PACE 2012

Flight Dynamics

14 – 18 May, 2012

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Subsystem Agenda

- Overview
- Block Diagram
- Subsystem Description
- Issues / Potential Risks / Future work
- Acronym List
- Backup Material

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Subsystem Overview

- **Orbit Requirements**
  - Altitude: 700 ± 10 km circular, Sun-synchronous
  - Descending node crossing time: 12 PM ± 10 minutes
  - Global instrument viewing coverage every two days
  - Mission Duration
    - Minimum: 3 years
    - Desired: 5 years
- **Orbit Selection**
  - Epoch: October 1, 2019 00:00:00.000 Z
  - Altitude: 700 km
  - Eccentricity: 0
  - Inclination: 98.1923°
  - Right Ascension of Ascending Node (RAAN): 11.7°
    - Corresponds to 12:09 PM descending node crossing time at orbit epoch
  - Argument of Perigee: 0°
  - Mean Anomaly: 0°
  - Orbit Period: 98.77 minutes
  - Maximum Eclipse Duration: 38.6 minutes
- **Mission ΔV of 233 m/s**
- **Orbit meets all requirements for 5-year mission**
- **Solar calibration sensor half-angle of 6.8° or larger required for 2 minute calibration event every day with no maneuvers**

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Requirements and Assumptions

- **Orbit Parameters**
  - Launch Date: October 1, 2019
  - Altitude: 700 ± 10 km circular, Sun-synchronous
  - Inclination: 98.1928°
  - Descending node crossing time: 12 PM ± 10 minutes
  - Global instrument viewing coverage every two days
  - Mission Duration
    - Minimum: 3 years
    - Desired: 5 years
  - End of Mission Plan
    - Controlled re-entry. Reduce orbit perigee to 50 km with 3-4 maneuvers
- **Spacecraft Parameters**
    - Mass: 1000 kg
    - Drag Area: 12 m^2
    - Cd : 2.2
- **Launch Vehicle: Antares**
  - Launch Dispersions (3σ) (for Taurus II)
    - Periapsis: $\pm$ 15 km, ΔV = 5 m/s
    - Apoapsis: $\pm$ 85 km, ΔV = 24 m/s
    - Inclination: $\pm$ 0.15, ΔV = 21 m/s
    - Total Dispersion Correction ΔV = 50 m/s
- **Solar Flux Model: January 2012 Schatten**

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Orbital Element Selection (1 of 2)

- **Initial orbital elements selected based on Earth J2 potential model with no drag to achieve Sun-synchronous nodal rate of ≈ 0.98561°/ day**
  - Epoch: October 1, 2019 00:00:00.000 Z
  - Altitude: 700 km
  - Eccentricity: 0
  - Inclination: 98.1928°
  - Right Ascension of Ascending Node (RAAN): 9.43745°
    - Corresponds to 12 PM descending node crossing time at orbit epoch
  - Argument of Perigee: 0°
  - Mean Anomaly: 0°
- **The nodal rate is a function of semi-major axis, eccentricity and inclination, so the nodal rate will drift over time from the Sun-synchronous rate**
  - Drag and Earth gravity potential will cause semi-major axis and eccentricity to vary with time
  - Solar and Lunar perturbations and Earth gravity potential will cause inclination to vary with time
  - The result is a drift from the desired nodal crossing time, commonly referred to as the mean local time

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Orbital Element Selection (2 of 2)

- **Knowledge about the orbit perturbations allows for passive inclination control to manage the mean local time drift**
  - Initial RAAN and inclination are altered from the ideal values to allow the orbit to drift through the allowable range of mean local time
- **Altered initial orbital elements selected based on 4x4 Earth potential model with Solar and Lunar perturbations and Jacchia-Roberts drag model**
  - Epoch: October 1, 2019 00:00:00.000 Z
  - Altitude: 700 km
  - Eccentricity: 0
  - Inclination: 98.1923°
  - Right Ascension of Ascending Node (RAAN): 11.7°
    - Corresponds to 12:09 PM descending node crossing time at orbit epoch
  - Argument of Perigee: 0°
  - Mean Anomaly: 0°
- **5-year orbit simulations were run with both the +2σ and -2σ Solar flux models to confirm that the mean local time over the mission remains within the specified bounds of 12 PM $\pm$ 10 minutes**
  - Further adjustments can be made to bias the average closer to 12 PM
  - No orbit maintenance maneuvers required

