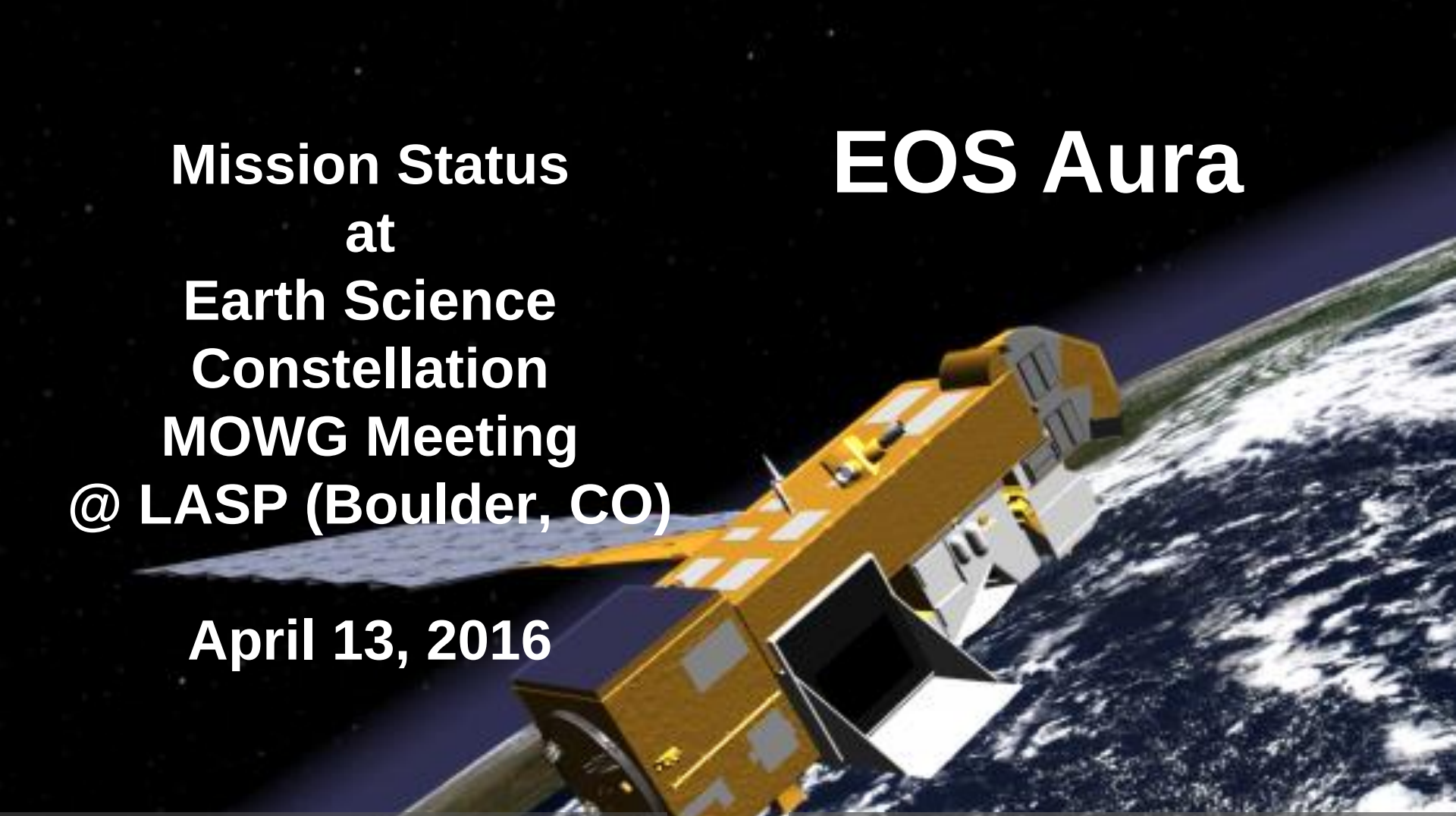
EOS Aura

Mission Status at Earth Science Constellation MOWG Meeting @ LASP (Boulder, CO)

April 13, 2016



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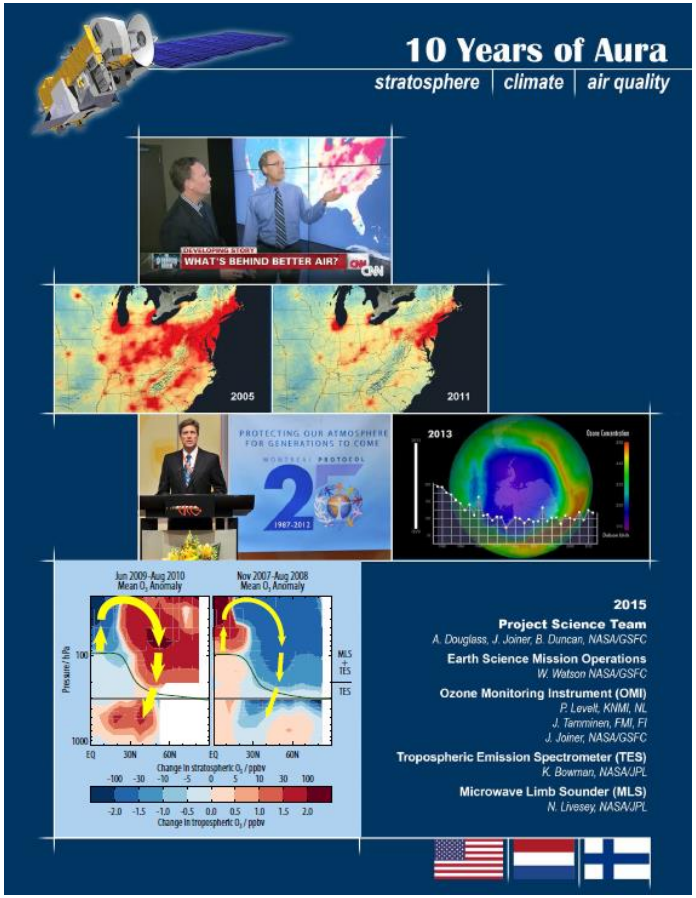
Topics

- Mission Summary
- Spacecraft Subsystems Summary
- Recent & Planned Activities
- Inclination Adjust Maneuvers
  - Spring 2016 Calendar
  - Long-Term Plan (in EOS FD 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 Aura Mission Summary

(Updates since June 2015 MOWG at GSFC)

- **07/15/04: Launch**
  - **6-Year Design Life**
- **09/30/10: End of Prime Mission Review**
- **07/22/13: Submitted Phase F Study**
- **03/03/15: Senior Review Proposal #4**
  - **Reliability Estimates thru 2022**
  - **Consumables through 2022+**
- **06/22/15: 2015 Mission Extension Senior Review Proposal Panel Report**
  - **#4 Ranked Earth Science Mission**
  - **Mission extension through FY19**
- **07/15/15: 11-Year Anniversary**
- **01/27/16: FOT Annual Review #9**



Changes since June 2015 MOWG at GSFC are in blue

Aura Spacecraft Subsystems

All subsystems configured to primary hardware

- **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) additional power drop on 04/25/2013***
    - » ***Simultaneously with GN&C Attitude Disturbance – attributed to MMOD Strike***
  - ***12/08/2014 ARE-4A power drop (first power drop anomaly in 15-months – last observed on Aura)***
  - ***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)***
    - » ***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) – Re-calibrated in Fall 2009***
- **Propulsion (PROP) – Nominal**
  - ***Dual Thruster Module (DTM-3) Anomaly (Aug 16, 2005)***
- **Thermal Control System (TCS) – Nominal**

