

**Mission Status at
Aura Science Team MOWG Meeting
Rotterdam, Netherlands
August 31, 2016**

EOS Aura

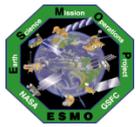
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Topics



- **Mission Summary**
- **Spacecraft Subsystems Summary**
- **Recent & Planned Activities**
- **Spacecraft Anomalies**
- **Data Capture**
- **Propellant Usage & Lifetime Estimates**
- **Overall Summary**
- **Additional Slides:**
 - **Spacecraft Maneuvers & Ground Track History**
 - **Mission Highlights & Past Spacecraft Anomalies**
 - **Reliability Estimates**

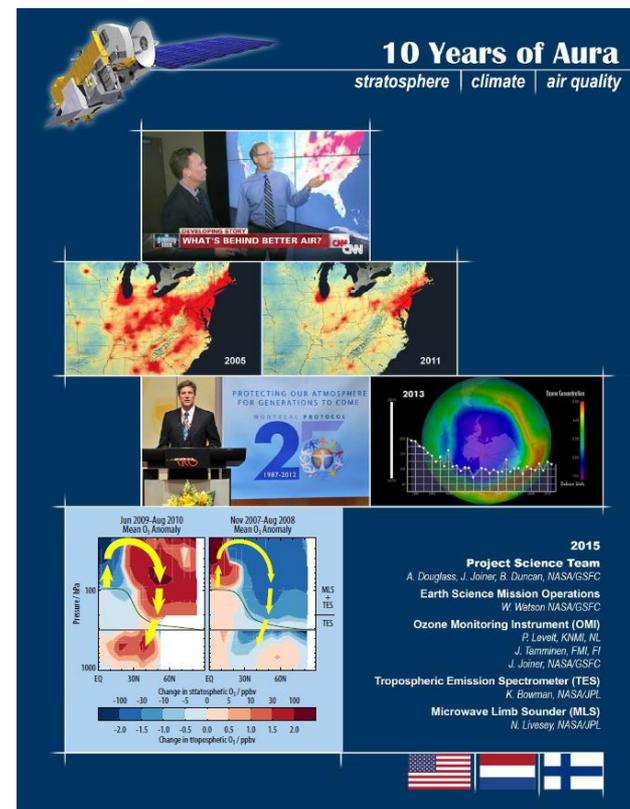


EOS Aura Mission Summary



(Changes since September 2014 MOWG @ College Park)

- **07/15/04: Launch**
 - 6-Year Design Life
- **09/30/10: End of Prime Mission Review**
- **09/16/14: STM & MOWG @ College Park**
- **03/04/15: Senior Review Proposal #4**
 - Reliability Estimates through 2021
 - Consumables through 2022
- **07/15/15: Aura 11-Year Anniversary**
- **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



(Changes since September 2014 MOWG @ College Park)

- **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



Summary of Activities

(Since the last MOWG on 09/16/2014)



- **62 CARA High Interest Orbital Debris Events (Tiers 1-4)**
 - **13 that required significant action (T3 / T4)**
 - » 01/19/2015: DMUM (QDAM) Postponed #9 due to post-maneuver conjunction (T4)
 - » 02/02/2015: Postponed 2/5 DMUM, Planned DAMs, 3 HIEBs (T4)
 - » 02/16/2015: 2/18 QDAM Postponed (T4)
 - » 11/06/2015: Postponed 11/05 DMUM (T4)
 - » 01/18/2016: Executed DAM (DMU #88) (T4)
 - » 03/15/2016: Executed DAM (DMU #90) (T4)
 - **Note: (T1 – Notify (email/phone), T2 – Conduct Briefing, T3 – Plan Maneuver, T4 – Execute Maneuver)**
- **1 Spacecraft EPS ARE power drop anomalies – no impact to operations**
 - **12/08/14 (ARE-4A)**
- **10 Significant instrument related anomalies (Generated NASA Anomaly Reports)**
 - **TES: 6 Stalls (8/17/15, 8/23/15, 11/8/15, 1/12/16, 7/20/16, 8/1/16), 1 Laser-B Anomaly (9/11/15), 1 Safe Events (3/27/16)**
 - **OMI: 1 Survival Event (5/29/16), 1 Safe Event (6/10/16)**
- **Spacecraft Delta-V Maneuvers: 24 Routine DMUMs and 9 IAMs**
- **2 Instrument Calibration Maneuvers**
 - **03/07/2015: MLS Yaw Slew #10 Lunar Cal, 03/25/2016: MLS Yaw Slew #11 Lunar Cal**
- **Completed 2 Series of Annual Inclination Adjust Maneuvers (2015 & 2016)**
- **Completed 2 EOS Flight Operations Annual Reviews (#8 - 01/20/15 & #9 - 01/27/16)**



Planned Activities

- **09/01/2016: Drag Make Up Maneuver (DMUM) #95 (Target as of 8/1/16)**
- **January 2017: Flight Operations Annual Review (#10)**
- **March 2017: Submit Senior Review Mission Extension Proposal**
- **April 2017: A-Train Science Symposium (Pasadena, CA)**
- **Spring 2017: Annual Inclination Adjust Maneuvers (DRAFT SCHEDULE)**
 - **03/02/17 (#49), 03/09/17 (#50), 03/23/17 (#51), & 03/30/17 (#52)**
- **Mid-to-Long-Term Plans**
 - **Continue to improve RMM/DAM execution**
 - » See additional details on CA automation (CRMS) in the following slide
 - **2016 Fall Earth Science Constellation (ESC) MOWG (Albuquerque, NM)**
 - » Update propellant budget, decommissioning analysis, reliability predictions,...
 - **Working on Lifetime & Decommissioning Analysis**
 - » Developing a retrograde maneuver capability - FOT conducting research, planning and analysis with FDS and ESMO
 - **2017 Senior Review Proposals**



Collision Risk Management Process Improvements

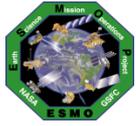


In response to the constantly increasing number of predicted close approaches with orbital debris and operational satellites (High Interest Events – HIEs) and anticipated updates to the US Air Force Space Fence which will significantly increase size of the Space Catalog (20K → 150-200K).

ESMO is developing a new ground system capabilities to autonomously identify and develop maneuver options to assist in Debris Avoidance Maneuver planning.

Collision Risk Management System (CRMS) capabilities 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**



DRAFT Spring 2017 Inclination Adjust Plan

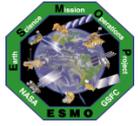


Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
19 Feb	20	21	22	23	24	25
26	27	28	1 March Aqua IAM #52	2 Aura IAM #49	3	4
5	6	7	8 Aqua IAM #53	9 Aura IAM #50	10	11
12	13	14	15 Spring Break	16 Spring Break	17	18
19	20	21	22 Aqua IAM #54	23 Aura IAM #51	24	25
26	27	28	29 Aqua IAM #55	30 Aura IAM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



