Maintaining Aura's Orbit Requirements Under New Maneuver Operations

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Session1-2

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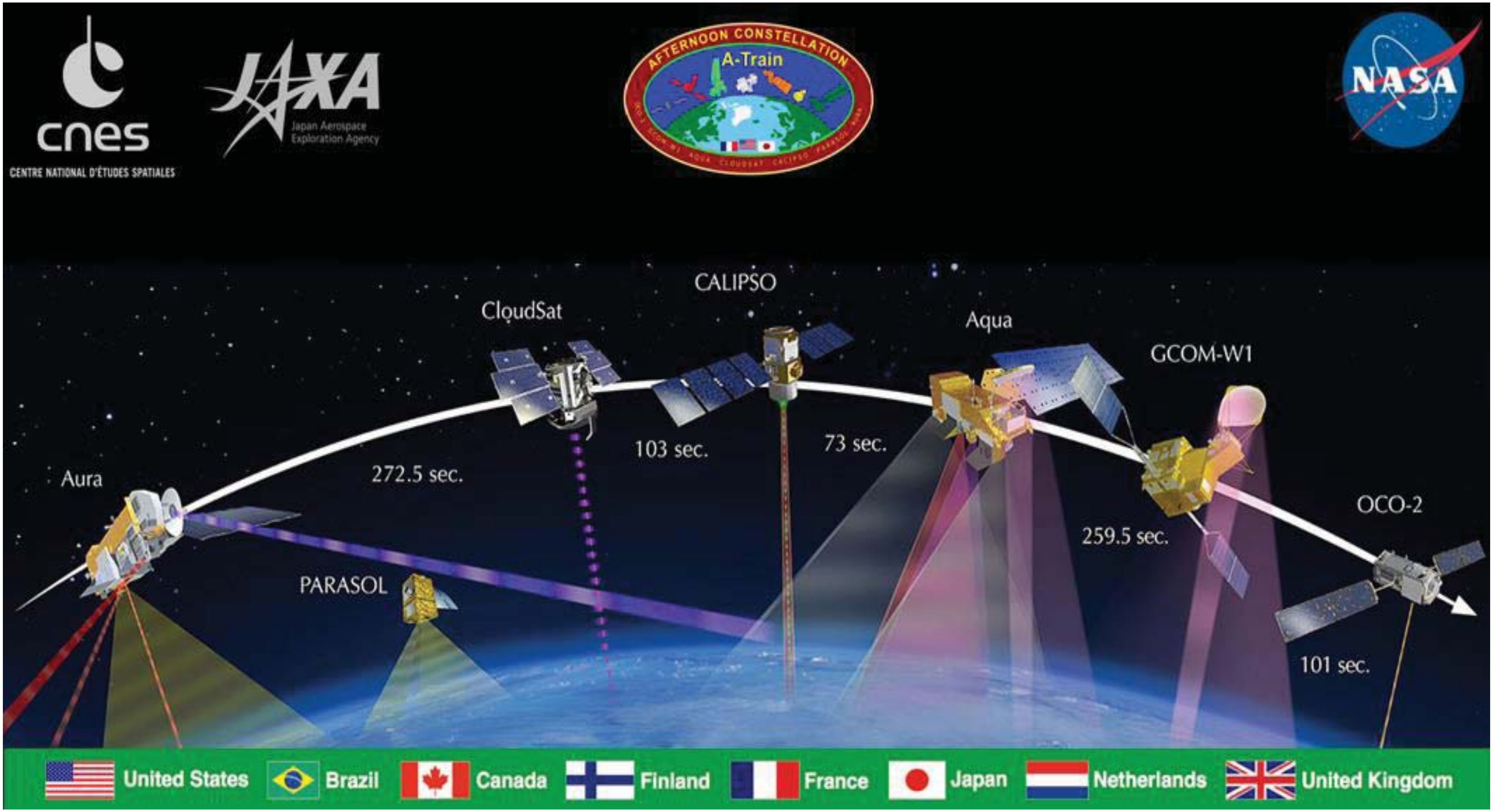
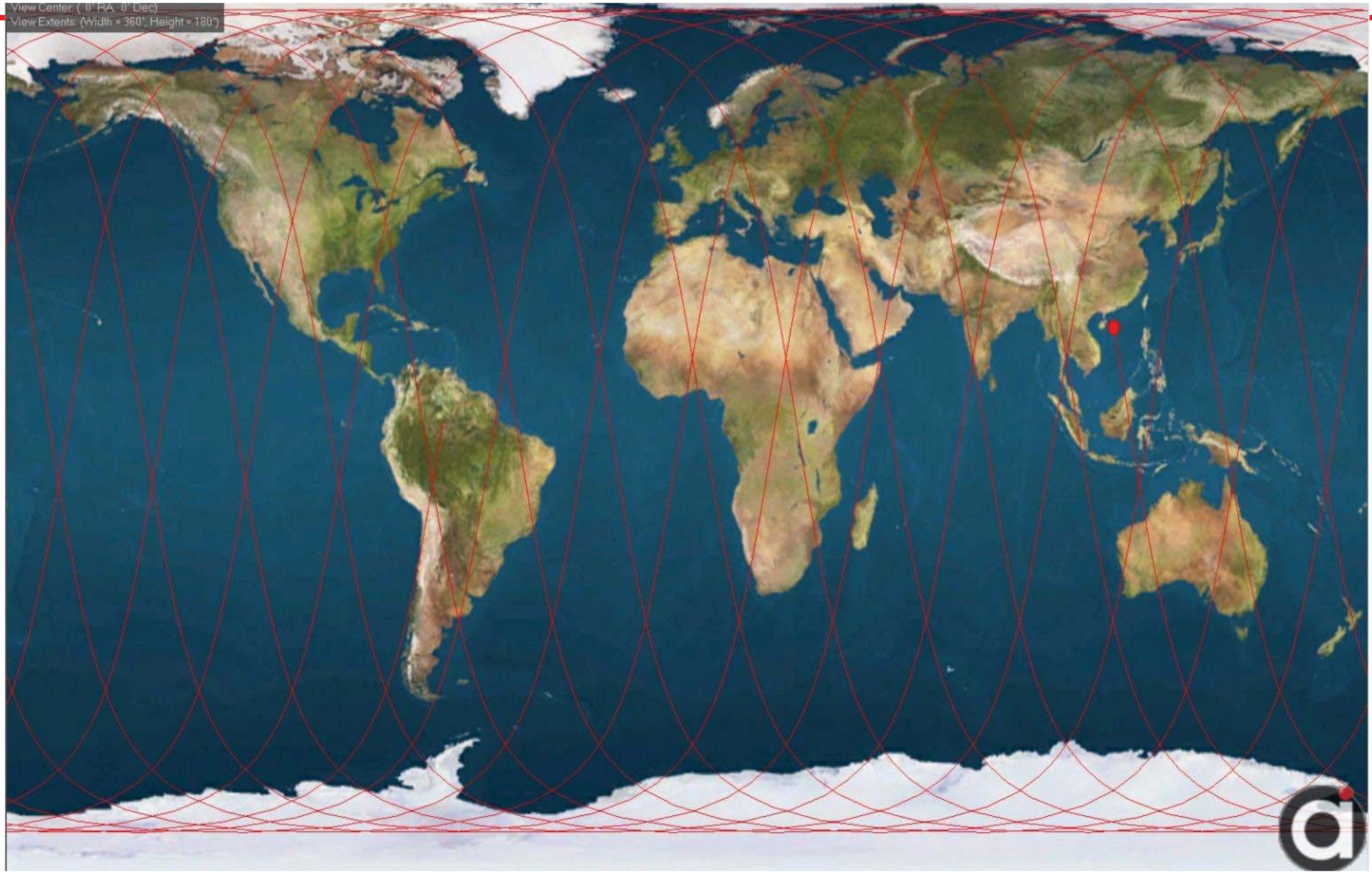
Overview

