Mission Status for Earth Science Constellation MOWG Meeting @ GSFC

June 13, 2017

Dominic Fisher
Aura Mission Director - Code 584
phone 301-286-3171
dominic.m.fisher@nasa.gov

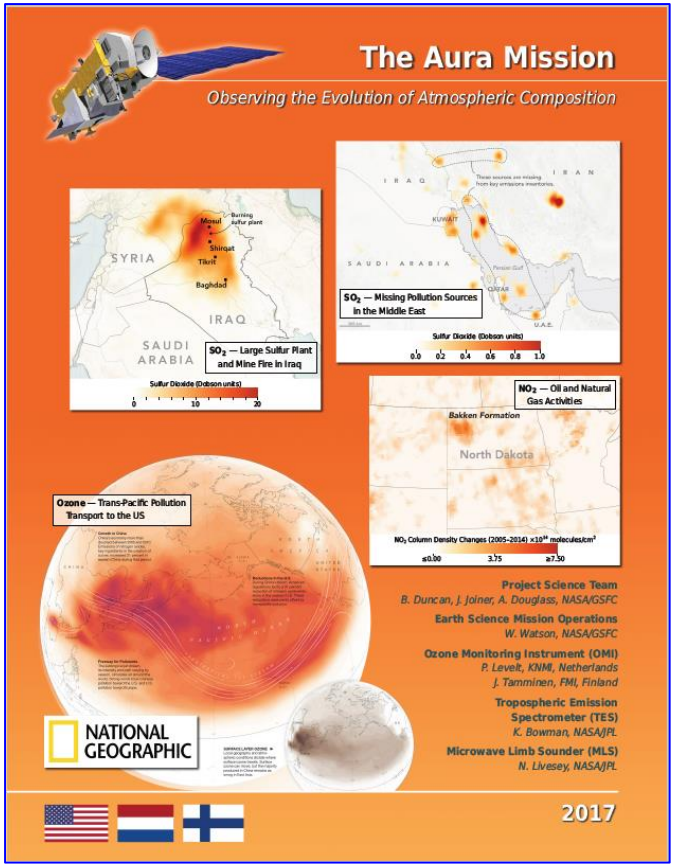
Topics

- Mission Summary
- Spacecraft Subsystems Summary
- Recent Activities
- Planned Activities
  - CRMS Process Improvement
  - Spring 2018 IAM Draft Schedule
- Propellant Usage & Lifetime Estimates
  - FDS Decommissioning Analysis
  - End of Mission Plan (EOMP)
- Overall Summary
- Additional Slides:
  - Spacecraft Maneuvers & Ground Track History
  - CA, Data Capture, & Ops Error Statistics

EOS Aura Mission Summary

(Updates since Sept 2016 MOWG in Albuquerque, NM)

- 07/15/04: Launch
  - 6-Year Design Life
- 09/30/10: End of Prime Mission Review
- 09/18/15: 2015 Mission Extension Senior Review Proposal Panel Report
  - #4 Ranked Earth Science Mission
  - Mission extension through FY17
- 07/15/16: Aura 12-Year Anniversary
- 01/25/2017: ESMO Annual Review #10
- 03/03/2017: Senior Review Proposal #5
  - Reliability Estimates thru 2022
  - Consumables through 2022



Aura Spacecraft Subsystems

(Updates since Sept 2016 MOWG in Albuquerque, NM)

- **Command & Data Handling (CDH) – Nominal**
  - **Formatter Multiplexer Unit (FMU) / Solid State Recorder (SSR) Anomaly**
    - » **Initial symptoms occurred December 4-18, 2007**
    - » **Newest symptoms started in January 2017 and remain active (impacting S-Band HK data capture)**
- **Communications (COMM) – Nominal**
- **Electrical Power System (EPS) – Nominal**
  - **Solar Panel Connector Anomaly – ARE-3C (01/12/2005)**
  - **Solar Array Offset (Reported 11/17/09, Corrected 06/29/10 and each year since)**
  - **Array Regulator Electronics (ARE) 5A Anomaly (03/12/2010 & 04/25/2013)**
    - » **03/12/2010: Simultaneous with GN&C Attitude Disturbance – attributed to MMOD Strike**
  - **Other older ARE Anomalies:**

    ARE-5C (9/27/12 & 2/4/13), ARE-1A (3/12/10 & 11/5/11), ARE-6A (9/14/13), & ARE-4A (12/08/14)
    - » **Estimated that Aura has lost 24 strings of solar cells out of a total of 132 strings**
    - » **Aura continues to have significant power margin where the life limiting item is fuel**
- **Flight Software (FSW) – Nominal**
- **Guidance, Navigation & Control (GN&C) – Nominal**
  - **Reaction Wheel Assembly (RWA) #3 Anomaly (12/03/2016) – Recovered on 12/13/16**
- **Propulsion (PROP) – Nominal**
- **Thermal Control System (TCS) – Nominal**

All subsystems configured to primary hardware

Recent Activities

(October 2016 – May 2017)

- **10 CARA High Interest Orbital Debris Events (Tiers 1-4) (As of 4/26/17)**
  - **5 required significant action (T3 / T4)**
  - **Last significant action: DMU #102 rescheduled due to post-maneuver concern**
- **2 Spacecraft Bus Anomalies**
  - **RWA #3 Spin-down (12/3/16) – recovered 12/13/16**
  - **FMU/SSR Anomaly – new symptoms since January 2017 – on-going**
- **6 Instrument Anomalies**
  - **MLS: R2 Phased Locked Loop (PLL) loss of lock – adjusted 3/08/17**
  - **OMI: 1 Instrument Survival Event (3/12/17) – recovered 3/16/17**
  - **TES: 5 ICS Stall Events (2016: 10/24; 2017: 2/5, 2/18, 2/26, 3/12) – on-going**
- **7 Spacecraft Maneuvers**
  - **6 Drag Make-up Maneuvers (DMUMs # 97 – 102)**
    - (3) Routine: 11/15/16, 12/15/16, 1/20/17,
    - (3) Impacted by CA: 10/13/16 (altered DMU), 3/26/17 (DAM), 5/3/17 (resched)
  - **4 Inclination Adjust Maneuvers (IAMs # 49 – 52)**
    - 3/2/17, 3/9/17, 3/23/17, 3/30/17
- **1 Instrument Calibration Maneuvers**
  - **MLS Yaw & Moon Scan #12 (3/14/17) (GSFC Code Red – FOT support remotely)**

Planned Activities

- **June 2017: Drag Make Up Maneuver (DMUM) #103**
- **July 2017: Update Lifetime & Decommissioning Analysis**
- **September 2017: OMI Science Team Meeting**
- **December 2017: Earth Science Constellation (ESC) MOWG (12/5-7 / Location TBD)**
  - Update propellant budget, decommissioning analysis, reliability predictions,…
- **January 2018: ESMO Annual Review #11**
- **Spring 2018: Annual Inclination Adjust Maneuvers (DRAFT SCHEDULE)**
  - 3/8/18 (#53), 3/15/18 (#54), 3/29/18 (#55), 4/12/18 (#56), & 4/19/18 (#57)
- **April 2018: Draft Aura Decommissioning Review**
  - Document Phase F spacecraft activities, any new products to be developed for SC / Inst Calibration, proposed Engineering Tests, and Passivation Sequence

- **Mid-to-Long-Term Plans**
  - **Continue to improve RMM / DAM execution**
    - » See additional details on CA automation (CRMS) in the following slide
  - **Aqua/Aura Maneuver Working Group**
    - » Develop retrograde maneuver capability and explore any fuel saving options
  - **EOS Automation (EA) – automation of routine operations**
    - » Phase II (Monitoring / Alerting) ORR – July 2017; Phase III - TBD

Collision Risk Management System (CRMS) Process Improvements

- In response to the constantly increasing number of predicted close approaches with orbital debris and operational satellites (High Interest Events – HIEs) and anticipated updates to the US Air Force Space Fence which will significantly increase size of the Space Catalog (20K ➔ 150-200K)

- ESMO has been developing new ground system capabilities to autonomously identify and develop maneuver options to assist in Debris Avoidance Maneuver (DAM) planning

- CRMS capabilities to include:
  - Goal is to develop an automated debris avoidance maneuver planning process
  - User defined collision risk thresholds
  - Maneuver optimization to address multiple conjunctions with secondary object conjunctions