Spacecraft Anomalies

Array Regulator Electronics Anomalies



Current Status



Last ARE Anomaly (4A) on 12/08/2014

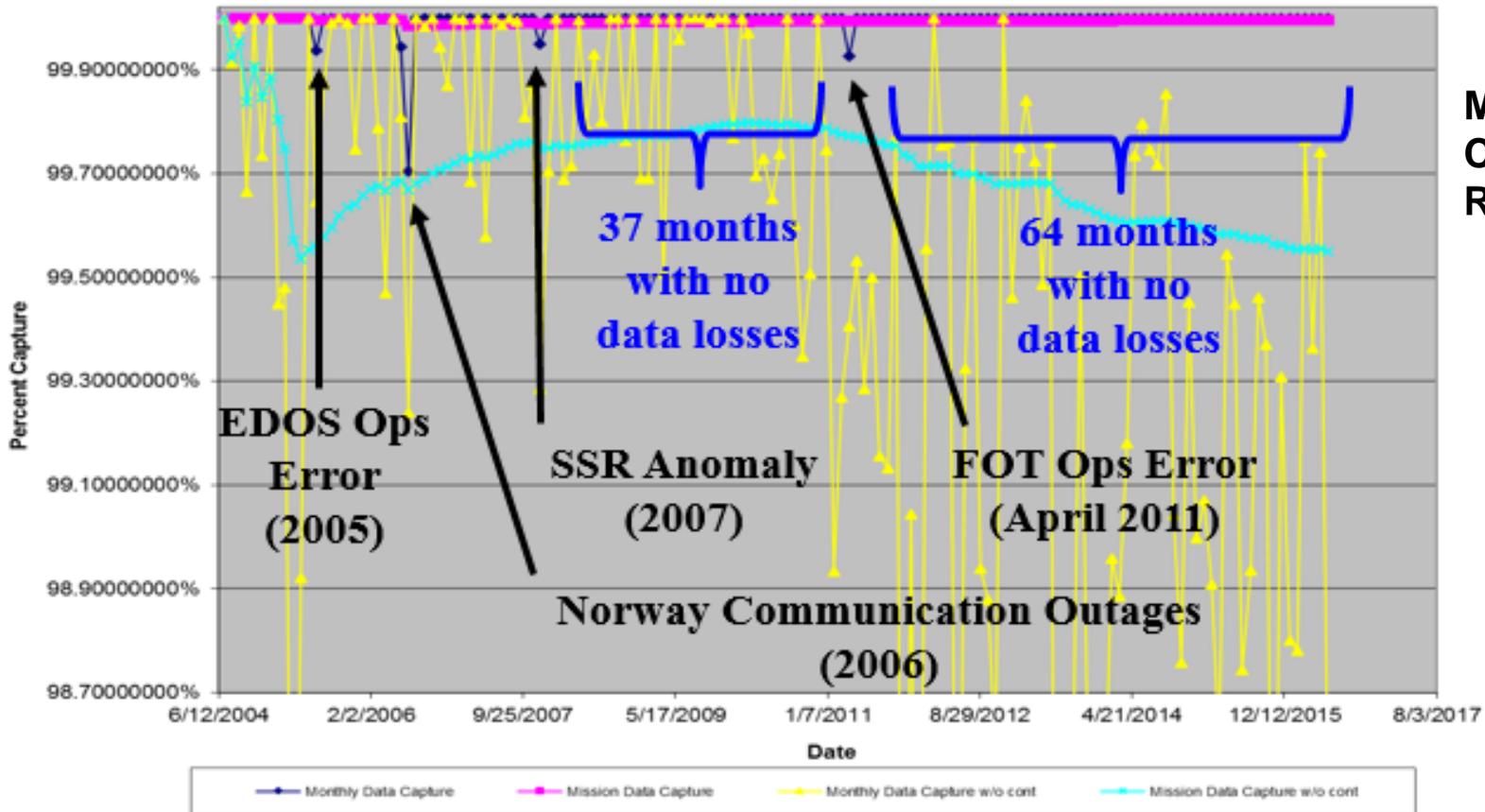
- **07/17/2013: Met with NGAS to review the results of their anomaly investigation to date (focus to date had been on Aqua ARE-6A that occurred 10/20/2011)**
 - Loss could be for many possible reasons including short or open circuits
 - Most failure modes exhibited by Aqua and Aura appear most likely to be caused by loss of output from multiple solar array strings (see NGAS Fishbone Diagram Analysis & Final Report)
 - Additional Aura ARE Anomalies due to other causes
 - » 01/12/2005: Disengaged Solar Array Connector (ARE-3C)
 - » 03/12/2010: MMOD (?) Vacuum Arching (ARE-5A)
- **09/25/2013: NGAS Follow-up Meeting (Focus on Aura investigation)**
- **09/27/2013: FOT reports ARE-6C current drop on 9/14 masked by TES transition to Safe on 9/22**
- **11/13/2013 & 12/11/2013: NGAS Follow-up Meeting (Focus on Aura investigation)**
- **01/15/2014: EPS Performance Review & Anomaly Closeout → 02/05/2014 → 03/05/2014**
- **03/05/2014: NGAS Investigation Status Meeting**
- **03/21/2014: Follow-up/Close-out Meeting while NGAS was at GSFC**
- **06/04/2014: NGAS Briefing – Final Briefing/Report planned for July**
- **07/28/2014: NGAS delivers draft final report and presentation**
- **09/17/2014: NGAS Briefing to ESMO and AETD at GSFC**
- **12/04/2014: EPS Power Working Group and initial Margins Analysis Meeting**
- **12/08/2014: ARE-4A Power Drop Anomaly #1 (Last observed on Aura) – Data sent to NGAS on 12/15/2014**
- **09/01/2015: EPS Power Working Group Meeting**
 - Aura appears to have lost output from about 25 of 132 strings – No impact to mission operations at this time
- **01/19/2016: EPS Power Working Group Meeting**
 - Reviewed 09/23/2015 Semi-annual EPS ARE State-of-Health Test (@equinox) – Nominal Performance
 - FOT & NGAS continues to closely monitor the overall performance of the Electrical Power System (EPS)



Data Capture – SSR Data Losses September 2014 to August 2016



- 64 months without a solid state recorder (SSR) data loss
- Last loss April 2011: OMI data loss 107/21:08:49-22:13:04 (FOT Ops Error)
- SSR Data Capture to 6/30/2016: 99.99550194%



