National Aeronautics and Space Administration

Concurrent Mission Design of NEA Scout & Lunar Flashlight, Solar Sail CubeSat Missions

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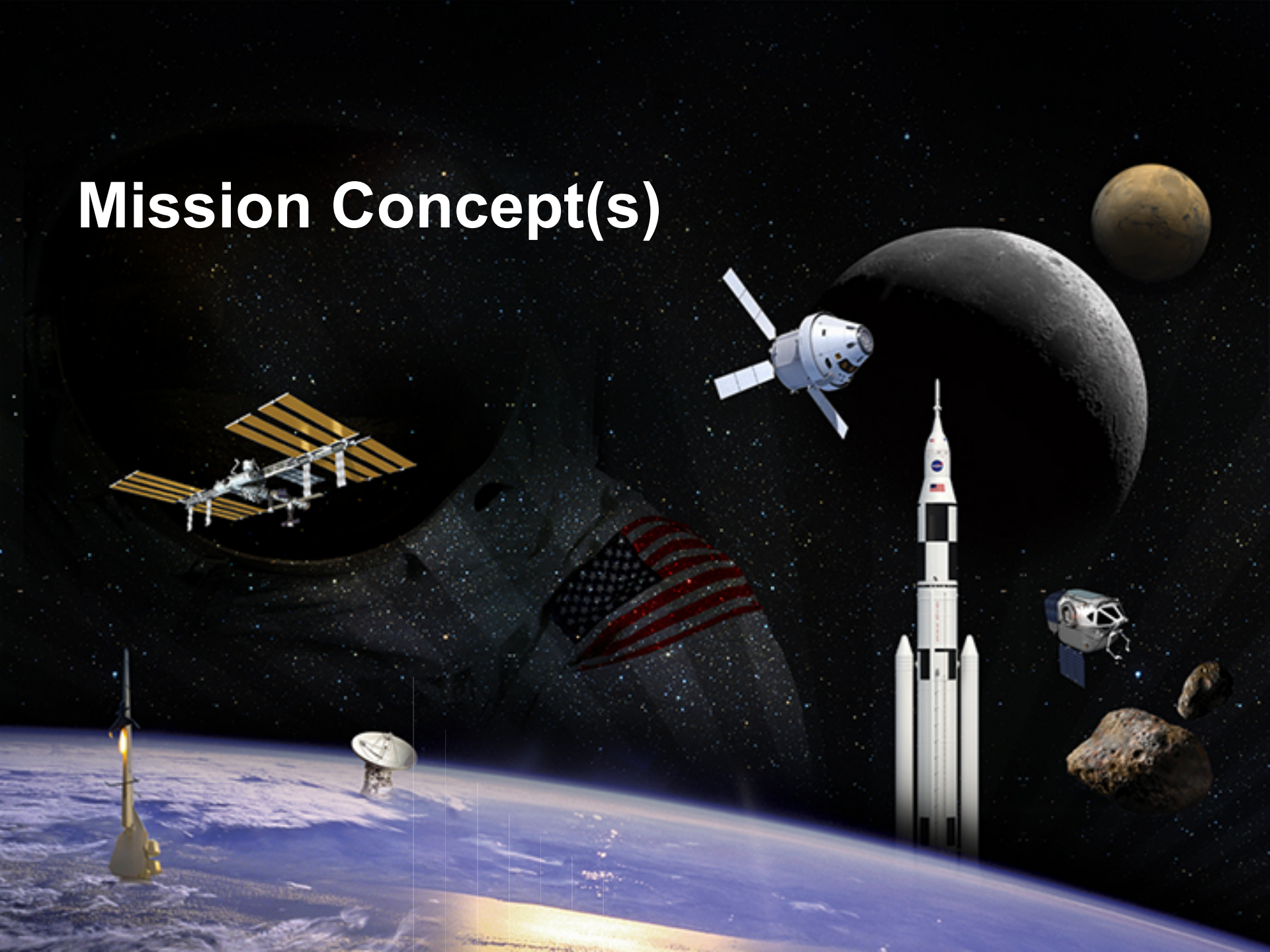
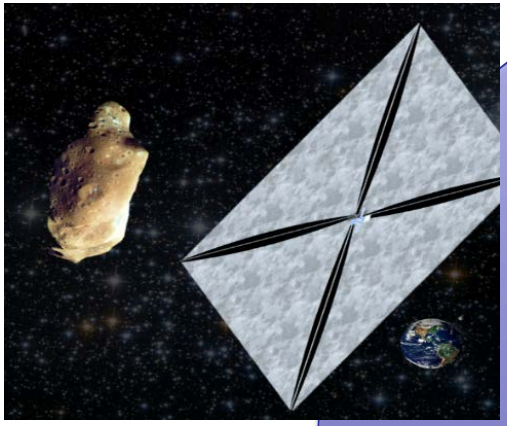
Mission Concept(s)



Mission Objectives & Drivers

NEA Scout



- Fly-by of near-Earth asteroid
- Telecom: LGA + HGA
- Camera for science & opnav
- Tracking & trajectory coupled (via solar sail)

Lunar Flashlight

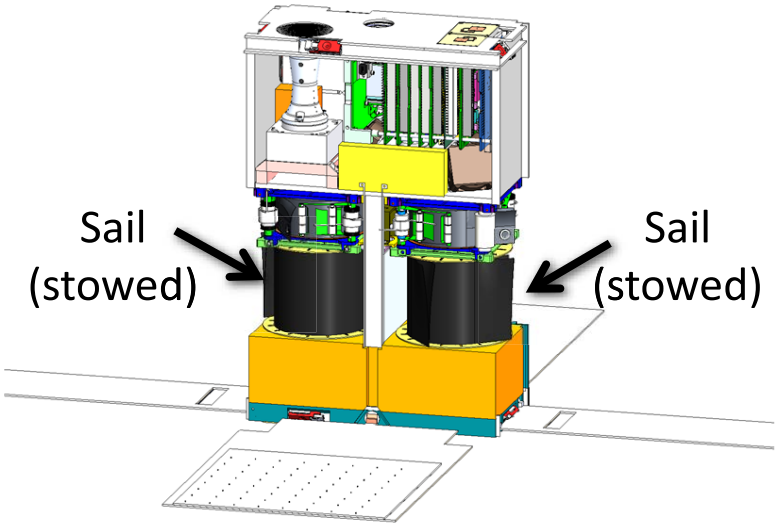
- Illuminate craters on lunar south pole to look for frozen H_20
- Telecom: LGA
- Sail reflects light into target craters
- Science & trajectory coupled (via solar sail)

- **6-U Cubesat form factor**
- **Common bus / hardware (mostly)**
- **Different science payloads**
- **Deployable solar sail**
- **Ride-share with EM-1**
- **30 month mission**

