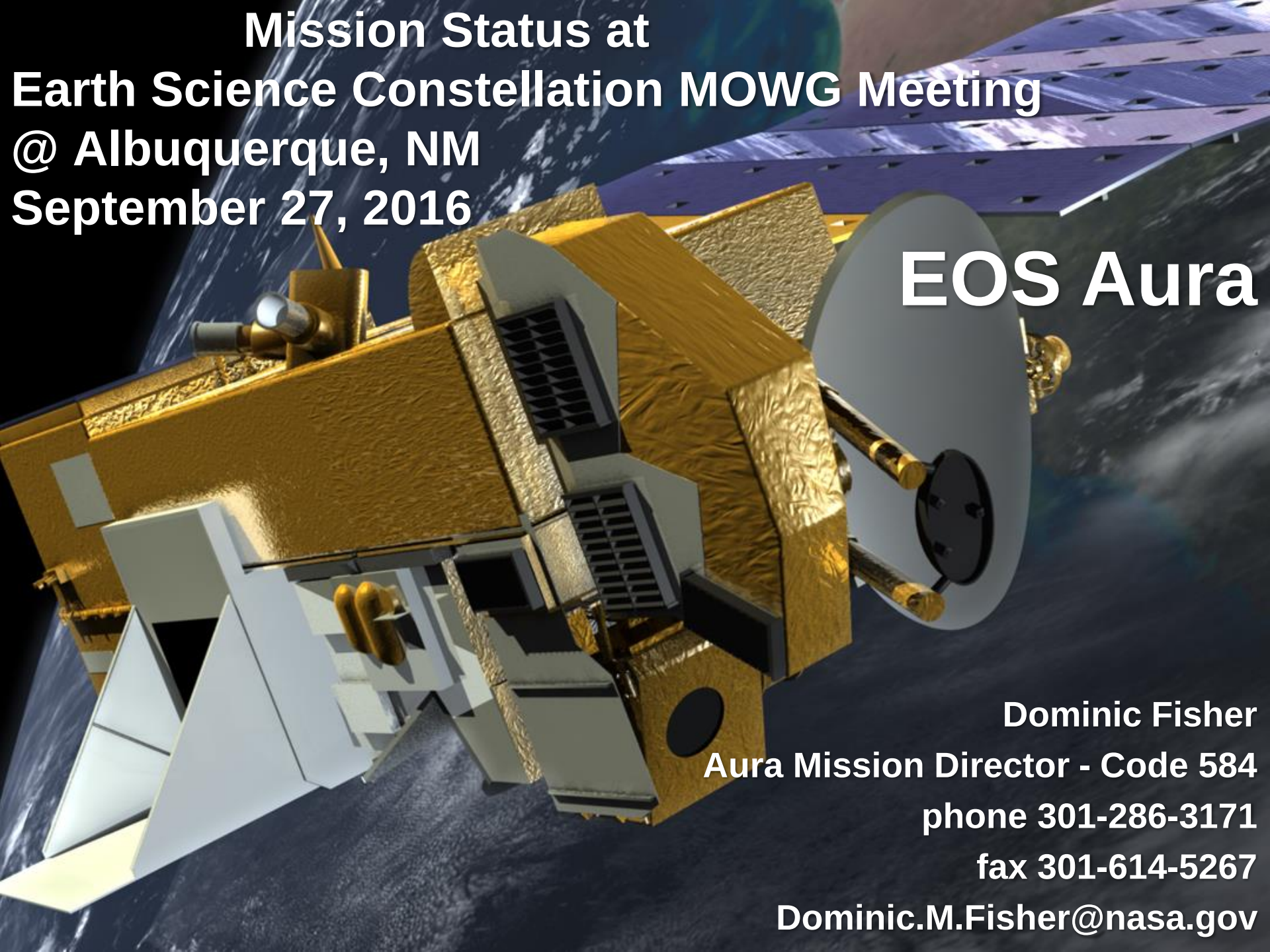
Mission Status at Earth Science Constellation MOWG Meeting @ Albuquerque, NM September 27, 2016



Dominic Fisher
Aura Mission Director - Code 584
phone 301-286-3171
fax 301-614-5267
Dominic.M.Fisher@nasa.gov

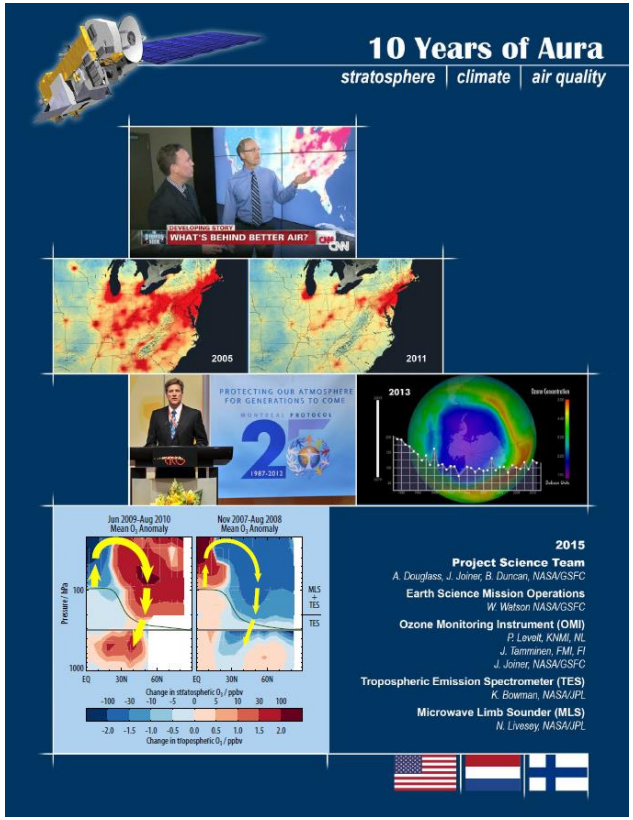
Topics

- **Mission Summary**
- **Spacecraft Subsystems Summary**
- **Recent Activities**
- **Planned Activities**
  - **CRMS Process Improvement**
  - **Spring 2017 IAM Draft Schedule**
- **Propellant Usage & Lifetime Estimates**
  - **FDS Decommissioning Analysis**
  - **End of Mission Plan (EOMP)**
- **Overall Summary**
- **Additional Slides:**
  - **Spacecraft Maneuvers & Ground Track History**
  - **HIEs, Data Capture, & Ops Error Statistics**

EOS Aura Mission Summary

(Updates since April 2016 MOWG in Boulder, CO)

- 07/15/04: Launch
  - 6-Year Design Life
- 09/30/10: End of Prime Mission Review
- 03/04/15: Senior Review Proposal #4
  - Reliability Estimates through 2021
  - Consumables through 2022
- 09/18/15: 2015 Mission Extension Senior Review Proposal Panel Report
  - #4 Ranked Earth Science Mission
  - Mission extension through FY17
- 01/27/16: ESMO Annual Review #9
- 07/15/16: Aura 12-Year Anniversary



Aura Spacecraft Subsystems

(Updates since April 2016 MOWG in Boulder, CO)

- **Command & Data Handling (CDH) – Nominal**
  - ***Solid State Recorder (SSR) Anomaly (December 4-18, 2007)***
    - » ***Returned November 2010 at reduced level – then subsided January 2011***
    - » ***Returned again 04/15/2012 – currently still "active"***
- **Communications (COMM) – Nominal**
- **Electrical Power System (EPS) – Nominal**
  - ***Solar Panel Connector Anomaly – ARE-3C (January 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 25 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**
  - ***Earth Sensor Assembly (ESA) Anomaly (05/29/2009 & 06/13/16) – Re-calibrated in Nov. 2009 & Aug. 2016***
- **Propulsion (PROP) – Nominal**
  - ***Dual Thruster Module (DTM-3) Anomaly (Aug 16, 2005)***
- **Thermal Control System (TCS) – Nominal**