- Background
  - Afternoon Constellation
  - Aura Operational Requirements
- No-slew maneuvers
- Alternate maneuver schemes
  - Mirror pole maneuvers
  - Hybrid maneuver scheme
- Open Issues

Afternoon Constellation

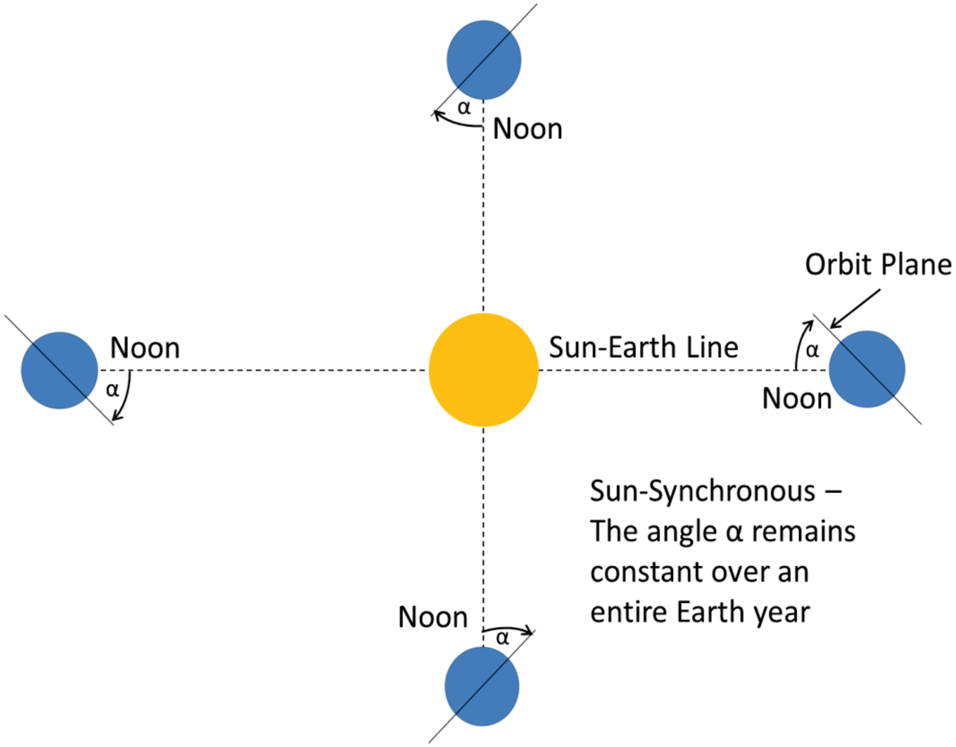


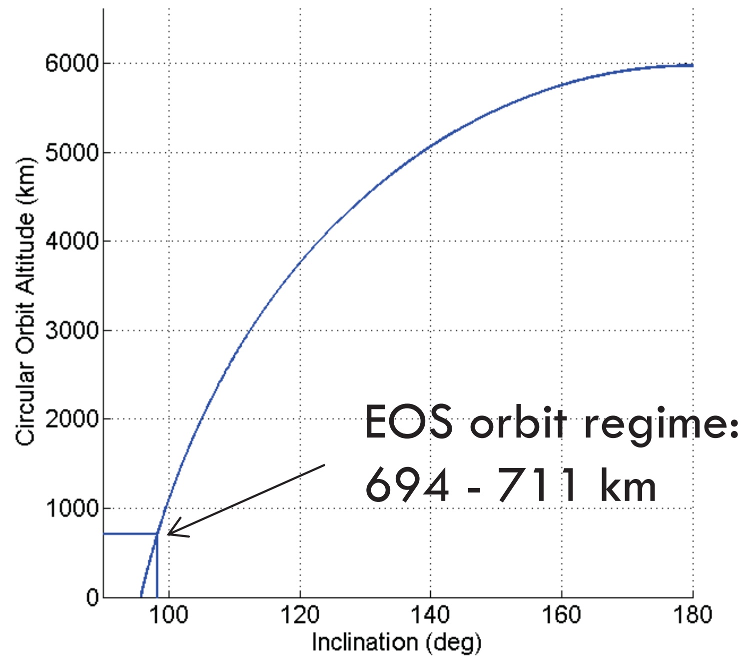
Ground Track



- **SMA control via Drag Make Up (DMU) maneuvers is required** to accurately maintain the ground track
- The ground track must stay on the WRS-2 path for science data collection
- DMU Frequency is driven by atmospheric drag