Recent Activities
(June 2015 – March 2016)

- **21 CARA High Interest Orbital Debris Events (June 2015 – March 2016)**
  - **3 that required significant action (Tier 3 + Tier 4) plus 11 additional Tier 2 HIEs**
    - » See charts 18 & 19 and CARA presentation
  - **6 RMM/DAMs PLANNED – 0 APPROVED/LOADED/WAIVED-OFF – 1 EXECUTED**
  - **0 Routine DMUMs were re-scheduled/re-planned (CARA Tier 4 HIEs)**
  - **7 Potential High Interest Events (PHIEs – Tier 1's) required monitoring and/or planning**
- **2 Instrument related anomalies – No spacecraft bus anomalies**
  - **On-going – TES Laser-B Anomaly**
  - **Intermittent – TES ICS Motor Degradation (1/06/2016 Stall #6)**
- **Spacecraft Delta-V Maneuvers: 9 Routine DMUMs, 2 IAMs and 1 DAMs**
  - **9 Routine Drag Make Up Maneuvers (DMUMs): #'s 80-89**
    - » 2015: 06/19, 07/23, 09/02, 10/01, 11/10, 12/09; 2016: 01/06, 01/18 (DAM), 03/02 …
  - **1 Debris Avoidance Maneuvers (01/18/16)**
  - **2 Inclination Adjust Maneuvers:**
    - » 2016: 3/10 (#45), 3/17 (#46), 4/7 (#47-Planned), and 4/21 (#48-Planned) (5/5 (Backup))
- **1 Instrument Calibration Maneuver – MLS Moon Scan on 3/25/2016 (#11)**

Planned Activities

- **- - - - - - - - - - 2016 - - - - - - - - - -**
- **Complete 2016 Inclination Adjust Maneuvers (IAMs)**
- **Mid-May 2016: Drag Make Up Maneuver (DMUM) #89**
- **8/30/16 – 9/02/16: Aura Science Team Meeting**
- **Fall 2016: Earth Science Constellation(ESC)/A-Train MOWG**
  - Update propellant budget, decommissioning analysis, reliability predictions,…
- **- - - - - - - - - - 2017 - - - - - - - - - -**
- **January 2017: Flight Operations Annual Review (#10)**
- **February 2017: Senior Review Proposal #5**
- **Spring 2017: Afternoon Constellation Science Meeting (?) & ESC MOWG**
- **Spring 2017: Annual Inclination Adjust Maneuvers (DRAFT SCHEDULE)**
  - 4/06/2017 (#49), 4/13/2017 (#50), 4/27/2017 (#51) & 5/04/2017 (#52)
- **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 → 150-200K)

ESMO is in the process of developing new ground system capabilities to autonomously identify and optimize Debris Avoidance Maneuver (DAM) planning options in a significantly reduced amount of time (essentially fully-automated end-to-end and continuously 24x7)

Collision Risk Management System (CRMS) capabilities include:

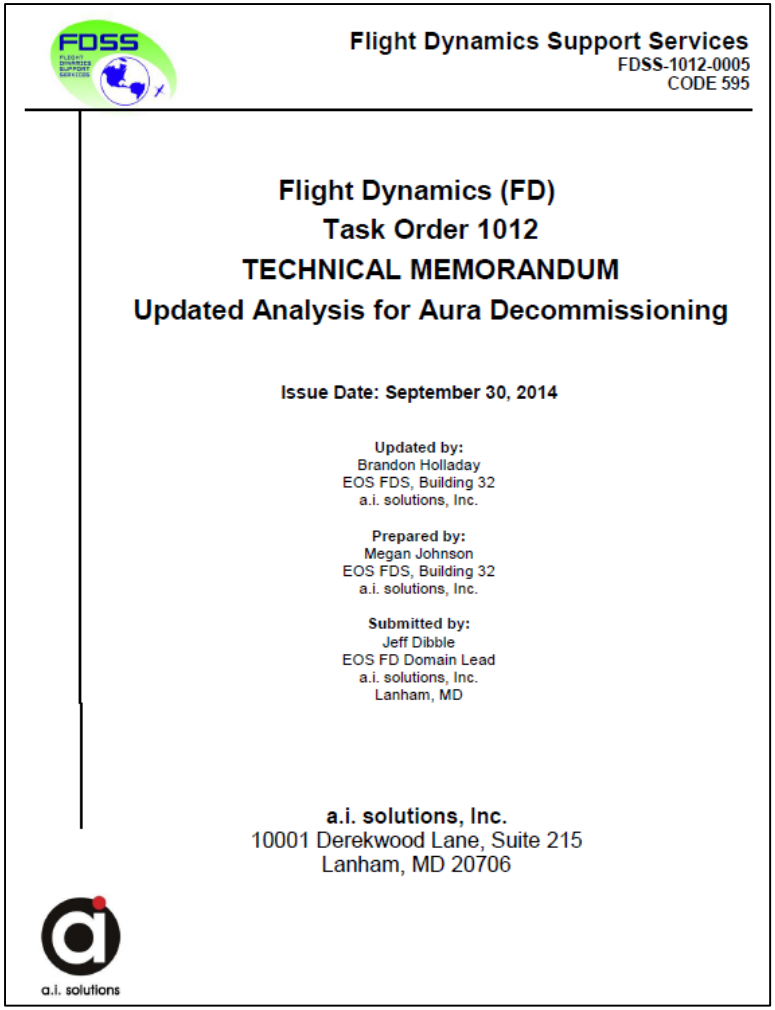
- **Goal is to develop a fully automated debris avoidance maneuver planning and maneuver screening process**
- **User defined and modifiable collision risk thresholds**
  - **Probability of collision, miss distances and time to TCA**
  - **Post-maneuver probability of collision**
- **Handles multiple secondary object conjunctions & repeaters**

DRAFT Spring 2017 Inclination Adjust Plan

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
19 **March**	20	21	22	23	24	25
26	27	28	29	30	31	1 **April**
2	3	4	5 **Aqua IAM #52**	6 **Aura IAM #49**	7	8
9	10	11	12 **Aqua IAM #53**	13 **Aura IAM #50**	14	15
16 **Easter**	17	18	19 **Spring Break**	20 **Spring Break**	21	22
23	24	25	26 **Aqua IAM #54**	27 **Aura IAM #51**	28	29
30	1 **May**	2	3 **Aqua IAM #55**	4 **Aura IAM #52**	5	6
7	8	9	10 **Aqua Backup**	11 **Aura Backup**	12	13
14	15	16	17	18	19	20

Aura Propellant Usage
(Updated September 2014)

- **Initial Aura lifetime fuel analysis in 2006**
- **Detailed Aqua & Aura lifetime analysis in 2008**
  - Presented to MOWG and at Aura End of Prime Mission Review in September 2010
- **Initial Aura Decommissioning Plan was delivered in September 2012**
  - Updated Lifetime Estimates
- **Updated August 29, 2013**
  - **Updated propellant trends for IAMs & DMUMs**
  - **Updated definitive fuel usage**
  - **Updated 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)
- **Updated September 30, 2014**
  - **Updated propellant trends for IAMs & DMUMs**
  - **Updated definitive fuel usage**
  - **Updated predicted solar flux levels**
- **Annual updates will be provided**
  - **Final will be produced 60 days before start of decommissioning**
- **Fuel Usage updated January 2016**