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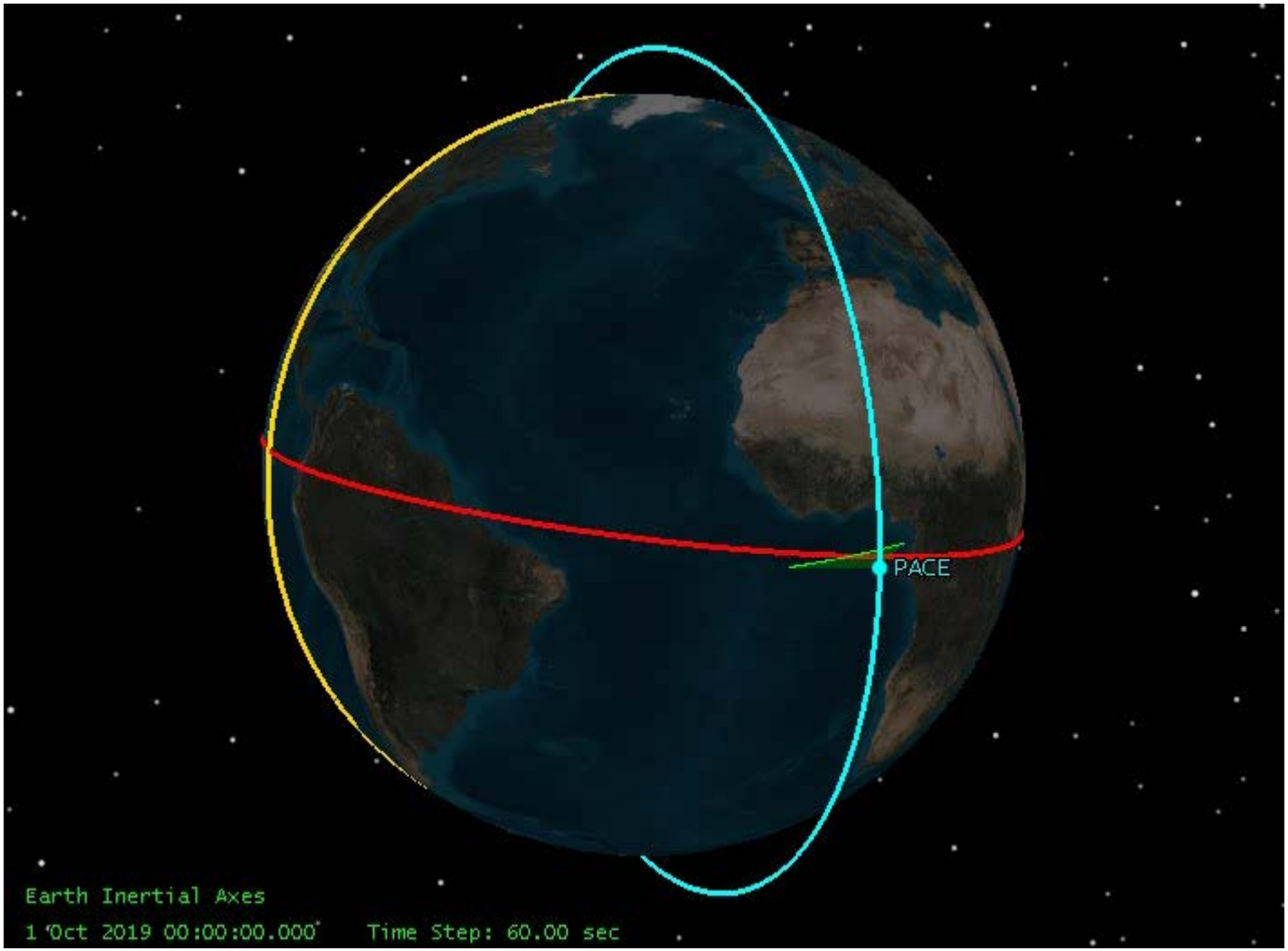
PACE Orbit



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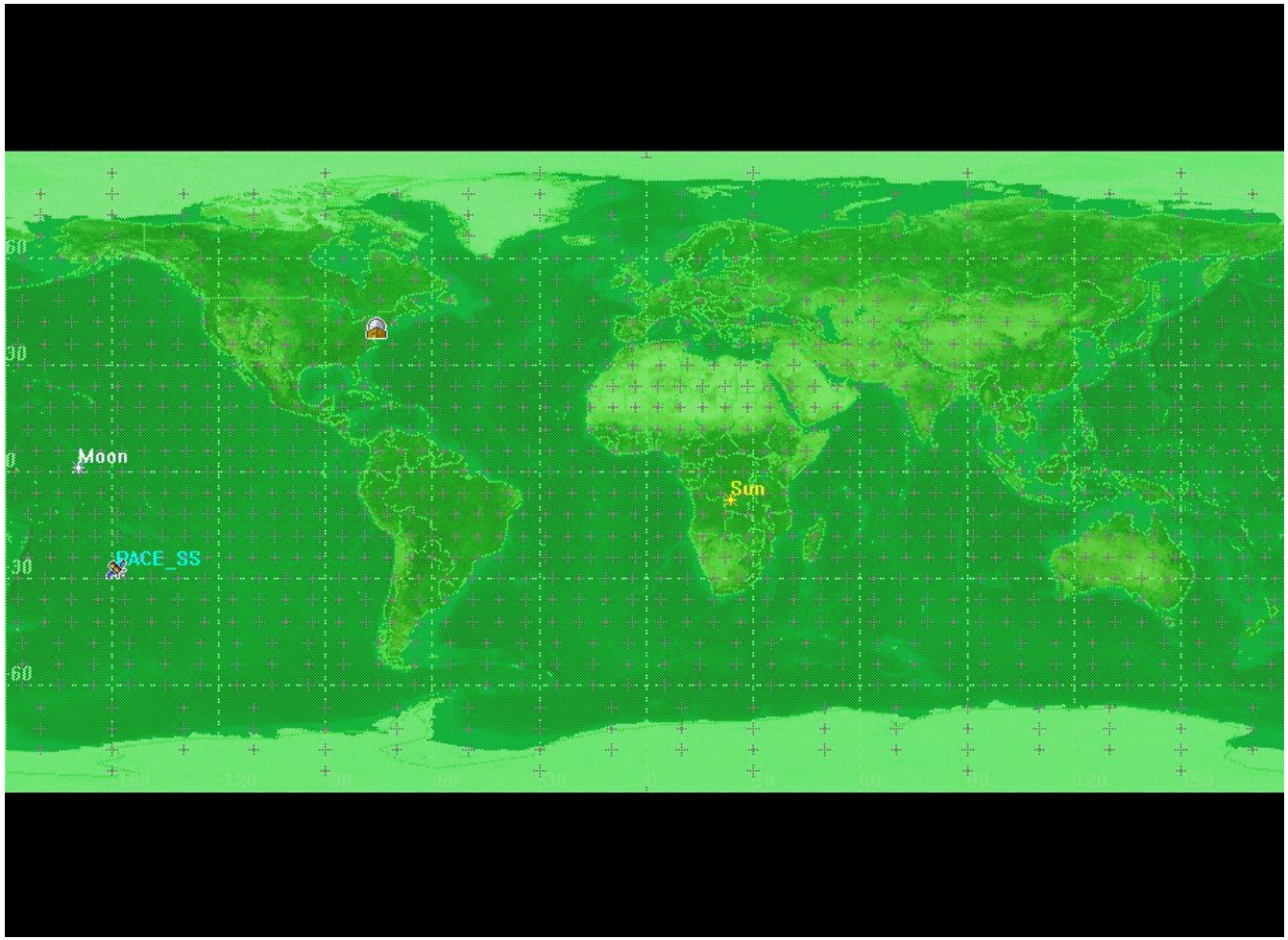
Global Coverage

