy the NASA requirements**
- **Aqua has a waiver to the 30-years from launch requirement**
- **Aqua will hold sufficient fuel in reserve to meet the 25-year requirement**



# Aqua DAS End of Life Predictions (September 2016)



● Predicted Fuel Usage ● 25yr Requirement ● 30yr Requirement — 2016 Residual Fuel Limit — 2015 Residual Fuel Limit

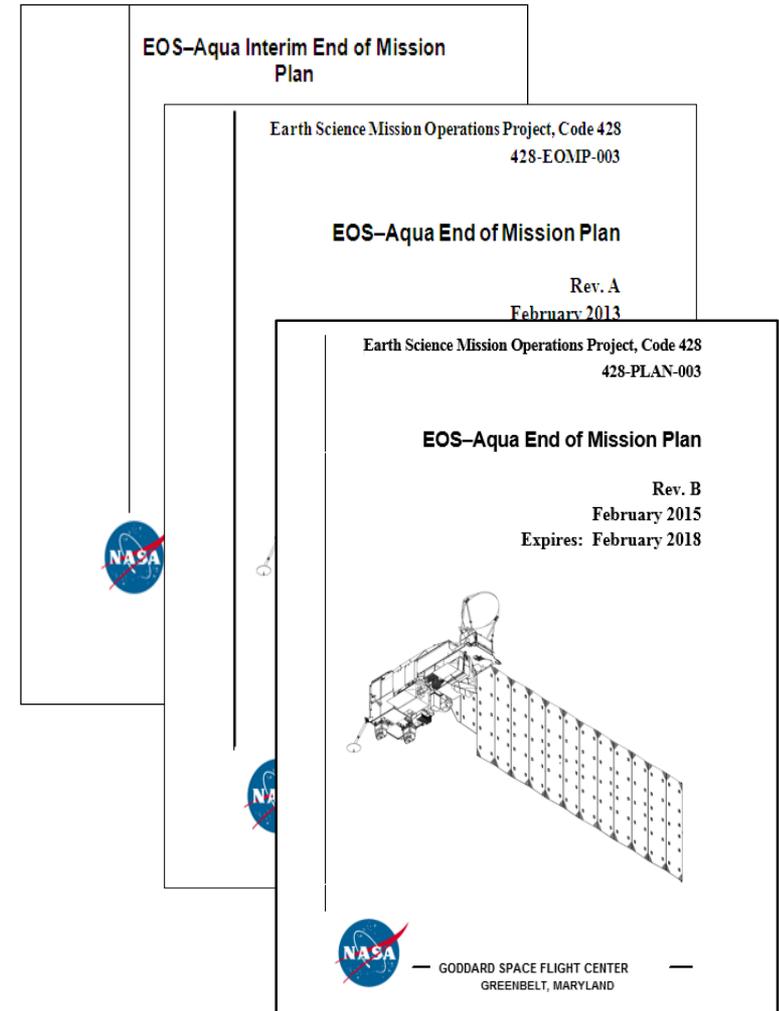




# NO Changes since last ESC MOWG Aqua End of Mission Plan



- Initial draft February 2009
- Produced the first “Interim” End of Mission Plan (EoMP) in May 2011
  - Approved by NASA HQ July 2011
- End of Mission Plan (Rev A): February 2013
  - Updated Lifetime Estimates (09/2012)
  - Added Small Object Collision Assessment
- End of Mission Plan (Rev B): February 2015
  - Final will be produced 60 days before EoM
  - Latest Annual Lifetime Estimate (09/2014)
  - Synopsis
    - » Safely exit the A-Train Constellation
    - » Passivate Aqua to the extent possible for uncontrolled reentry
    - » Aqua has **five (5)** approved waivers for passivation
      - Pressurant Passivation
      - Large Object Collision Probability
      - Small Object Collision Probability
      - Orbital Lifetime (30-Year)
      - Re-entry Risk (Un-controlled)
    - » **Waivers were approved in May 2013**
- **Next End of Mission Plan (Rev C): Feb 2017**