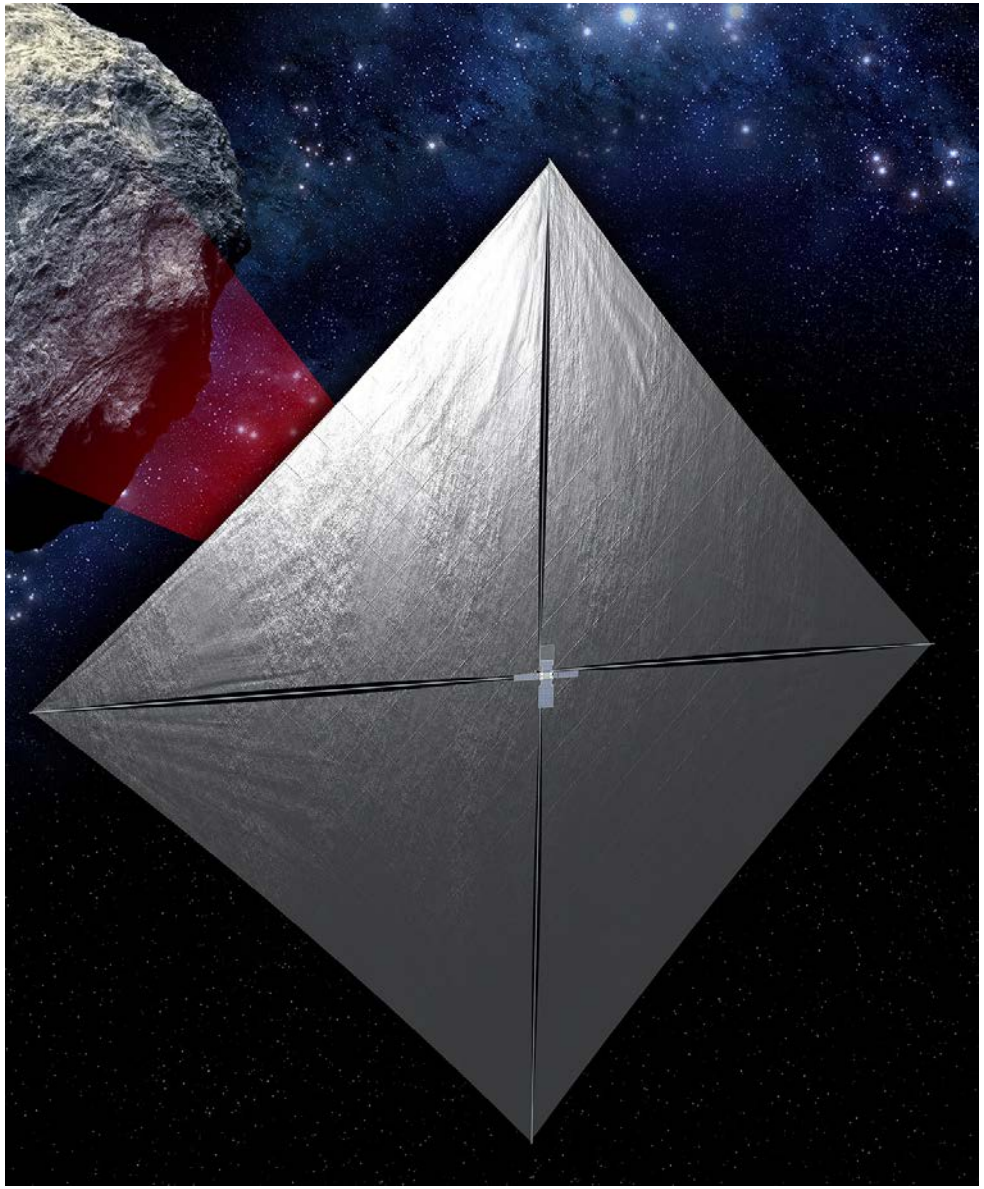
Additional programmatic goal: identify benefits & drawbacks of parallel CubeSat mission development

NEA Scout & Lunar Flashlight Hardware

LGA + Camera (NEA Scout)