- **Selected orbit meets requirement of global coverage every 2 days**



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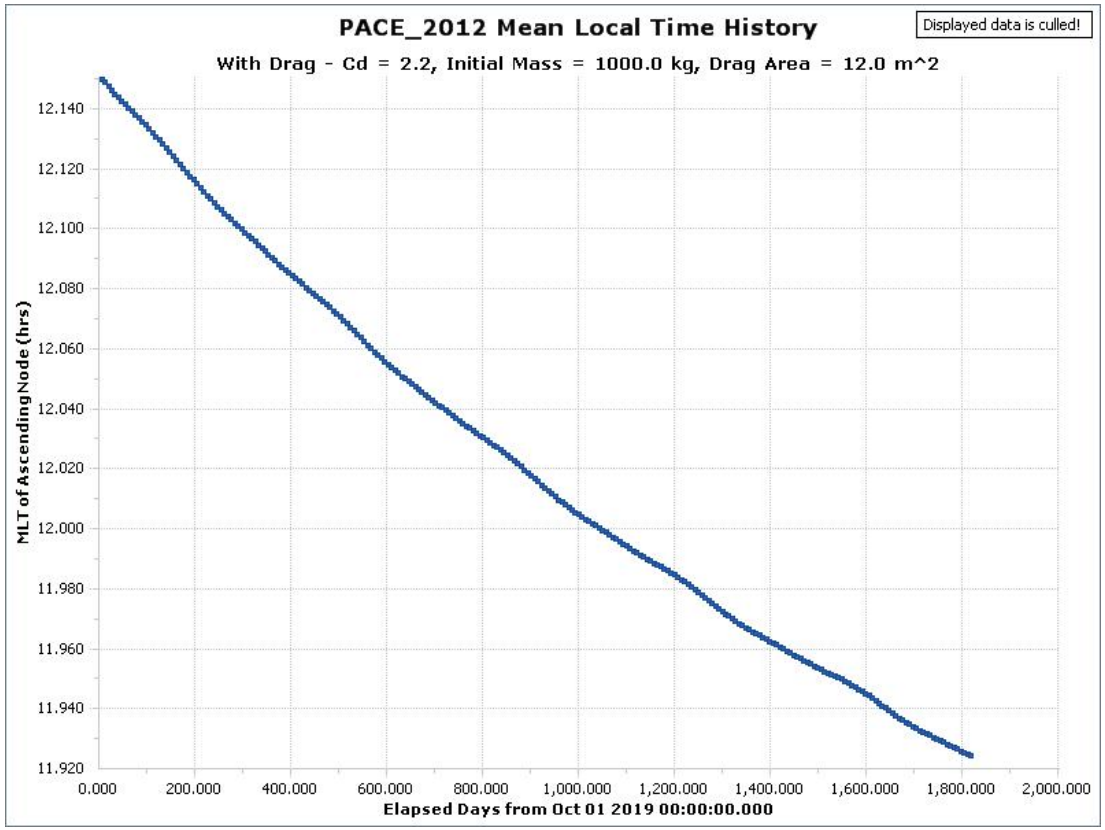
Mean Local Time History, -2σ Flux

