

EOS Terra

Terra Constellation Exit/Future Maneuver Plans Update

Sept 27-29th, 2016



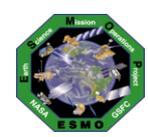
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Terra Mission Director - Code 428

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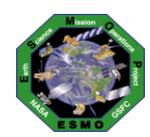
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Brief History of Terra EOM Work



- Fuel ~ 100kgs triggering maneuver option analysis – **Summer/Fall 2013**
 - Options sent to IOTs for their feedback – **Apr 2014**
 - **EOM Engineering Peer Review – July 2014**
 - Science Team Meeting – **Aug 2014**
 - IOT feedback received – **Sept 2014 (Proposed plan selected)**
 - **Constellation MOWG – Oct 2014**
 - Briefing to NASA Program Exec – **Jan/Feb 2015**
 - Waivers generated and sent for Goddard Signatures – **Feb 2015**
 - Terra Senior Review Proposal Submitted – **Mar 2015**
 - Waiver signatures received for Goddard – **June 2015**
 - **Constellation MOWG – June 2015**
 - Aerospace presented their debris risk analysis
 - Science Team Meeting – **March 2016**
 - **Constellation MOWG – April 2016**
 - Removed “Baseline” Plan and Created new “fallback” options – **May->Aug 2016**
 - **Constellation MOWG – September 2016**
-
- **Final Decision Deadline – Prior to Feb 2018**

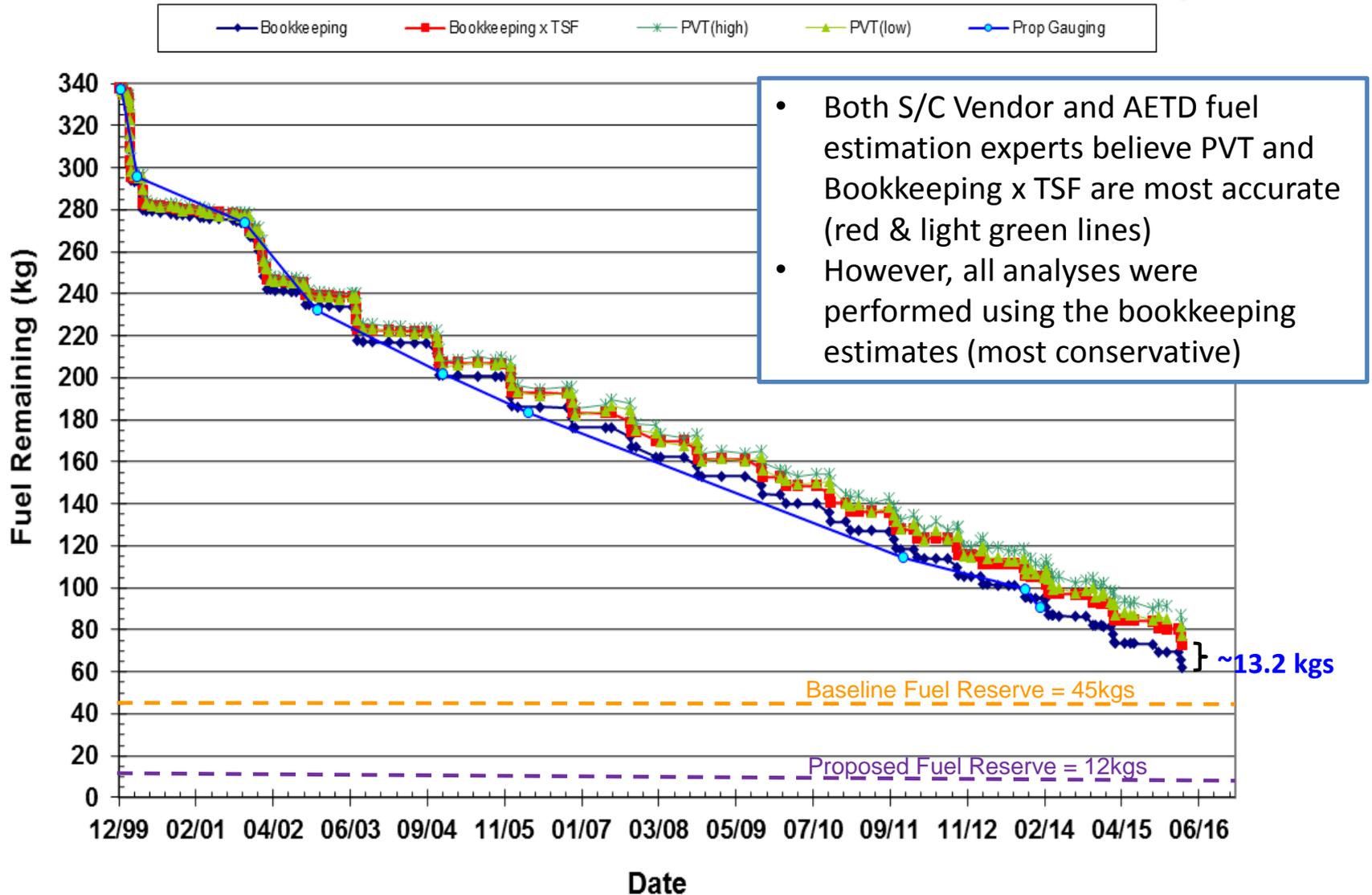


Lifetime Fuel Estimates

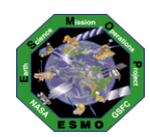


Terra Fuel Usage Comparison

Fuel Usage Approximations:
 ~4 kg of fuel for every IAM
 ~0.15 kg of fuel for every DMU



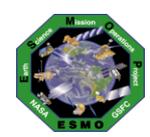
- Both S/C Vendor and AETD fuel estimation experts believe PVT and Bookkeeping x TSF are most accurate (red & light green lines)
- However, all analyses were performed using the bookkeeping estimates (most conservative)



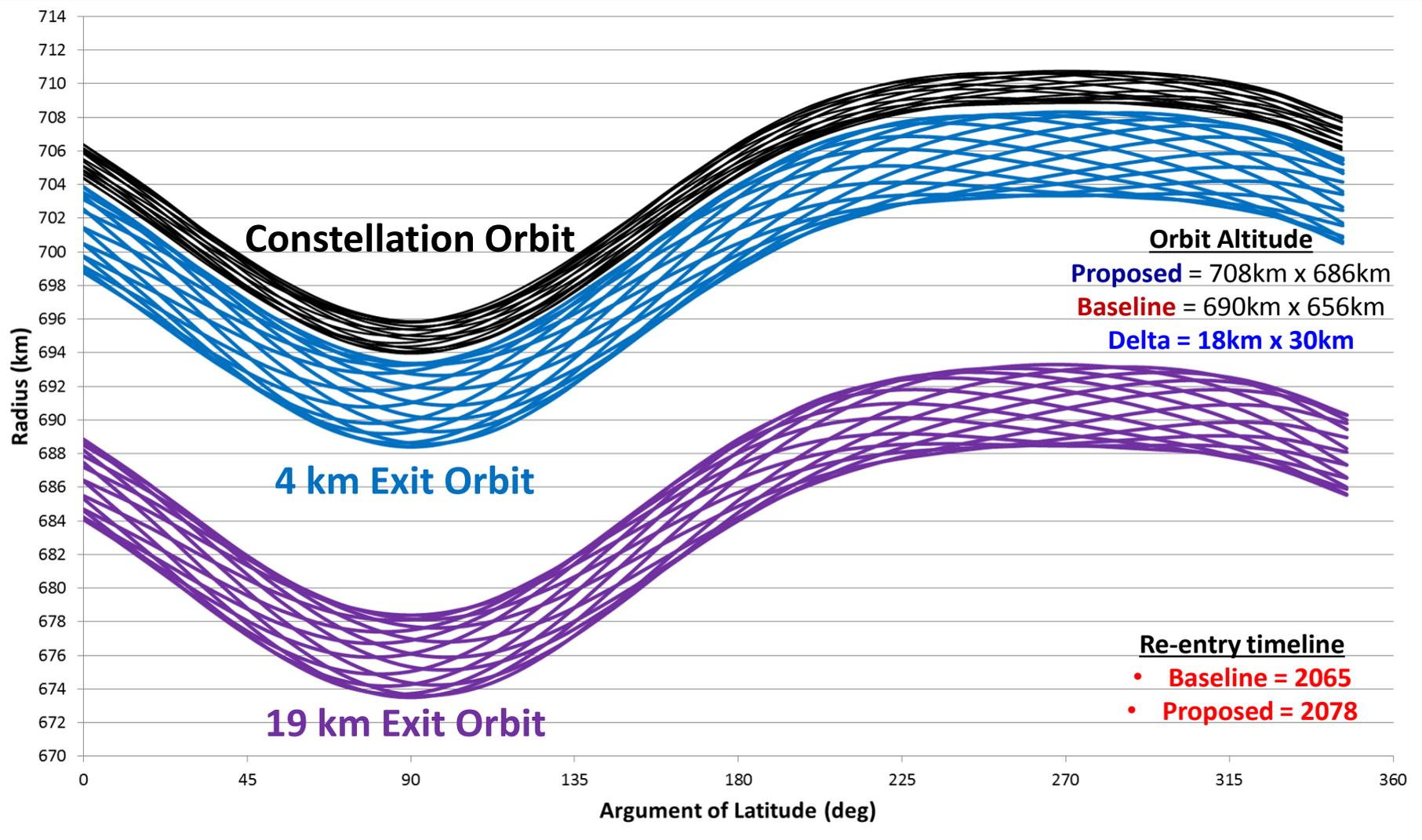
Baseline vs. Proposed Plan Origin



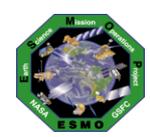
- **Baseline Plan (19km)**: Based on the **2010** definition from the **Afternoon Constellation Operations Coordination Plan**:
 - “The **apogee** of a spacecraft that has exited the constellation must be at least **2 kilometers below the minimum perigee** of all current constellation members.”
 - To effectively exit the Constellation, exited spacecraft’s maximum apogee must be lowered below **692 km**, which is **19 km** below constellation members’ maximum apogee
- **Proposed Plan (4km)**: Based on the **Current Constellation Coordination Plan signed by all member missions**:
 - Safe constellation exit is defined by being completely **outside** the constellation “envelope”
 - To effectively exit the Constellation, exited spacecraft’s maximum apogee will be at least **4 km** below constellation members’ maximum **apogee**



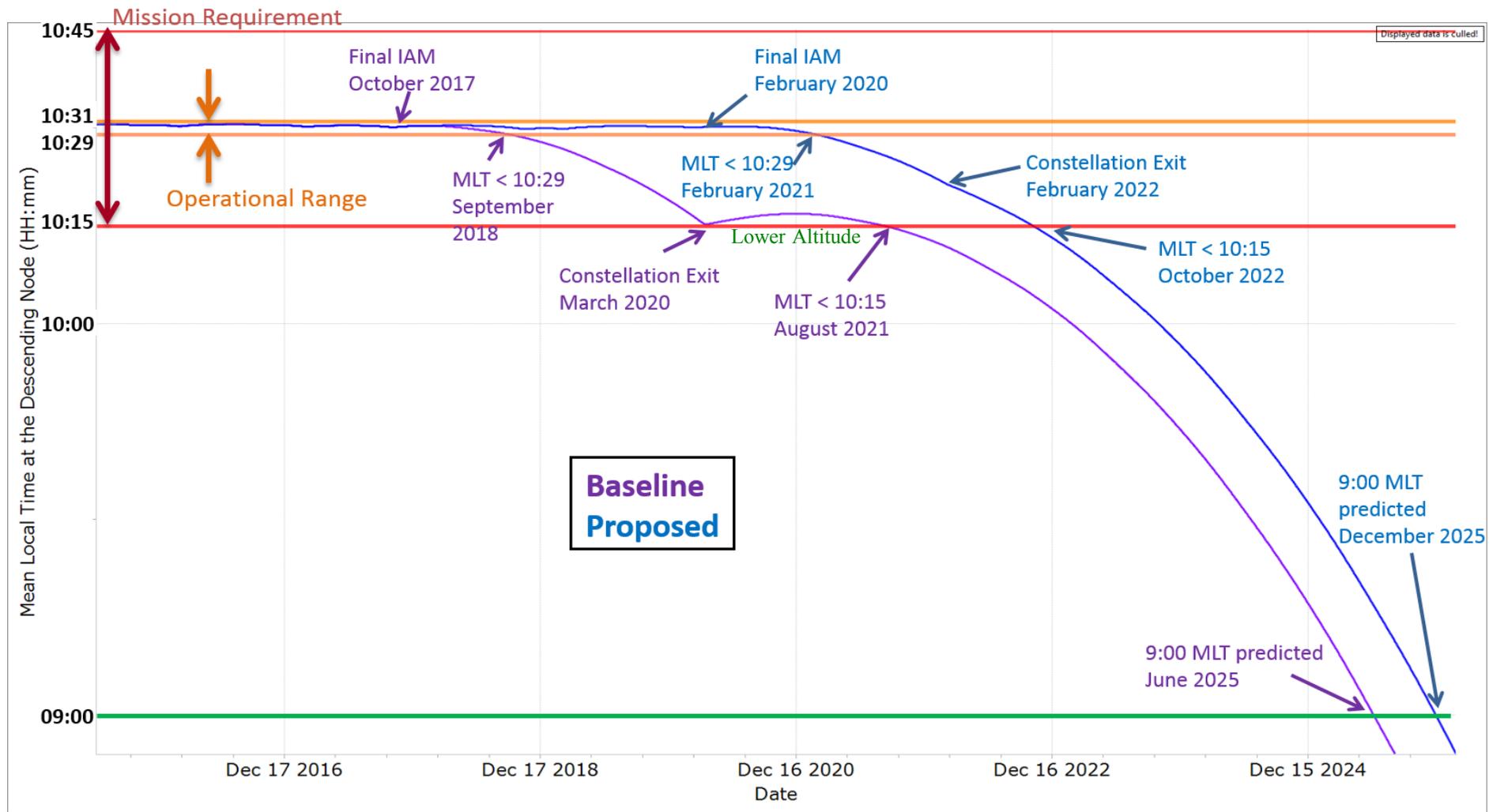
Resultant Exit Orbit w/ varied Eccentricity



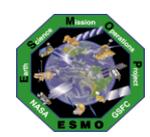
***NOTE*:** No Orbital Interaction with the Constellation



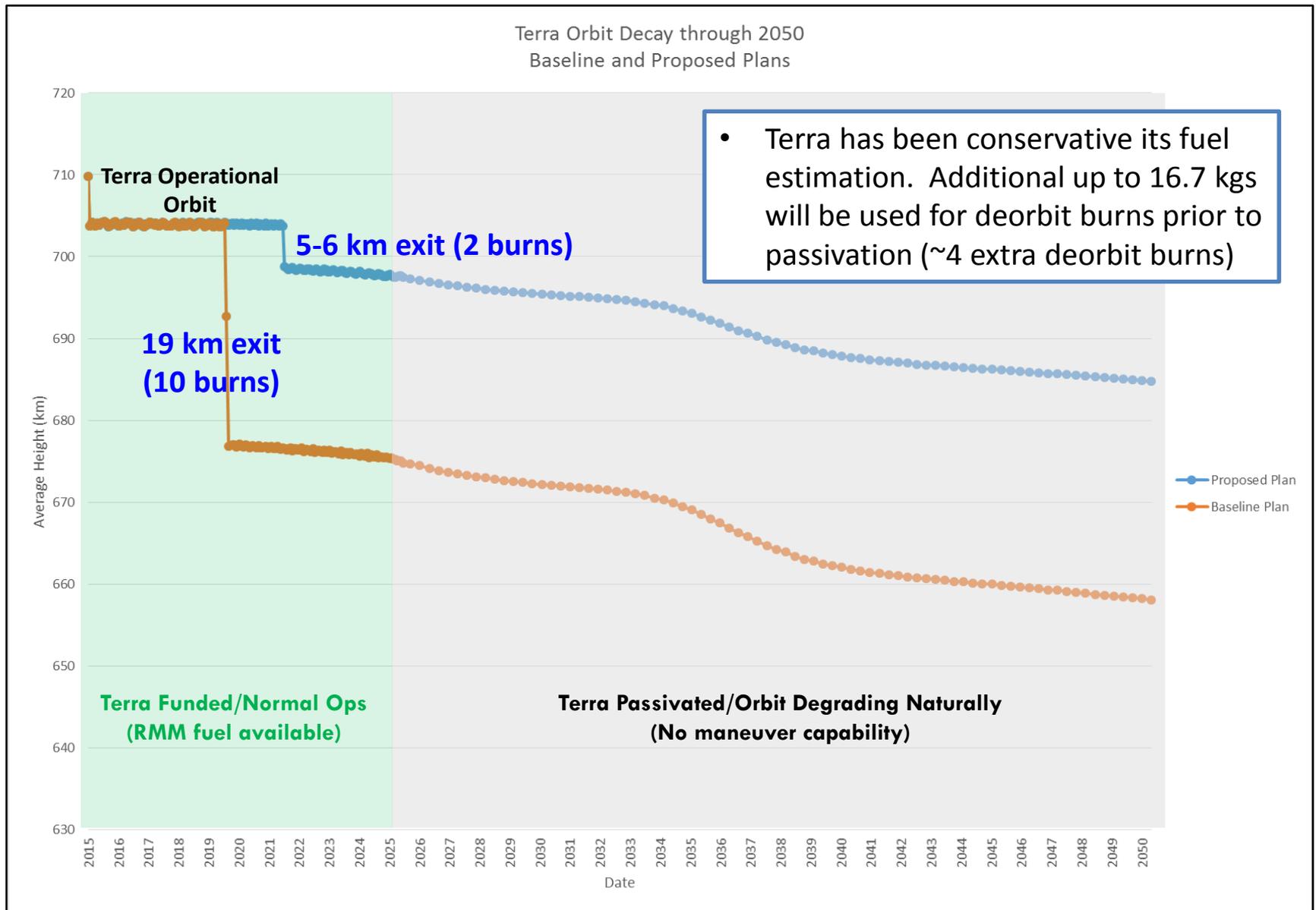
Baseline vs. Proposed Constellation Exit Plan (MLT)



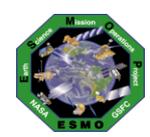
- Difference in overall mission lifetime between baseline and proposed plan is 5 months
- Difference in science collection is additional ~3years at tight MLT and current altitude
 - RMM fuel would be maintained throughout the mission lifetime



Long-Term Orbit Altitude



- Decay Rates based on FreeFlyer analysis



Concerns Raised by MOWG



1. Exit of 4km not low enough

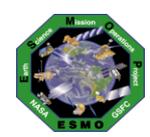
– Concern addressed:

- Terra plans (and has always planned) to perform 2 exit burns to lower 5-6 kms below the constellation envelope

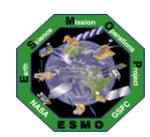
2. Possible debris source after constellation exit

– Concern addressed:

- Reserve RMM fuel up until passivation
- Updated proposed plan and all new options include orbit lowering burns prior to passivation



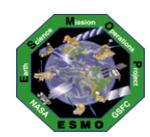
REVISED LIFETIME PROPOSAL AND FALLBACK OPTIONS



Updates for this MOWG



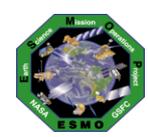
- **Removed Baseline option**
 - Based on old constellation requirement that no longer exists, therefore no reason to execute this plan
- **Updated fuel estimate to predicted values instead of most conservative values**
 - Conservative fuel analysis still performed to show range for reentry date
- **Created new Fallback options if Proposed Plan is not approved**
 - All new plans show constellation exit of 5-6kms and orbit lowering burns prior to passivation
- **Updated charts to show decommissioning/orbit lowering burns prior to passivation**
 - Show altitude through re-entry for all options



Future Work



- Kurt's Hierarchy of Options is as follows:
 1. Proposed Plan (3 years extra at tight MLT & altitude) - **DONE**, add extra fuel piece
 2. Tight MLT and Altitude until after LDSC - **DONE (Option 4)**
 3. Altitude the same until after LDSC - **Option 3 + Oct 2016 INC**
 4. Altitude the same until we need to lower due to interfering with other missions - **NEW**
- Redo lifetime analysis for Baseline (reentry date only) and Proposed with new drag models
- (5) Create a burn everything now (Jan 2017) case to show earliest possible reentry (reentry date needed only)
- Make a comparison table of all options which includes dates for:
 - Tight MLT exit, Mission MLT exit, Constellation Exit, Deorbit & Re-entry
- Make MLT and Altitude plots that contain all options on the same graph

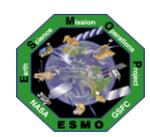


Updated/New Future Maneuver Plans

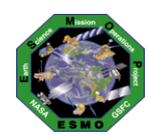


The following decommissioning options use an updated constellation “Envelope” definition for their constellation exit planning and are included in this package.

- **Option 1: Updated Proposed Plan (using expected fuel) – BEST for SCIENCE**
 - Terra performs nominal IAM and DMU planning thru Fall 2021.
 - Constellation Exit is performed in Jan 2022.
 - Decommissioning maneuvers (decreasing perigee) are planned with predicted fuel (add 13.2 kg over conservative) and unusable fuel (trapped in lines) of 2.3 kg (average of range provided by s/c vendor).
- **Option 2: Stop IAMs & DMUs after Fall 2016, exit constellation in 2018, drift until end of mission – lower orbit & passivate – RESERVE ALL REMAINING FUEL for future orbit lowering burns**
 - Terra will discontinue all Inclination & Drag Make Up maneuvers after the Fall 2016 series
 - Constellation Exit performed in early 2018
 - Terra takes science while drifting both MLT and Altitude until decision to end mission
 - Terra performs perigee-lowering burns with all remaining fuel at ~ MLT of 9:00 AM prior to spacecraft passivation
- **Fallback Option 1: Maintain Current Orbit (MLT & Altitude) until after LDSC**
 - Terra will perform nominal IAM and DMU planning until after LDSC (Aug 2017)
 - Constellation Exit performed in early 2018
 - Terra takes science while drifting both MLT and Altitude until decision to end mission
 - Terra performs perigee-lowering burns with all remaining fuel at ~ MLT of 9:00 AM prior to spacecraft passivation
- **Fallback Option 2: Maintain Orbit Altitude until after LDSC**
 - Terra will discontinue all Inclination series after the Fall 2016 series
 - Will still perform DMUs until constellation exit in early 2018
 - Terra takes science while drifting both MLT and Altitude until decision to end mission
 - Terra performs perigee-lowering burns with all remaining fuel at ~ MLT of 9:00 AM prior to spacecraft passivation
- **Fallback Option 3: Maintain Orbit Altitude for as long as possible**
 - Terra will discontinue all Inclination series after the Fall 2016 series
 - Will still perform DMUs until required to lower due to proximity to other mission or other reason (est @ MLT of 9AM)
 - Terra immediately performs perigee-lowering burns with all remaining fuel prior to spacecraft passivation



REVISED PROPOSED PLAN



Proposed Plan with additional fuel (Option 6)

Lifetime and Decommission Maneuvers



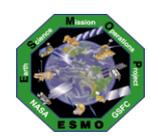
- Terra Lifetime:**

Mission Year (-)	Inclination Maneuvers (-)	DMU Maneuvers (-)	Fuel Used (kg)	Fuel Remaining (kg)
2016	0 Spring, 1 Fall	1	3.92	73.43
2017	2 Spring, 2 Fall	3	15.05	58.39
2018	1 Spring, 2 Fall	1	10.79	47.59
2019	2 Spring, 1 Fall	3	10.77	36.82
2020	2 Spring, 0 Fall	2	7.11	29.72
2021	0 Spring, 0 Fall	2	0.23	29.48

- Terra constellation exit and perigee-lowering:**

Mission Year (-)	Maneuver Type (-)	Fuel Used (kg)	Fuel Remaining (kg)
1/11/2022	Envelope Exit #1	3.44	26.04
1/11/2022	Envelope Exit #2	3.42	22.62
2/19/2026	De-orbit #1	3.40	19.21
2/24/2026	De-orbit #2	3.39	15.83
2/26/2026	De-orbit #3	3.37	12.46
3/3/2026	De-orbit #4	3.35	9.11
3/5/2026	De-orbit #5	3.33	5.78
3/10/2026	De-orbit #6	3.31	2.47

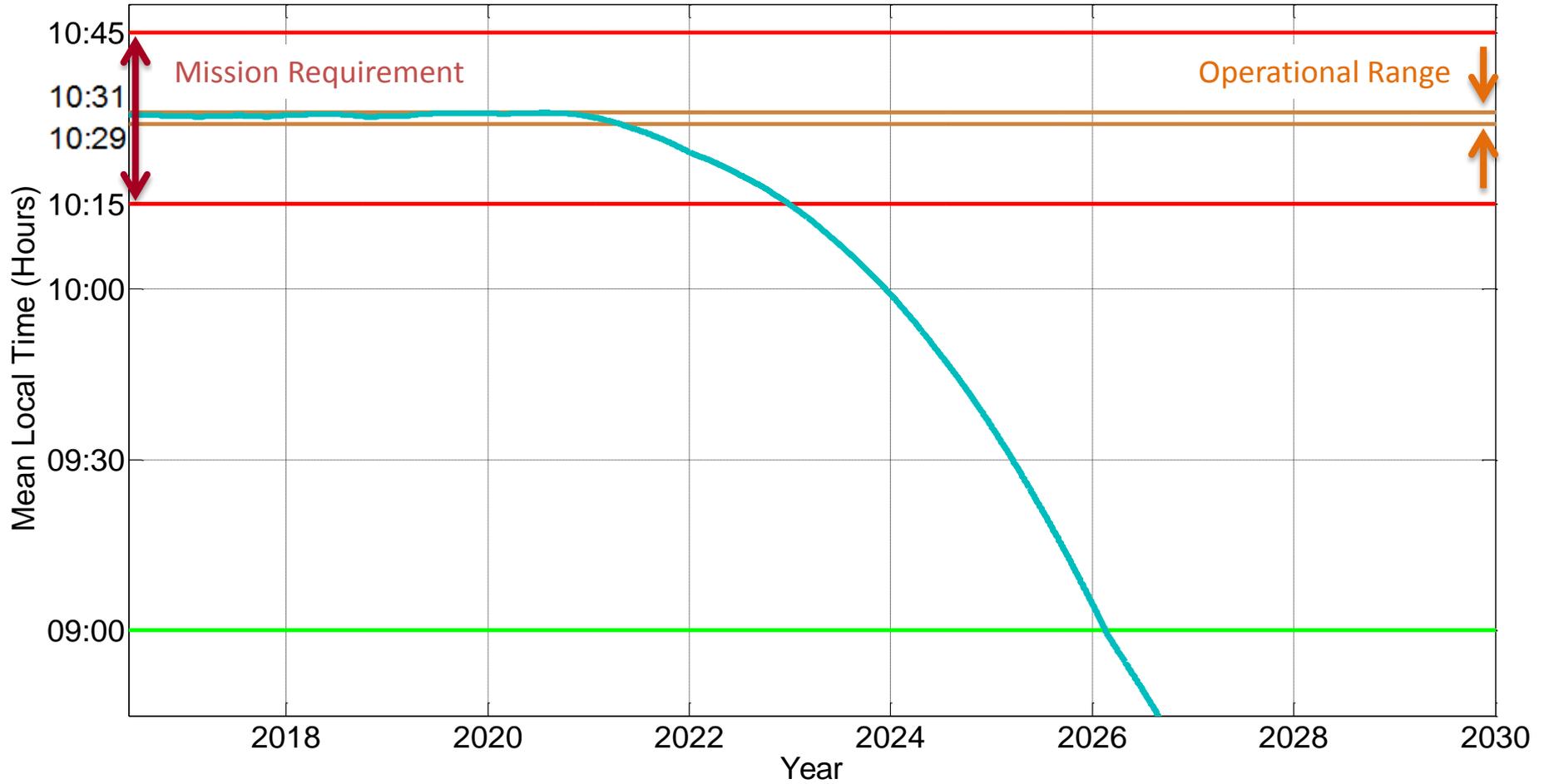
Terra will drift to an MLT of 9:00 AM after constellation exit

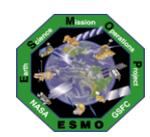


Proposed Plan with additional fuel (Option 6)



Mean Local Time

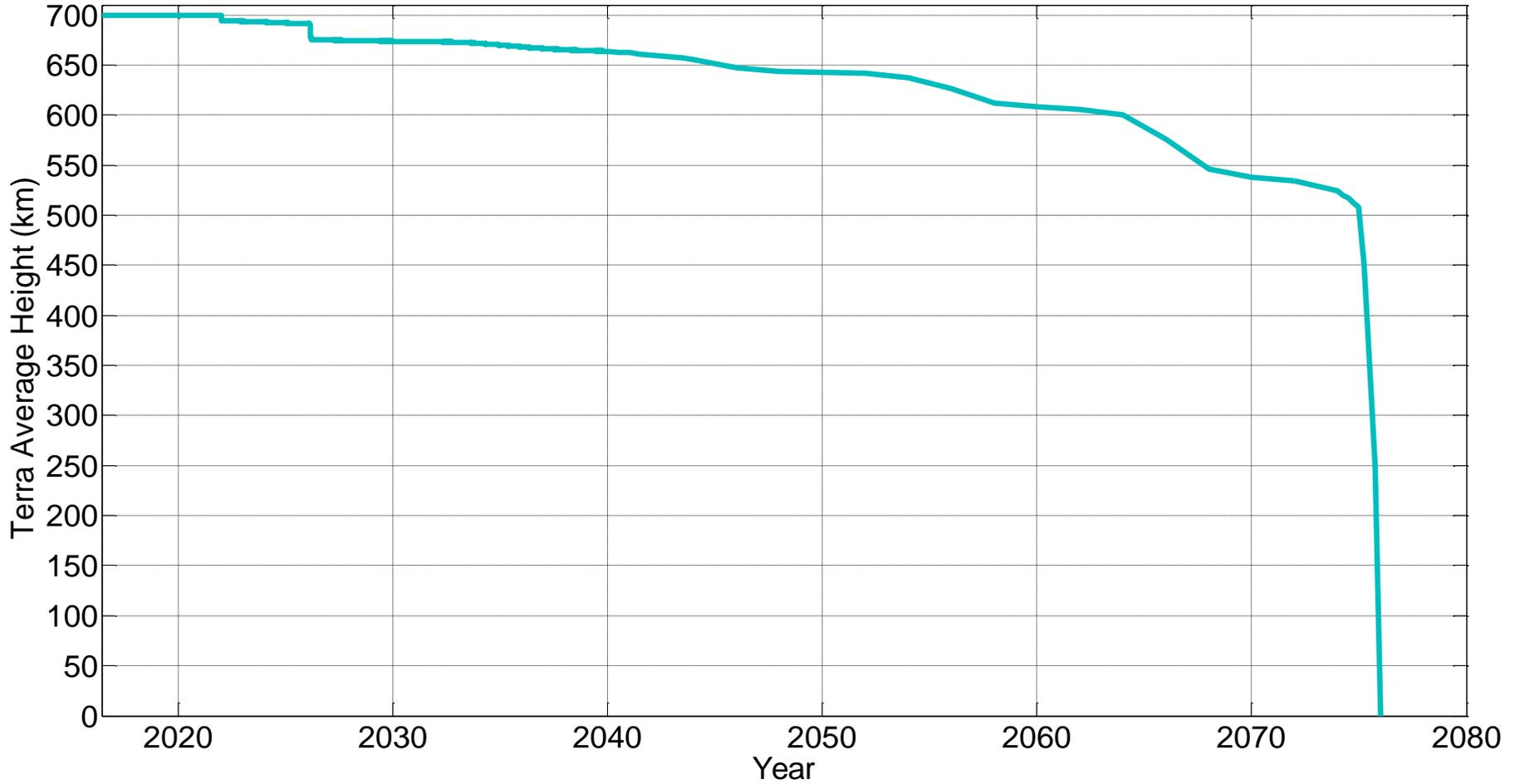




Proposed Plan with additional fuel (Option 6)

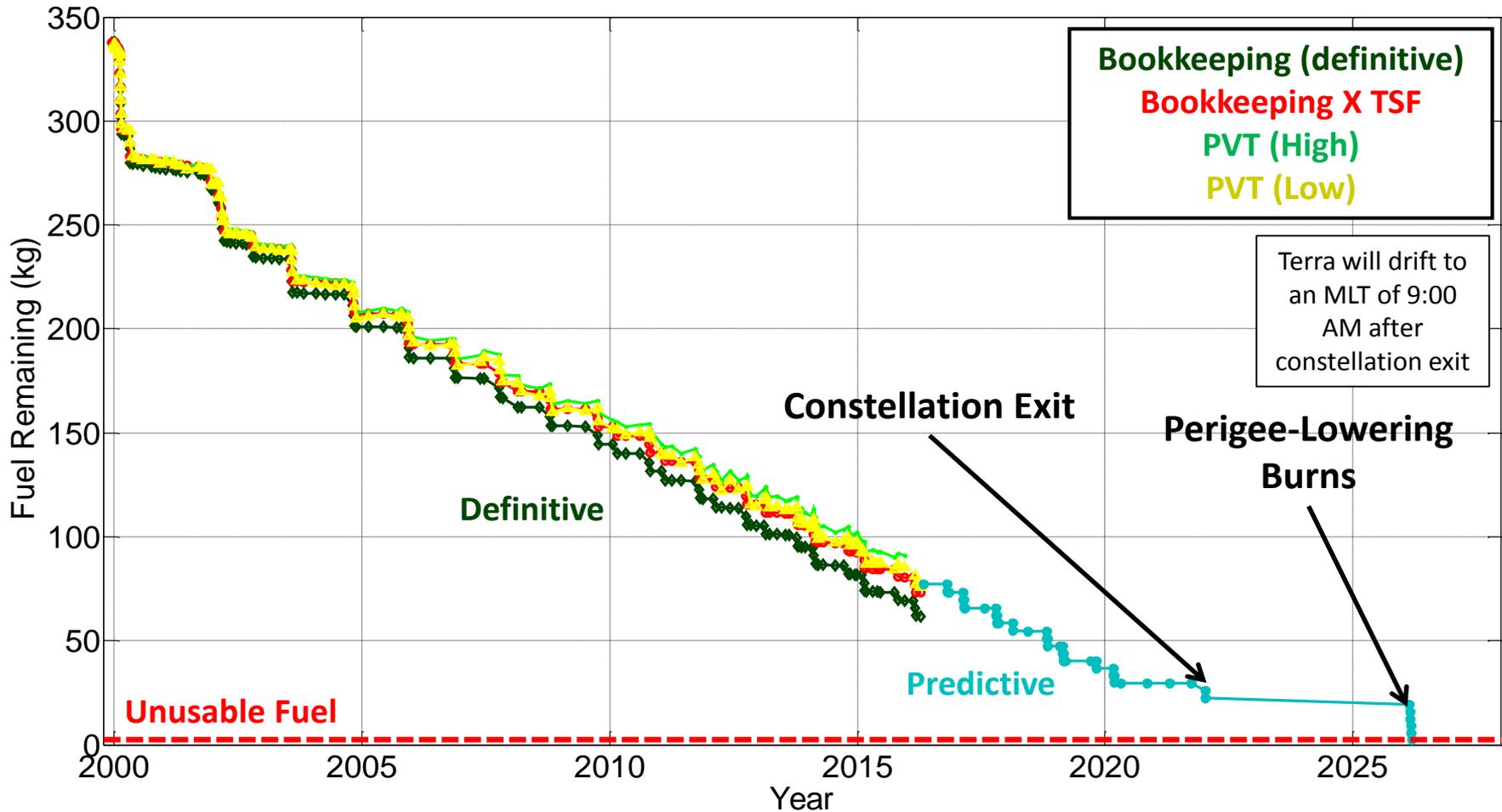


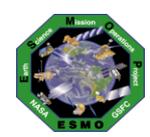
Lifetime Average Height



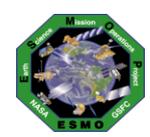
Proposed Plan with additional fuel (Option 6)

Lifetime Fuel Estimates





FALLBACK OPTIONS



Stop all IAMs after Fall 2017 with additional fuel (Option 9)