All subsystems configured to primary hardware

Recent Activities

(April 2016 – September 2016)

- **5 CARA High Interest Orbital Debris Events (Tiers 1-4)**
  - **0 required significant action (T3 / T4)**
  - **Last significant actions: DAM 1/18/16, DAM 3/15/16, DAM Waived 3/17/16**
- **1 Minor Spacecraft Bus Anomaly**
  - **Earth Sensor Assembly (ESA) Anomaly (6/13/16) – Updated threshold 8/18/16**
- **7 Significant instrument related anomalies (Generated NASA Anomaly Reports)**
  - **TES: 4 ICS Motor Stall Events (7/20/16, 8/1/16, 8/4/16, 8/15/16),**
  - **1 Instrument Safe Mode Event (8/19/16)**
  - **OMI: 1 Instrument Survival Event (5/29/16), 1 Instrument Safe Event (6/10/16)**
- **6 Spacecraft Maneuvers:**
  - **4 Routine Drag Make-up Maneuvers (DMUMs):**
    - » 2016: 5/26 (#92), 6/23 (#93), 7/28 (#94) and 8/31 (#95)
  - **2 Inclination Adjust Maneuvers (IAMs):**
    - » 2016: 4/7 (#47) and 4/21 (#48),
    - » The other Spring 2016 IAMs, #45 (3/10) & #46 (3/23), weren't included in this reporting period
- **0 Instrument Calibration Maneuvers**
  - **Next MLS Yaw & Moon Scan: Spring 2017**

Planned Activities

- **October 2016: Drag Make Up Maneuver (DMUM) #96**
- **November 2016: Updated Decommissioning Plan**
- **December 2016: Updated Reliability & Lifetime Estimates**
- **January 2017: Flight Operations Annual Review (#10)**
- **January 2017: Updated End of Mission Plan (EOMP)**
- **February 2017: Extended Mission Senior Review Proposal**
- **Spring 2017: A-Train Science Symposium (4/19-21/2017 - Pasadena, CA)**
- **Spring 2017: Annual Inclination Adjust Maneuvers (DRAFT SCHEDULE)**
  - 3/02/17 (#49), 3/09/17 (#50), 3/23/17 (#51), & 3/30/17 (#52)
- **Spring 2017: Earth Science Constellation (ESC) MOWG (Dates TBD – GSFC, MD)**
  - Update propellant budget, decommissioning analysis, reliability predictions,…

- **Mid-to-Long-Term Plans**
  - **Continue to improve RMM / DAM execution**
    - » See additional details on CA automation (CRMS) in the following slide
  - **EOS Automation (EA) – automation of routine operations**

Collision Risk Management System 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

- Collision Risk Management System (CRMS) capabilities will 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 4.0 (ΔORR 8/24/16)

DRAFT Spring 2017
Inclination Adjust Plan

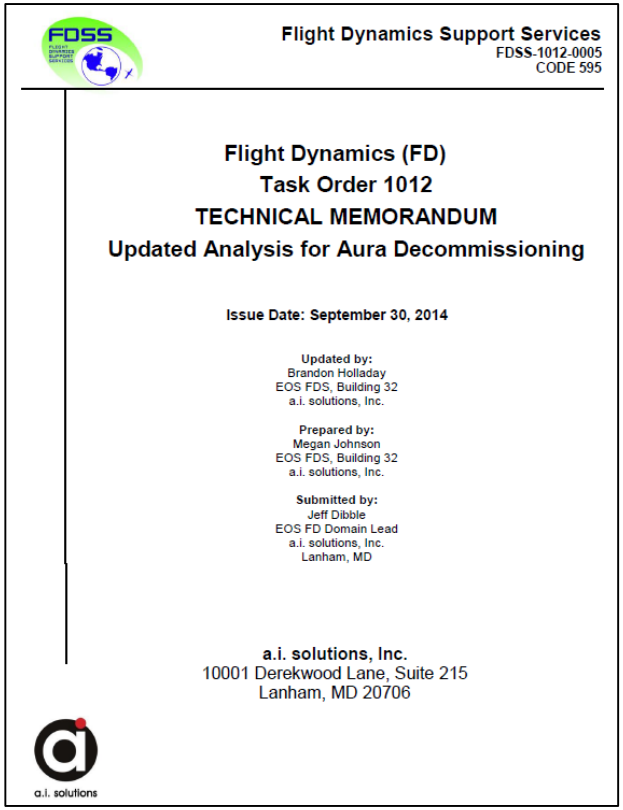
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
19 **Feb**	20	21	22	23	24	25
26	27	28	1 March **Aqua IAM #52**	2 **Aura IAM #49**	3	4
5	6	7	8 **Aqua IAM #53**	9 **Aura IAM #50**	10	11
12	13	14	15 **Spring Break**	16 **Spring Break**	17	18
19	20	21	22 **Aqua IAM #54**	23 **Aura IAM #51**	24	25
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

A-Train Science Symposium in Pasadena, CA

Aura Propellant Usage
(Update expected September 2016)

- **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 (September): Updated Decommission Plan**
  - Investigating potential retrograde maneuver options and lifetime extending options

- **Annual updates will be provided each September**
  - Final will be produced 60 days before start of decommissioning



FOSS

Flight Dynamics Support Services
FDSS-1012-0005
CODE 595

Flight Dynamics (FD)
Task Order 1012
TECHNICAL MEMORANDUM
Updated Analysis for Aura Decommissioning

Issue Date: September 30, 2014

Updated by:
Brandon Holladay
EOS FDS, Building 32
a.i. solutions, Inc.

Prepared by:
Megan Johnson
EOS FDS, Building 32
a.i. solutions, Inc.