Mission
Capture
Req. = 95%

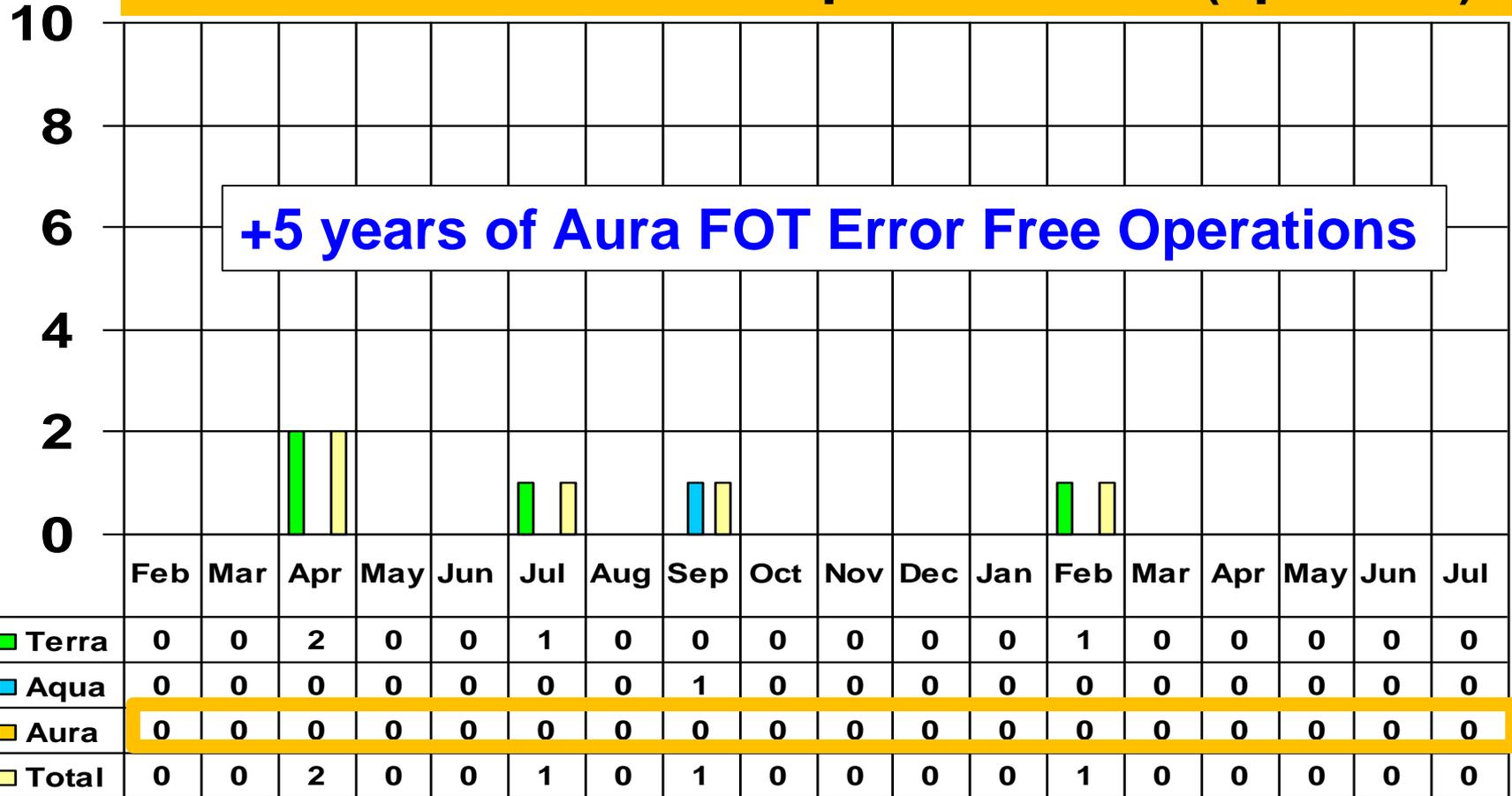


Operational Errors

(18-Months: February 2015 – July 2016)



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





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**



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
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Submitted by:
Jeff Dibble
EOS FD Domain Lead
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a.i. solutions



Remaining Fuel Estimate

(September 2014)

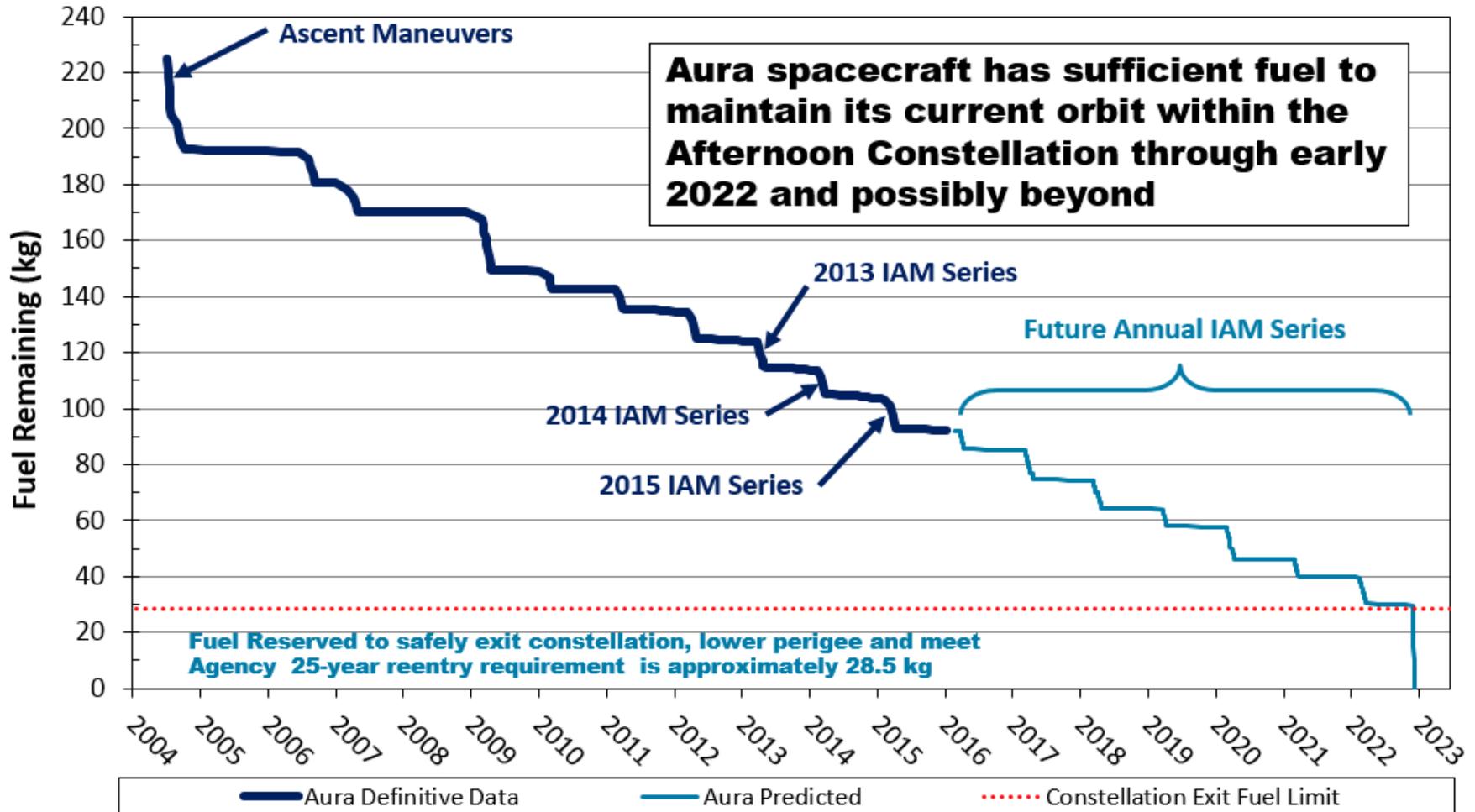


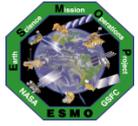
- **Long-term orbit simulations were run for Aura through Feb 2023**
 - **Used mean nominal Schatten solar flux predictions**
 - **Estimated the frequency of drag make-up maneuvers to maintain Aura's WRS-2 ground track requirements**
 - **Estimated the required number of annual inclination maneuvers 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)

