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International Earth Science Constellation Mission Operations Working Group June 2-4, 2015 Aqua/Aura No-Slew Maneuver Results D. Pachura, B. Holladay, D. Tracewell EOS FDS, esmo-eos-fds@lists.nasa.gov, +1.301.416.5050

Agenda

- *Background*
- *Aqua no-slew results December 19, 2012 to Current*
 - Inclination change
 - RAAN change
- *Aura no-slew results July 12, 2012 to Current*
 - Inclination change
 - RAAN change
- *Aqua comparison of definitive to predicted data*
- *Aura comparison of definitive to predicted data*
- *Conclusions*

Background

- *Performing drag makeup maneuvers (DMU) and risk mitigation maneuvers (RMM) without slewing the spacecraft is operationally desirable*
 - However, a small out-of-plane component is introduced during maneuvers
- *Analysis has shown that performing no-slew DMU maneuvers at the poles minimizes the change in inclination*
 - Change in RAAN can be nominally canceled out by executing maneuvers in pairs at opposing poles
 - Referred to as “mirror pole maneuvers”
 - Introduces small negative effect on frozen orbit (eccentricity and Argument of Perigee)
- *Expect minimal impact to the MLT (hence no impact to the MLT separation between Aqua and the constellation members)*

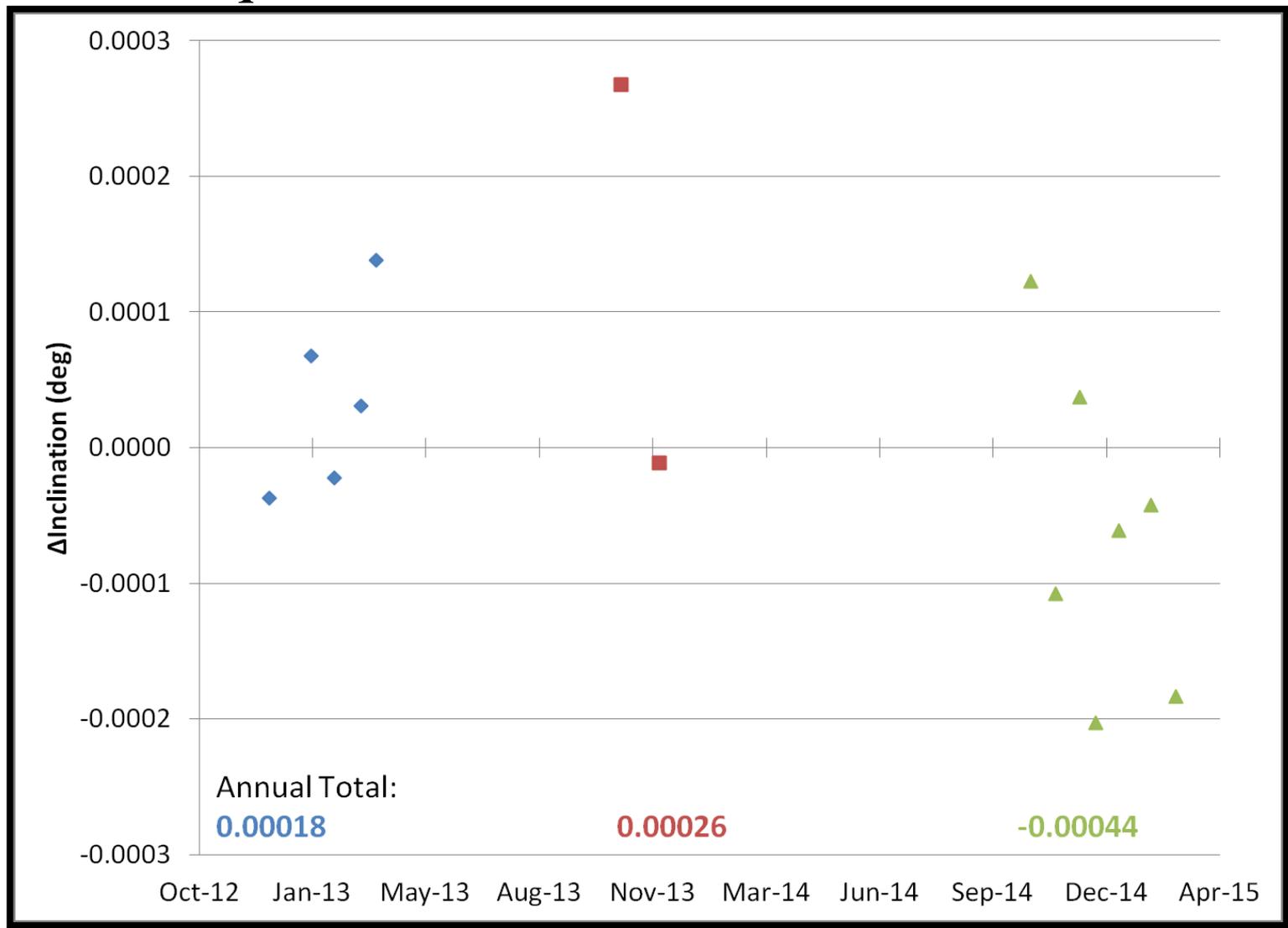
Background

- ***In 2012, Aqua and Aura began demonstrating no-slew maneuver capability***
 - Aura has been performing exclusively no-slew maneuvers since December 2012
 - Prior to October 2014, Aqua performed slewed maneuvers for DMUs and no-slew maneuvers for RMMs
 - Since October 2014, Aqua has performed exclusively no-slew maneuvers
- ***Both spacecraft now operate with a hybrid maneuver scheme***
 - Maneuvers are nominally performed at alternating “mirror pole” locations
 - 1-2 frozen orbit maneuvers per year are added to maintain frozen orbit requirements
 - RMM locations are dictated by conjunction timing and geometry

Aqua No-Slew Demonstration Results

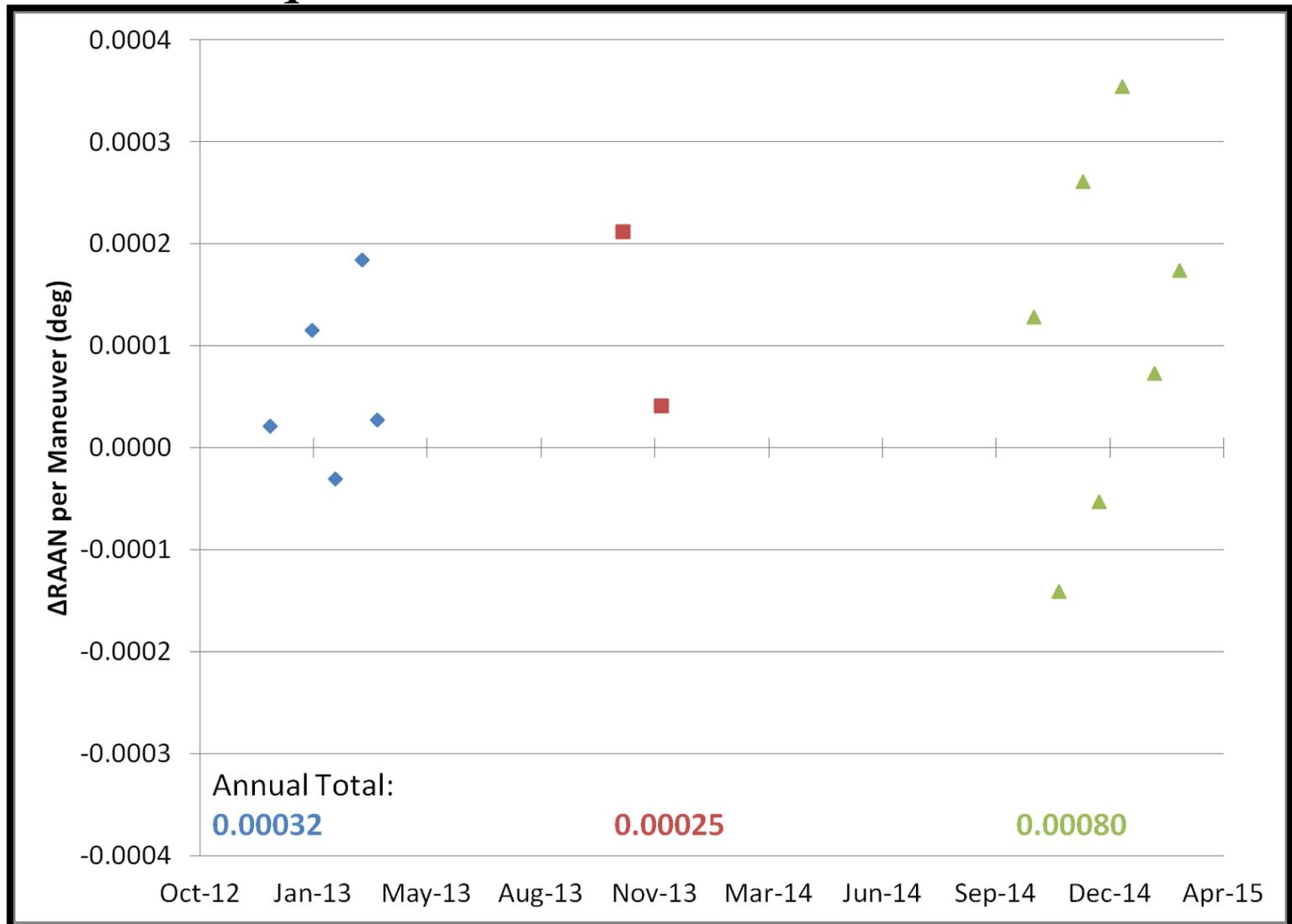
- *Aqua has executed 14 no-slew maneuvers since Dec 19, 2012*
- *The standard deviation of the maneuver SMA error for no-slew maneuvers is $\pm 6.9\%$ difference in the predicted to definitive data*
 - Excludes the first no-slew maneuver
 - Includes both DMU and RMM maneuvers
 - Historical slewed maneuvers had an accuracy of $\pm 6.5\%$
 - Prediction accuracy will increase as more data is collected for various burn durations and orbit locations
 - No-slew maneuvers have been sized from 3.0 – 60.0 seconds