Submitted by:
Jeff Dibble
EOS FD Domain Lead
a.i. solutions, Inc.
Lanham, MD

a.i. solutions, Inc.
10001 Derekwood Lane, Suite 215
Lanham, MD 20706

a.i. solutions

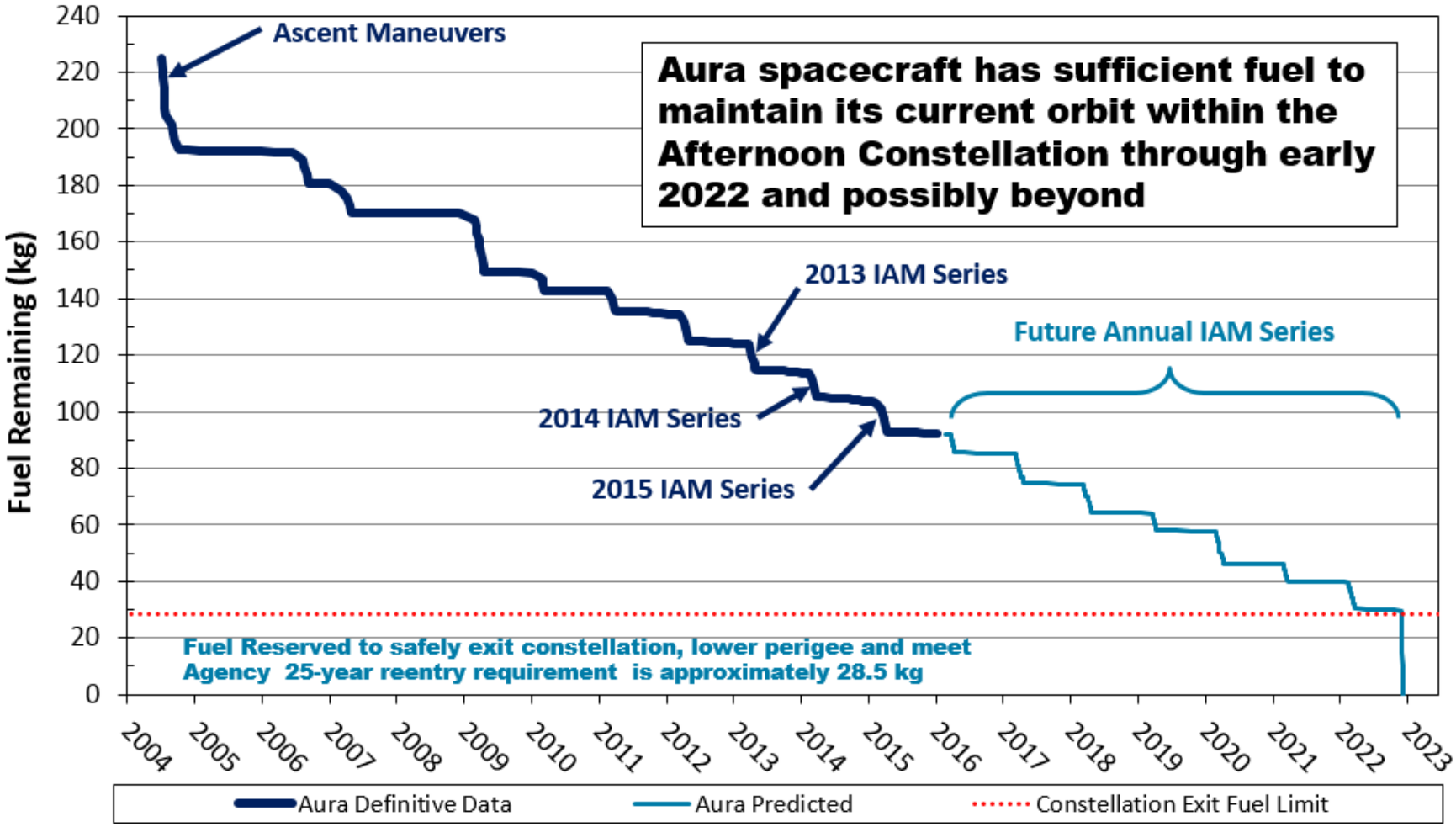
Remaining Fuel Estimate

(Update expected September 2016)

- Long-term orbit simulations were run for Aura through Feb 2023
  - Used mean nominal Schatten solar flux predictions
  - 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
  - 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 show that the spacecraft will have sufficient fuel to maintain its current orbit within the Afternoon Constellation through at least early 2022* and possibly beyond
- 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

*** 2022 estimate based on 2014 analysis**

Fuel Usage: Actual & Predicted
(Updated January, 2016)

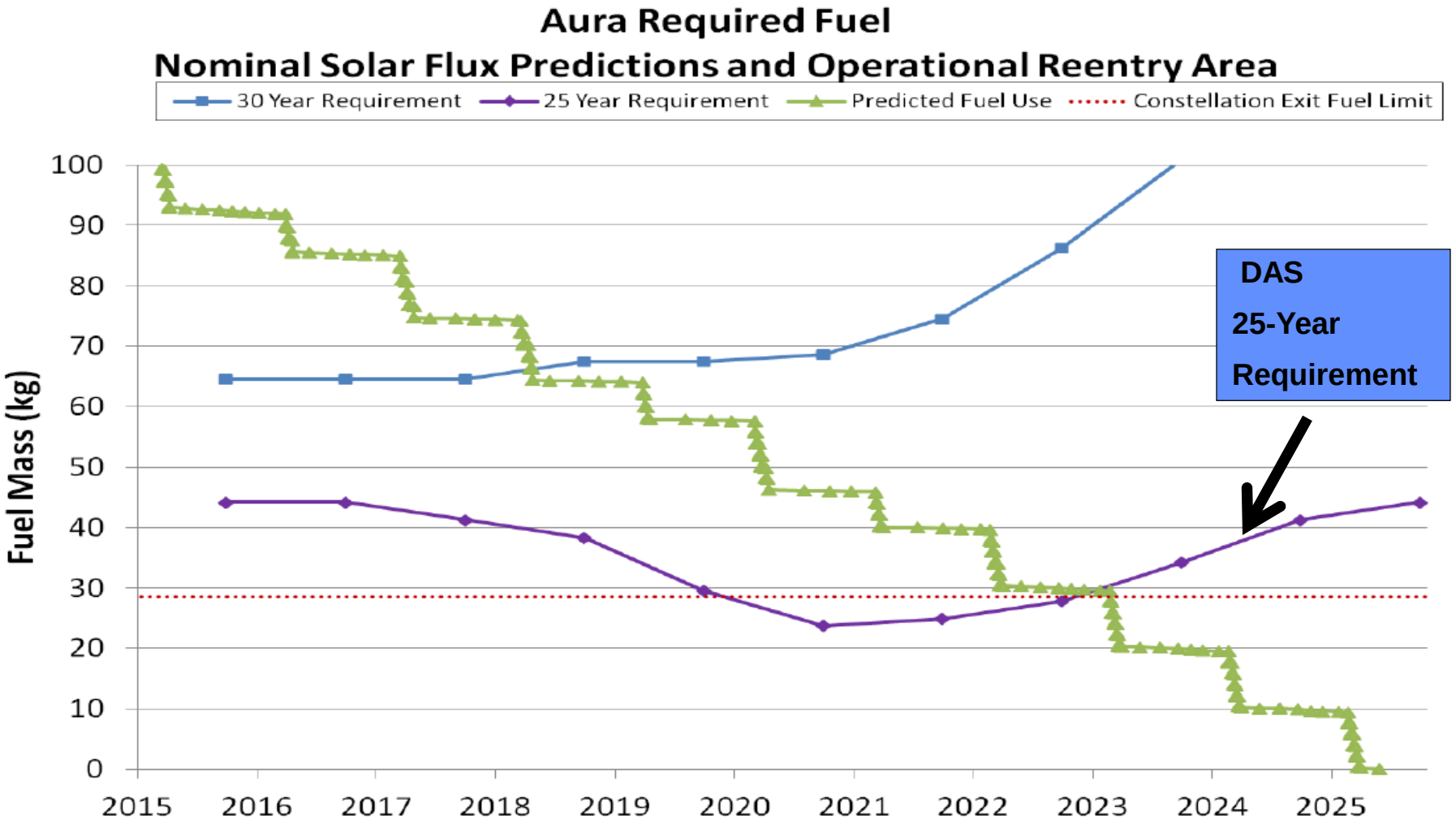


Debris Assessment Software
(September 2014 – No Changes or Updates)

- 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:
  - The operational orbit parameters
  - The mission launch date
  - Length of a mission's lifetime
- 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 NASA requirements
- Aura will have enough fuel onboard to safely exit the constellation and de-orbit to the DAS recommended perigee out through the 2023 time frame

Aura DAS End of Life Predictions

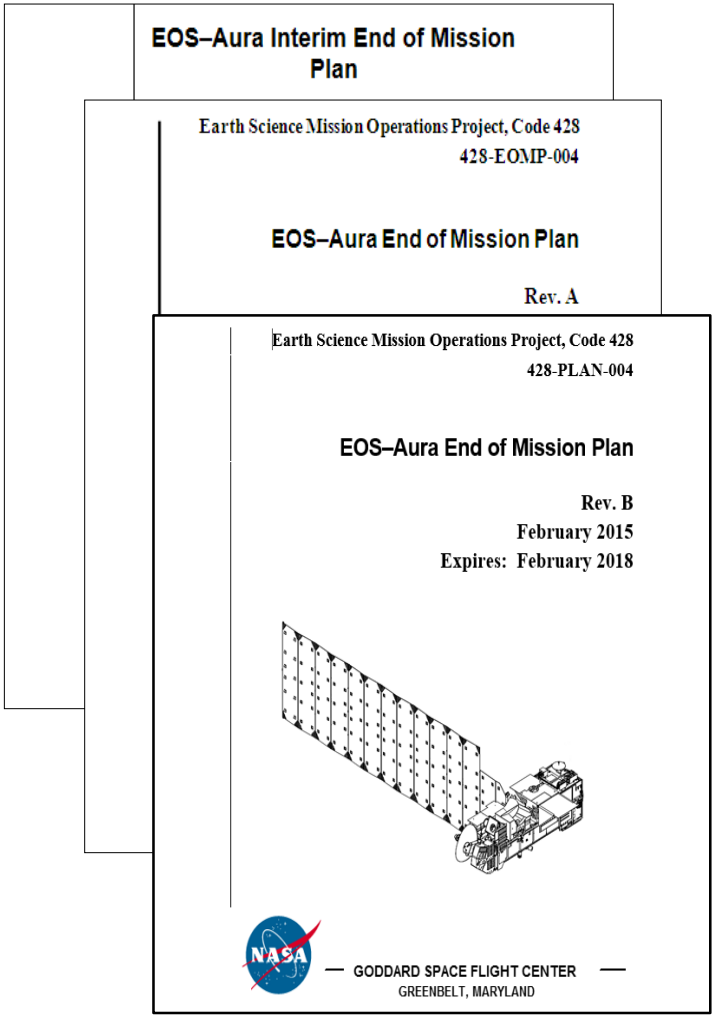
(September 2014 – No Changes or Updates)