# Summary

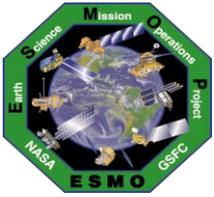


- **Spacecraft Status - GREEN**
- **Instrument Status - GREEN**
  - **AIRS, AMSU, CERES & MODIS:**
    - » **Operations Nominal – Producing Great Science**
  - **HSB: Survival Mode since 2/5/2003**
  - **AMSR-E: Powered Down 03/03/2016**
- **Data Capture/L0 Processing Status – GREEN**
  - **SSR Data Capture to 07/31/2016: 99.97884781%**
- **Data Latency – Excellent**
- **Ground Systems – Responding to new security requirements and upgrades to obsolete hardware or COTS systems, as required**
  - **Automation Effort: CDR 2/2013, Phase II CDR 1/29/2014, Delivery 2/2/2015**
  - **Phase II: R2.6.1 Development & Testing 9/1/2015 – 8/30/2016 (ongoing)**
  - **ORR: Mid-September 2016 with Eclipse 19.06**



# Additional Slides

**Orbit Maintenance Maneuvers  
Conjunction Assessment High Interest Events  
Ground Track Error & Mean Local Time History  
Spacecraft Orbital Parameters Trends & Predictions**

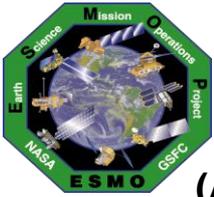


# Orbit Maintenance



**KEY: Updates since last MOWG in blue**

- **Mission Requirement:** Perform Drag Make-Up Maneuvers (DMUMs) to maintain Aqua's ground track error (GTE) with respect to the World Reference System (WRS-2) within +/-10 Km at the Descending Node
  - Changed from +/-20 Km with DMUM #19 (1/12/05)
  - **109 DMUMs** have been performed to date (**Last #109 on 7/21/2016, Next #110 on 8/24**)
  - Variation in performance from -20.9% (cold) to +24% (hot) #108 was 20.9% COLD
- **Control Box Excursions:** Since 2012 there have been 6 Control box Excursions
  - 4 on +10km front-side: 11/4/12 to 11/14/12, 10/23/13 to 10/24/13 and 3/6/14 to 3/10/14
    - » 03/16/2015 to 04/02/2015
  - 2 on -10km back-side: 11/07/13 to 12/14/13 (Emergency DAM on 10/24 and DAM on 11/28)
    - » 04/02/2016 to 05/07/2016
- **Mission Requirement:** Perform inclination adjust maneuvers (IAMs) to maintain the Mean Local Time (MLT) as measured at the Ascending Node between 1:30 and 1:45 MLT (Mission Goal starting in 2011: 13:35:45 +/- 45 seconds)
  - **51 Inclination Adjustment Maneuvers (IAMs)** performed to date
    - » Fall 2003 (1), Spring 2004 (1), Fall 2004 (5), 2005 (NONE)
    - » Fall 2006 (4 of 6 - cancelled final 2 burns), Spring 2007 (4 - interrupted 2-weeks),
    - » Spring 2008 – NONE per special request from PARASOL
    - » Spring 2009 (9), Spring 2010 (3), Spring 2011 (3), Spring 2012 (4)
    - » Spring 2013 (4 with #3 being delayed 1-week), Spring 2014 (4), Spring 2015 (5)
    - » Spring 2016 (all 4 IAMs completed, one had to be re-scheduled)



# Aqua Conjunction Assessment High Interest Events (HIEs)



(April 2016 – September 2016: 9 CARA HIEs – 2 Required Significant Action)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2016	2	3	3	2	5	0	2	x	x				17
Tier 1													
Tier 2	2	2	0	0	3	0	2	x	x				9
Tier 3	0	1	0	1	1	0	0	x	x				3
Tier 4	0	0	0	0	0	0	0	x	x				0