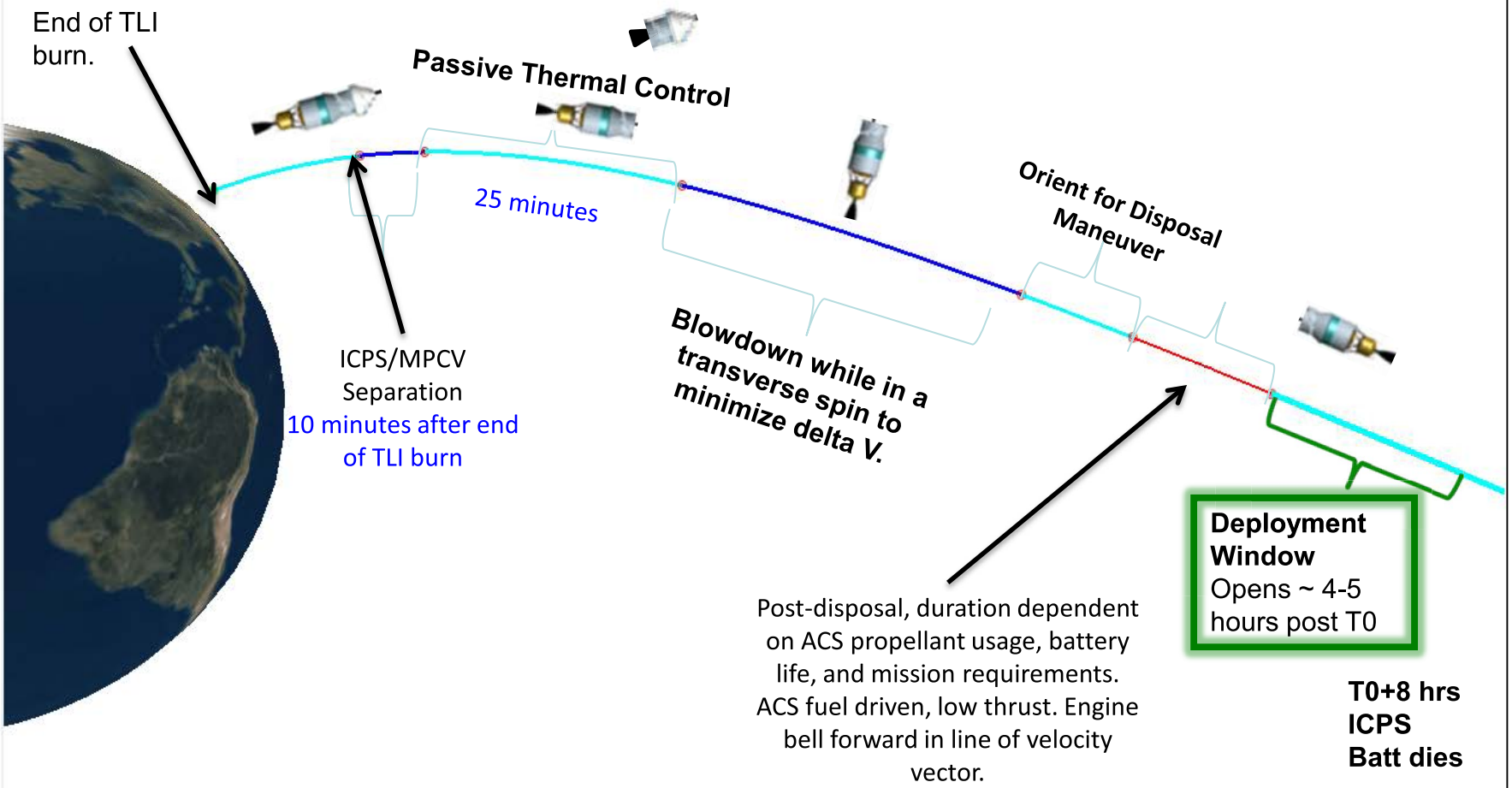


LGA + HGA (NEA Scout)
Solar panels

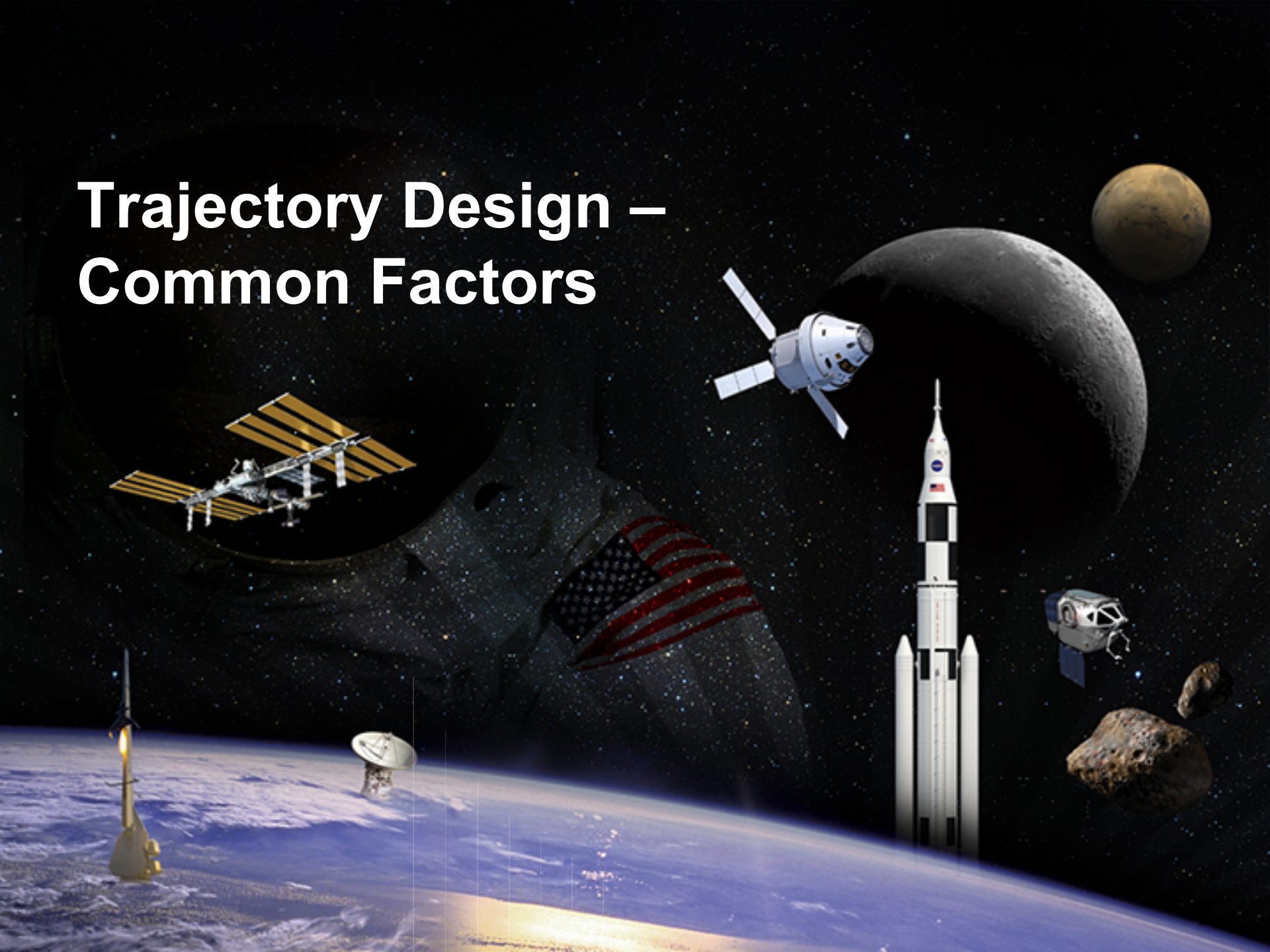


SLS EM-1: Launch and Ejection Phase

- **Launch window up to 2 Hrs long (depends on launch day in one week window recurring every month)**



Trajectory Design – Common Factors

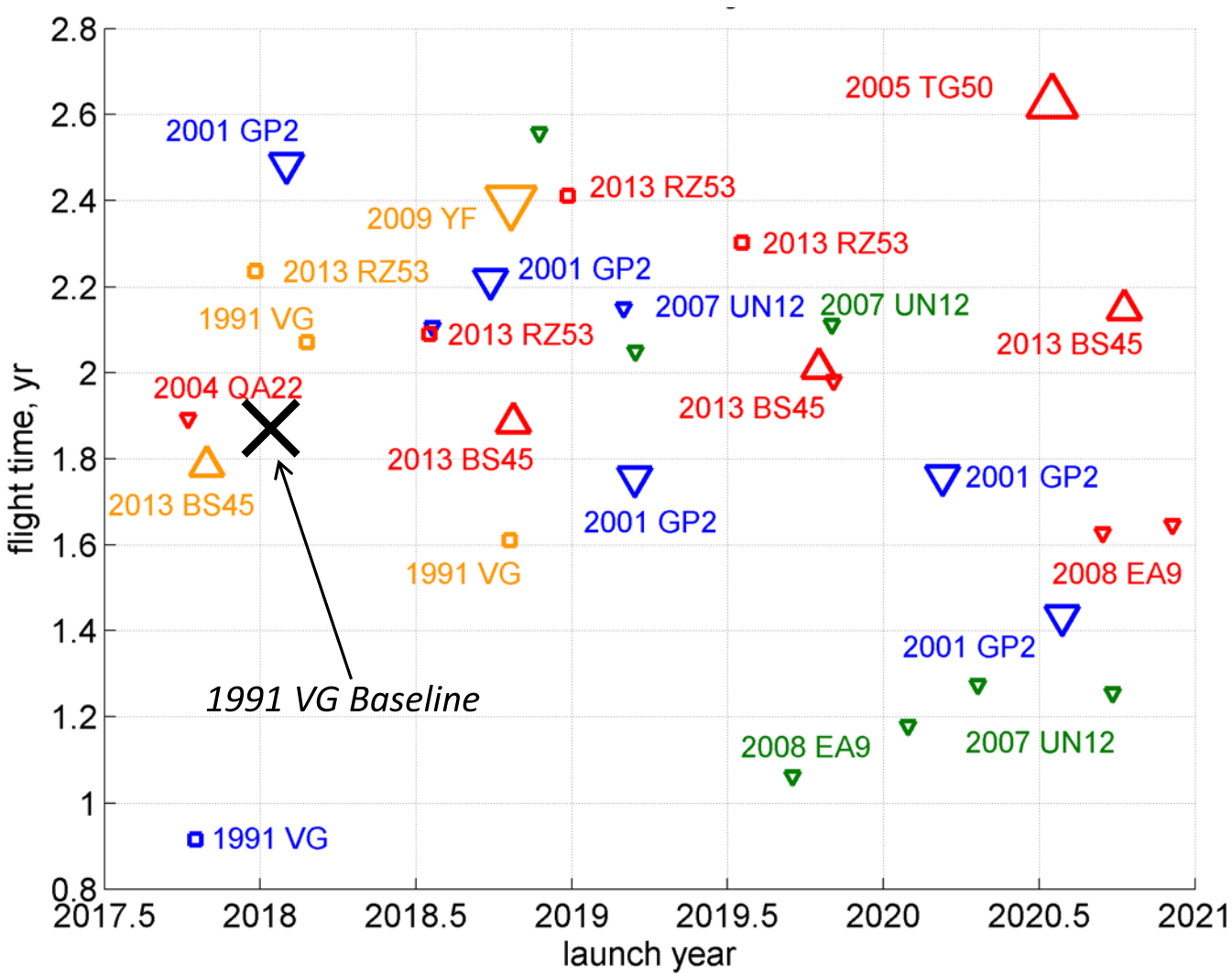


Key Requirements & Assumptions

- Driving
  - 2.5 year maximum mission duration
  - Compatibility with EM-1 launch and deployment
  - Assumed launch December 2017 (now 2018)
  - Post-ejection ΔV to initialize lunar flyby < 10 m/s
- Sail
  - 11-12 kg spacecraft, 80 m^2 sail area
  - Design Characteristic Acceleration: 0.0601 mm/s^2
  - Deploy after first lunar flyby
  - Sail normal to sun angle ≤ 50° (NEA Scout), 60° (Lunar F)
  - Duty cycle:
    - NEA Scout = 90% (0.0541 mm/s^2)
    - Lunar Flashlight = 85% (0.0511 mm/s^2)
      - More conservative than NEAS due to lunar orbit with close perilune