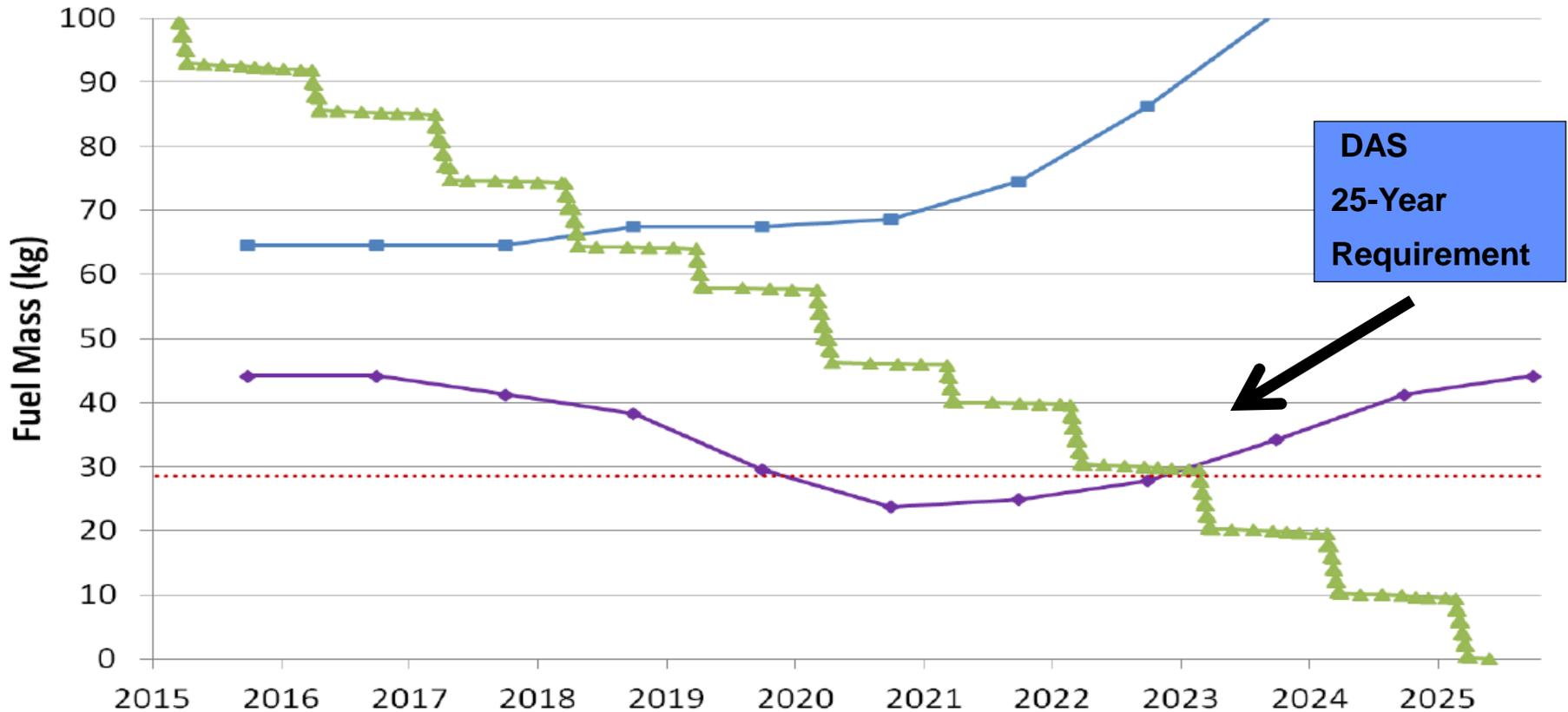


No Changes or Updates

Aura Required Fuel

Nominal Solar Flux Predictions and Operational Reentry Area

—■— 30 Year Requirement —◆— 25 Year Requirement —▲— Predicted Fuel Use ····· Constellation Exit Fuel Limit

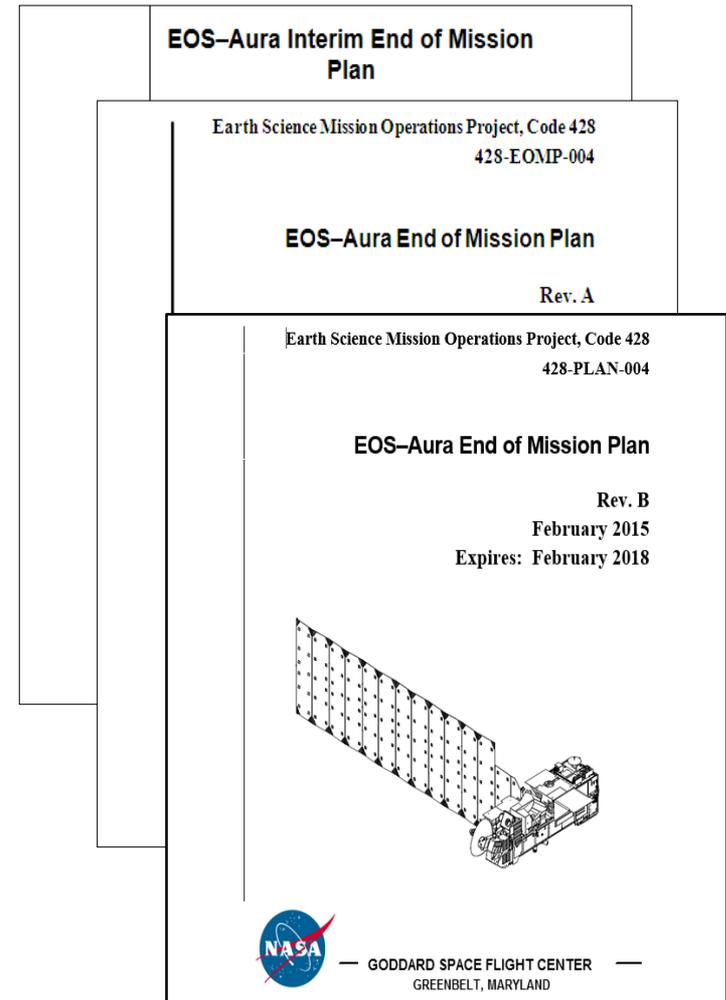




Aura End of Mission Plan (EOMP)



- 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: Operating Normally – Showing signs of aging and reaching end-of-life**
 - » 09/09/15: TES Laser B Anomaly (on-going activities to extend life)
 - » 03/27/16: TES Power on Reset (POR) Anomaly (Recovery is currently on-going)
 - » TES ICS Stalls (#3, 8/16/15), (#4, 8/23/15), (#5, 11/7/15), (#6, 1/12/16), (#7, 7/20/16), & (#8, 8/1/16)
- **Data Capture/L0 Processing Status – GREEN**
 - **SSR Data Capture to 06/30/2016: 99.99550194%**
- **Ground Systems** – Responding to new security requirements and upgrades to obsolete hardware or COTS systems, as required – Automation efforts are underway



Additional Charts

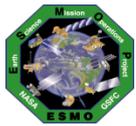
Maneuvers & Ground Track History Orbital Trends



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 09/01/2016 (#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)