Aqua No-Slew Δ Inclination Results



Annual Δ inclination induced by no-slew maneuvers has been minimal

Aqua No-Slew Δ RAAN Results

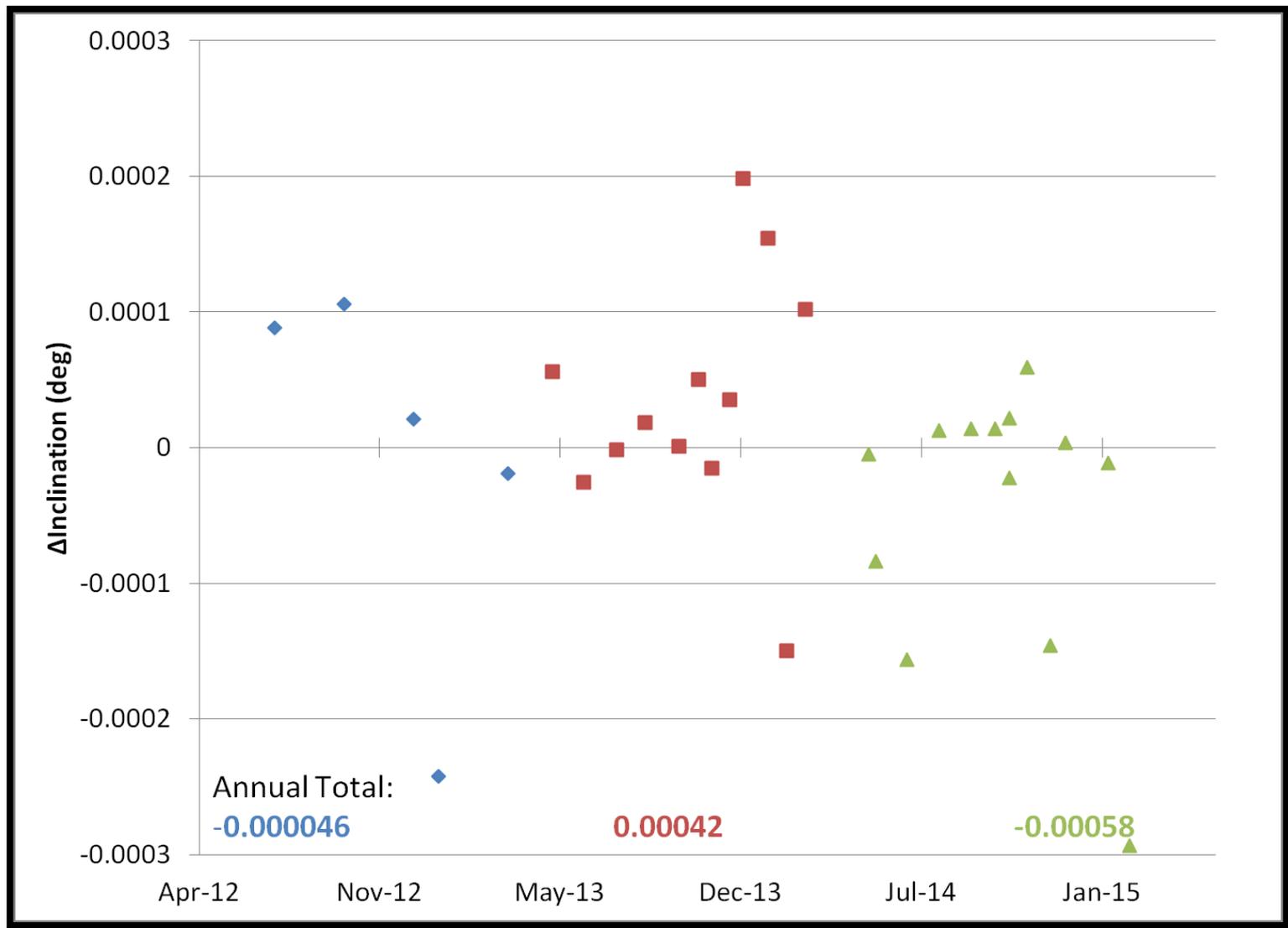


Annual Δ RAAN induced by no-slew maneuvers has been minimal

Aura No-Slew Demonstration Results

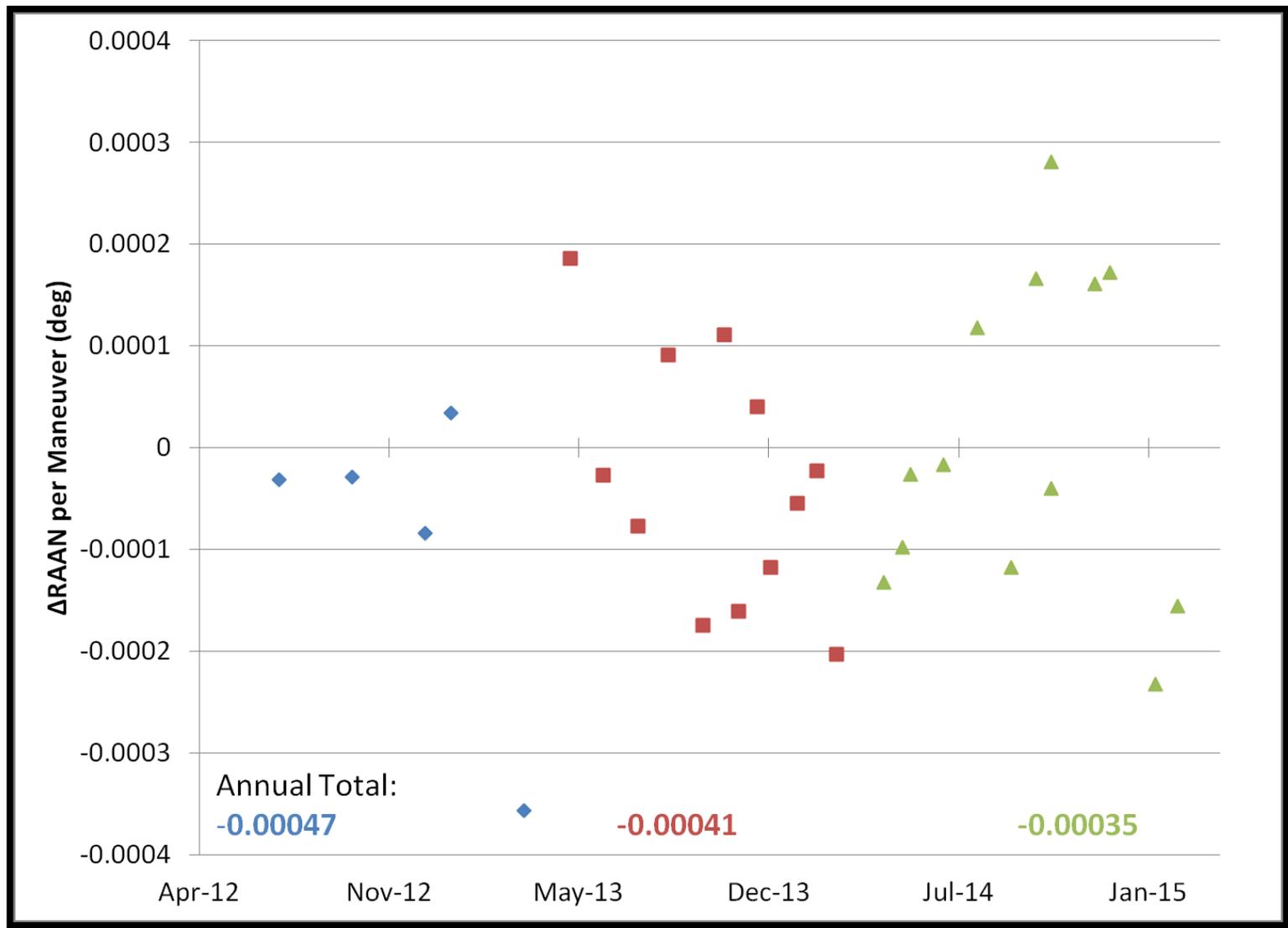
- *Aura has executed 32 no-slew DMU maneuvers since July 19, 2012*
- *The standard deviation of the maneuver SMA error for no-slew maneuvers is $\pm 2.1\%$ difference in the predicted to definitive data*
 - Excludes the first no-slew maneuver
 - Historical slewed maneuvers had an accuracy of $\pm 3.1\%$
 - Current prediction accuracy is now comparable to historical slewed accuracies
 - No-slew maneuvers have been sized from 8.0 – 44.0 seconds