Aura End of Mission Plan (EOMP)

(No Changes or Updates)

- **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**
  - **Final will be produced 60 days before EoM**
  - **Latest Annual Lifetime Estimate (09/2014)**
  - **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**
- **Next End of Mission Plan (Rev C): Feb 2017**



Summary

- **Spacecraft Status - GREEN**
- **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 – Tested Annually – Latest: 08/18/14 - 09/30/14**
    - » **01/02/2016: R2_GUNNBIAS_V Yellow Alarms (due to aging, limit changes TBD)**
  - **OMI: Operating Normally**
    - » **Field-of-View Anomaly started in September 2007 – currently stable**
    - » **03/03/16: OMI-IAM Command Reject Anomaly – recovered 03/16/16**
    - » **05/29/16: OMI Survival Mode Transition (Recovered 06/09/16)**
    - » **06/10/16: OMI Safe Mode Transition (Recovered 06/13/16)**
  - **TES: Modified Normal Operations**
    - » **03/27/16: TES Power on Reset (POR) Anomaly**
    - » **08/08/16: TES Laser B End of Life (EOL), transitioned to SIMCLK mode of science**
    - » **TES ICS Stalls (#7, 7/20/16), (#8, 8/1/16), (#9, 8/4/16), and (#10, 8/15/16)**
    - » **08/19/16: TES Safe Mode Event – ICS over-current triggered fault management**
- **Data Capture/L0 Processing Status – GREEN**
  - **SSR Data Capture to 07/30/2016: 99.99552737%**
- **Ground Systems – Responding to new security requirements and upgrades to obsolete hardware or COTS systems, as required – Automation efforts are underway**

Additional Charts

Maneuvers & Ground Track History
Orbital Trends

Aura Conjunction Assessment
High Interest Events (HIEs)

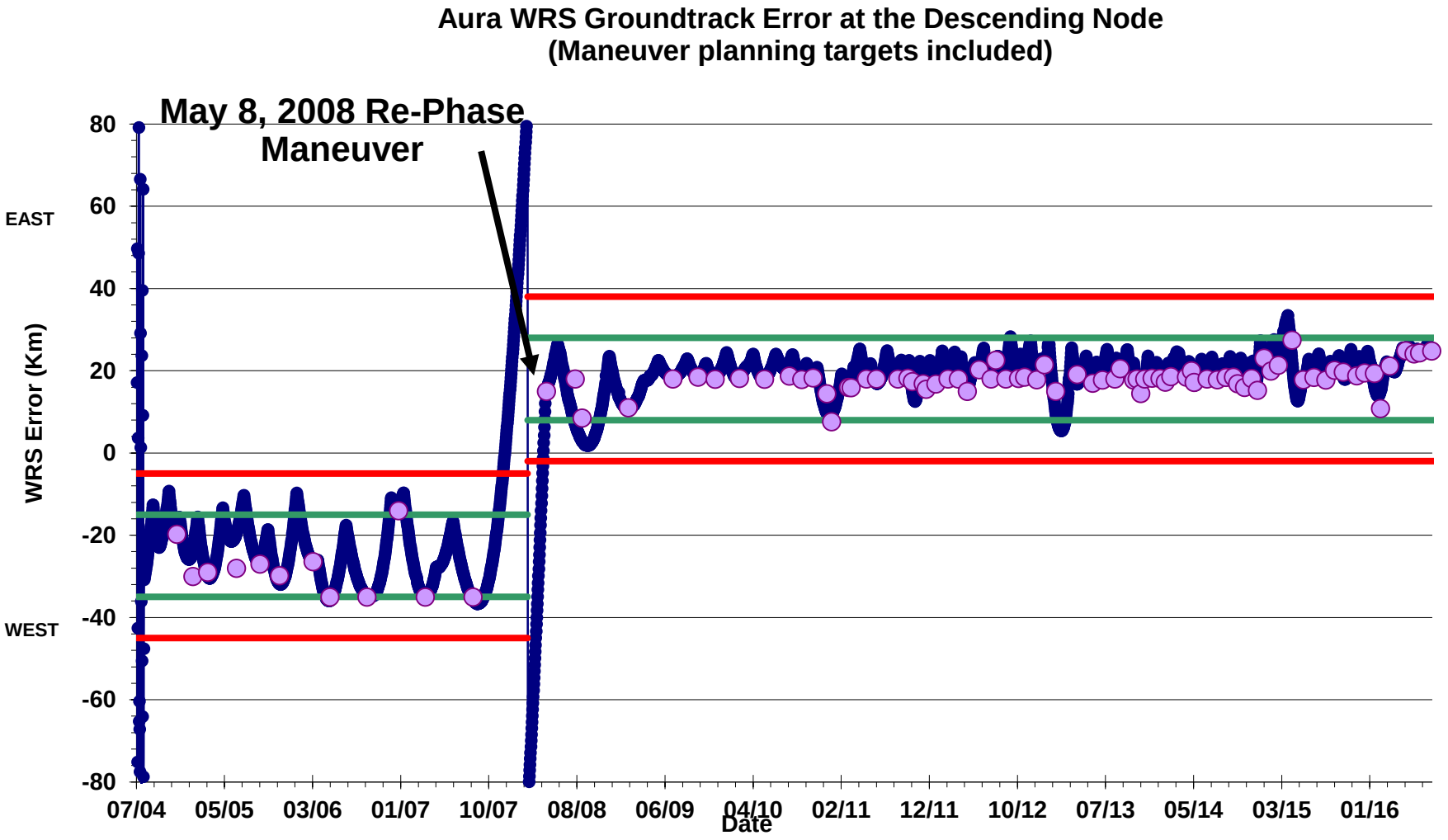
Data Capture & Operations Errors

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 94 routine DMUMs have been performed**
  - **07/19/2012: DMUM # 43 No Yaw Slew Maneuver (NYS) #1 – NYS Maneuvers (37)**
  - **Last maneuver 07/28/2016 (#94) – Next maneuver 08/31/2016 (#95)**
  - **Variation in performance from –3.5% (cold) to +3.3% (hot)**
- **Conducted 11 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)**
  - **Variation in performance from -4.5% (cold) to +1.9% (hot)**