2013: 28 CARA HIEs – 9 required significant action  
 2014: 34 CARA HIEs – 14 required significant action  
 2015: 26 CARA HIEs – 16 required significant action

Tier 1 – Notify (email/phone), Tier 2 – Conduct Briefing,  
 Tier 3 – Plan Maneuver, Tier 4 – Execute Maneuver

**2016 thru 07/31/2016: 17 CARA HIEs – 3 that required significant action (Tiers 3 & 4)**

- 02/26/2015: CA vs. 35970 at 05:25:29 GMT – DAMs planned, self-mitigated (T3)
- 04/09/2016: CA vs. 10144 at 18:00:00 GMT – DAMs planned, self-mitigated (T3)
- 05/13/2016: CA vs. 40578 at 02:28:11 GMT – DAMs planned (TBC), self-mitigated (T3)
- 07/19/2016: CA vs. 33865 at 01:20:56 GMT – Monitored (T2)
- 07/23/2016: CA vs. 29081 at 09:59:13 GMT – Monitored (T2)

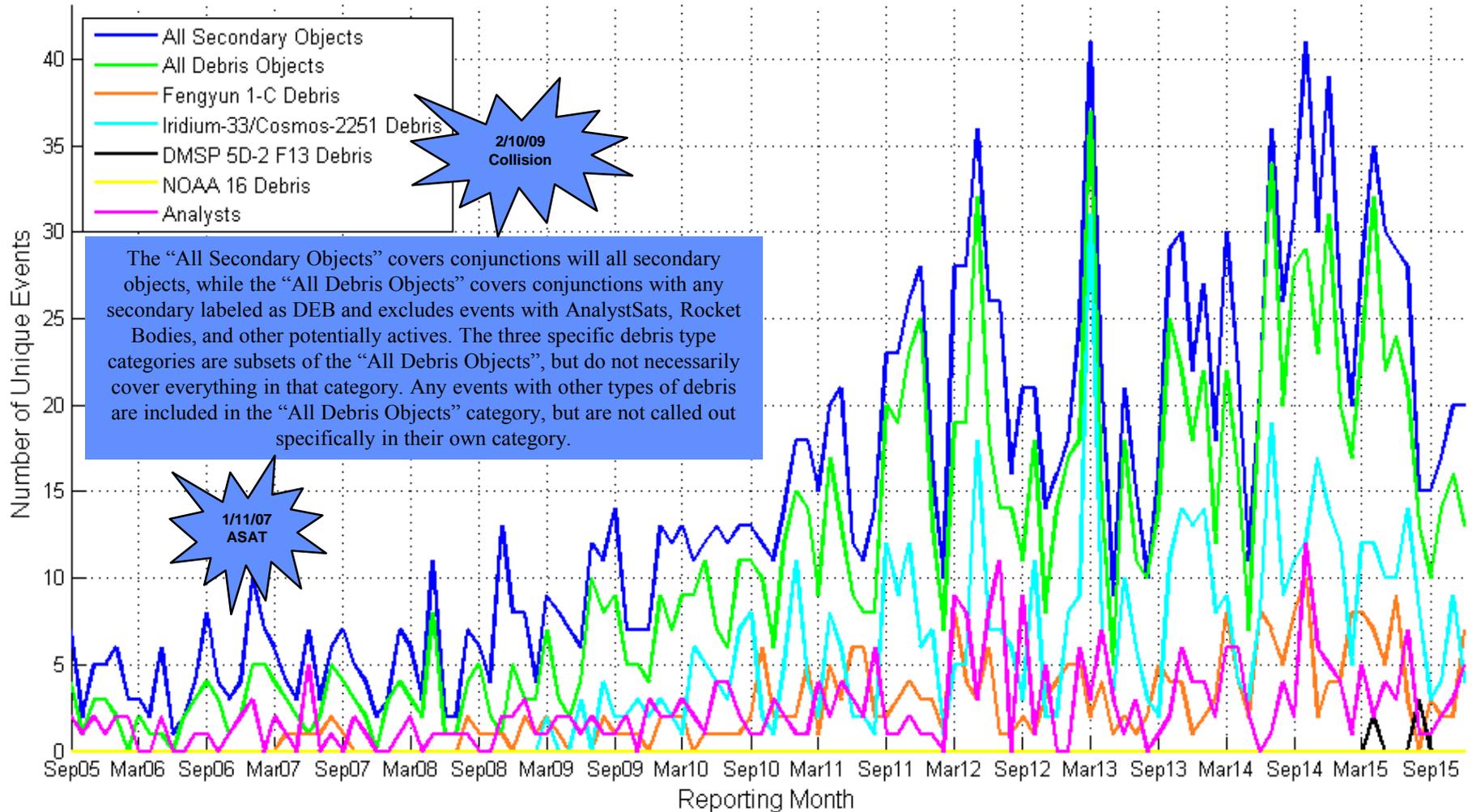
**Aqua Summary: 3 DAMs Planned, 0 DAMs Executed, 3 DAMs that self-mitigated  
 0 Routine maneuvers were postponed/replanned and/or rescheduled (Tier 4s)**