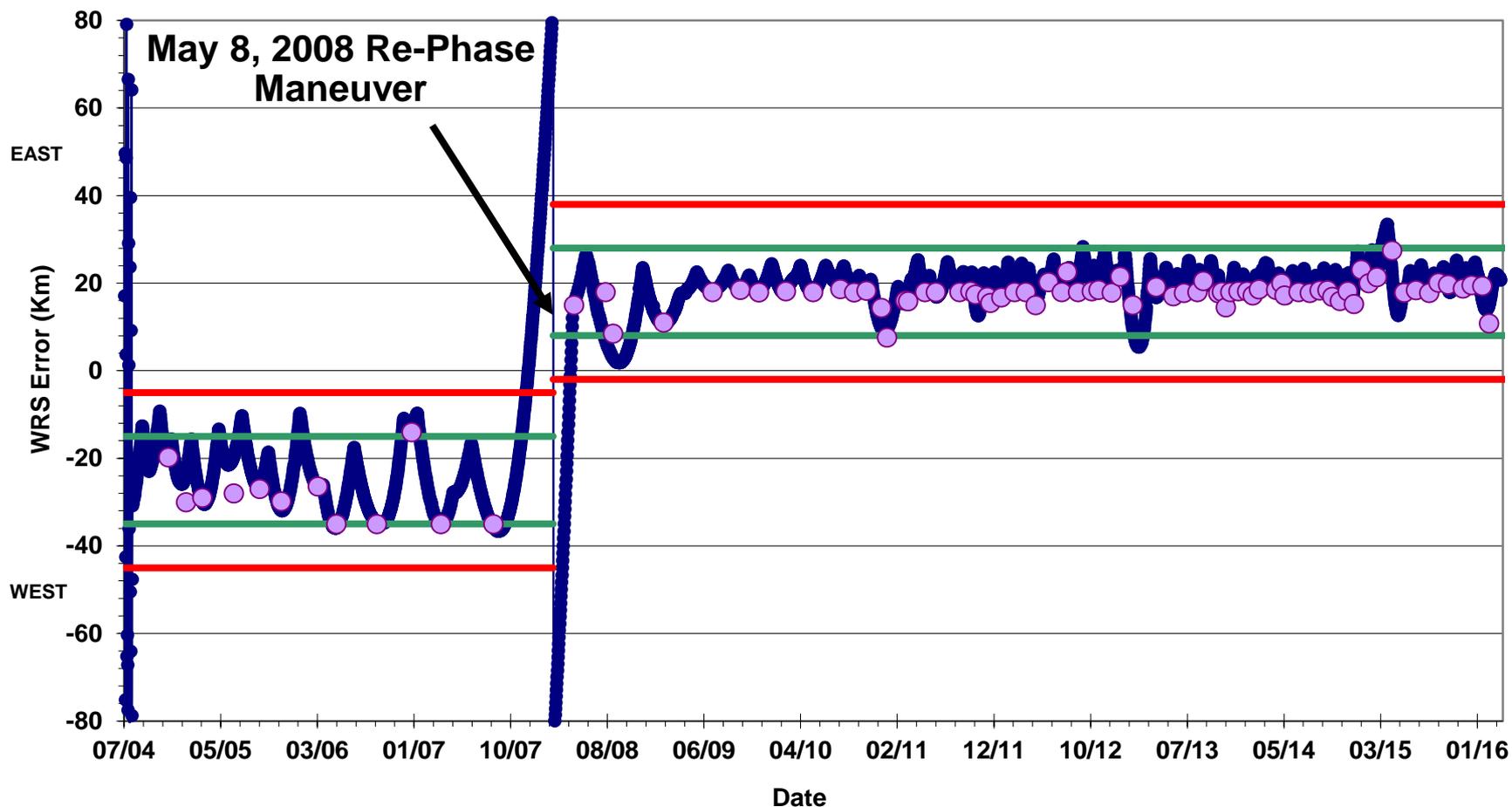


WRS Ground Track Error (GTE)

(As of March 27, 2016)



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



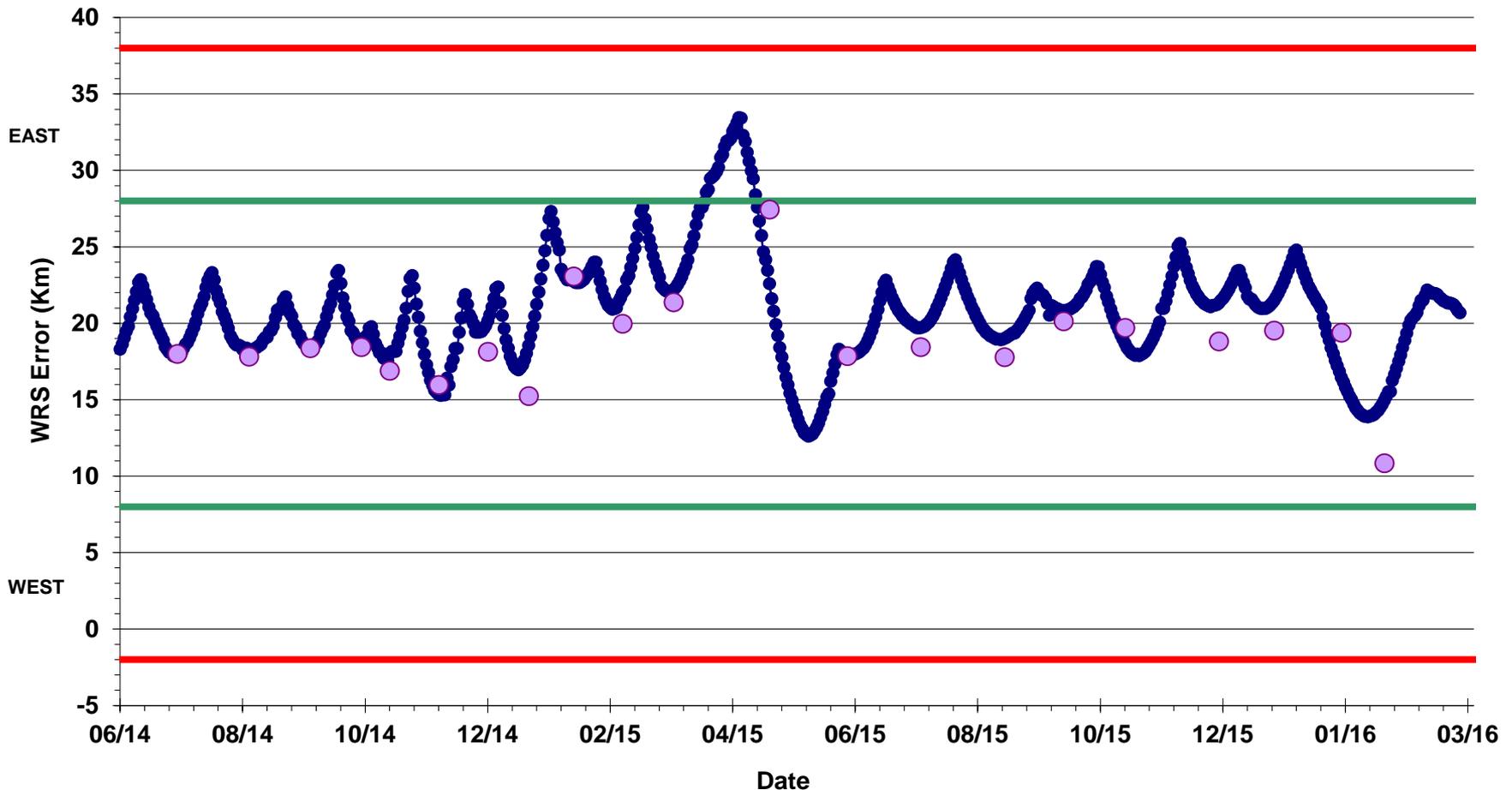


WRS Ground Track Error (GTE)