- **Maximum: 12:09:00 PM**
- **Minimum: 11:55:26 PM**
- **End: 11:55:26 PM**



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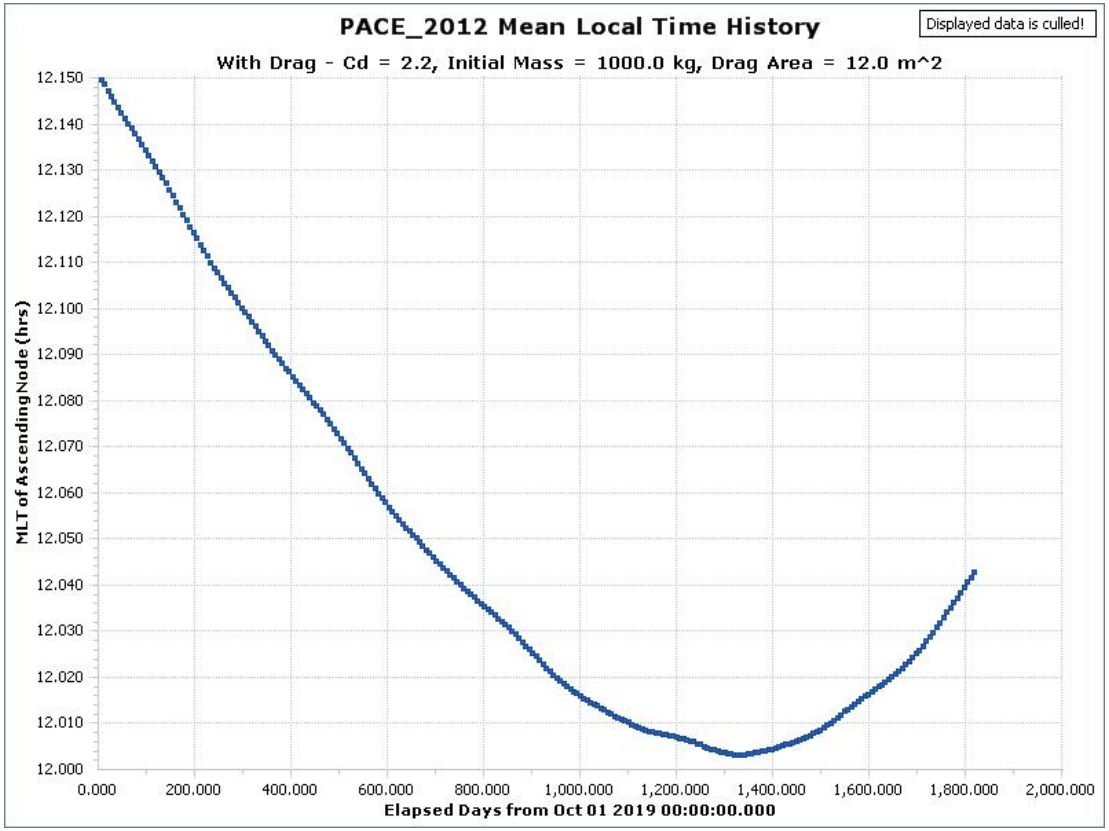
Mean Local Time History, +2σ Flux

- **Maximum: 12:09:00 PM**
- **Minimum: 12:00:10 PM**
- **End: 12:02:35 PM**



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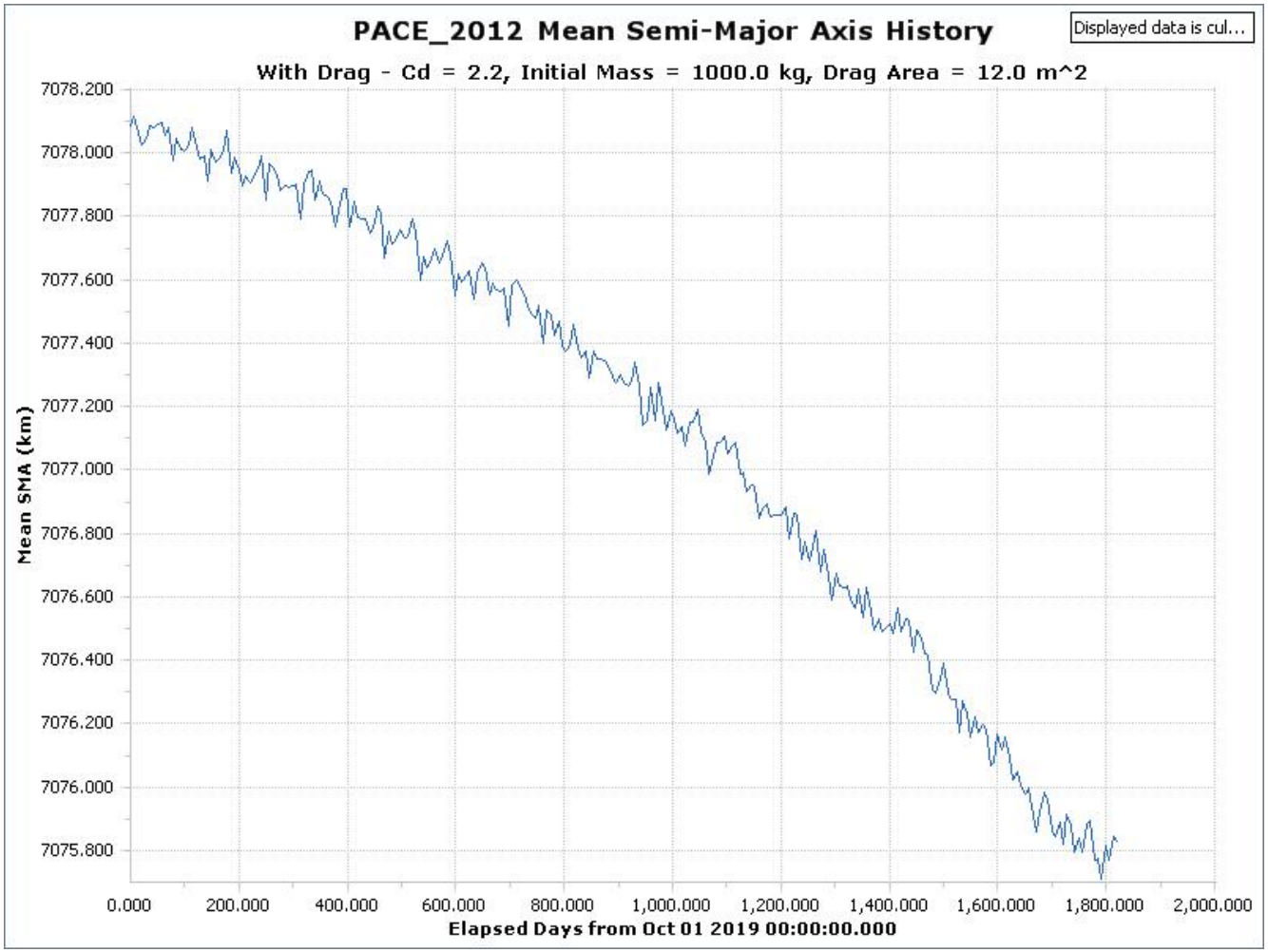
Mean Semi-Major Axis History, -2σ Flux