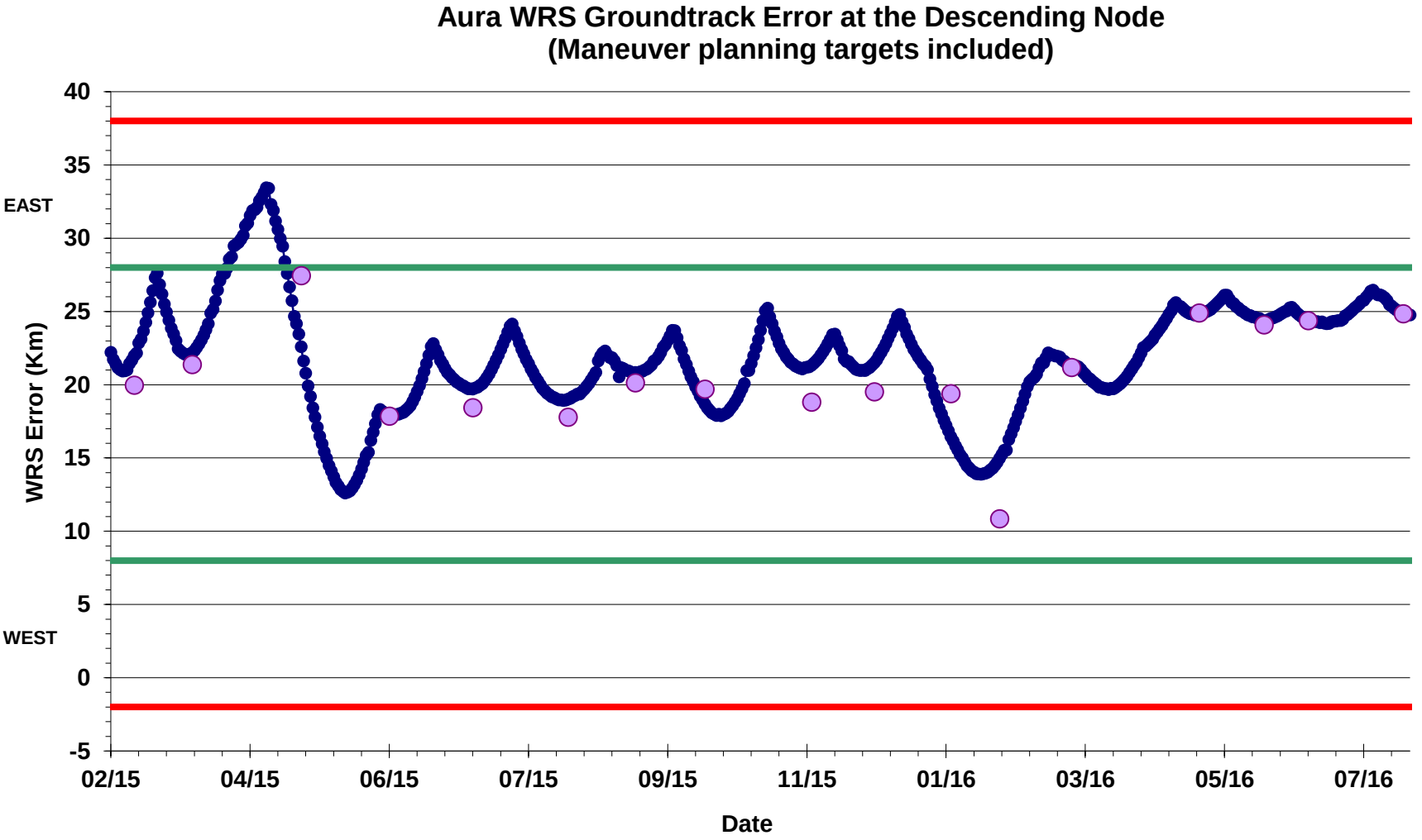
WRS Ground Track Error (GTE)

(As of August 15, 2016)



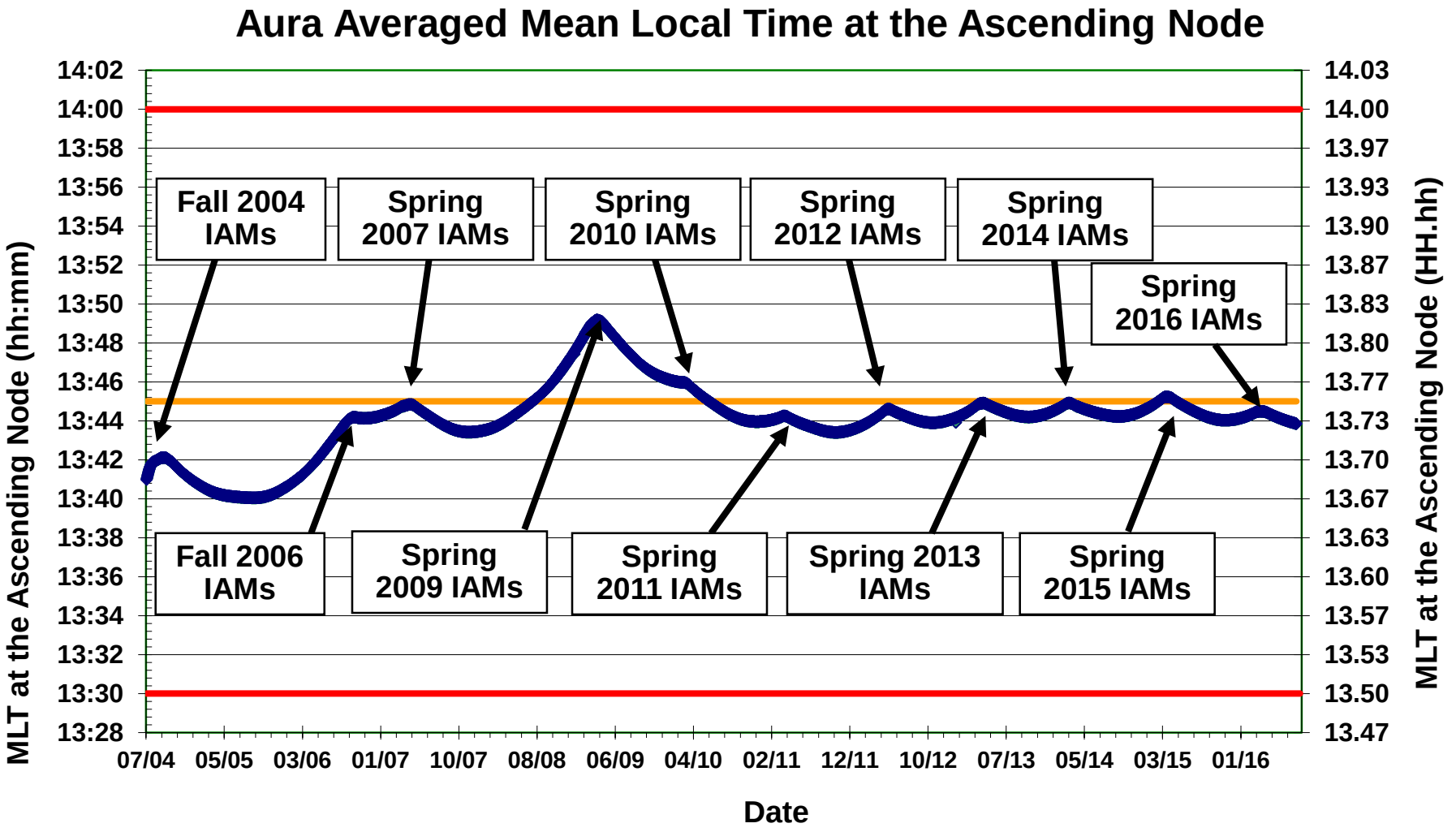
WRS Ground Track Error (GTE)