(As of March 27, 2016) Past 18+ months



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

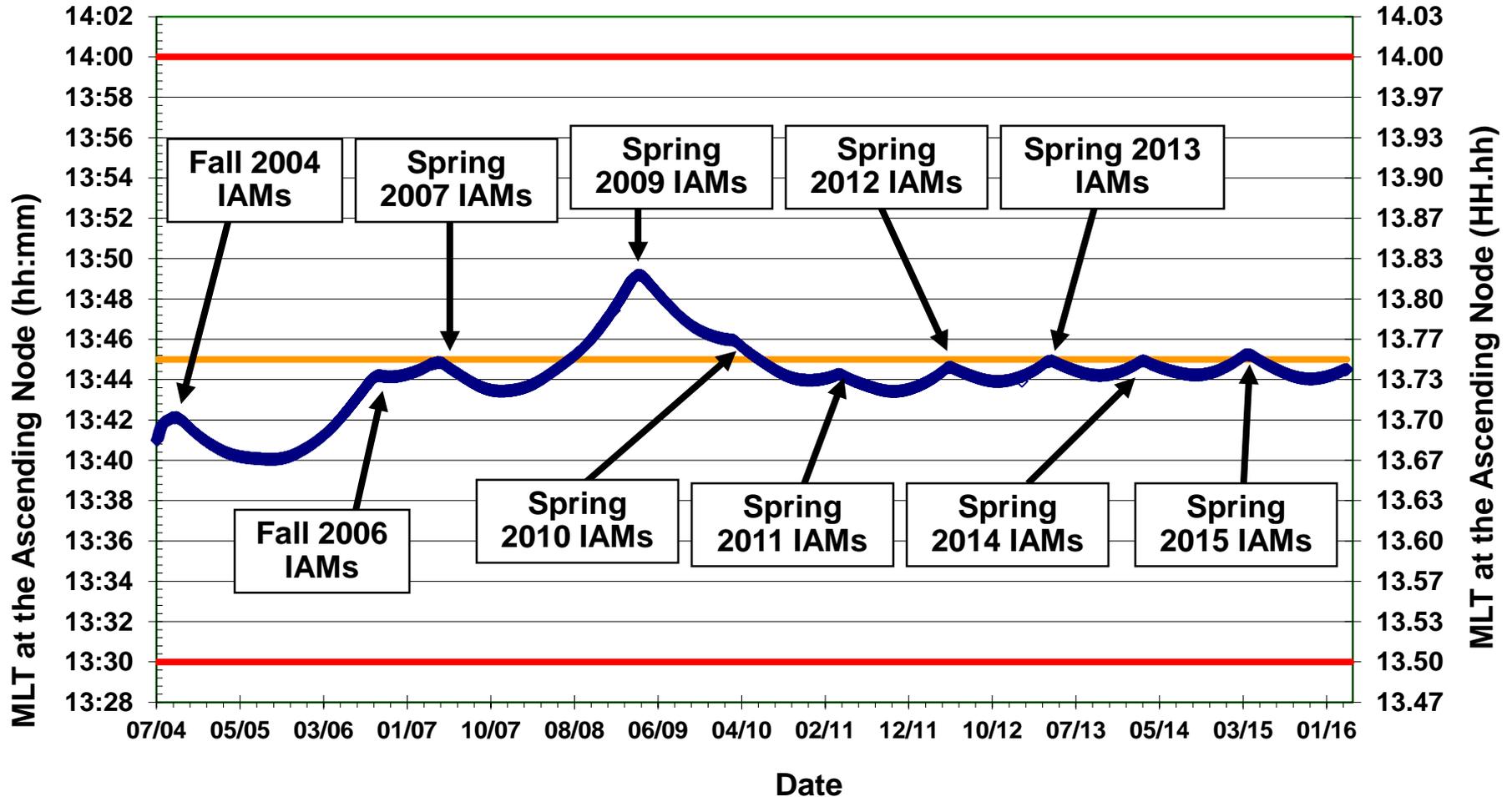




Aura Averaged MLT @ Ascending Node (As of March 27, 2016)