Sun Synchronous Orbits





- **MLT control via Inclination Adjust Maneuvers (IAMs) is required** to accurately maintain along-track separation between missions and repeatable lighting conditions
- Nominally perform 3-5 maneuvers per year in the Spring
- MLT deviations driven by luni-solar pertubations acting on inclination
- A further mission requirement constricts the **MLT prediction to vary by no more than ± 2 seconds over the course of one year**

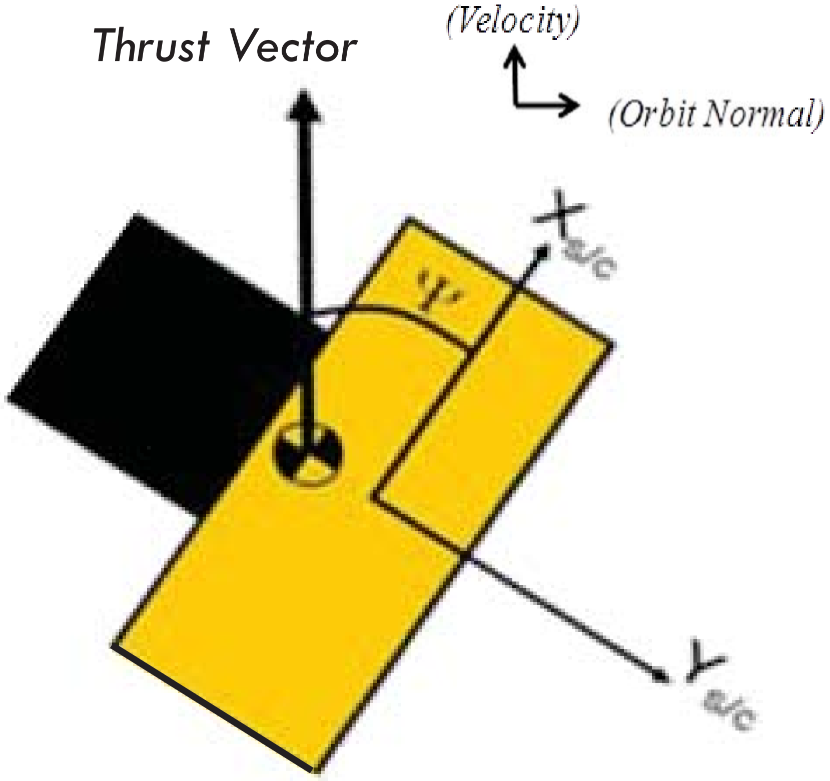
Aura Orbit Properties

Orbital Element	Value
WRS-2 Ground Track	18 ± 20 km mission requirement 18 ±- 10 km operational requirement
Mean Local Time Aura	13:30:00 to 14:00:00 8.5 minutes ± 15 seconds w.r.t Aqua
Mean Local Time Aqua	13:35:00 to 13:36:30
Semi-major Axis	7077.7 km ± 0.3 km
Inclination	98.2 ± 0.15 degrees
Argument of Perigee	90 ± 20 degrees
Eccentricity	0.0012 ± 0.0004

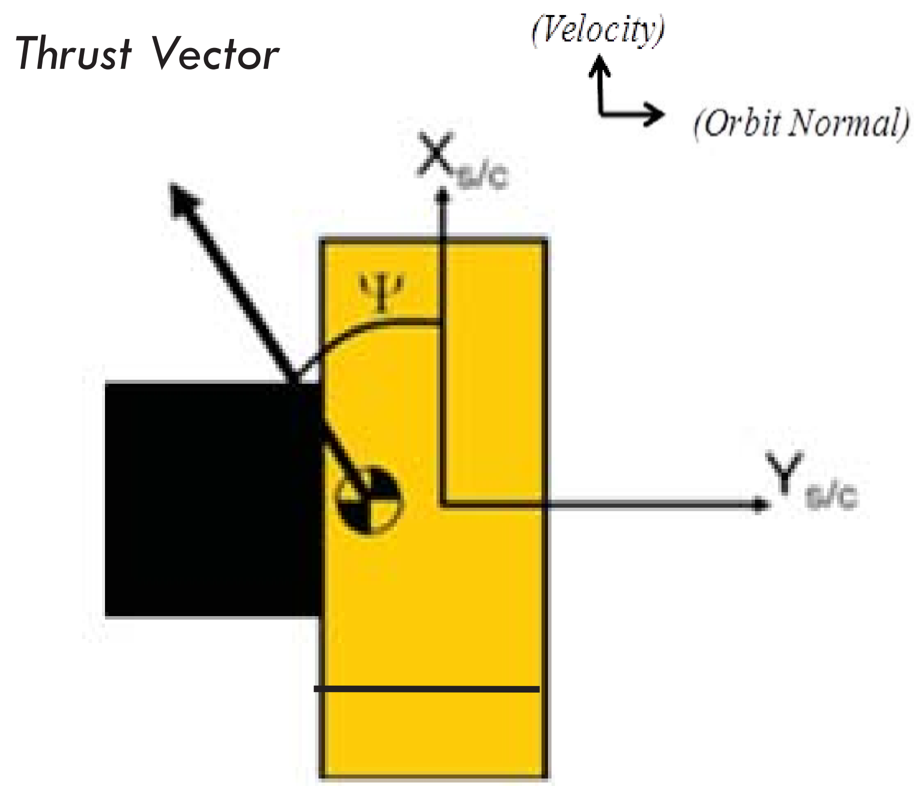
Slewed vs No-slew Maneuvers

- How can the mission requirements be maintained with an added orbit-normal delta-V?

