



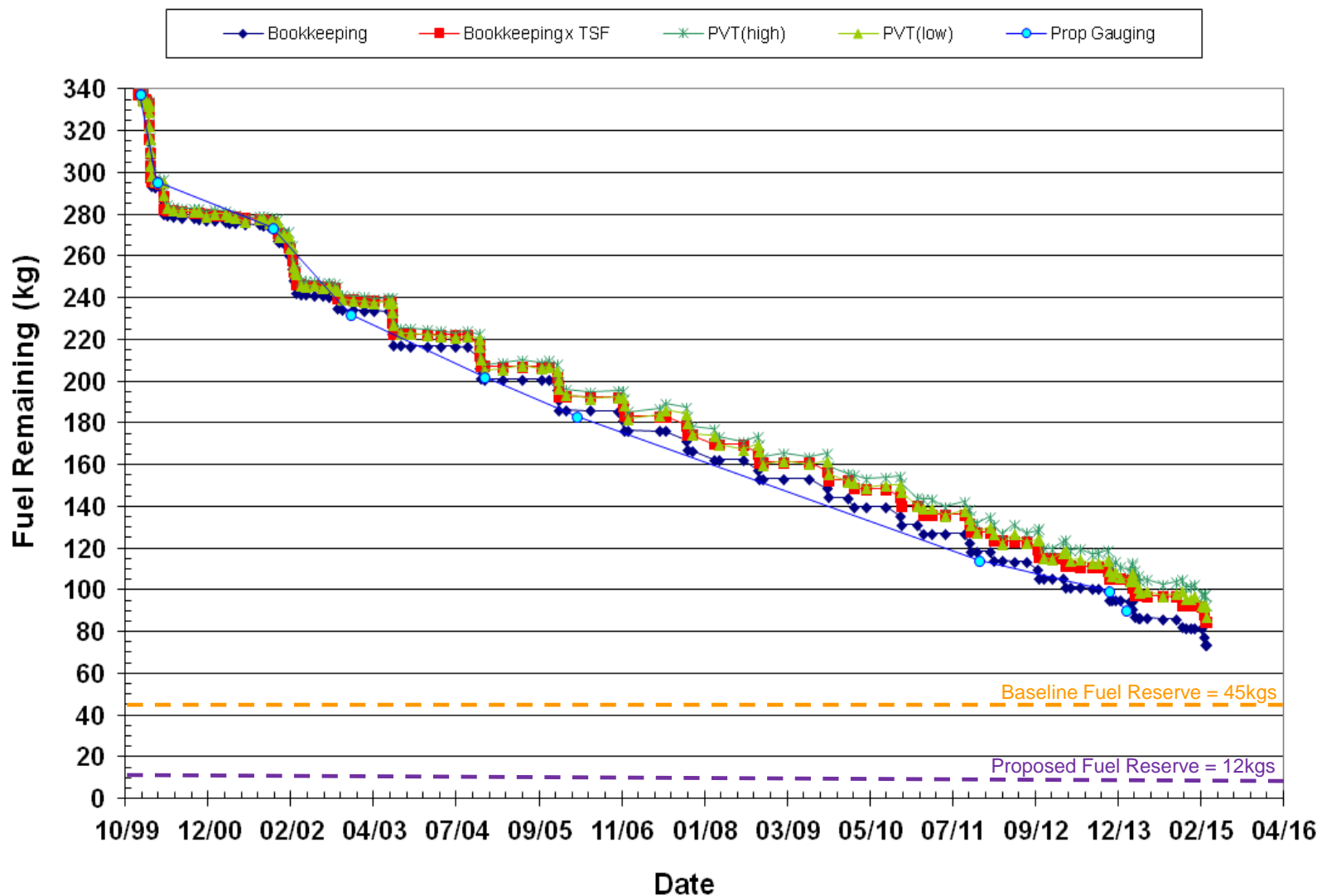
Terra Constellation Exit (Part 2)