FDSS

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:
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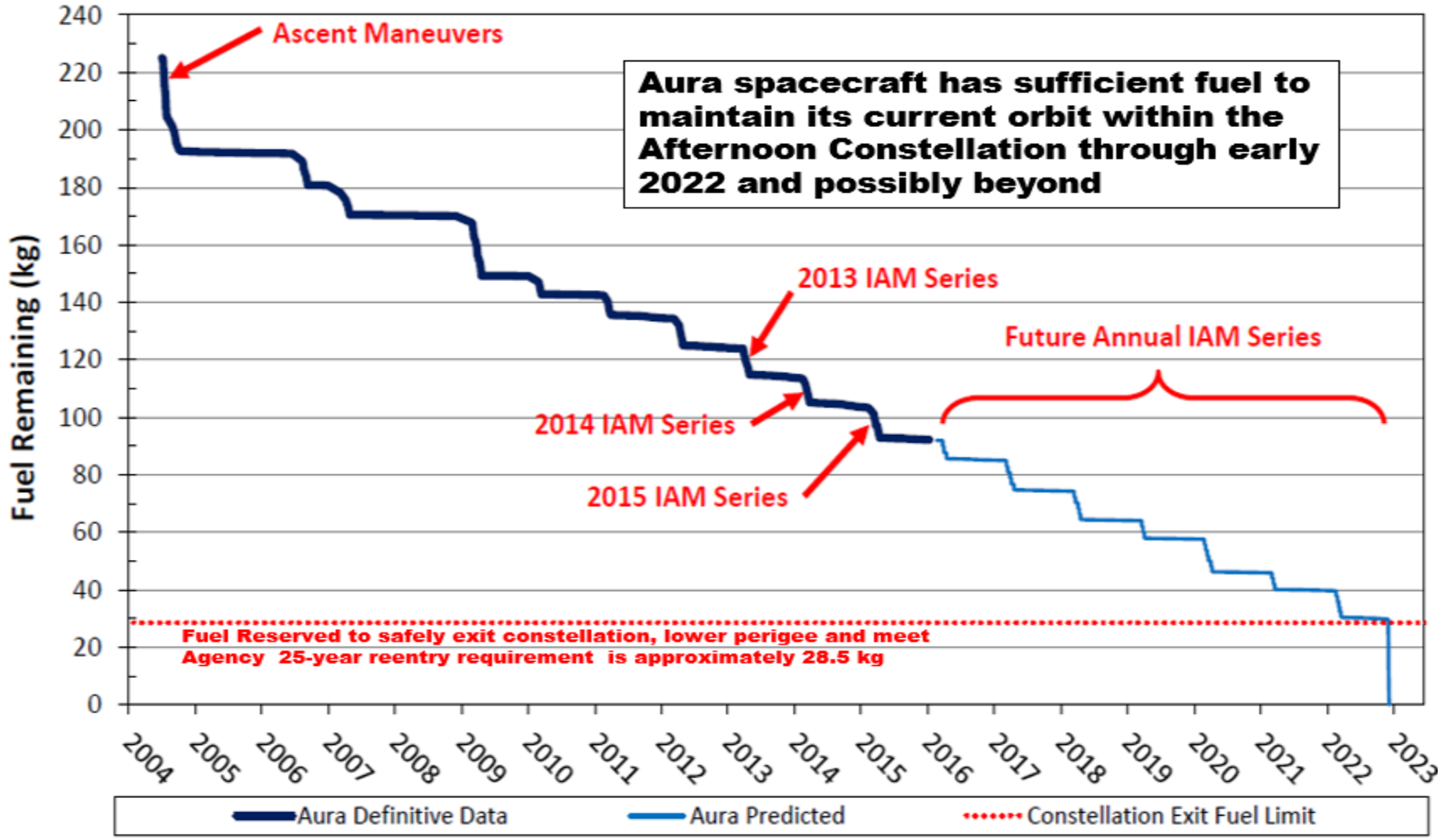
Remaining Fuel Estimate
(September 2014)

- 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 after each series of inclination adjust maneuvers
  - **Next full update: September 2016**

Fuel Usage: Actual & Predicted

(Updated January, 2016)



Debris Assessment Software

(September 2014)

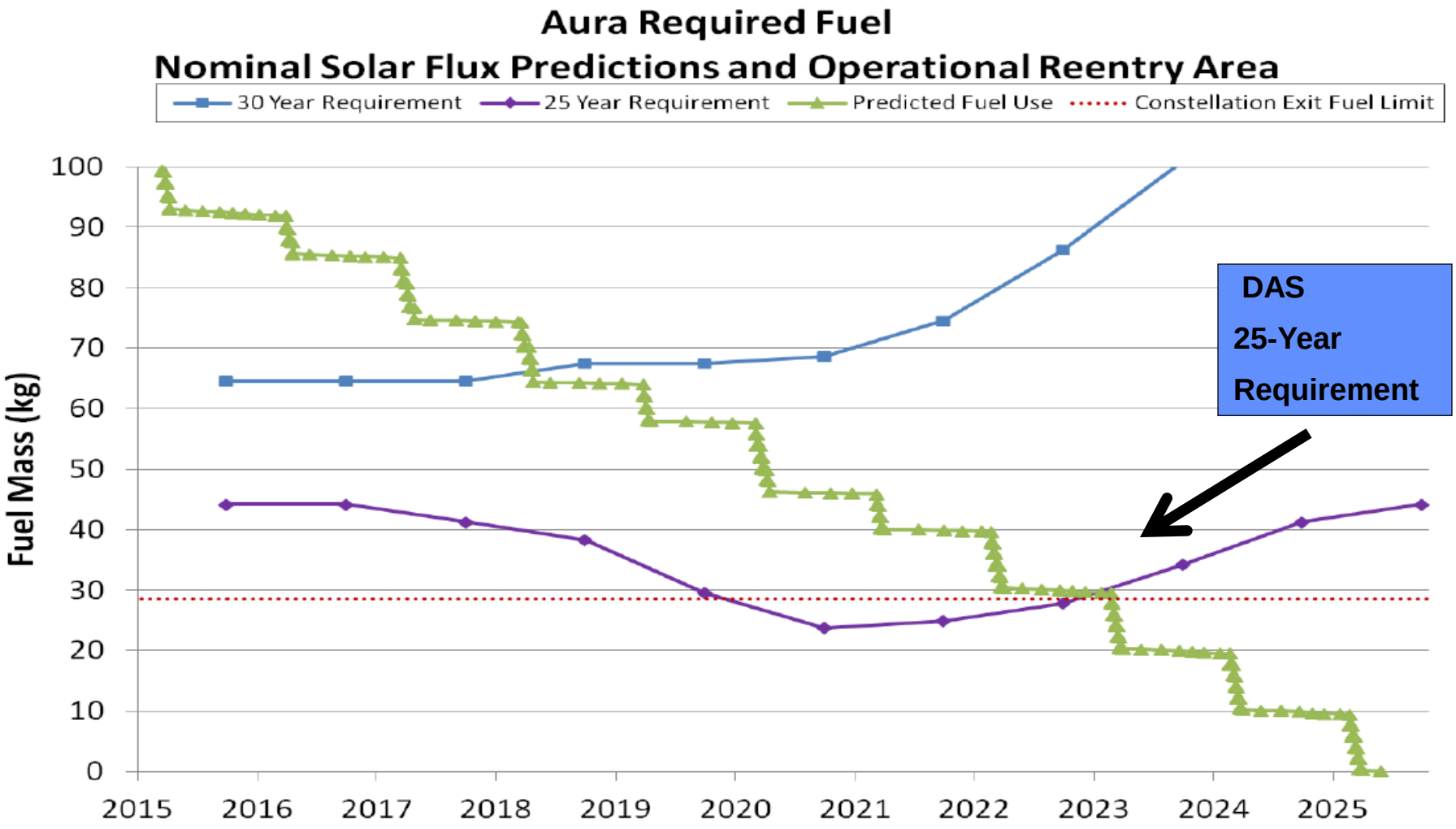
- The Debris Assessment Software (DAS) was created by the Orbital Debris Office in Johnson Space Center and is the Agency standard for end of mission life analyses and lifetime estimations
  - Current Version 2.0.2
- DAS requires several inputs describing the spacecraft's mission:
  - The operational 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