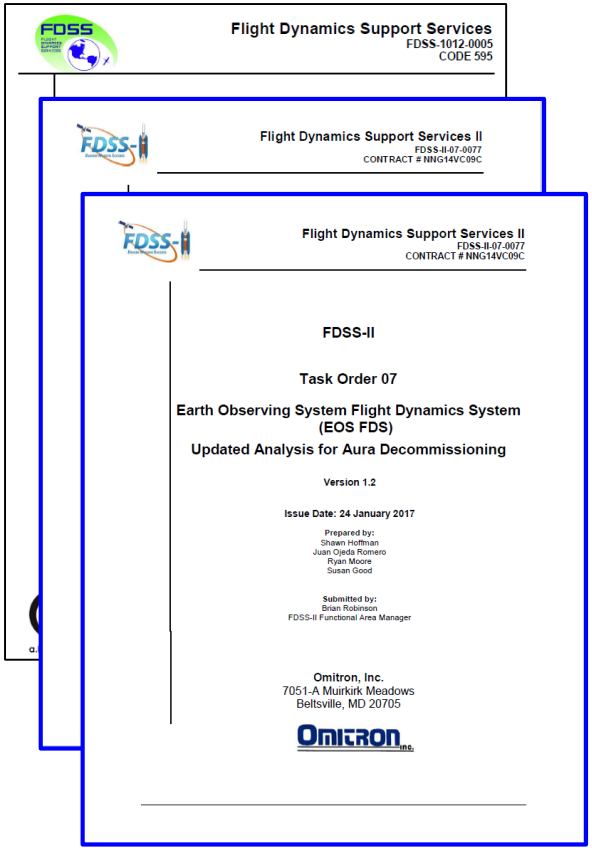
- EOC is currently operating with CRMS Release 5.0 (ORR 2/9/17)

DRAFT Spring 2018
Inclination Adjust Plan

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
18 **Feb**	19	20	21	22	23	24
25	26	27	28	1March	2	3
4	5	6	7 **Aqua IAM #56**	8 **Aura IAM #53**	9	10
11	12	13	14 **Aqua IAM #57**	15 **Aura IAM #54**	16	17
18	19	20 **Equinox**	21 **Spring Break**	22 **Spring Break**	23	24
25	26	27 **Aura ID**	28 **Aqua IAM #58**	29 **Aura IAM #55**	30	31 **Aqua ID**
1 **April Easter**	2	3	4 **Easter Break**	5 **Easter Break**	6	7
8	9	10	11 **Aqua IAM #59**	12 **Aura IAM #56**	13	14
15	16	17	18 **Aqua IAM #60**	19 **Aura IAM #57**	20	21
22	23	24	25 **Aqua Back-up**	26 **Aura Back-up**	27	28
29	Golden Week in Japan					

Aura Propellant Usage
(Updated report January 2017)

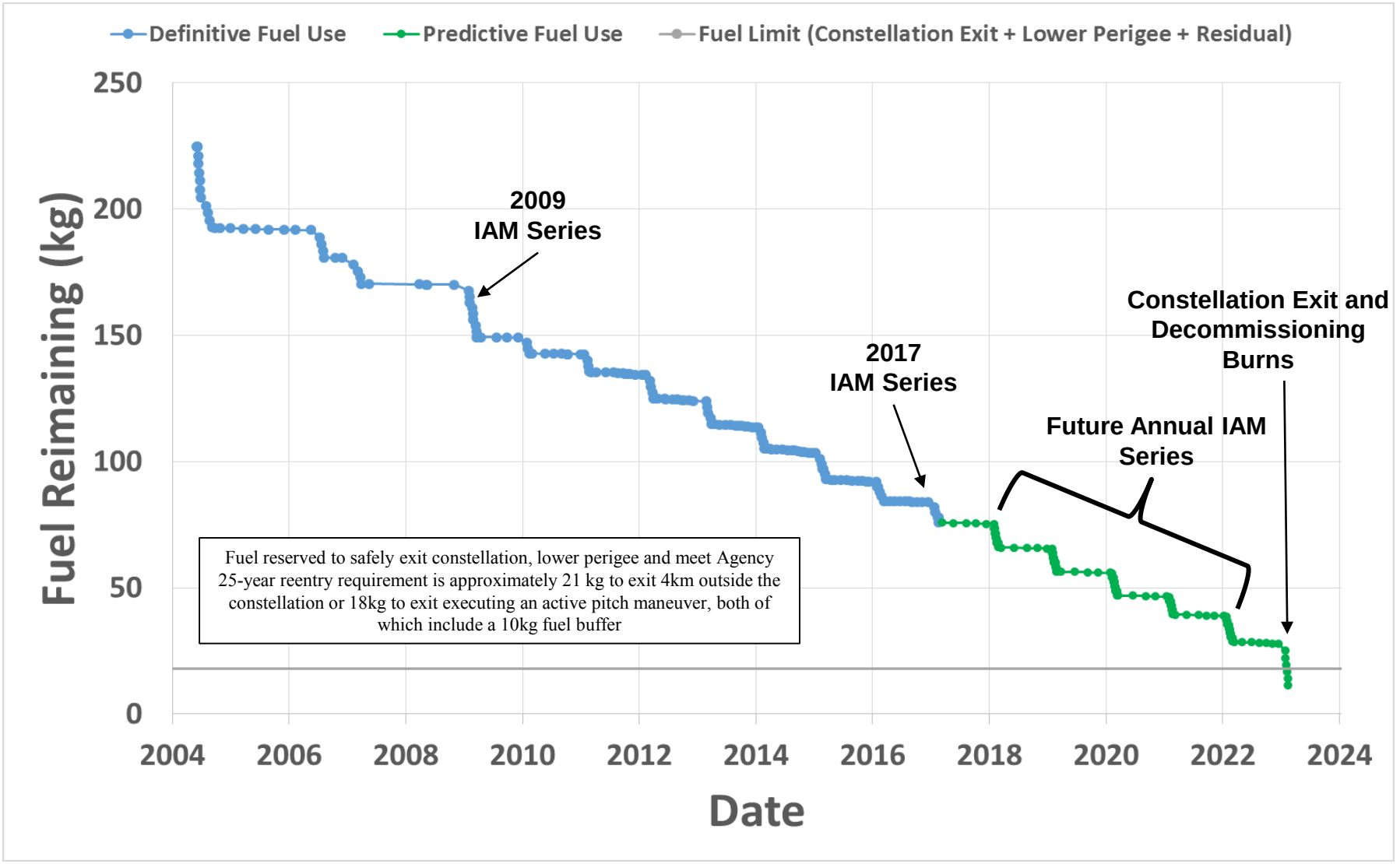
- **2006: Initial Aura lifetime fuel analysis**
- **2008: Detailed Aqua & Aura lifetime analysis**
  - Presented to MOWG and at Aura End of Prime Mission Review in September 2010
- **2012 (September): Initial Aura Decommissioning Plan**
  - Updated Lifetime Estimates
- **2013 (August): Updated Decommissioning Plan**
  - Updated propellant trends for IAMs & DMUMs
  - Updated definitive fuel usage and predicted solar flux levels
  - Updated Constellation Exit Plan
    - Safely exiting the Afternoon Constellation requires that Aura'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)
- **2014 (September): Updated Decommissioning Plan**
  - Updated propellant trends for IAMs & DMUMs
  - Updated definitive fuel usage and predicted solar flux levels
- **2015 (September): Decommission Plan Update Postponed**
  - Postponed to allow additional time to evaluate long-term plan and decommissioning maneuvers
- **2016 (December): Updated Decommission Plan (v1.1)**
  - Updated definitive fuel usage & predicted solar flux levels
  - Updated propellant estimates for IAMs & DMUs
  - Jan. 2017 update v1.2 delivered (included MLT Drift Impact with L8)
- **Annual updates will be provided each July (starting in 2017)**
  - Final will be produced 60 days before start of decommissioning



Remaining Fuel Estimate
(Updated December 2016)

- **Long-term orbit simulations were run for Aura through Feb 2023**
  - **Used mean nominal Schatten solar flux predictions (Nov 2016)**
  - **Estimated the frequency of drag make-up maneuvers to maintain Aura's WRS-2 ground track requirements**
  - **Estimated the required number of annual inclination maneuvers for Aura to maintain it's mean local time (MLT) requirement (25 IAMs through 2023)**
  - **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 Aura shows that the spacecraft will have sufficient fuel to maintain its current orbit within the Afternoon Constellation through 2022 (before 2023 IAM series).**
- **Aura will hold sufficient fuel in reserve after exiting the constellation to lower perigee such that reentry will meet the NASA 25-year reentry requirement.**
- **Analyses are updated annually by ESMO Flight Dynamics Team**
  - **Currently investigating various retrograde maneuver options and inclination/mean local time options to extend the potential lifetime**

Fuel Usage: Actual & Predicted
(Updated December 2016)