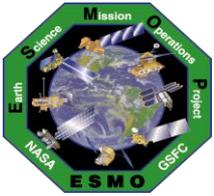


# Aqua Conjunction Assessment Statistics



(September 2005 thru December 2015)



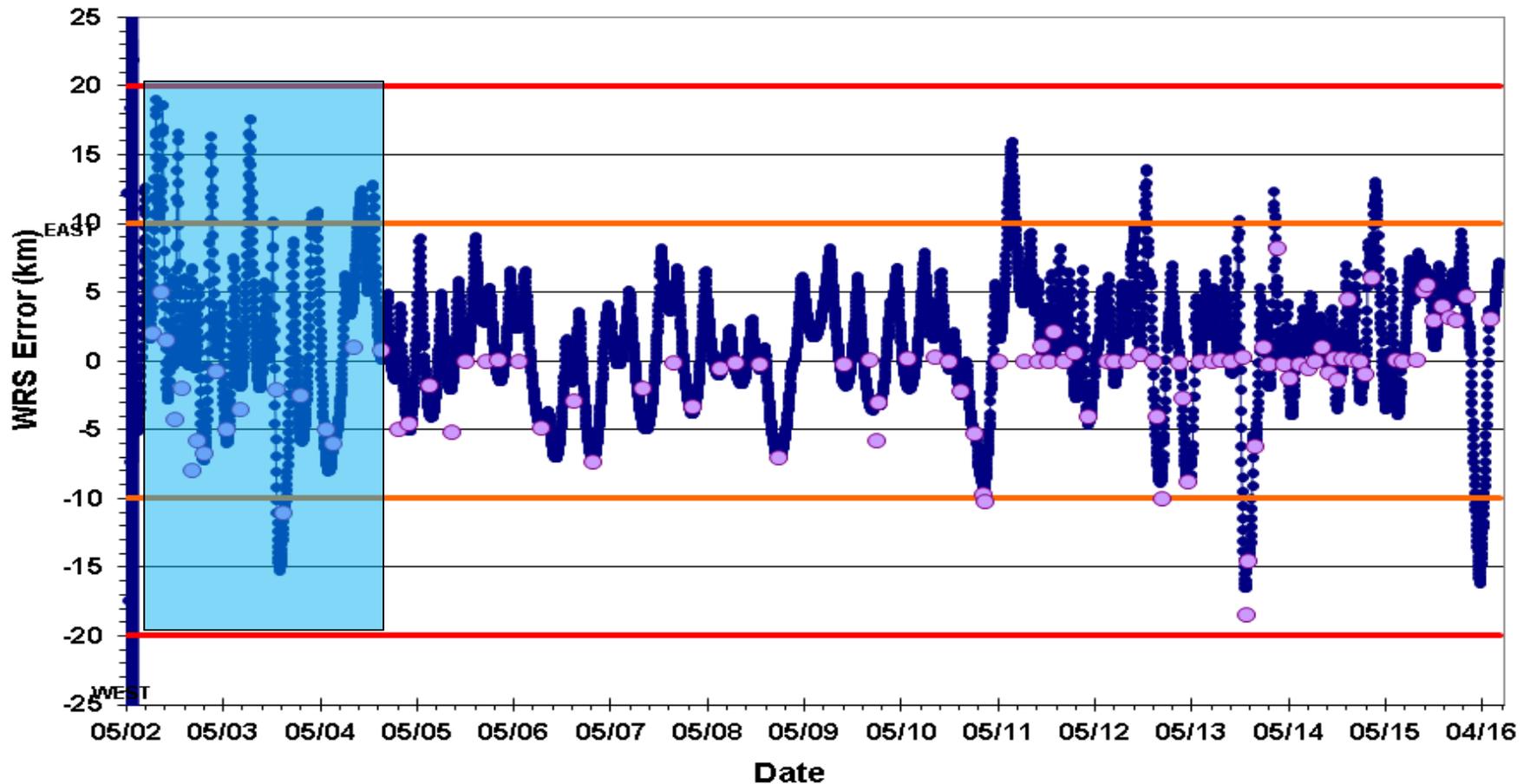


# WRS Ground Track Error (GTE)

(As of July 31, 2016)