No Changes or Updates

Aura DAS End of Life Predictions

(September 2014)

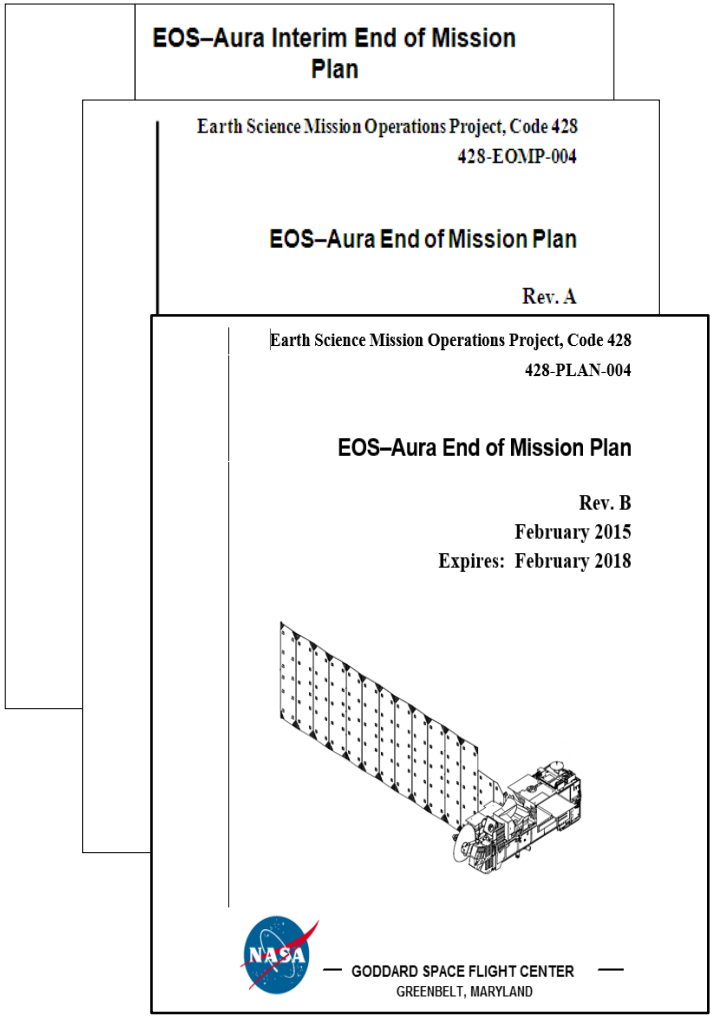
No Changes or Updates



Changes since last ESC MOWG

Aura 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**
- **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**
    - » **08/06/2013: 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**
  - **OMI: Operating Normally**
    - » **Field-of-View Anomaly started in September 2007 – currently stable**
  - **TES: Operating Normally – Showing signs of aging and reaching end-of-life**
    - » **07/09/2014: TES Laser A Failure (Switched to Laser B on 07/23/2014)**
      - **TES returned to routine Special Observation operations on 07/26/2014**
    - » **09/09/2015: TES Laser B Anomaly (on-going activities to extend life)**
    - » **TES ICS Stalls (#3, 08/16/15), (#4, 08/23/15), (#5, 11/07/15), and (#6, 01/12/2016)**
- **Data Capture/L0 Processing Status – GREEN**
  - **SSR Data Capture to 03/31/2016: 99.99540870% (2/29/16)**
- **Ground Systems – System Upgrades completed no current issues**
  - **Responding to new security requirements and upgrades to obsolete hardware or COTS systems, as required**
  - **Automation Effort underway**

Additional Charts

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 ESC MOWG in blue

- **Mission Requirements: Perform Drag Make-Up Maneuvers (DMUMs) to maintain 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**
- **Control Box Excursions: To date there have been 3 Control box Excursions**
  - **2 on +10km front-side: 9/5/12 to 9/6/12, and 03/23/2015 to 04/17/2015 (increase in drag)**
  - **1 on -10km back-side: 2/12/13 to 3/13/13 (drop in drag after DMUM on 1/16/13)**
- **To date a total of 89 routine DMUMs have been performed**
  - **07/19/2012: DMUM # 43 No Yaw Slew Maneuver (NYS) #1 – NYS Maneuvers (37)**
  - **Last maneuver 03/02/2016 (#89) – Next maneuver ~ May 2016 (#90)**
  - **Variation in performance from –6.7% (cold) to +5.3% (hot)**
- **Conducted 10 series of inclination adjustment maneuvers – #11 in progress**
  - **Fall 2004 (4), Fall 2006 (4 of 6), Spring 2007 (4), Spring 2009 (9), Spring 2010 (3), Spring 2011 (3), Spring 2012 (4), Spring 2013 (4), Spring 2014 (4) & Spring 2015 (5)**
  - **Variation in performance from -4.5% (cold) to +1.9% (hot)**