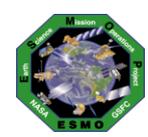
Lifetime and Decommissioning Maneuvers

- Terra lifetime:**

Mission Year (-)	Inclination Maneuvers (-)	DMU Maneuvers (-)	Fuel Used (kg)	Fuel Remaining (kg)
2016	1 Fall	1	3.92	71.07
2017	2 Spring. 2 Fall	3	15.05	56.02

- Terra decommissioning :**

Mission Date (-)	Maneuver Type (-)	Fuel Used (kg)	Fuel Remaining (kg)
1/11/2018	Envelope Exit #1	3.62	52.40
1/11/2018	Envelope Exit #2	3.60	48.80
12/19/2023	De-orbit #1	3.57	45.23
12/21/2023	De-orbit #2	3.55	41.68
12/26/2023	De-orbit #3	3.53	38.15
12/28/2023	De-orbit #4	3.51	34.64
1/2/2024	De-orbit #5	3.49	31.15
1/4/2024	De-orbit #6	3.47	27.68
1/9/2024	De-orbit #7	3.45	24.23
1/11/2024	De-orbit #8	3.43	20.80
1/16/2024	De-orbit #9	3.41	17.39
1/18/2024	De-orbit #10	3.39	14.00
1/23/2024	De-orbit #11	3.37	10.63
1/25/2024	De-orbit #12	3.35	7.28
1/30/2024	De-orbit #13	3.34	3.94



Stop all IAMs after Fall 2016 (Option 7)

Lifetime and Decommission Maneuvers

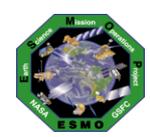


- Terra Lifetime:**

Mission Year (-)	Inclination Maneuvers (-)	DMU Maneuvers (-)	Fuel Used (kg)	Fuel Remaining (kg)
2016	0 Spring, 1 Fall	1	3.92	73.43
2017	0 Spring, 0 Fall	2	0.21	73.22

- Terra constellation exit:**

Mission Year (-)	Maneuver Type (-)	Fuel Used (kg)	Fuel Remaining (kg)
1/11/2018	Envelope Exit #1	3.72	69.51
1/11/2018	Envelope Exit #2	3.69	65.81



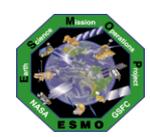
Stop all IAMs after Fall 2016 (Option 7)

Lifetime and Decommission Maneuvers



- Terra perigee-lowering maneuvers:

Mission Date (-)	Maneuver Type (-)	Fuel Used (kg)	Fuel Remaining (kg)
6/21/2022	De-orbit #1	3.67	62.14
6/23/2022	De-orbit #2	3.64	58.50
6/28/2022	De-orbit #3	3.62	54.88
6/30/2022	De-orbit #4	3.60	51.28
7/5/2022	De-orbit #5	3.57	47.71
7/7/2022	De-orbit #6	3.55	44.16
7/12/2022	De-orbit #7	3.53	40.63
7/14/2022	De-orbit #8	3.51	37.12
7/19/2022	De-orbit #9	3.49	33.63
7/21/2022	De-orbit #10	3.47	30.16
7/26/2022	De-orbit #11	3.45	26.71
7/28/2022	De-orbit #12	3.43	23.29
8/2/2022	De-orbit #13	3.41	19.88
8/4/2022	De-orbit #14	3.39	16.49
8/9/2022	De-orbit #15	3.37	13.12
8/11/2022	De-orbit #16	3.35	9.77
8/16/2022	De-orbit #17	3.33	6.43
8/18/2022	De-orbit #18	3.32	3.11



Constellation exit at MLT of 9:00 AM (Option 8)

Lifetime and Decommission Maneuvers

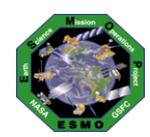


- Terra lifetime:**

Mission Year (-)	Inclination Maneuvers (-)	DMU Maneuvers (-)	Fuel Used (kg)	Fuel Remaining (kg)
2016	0 Spring, 1 Fall	1	3.92	73.43
2017	0 Spring, 0 Fall	2	0.21	73.22
2018	0 Spring, 0 Fall	3	0.27	72.96
2019	0 Spring, 0 Fall	1	0.08	72.88
2020	0 Spring, 0 Fall	2	0.15	72.73
2021	0 Spring, 0 Fall	3	0.33	72.39

- Terra constellation exit :**

Mission Year (-)	Maneuver Type (-)	Fuel Used (kg)	Fuel Remaining (kg)
12/14/2021	Envelope Exit #1	3.71	68.68
12/14/2021	Envelope Exit #2	3.69	64.99



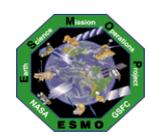
Constellation exit at MLT of 9:00 AM (Option 8)

Lifetime and Decommission Maneuvers

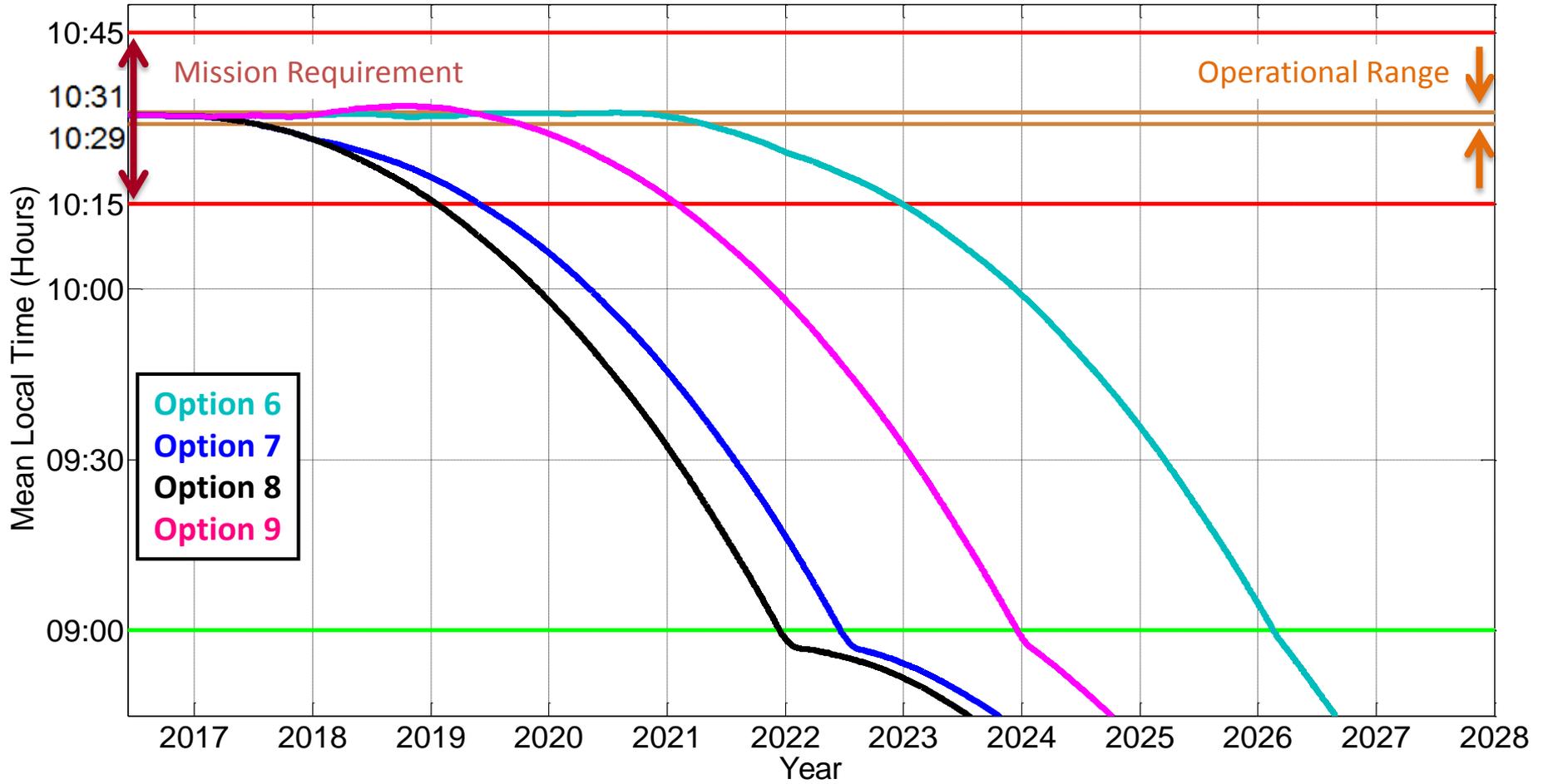


- Terra perigee-lowering maneuvers :

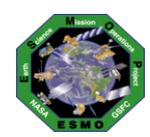
Mission Date (-)	Maneuver Type (-)	Fuel Used (kg)	Fuel Remaining (kg)
12/16/2021	De-orbit #1	3.66	61.33
12/21/2021	De-orbit #2	3.64	57.69
12/23/2021	De-orbit #3	3.61	54.08
12/28/2021	De-orbit #4	3.59	50.49
12/30/2021	De-orbit #5	3.57	46.92
1/4/2022	De-orbit #6	3.55	43.37
1/6/2022	De-orbit #7	3.53	39.84
1/11/2022	De-orbit #8	3.50	36.34
1/13/2022	De-orbit #9	3.48	32.86
1/18/2022	De-orbit #10	3.46	29.39
1/20/2022	De-orbit #11	3.44	25.95
1/25/2022	De-orbit #12	3.42	22.53
1/27/2022	De-orbit #13	3.40	19.12
2/1/2022	De-orbit #14	3.39	15.74
2/3/2022	De-orbit #15	3.37	12.37
2/8/2022	De-orbit #16	3.35	9.02
2/10/2022	De-orbit #17	3.33	5.69
2/15/2022	De-orbit #18	3.31	2.38



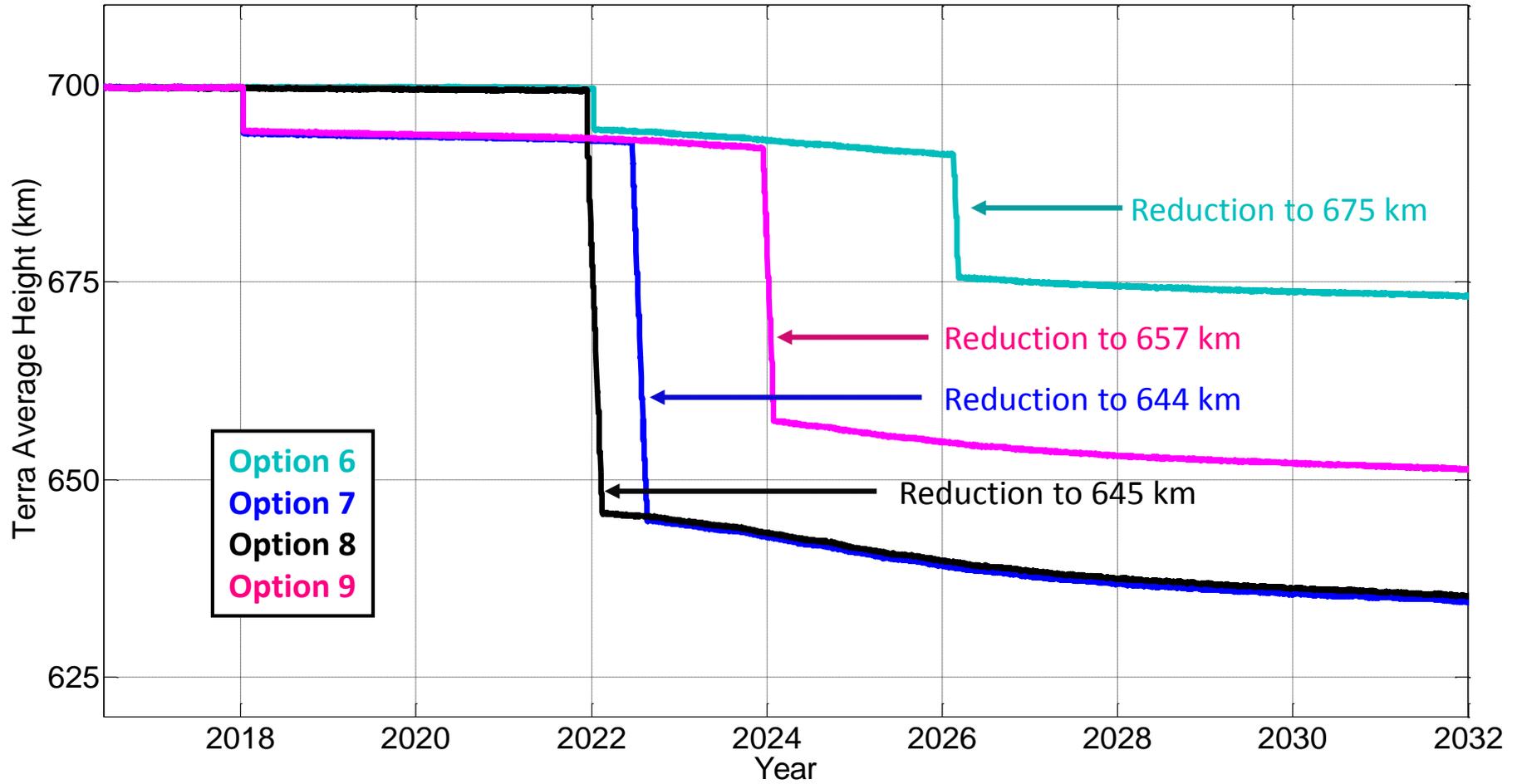
Mean Local Time

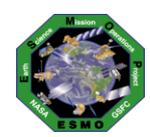


8/18/2016

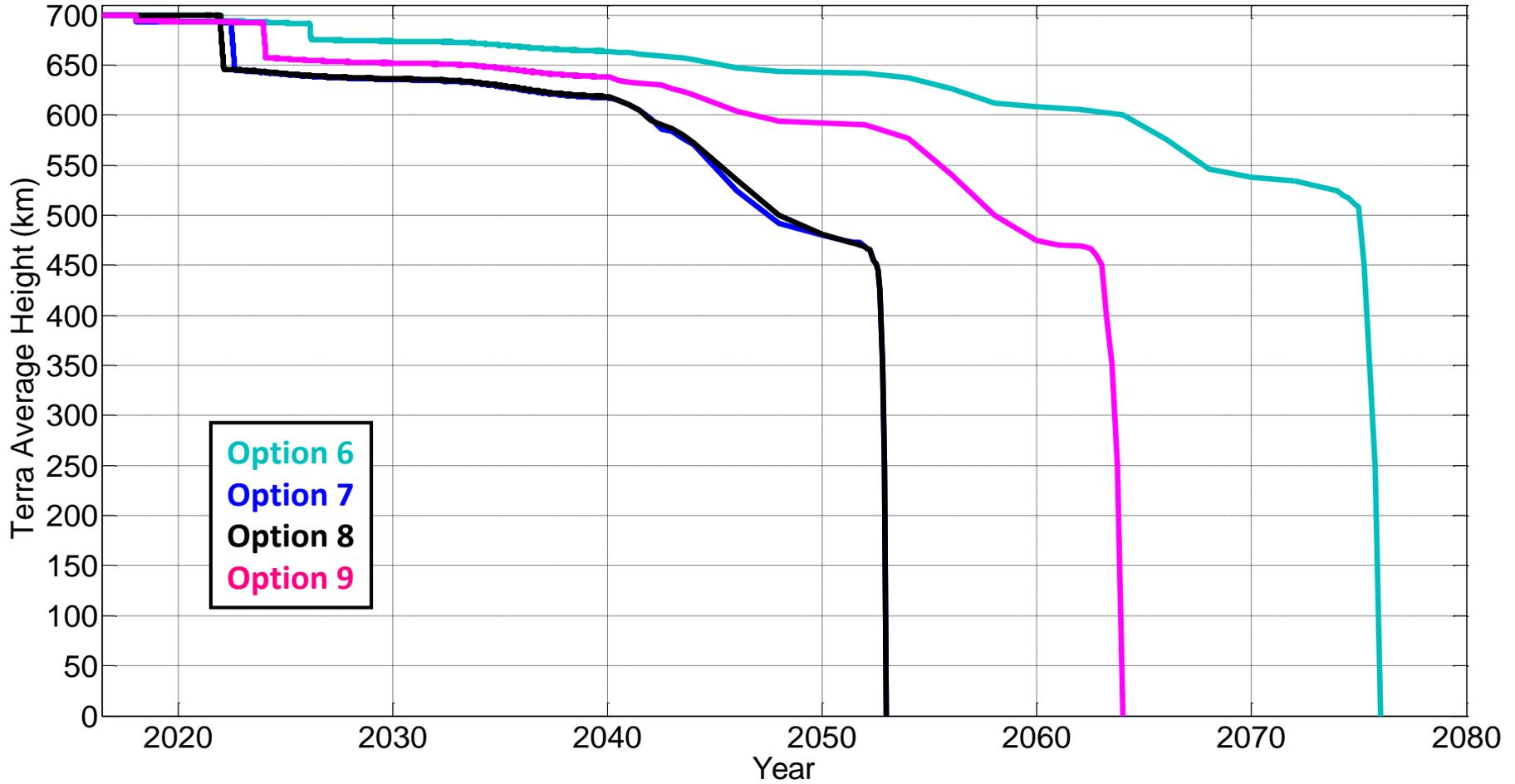


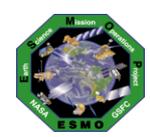
Final Average Height



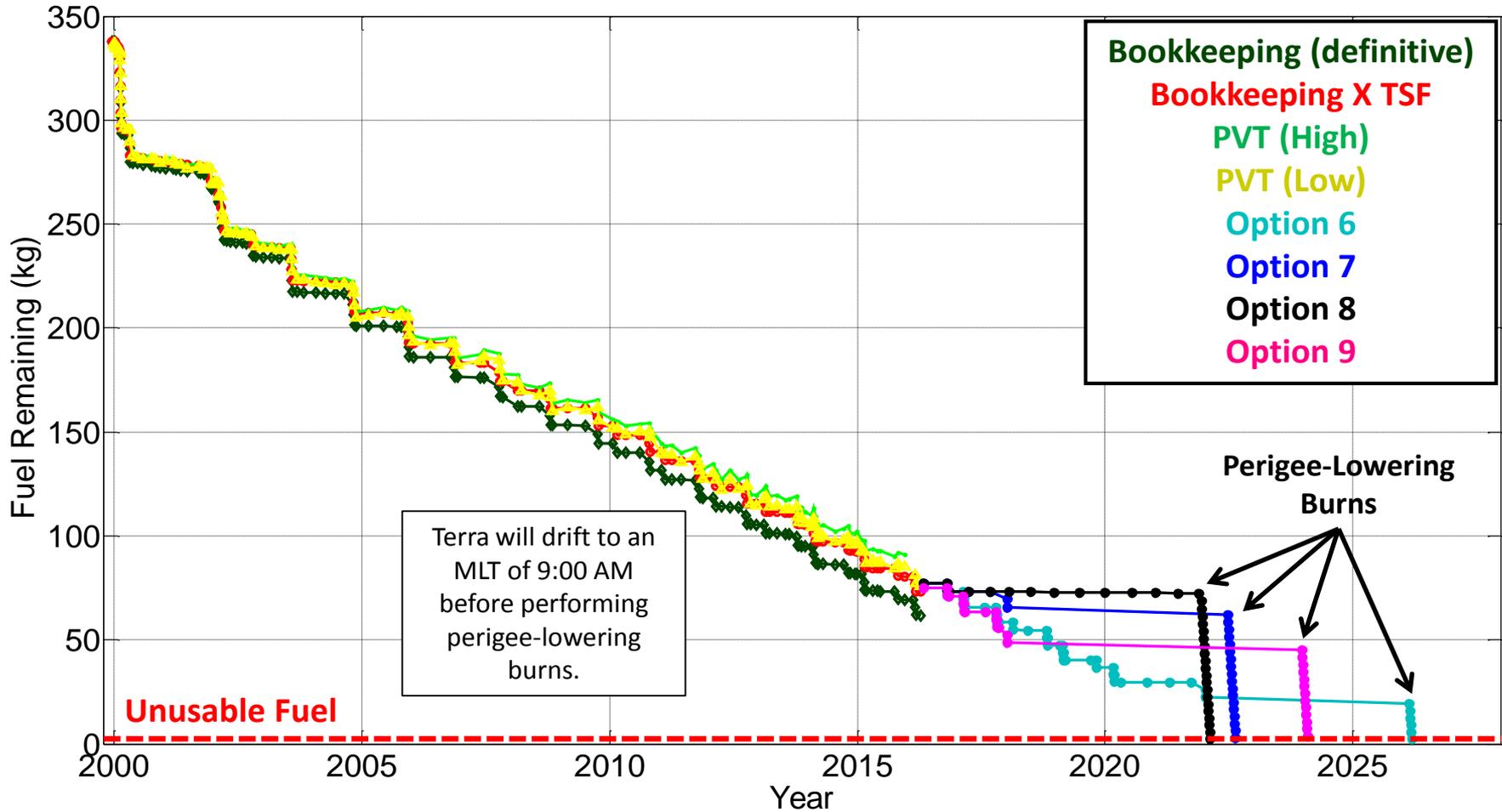


Lifetime Average Height

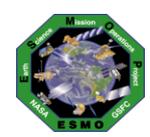




Lifetime Fuel Estimates



8/18/2016

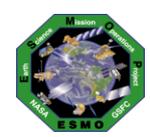


Post Orbit Lowering Interaction Analysis

Summary and Results



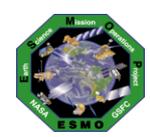
- **Purpose**: Confirm that the post-deorbit apogee will remain below the Constellation orbit for Terra options 3, 4, and 5
- The post-deorbit radius was compared to the Constellation radius and the results plotted
- For all three cases, apogee remains below the Constellation Orbit



Deorbit case summaries / Inputs



- **Option 3**
 - Deorbit burns executed on 02/15/2022 through 03/31/2022
 - Plot covers 02/10/2022 through 10/21/2024
- **Option 4**
 - Deorbit burns 12/26/2023 through 01/23/2024
 - Plot 1 covers 12/23/2023 through 10/03/2024
 - Plot 2 covers 10/03/2024 through 10/07/2027
- **Option 5**
 - Deorbit burns 12/26/2023 through 02/13/2024
 - Plot covers 12/23/2023 through 12/19/2026