Trajectory Design – NEA Scout

NS Rendezvous Target Search

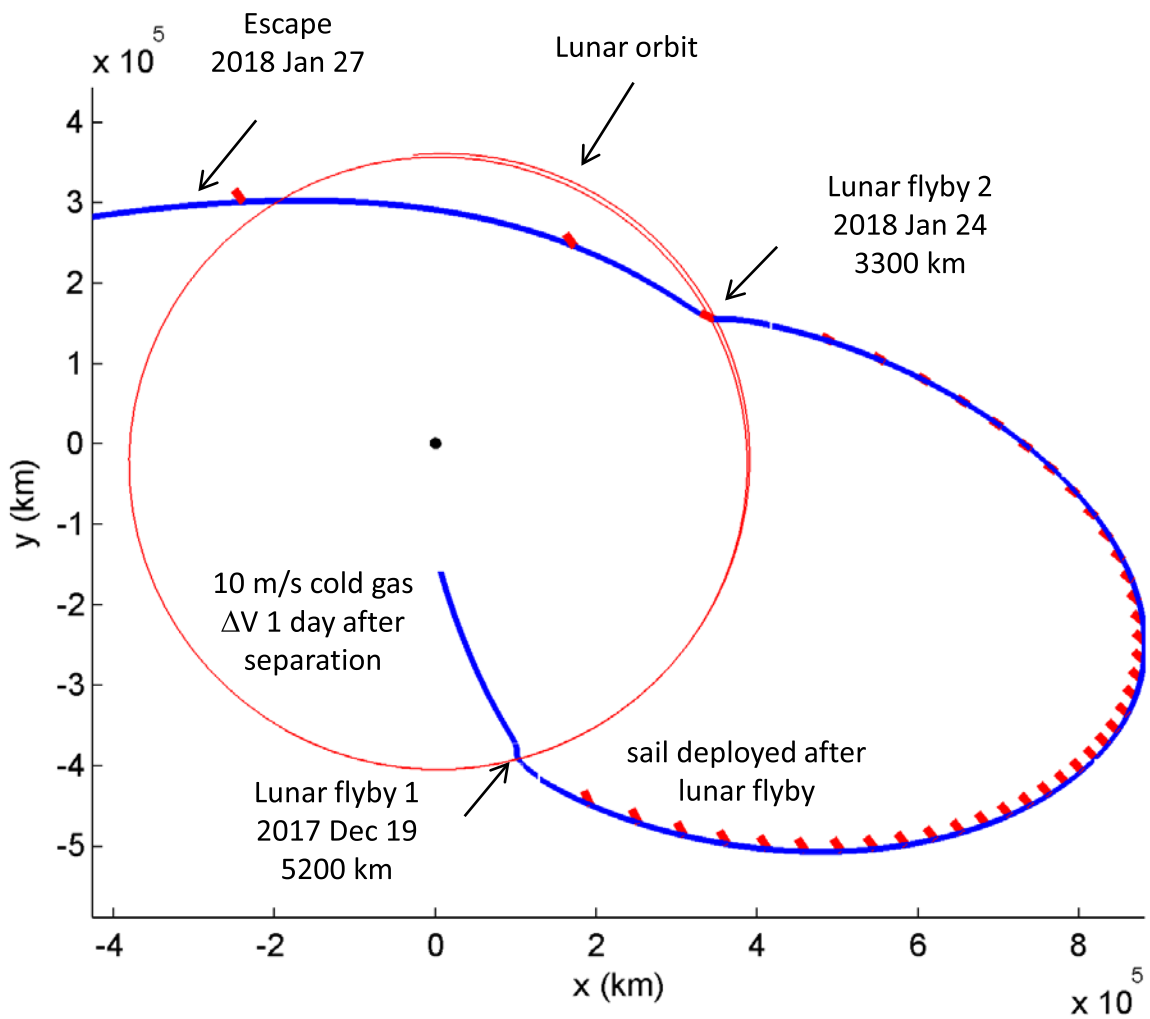


- Colors (AU)
  - blue < .25
  - green < .5
  - orange < .75
  - red < 1
- Shape (OCC)
  - △ under 2
  - □ under 4
  - ▽ under 7
- Size (appx dia.)
  - small < ~15 m
  - med. < ~30 m
  - large < ~50 m

Local minima for flight time. Flight time increases linearly with pre-escape loiter time
Flight time increases non-linearly with delayed escapes

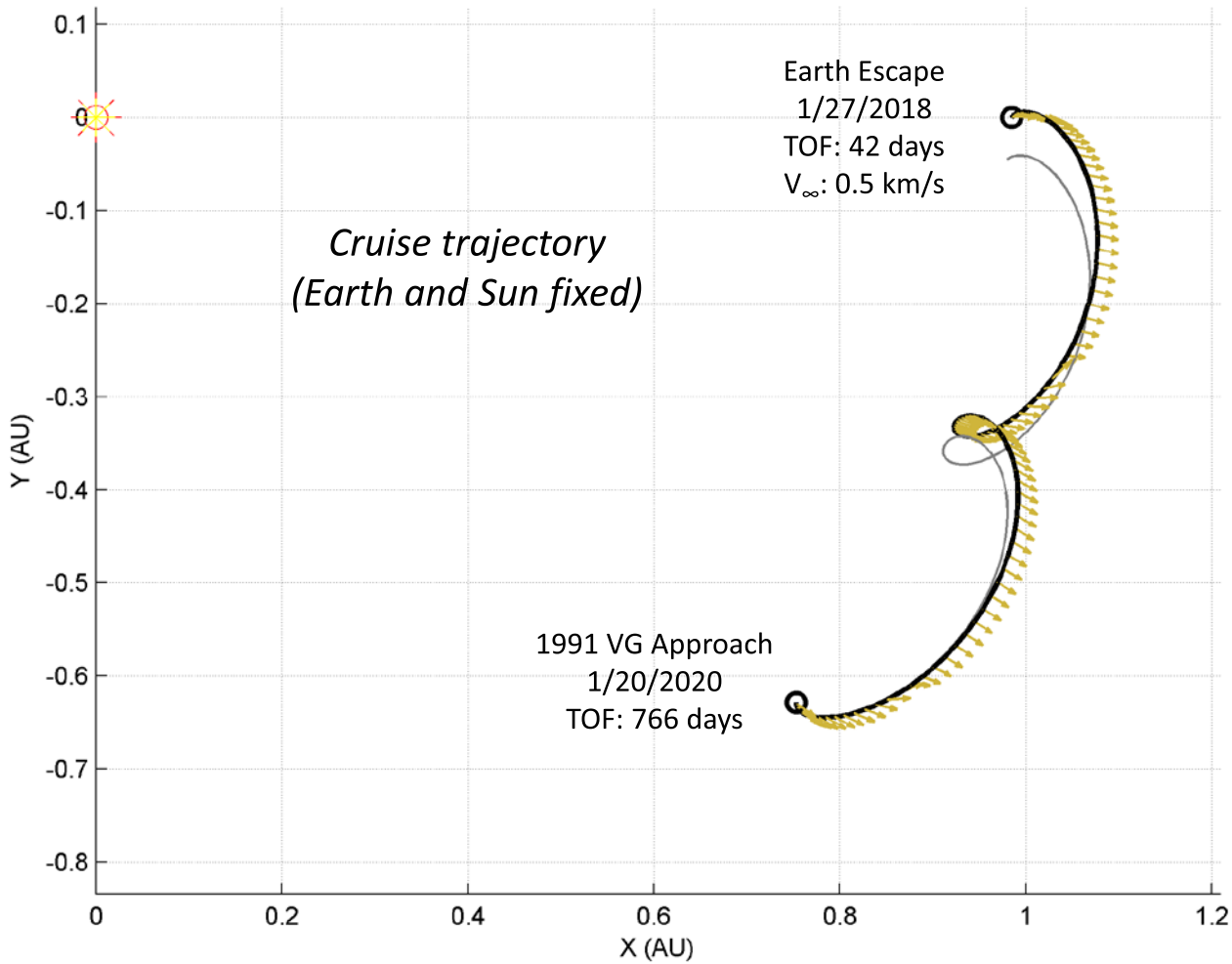
NS Double Lunar Flyby Escape

- High thrust required to target 1st lunar flyby
  - First nav solution within 12 hours of separation
  - First TCM within 24 hours
  - Cleanup TCM within 36 hours
- No data on disposal burn dispersions yet
  - 1+ month of solar sailing available to clean up flyby errors
- Daily tracking and trajectory updates approaching 2nd lunar flyby reduce error
  - 12 mrad pointing control error results in ~1 m/s flyby ΔV error