Aura Conjunction Assessment High Interest Events

(June 2015 – February 2016: 21 CARA HIEs – 3 Required Significant Actions

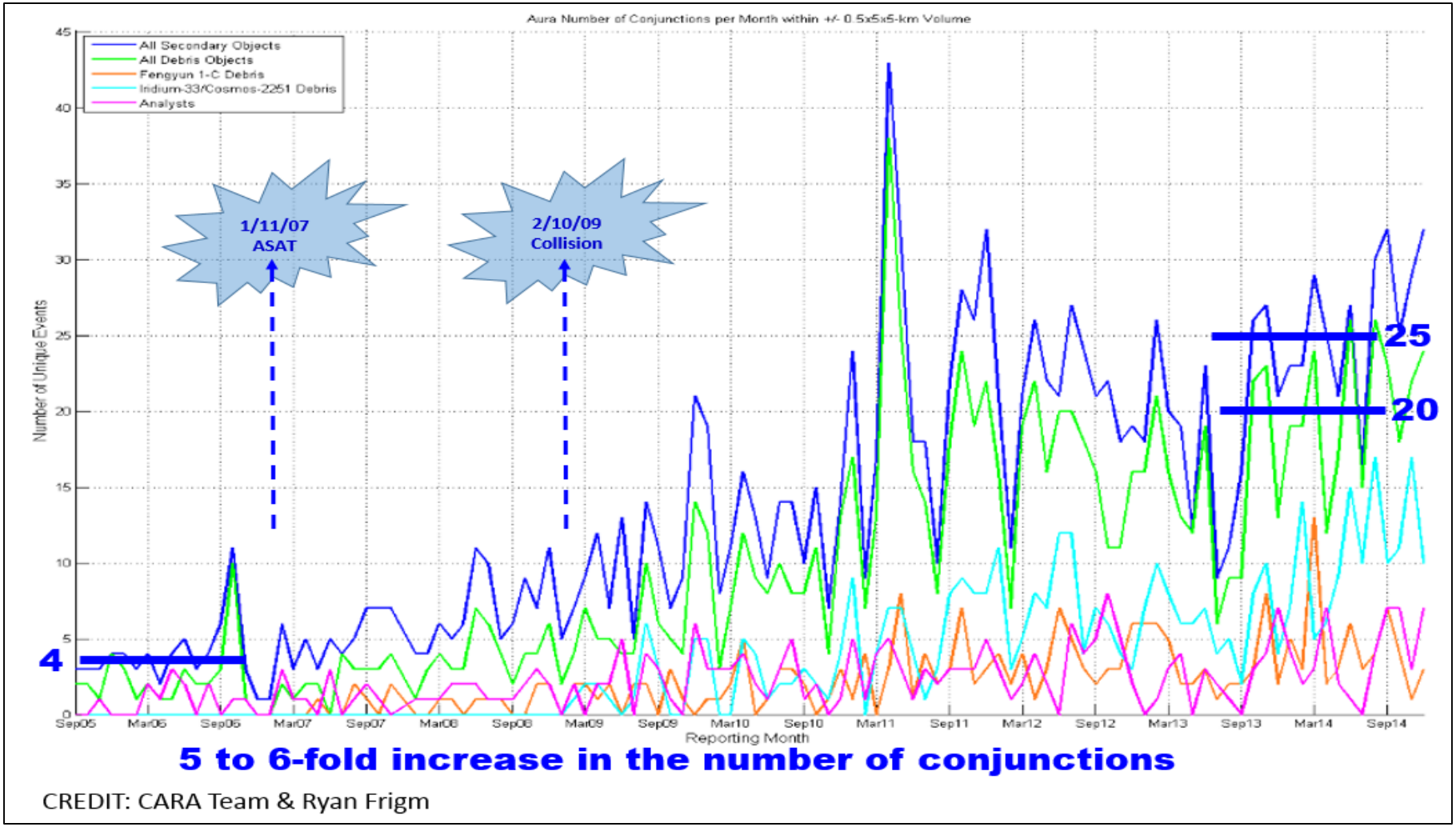
1. **08/08/2015: CA vs. 31934 on 08/08 at 05:24:05 GMT – Monitored the conjunction but no action required (T2)**
2. **08/20/2015: CA vs. 35858 on 08/20 at 18:40:52 GMT - Monitored the conjunction but no action required (T2)**
3. **08/29/2015: CA vs. 89477 on 08/29 at 07:51:15 GMT – Short notice, DAMs planned, Pc dropped within hours of TCA (T3)**
4. **09/05/2015: CA vs. 82072 on 09/05 at 06:07:42 GMT – Monitored the conjunction but no action required (T2)**
5. **10/05/2015: CA vs. 24197 on 10/05 at 05:25:53 GMT – Monitored but no action (T2)**
6. **11/06/2015: CA vs. 32344 on 11/06 at 10:08:35 GMT – Postponed 11/05 DMUM (T4)**
7. **11/25/2015: CA vs. 34723 on 11/25 at 07:01:35 GMT – Monitored pre-holiday conjunction, self-mitigated (T2)**
8. **12/13/2015: CA vs. 30478 on 12/13 at 10:55:19 GMT – Monitored but no action (T2)**
9. **12/27/2015: CA vs. 32072 on 12/27 at 17:39:38 GMT – Monitored but no action (T2)**
10. **12/31/2015: CA vs. 36532 on 12/31 at 17:58:02 GMT – Monitored but no action (T2)**
11. **01/07/2016: CA vs. 08063 on 01/07 at 13:10:54 GMT – Monitored but no action (T2)**
12. **01/18/2016: CA vs. 34215 on 01/19 at 01:17:07 GMT – DAM executed (T4)**
13. **02/10/2016: CA vs. 82292 on 02/10 at 01:54:30 GMT – Monitored but no action (T2)**
14. **02/12/2016: CA vs. 32102 on 02/12 at 04:39:52 GMT – Monitored but no action (T2)**

Aura Summary:

2 DAMs Planned, 1 DAMs Executed, 1 DAMs self-mitigated, 0 DAMs approved and waived-off

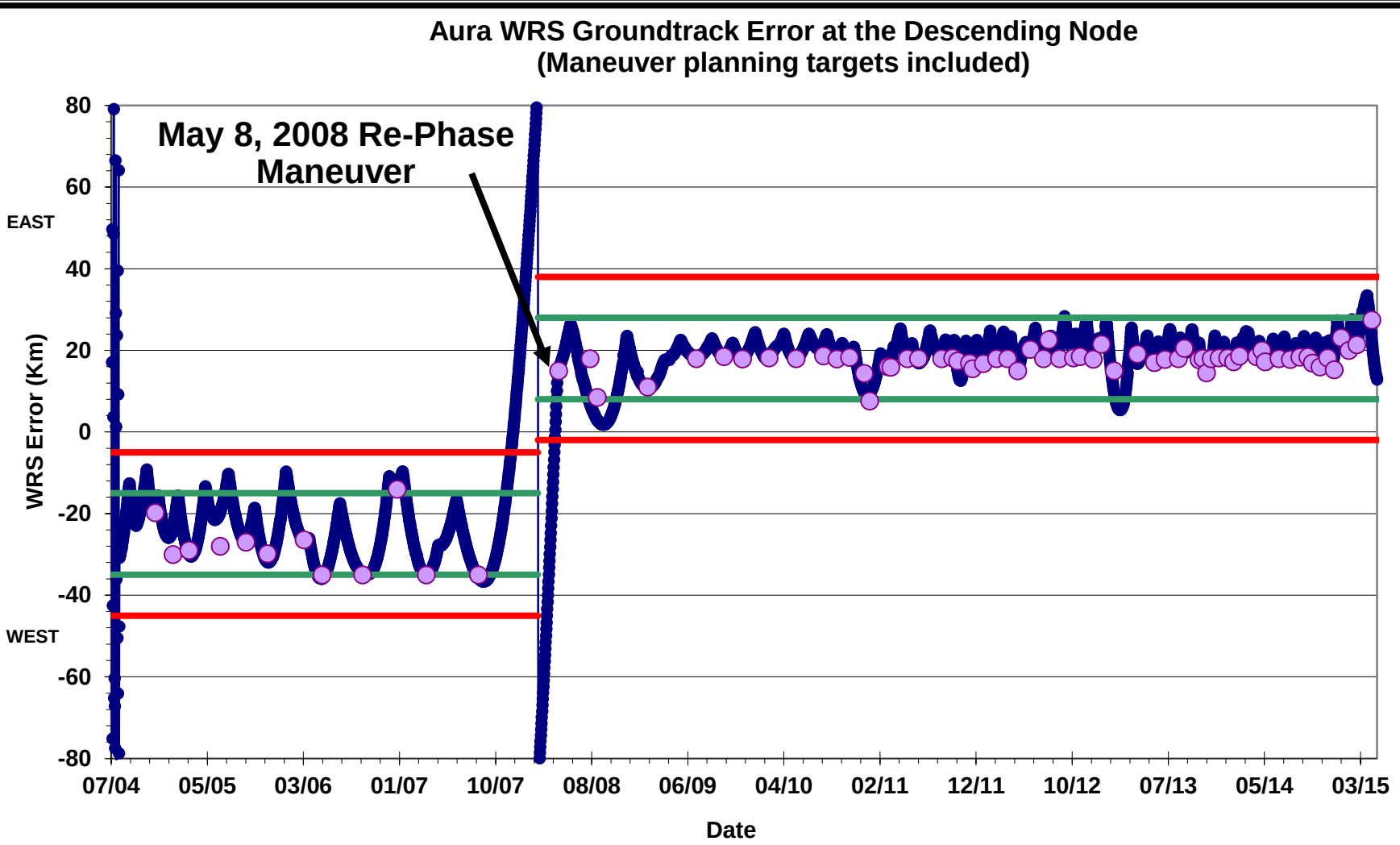
1 Routine maneuvers rescheduled (Tier 4s)

Aura Conjunction Assessment Statistics
(September 2005 thru December 2014)



WRS Ground Track Error (GTE)

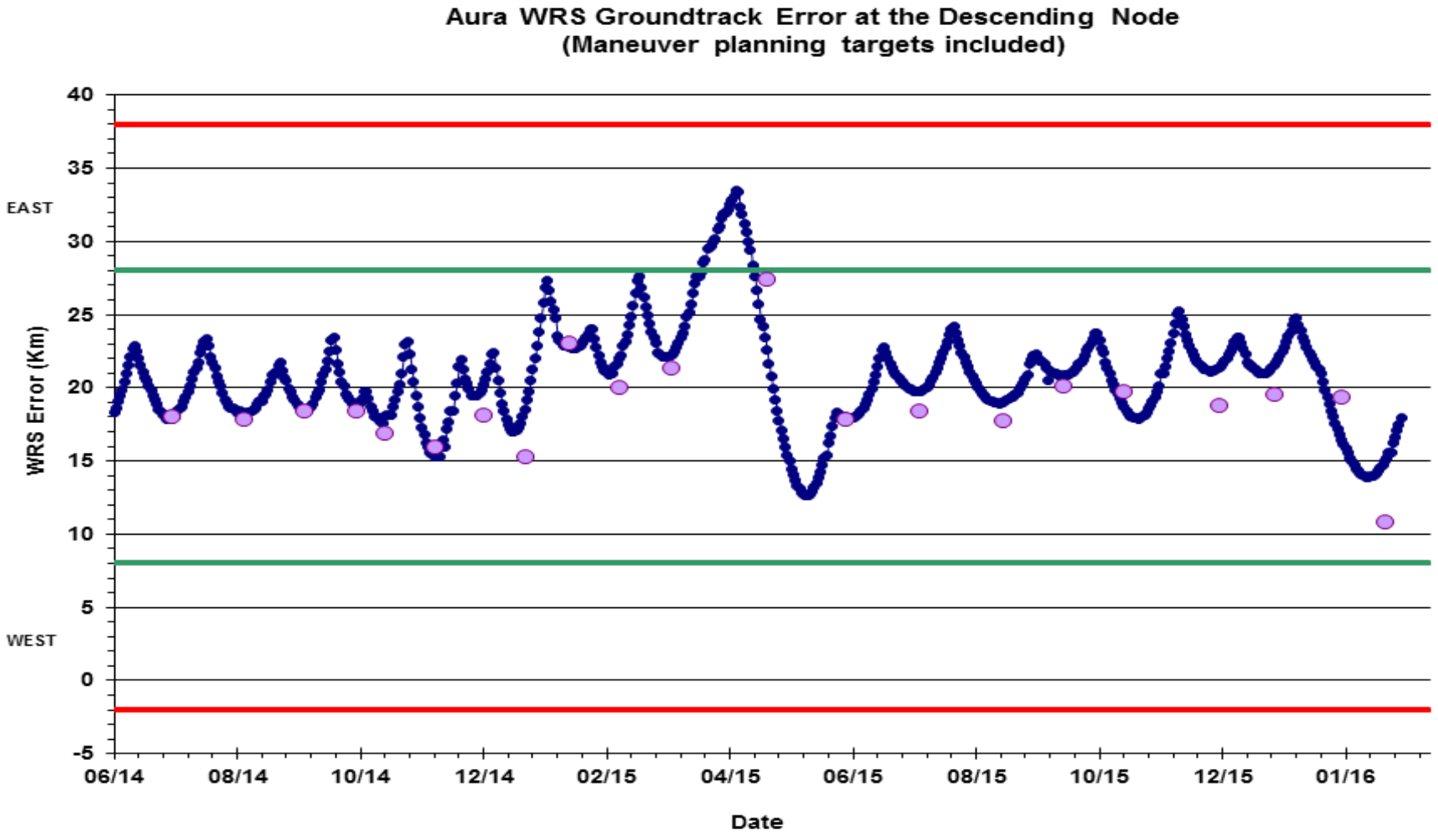
(As of May 24, 2015)



WRS Ground Track Error (GTE)

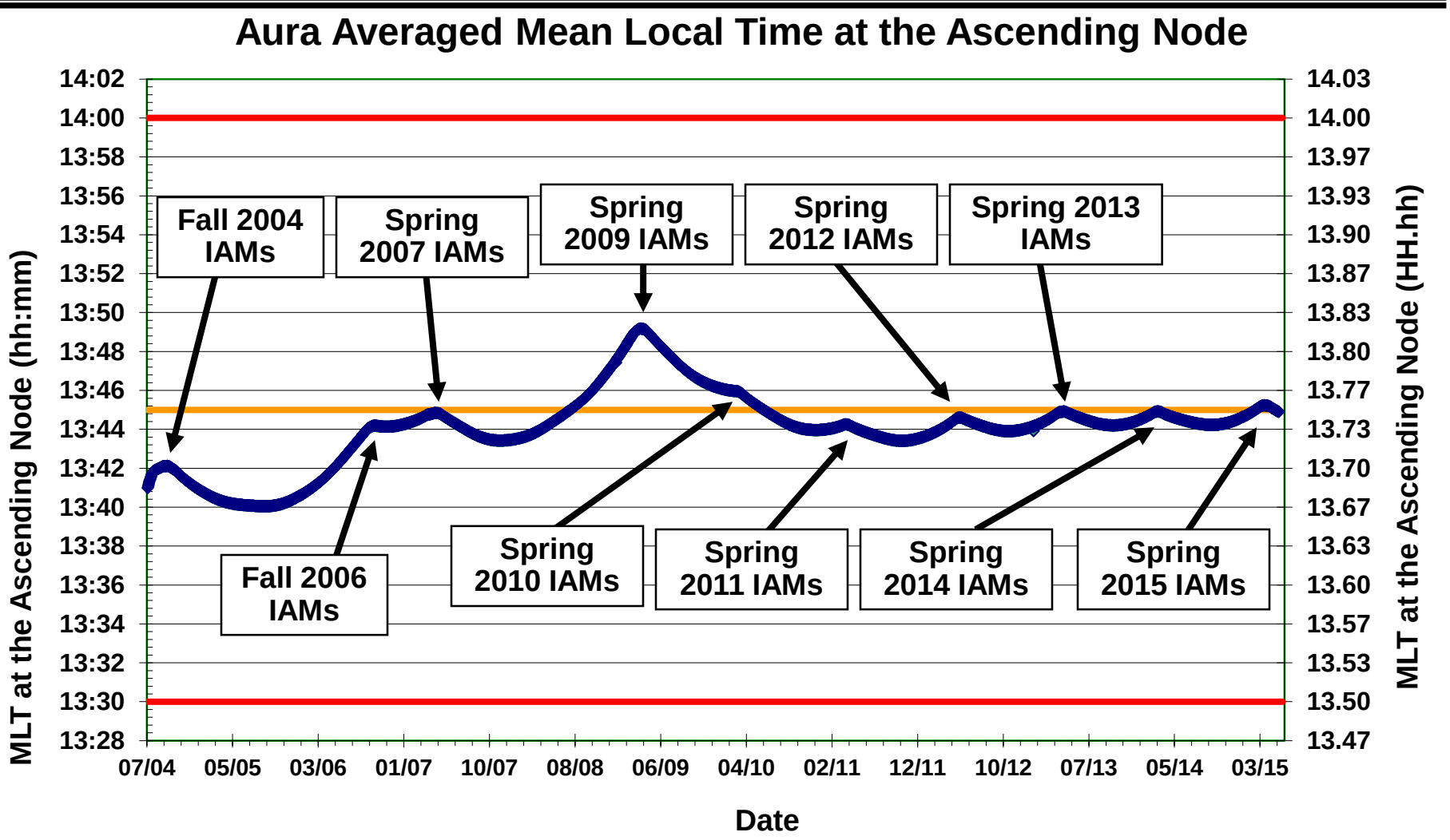
(As of March 1, 2016)