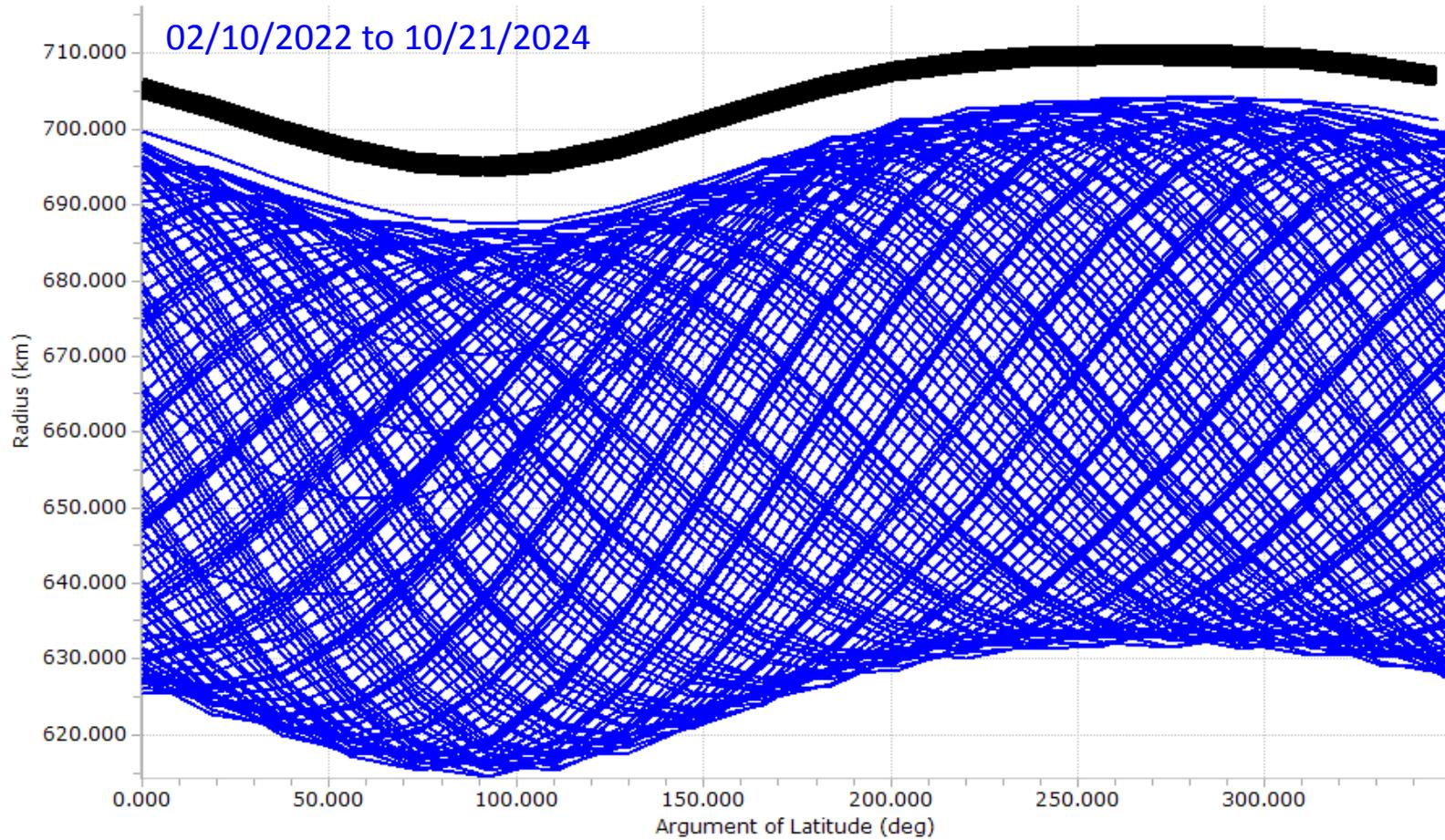


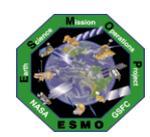
Option 3 Results



Option 3 De-Orbit vs. Constellation Radius

07/19/2016



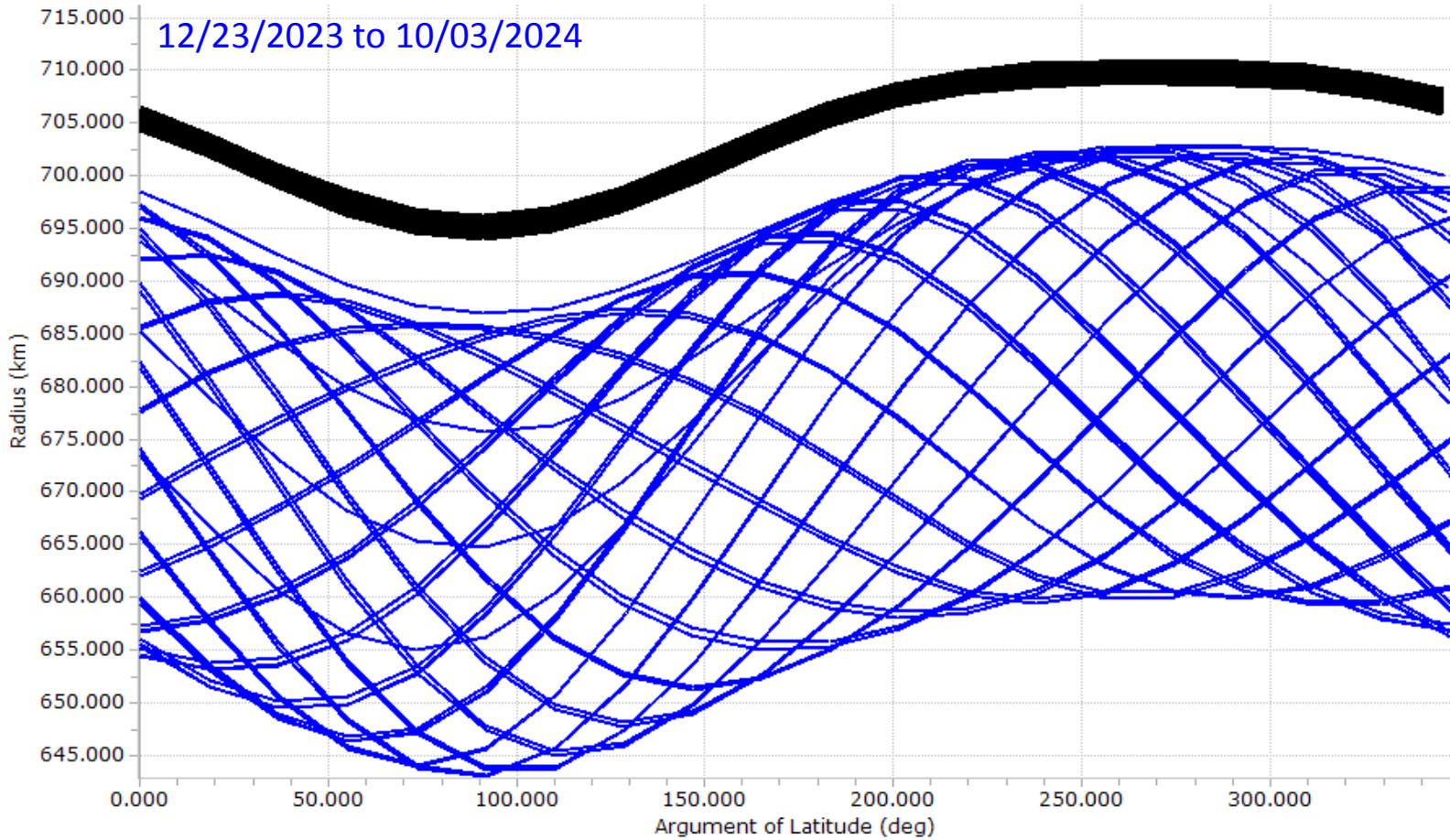


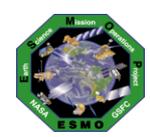
Option 4 Results



Option 4 De-Orbit vs. Constellation Radius

07/19/2016



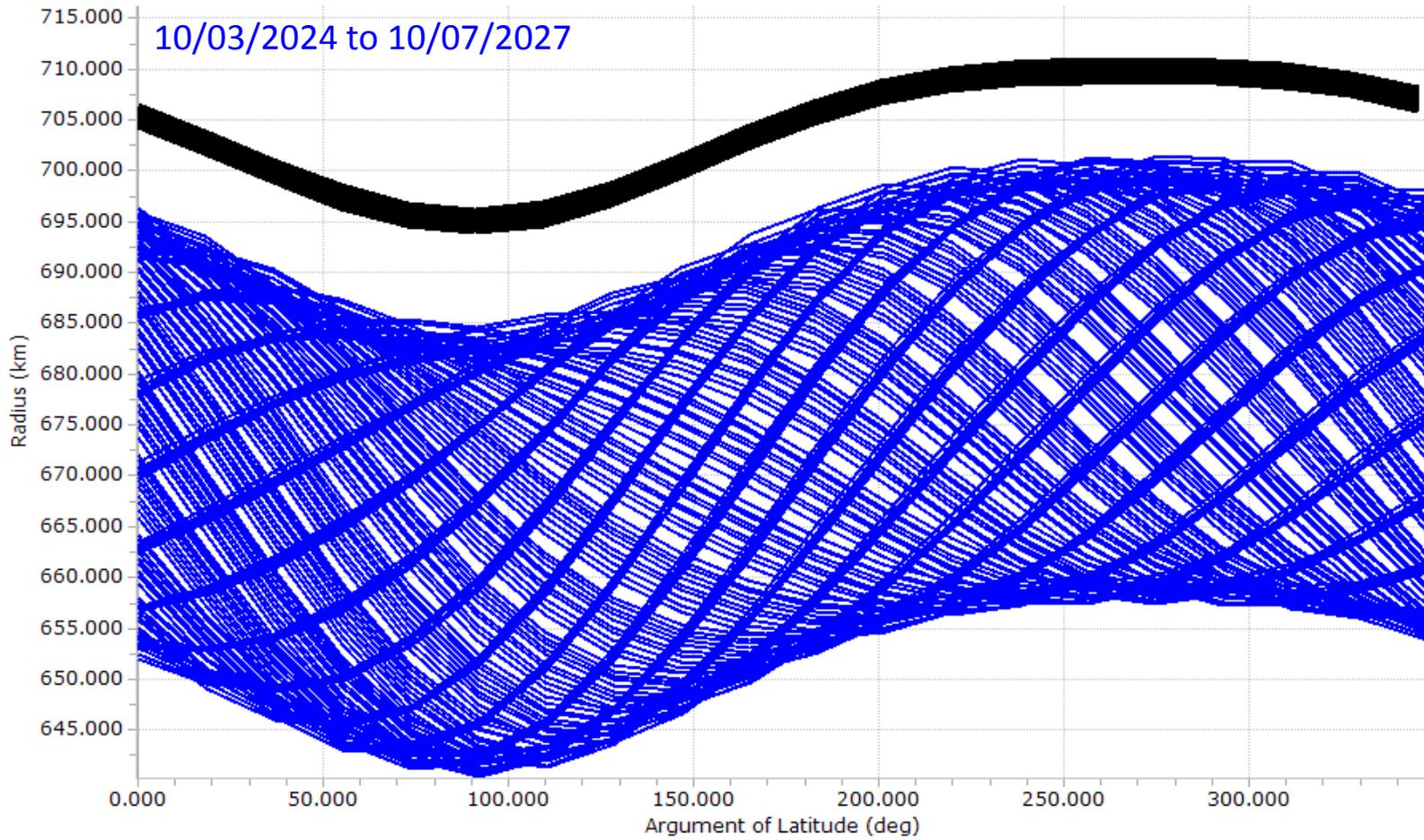


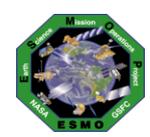
Option 4 Results



Option 4 De-Orbit vs. Constellation Radius

07/19/2016



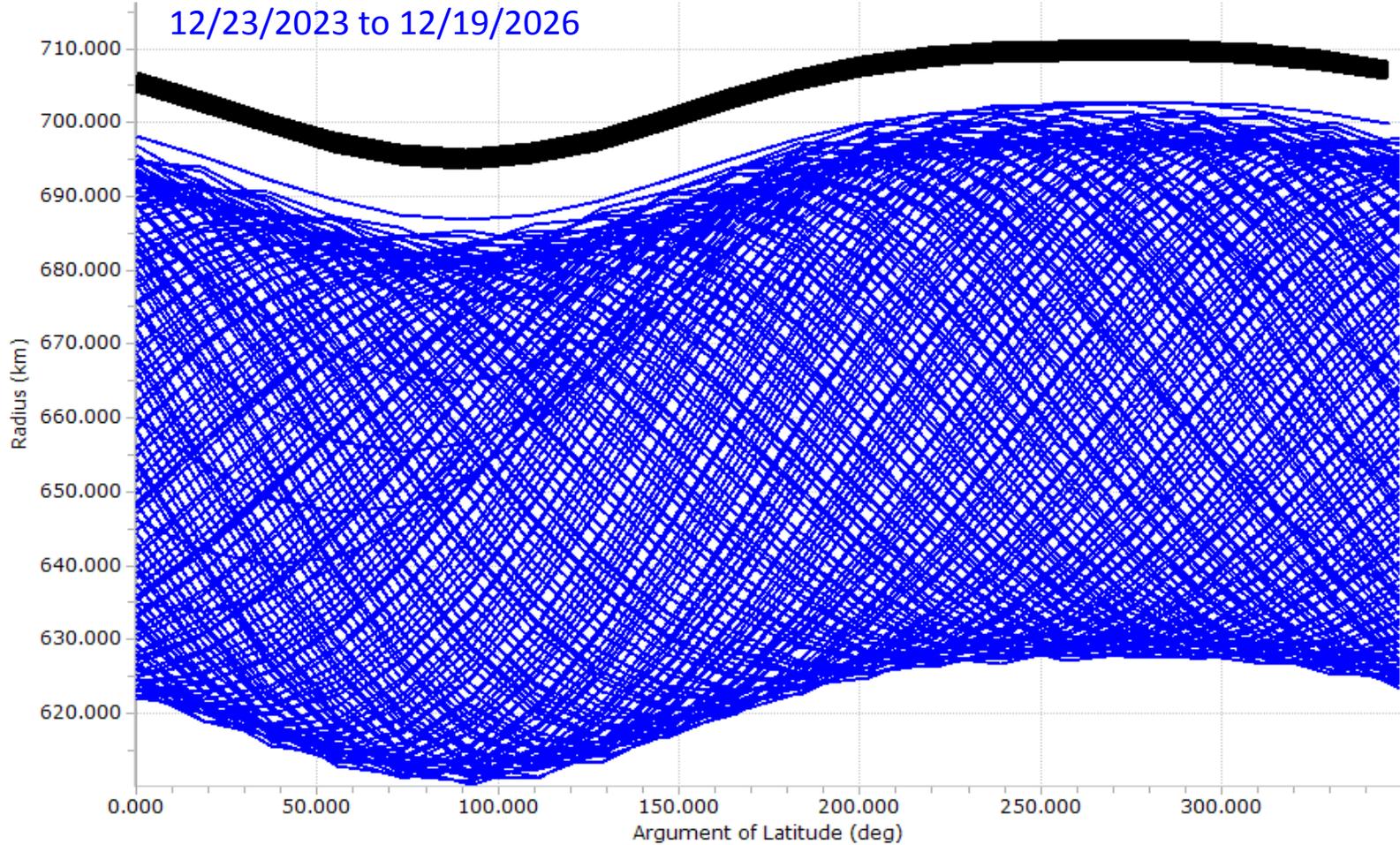


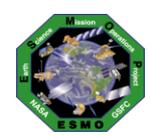
Option 5 Results



Option 5 De-Orbit vs. Constellation Radius

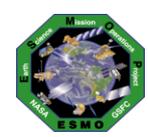
07/19/2016





Debris Assessment Software

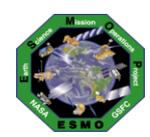
DISPOSAL ORBIT



Debris Assessment Software



- ***The Debris Assessment Software (DAS) was created by the Orbital Debris Office in Johnson Space Center and is currently on version 2.0.2***
- ***DAS utilizes predicted F10.7 values for solar flux based on sine and cosine curve fits to definitive data***
- ***The DAS contains a separate utility to estimate time-on-orbit, given the following inputs:***
 - The operational orbit parameters
 - The “Start” date (ex. Decommissioning date)
- ***In turn, DAS outputs:***
 - Calculated Orbit Lifetime from the “Start” date
 - The last year of propagation
- ***This tool was used to find the reentry dates for the different plans.***
- ***The Area to Mass ratio used in this analysis used a tumbling area (43.95 m²) based on NASA-STD-8719.14A compared to Terra’s operational area (40.5 m²). A higher area decreases the time on orbit therefore Terra reenters early.***



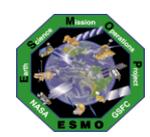
Disposal Orbits

Time-on-Orbit Comparisons



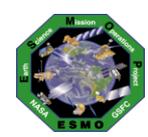
- An A/M Ratio of 0.0099 was used in the DAS 2.02 Time-on-Orbit tool. This was calculated using Terra's tumbling area.***

Decommissioning Plan	Final Apogee (km)	Final Perigee (km)	Year of final de-orbit burn	On orbit time (yrs)	Reentry date
Baseline	689.08	672.05	2020	44	2064
Proposed Plan with conservative fuel estimate (Option 2)	706.50	689.76	2022	54	2076
Stop all IAMs after Spring 2016 with conservative fuel estimate (Option 3)	703.83	633.38	2022	34	2056
Stop all IAMs after Fall 2017 with conservative fuel estimate (Option 4)	702.58	660.02	2024	44	2068
Stop all IAMs after Fall 2017 with additional fuel (Option 5)	701.76	635.22	2024	40	2064
Proposed Plan with additional fuel (Option 6)	702.31	671.43	2026	50	2076
Stop all IAMs after Fall 2017 with additional fuel and updated fuel buffer (Option 9)	701.69	635.59	2024	40	2064
Stop all IAMs after Fall 2016 (Option 7)	701.00	608.50	2022	31	2053
Stop all IAMs after Fall 2016 and exit at MLT of 9:00 AM (Option 8)	700.26	613.76	2022	31	2053



Additional Slides

- **Lifetime Maneuver Table**
- **Solar Flux Used in Analysis**
- **Aerospace Risk Assessment Study Results**



Lifetime Maneuver Summary



Baseline Plan

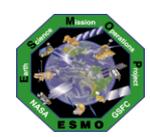
Mission Year (-)	Inclination Maneuvers (-)	Delta Inclination (Deg)	DMU Maneuvers (-)	Fuel Used (kg)	Fuel Remaining (kg)
2015	2 Spring, 1 Fall	0.011873	7	12.427	69.175
2016	2 Spring, 1 Fall	0.044187	3	11.559	57.616
2017	2 Spring, 2 Fall	0.043461	3	14.945	42.671
2018	0 Spring, 0 Fall	0	2	0.210	42.461
2019	0 Spring, 0 Fall	0	2	0.188	42.273
2020	0 Spring, 0 Fall	0	0	0	42.273

Proposed Plan

Mission Year (-)	Inclination Maneuvers (-)	Delta Inclination (Deg)	DMU Maneuvers (-)	Fuel Used (kg)	Fuel Remaining (kg)
2015	2 Spring, 1 Fall	0.011891	7	12.389	69.213
2016	2 Spring, 1 Fall	0.033162	3	11.579	57.634
2017	2 Spring, 2 Fall	0.04346	3	14.962	42.672
2018	1 Spring, 2 Fall	0.031675	3	10.964	31.708
2019	2 Spring, 1 Fall	0.031061	3	10.733	20.975
2020	2 Spring, 0 Fall	0.02046	2	7.067	13.908
2021	0 Spring, 0 Fall	0	2	0.169	13.739
2022	0 Spring, 0 Fall	0	0	0	13.739

****Predictions as of September 21st, 2015***

- In either case, DMUs are performed for ~2 years after inclination maneuvers stop (orbit altitude maintained)



Option 3 Plan



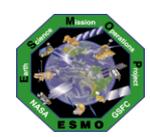
Lifetime and Decommission Maneuvers

- Terra Lifetime:

Mission Year (-)	Inclination Maneuvers (-)	DMU Maneuvers (-)	Fuel Used (kg)	Fuel Remaining (kg)
2016 - 2017	0	3	0.3840	61.4646

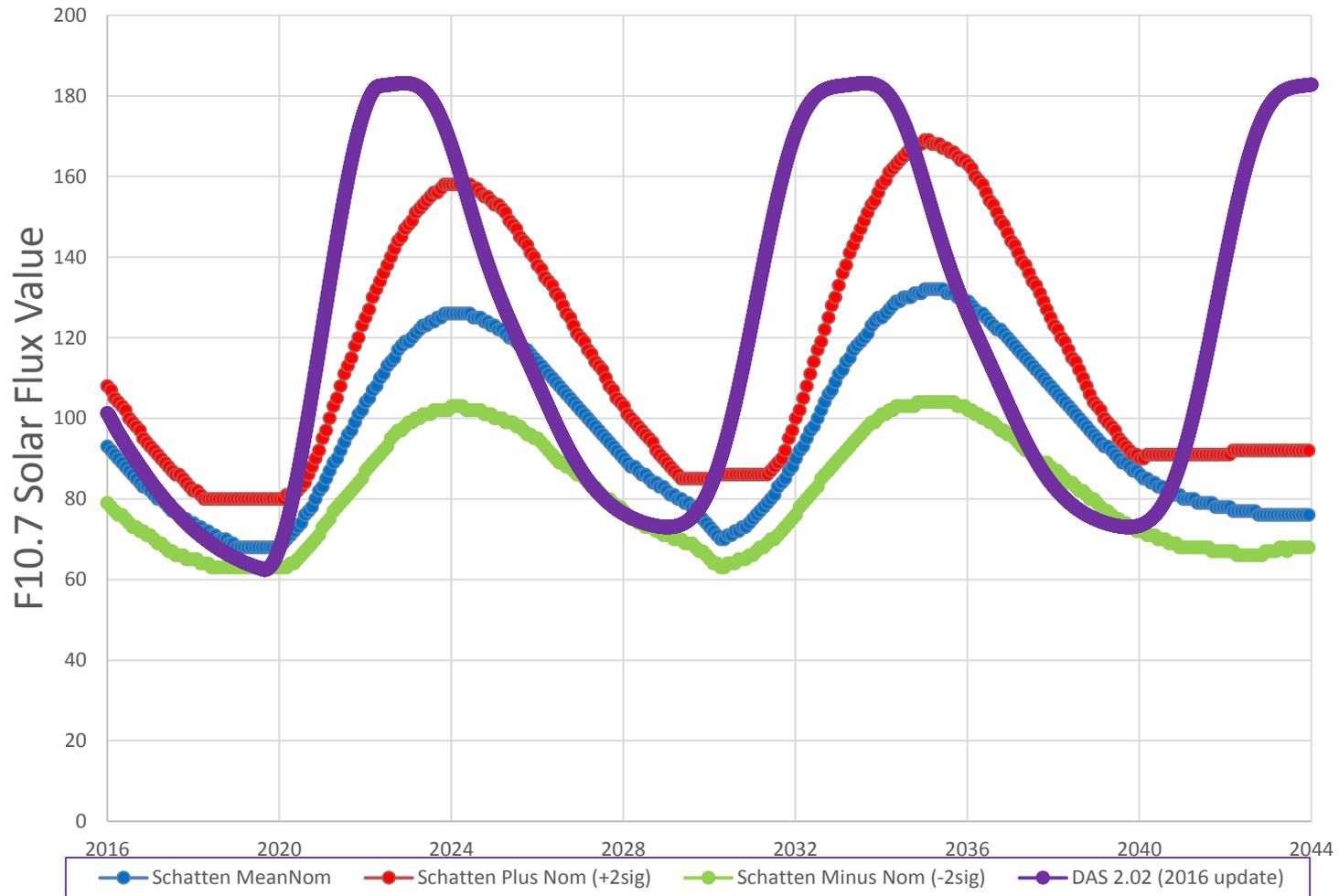
- Terra Decommissioning:

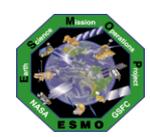
Mission Year (-)	Maneuver Type (-)	Fuel Used (kg)	Fuel Remaining (kg)
1/11/2018	Envelope Exit #1	3.7451	57.7195
1/11/2018	Envelope Exit #2	3.7201	53.9994
2/15/2022	De-orbit #1	3.6956	50.3039
2/17/2022	De-orbit #2	3.6716	46.6323
2/22/2022	De-orbit #3	3.6482	42.9841
2/24/2022	De-orbit #4	3.6252	39.3589
3/1/2022	De-orbit #5	3.6028	35.7561
3/3/2022	De-orbit #6	3.5808	32.1754
3/8/2022	De-orbit #7	3.5592	28.6161
3/10/2022	De-orbit #8	3.5381	25.0780
3/15/2022	De-orbit #9	3.5174	21.5606
3/17/2022	De-orbit #10	3.4971	18.0634
3/22/2022	De-orbit #11	3.4773	14.5862
3/24/2022	De-orbit #12	3.4578	11.1284
3/29/2022	De-orbit #13	3.4386	7.6898