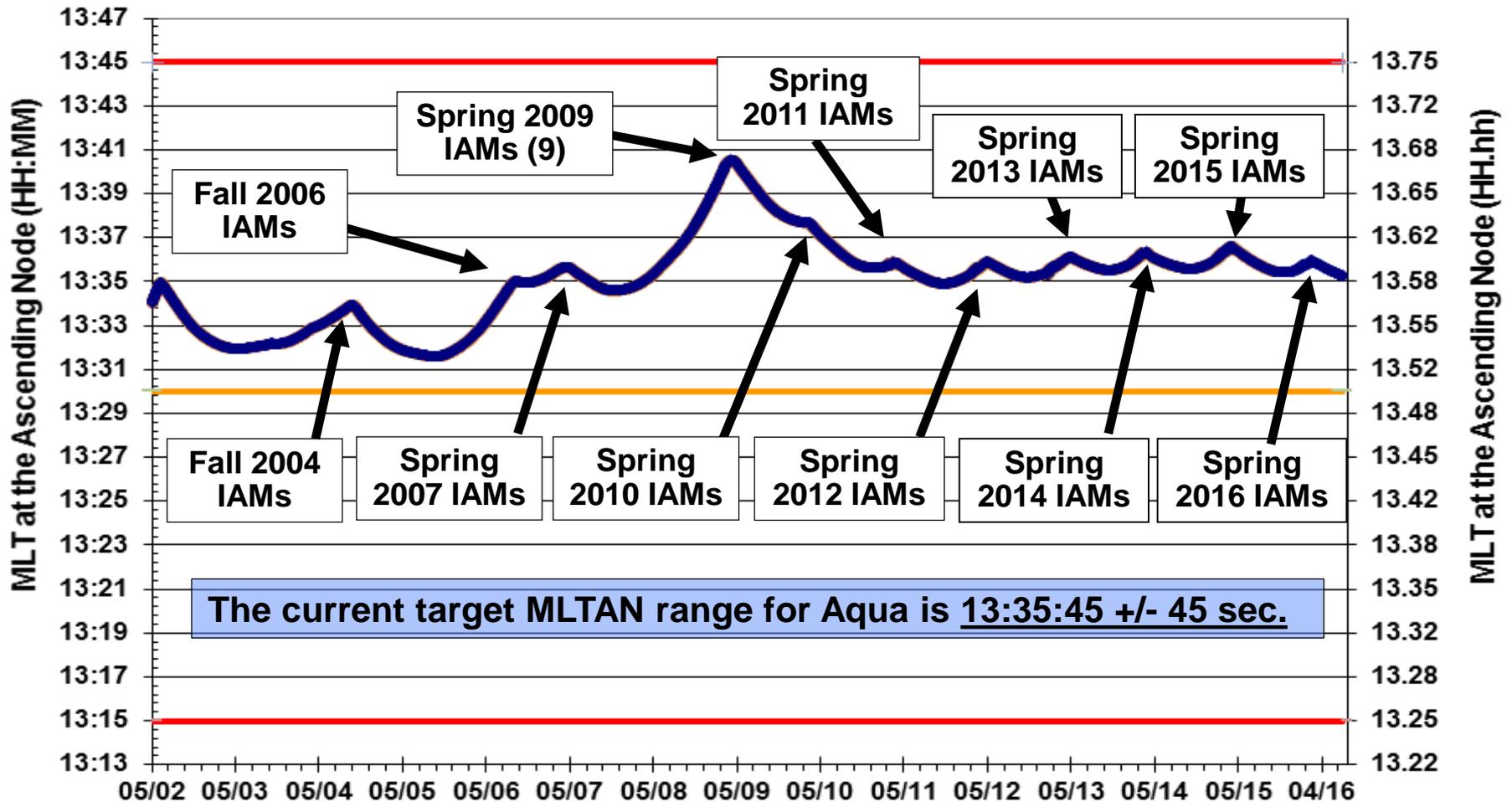


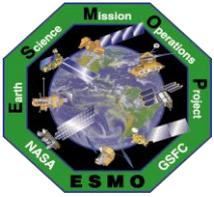
Aqua WRS Groundtrack Error at the Descending Node  
(Maneuver planning targets included)