Slewed DMUs



No-Slew DMUs



***Aqua:* $\Psi = 14.350°$**
***Aura:* $\Psi = 13.493°$**

Effect of No-slew Maneuvers

$$\frac{da}{dt} = \frac{2}{n\sqrt{1-e^2}}\left(e\sin(v)F_R + \frac{p}{r} r F_S\right)$$

$$\frac{de}{dt} = \frac{\sqrt{1-e^2}}{na}\left(\sin(v)F_R + \left(\cos(v) + \frac{e+\cos(v)}{1+e\cos(v)} r\right)F_S\right)$$

$$\frac{di}{dt} = \frac{r}{na^2\sqrt{1-e^2}} F_w \cos(v)$$

$$\frac{d\Omega}{dt} = \frac{r}{na^2\sqrt{1-e^2}} F_W \frac{\sin(v)}{\sin(i)}$$

$$\frac{d\omega}{dt} = \frac{\sqrt{1-e^2}}{na^2 e}\left\{-\cos(v)F_R + \sin(v)\left(1+\frac{r}{p}\right)F_s\right\} - \frac{r\cot(i)\sin(v)F_w}{h}$$

$$\frac{dM_o}{dt} = \frac{1}{na^2 e}\{(p\cos(v) - 2er)F_R - (p+r)\sin(v)F_S\}$$

Legend: **Equations in the RSW frame**

a: Semi-major axis **e:** eccentricity **v:** argument of latitude **w:** argument of perigee

n: mean motion **i:** inclination **r:** radial distance from Earth's center **t:** time

Ω: RAAN **p:** $a(1\text{-}e^2)$ **F_R:** Force parallel to position vector

F_w: Force in the instantaneous direction of angular momentum vector

F_s: Force normal to the position vector along the S axis

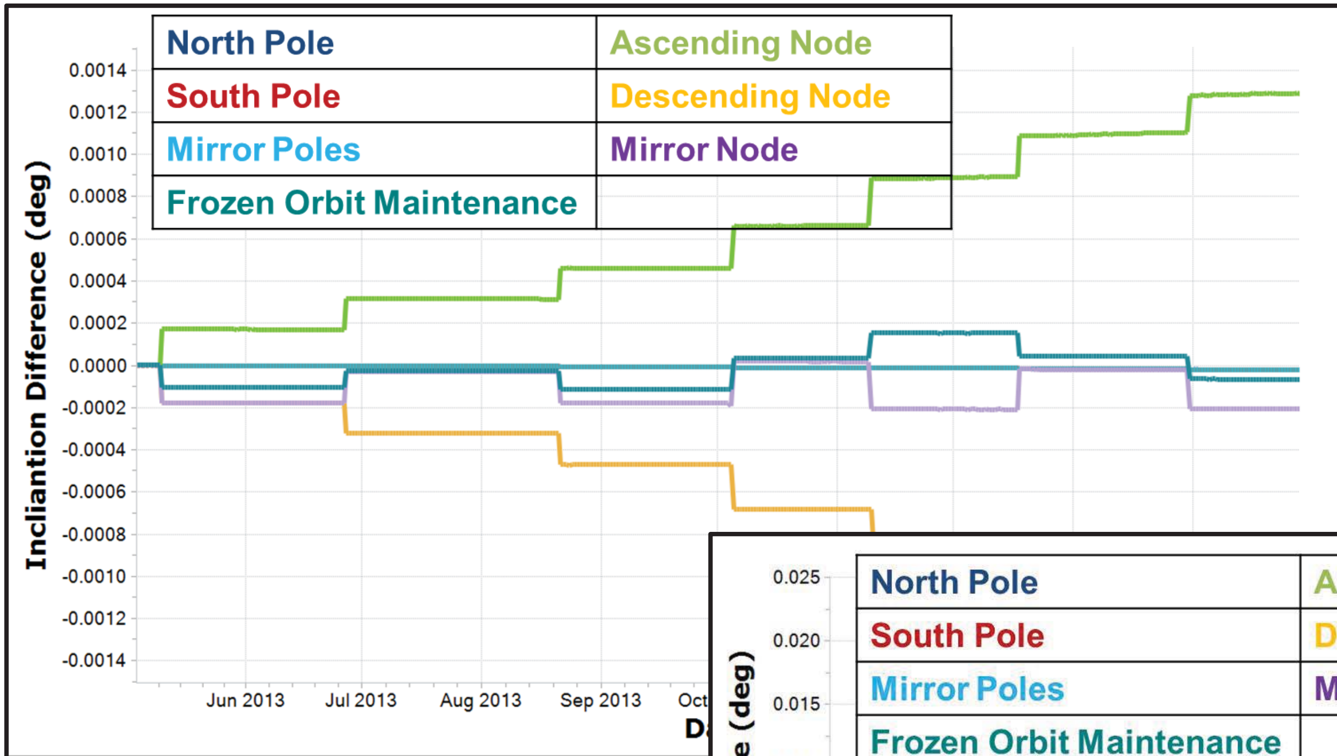
Benefits of No-slew Maneuvers

- Pros
  - **Simplified** spacecraft commanding
  - **Minimized** required communications coverage
  - **Reduced** science data collection loss per maneuvers
  - **Simplified** maneuver planning for emergency scenarios
  - **Improved** maneuver predictions
  - **Reduced** man hours for maneuver execution
- Cons
  - **Increased** complexity in long and short term maneuver planning
  - **No historical data** for maneuver trending