Predicted Solar Flux Data

April 2016 Schatten and March 2016 DAS





Constellation Envelope



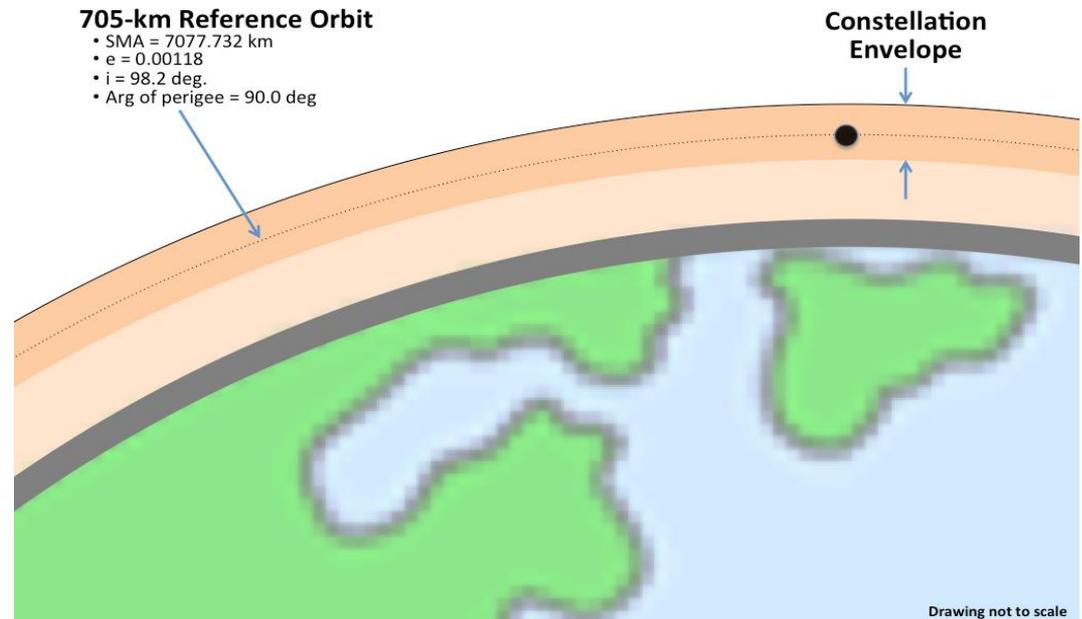
Definition

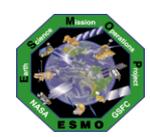
- All additional options are based on being completely **outside** the Constellation “envelope” and are represented by the following equation*:

$$|sma_R - sma_B| - |sma_R * e_R - sma_B * e_{BMax}| > \text{Margin} + \text{Frozen Orbit Tolerance}$$

Where:

- sma_R = Mean semi-major axis of the 705km Reference Orbit
- e_R = Mean eccentricity of the 705km Reference Orbit
 - Margin = 2.5 km
- Frozen Orbit Tolerance = 1.5 km and is based on a maximum eccentricity deviation of 0.0002
- B subscript references the satellite in question (e.g. Terra)





Debris Risk Study Results

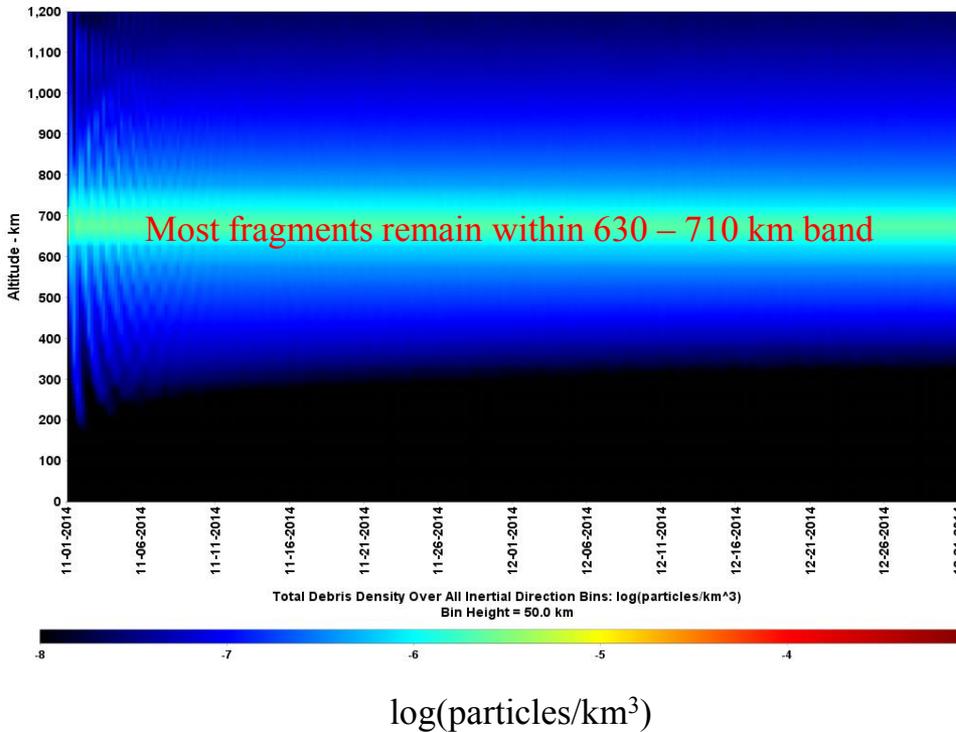


- Aerospace Corp tasked to review risk to Constellation if proposal approved

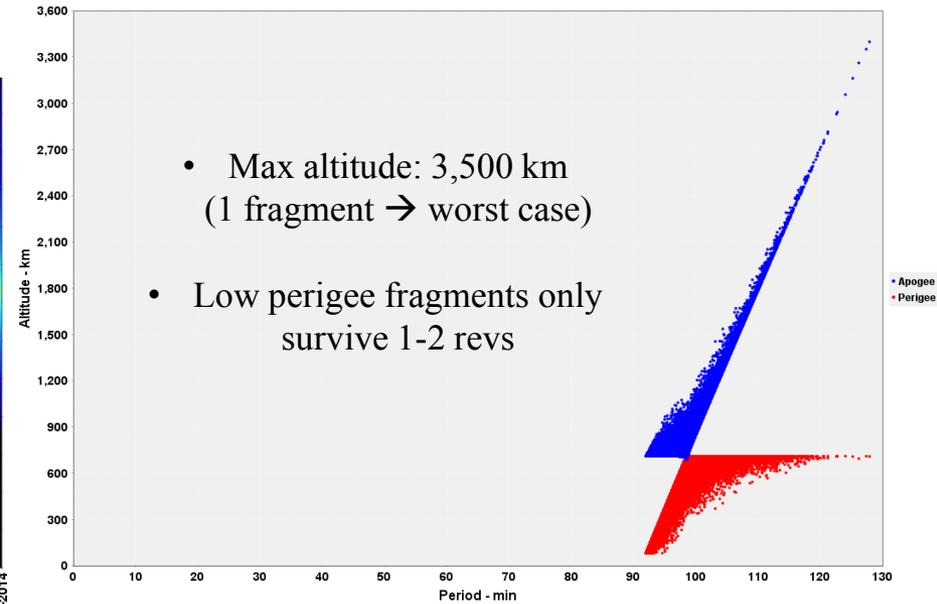
Aerospace Corp. Debris Risk Assessment Results

Debris Distribution by Altitude (60-Day)

100% Terra Breakup

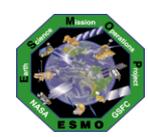


Gabbard Plot of Fragment Distribution



Debris field is spread over thousands of kilometers

- Debris field is concentrated over **80km** band
- Debris spreads over **3000kms** of orbit altitude = **No “Safe” Disposal Orbit** (other than the ocean)



Debris Risk Study Results (cont)



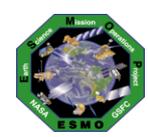
- **Difference in Risk is SMALL:** The Aerospace Corporation found for a 100% breakup of Terra

Worst-Case Risk	Probability	Delta	Odds
Current	9.20E-06		1 in 108,700
Terra break-up @ 19km	9.70E-06	5.4%	1 in 103,100
Terra break-up @ 4km	1.00E-05	8.7%	1 in 100,000

Perspective

- From NOAA website (US only) -> Odds of being struck by lightning in your lifetime (80 years) = **1 in 12,000**
 - Odd of **dying** in a car accident (US only) = **1 in 4,000-8,000/year** ; **1 in 50-100/lifetime**
 - Odds of hitting Powerball jackpot = **1 in 175,223,510**
- **Other LARGE objects close by:** Based on a review of SATCAT at JSpOC, there are currently **772 other objects** with a cross sectional area greater than **12.6 square meters** or a radius larger than 2 meters that cross through altitudes of **685 to 725 km**.
 - Approximately 103 of these objects are in near circular orbits such that they remain within the altitude band for most if not all of their orbit. For comparison then, there are **already 103 Terra-sized objects** near enough to the 705 km constellation to **create a risk similar** to the results reported in this study.

- **Risk to Constellation between exit at 19km vs. 4km is very SMALL ($\Delta=3.3\%$)**
 - **Risk exists today and in the future, regardless of what Terra does**



Terra Science Team Meeting Results

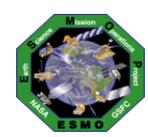


- **Attendees:** NASA Program Exec, Project Scientist, Mission Director, Instrument Team Leads, Instrument Scientist, Instrument Data Processing experts, JPL Management & Flight Dynamics expert

- **Topics covered**
 - Future Lunar Deep Space Calibration Maneuver (LDSC)
 - Future maneuver plans (Baseline & Proposed or Other Options)
 - Impacts to each instruments science data due to an MLT or Altitude change
 - Content of report & recommendation from the team to NASA HQ and Science Panel

- **Meeting Summary**
 - As stated by 2015 Senior Review Panel, Terra will continue to collect high quality data of sufficient value to warrant mission continuation regardless of if waiver is approved
 - Longer science record (closer to 20 years) increases probability that secular climate trends can be distinguished from inter-annual variability
 - A change in MLT of 15 mins equates to a 1% change in cloud fraction for boundary layer stratocumulus clouds
 - A change in MLT of 15 mins equates to a 1°C change in mean land surface temperature or 0.025 °C in sea surface temperature
 - Change to Altitude & Inclination (MLT) will change WRS-2 ground track & 16 day repeat cycle
 - Change to Altitude will require changes to Level 1 processing for both ASTER and MISR
 - Changes will take approximately 1 year for ASTER and 2 years for MISR

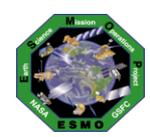
- **Decisions Made**
 1. Lunar Deep Space Calibration Maneuver will take place in July 2017 regardless of waiver approval
 - May perform Deep Space Calibration without the moon for CERES at some future data as well
 2. Recommendation from instrument teams and project scientist will be to request the 3 additional years at the current MLT and altitude



Terra Science Team Meeting Results



- **Other Options Maneuver Plans to be analyzed**
 - 3. Stop all IAMs now (Savings of 4 IAMs to Baseline plan)**
 - Perform 4+ Km Constellation Exit after LDSC (early 2018)
 - Drift MLT to 9am (or farther)
 - Use all remaining fuel to lower orbit – Bookkeeping method with conservatism used as fuel estimate
 - 4. Continue with next 4 IAMs (as planned in Baseline plan)**
 - Perform 4+ km Constellation Exit after LDSC (early 2018)
 - Drift MLT to 9am (or farther)
 - Use remaining fuel to lower orbit
 - a) **Bookkeeping method with conservative fuel estimate**
 - b) **PVT/Expected fuel (13.2 kgs more) plus additional fuel from lines (3.5 kgs) = 16.7 kgs possible extra fuel**
 - » **5 kg of propellant is assumed unusable** (will remain in propulsion lines) - **Believed to be overly conservative value**
 - Spacecraft manufacturer has since estimated 1.5 kg (with worst case of 3.9 kg)
 - The remaining 1.1 - 3.5 kg will be conserved for future RMMs
 - One RMM approximately 0.1kgs of fuel, so approximately **11-35 RMMs** in reserve
 - Only **10 RMMs** performed on Terra since launch (15+ years)
- **Next Steps**
 - Present summary of findings from meeting to Science Panel and NASA HQ (4/6) – **COMPLETE**
 - **Feedback from panel is that there is a science case to justify requesting the proposed 3 years of tight MLT and current altitude**
 - Perform analysis on potential other options (listed above) to be ready if waiver is denied
 - **Expected completion by June 2016**
 - Provide analysis to decision makers and await final decision



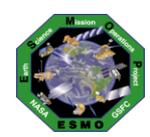
Disposal Orbits

Time-on-Orbit Comparisons



- ***If the Operational Area (40.5 m²) was used for the area-to-mass ratio.***
- ***A/M = 0.00914.***

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Questions