- **Decay of just over 2 km over 5 years**



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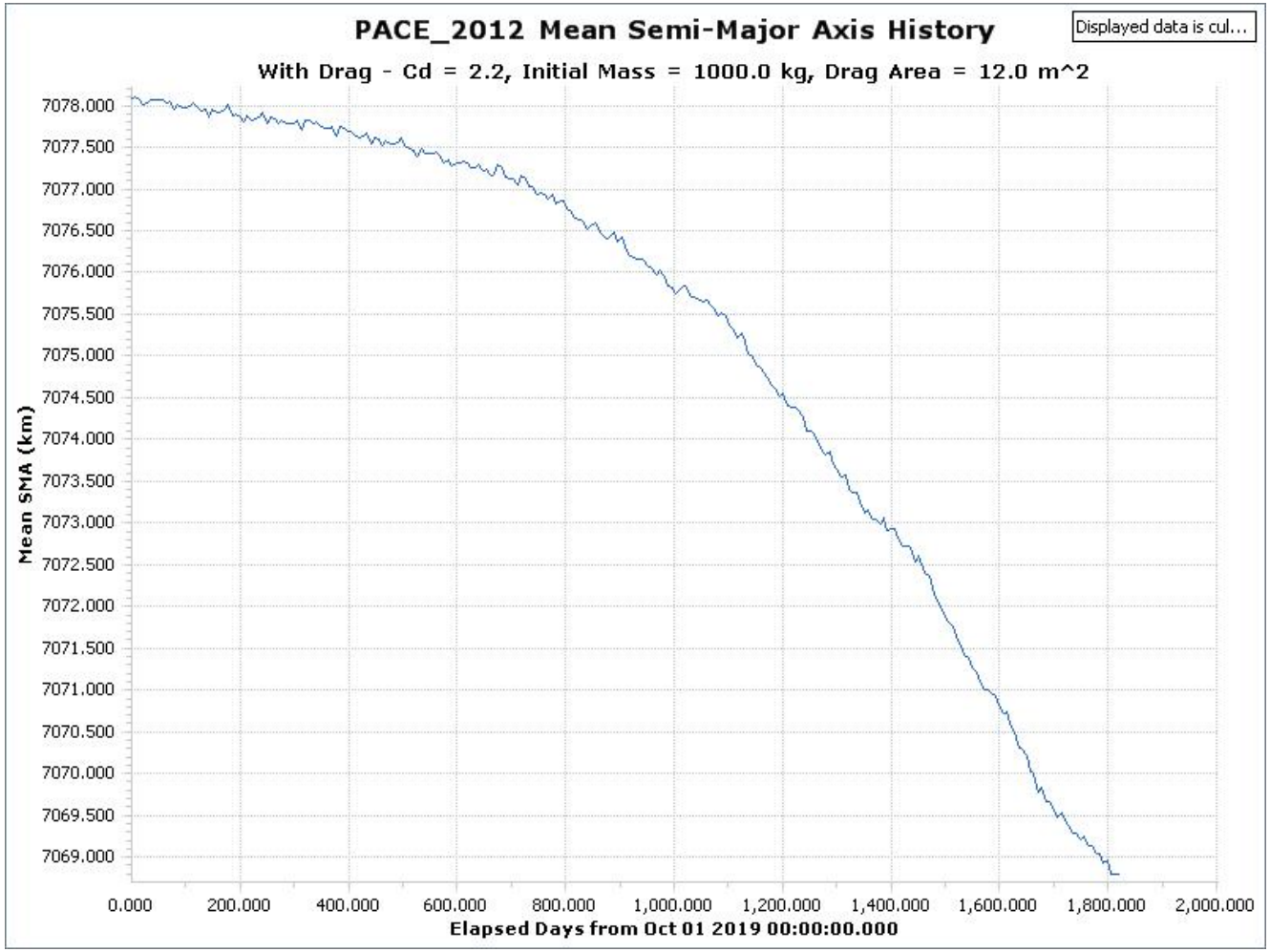
Mean Semi-Major Axis History, +2σ Flux