Aura No-Slew Δ Inclination Results



Annual Δ inclination induced by no-slew maneuvers has been minimal

Aura No-Slew Δ RAAN Results



Annual Δ RAAN induced by no-slew maneuvers has been minimal

DEFINITIVE TO PREDICTED DATA COMPARISON

Aqua Maneuver Predictions

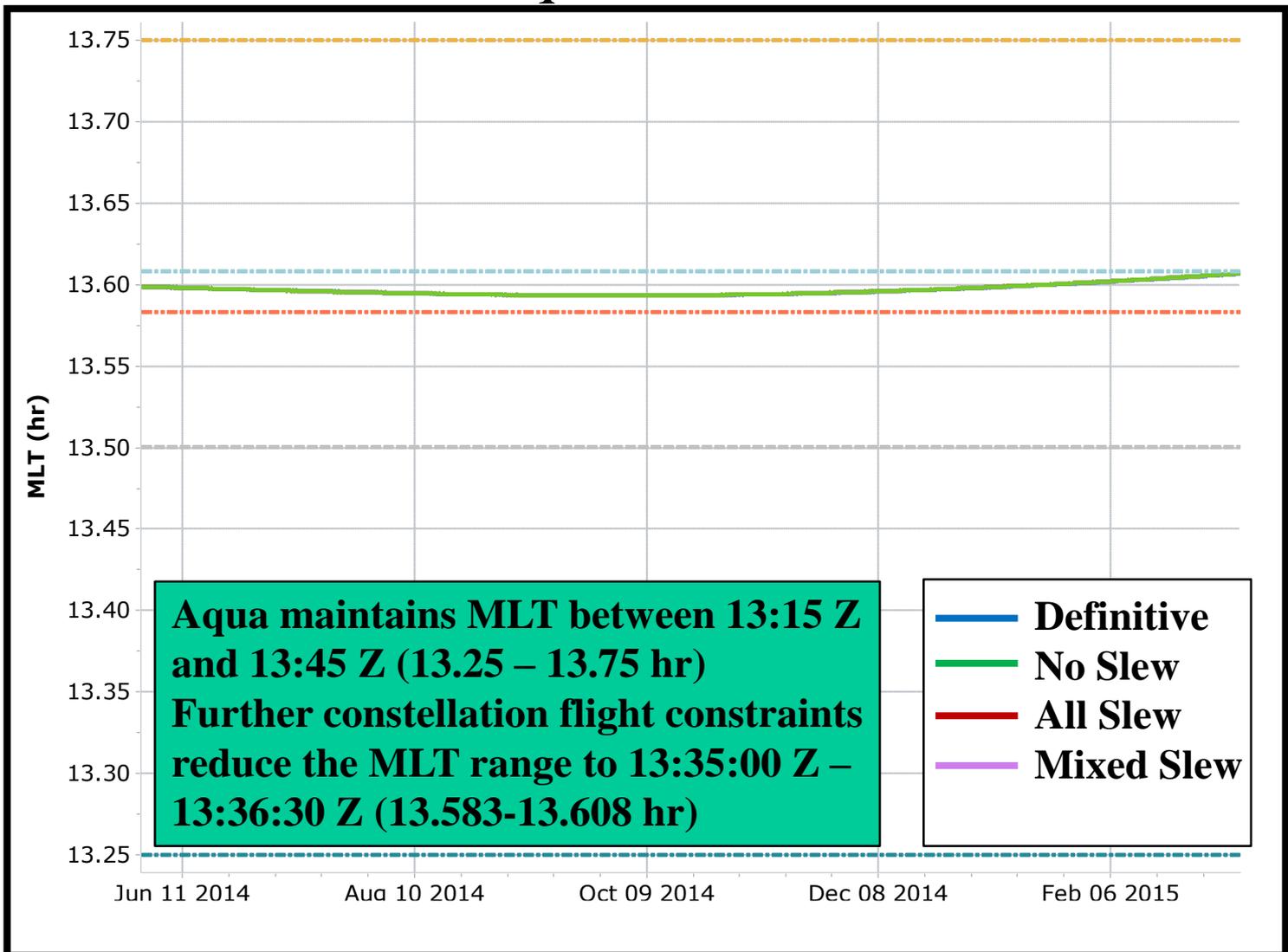
- *Aqua and Aura utilize similar lifetime simulations for yearly IAM planning and lifetime predictions*
- *In 2014, three lifetime analysis were performed utilizing the Spring 2014 Schatten solar flux values*
 - **All Slew** – All 2014 DMU's modeled as slewed maneuvers
 - **No-Slew** – All 2014 DMU's modeled as no-slew maneuvers
 - **Mixed Slew** – Included in the Summer 2014 lifetime update, DMU's up to October 2014 model as slewed maneuvers. All maneuvers after which are modeled as slewed
- *The next slides show a comparison of definitive data, “mixed” prediction, slewed prediction, and no-slew prediction for various orbit parameters*

Aqua Maneuver Predictions

- Between the Spring 2014 and the Spring 2015 IAM campaigns Aqua performed substantially more DMUs than predicted in all three lifetime analysis performed in summer 2014*
- Operationally, Aqua maneuvers more frequently due to a desired WRS “buffer” not yet accounted for in the lifetime predictions*

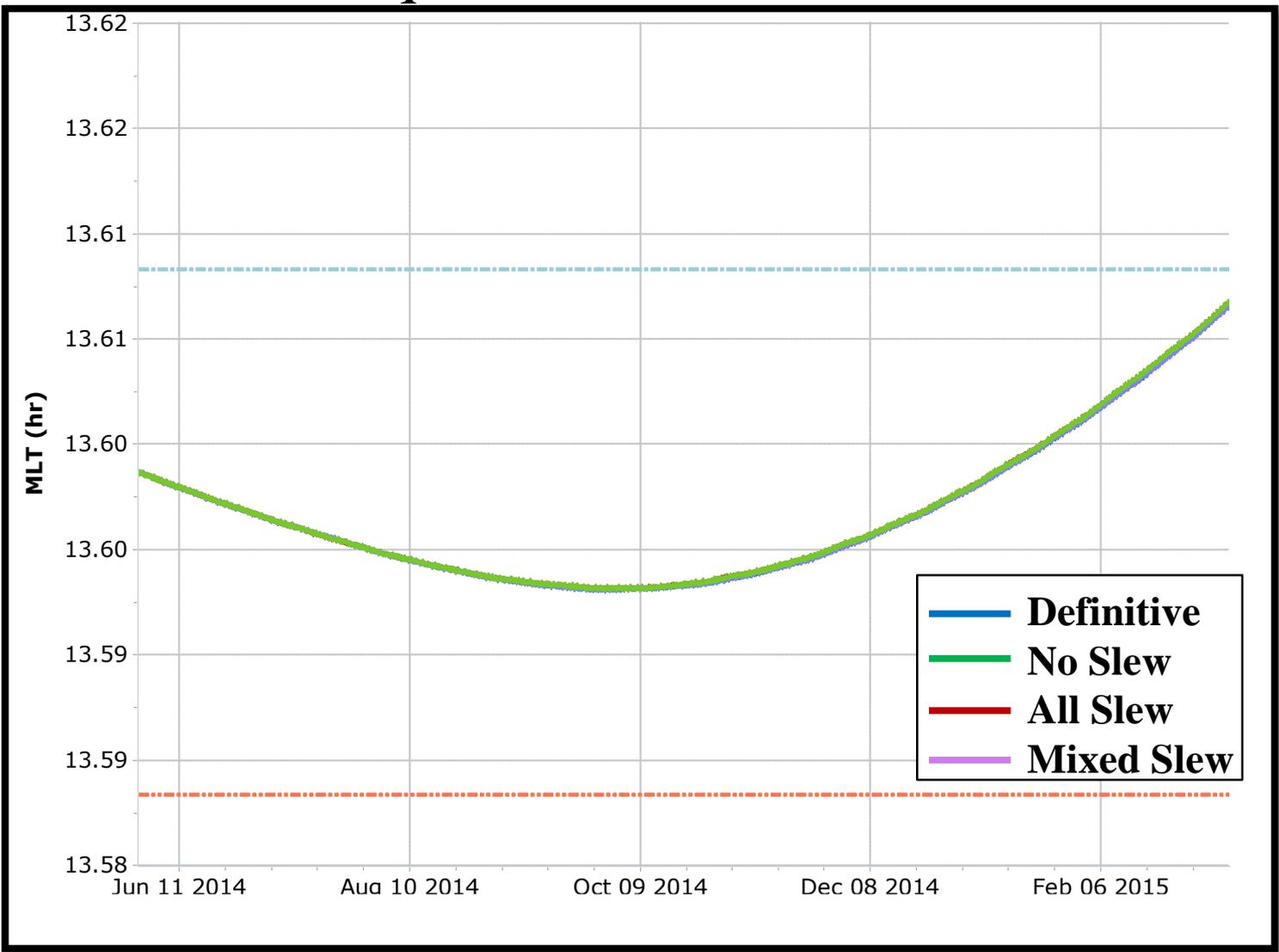
Maneuver Type	Definitive Maneuver Count	No-Slew Lifetime Count	All Slew Lifetime Count	Mixed Slew Lifetime Count
RMM – No-Slew	1	0	0	0
DMU - Slew	8	0	6	6(TBR)
DMU – No-Slew Mirror Pole	5	6(TBR)	0	2(TBR)
DMU – No-Slew Frozen Orbit	1	(TBR)	0	0
Total	15	6	6	8