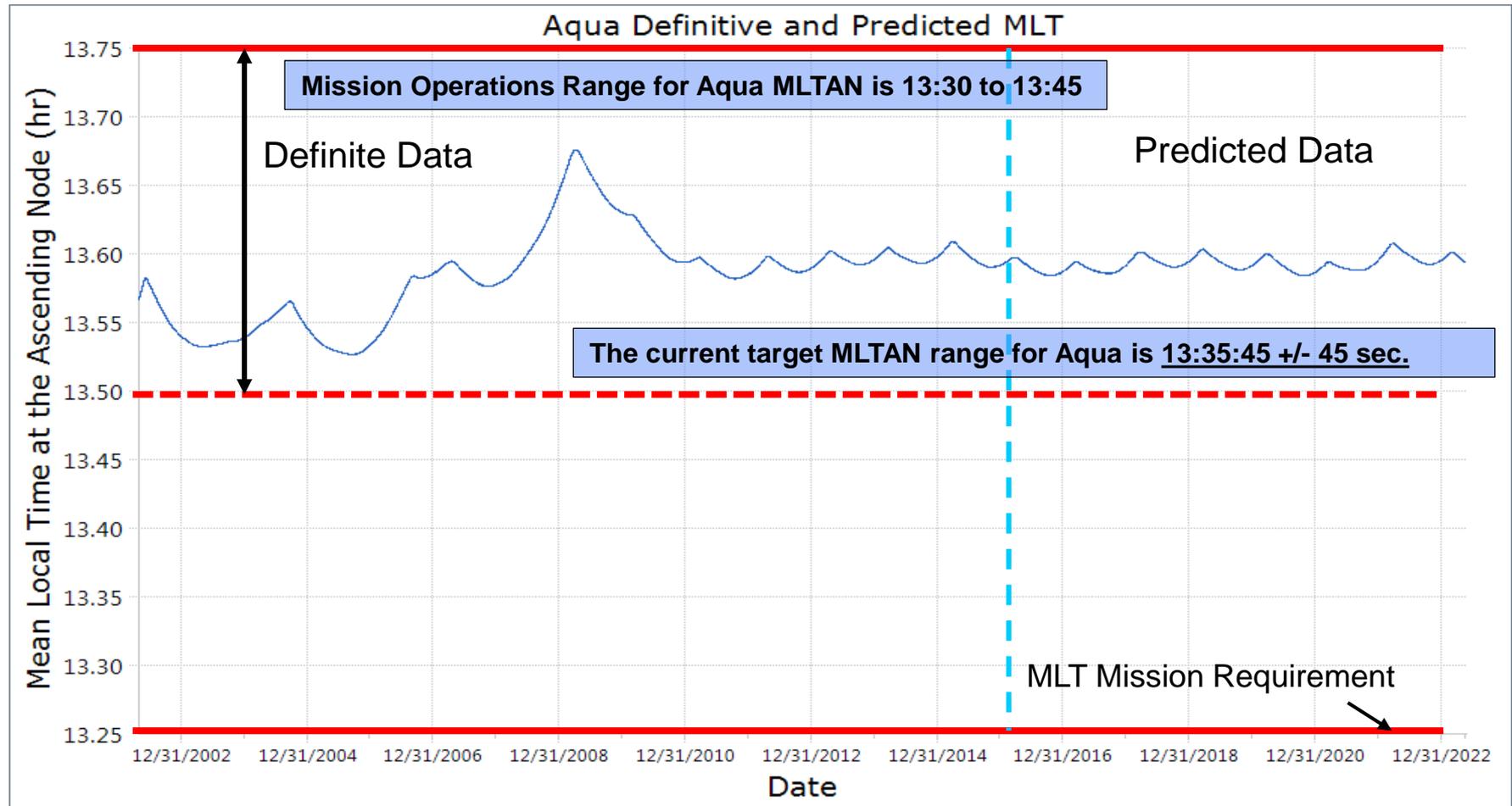


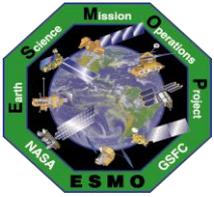
# Aqua Averaged MLT @ Ascending Node (As of July 31, 2016)





# Aqua MLT @ Ascending Node (as of Feb 16, 2016)





# Inclination/MLT Maintenance (Summer 2016)



- **EOS Flight Dynamics has analyzed and updated the nominal inclination schedule that ensures Aqua's mean local time of the ascending node (MLTAN) remains within the current target range.**
  - The current target MLTAN range for Aqua is 13:35:45 +/- 45 sec.
  - Aqua's current mission MLTAN requirements are {13:30:00 - 13:45:00}
  - Aqua's performance from the **2016 inclination series was 0.015% HOT**
- **Proposed long-term inclination adjust plan is predicted to keep Aqua within the target MLTAN range.**
  - Nominal case schedules Aqua inclination maneuvers that are not on weeks starting with Easter. The maneuvers are not currently centered around the ideal dates.
  - **Currently investigating Extended Mission Operations Options**
- **Will re-visit/re-validate the long-term plan after each series of annual inclination adjust maneuvers.**
- **See EOS Flight Dynamics Presentation for long-term plan.**