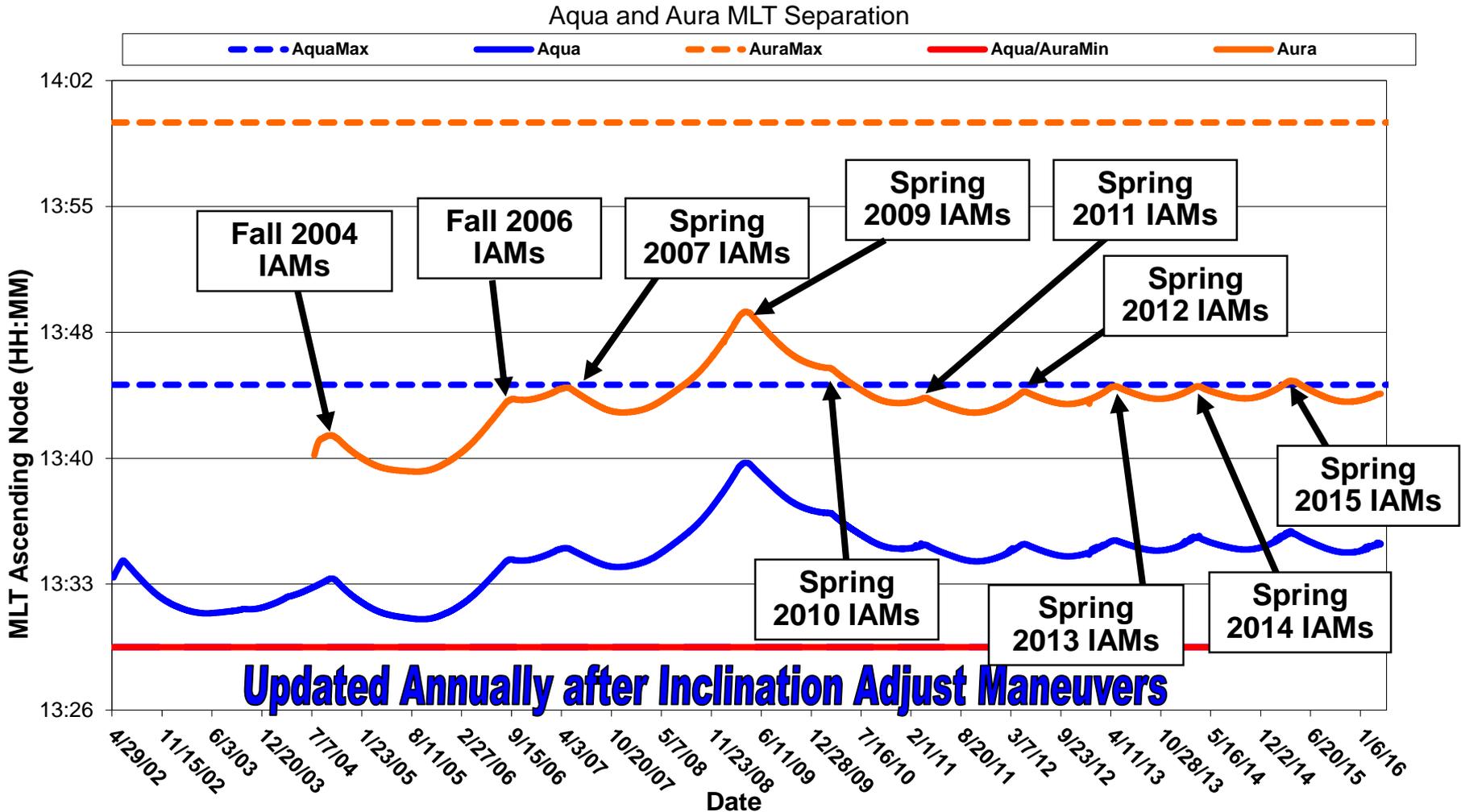


Aura Averaged Mean Local Time at the Ascending Node



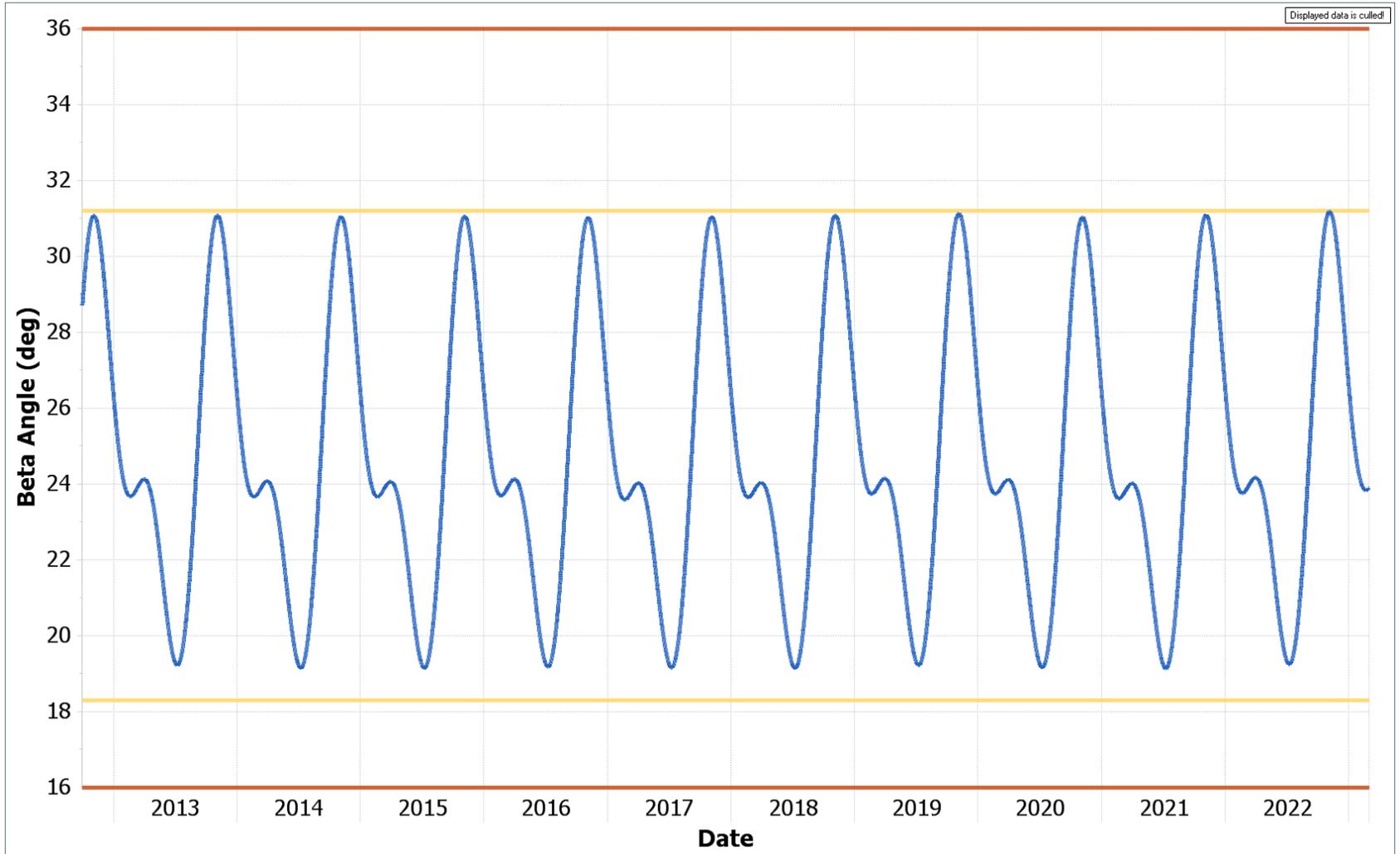


Aqua/Aura Mean Local Time (MLT) @ Ascending Node





Aura Predicted Beta Angle (With Yearly Inclination Maneuvers)