- **Decay of just under 10 km over 5 years**



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ΔV Budget

- **Mission ΔV budget**

– Launch Vehicle Dispersion Correction	50 m/s(1)
– End of Mission Disposal	183 m/s(2)
– Total	233 m/s

- **Assumptions**
  1) Launch vehicle dispersion correction assumes Taurus II dispersions
     - Dispersion data not available for Antares
  2) 3-4 maneuvers to reduce periapsis altitude to 50 km

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Calibration Geometry Notes

- **Beta angle evolution affects Solar calibration viewing**
- **To ensure Solar calibration viewing opportunities of at least 2 minutes each day, the half-angle of the field-of-view must be approximately 6.8° or larger**
- **Lunar calibration viewing opportunities greater than 1 minute for phase angles of 7° ± 0.1° (first year opportunities at left) appear to be available each month except June 2020**
- **There are no issues with availability of Lunar calibration viewing opportunities greater than 1 minute for phase angles of 7° ± 0.5°**

Access	Start Time (UTCG)	Stop Time (UTCG)	Duration (min)
1	10/13/19 10:12 AM	10/13/19 10:48 AM	36.924
2	10/14/19 7:41 AM	10/14/19 8:17 AM	36.555
3	11/12/19 1:53 AM	11/12/19 2:12 AM	19.552
4	11/13/19 1:50 AM	11/13/19 2:01 AM	11.088
5	12/11/19 4:18 PM	12/11/19 4:23 PM	5.207
6	12/12/19 6:40 PM	12/12/19 6:52 PM	11.865
7	1/11/20 7:34 AM	1/11/20 7:56 AM	21.949
8	2/8/20 8:18 PM	2/8/20 8:27 PM	8.775
9	2/9/20 5:27 PM	2/9/20 5:51 PM	23.812
10	3/9/20 8:48 AM	3/9/20 9:09 AM	20.809
11	3/10/20 2:12 AM	3/10/20 2:21 AM	9.166
12	4/7/20 6:01 PM	4/7/20 6:29 PM	27.721
13	4/8/20 11:35 AM	4/8/20 11:35 AM	0.164
14	5/7/20 12:33 AM	5/7/20 12:37 AM	4.074
15	5/7/20 9:27 PM	5/7/20 9:51 PM	23.892
16	6/6/20 8:01 AM	6/6/20 8:02 AM	0.791
17	7/4/20 3:19 PM	7/4/20 3:42 PM	22.914
18	7/5/20 5:27 PM	7/5/20 5:50 PM	22.932
19	8/3/20 3:06 AM	8/3/20 3:14 AM	7.848
20	8/4/20 3:30 AM	8/4/20 3:57 AM	27.184
21	9/1/20 6:14 PM	9/1/20 6:37 PM	22.938
22	9/2/20 3:40 PM	9/2/20 4:14 PM	33.032

Global Statistics

Min Duration	13	4/8/20 11:35 AM	4/8/20 11:35 AM	0.164
Max Duration	1	10/13/19 10:12 AM	10/13/19 10:48 AM	36.924
Mean Duration				18.145
Total Duration				399.192

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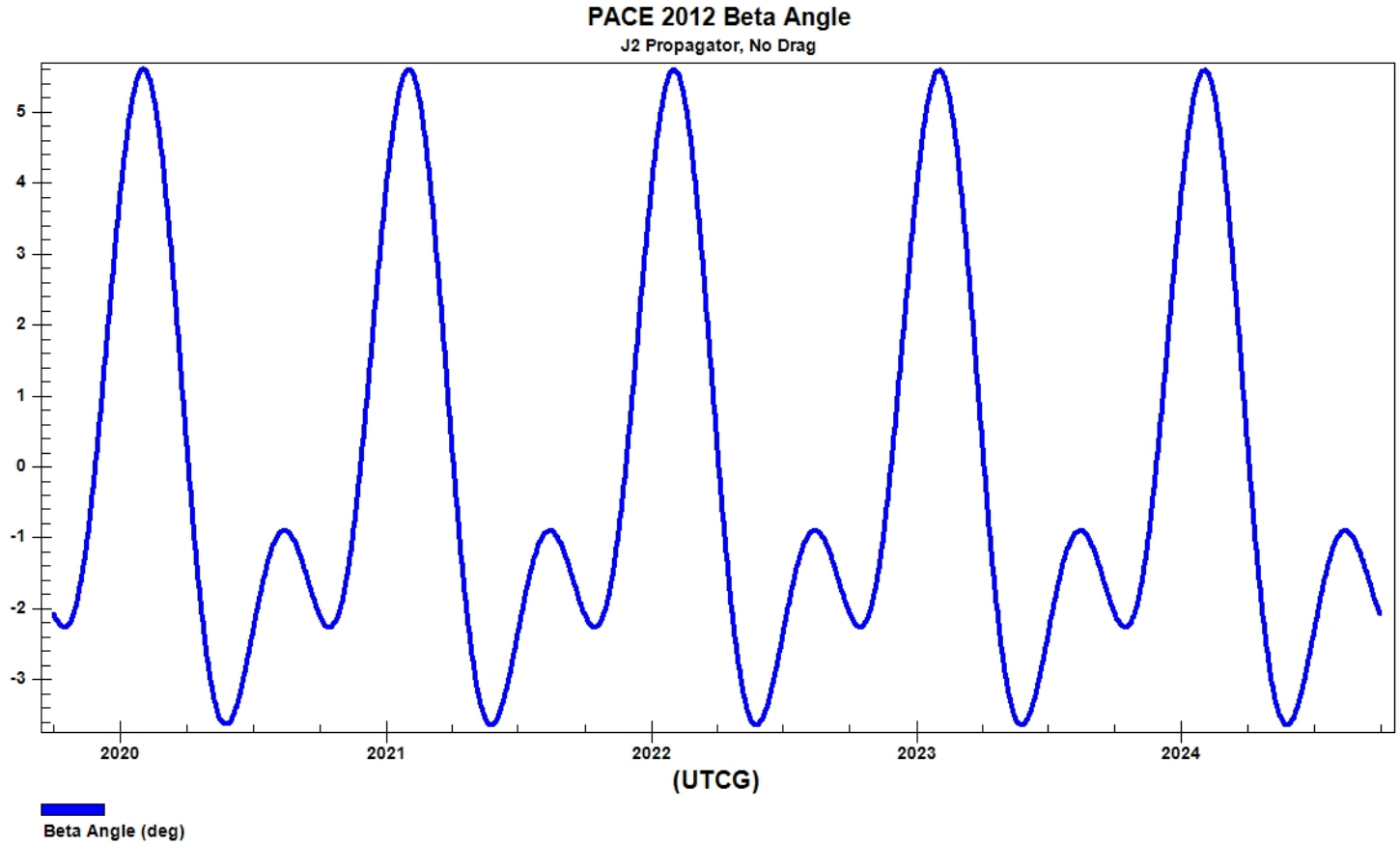
Beta Angle Evolution (1 of 3)