Aqua MLT



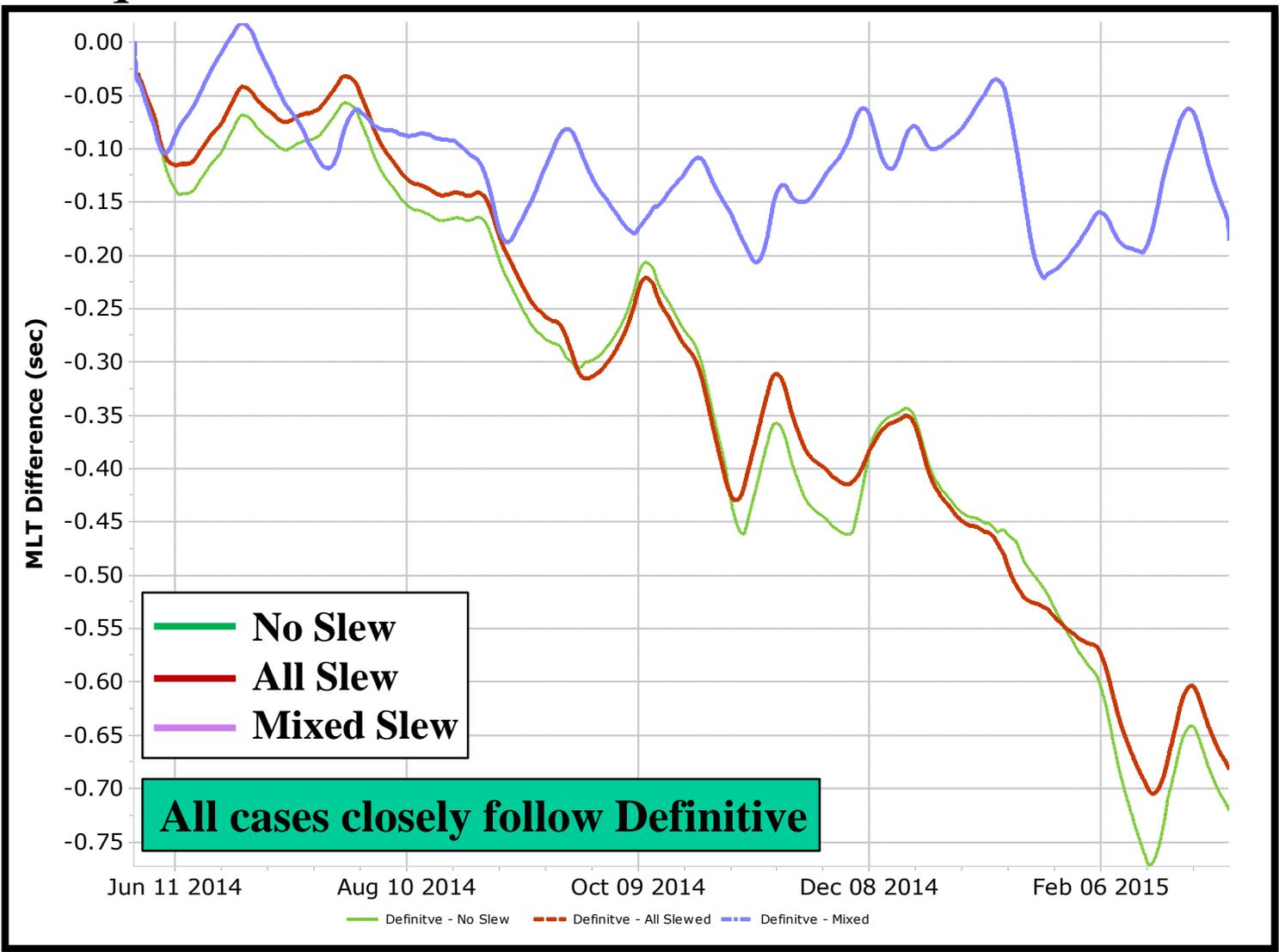
Note: Lines overlay

Aqua MLT - Zoomed

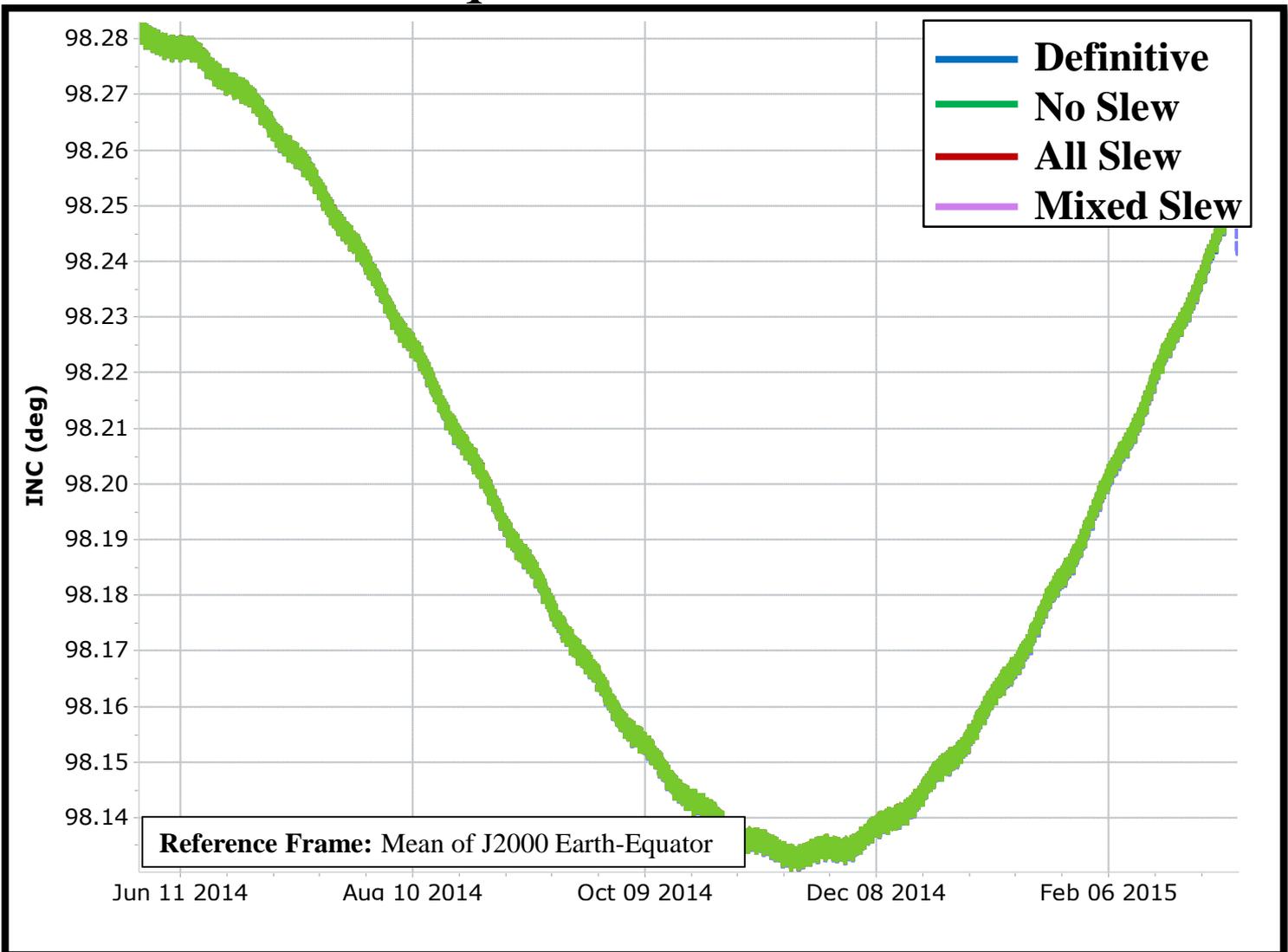


Note: Lines overlay

Aqua MLT Difference: Definitive - Predicted