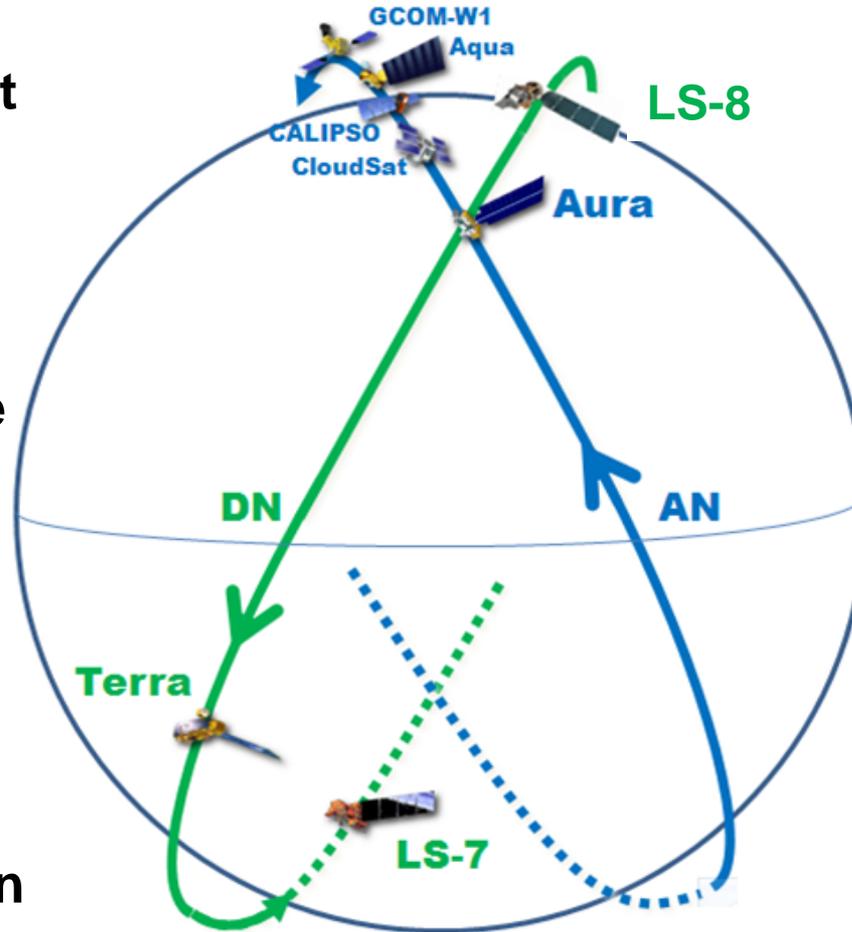
Aura and Landsat-8 (LS-8) Orbit Phasing



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

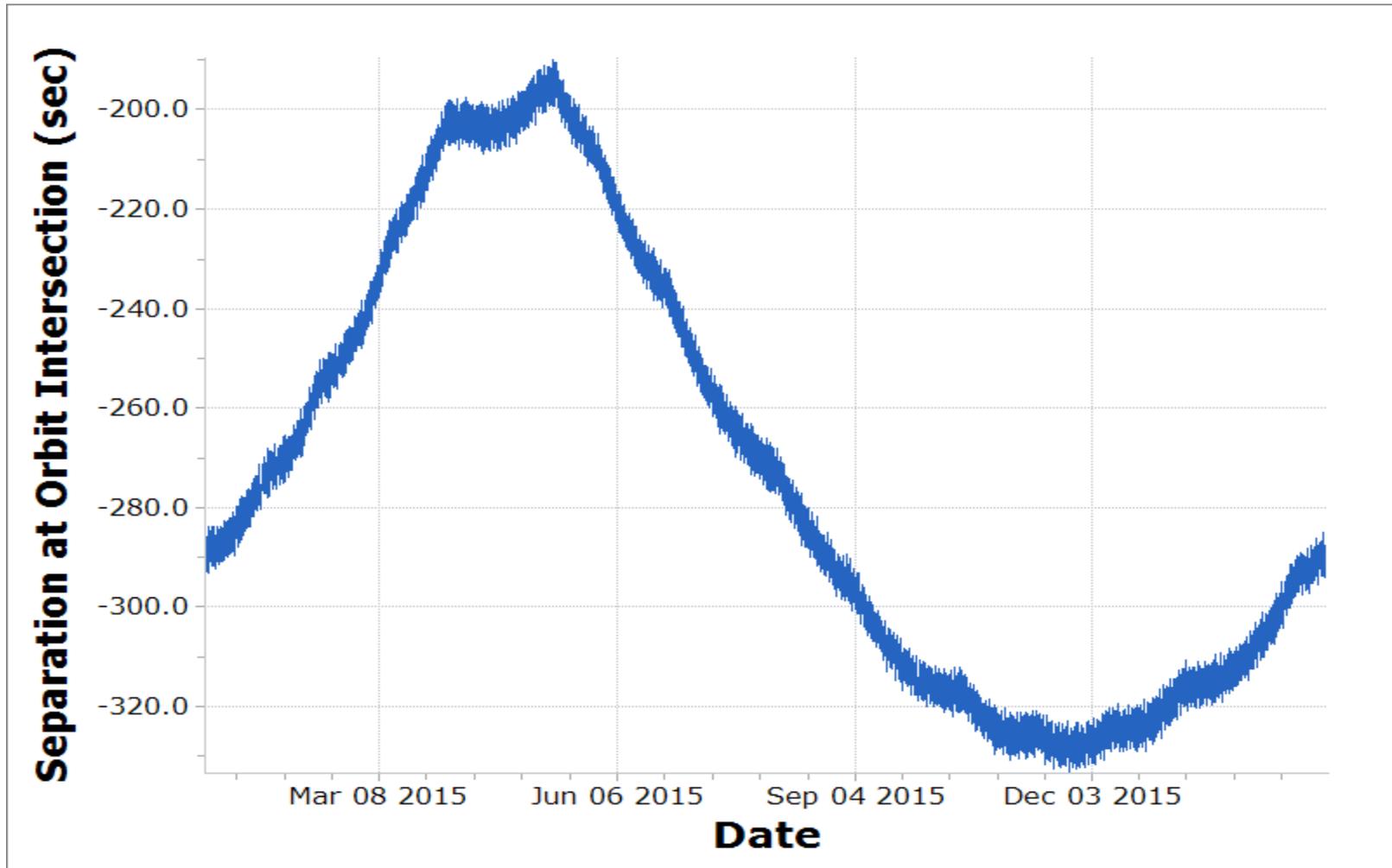
By Design –
LS-8 and LS-7
are 1/2 orbit apart



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



(as of March 01, 2016)

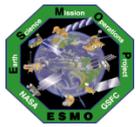




Questions



Backup Charts



Aura Conjunction Assessment High Interest Events



Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2014	1	2	3	3	0	3	2	3	4	2	6	4	33
T3	0	2	2	1	0	1	0	2	0	0	1	0	9
T4	0	0	0	0	0	1	0	0	1	0	0	0	2
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2015	3	5	3	3	4	0	1	3	2	2	3	3	32
T3	0	0	0	1	2	0	0	1	0	0	0	0	4
T4	1	2	0	0	0	0	0	0	0	0	1	0	4
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2016	5	2	6	2	1	1							17
T3	0	0	1	0	0	0							1
T4	1	0	1	0	0	0							2

Note: (T1 – Notify (email/phone), T2 – Conduct Briefing, T3 – Plan Maneuver, T4 – Execute Maneuver)

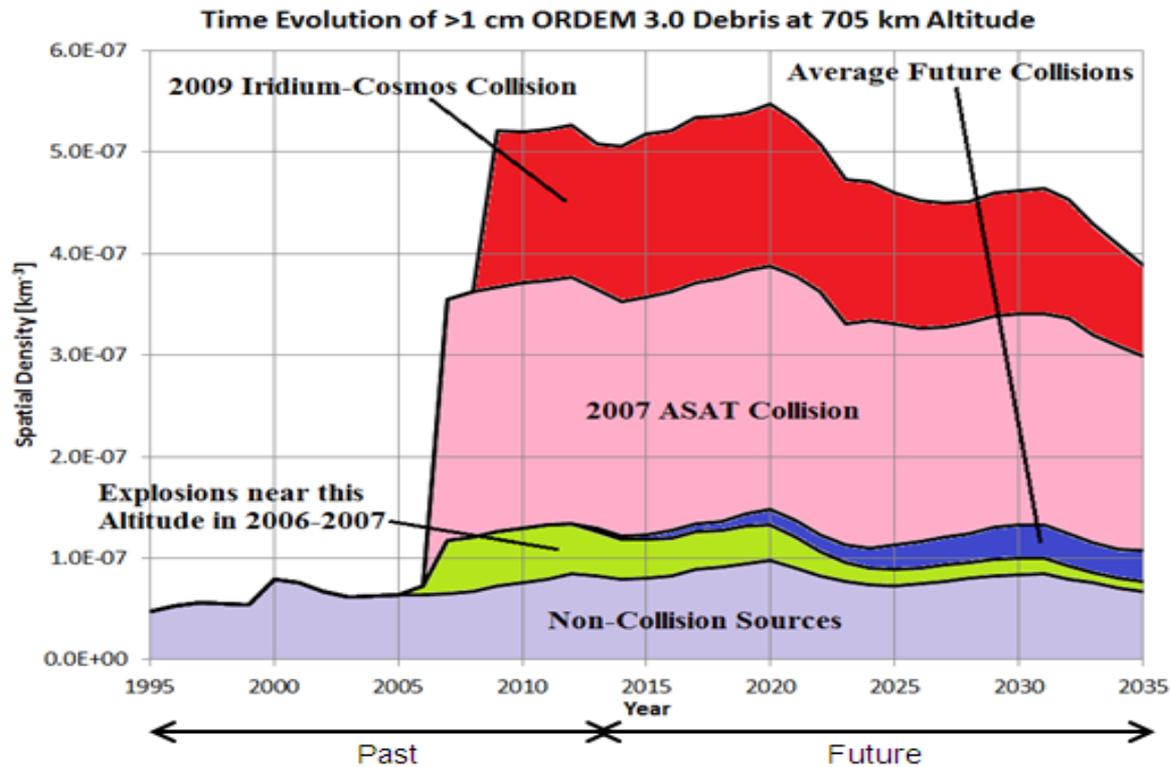


Future Debris Population



National Aeronautics and Space Administration

Future Population > 1 cm



Orbital Debris Program Office



Future Space Catalog



WHAT CAN BE TRACKED NOW

~20,000 SPACE DEBRIS OBJECTS

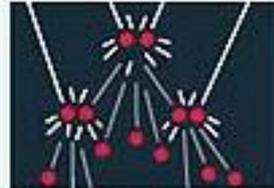


DOCUMENTED DEBRIS:



WHAT SPACE FENCE WILL TRACK

~200,000 SPACE DEBRIS OBJECTS



TIPPING POINT

Space debris has reached a tipping point, an unstoppable chain reaction of collisions.



SPEED OF IMPACT

Traveling at nearly 17,000 miles per hour, a debris piece as small as a speck of paint can damage and destroy a satellite.

MODERN LIFE RELIES ON SATELLITES IN SPACE FOR:

