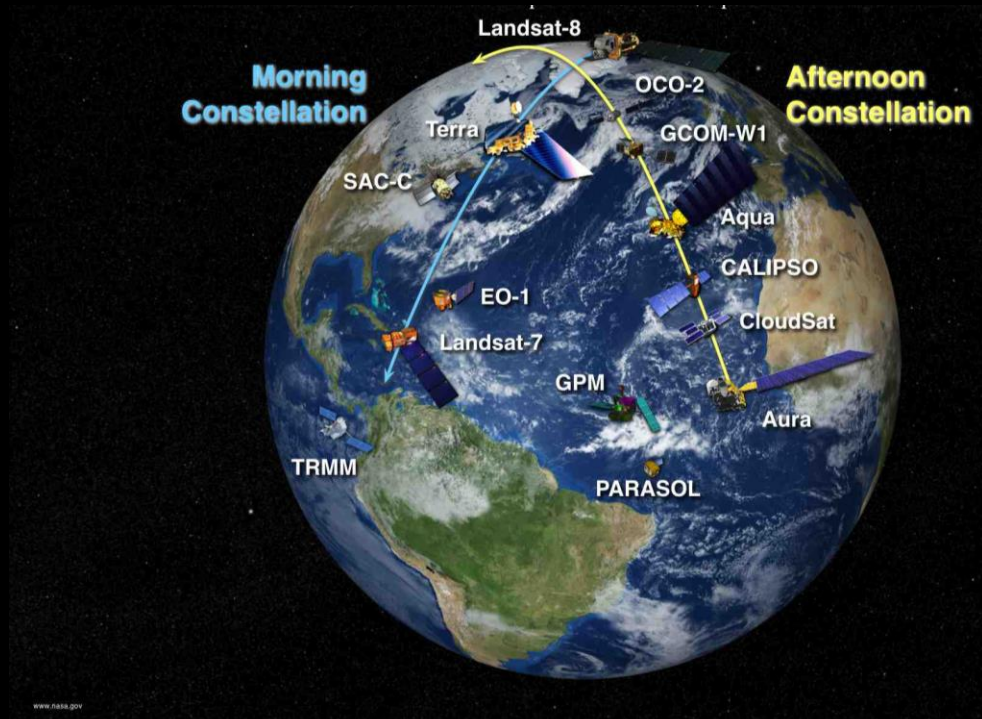

United States Brazil Canada Finland France Japan Netherlands United Kingdom

International Earth Science Constellation Mission Operations Working Group

June 2-4, 2015

Terra Future Maneuver Plans

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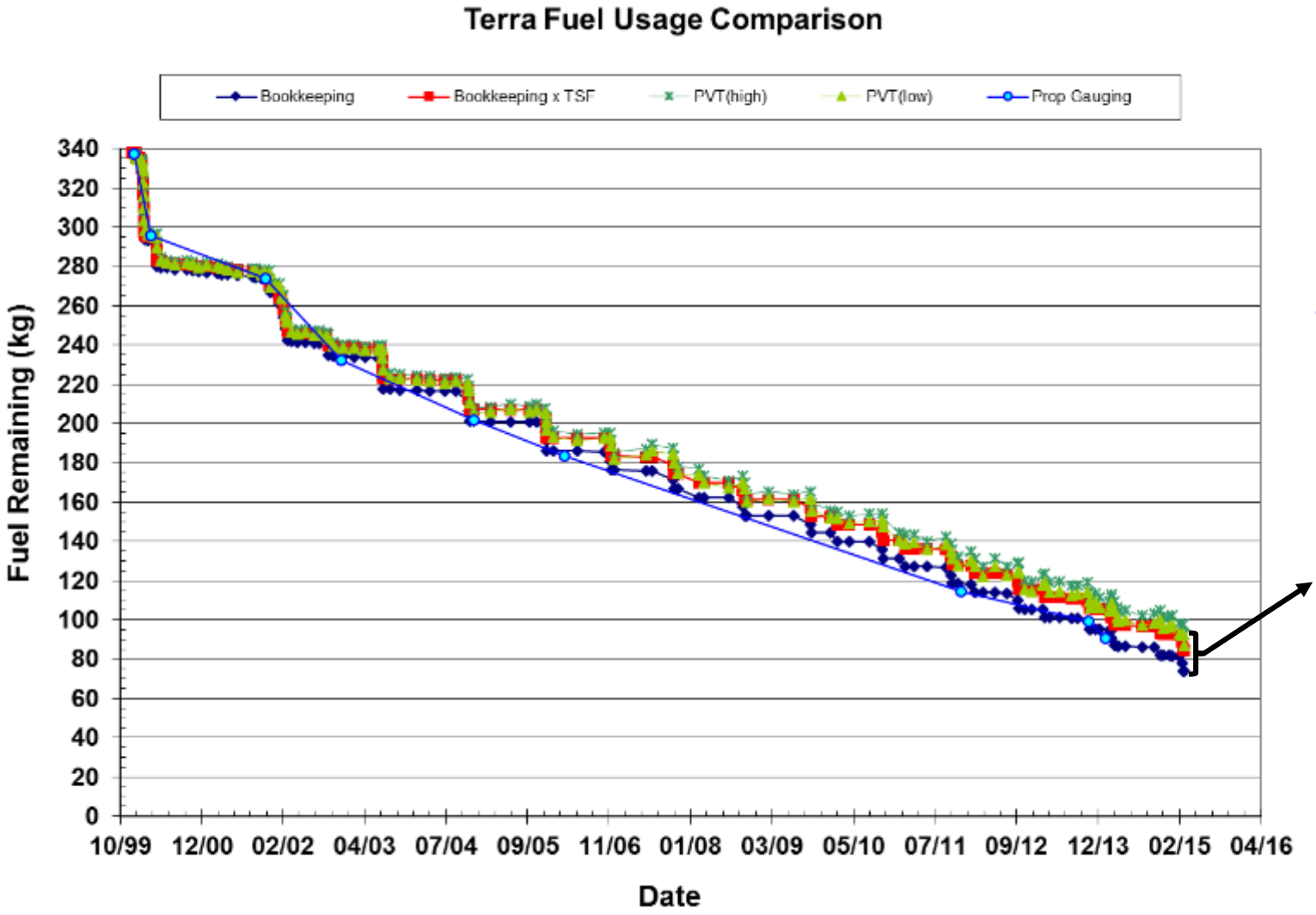
Agenda

- Fuel Usage Based on Multiple Estimation Strategies
- Terra Requirements Overview
- 19 km vs. 4 km
- Analysis Assumptions
- Maneuver Plans Through 2017
- Maneuver Plans Beyond 2017
  - Option A
  - Option B

Fuel Usage Based on Multiple Estimation Strategies



All analyses based on "worst case" fuel levels

10-15 kg span using varying estimation types

Terra Requirements Overview
Level 1 Mission Requirements

- Mean Local Time at the Descending Node
  - 10:15 to 10:45 AM
- Mean Semi-Major Axis Height
  - 705 km
- Altitude Range
  - 694 to 711 km
- Repeat Ground Track
  - 16 day cycle

Note: Verification of requirements in progress, slide still in work

19 km vs. 4 km Origin

- 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
- Based on the **2014** Constellation Coordination Plan just 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

Analysis Assumptions

- **Terra will perform 320-second retrograde constellation exit maneuvers centered at apogee or perigee**
  - The maneuver burn durations are restricted to 320 seconds due to attitude disturbances on burn durations longer than 320 seconds
- **Maneuvers will be executed in pairs** (1 apogee, 1 perigee)
  - ~300 minute settling time in between burns
  - Maneuver pairs on Tuesdays & Thursdays
- **5 kg of propellant is assumed unusable *in the analysis***
  - Spacecraft manufacturer estimates 1.5 kg - 3.9 kg of fuel will remain in propulsion lines
  - The remaining 1.1 - 3.5 kg will be conserved for possible RMMs prior to passivation
    - One RMM is ~0.1kg of fuel, leaving roughly **11-35** RMMs in reserve
    - Only **8** RMMs performed on Terra since launch (15+ years)
  - All plans use the most conservative estimate for the initial fuel level and the most conservative prediction method for future maneuvers

Maneuver Plans *Through* 2017

- The table below summarizes the results of the **Terra** lifetime maneuver simulation:

Mission Year (--)	Inclination Maneuvers (--)	Delta Inclination (Deg)	DMU Maneuvers (--)	Fuel Used (kg)	Fuel Remaining (kg)
2014	2 Spring, 1 Fall	0.036131	8	13.024	81.811
2015	2 Spring, 1 Fall	0.033869	4	12.202	69.609
2016	1 Spring, 2 Fall	0.033105	2	11.350	58.259
2017	2 Spring, 2 Fall	0.043276	2	14.624	43.635

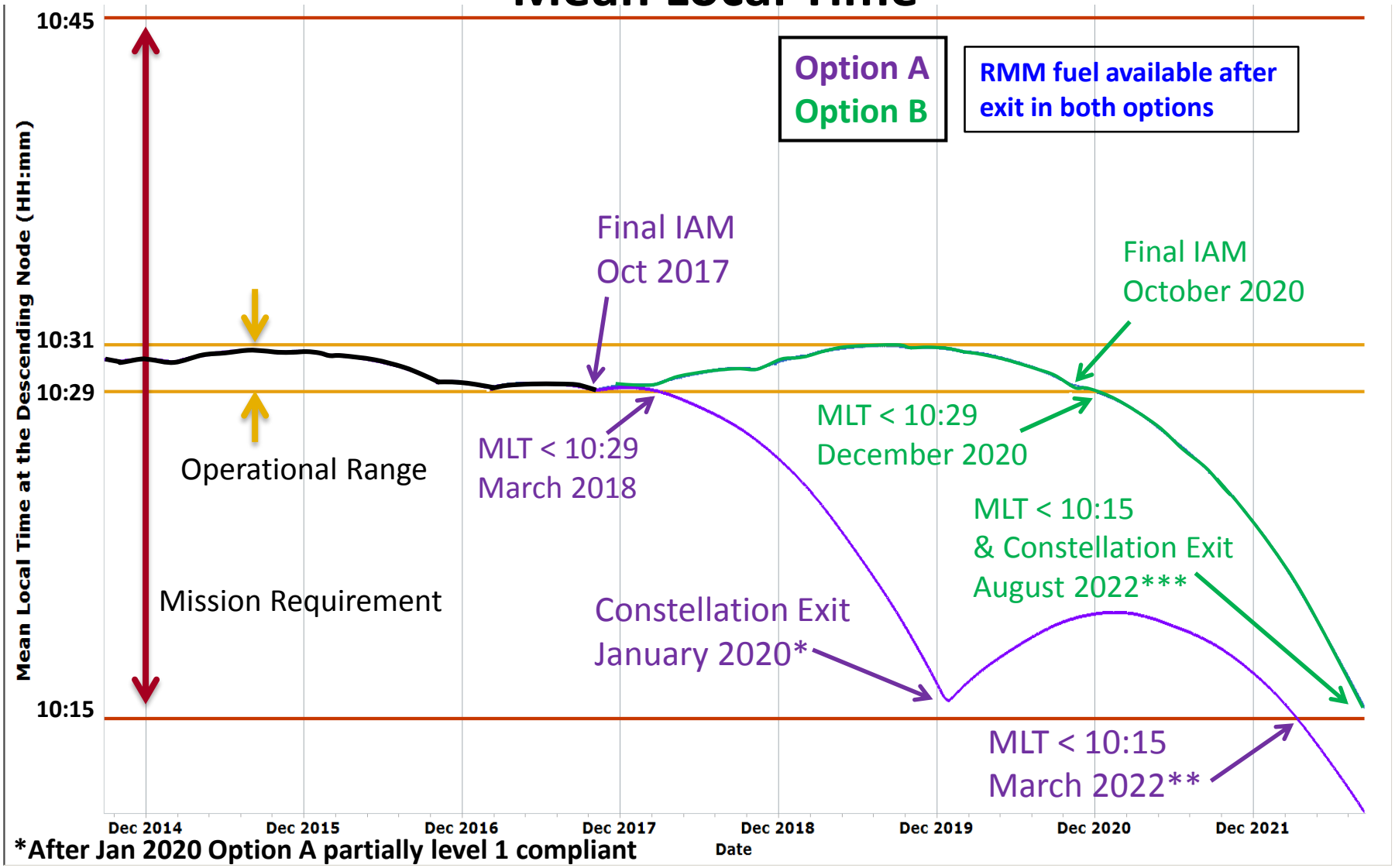
-

Maneuver Plans *Beyond* 2017

- **Option A**
  - Formerly “Baseline Plan”
  - Lowers Terra at least **19 km** below the constellation
- **Option B**
  - Formerly “Proposed Plan”
  - Lowers Terra at least **4 km** below constellation

Maneuver Plans *Beyond* 2017

Mean Local Time



*After Jan 2020 Option A partially level 1 compliant

**After Mar 2022 Option A not Level 1 compliant

***After Aug 2022 Option B not Level 1 compliant

Maneuver Plans *Beyond* 2017

Option A

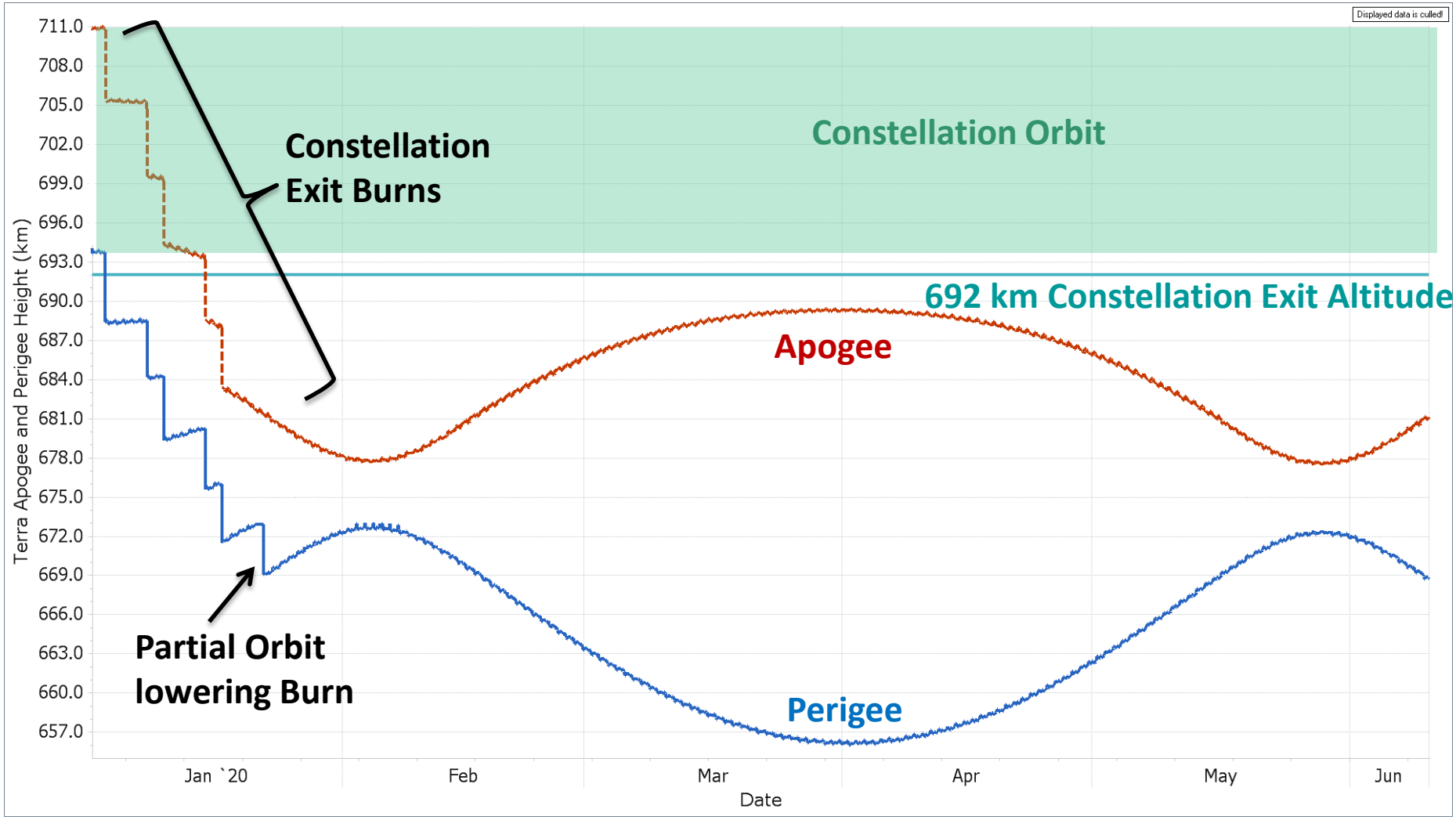
- The table below summarizes the results of the **Terra** lifetime maneuver simulation:

Mission Year (--)	Inclination Maneuvers (--)	Delta Inclination (Deg)	DMU Maneuvers (--)	Fuel Used (kg)	Fuel Remaining (kg)
2018	0 Spring, 0 Fall	0	2	0.214	44.578
2019	0 Spring, 0 Fall	0	2	0.160	44.418

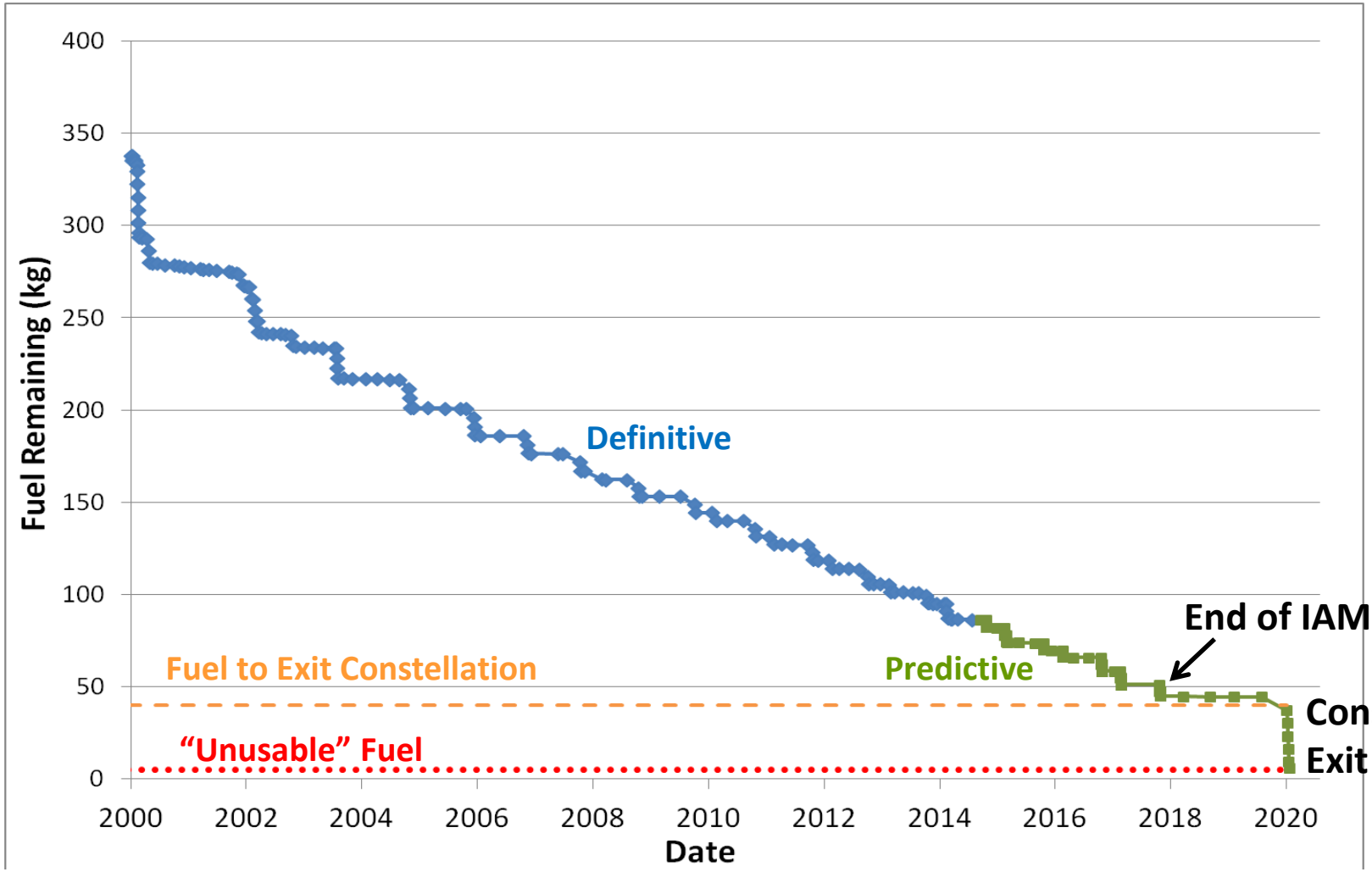
- ~45 kg of fuel are needed for constellation exit
  - Includes the 5 kg of unusable fuel
  - 10 maneuvers to exit constellation
- **Note**: This is only a representative maneuver scenario given the current mission requirements and solar flux predictions.

Maneuver Plans *Beyond* 2017 - Option A

Apogee and Perigee Height - 2020



Maneuver Plans *Beyond* 2017 - Option A
Lifetime Fuel Estimates



Maneuver Plans *Beyond* 2017

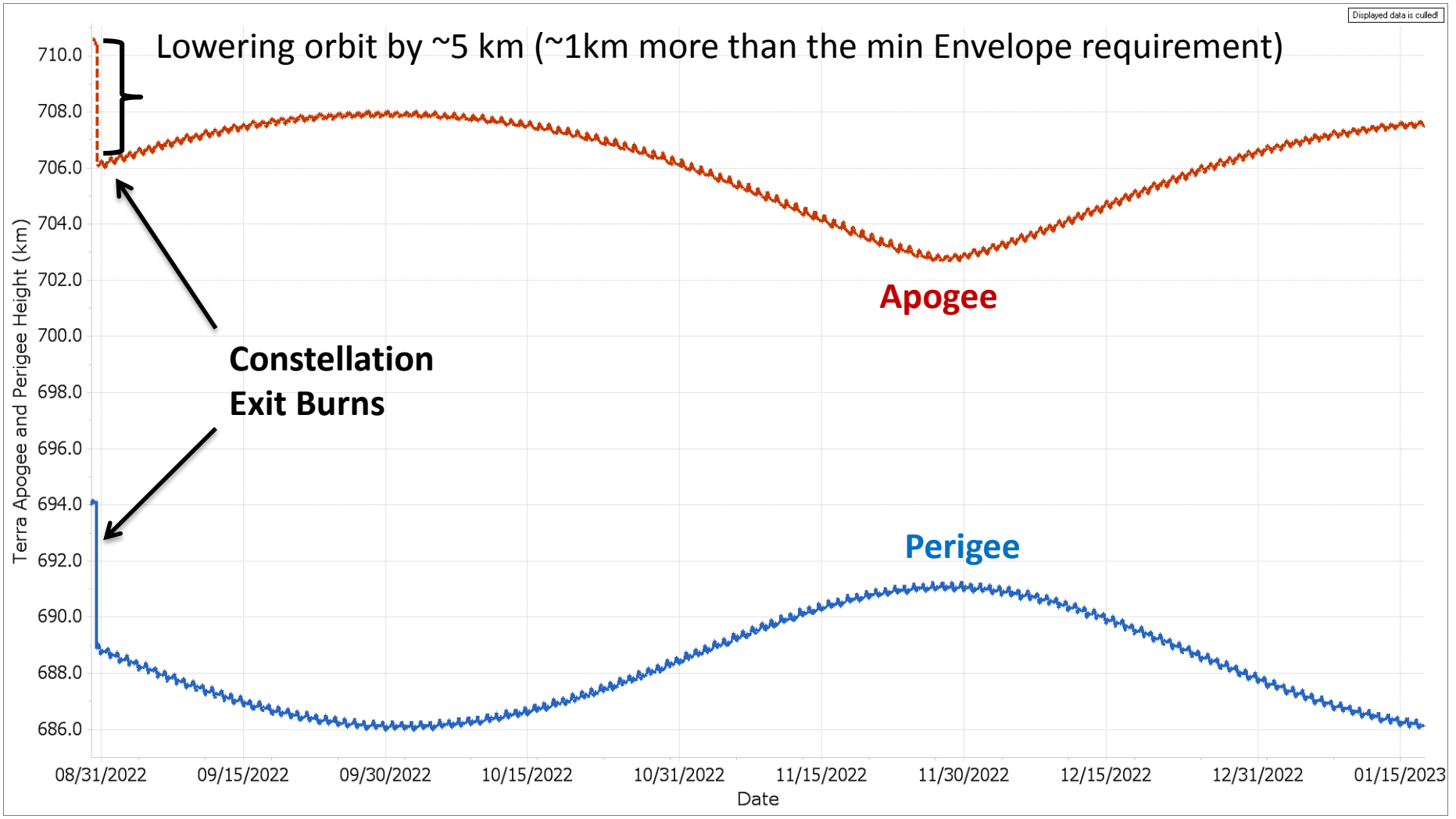
Option B

- The table below summarizes the results of the **Terra** lifetime maneuver simulation:

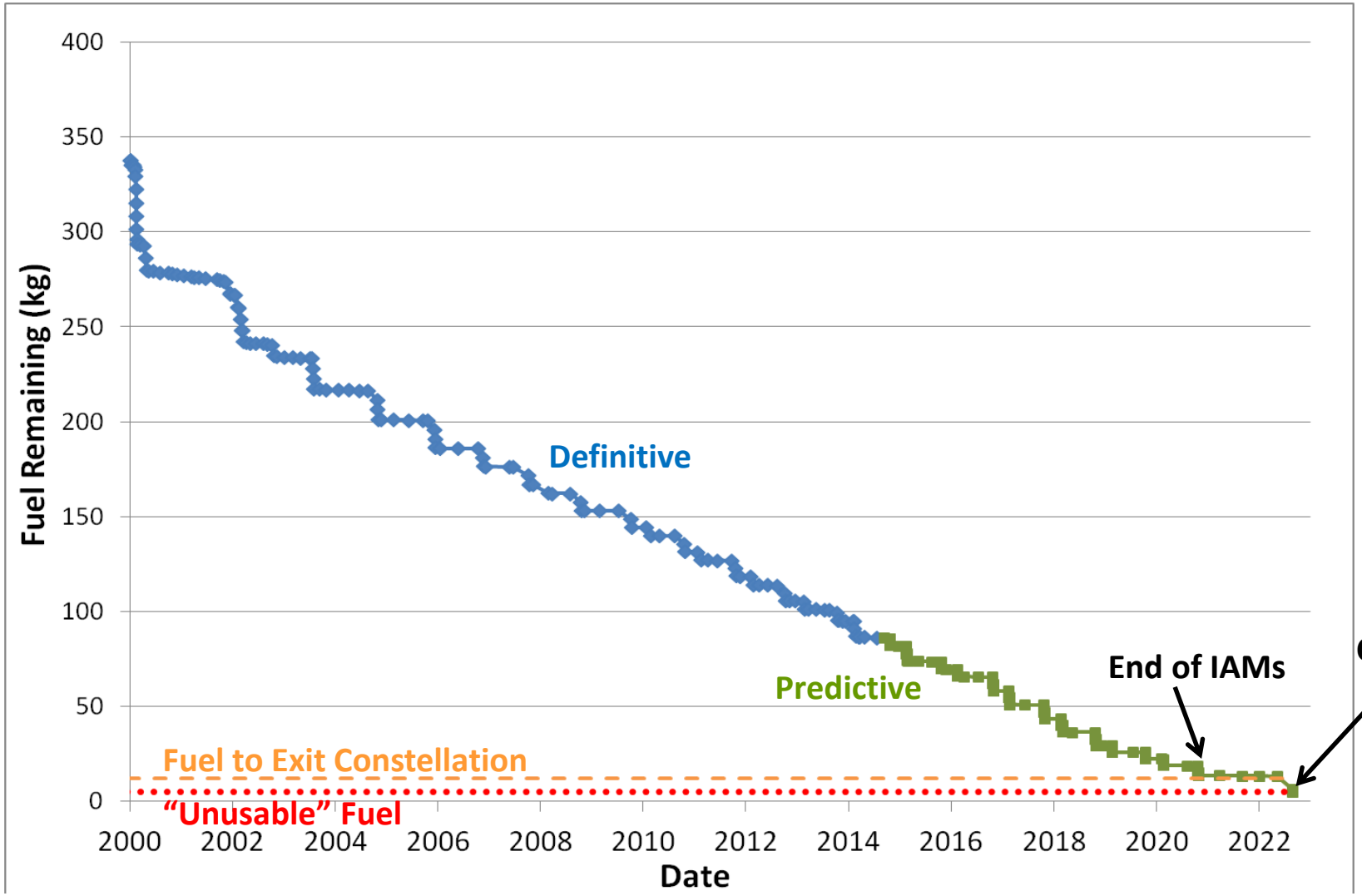
Mission Year (--)	Inclination Maneuvers (--)	Delta Inclination (Deg)	DMU Maneuvers (--)	Fuel Used (kg)	Fuel Remaining (kg)
2018	2 Spring, 2 Fall	0.041948	2	14.251	29.384
2019	1 Spring, 1 Fall	0.020578	1	6.999	22.385
2020	1 Spring, 2 Fall	0.025624	2	8.738	13.647
2021	0 Spring, 0 Fall	0	2	0.197	13.45
2022	0 Spring, 0 Fall	0	3	0.439	13.011

- ~12 kg of fuel are needed for constellation exit
  - Includes the 5 kg of unusable fuel
  - 2 maneuvers to exit constellation
- **Note**: This is only a representative maneuver scenario given the current mission requirements and solar flux predictions.

Maneuver Plans *Beyond* 2017 - Option B
Apogee and Perigee Height - 2022

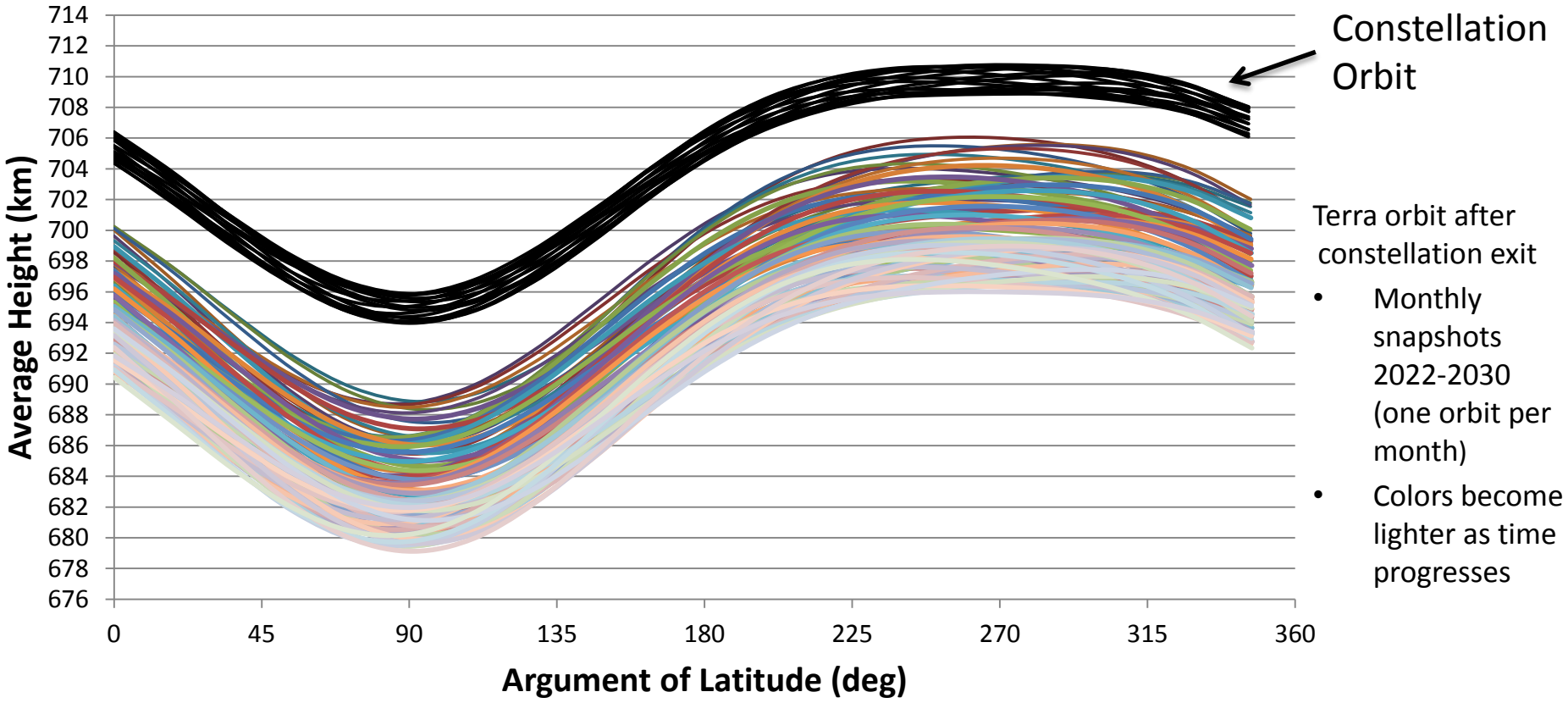


Maneuver Plans *Beyond* 2017 - Option B
Lifetime Fuel Estimates



Maneuver Plans *Beyond* 2017 - Option B

Long Term Terra Orbit After Constellation Exit



- Over eight years the orbit eccentricity remains fairly consistent, which can be seen on the plot due to the apogee and perigee remaining at similar argument of latitude locations

Date of Interest Summary

Plan Name	Analysis Year	Last IAM Date	Date Crossing 10:29AM MLTDN	Constellation Exit Date	Date Crossing 10:15AM MLTDN
Option A	Fall 2014	Oct 2017	Mar 2018	Jan 2020	Mar 2022
	Spring 2015	Mon 20YY	Mon 20YY	Mon 20YY	Mon 20YY
Option B	Fall 2014	Oct 2020	Dec 2020	August 2022	August 2022
	Spring 2015	Mon 20YY	Mon 20YY	Mon 20YY	Mon 20YY

Note: Items in red still to be updated

QUESTIONS?

For any questions or comments in the future please contact:

ESMO-EOS-FDS@lists.nasa.gov

Back-Up Slides

- Constellation Exit Equation
- Drag Models

Maneuver Plans *Beyond* 2017 - Option B

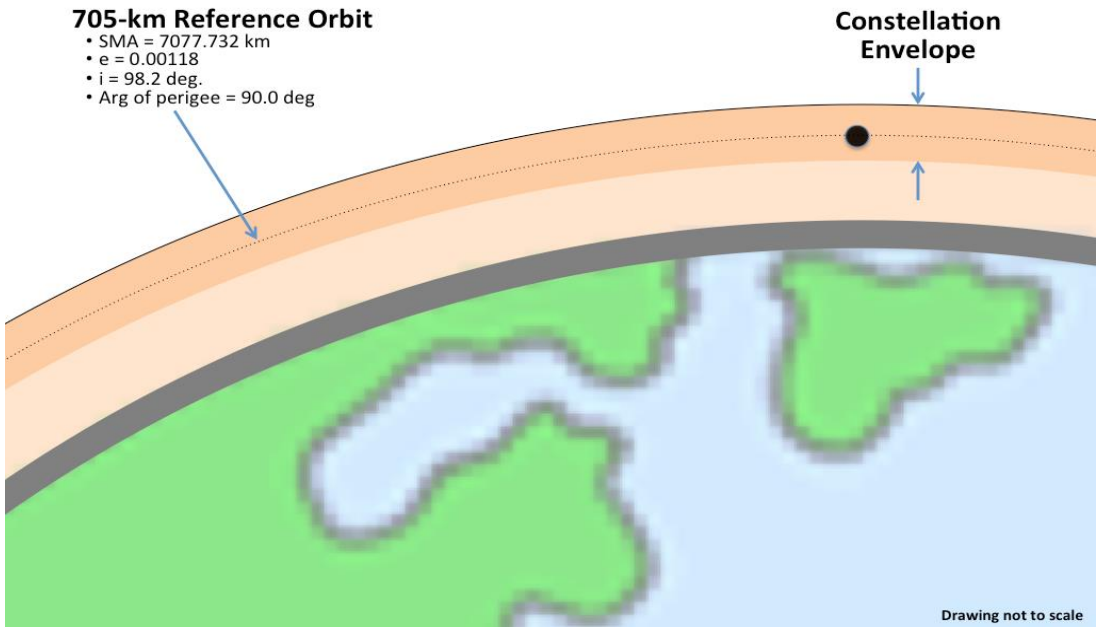
Definition

- Based on being the constellation "envelope" and is represented by completely **outside** the following equation:

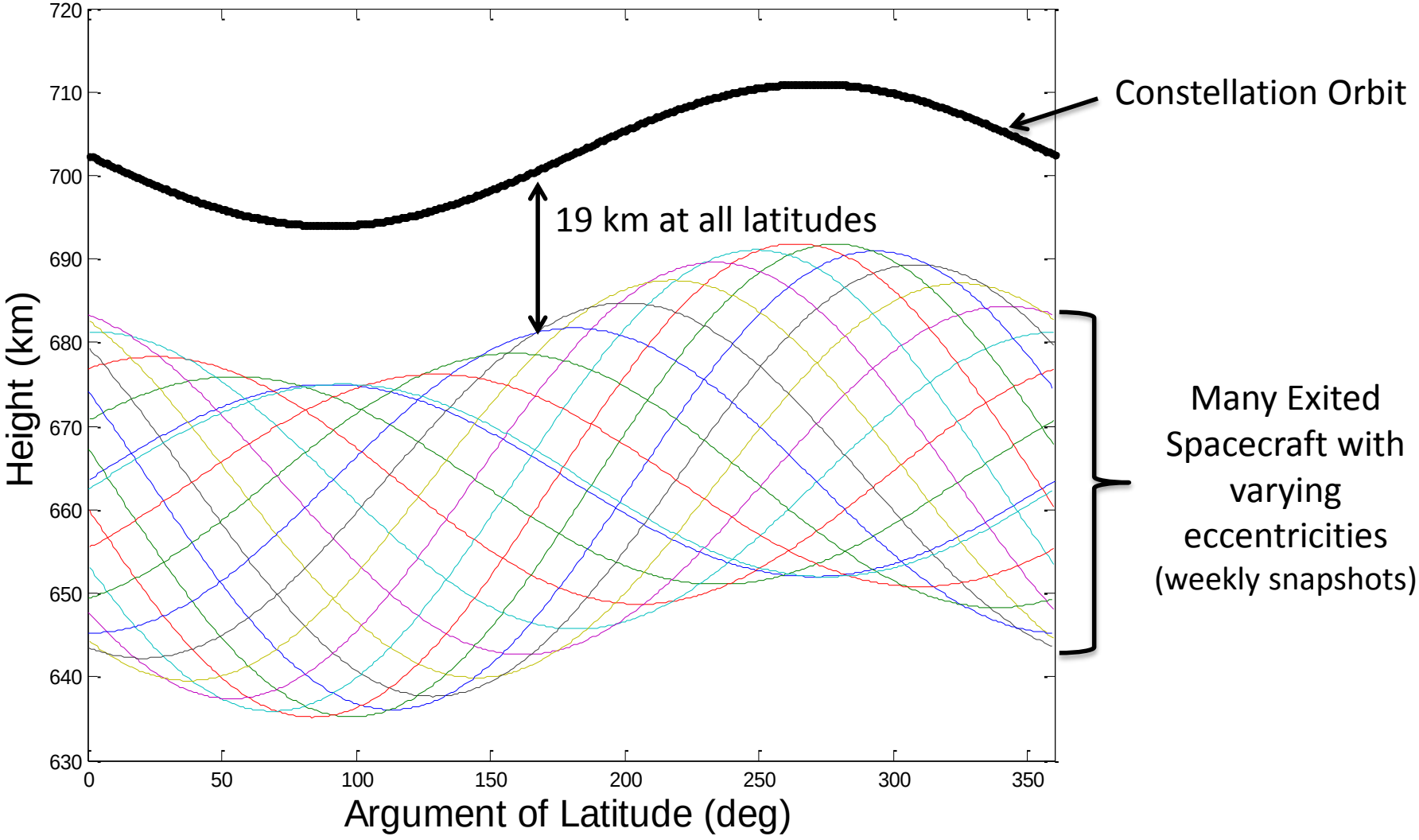
$$\left|sma_R - sma_B\right| - \left|sma_R * e_R - sma_B * e_{BMax}\right| > \text{Margin + Frozen Orbit Tolerance}$$

Where:

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

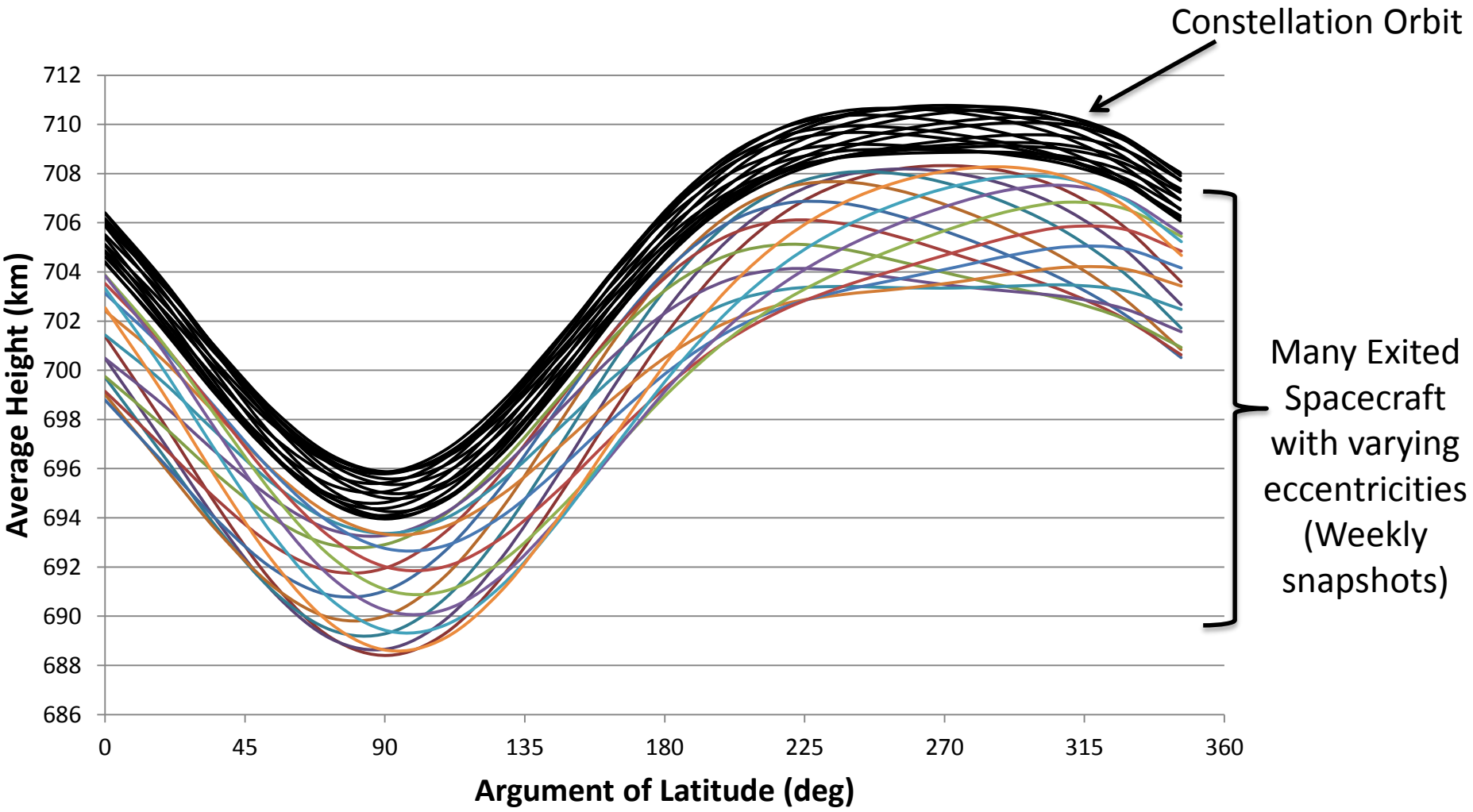


2010 Constellation Exit Definition – Option A
Exited Spacecraft and the Constellations



Source: Jonathan Brown March 2013 MOWG

2014 Constellation Exit Definition – Option B
Any Exited Spacecraft and the Constellations



Maneuver Plans *Beyond* 2017 - Option A
Comparison to Fall 2014 MOWG Plans

Analysis Year	Last IAM Date	Date Crossing 10:29AM MLTDN	Date Crossing 10:15AM MLTDN	Constellation Exit Date	Date Crossing 10:15AM MLTDN
Fall 2014	Oct 2017	Mar 2018	Jan 2020	Jan 2020	Mar 2022
Spring 2015	Mon 20YY	Mon 20YY	Mon 20YY	Mon 20YY	Mon 20YY

- Fall 2014 and Spring 2015 IAM performance
  - Predicted delta-i: 0.035580 deg
  - Achieved delta-i: 0.036490 deg
- Other contributing factors
  - TBD, needs more updates from post-IAM analysis

Maneuver Plans *Beyond* 2017 - Option B
Comparison to Fall 2014 MOWG Plans

Analysis Year	Last IAM Date	Date Crossing 10:29AM MLTDN	Date Crossing 10:15AM MLTDN	Constellation Exit Date
Fall 2014	Oct 2020	Dec 2020	Aug 2022	Aug 2022
Spring 2015	Mon YYYY	Mon YYYY	Mon YYYY	Mon YYYY

- Fall 2014 and Spring 2015 IAM performance
  - Predicted delta-i: 0.035580 deg
  - Achieved delta-i: 0.036490 deg
- Other contributing factors
  - TBD, needs more updates from post-IAM analysis