- **With J2 Earth potential only, the beta angle ranges between approximately -3.6° and +5.6°**



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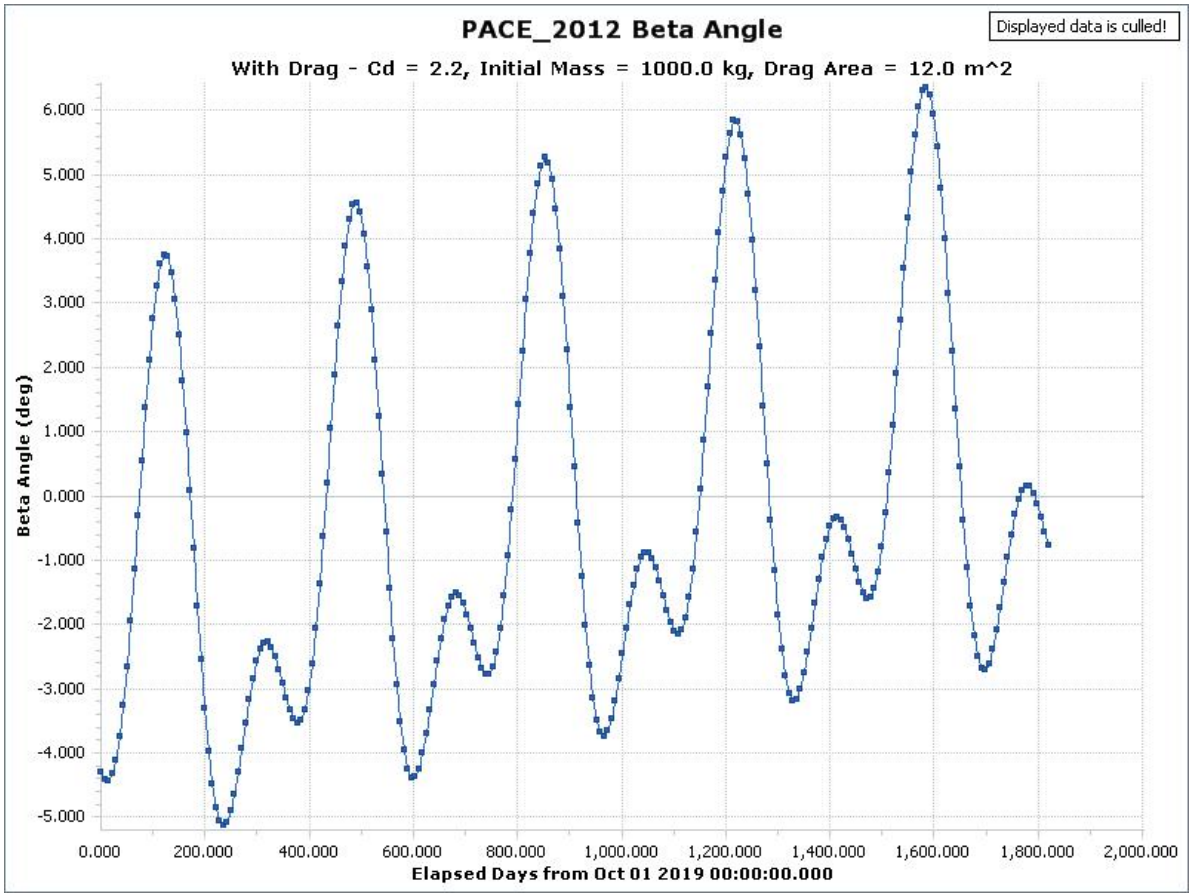
Beta Angle Evolution (2 of 3)