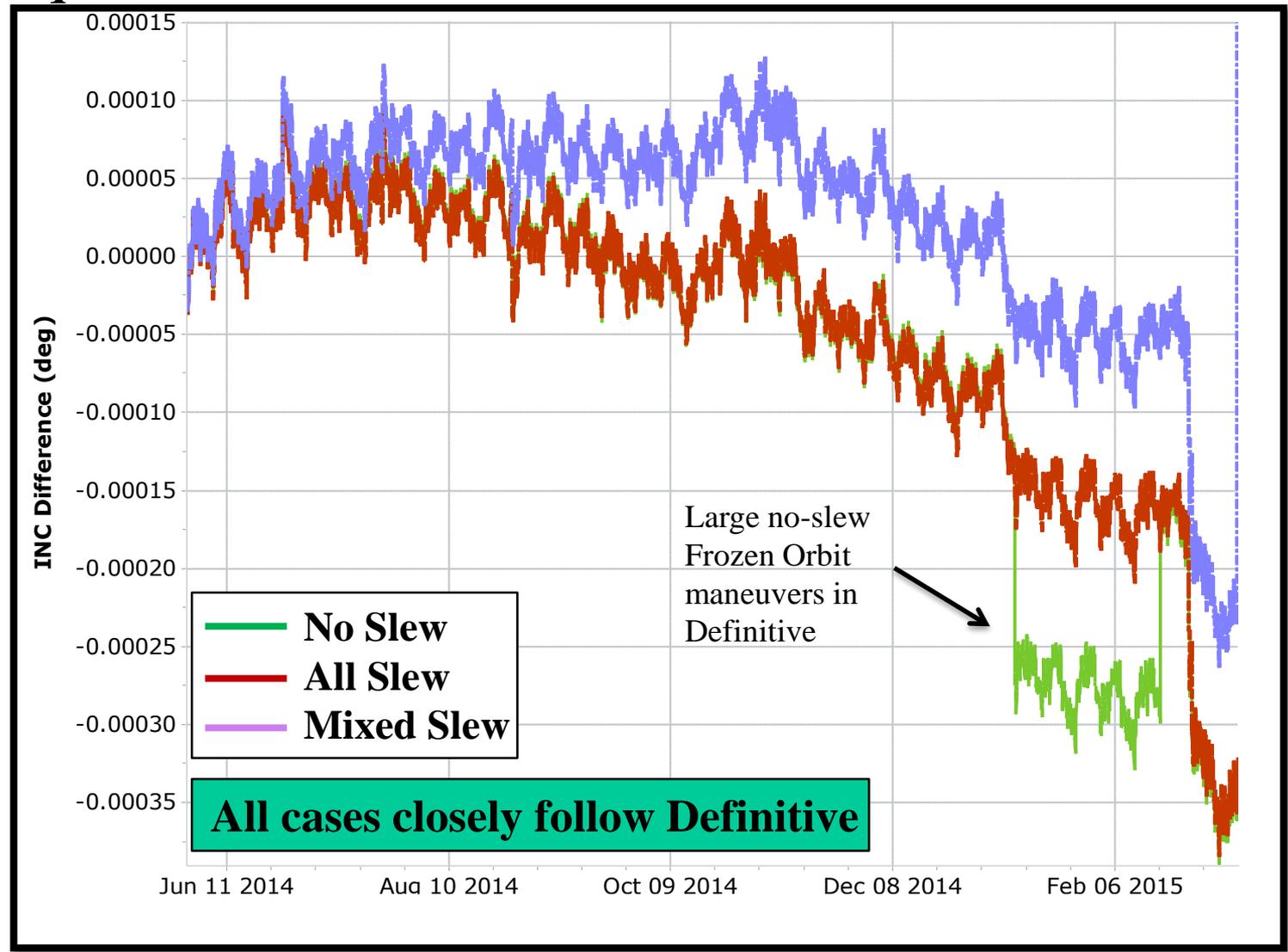


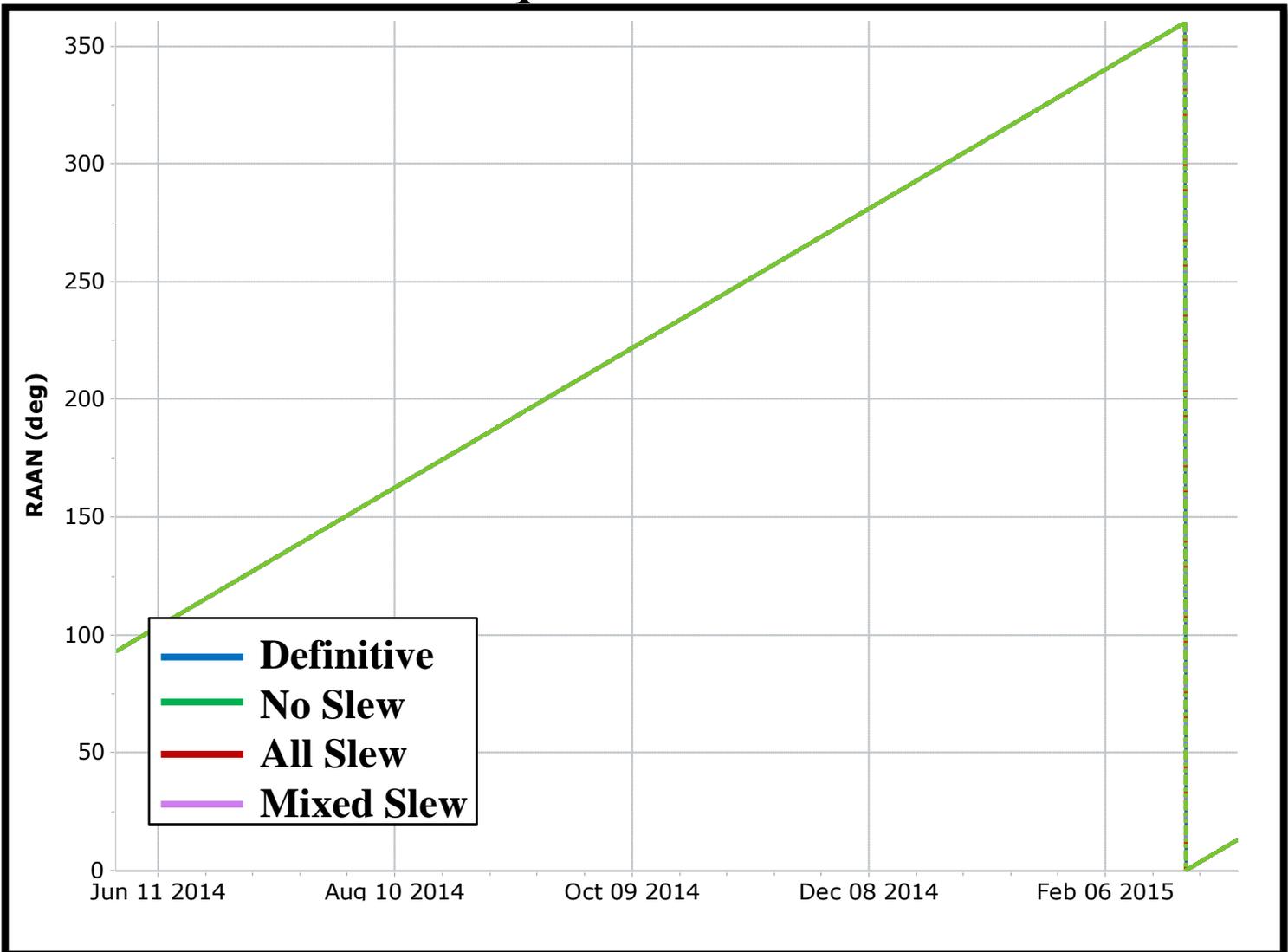
Aqua Inclination



Note: Lines overlay

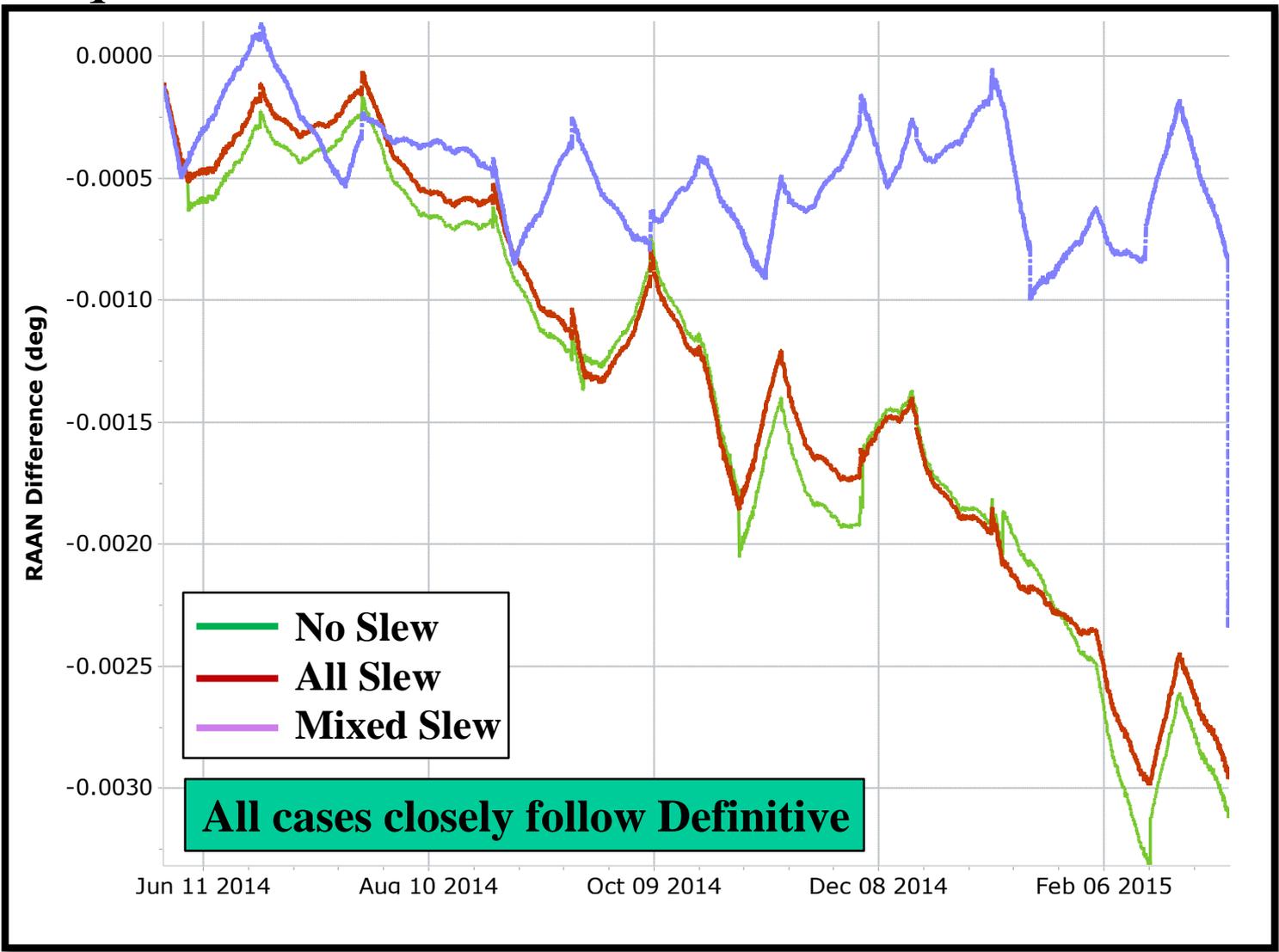
Aqua Inclination Difference: Definitive - Predicted



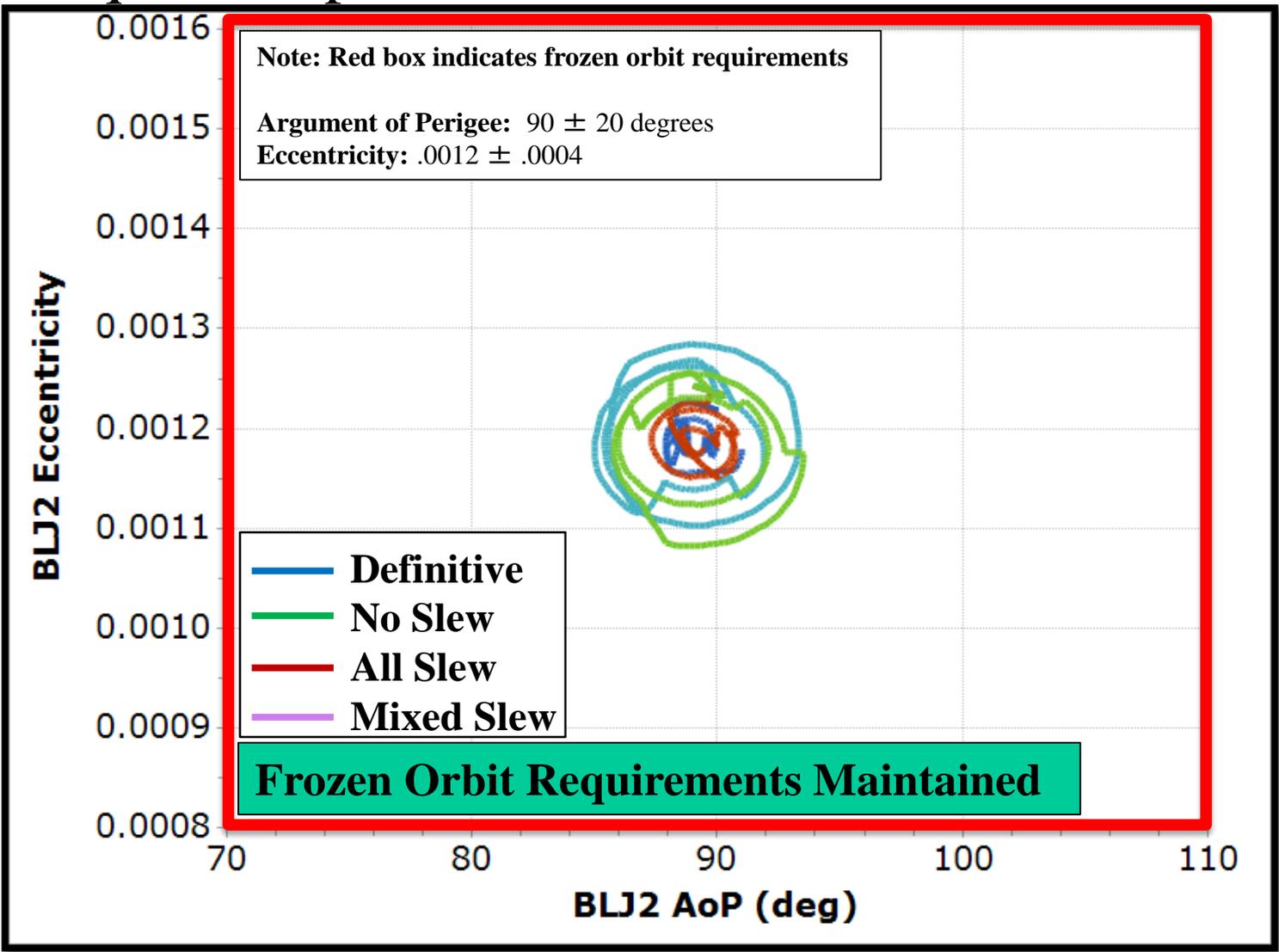


Note: Lines overlay

Aqua RAAN Difference: Definitive - Predicted



Aqua Comparison of Frozen Orbit Parameters



Aura Maneuver Predictions

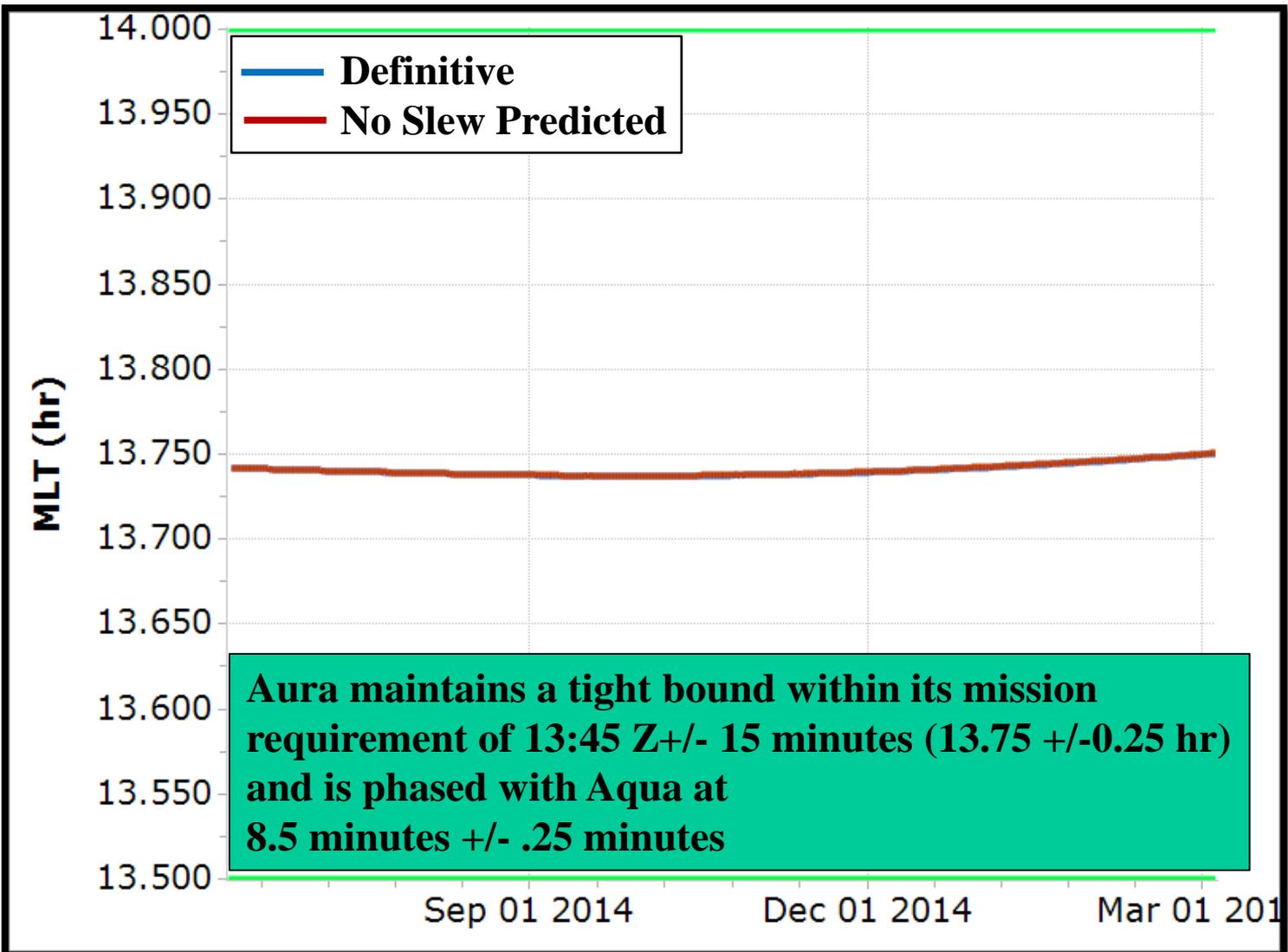
- *Aqua and Aura utilize similar lifetime simulations for yearly IAM planning and lifetime predictions*
 - The Summer 2014 prediction used the Spring 2014 Schatten solar flux values
- *The next slides show a comparison of definitive data and no-slew predictions from Summer 2014 for various orbit parameters*

Aura Maneuver Predictions

- *Between the Spring 2014 and the Spring 2015 IAM campaigns Aqua performed more maneuvers than predicted by the lifetime predictions*
- *Operationally, Aura maneuvers more frequently due to a desired WRS “buffer” not yet accounted for in the lifetime predictions*

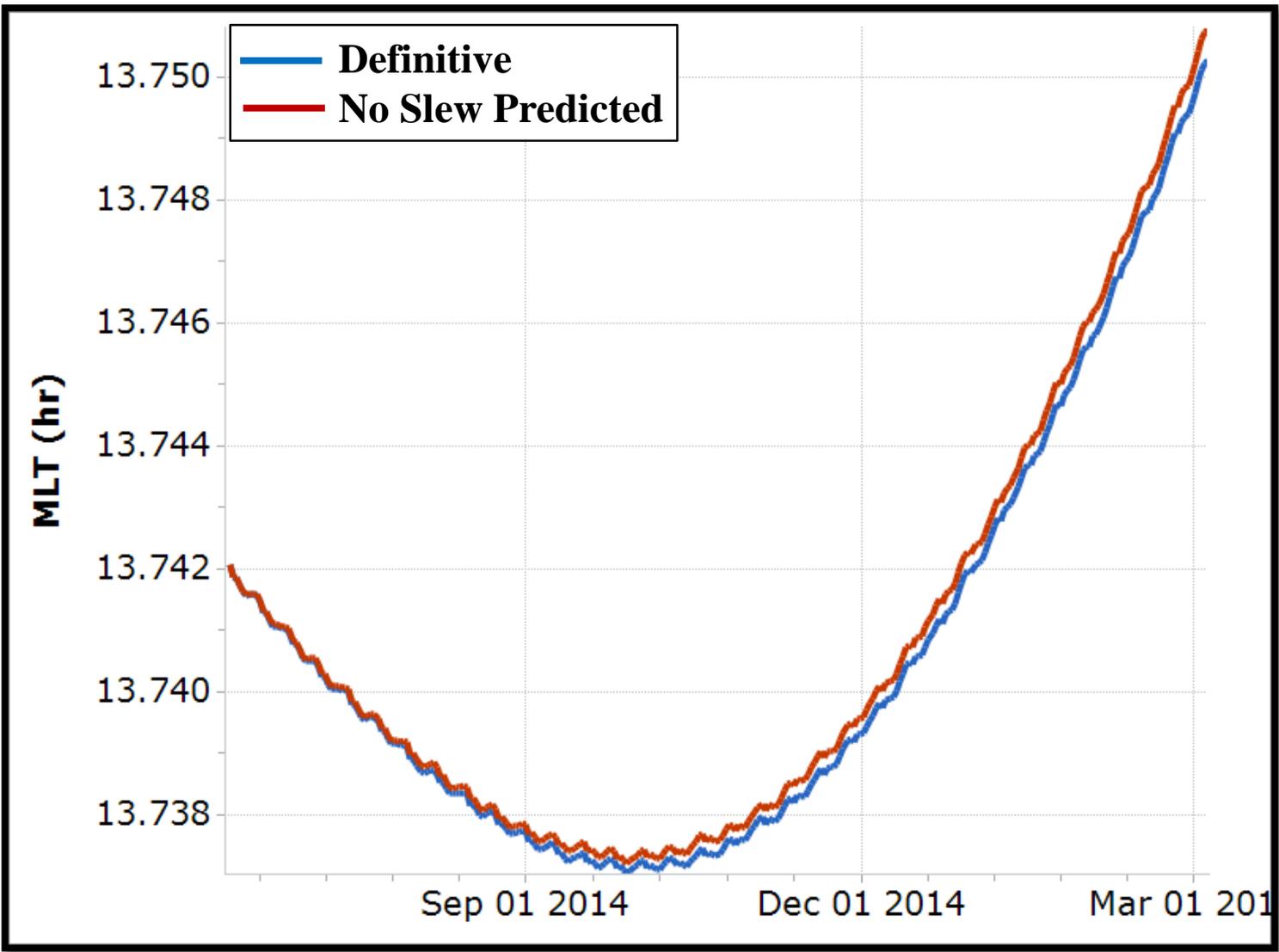
Maneuver Type	Definitive Maneuver Count	Summer 2014 Lifetime Count
RMM – No Slew	(1) *	-
DMU - Slew	0	0
DMU – Mirror Pole	8	6
DMU – Frozen Orbit	6	1
Total	14	7

*Occurred at Mirror Pole location



Note: Lines overlay

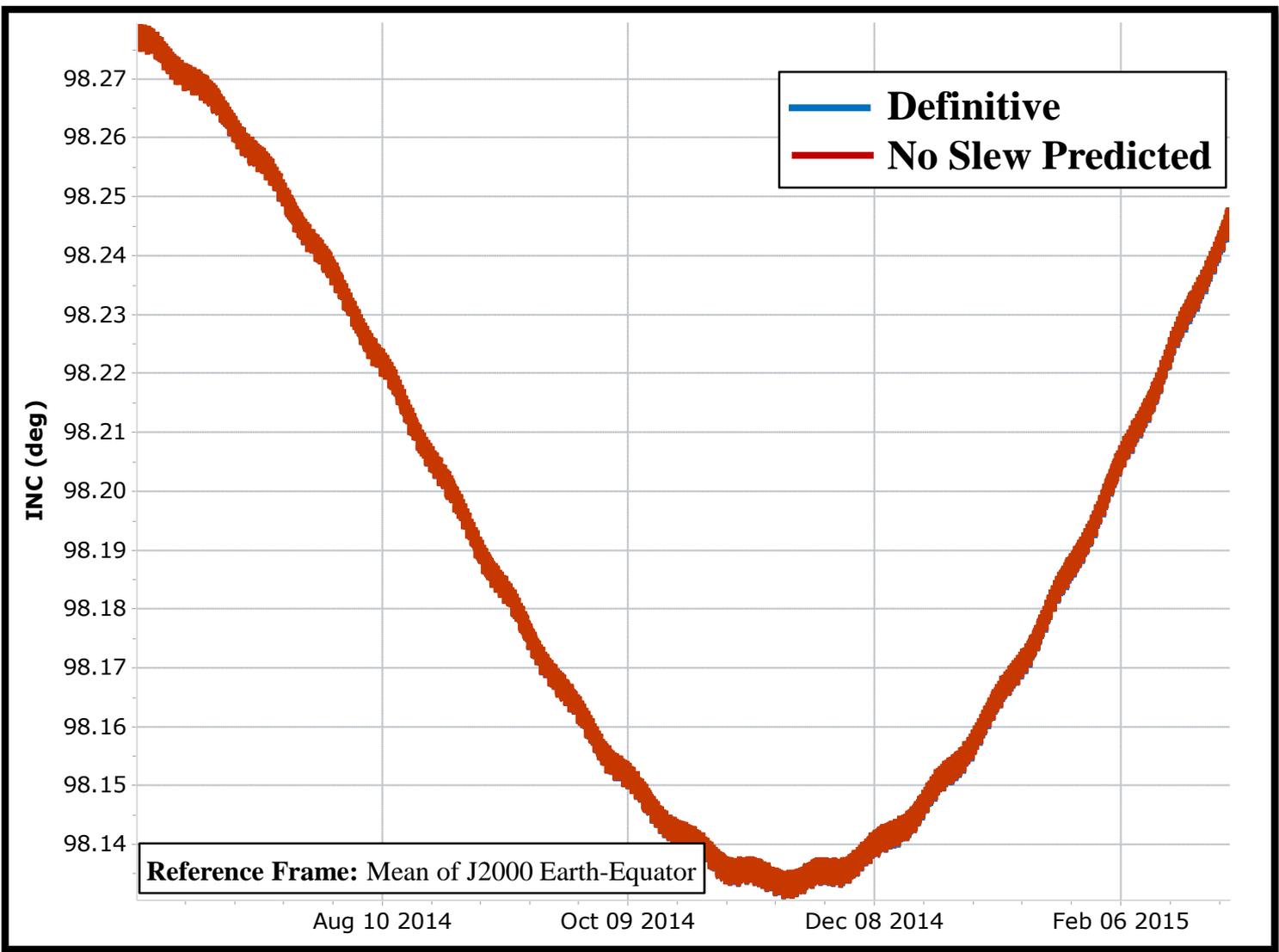
Aura MLT Zoom



Aura MLT Difference: Definitive - Predicted

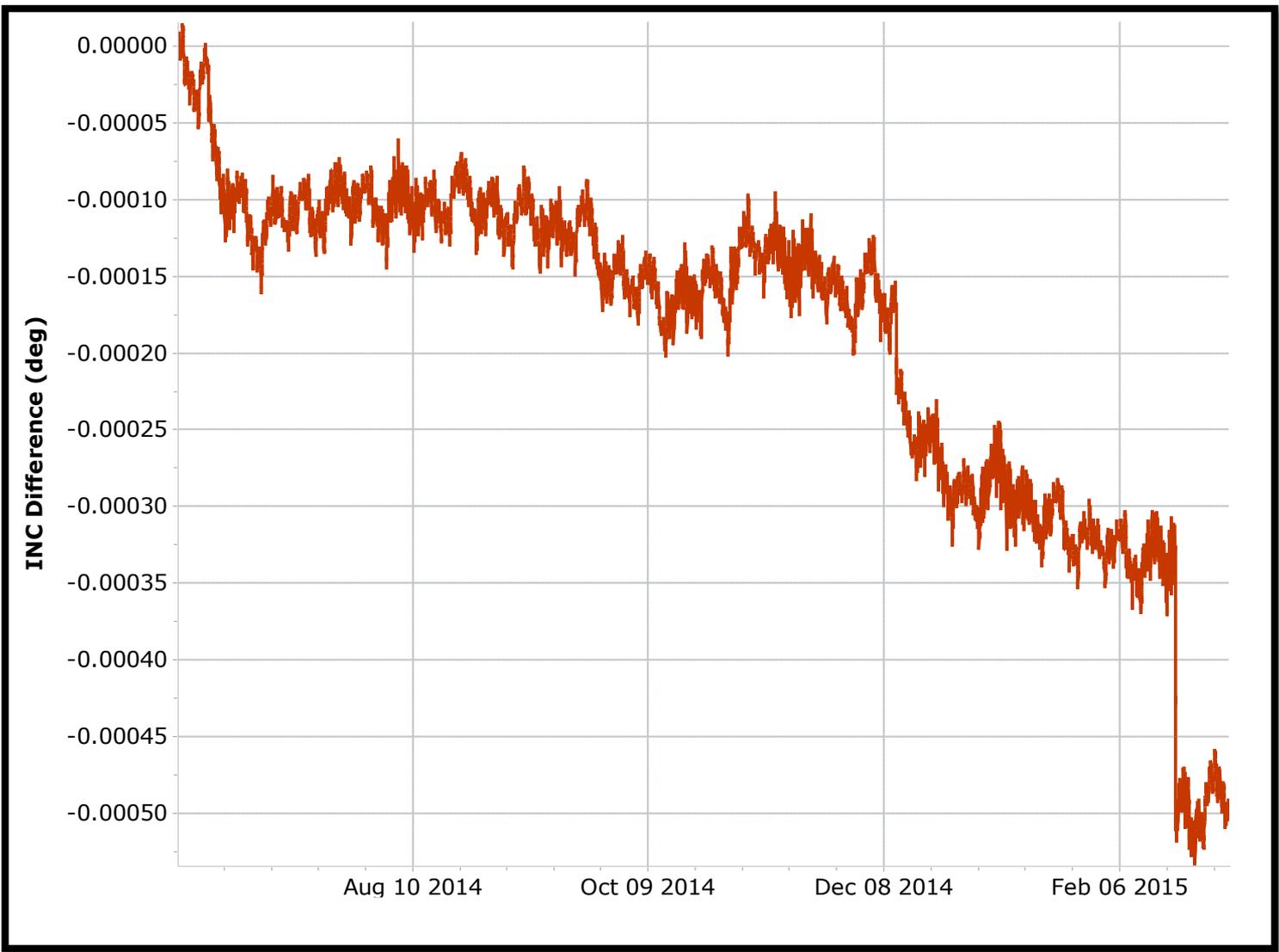


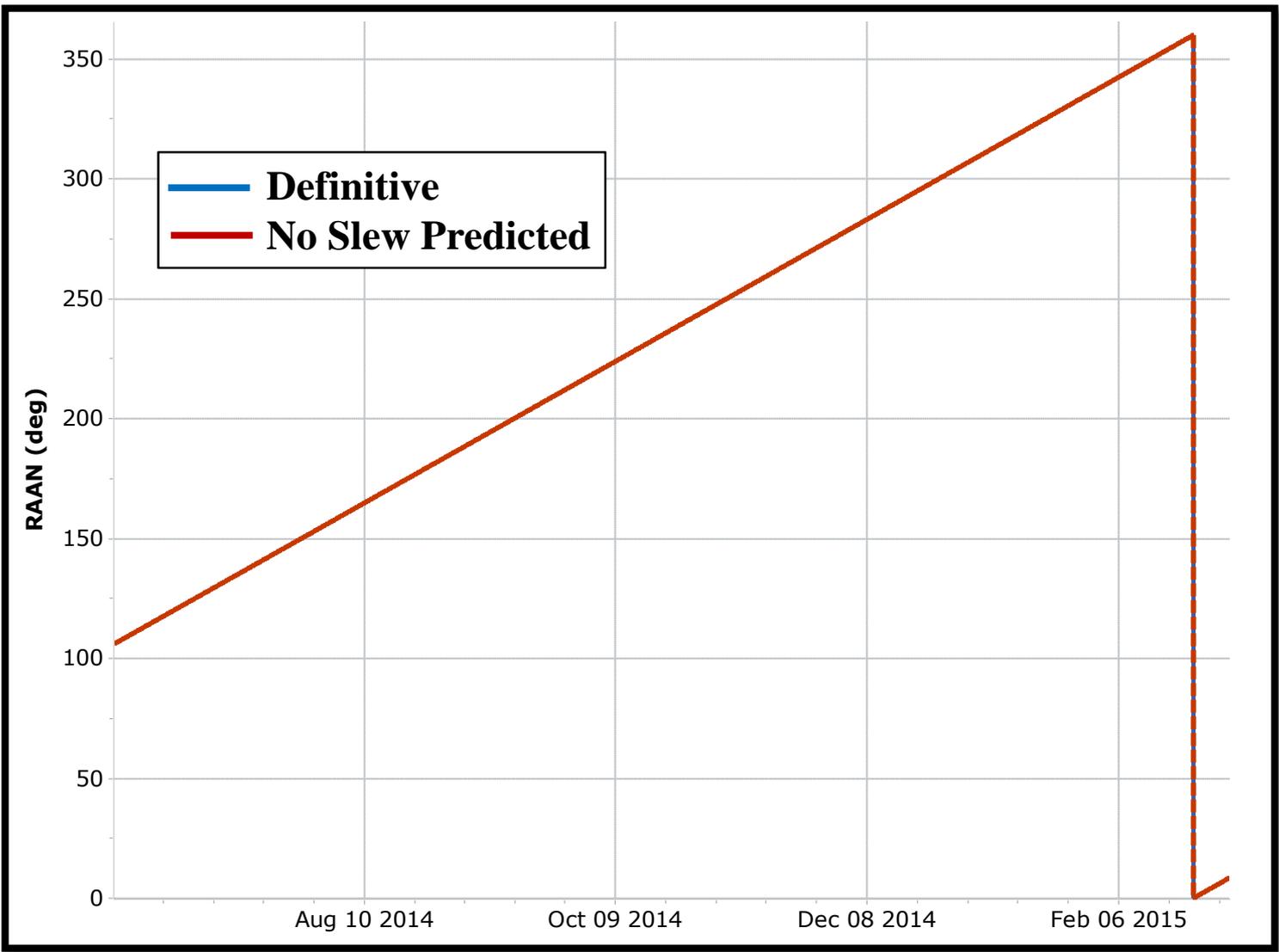
Aura Inclination



Note: Lines overlay

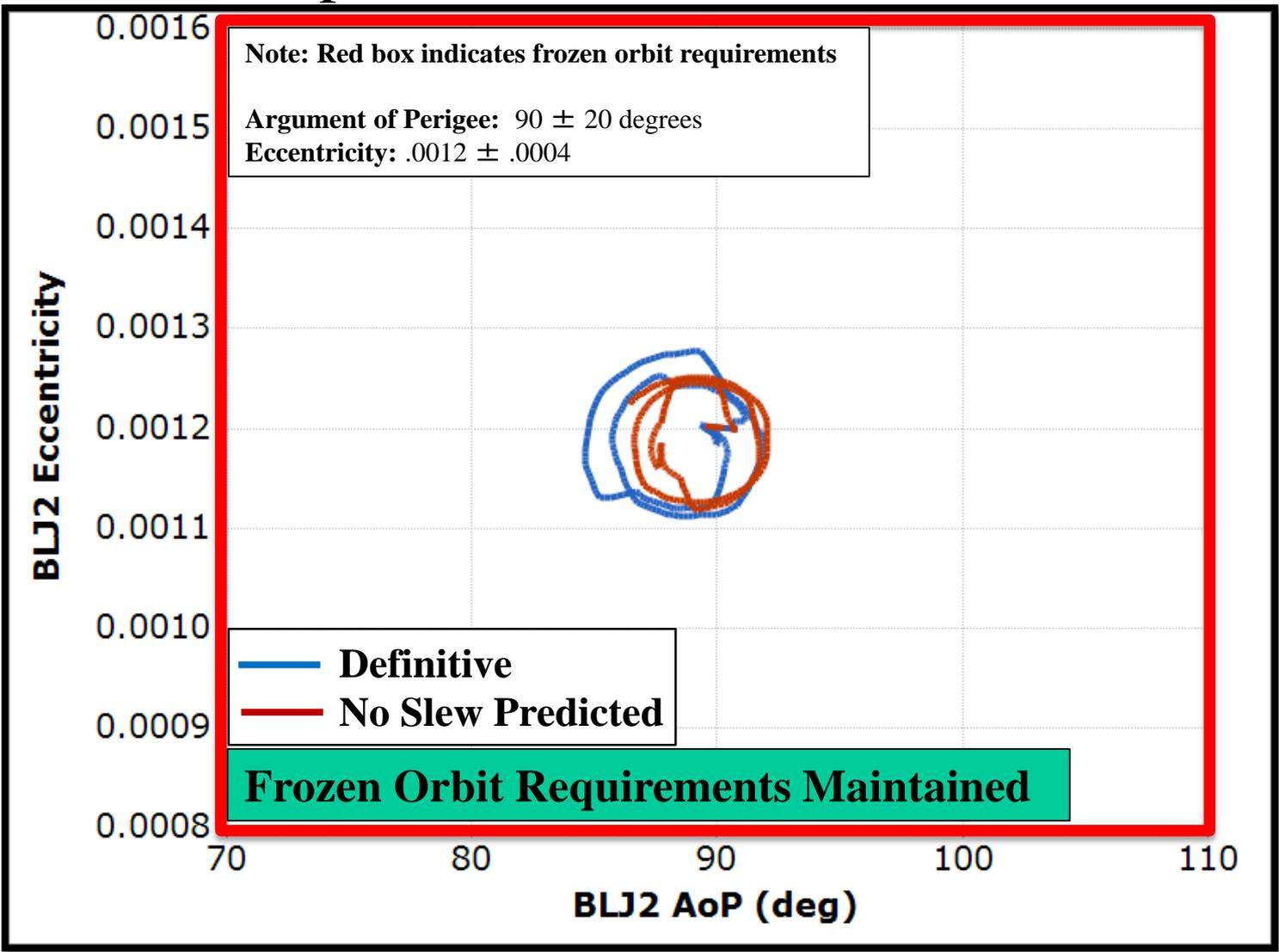
Aura Inclination Difference: Definitive - Predicted





Note: Lines overlay

Aura Comparison of Frozen Orbit Parameters



- *Analysis has shown that minimal (2-3) frozen orbit maneuvers per year should be sufficient to maintain long-term frozen orbit requirements*
 - Frozen orbit adequately maintained in 2014
- *± 2 seconds/year error goal for MLT prediction was achieved for 2014 using post-INC predictions*
 - Each IAM series will “reset” Aqua and Aura’s MLT
- *The under prediction of the drag environment during 2014 has had some impact on MLT and frozen orbit prediction accuracy due to the substantial increase in number of maneuvers executed*

Questions?

- *Future no-slew DMU performance will continue to become more accurate as data is collected*
- *Aqua's long-term prediction can be found on CCS*
 - Long-term plan based on hybrid maneuver scheme
- *Please contact us with any comments or questions at:*
esmo-eos-fds@lists.nasa.gov



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BACKUP

- ***Re-evaluate the hybrid maneuver scheme with an updated Schatten solar flux prediction***
 - Include studies utilizing the plus/minus mean nominal and early/late Schatten predictions for a fuller understanding of the drag effects on the hybrid maneuver scheme
- ***Consider using INC and RAAN change to aid in long-term MLT maintenance***
 - Could potentially execute DMUs at nodes to get MLT change to eliminate some future IAMs
 - Could have minor fuel saving potential

- ***Look at other maneuver schemes for no-slew e.g. Split each maneuver into a pair performed at each pole***
 - This would allow time between maneuvers to be more tightly controlled, keep mirror pole maneuver sizes consistent, reduce concern of a large amount of time between maneuvers during low drag
- ***Further improvements to lifetime simulation***
 - Lifetime simulation currently uses a static coefficient of drag (C_d). Accuracy could be improved by incorporating dynamic modeling
 - Update script to target maneuvers earlier to match reality of more conservative maneuvers during high drag

Aura Demonstration Results

Maneuver	Date	Maneuver Duration (seconds)	Delta-INC (deg)	Delta-RAAN (deg)
Aura DMU 43*	Jul 19, 2012	8.00	8.82E-05	-3.11E-05
Aura DMU 46	Oct 04, 2012	8.00	1.06E-04	-2.91E-05
Aura DMU 50	Dec 20, 2012	14.50	2.10E-05	-8.42E-05
Aura DMU 51	Jan 16, 2013	33.00	-2.42E-04	3.37E-05
Aura DMU 52	Apr 03, 2013	38.50	-1.91E-05	-3.57E-04
Aura DMU 53	May 22, 2013	25.00	5.60E-05	1.86E-04
Aura DMU 54	Jun 26, 2013	17.50	-2.53E-05	-2.75E-05
Aura DMU 55	Aug 01, 2013	21.50	-1.62E-06	-7.74E-05
Aura DMU 56	Sep 02, 2013	17.75	1.87E-05	9.07E-05

*This maneuver was planned based on slewed data. Subsequent maneuvers used only no-slew data.

Aura Demonstration Results

Maneuver	Date	Maneuver Duration (seconds)	Delta-INC	Delta-RAAN
Aura DMU 57	Oct 09, 2013	27.50	9.83E-07	-1.75E-04
Aura DMU 58	Oct 31, 2013	25.50	5.00E-05	1.11E-04
Aura DMU 59	Nov 15, 2013	19.50	-1.55E-05	-1.61E-04
Aura DMU 60	Dec 05, 2013	15.00	3.52E-05	4.05E-05
Aura DMU 61	Dec 19, 2013	34.50	1.98E-04	-1.18E-04
Aura DMU 62	Jan 16, 2014	26.25	1.54E-04	-5.47E-05
Aura DMU 63	Feb 06, 2014	23.75	-1.50E-04	-2.26E-05
Aura DMU 64	Feb 26, 2014	34.00	1.02E-04	-2.03E-04
Aura DMU 65	Apr 17, 2014	25.00	1.67E-05	-1.32E-04
Aura DMU 66	May 07, 2014	23.50	-4.68E-06	-9.75E-05
Aura DMU 67*	May 15, 2014	8.00	-8.38E-05	-2.66E-05

Aura Demonstration Results

Maneuver	Date	Maneuver Duration (seconds)	Delta-INC (deg)	Delta-RAAN
Aura DMU 68	Jun 19, 2014	23.25	-1.56E-04	-1.67E-05
Aura DMU 69	Jul 24, 2014	21.00	1.28E-05	1.18E-04
Aura RMM 70	Aug 29, 2014	21.00	1.37E-05	-1.18E-04
Aura DMU 71	Sep 24, 2014	31.50	1.39E-05	1.66E-04
Aura DMU 72	Oct 10, 2014	19.25	2.20E-05	-4.01E-05
Aura DMU 73	Oct 30, 2014	44.00	-2.26E-05	2.81E-04
Aura DMU 74	Nov 25, 2014	36.50	5.89E-05	-4.32E-04
Aura DMU 75	Dec 11, 2014	35.00	-1.46E-04	1.61E-04
Aura DMU 76	Jan 06, 2015	39.00	3.72E-06	1.72E-04

Total Inclination change since Spring 2014 IAM Series: TBR degrees

*DMU 67 was a demonstration burn for FOT RMM (QDAM) capabilities

Aura Demonstration Results

Maneuver	Date	Maneuver Duration (seconds)	Delta-INC	Delta-RAAN
Aura DMU 77	Jan 28, 2015	22.000	-1.11E-05	-2.32E-04
Aura DMU 78	Feb 20, 2015	33.750	-2.93E-04	-1.56E-04

Aqua Demonstration Results

Maneuver	Date	Maneuver Duration (seconds)	Delta-INC (deg)	Delta-RAAN (deg)
Aqua DMU 66*	Dec 19, 2012	3.00	-3.72E-05	2.15E-05
Aqua DMU 67	Jan 25, 2013	22.50	6.73E-05	1.15E-04
Aqua DMU 68	Feb 14, 2013	30.75	-2.26E-05	-3.10E-05
Aqua DMU 69 - RMM	Mar 10, 2013	15.75	3.05E-05	1.84E-04
Aqua DMU 70 - RMM	Mar 23, 2013	21.50	1.38E-04	2.74E-05
Aqua DMU 76- RMM	Oct 25, 2013	27.50	2.67E-04	2.11E-04
Aqua DMU 77 - RMM	Nov 28, 2013	19.50	-1.15E-05	4.12E-05
Aqua DMU 90 - RMM	Oct 21, 2014	31.00	1.23E-04	1.28E-04
Aqua DMU 91	Nov 12, 2014	48.50	-1.07E-04	-1.41E-04
Aqua DMU 92	Dec 03, 2014	60.00	3.70E-05	2.61E-04

*This maneuver was planned based on slewed data. Subsequent maneuvers used only no-slew data.



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Aqua Demonstration Results

Maneuver	Date	Maneuver Duration (seconds)	Delta-INC (deg)	Delta-RAAN (deg)
Aqua DMU 93	Dec 17, 2014	31.75	-2.03E-04	-5.30E-05
Aqua DMU 94	Jan 07, 2015	53.00	-6.09E-05	3.54E-04
Aqua DMU 95	Feb 04, 2015	24.25	-4.25E-05	7.26E-05
Aqua DMU 96	Feb 26, 2015	46.25	-1.83E-04	1.74E-04