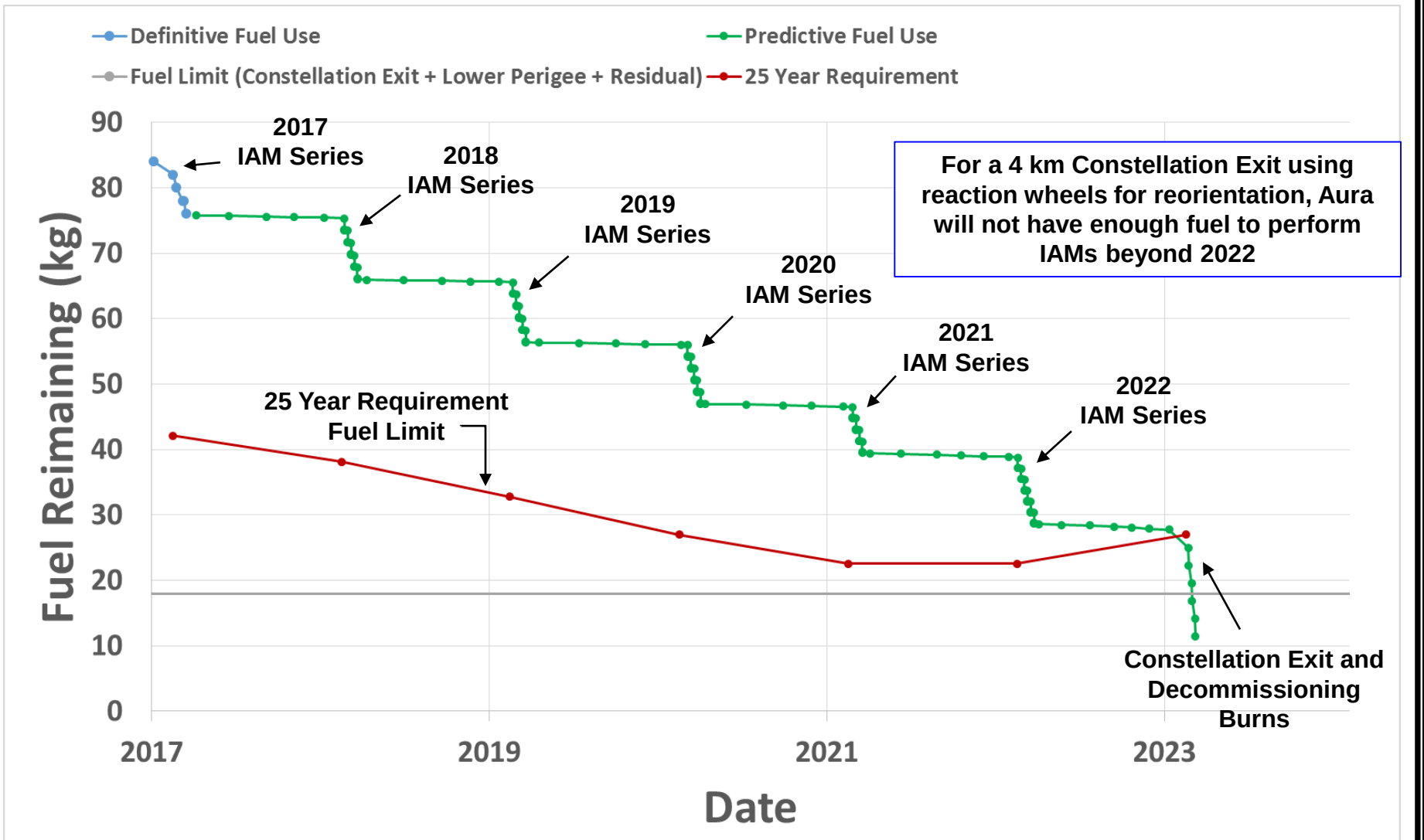


Debris Assessment Software
(Updated December 2016)

- **The Debris Assessment Software (DAS) was created by the Orbital Debris Office at Johnson Space Center and is the Agency standard for end of mission life analyses and lifetime estimations (Version 2.0.2)**
- **DAS requires several inputs describing the spacecraft's mission:**
  - Start apogee – Average Height (~691 km, at constellation exit)
  - Spacecraft dry mass (2796.546 kg) – includes 1.2 kg of unusable fuel and 4.8 kg of uncertainty
  - Tumbling Area (46.1 m^2) (FDSS-II-07-0085_Aura Average Area _V1.0 (3/1/17))
  - Area-to-Mass Ratio =Tumbling Area/Dry mass (0.016485 m^2/kg)
  - Start inclination (98.2^o)
  - Launch date (07/15/2004)
- **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
- **Aura has a waiver to the 30-years from launch requirement**
- **Aura will hold sufficient fuel in reserve to meet the 25-year requirement**

Aura DAS End of Life Predictions

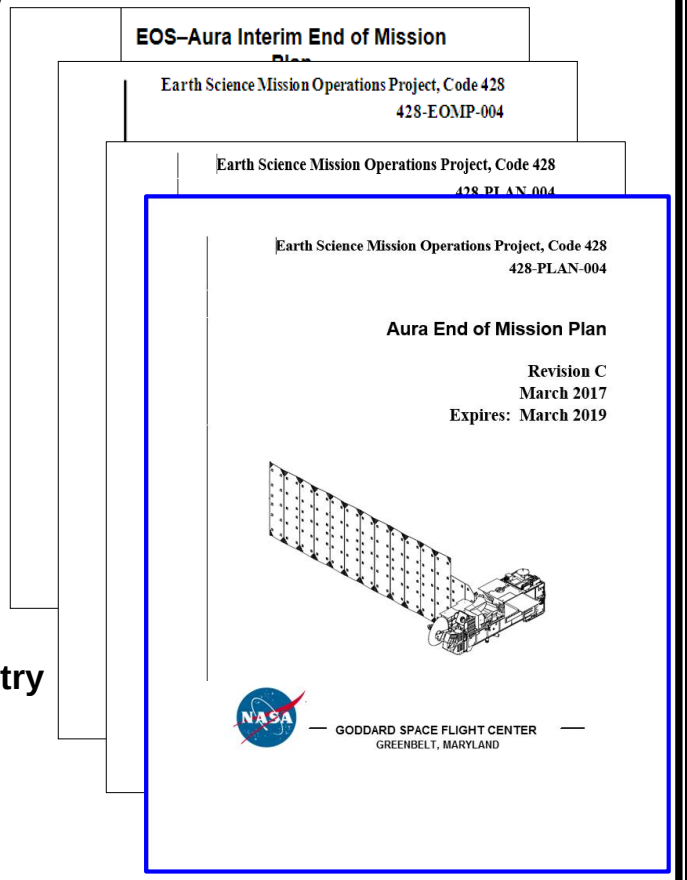
(Updated December 2016)



Aura End of Mission Plan (EOMP)

(Updated March 2017)

- Initial draft February 2009
- Produced the first "Interim" End of Mission Plan (EoMP) in May 2011
  - Approved by NASA HQ July 2011
- Produced EoMP Rev A: February 2013
  - Updated Lifetime Estimates (09/2012)
  - Added Small Object Collision Assessment
- Produced EoMP Rev B: February 2015
  - Updated Lifetime Estimate (09/2014)
- Produced EoMP Rev C: March 2017 (in Review Cycle)
  - Updated Lifetime (12/2016) & Reliability estimates
- Final will be produced 60 days before End of Mission
- Synopsis
  - Safely exit the A-Train Constellation
  - Passivate Aura to the extent possible for uncontrolled reentry
  - Aura 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



Summary

- **Spacecraft Status – GREEN**
  - **CDH: FMU/SSR Anomaly - No HK data recording to Partition 31 since 03/21/17**
  - **GNC: RWA #3 Spin-down 12/03/16 – Successful Recovery 12/13/16**
- **Instrument Status - GREEN**
  - **HIRDLS: Chopper Stalled 03/17/08 – Not collecting science data**
  - **MLS: Operating Normally – Only periodic Band 13 measurements**
    - » **08/06/13: Band 12 Shut down (reached end of useful life – 2-year design)**
    - » **THz module in Standby Mode – Expect final set of measurements to be in Aug. 2017**
    - » **02/25/2017: R2 Lock Status Yellow Alarms (due to aging, voltage fine-tuned 03/08/17)**
  - **OMI: Operating Normally**
    - » **Field-of-View Anomaly started in September 2007 – currently stable**
    - » **03/12/17: OMI Survival Mode Transition (Recovered 03/16/17)**
  - **TES: Operating Normally**
    - » **01/22/17: Laser A testing resulted in laser fringes; Science mode transition 01/24/17**
    - » **TES ICS Stalls (#11 - 15) - 10/24/17, 02/05/17, 02/18/17, 02/26/17, and 03/12/17**
- **Data Capture/L0 Processing Status – GREEN**
  - **SSR Data Capture to 04/30/2017: 99.99573138%**
- **Ground Systems – GREEN**
  - **EOS Automation (EA) – R2.7 Testing w/ Online Build 20.01 – ORR ~July 2017**
  - **04/11/2017: MMS Build 24.2.0 (RHEL7) Transition for Aura**

Additional Charts

Maneuvers & Ground Track History
Orbital Trends

Aura Conjunction Assessment
High Interest Events (HIEs)

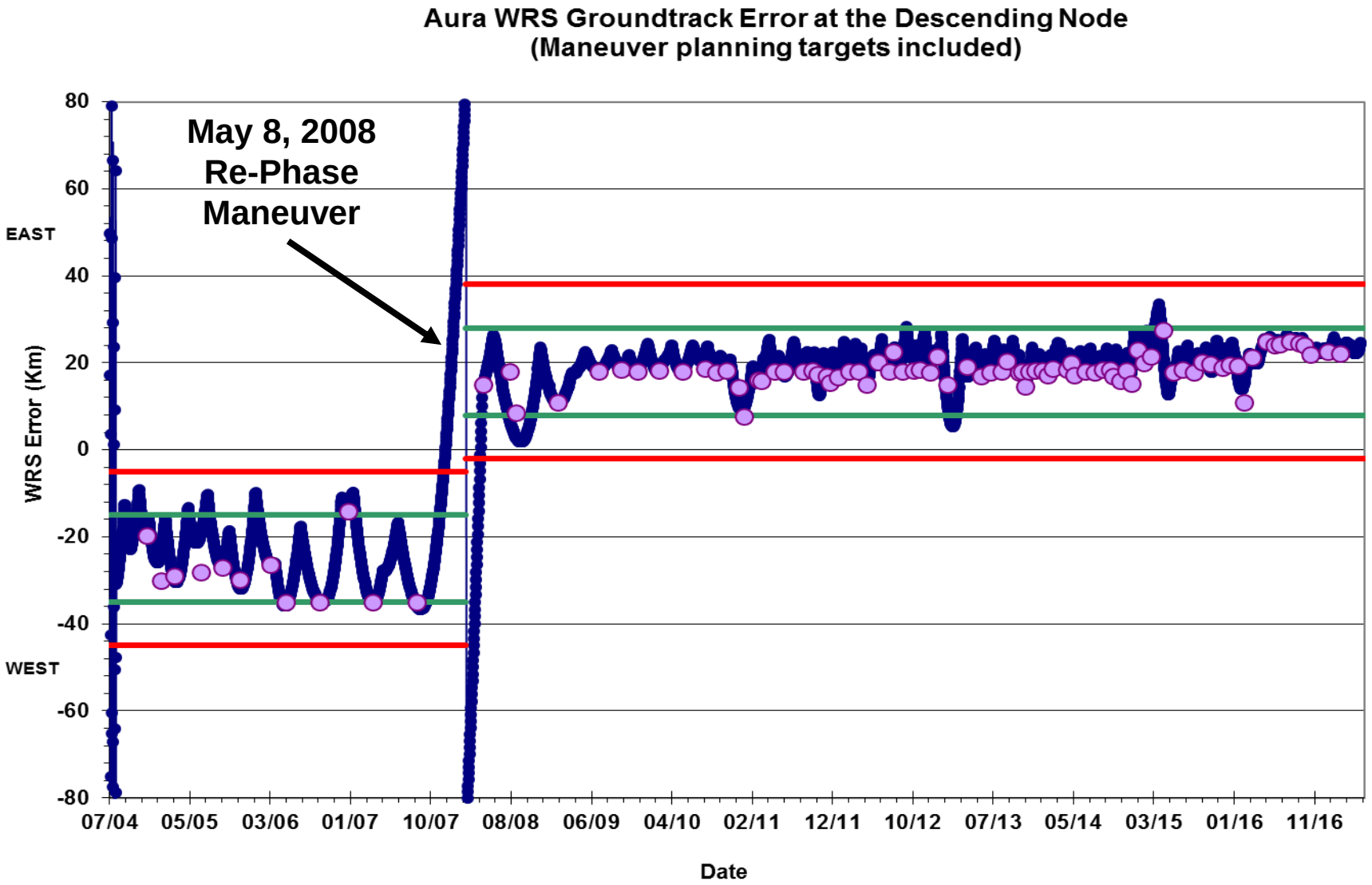
Data Capture & Operations Errors

Orbit Maintenance

- **Mission Requirements: Perform Drag Make-Up Maneuvers (DMUMs) to maintain Aura's Ground Track Error (GTE) with respect to the World Reference System (WRS-2)**
  - **Requirement: +/-20 Km as measured at the Descending Node**
- **To meet coincident viewing requirements, Aura's initial ground track was offset from Aqua's by one WRS path plus 25.4 Km**
  - **Aura was maintained -5.4 to -45.4 Km west of Aqua until late 2007**
  - **Since May 8, 2008, a new control box, +/- 10 Km from a +18 Km (east) offset of the Aqua WRS-2 path is used to maintain MLS-CALIPSO viewing request**
- **To date a total of 102 routine DMUMs have been performed**
  - **07/19/2012: DMUM # 43 No Yaw Slew Maneuver (NYS) #1 – NYS Maneuvers (37)**
  - **Last maneuver 05/03/2017 (#102) – Next maneuver ~06/21/2017 (#103)**
  - **Variation in performance from –3.5% (cold) to +3.3% (hot)**
- **Conducted 12 series of inclination adjustment maneuvers**
  - **Fall '04 (4), Fall '06 (4 of 6), Spring '07 (4), Spring '09 (9), Spring '10 (3), Spring '11 (3), Spring '12 (4), Spring '13 (4), Spring '14 (4), Spring '15 (5), Spring '16 (4), & Spring '17 (4)**
  - **Variation in performance from -4.5% (cold) to +1.9% (hot)**

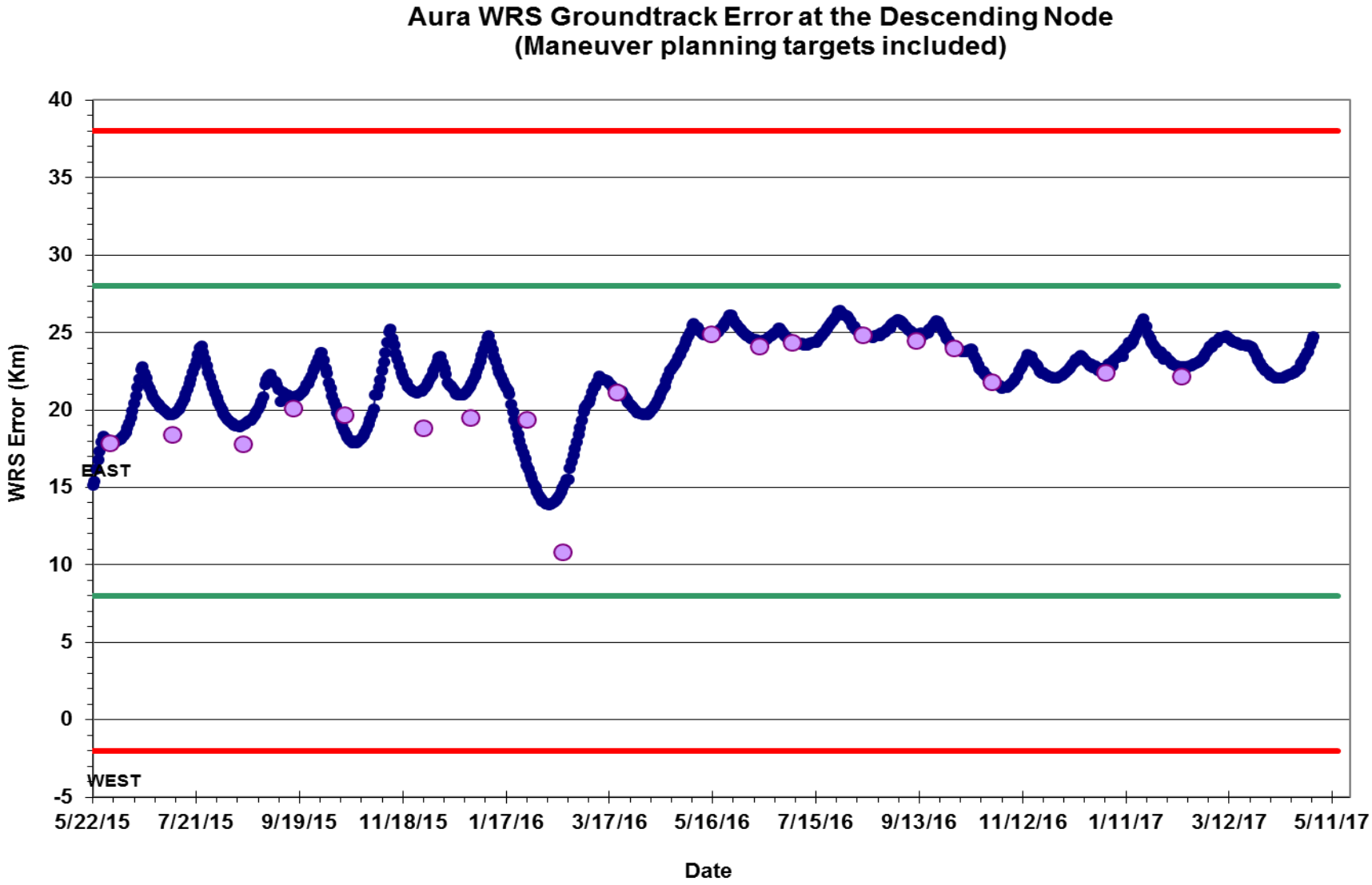
WRS Ground Track Error (GTE)

(As of May 1, 2017)



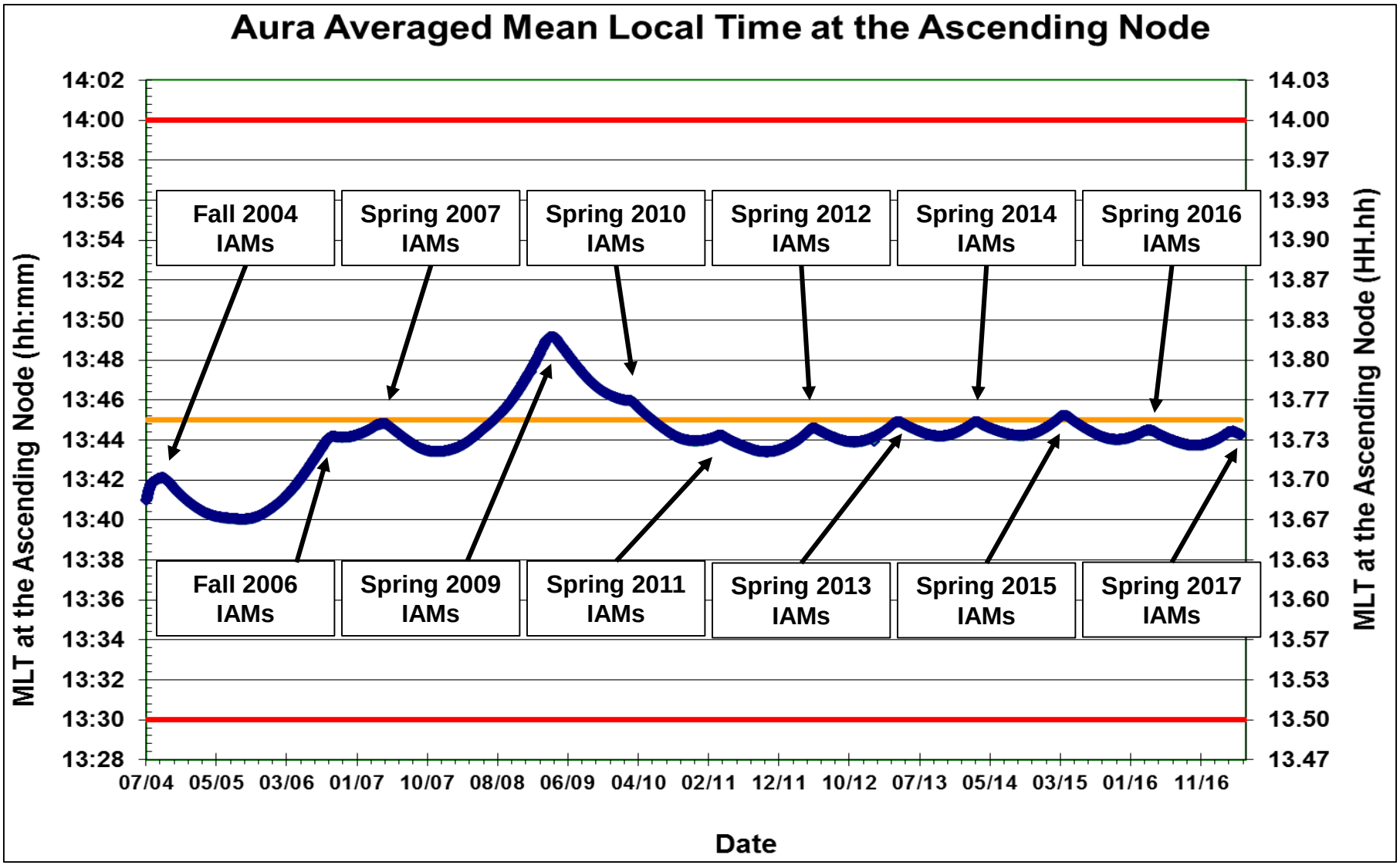
WRS Ground Track Error (GTE)

(As of May 1, 2017) Past 18+ months



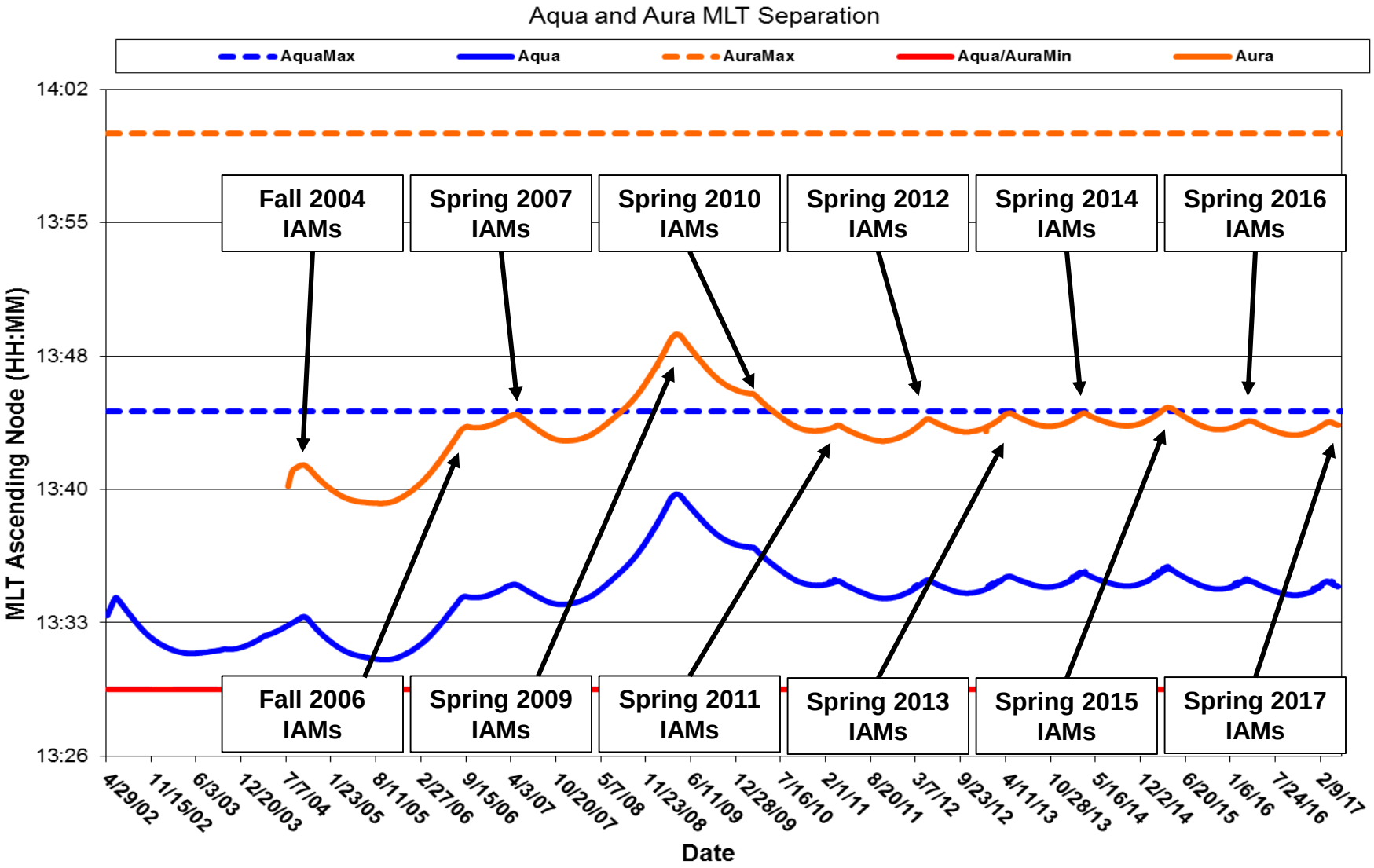
Aura Averaged MLT @ Ascending Node

(As of May 1, 2017)

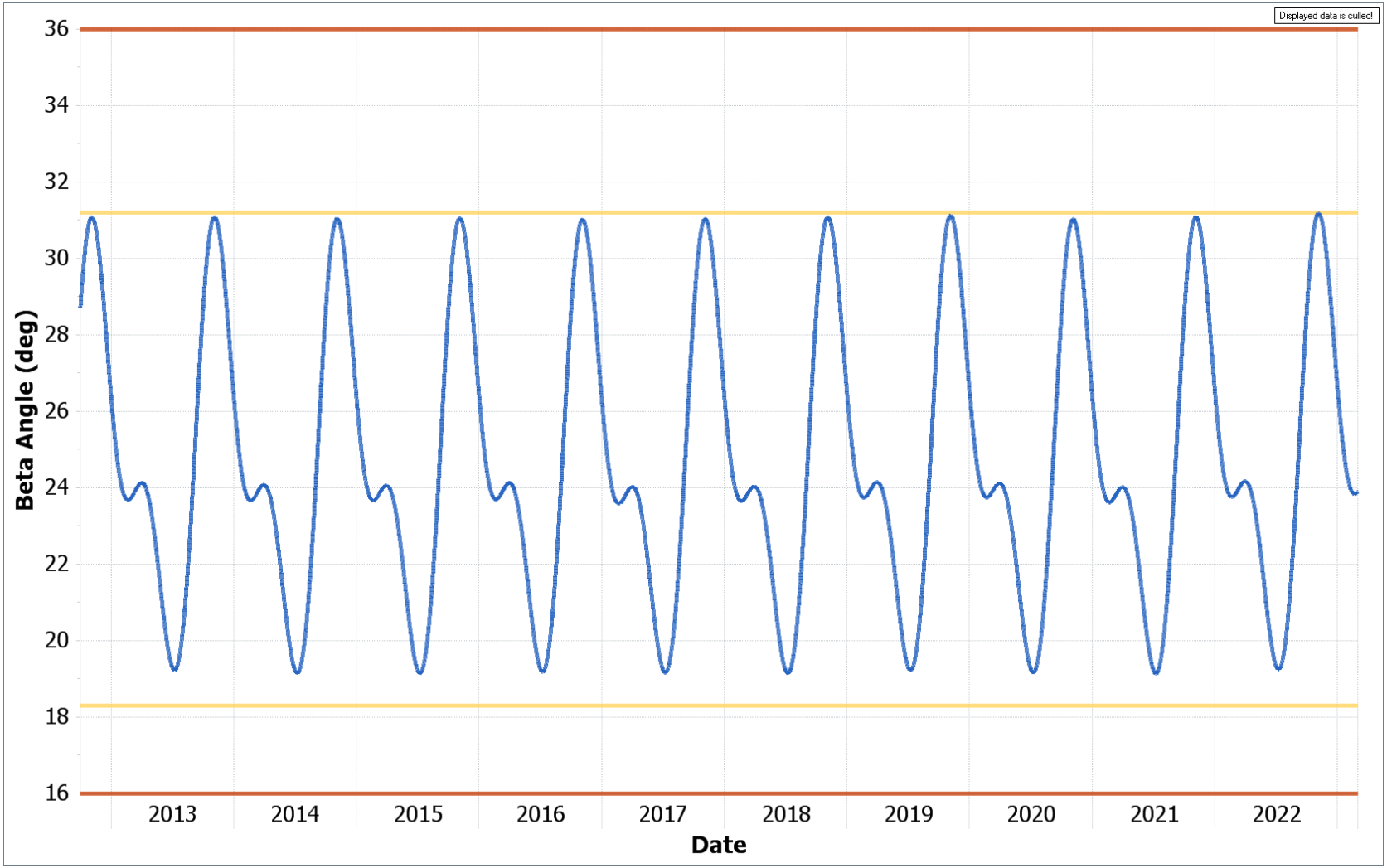


Aqua/Aura Mean Local Time (MLT)

@ Ascending Node (as of May 1, 2017)



Aura Predicted Beta Angle
(With Yearly Inclination Maneuvers)

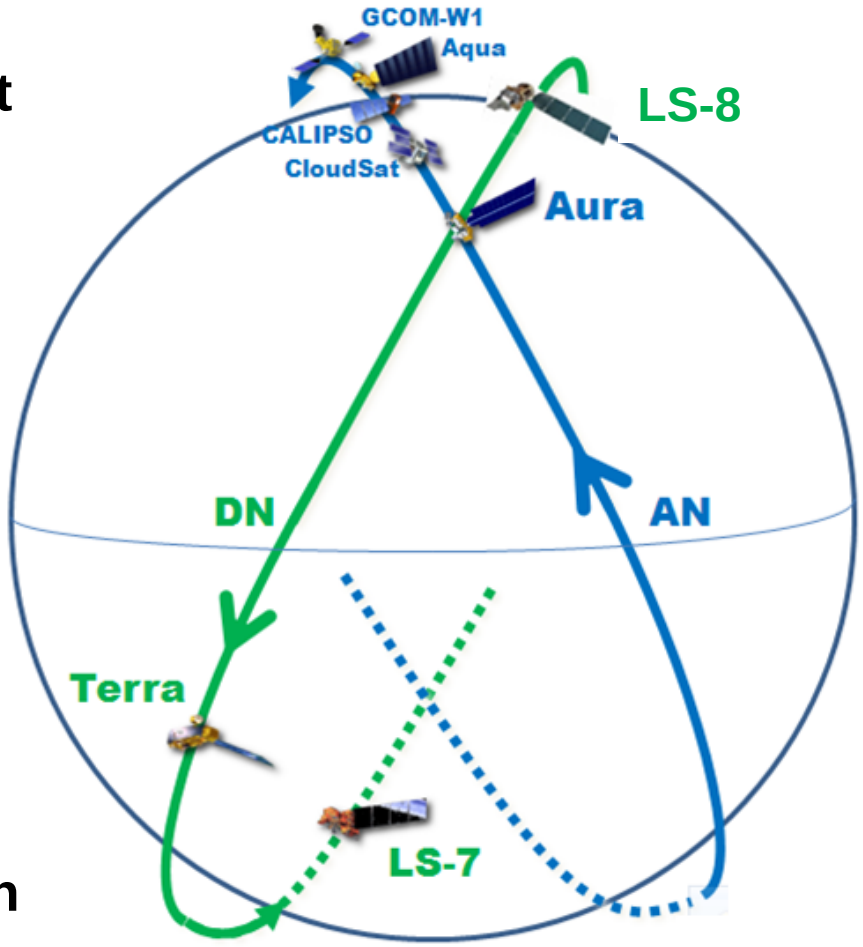


Aura and Landsat-8 (LS-8)
Orbit Phasing

With Aura in the intersection point LS-8 will be ~ 77 seconds away from the intersection Point worse case

Typically 265 – 365 seconds

Terra ~ 30 min behind LS-7

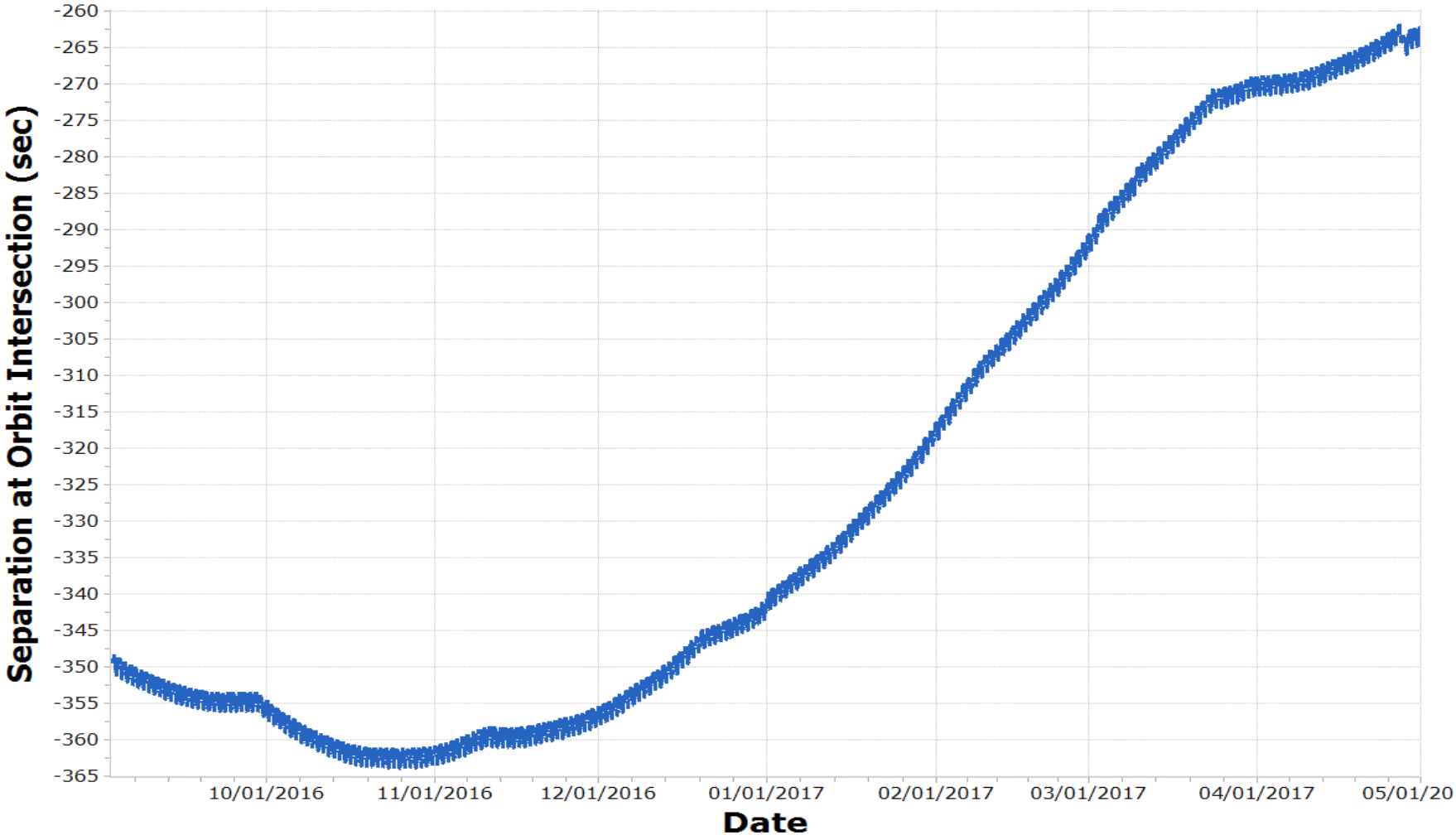


1 Orbit = ~ 100 minutes

By Design – LS-8 and LS-7 are ½ orbit apart

LS-8/Aura Phasing at Poles

@ Northern Intersection Point (as of May 1, 2016)



Aura Conjunction Assessment

High Interest Events (HIEs)

	Oct `16	Nov `16	Dec `16	Jan `17	Feb `17	Mar `17	Apr `17	May `17	Total
Tier 1	1	0	0	1	0	0	0		2
Tier 2	1	0	0	0	1	1	0		3
Tier 3	0	0	0	0	1	1	0		2
Tier 4	1	0	0	0	0	1	1		3
Total	3	0	0	1	2	3	1		10

2013: 29 CARA HIEs – 14 required significant action (T2-T4)
2014: 33 CARA HIEs – 18 required significant action (T2-T4)
2015: 32 CARA HIEs – 18 required significant action (T2-T4)

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

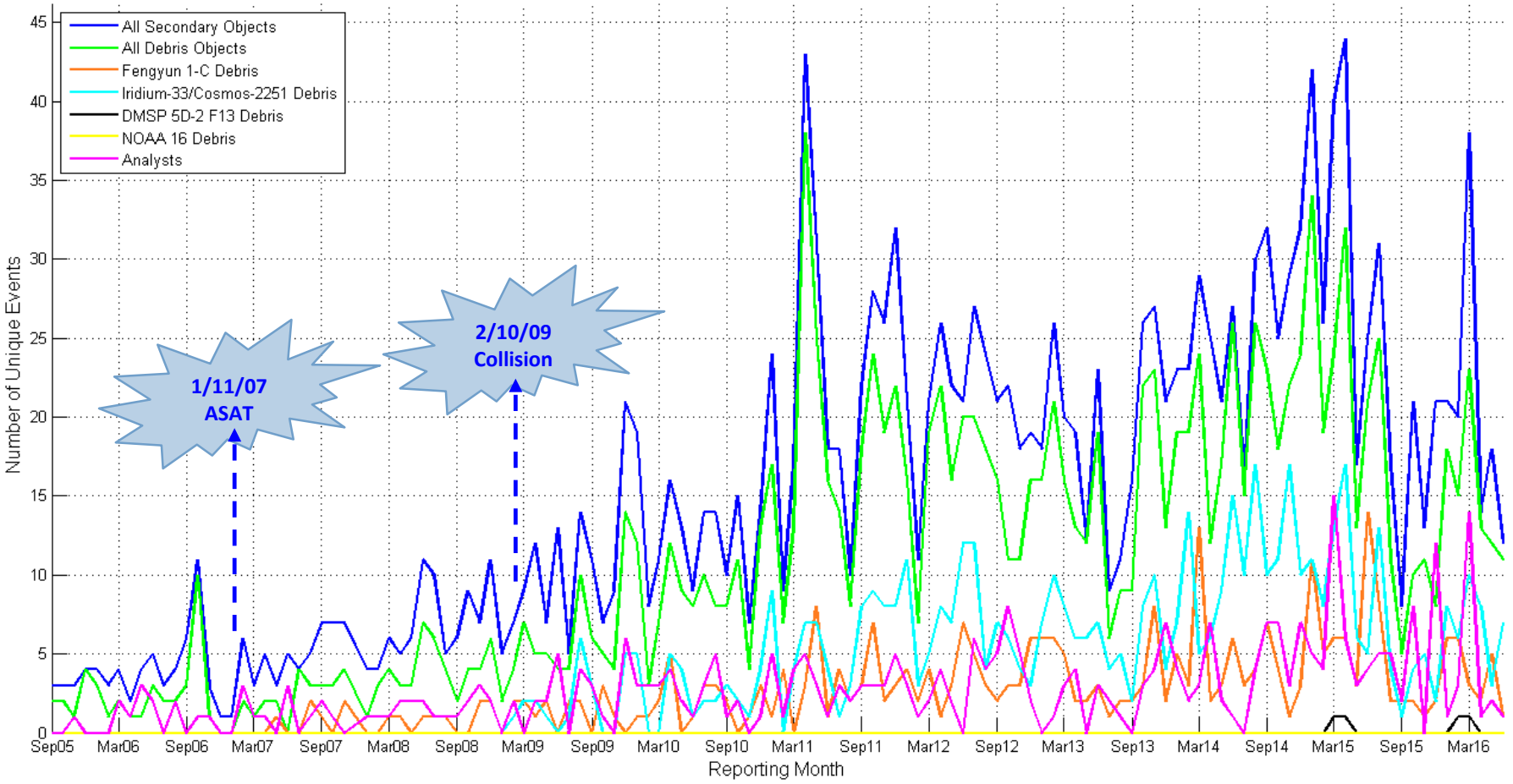
2016: 24 CARA HIEs – 16 required significant action (T2-T4)

15. 10/13/2016: CA vs. 32228 on 10/17 at 14:25:22 GMT – Modified a planned DMU to mitigate post-maneuver concern (T4)
16. 10/21/2016: CA vs. 39596 on 10/23 at 22:54:34 GMT – Monitored but no action required (T2)

2017: 7 CARA HIEs (thru 04/26/2017) – 6 required significant monitoring and/or actions (T2-T4)