NS Cruise to 1991 VG

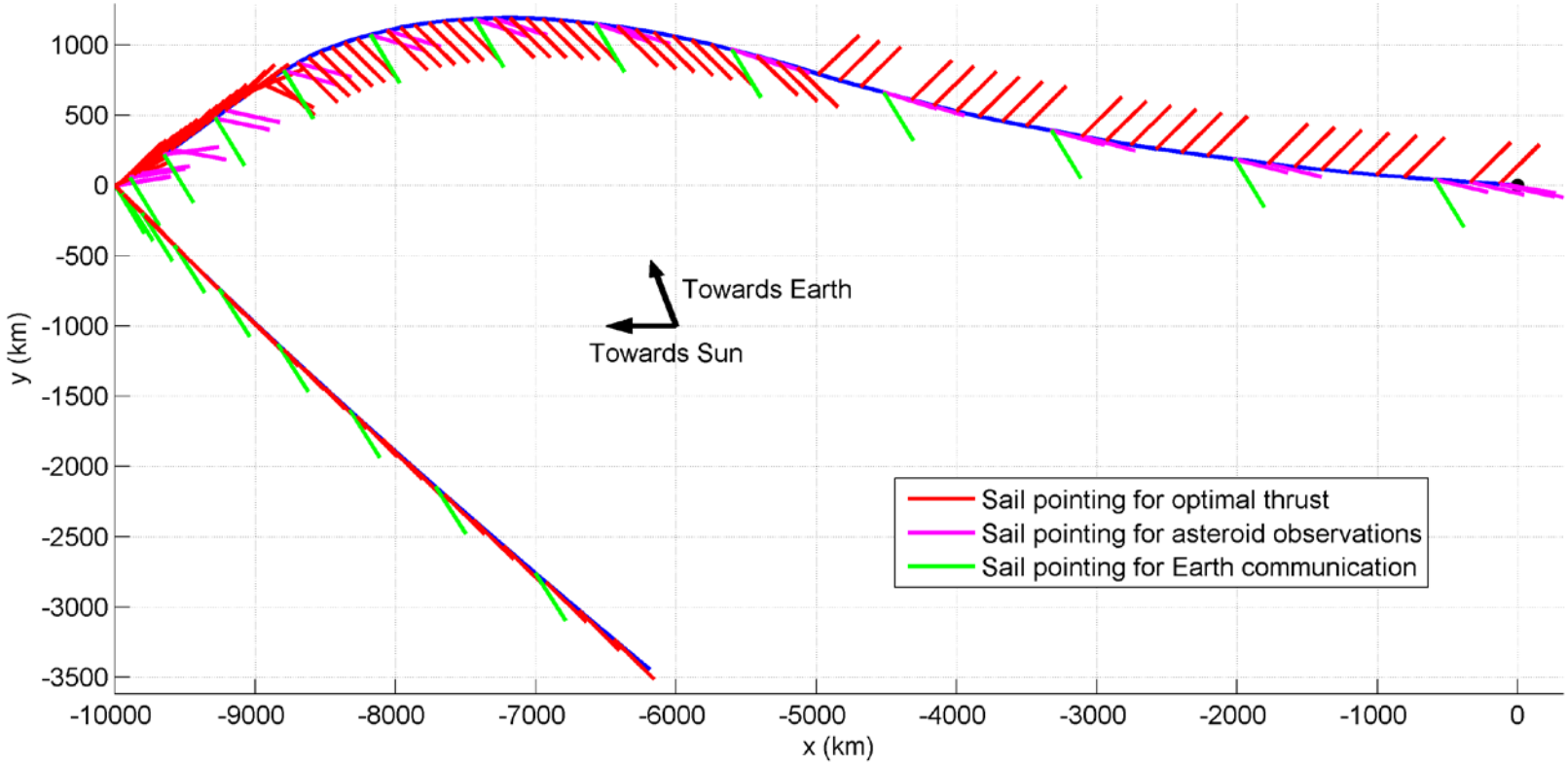
- Cruise flight time 724 days (~ 2.0 years)
- Max Earth distance ~0.7 AU
- Target position ellipse 3400/10/10 km, 1σ
  - Opportunity to recover object in 2017



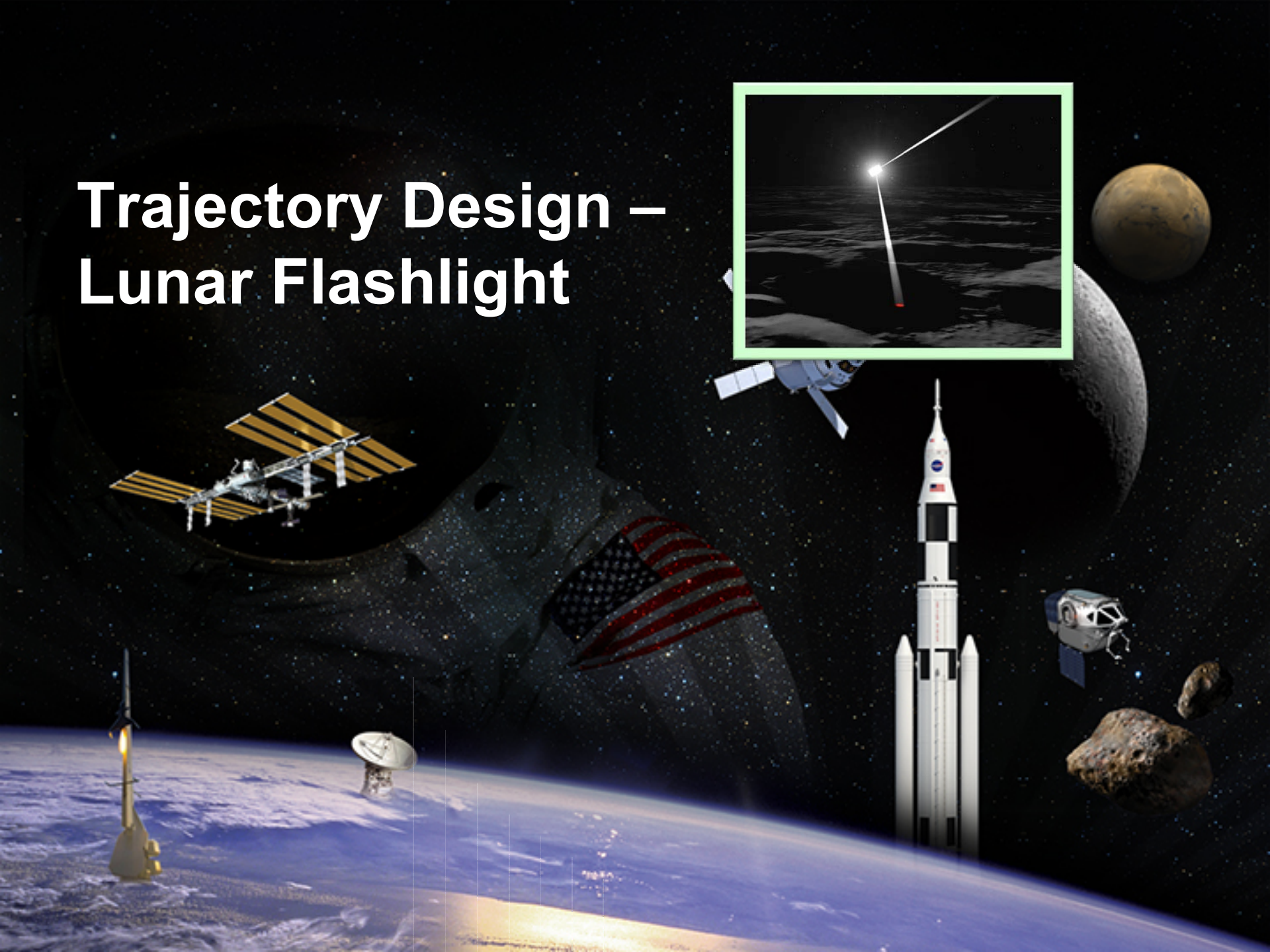
NS 1991 VG Detection, Approach & Flyby

- **50 deg** max constraint on sail angle
- **7000-10000 km** distance @ detection
- Detection velocity ~ **0-15 m/s**

- Flyby velocity ~ **18 m/s**
- Flyby altitude: **500 m**
- TOF ~ **7.5 + 12.5 days**