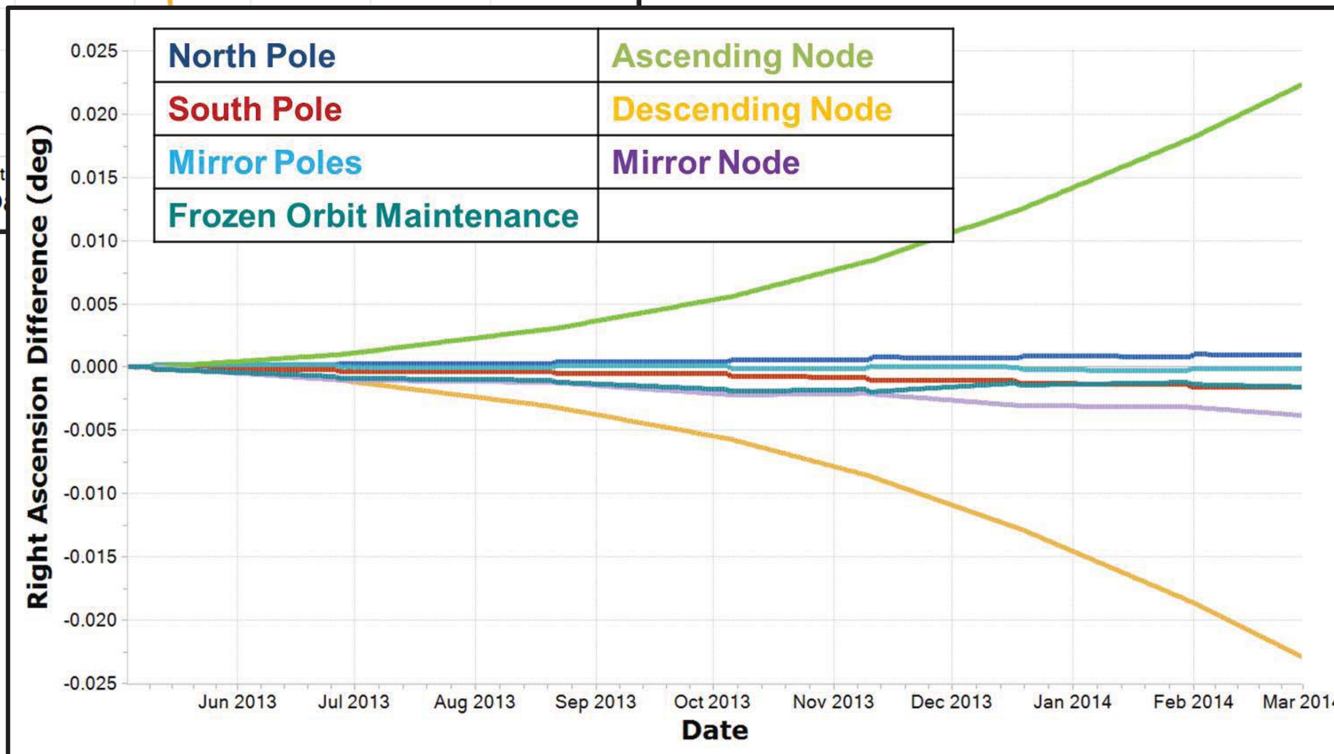
Maneuver Strategies

- **Frozen Orbit Maintenance**
  - Original strategy to maintain argument of perigee and eccentricity values
- **Mirror Pole Paired Burns**
  - Alternates maneuvers at North and South Pole
  - Each pair cancels out added delta-inclination
- North Pole Only
- South Pole Only
- Mirror Node Paired Burns
  - Alternates maneuvers at Ascending and Descending Nodes
- Ascending Node Only
- Descending Node Only
- **Hybrid Strategy**
  - Maneuvers are Mirror Pole Paired Burns or Frozen Orbit Maintenance burns depending on the time of year