(As of August 15, 2016) Past 18+ months



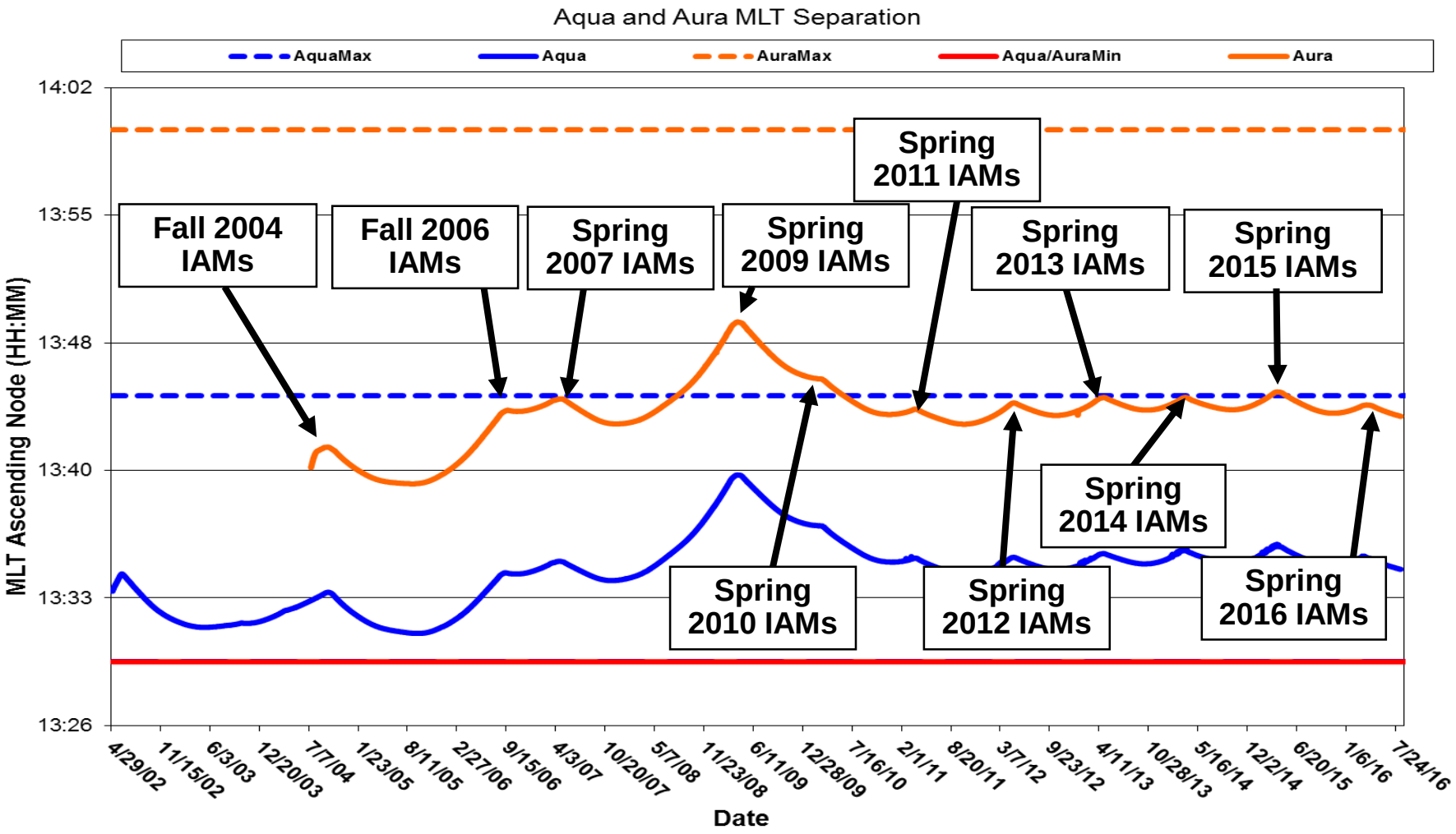
Aura Averaged MLT @ Ascending Node

(As of August 15, 2016)

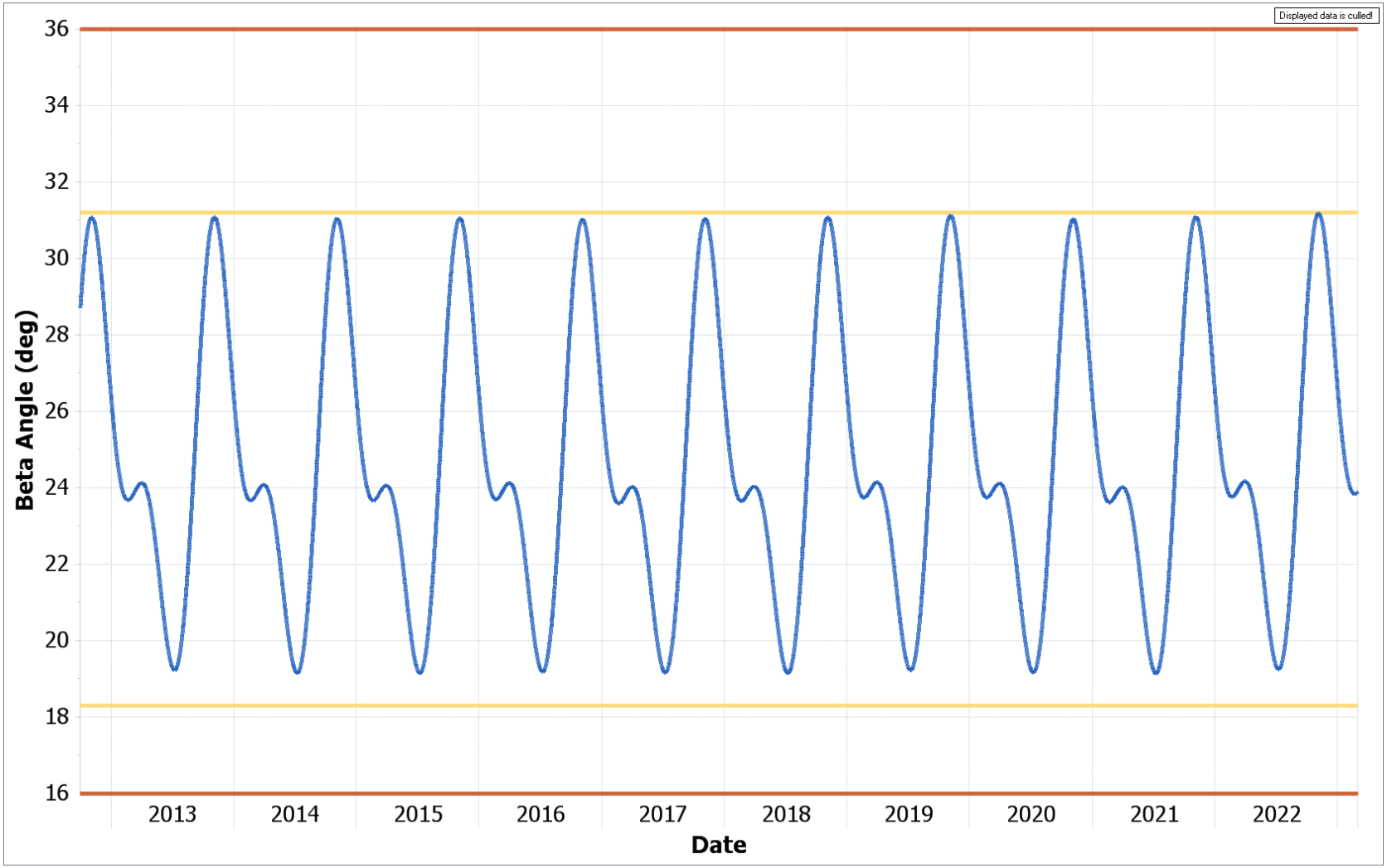


Aqua/Aura Mean Local Time (MLT)

@ Ascending Node (as of August 15, 2016)



Aura Predicted Beta Angle
(With Yearly Inclination Maneuvers)