Dimitrios Mantziaras – Terra Mission Director

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

Terra Fuel Usage Comparison

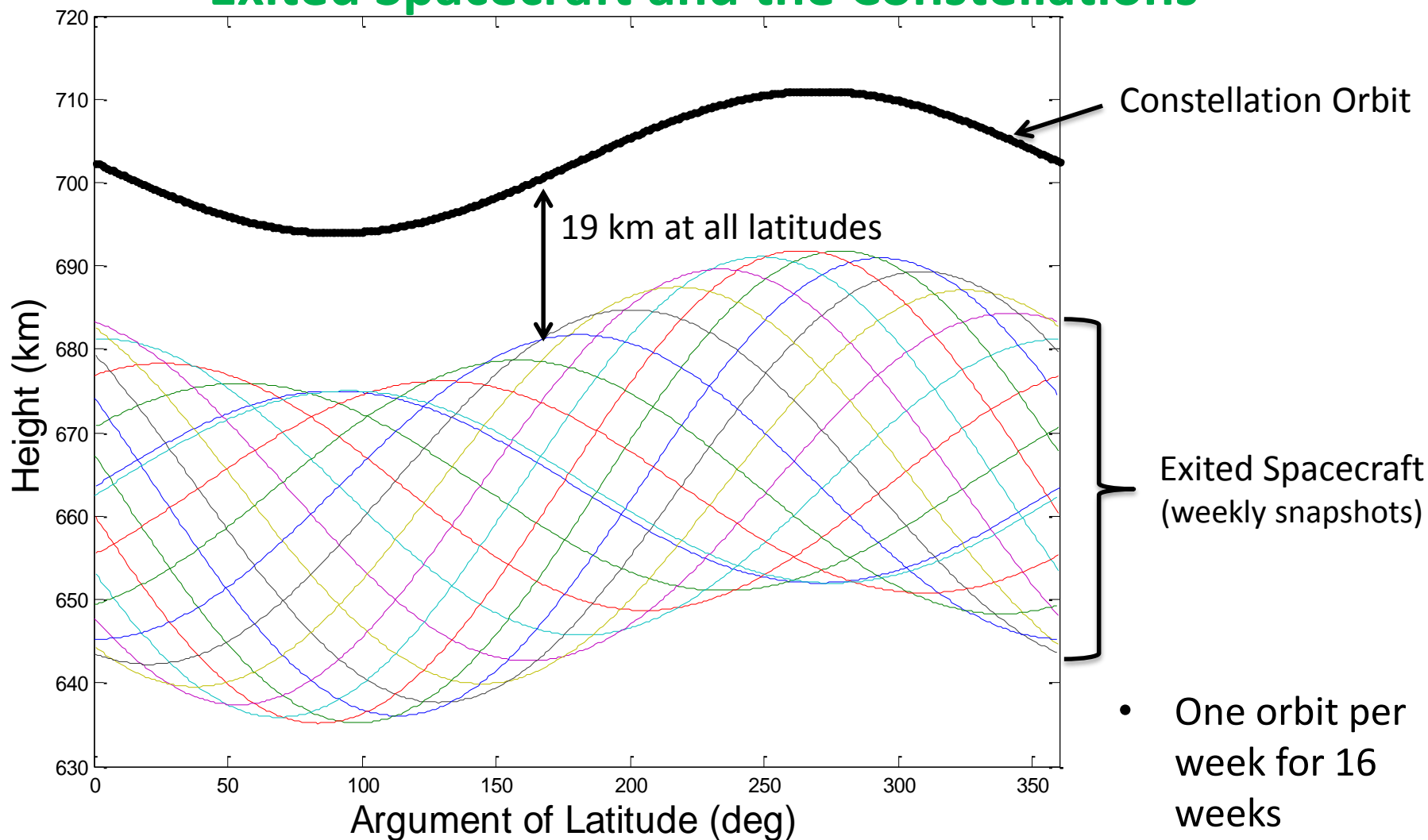


19 km vs. 4 km Origin

- 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

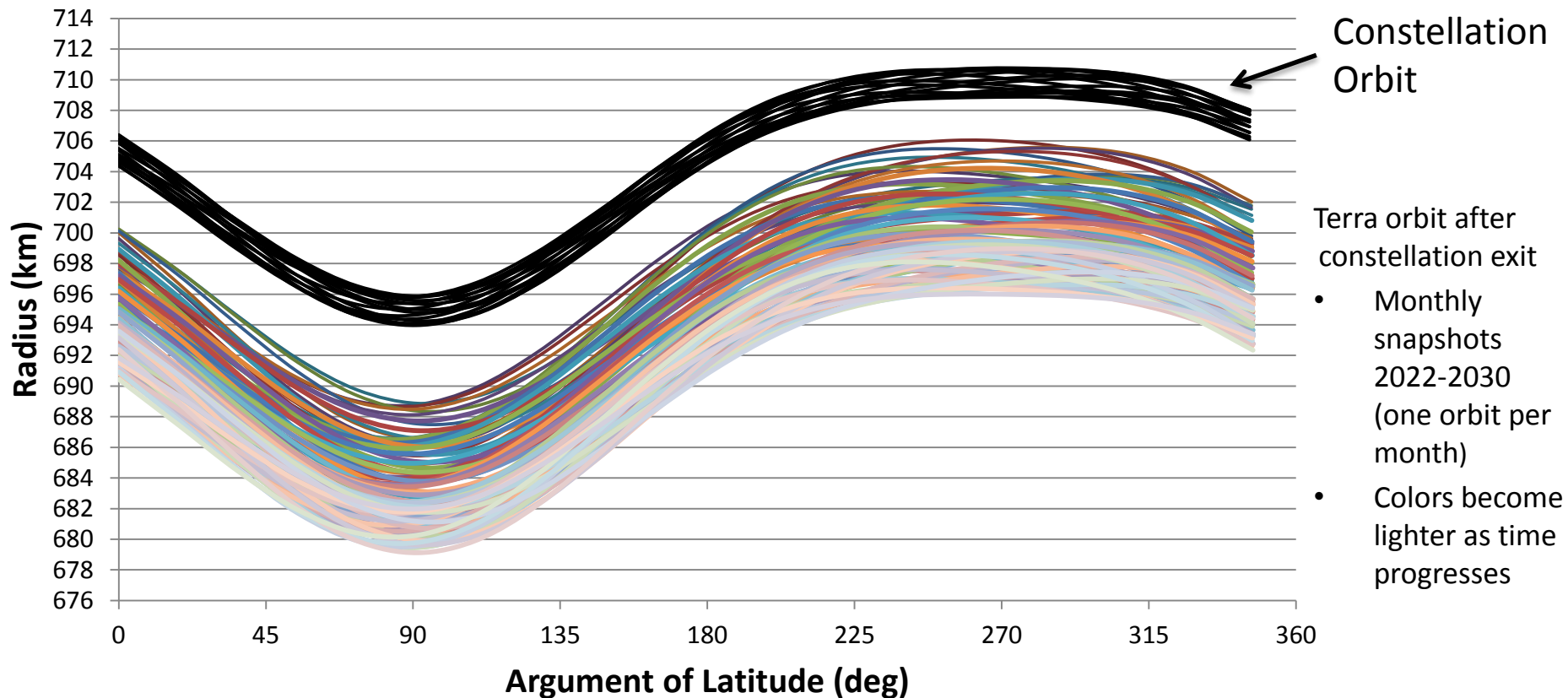
Baseline Constellation Exit Plan

Exited Spacecraft and the Constellations



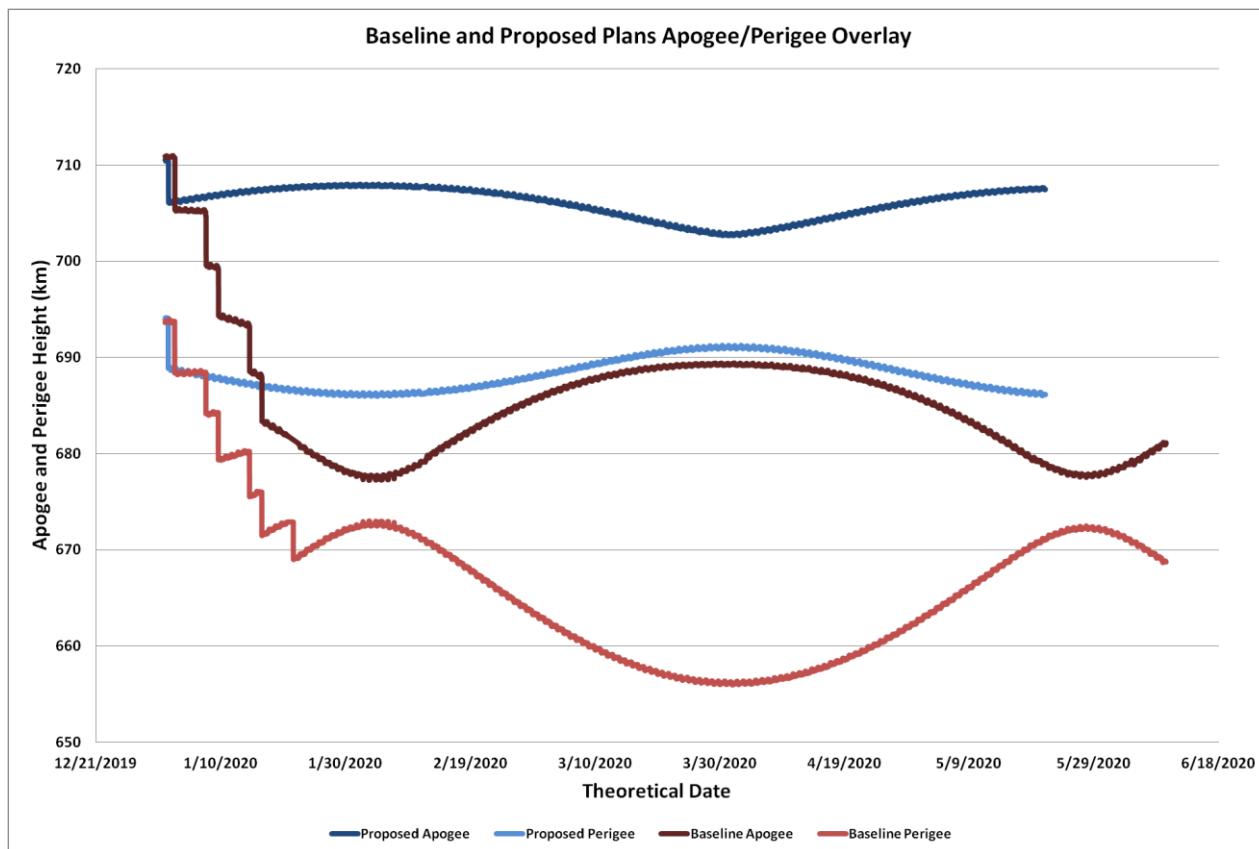
Proposed Constellation Exit Plan

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

Baseline vs. Proposed Orbit Overlay



Orbit Altitude

Proposed = 708km x 686km

Baseline = 690km x 656km

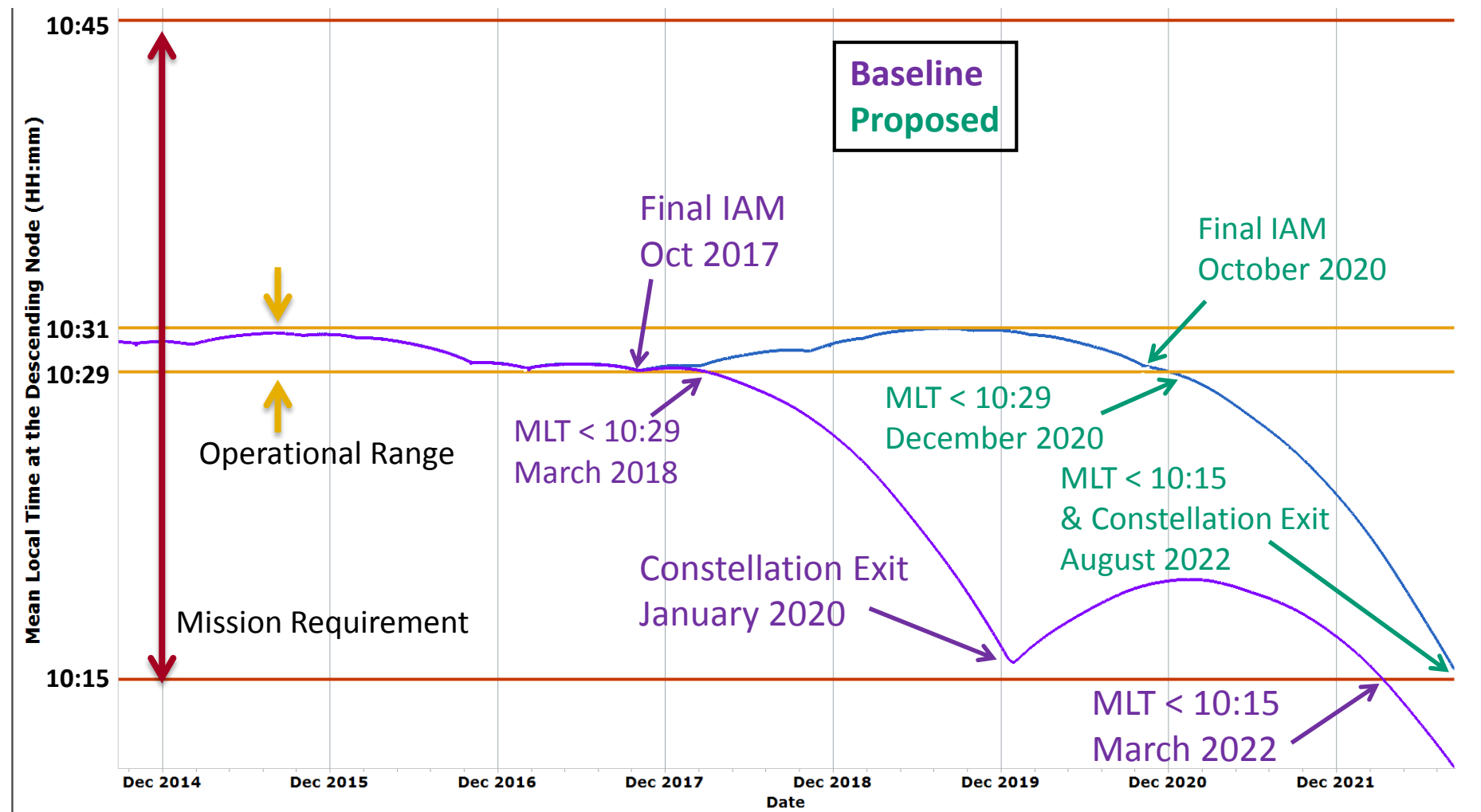
Delta = 18km x 30km

Re-entry timeline

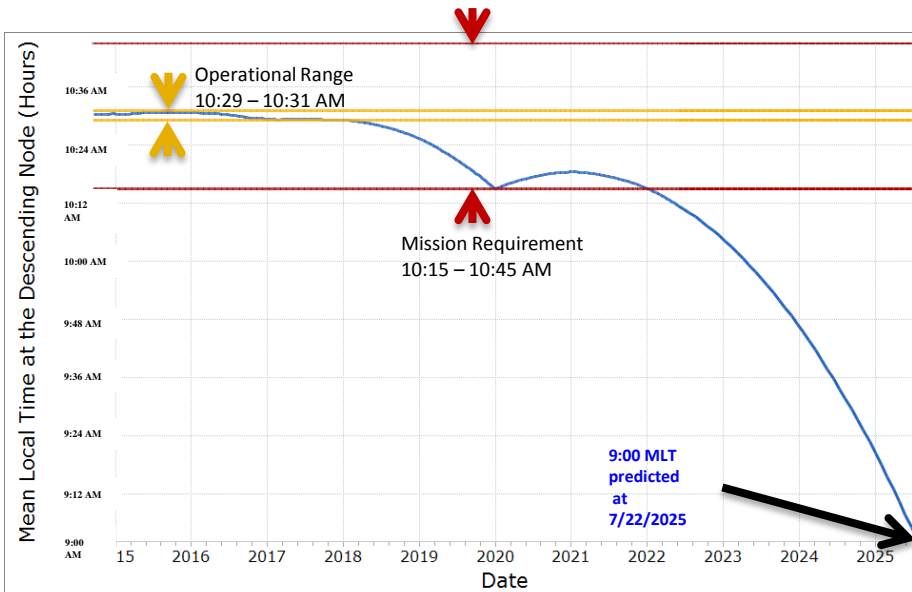
- Baseline = 2057
- Proposed = 2077

Baseline vs. Proposed Constellation Exit Plan

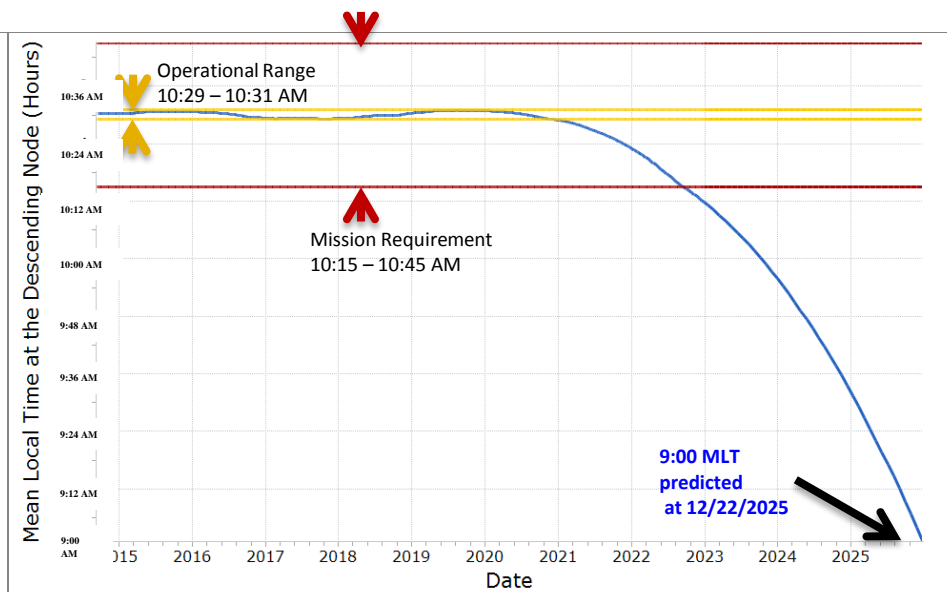
Mean Local Time Prediction



Baseline Plan Long Term Mean Local Time



Proposed Plan Long Term Mean Local Time



- 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

Obstacles to Approval

Debris Concerns

- **During Peer Review of Proposed Plan (July 2014), a concern was raised regarding possible debris field if Terra had collision after constellation exit**
 - Proposed plan leaves Terra 5kms below constellation as opposed to baseline 19km
 - **NOTE****- Terra will have reserve fuel to perform RMMs for some time after constellation exit (dependent on mission performance/funding)

Analysis

- **FDS performed initial analysis showing increase in risk of debris entering constellation orbit was minimal**
 - ~4% increase worst case
- **Aerospace Corporation tasked with performing full analysis to determine difference in risk between 4km and 19km**
 - If risk too high, they will also determine a safe disposal orbit altitude



Mission Operations Working Group

June 2-4, 2015

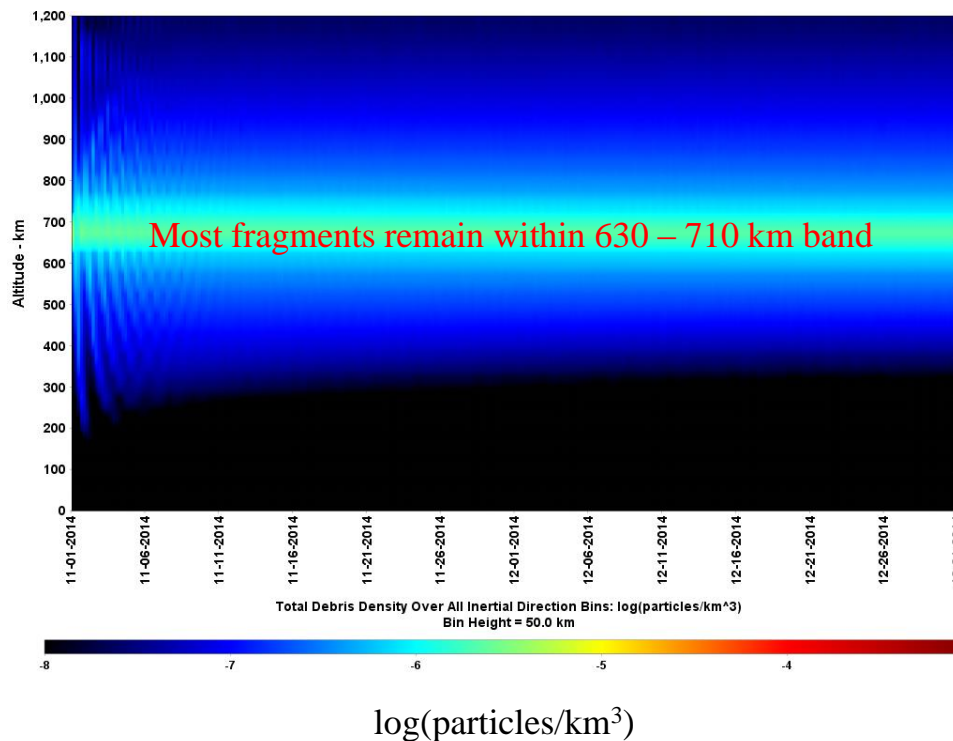


BACK-UP SLIDES

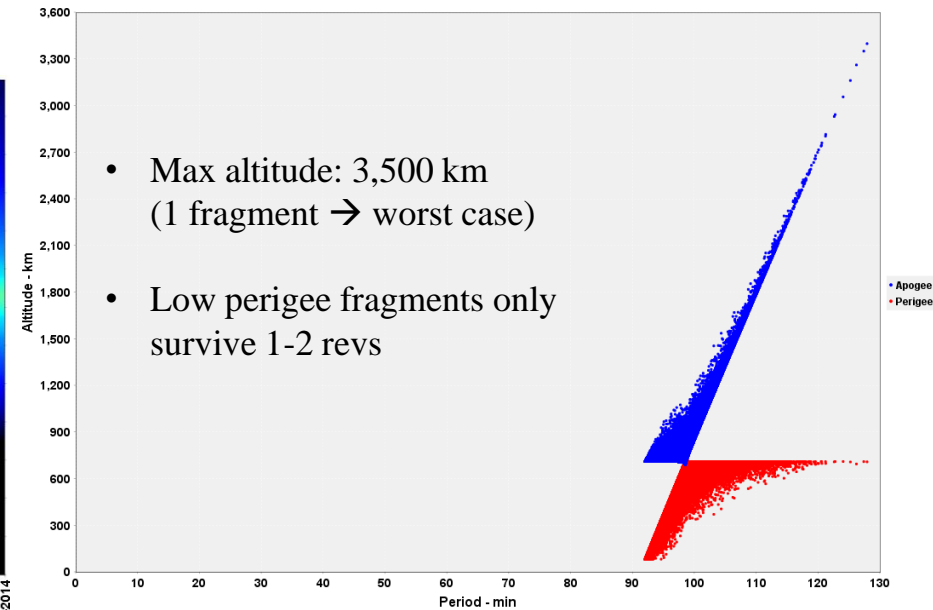
Aerospace Corp. Debris Risk Assessment Results

Debris Distribution by Altitude (60-Day)

100% Terra Breakup



Gabbard Plot of Fragment Distribution



Debris field is spread over thousands of kilometers

Conclusions from Aerospace Study

- The Aerospace Corporation finds that the increased collision risk to a typical member of the 705 km Earth Science Constellations from debris generated by a catastrophic breakup of Terra is small for both the -4 km case and the -19 km case. The long-term total risk (including background risk) due to a Terra breakup at **-19 km is 9.7×10^{-6}** , while that at **-4 km is 1.0×10^{-5}** . For perspective, note that the typical **pre-breakup** background risk is approximately **9.2×10^{-6}** impacts per day. This indicates a very modest increase in total long-term risk.

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 lightening 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**
- Another important note is that Terra, of course, is not the only object that could pose a risk to the 705 km Earth Observing Constellation if it were to collide with another object. 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.

Time to Re-entry

- **NASA Re-Entry Requirements**

“The spacecraft must reenter within 25 years after the end of the mission lifetime but no more than 30 years from mission launch.”