- **4x4 Earth potential with Solar, Lunar and drag perturbations and -2σ flux result in the beta angle drift shown below, ranging between approximately -5.2° and +6.3°**



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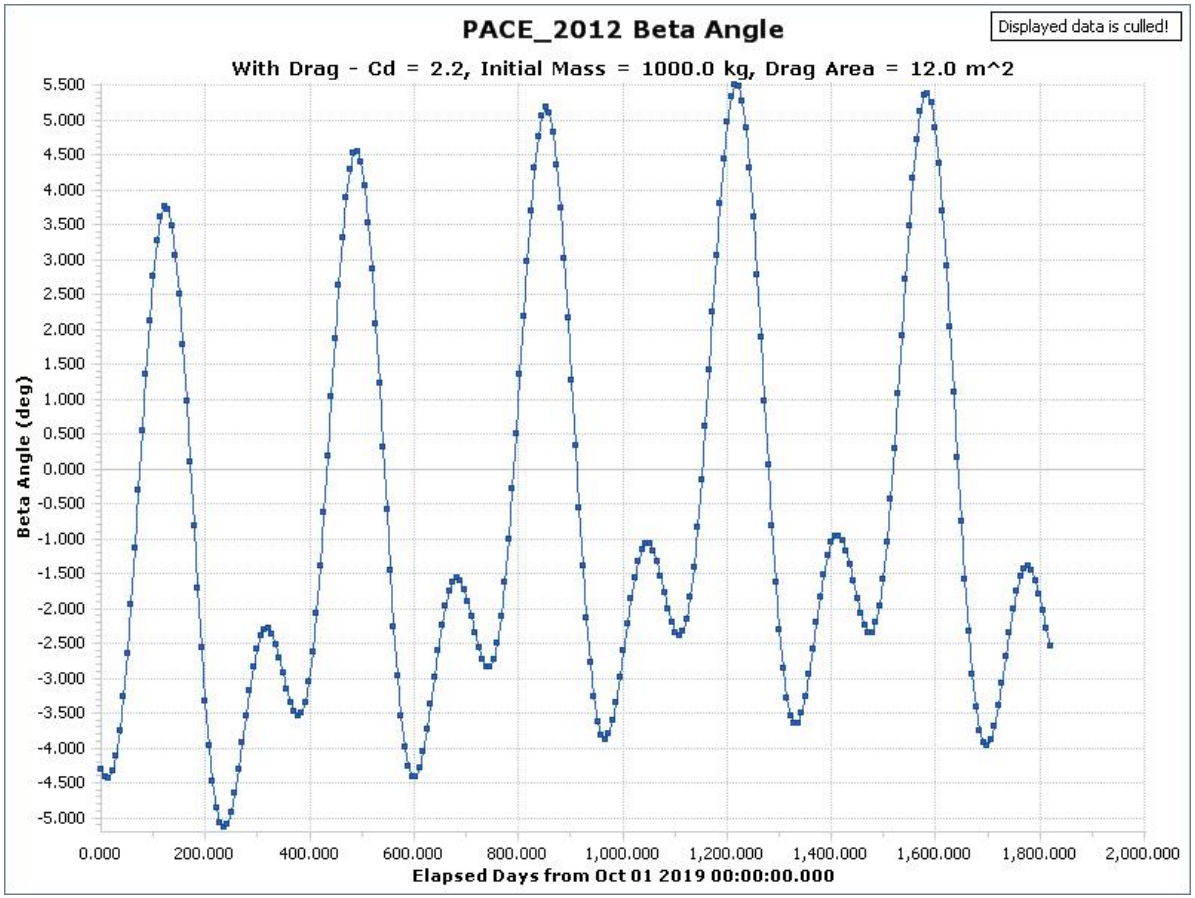
Beta Angle Evolution (3 of 3)

- **4x4 Earth potential with Solar, Lunar and drag perturbations and +2σ flux result in the beta angle drift shown below, ranging between approximately -5.1° and +5.5°**



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Issues / Potential Risks / Future Work

- **Mean local time drift rate is dependent on drag. Adjustments to initial orbit elements may be necessary if the area to mass ratio changes significantly**
- **Currently, there is not an "easy" way to indicate which side of the spacecraft the Moon will be on during a calibration event**

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Alternative EOM Disposal Strategy Analysis

- **In response to a request to determine what periapsis altitude would be necessary for the orbit to decay within 25 years of mission end-of-life**
- **Propagation begins on October 1, 2024 using January 2012 Schatten -2σ Solar flux model**
- **Coefficient of drag: 2.2**
- **Drag Area: 12 m^2**
- **Calculations made for 3 initial dry masses**
  - Initial dry mass of 823 kg (from study results)
    - Required periapsis altitude: ≈ 540 km
    - DV: ≈ 43 m/s
    - Propellant mass: ≈ 17 kg (I_{SP} = 220 s)
  - Initial dry mass of 1100 kg
    - Required periapsis altitude: ≈ 510 km
    - DV: ≈ 52 m/s
    - Propellant mass: ≈ 27 kg (I_{SP} = 220 s)
  - Initial dry mass of 1400 kg
    - Required periapsis altitude: ≈ 490 km
    - DV: ≈ 57 m/s
    - Propellant mass: ≈ 38 kg (I_{SP} = 220 s)
- **The orbit lifetime was 24-25 years for all cases**

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