Mirror Pole Maneuver Strategy

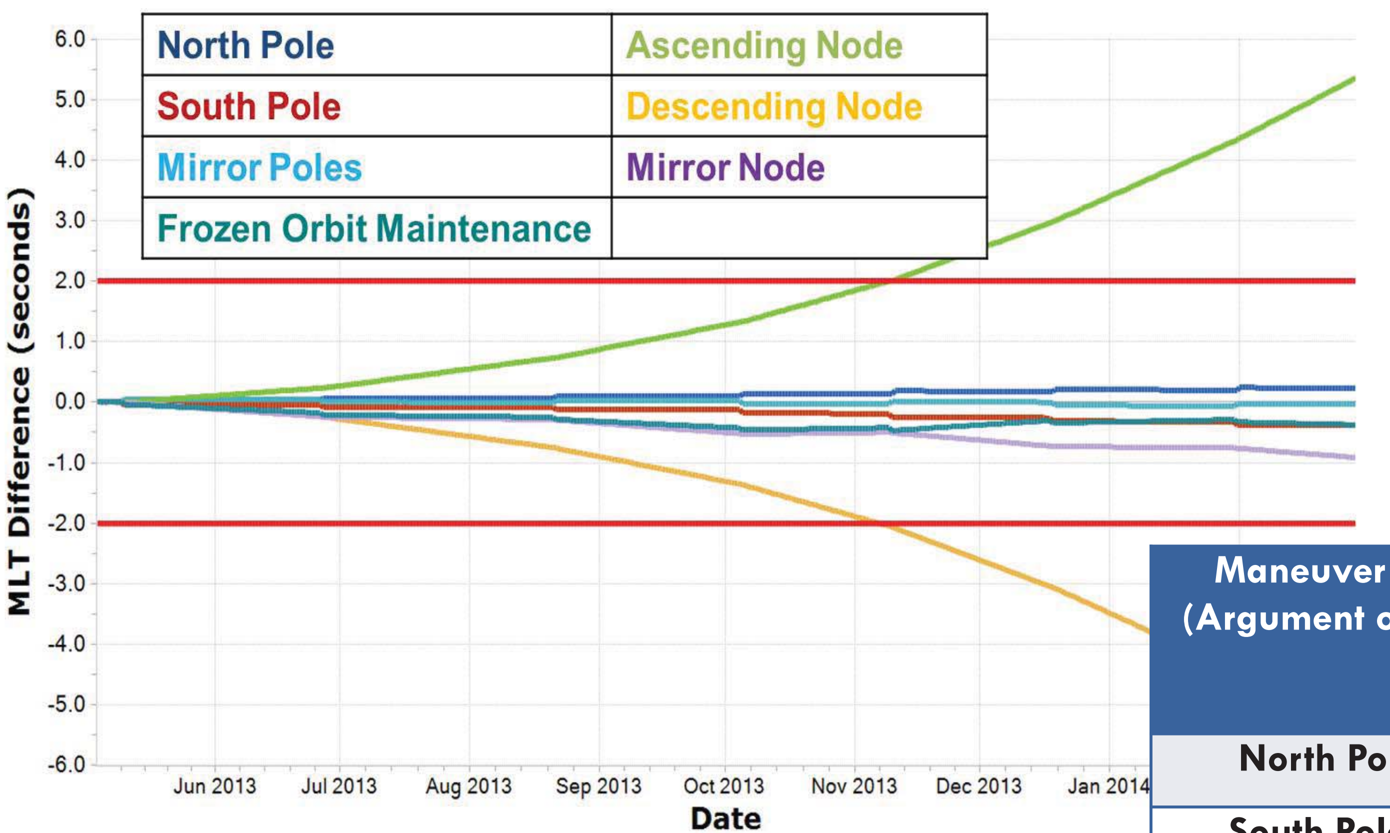


Maneuvering at the poles produces zero net inclination change



Maneuvering at the poles produces zero net RAAN change

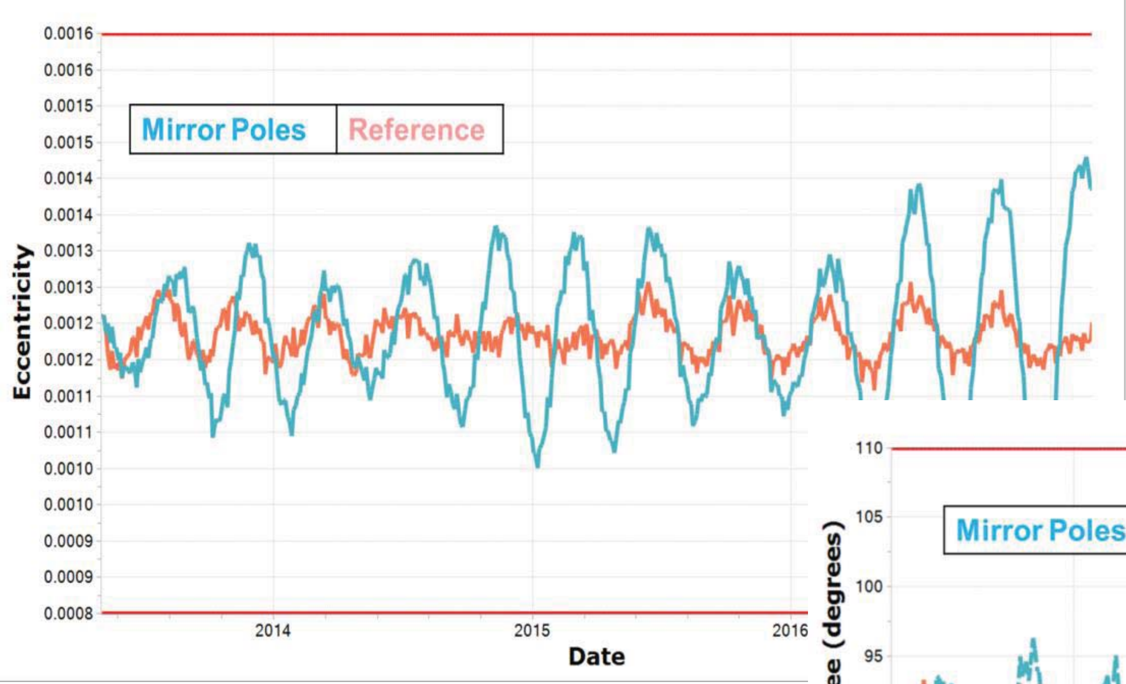
No-Slew effect on MLT

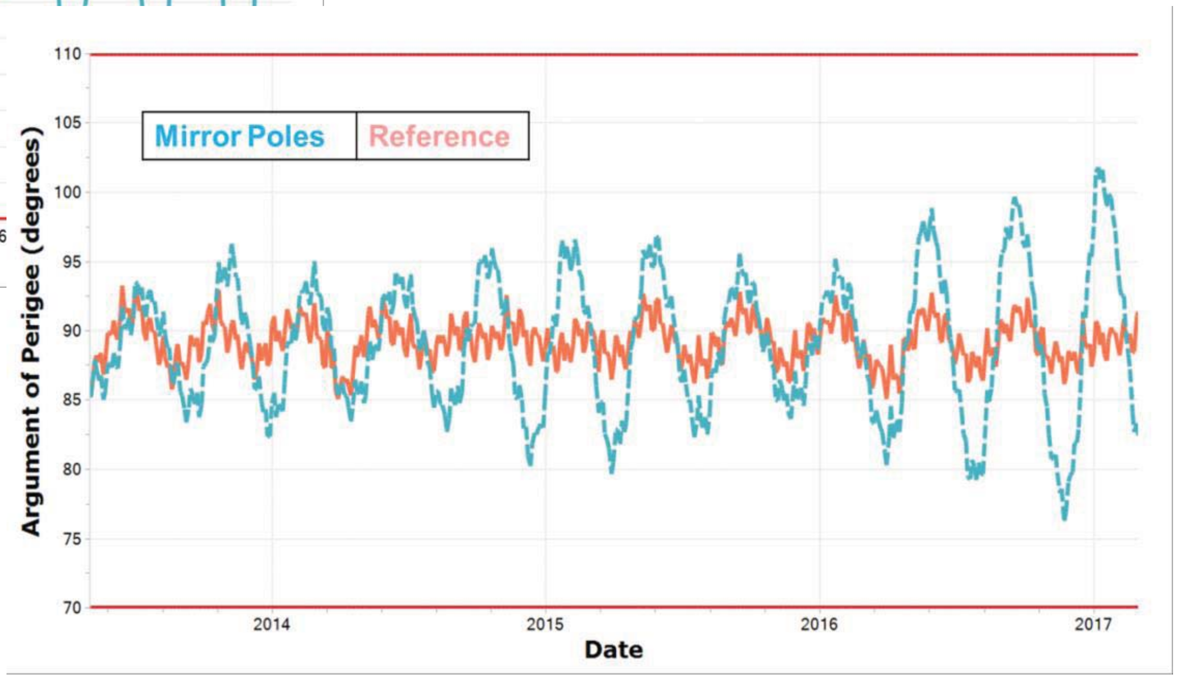


- The Mirror Poles strategy accrues the least MLT difference over time

Maneuver Location (Argument of Latitude)	Mean Local Time Difference over 10.5 months (seconds)
North Pole (90°)	+ 0.225
South Pole (270°)	- 0.380
Mirror Poles (90°/270°)	- 0.035
Ascending Node (0°)	+ 5.364
Descending Node (180°)	- 5.494
Mirror Nodes (0°/180°)	- 0.914
Frozen Orbit Maintenance (various)	- 0.374