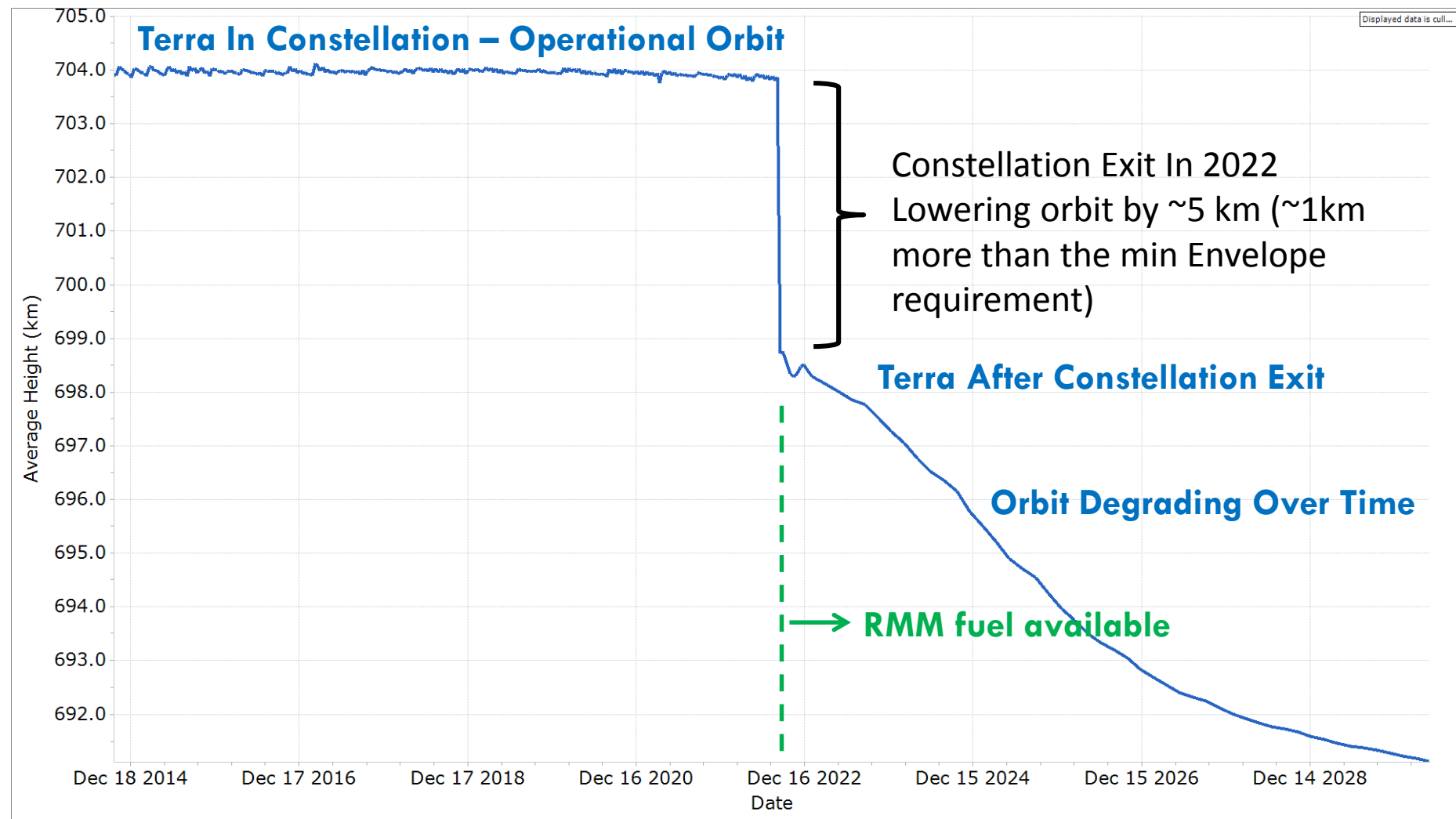
- 4.6-1 within NS8719.14
- For Terra, 30 year requirement = 2029
- Terra holds a waiver for both requirements based on the baseline plan

- **Time on Orbit Comparison**

- Used Debris Assessment Software (DAS) 2.0.2
- Looked at re-entry dates for both constellation exit plans
 - Baseline = 2057
 - Proposed = 2076
- Increases time to re-entry by 19 years

Proposed Constellation Exit Plan

Terra Average Height



Drag Models