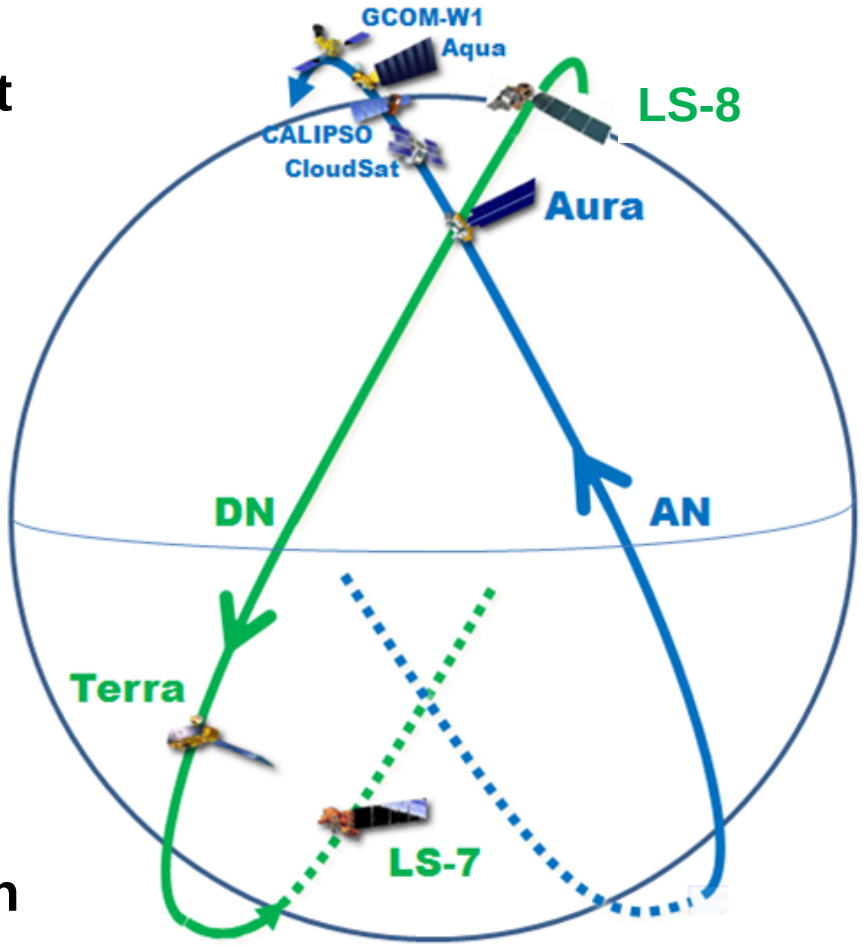


Aura and Landsat-8 (LS-8)
Orbit Phasing

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

Typically 330 – 190 seconds

Terra ~ 30 min behind LS-7

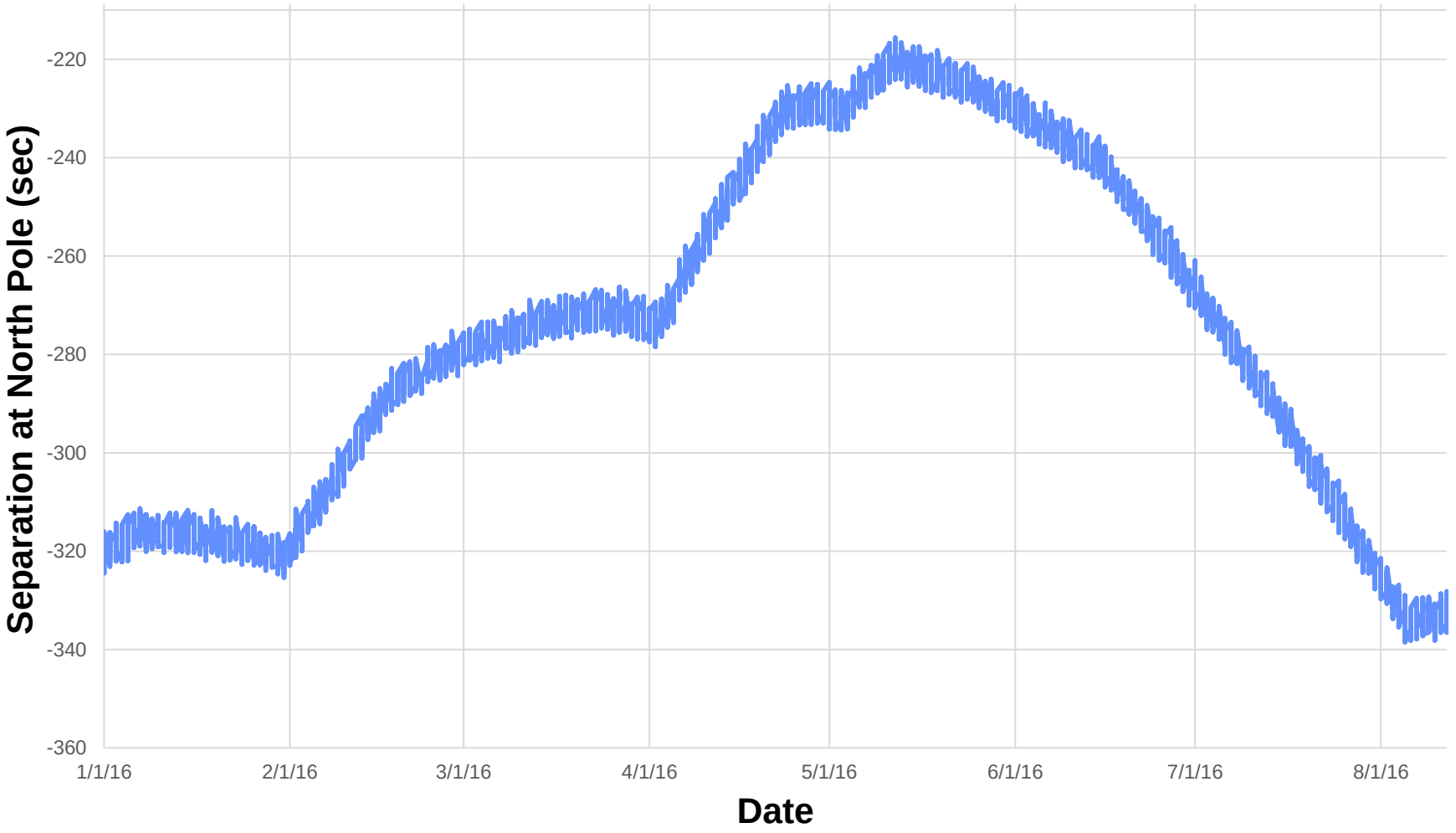


1 Orbit = ~ 100 minutes

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

LS-8/Aura Phasing at Poles

@ Northern Intersection Point (as of August 15, 2016)



Aura Conjunction Assessment

High Interest Events (HIEs)

2016	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Tier 1	3	0	3	1	0	0	0						7
Tier 2	1	2	1	1	1	1	1						8
Tier 3	0	0	1	0	0	0	0						1
Tier 4	1	0	1	0	0	0	0						2
Total	5	2	6	2	1	1	1						18

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)

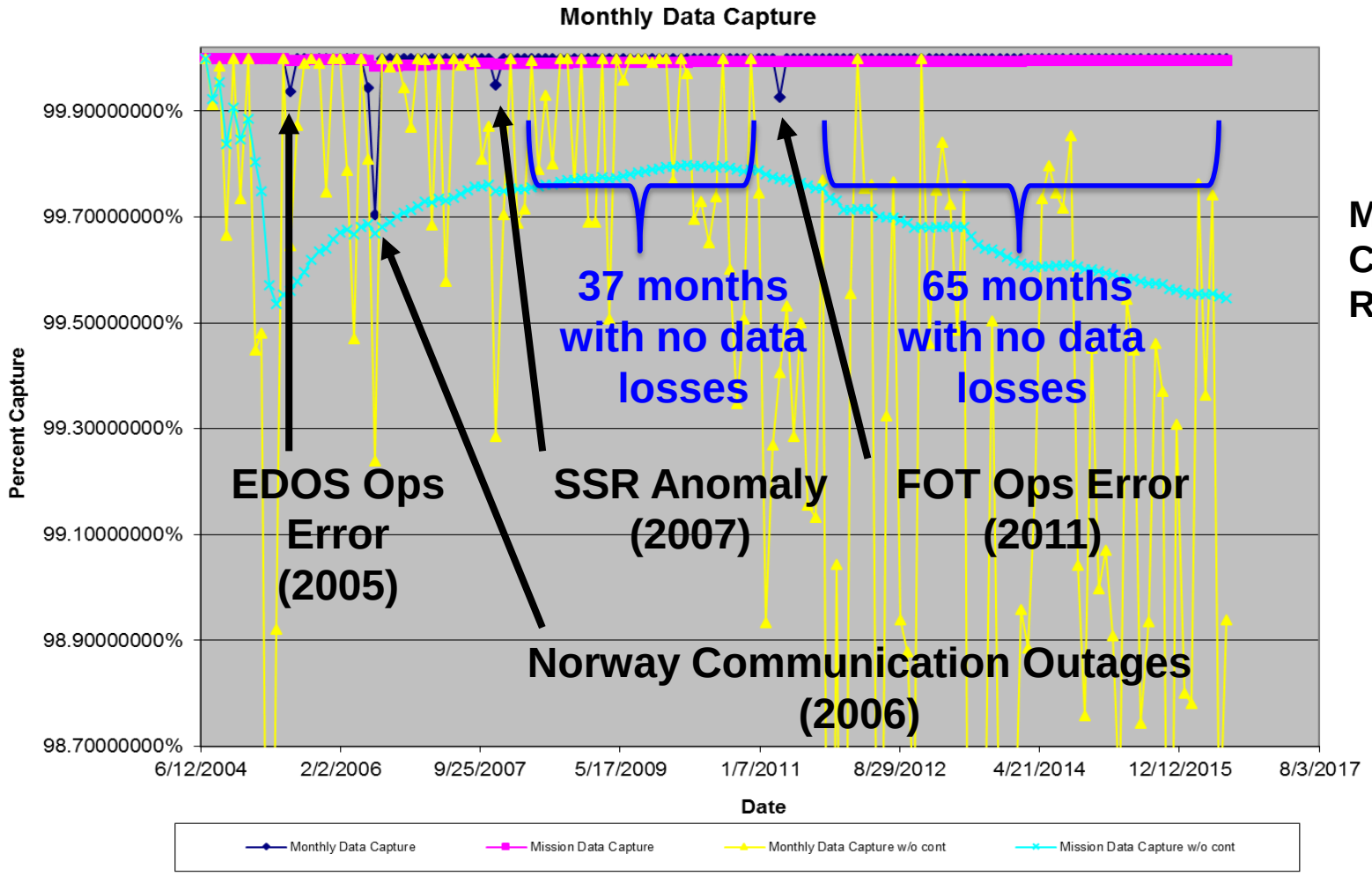
Tier 1 – Notify (email/phone), Tier 2 – Conduct Briefing,
Tier 3 – Plan Maneuver, Tier 4 – Execute Maneuver

2016: 18 CARA HIEs (thru 07/21/2016) – 11 required significant monitoring and/or actions (T2-T4)

1. **01/05/2016: CA vs. 8063 on 01/07 at 13:10:54 GMT – Considered modifying planned DMU, Pc rolled off, no action req'd (T2)**
2. **01/18/2016: CA vs. 37770 on 01/19 at 02:16:20 GMT – Executed DAM (DMU #88) (T4)**
3. **02/05/2016: CA vs. 82292 on 02/10 at 01:54:30 GMT – Monitored but no action required (T2)**
4. **02/10/2016: CA vs. 32102 on 02/12 at 04:39:52 GMT – Monitored but no action required (T2)**
5. **03/12/2016: CA vs. 39842 on 03/12 at 08:07:07 GMT – Post-IAM, monitored but no modification required (T2)**
6. **03/15/2016: CA vs. 34726 on 03/16 at 08:27:49 GMT – Executed DAM (DMU #90) (T4)**
7. **03/17/2016: CA vs. 37549 on 3/17 at 23:20:48 GMT – Planned/Approved DAM, waived-off maneuver (T3)**
8. **04/10/2016: CA vs. 35991 on 04/11 at 12:15:55 GMT – Monitored and reviewed MTS plot but no action required (T2)**
9. **05/02/2016: CA vs. 28950 on 05/07 at 16:18:47 GMT – Monitored post-maneuver conjunction for DMU #91 on 5/4 (T2)**
10. **06/10/2016: CA vs. 35858 on 06/11 at 21:46:49 GMT – Monitored but no action required (T2)**
11. **07/20/2016: CA vs. 89223 on 07/21 at 07:51:35 GMT – Monitored but no action required (T2)**

Monthly Data Capture

SSR Data Capture to 07/31/2016: 99.99552737%

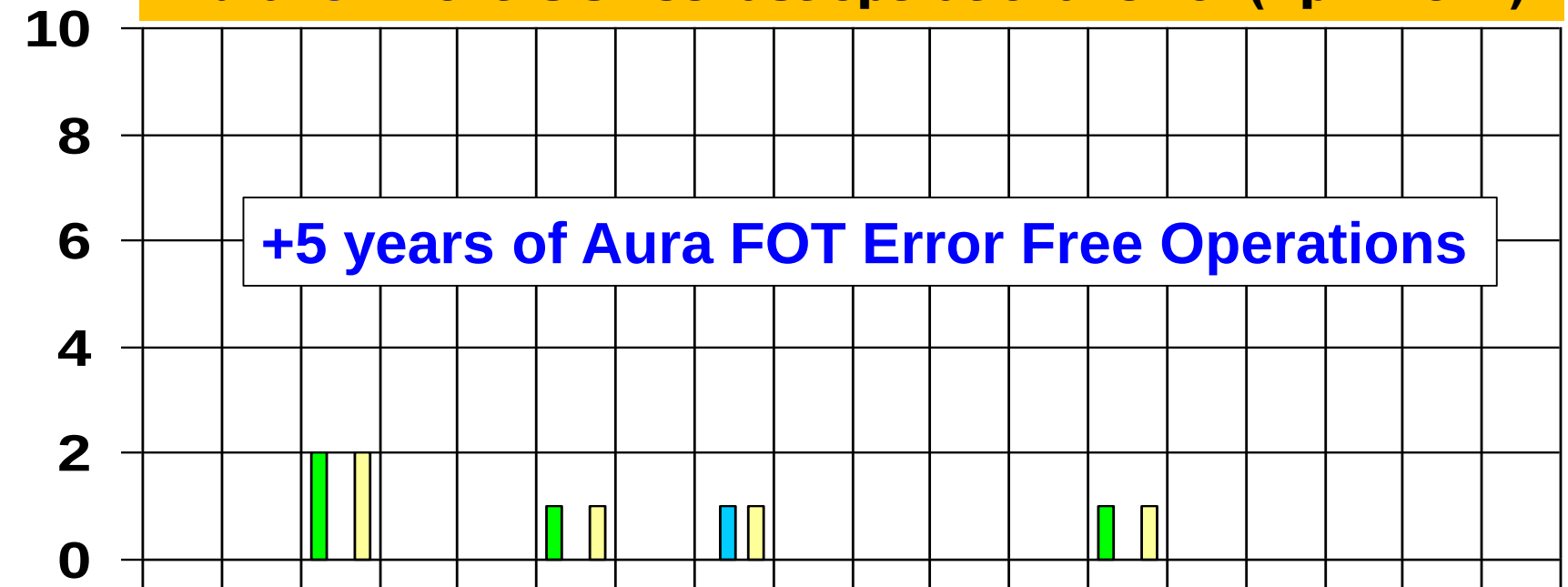


Mission Capture Req. = 95%

Operational Errors

(18-Months: February 2015 – July 2016)

Aura: 64 Months since last operational error (April 2011)



	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
Terra	0	0	2	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0
Aqua	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Aura	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	0	0	2	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0

Questions