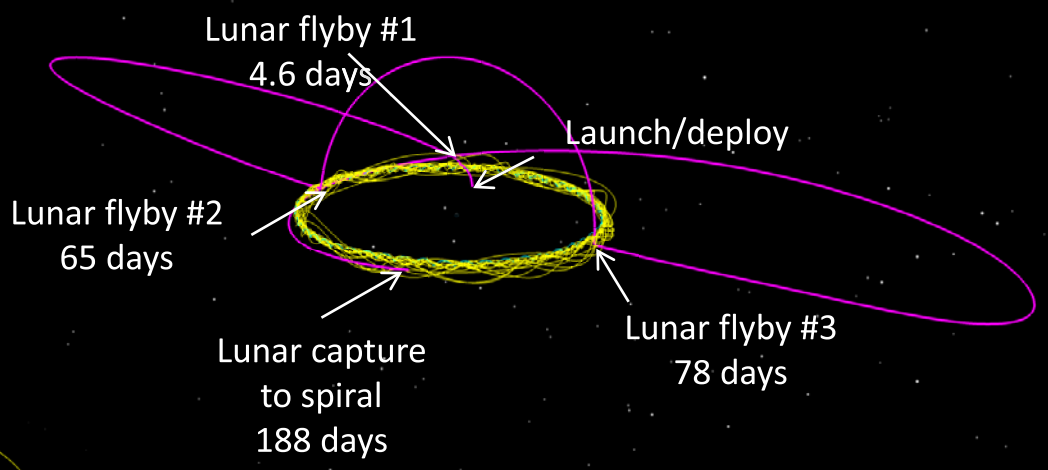
Trajectory Design – Lunar Flashlight

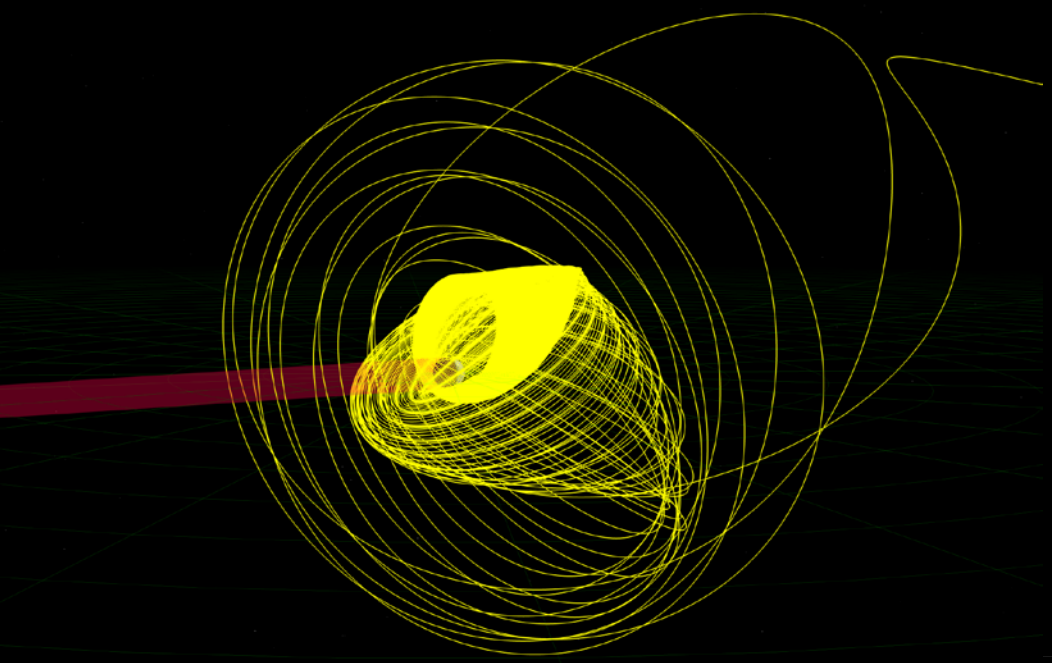


LF Mission Description – Cruise & Lunar Spiral

Cruise Phase (~190 days) ➔

- Post-ejection ΔV = 9 m/s
- 3 lunar flybys
- Lunar capture at E-M L2





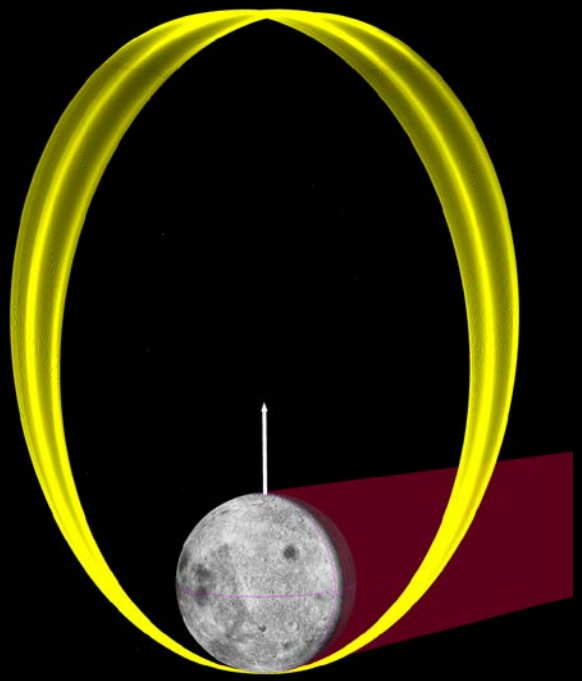
🡐 Lunar Spiral Phase (~420 days)

- June 13, 2018 – Aug 7, 2019
- 60,000 km to 9,000 km apolune

LF Mission Description – Science

Science Phase (~40 days)

- July 29, 2019 – Sep 7, 2019
- Begins 9 days before end of spiral
- 78 passes
- average viewing period < 10° from pole: 136 sec
- average viewing period < 6° from pole: 88 sec
- 9,000 km x 20 km orbit, orbital period 12.3 hr
- Global coverage achieved
- More than 25 passes at less than 20 km altitude

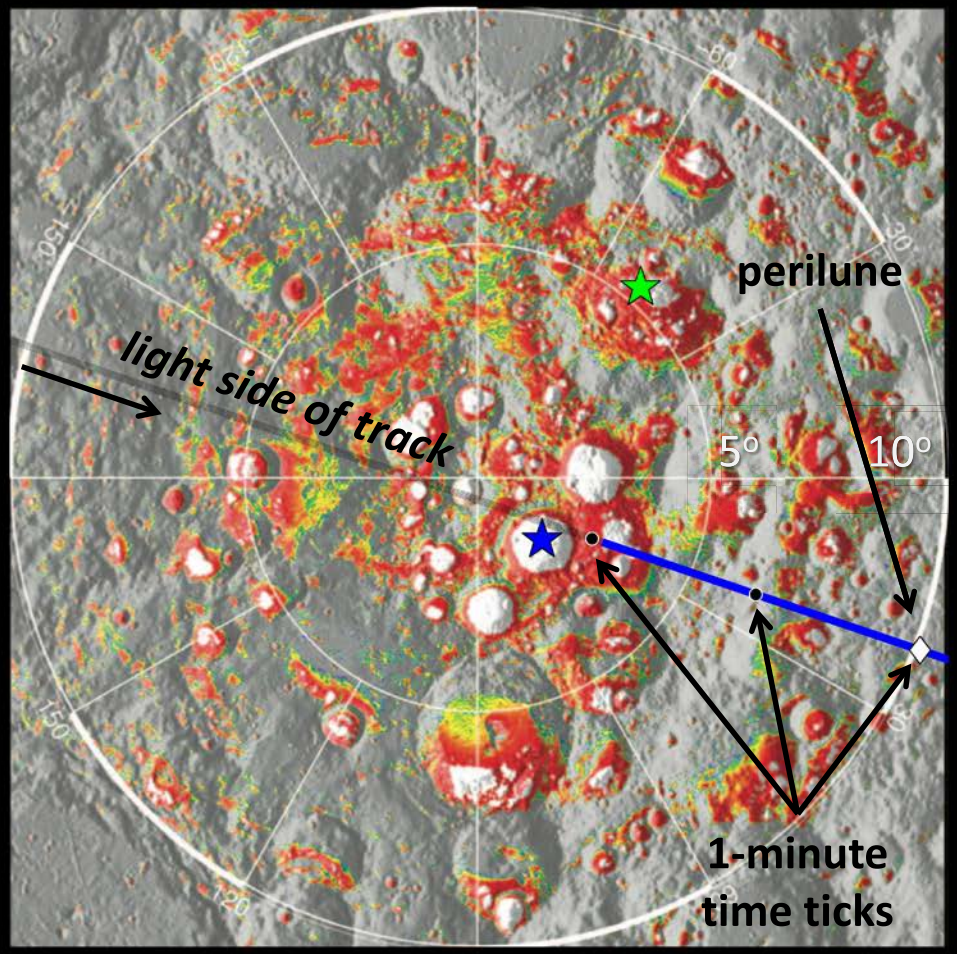


Total Flight Time (Launch to end of science) = ~630 days (1.7 years)
Flight times for other launch dates may require as much as 2.5 years

July 29, 2019 TOTAL PASSES: 1

Lunar South Pole Passes

< 20 km :	0
20-30 km :	0
30-50 km :	0
50-100 km :	0
100-150 km :	0
150-200 km :	**1**