Past 18+ months



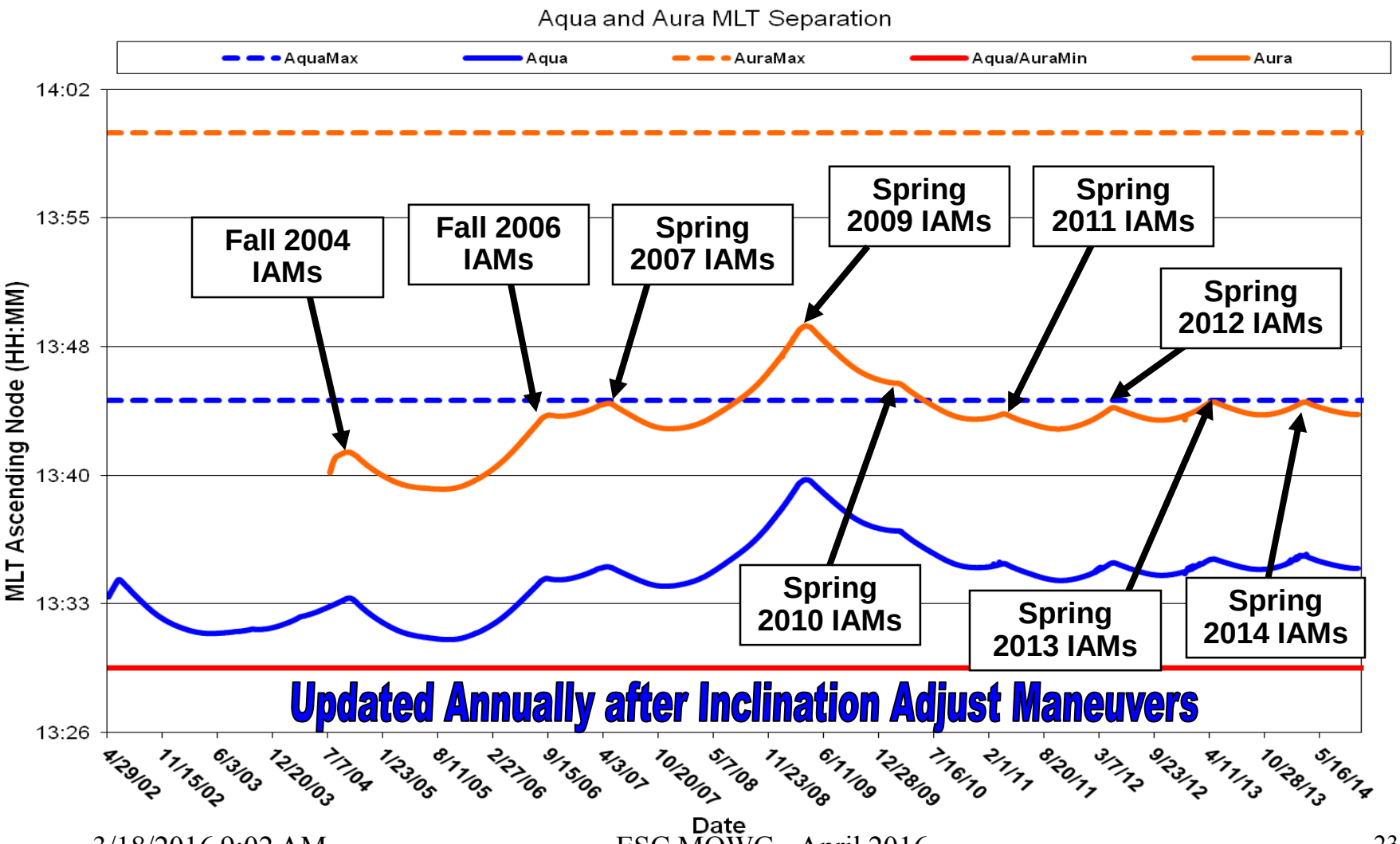
Aura Averaged MLT @ Ascending Node

(As of May 24, 2015)

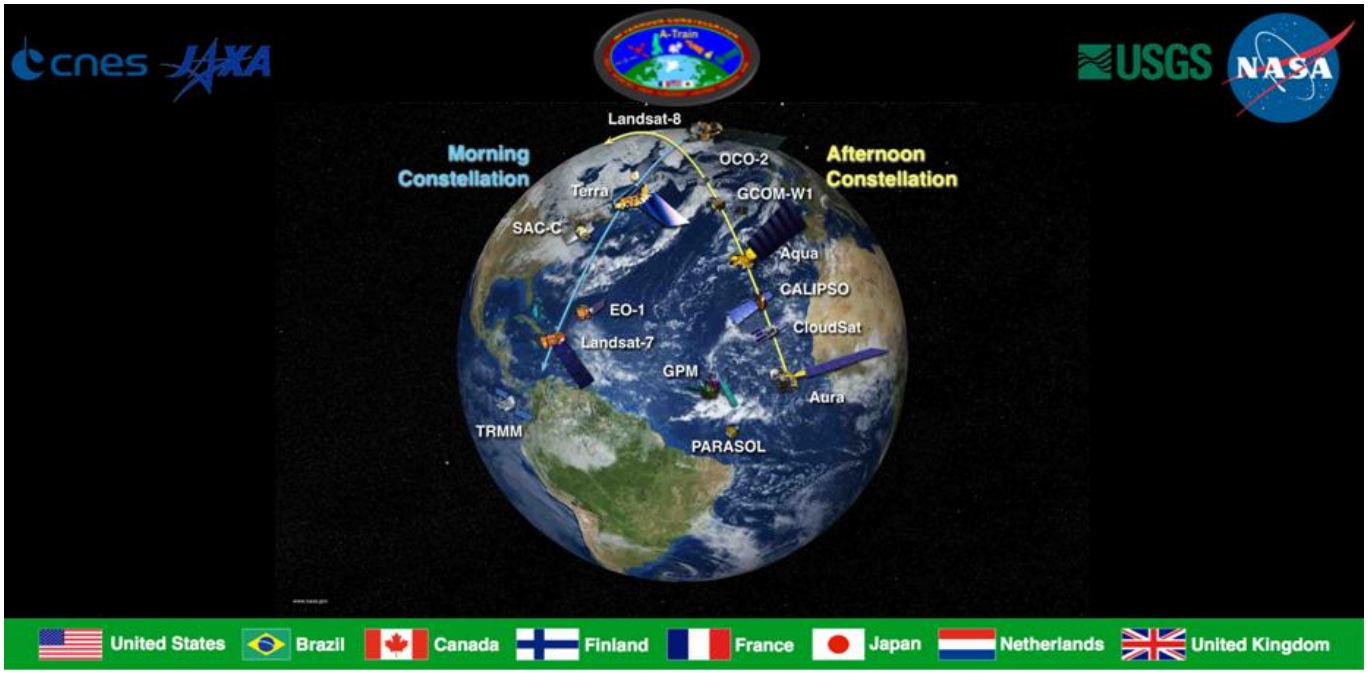


Aqua/Aura Mean Local Time (MLT)

@ Ascending Node



Inclination/MLT Maintenance
(Long-Term Plan)



International Earth Science Constellation
Mission Operations Working Group
June 02-04, 2015

Aqua and Aura Results from Spring 2015 IAM Campaign

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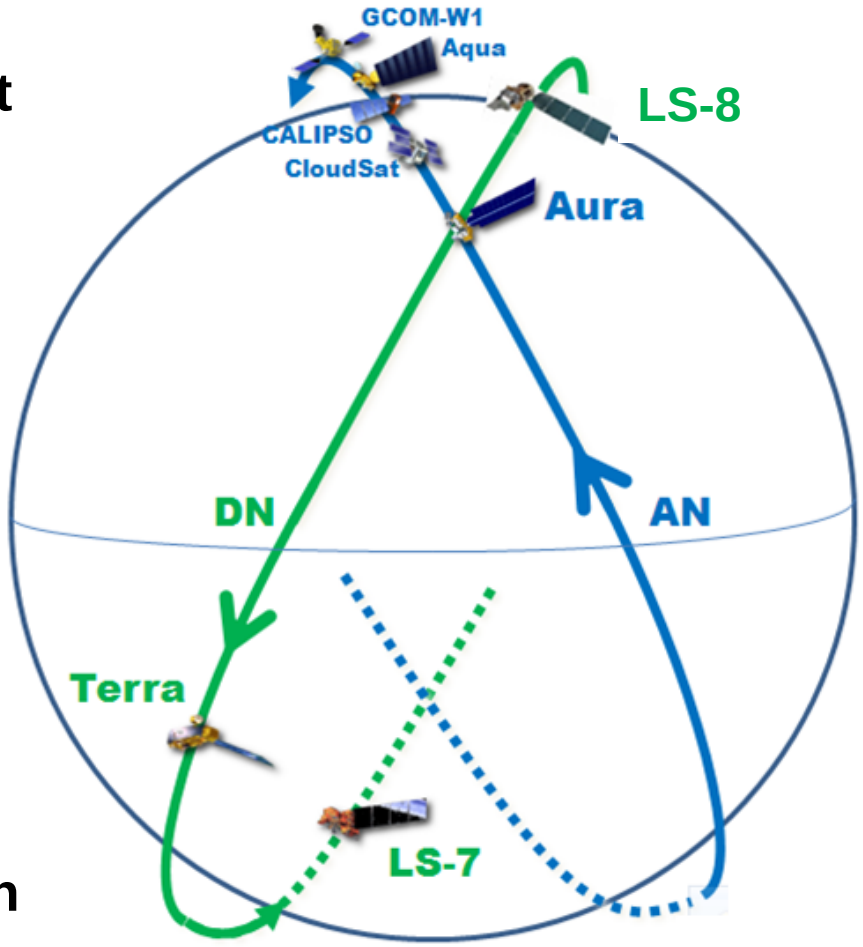
Aura and Landsat-8 (LS-8) Orbit Phasing

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

Typically 320 – 180 seconds

Terra ~ 30 min behind LS-7

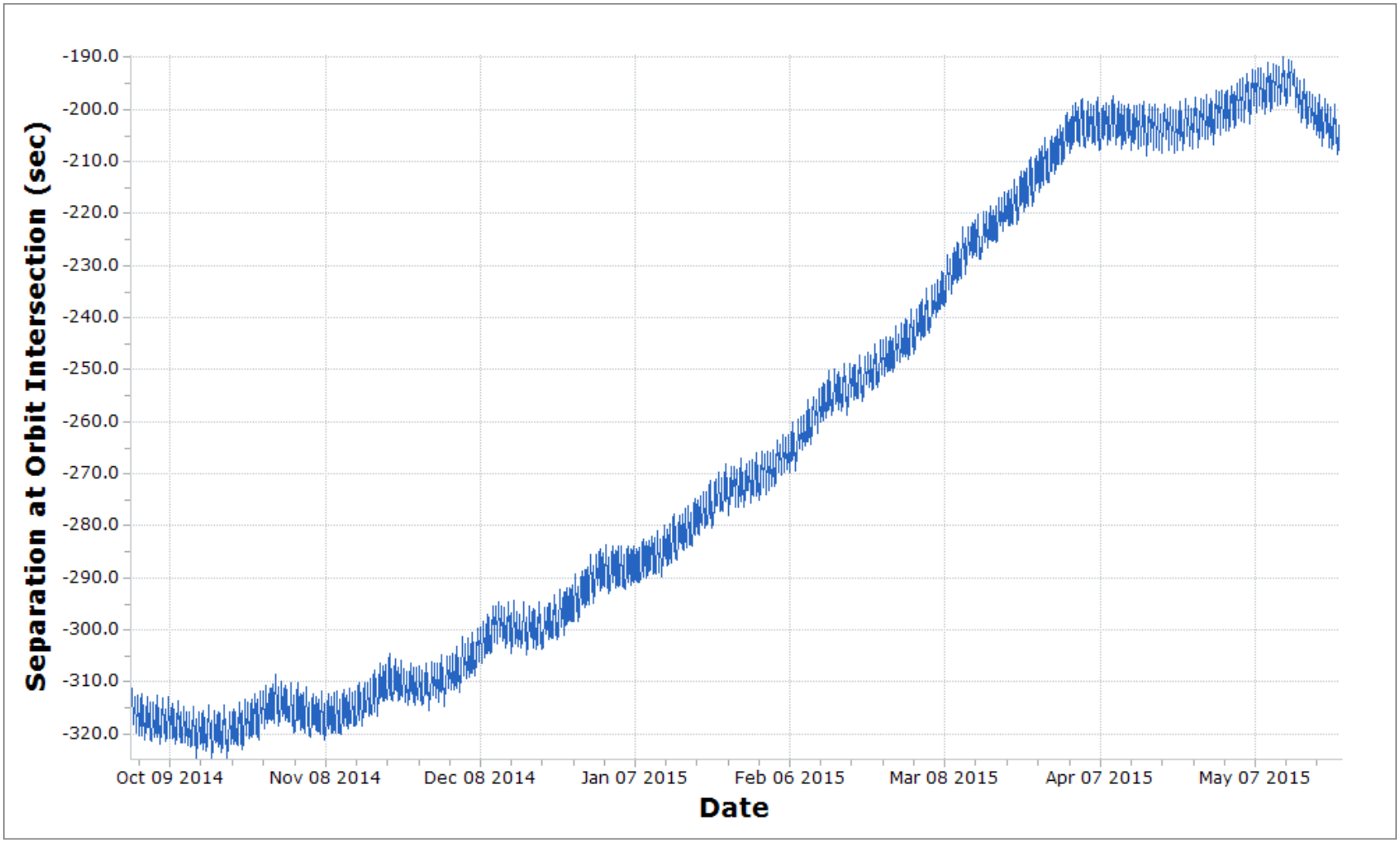


1 Orbit = ~ 100 minutes

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

LS-8/Aura Phasing at Poles @ Northern Intersection Point

(as of May 24, 2015)




Mission
Operations
Project
GSFC
ESMO
NASA
Science
Earth


NASA

Questions