Mirror Pole Maneuvers – Frozen Orbit



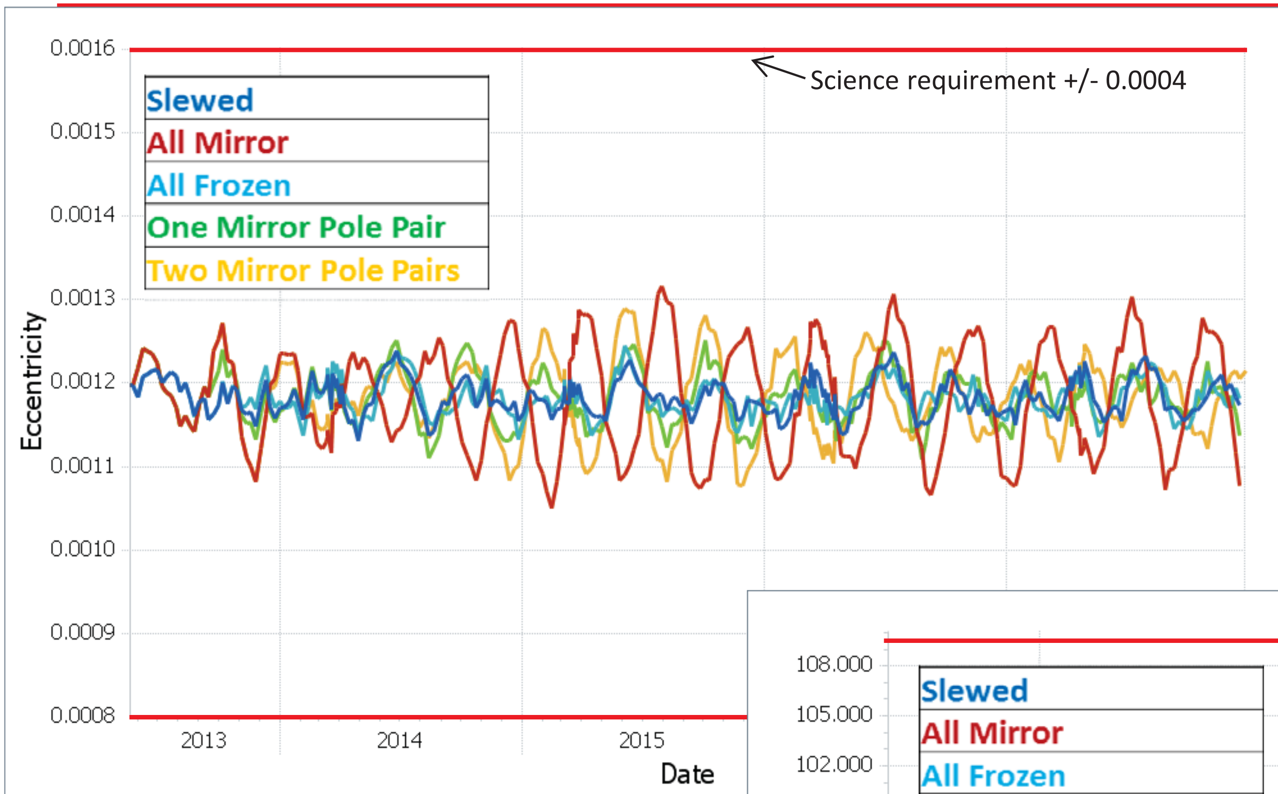


- The mirror pole strategy causes the amplitude of the argument of perigee and eccentricity to grow over time

Hybrid Maneuver Strategy

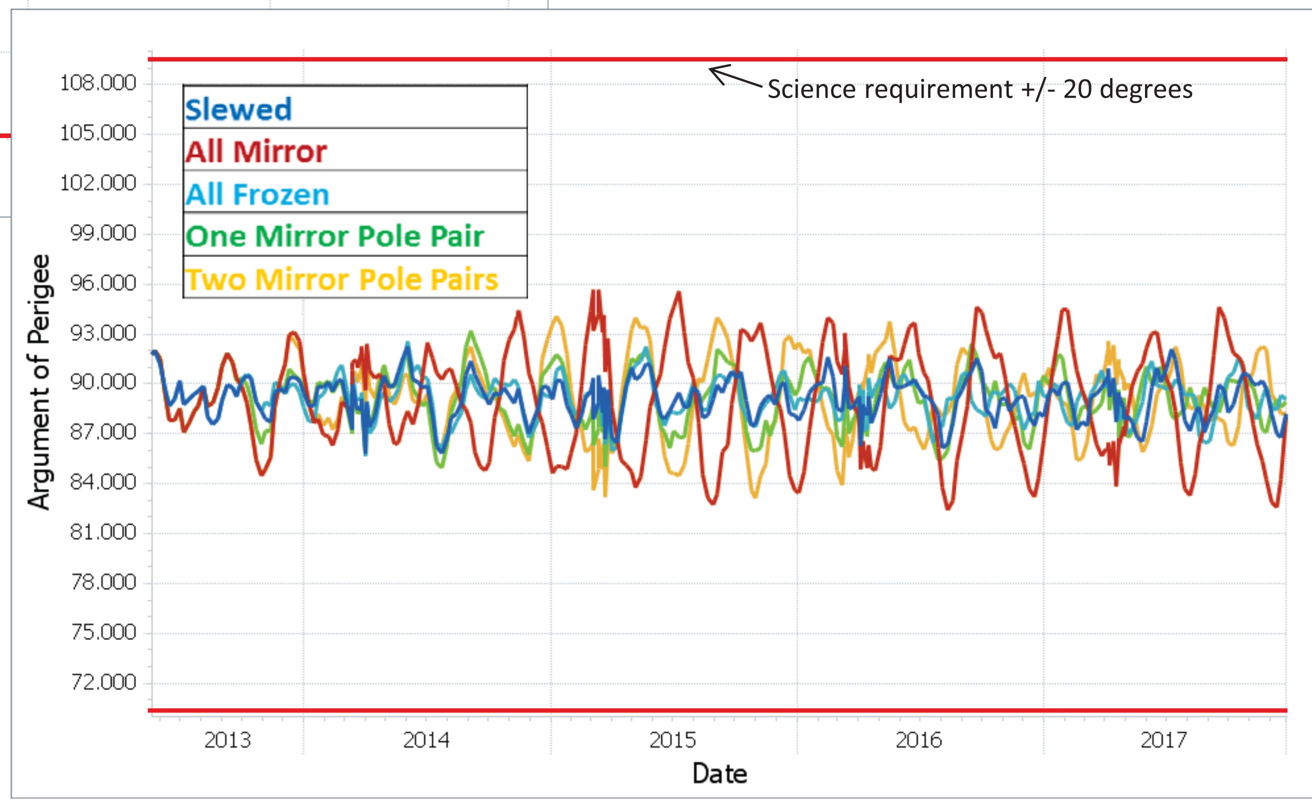
- **Can MLT and Frozen Orbit control be optimized?**
  - Want to do mirror pole paired burns directly following Spring IAM series
  - Switch to frozen orbit maintenance maneuvers late in the year to minimize the time the delta-INC can accumulate prior to IAM series
- Case studies:
  - **Slewed:** all maneuvers used for frozen orbit control
  - **All Mirror Pole:** no-slew maneuvers
  - **All Frozen Orbit:** no-slew with frozen orbit control
  - **One Mirror Pole Pair:** once one pair is completed, switch to frozen orbit control
  - **Two Mirror Pole Pairs:** once two pairs are completed, switch to frozen orbit control