< 20 km
20-30 km
30-50 km
50-100 km
100-150 km
150-200 km

★ Shoemaker crater ★ LCROSS site

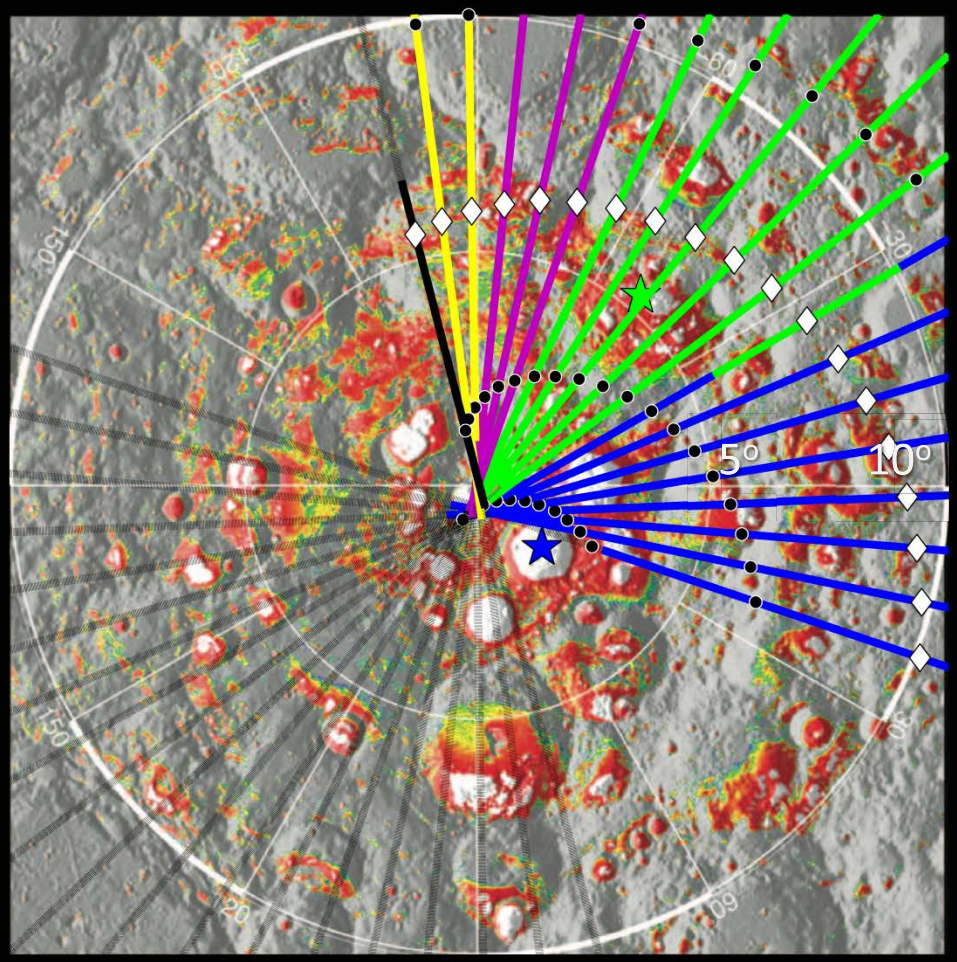
median longitude: **24.6°E**

Start Science

TOTAL PASSES: **19**

Lunar South Pole Passes

< 20 km :	**1**
20-30 km :	0
30-50 km :	2
50-100 km :	3
100-150 km :	6
150-200 km :	7



< 20 km

20-30 km

30-50 km

50-100 km

100-150 km

150-200 km

★ Shoemaker crater

★ LCROSS site

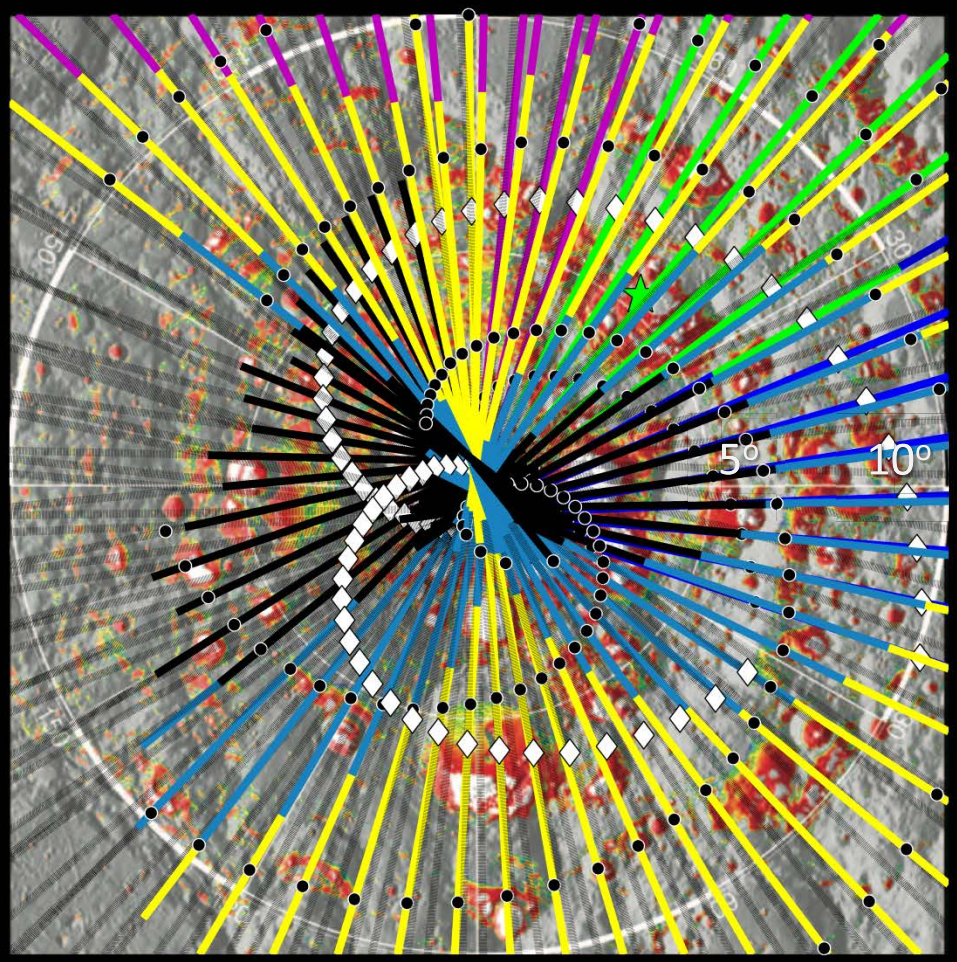
days: **9.39**

End

TOTAL PASSES: 78

Lunar South Pole Passes

< 20 km :	**34**
20-30 km :	23
30-50 km :	5
50-100 km :	3
100-150 km :	6
150-200 km :	7