# Inclination/MLT Maintenance (Long-Term Plan)



## International Earth Science Constellation

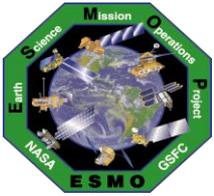
### Mission Operations Working Group

September 27-29, 2016

### Aqua Spring 2017 IAM Series

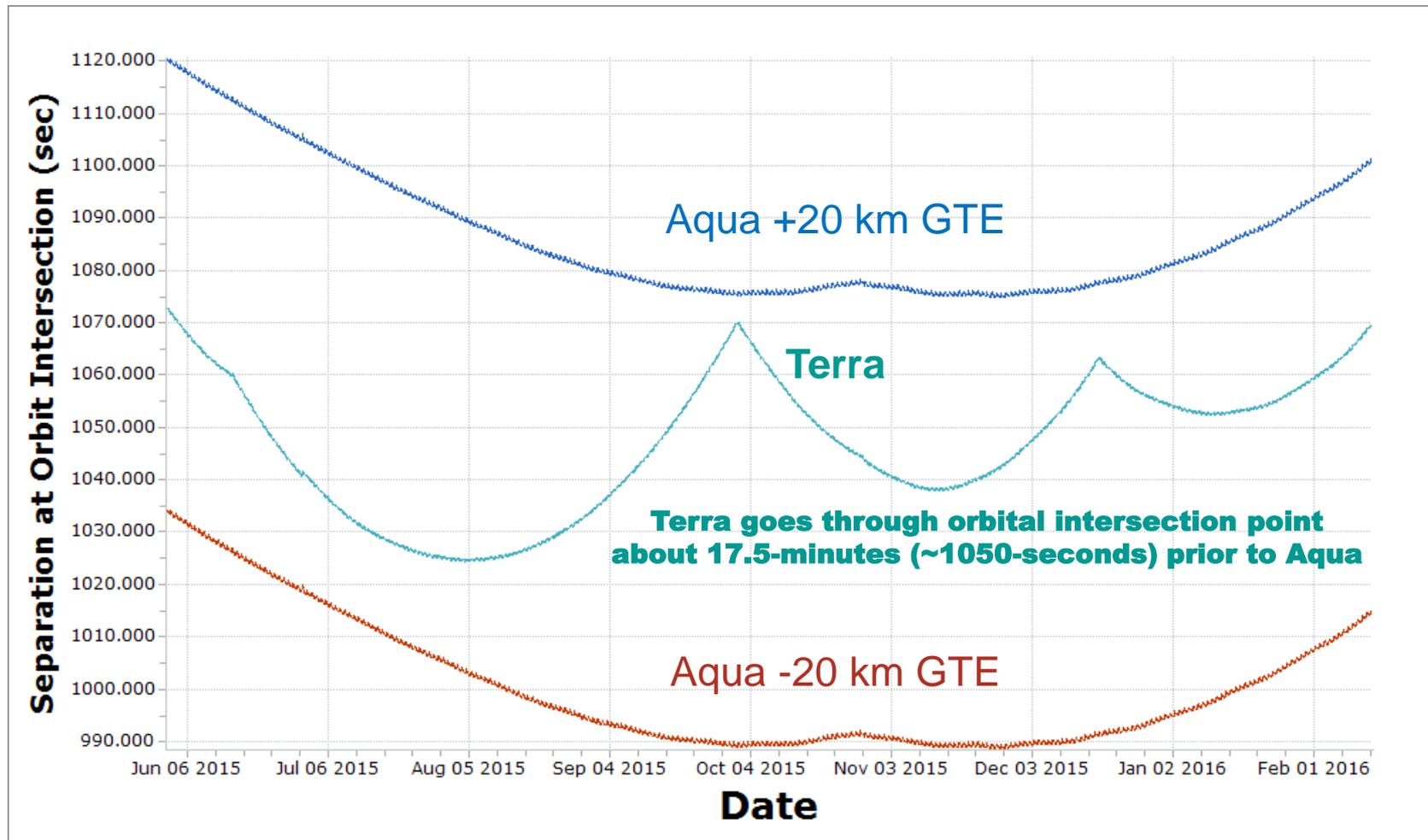
Susan Good

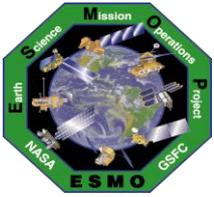
EOS FDS, [esmo-eos-fds@lists.nasa.gov](mailto:esmo-eos-fds@lists.nasa.gov), +1.301.416.5050



# Terra to Aqua Phasing

(as of Feb 16, 2016)





# Questions