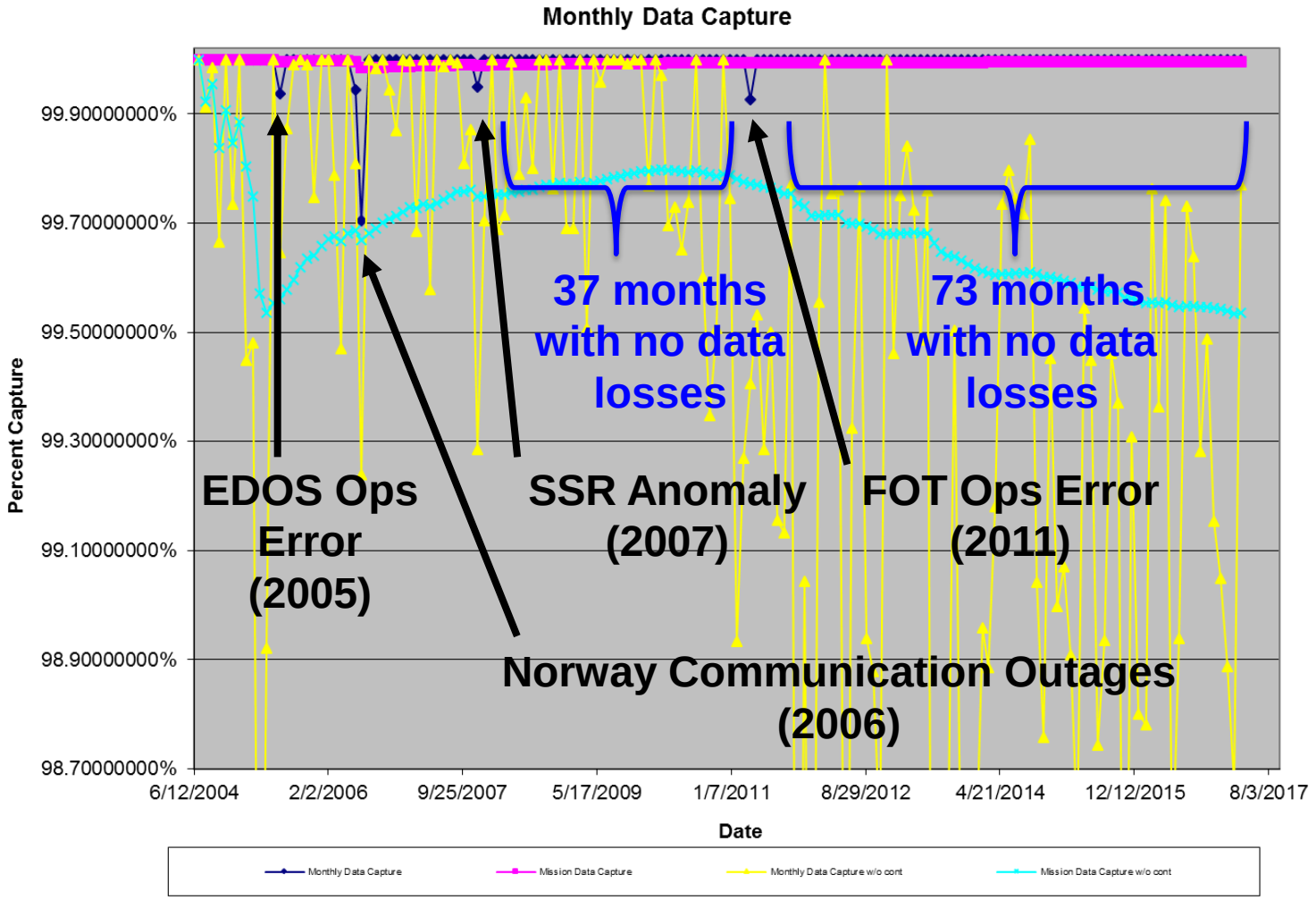
1. 02/01/2017: CA vs. 13482 on 02/03 at 04:53:36 GMT – HIE briefing but Pc dropped off, continued to monitor (T2)
2. 02/13/2017: CA vs. 35863 on 02/15 at 21:34:48 GMT – DAM planned but conjunction Pc rolled off (T3)
3. 03/08/2017: CA vs. 23547 on 03/12 at 01:36:07 GMT – Post-IAM HIE, screened hot and cold burn cases (T3)
4. 03/11/2017: CA vs. 34363 on 03/13 at 03:24:52 GMT – MTS plots generated but Pc dropped off (T2)
5. 03/26/2017: CA vs. 25759 on 03/26 at 13:39:58 GMT – Executed DAM for HIE with very small miss distance (T4)
6. 04/26/2017: CA vs. 189908 on 04/28 at 17:27:28 GMT – Rescheduled planned DMU due to post-maneuver conjunction (T4)

Aura Conjunction Assessment
(September 2005 thru June 2016) (No Change)



Monthly Data Capture

SSR Data Capture to 04/30/2017: 99.99573138%

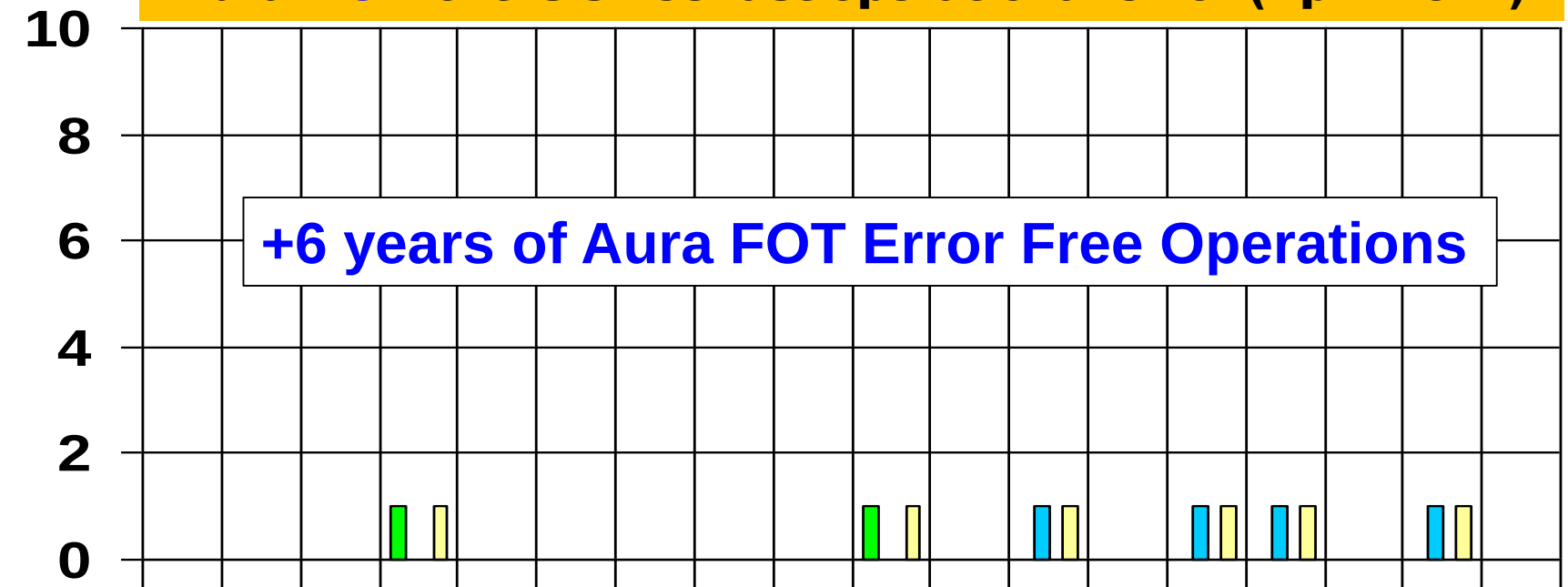


Mission Capture Req. = 95%

Operational Errors

(18-Months: November 2015 – April 2017)

Aura: 73 Months since last operational error (April 2011)



	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Terra	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Aqua	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1	0
Aura	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	1	0	0	0	0	0	1	0	1	0	1	1	0	1	0

Questions

Abbreviations / Acronyms List

AN –	Ascending Node
ARE –	Array Regulator Electronics
ASAT –	Anti-satellite Weapon
CA –	Conjunction Assessment
CARA –	Conjunction Assessment Risk Analysis
CDH –	Command & Data Handling
CRMS –	Collision Risk Management System
DAM –	Debris Avoidance Maneuver
DAS –	Debris Assessment Software
DMSP –	Defense Meteorological Satellite Program
DN –	Descending Node
DMUM –	Drag Make-up Maneuver
EA –	EOS Automation
EDOS –	EOS Data Operations System
EOC –	EOS Operations Center
EOMP –	End of Mission Plan
EOS –	Earth Observing System
EPS –	Electrical Power System
ESC –	Earth Science Constellation
ESMO –	Earth Science Mission Operations
FDS –	Flight Dynamics System
FMU –	Formatter Multiplexer Unit
FOT –	Flight Operations Team
FSW –	Flight Software
FY –	Fiscal Year
GMT –	Greenwich Mean Time
GNC –	Guidance Navigation & Control
GSFC –	Goddard Space Flight Center
GTE –	Ground Track Error
HIE –	High Interest Event
HIRDLS –	High Resolution Dynamics Limb Sounder
HK -	Housekeeping
HQ -	Headquarters
IAM –	Inclination Adjustment Maneuver
ICS –	Interferometer Control System
ID –	Ideal Date
kg -	kilogram
km –	kilometer
L0 –	Level-Zero
LS -	Landsat
MLS –	Microwave Limb Sounder
MLT –	Mean Local Time
MMOD –	Micrometeorite Orbital Debris
MMS –	Mission Management System
MOWG –	Mission Operations Working Group
MTS –	Maneuver Trade Space
NASA –	National Aeronautics & Space Administration
NOAA –	National Oceanic and Atmospheric Administration
NYS –	No Yaw Slew
OMI –	Ozone Monitoring Instrument
ORR –	Operational Readiness Review
PROP -	Propulsion
Pc –	Probability of Collision
PLL –	Phased Locked Loop
R2 –	Receiver 2
RHEL –	Red Hat Enterprise Linux
RMM –	Risk Mitigation Maneuver
RWA –	Reaction Wheel Assembly
SC -	Spacecraft
SSR –	Solid State Recorder
TBD –	To Be Determined
TCS –	Thermal Control System
TES –	Tropospheric Emissions Spectrometer
THz -	Terahertz
WRS –	World Reference System