Hybrid Maneuver Strategy – Eccentricity

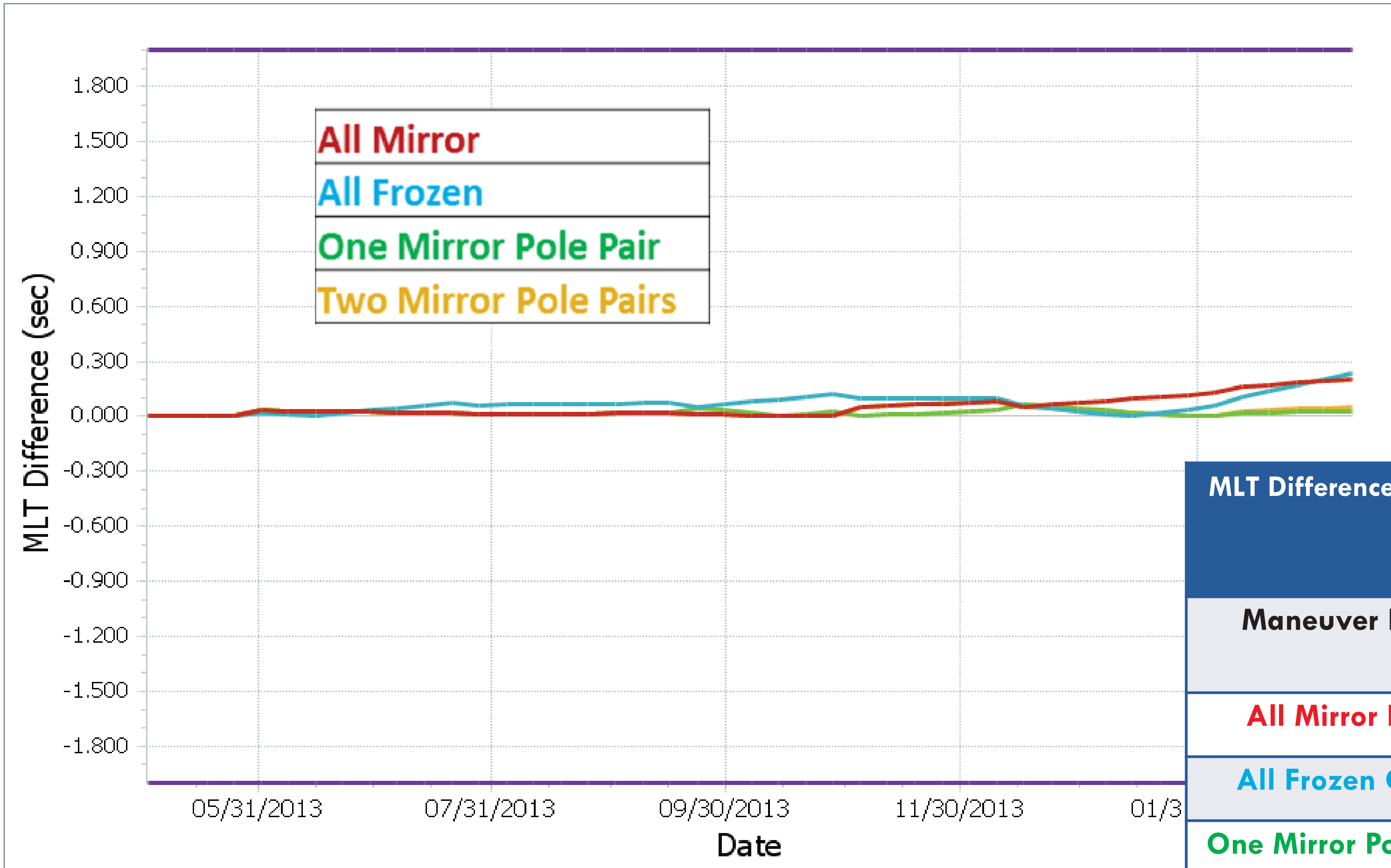


Maneuver Plan	Max Eccentricity Difference (4 Years)
All Slew	6.25E-05
All Mirror Pole	1.47E-04
All Frozen Orbit	5.69E-05
One Mirror Pole Pair	8.06E-05
Two Mirror Pole Pairs	1.20E04

Maneuver Plan	Max Argument of Perigee Difference (4 Years)
All Slew	3.12
All Mirror Pole	6.64
All Frozen Orbit	3.19
One Mirror Pole Pair	3.76
Two Mirror Pole Pairs	5.78



Hybrid Maneuver Scheme - MLT



MLT Difference Compared to a Slewed Maneuver Strategy	
Maneuver Plan	MLT Difference (sec) over one year
All Mirror Pole	0.20
All Frozen Orbit	0.24
One Mirror Pole Pair	0.03
Two Mirror Pole Pairs	0.05

- All maneuver strategies maintained the +/- 2 second prediction requirement over one year

Conclusion

- No-slew operations bring additional complexity when planning DMU maneuvers
  - Changes to MLT
  - Changes in frozen orbit when compensating for MLT change
- The Mirror Pole Paired maneuver strategy works to maintain MLT but degrades the frozen orbit
- The hybrid maneuver strategy is able to address both concerns by combining the mirror pole paired burns strategy with frozen orbit burns throughout the year

Open Issues

- Further analysis of the effects atmospheric density has on the hybrid maneuver scheme
  - Mirror pole maneuver strategy is effected differently in a low drag environment than a high drag one
  - Frequency of maneuvers will also change when to switch from mirror pole to frozen orbit burns
- Investigate the effect Risk Mitigation Maneuvers (RMMs) on mission requirements
- Lifetime simulation of no-slew operations on Aqua, the Afternoon Constellation lead mission