< 20 km

20-30 km

30-50 km

50-100 km

100-150 km

150-200 km

★ Shoemaker crater

★ LCROSS site

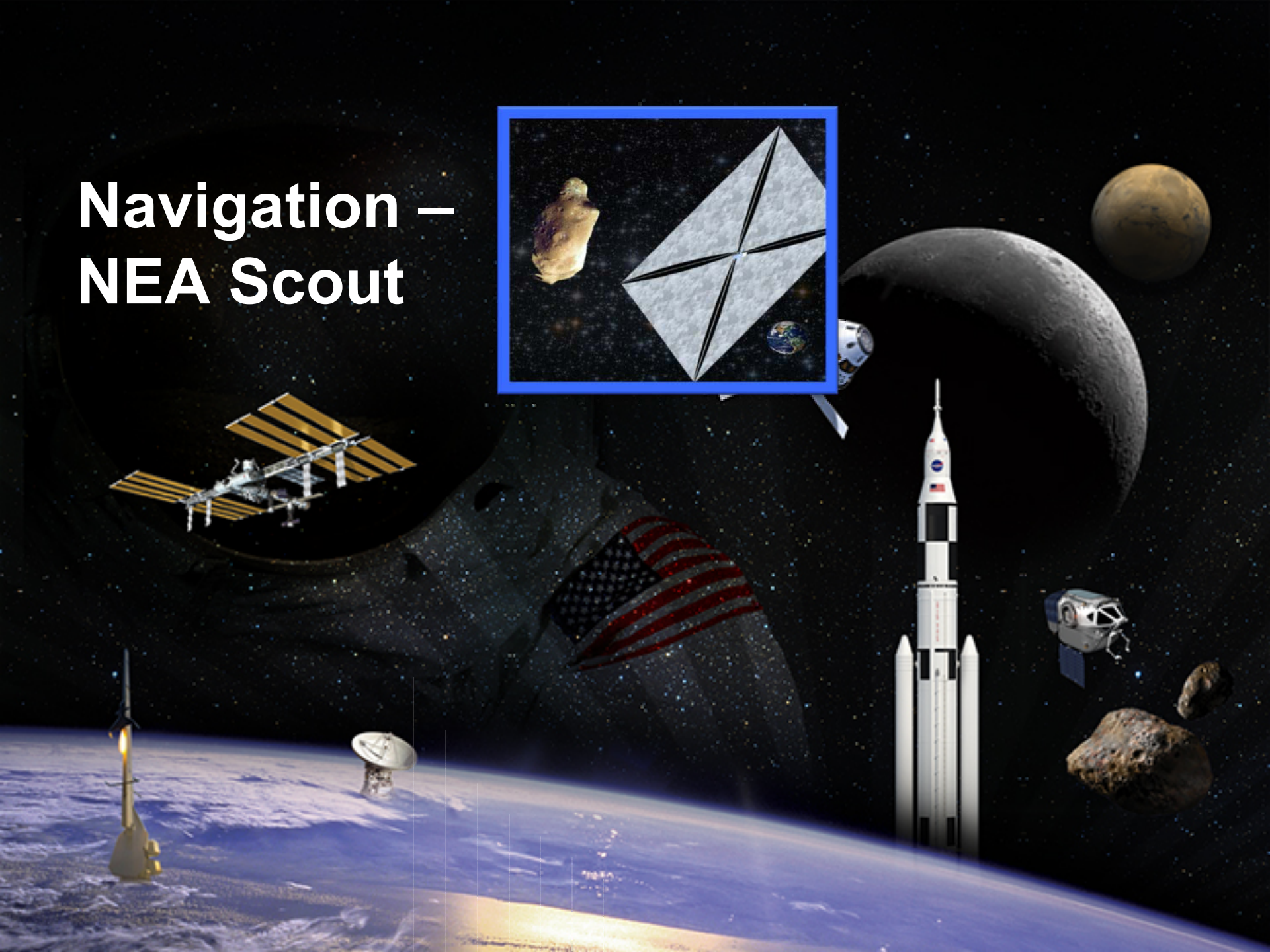
days: **39.62**

Navigation

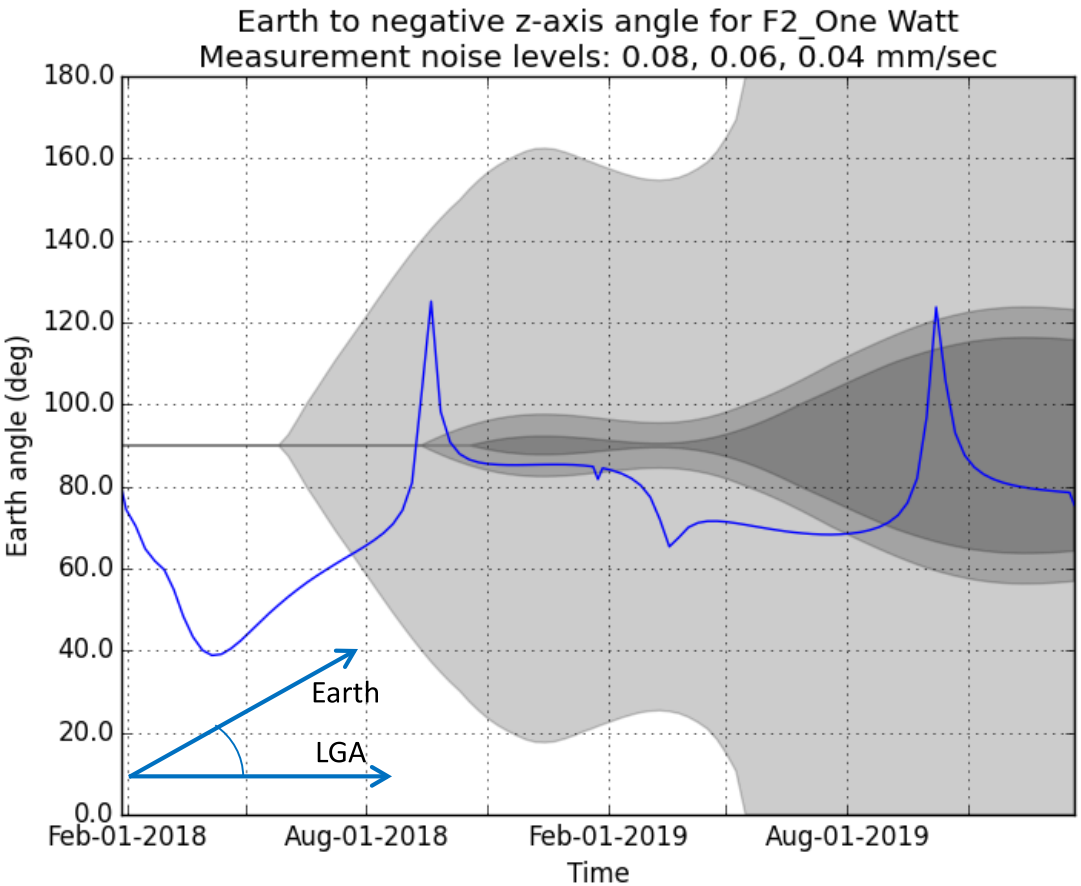
Navigation Overview

- Radiometric (both missions)
  - Doppler [range-rate]
  - SRA [range]
  - DDOR [range]
    - For critical events (e.g., post-ejection, LF orbit capture)
- Optical (NEA Scout)
  - Science camera
  - On approach to target body

Navigation – NEA Scout

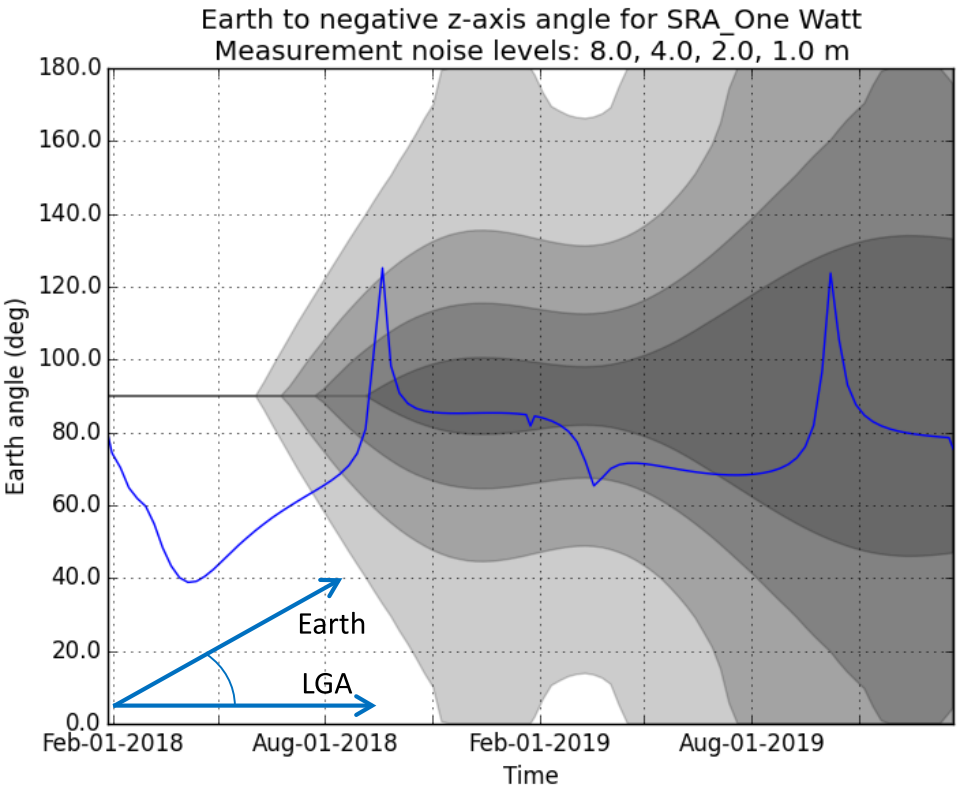


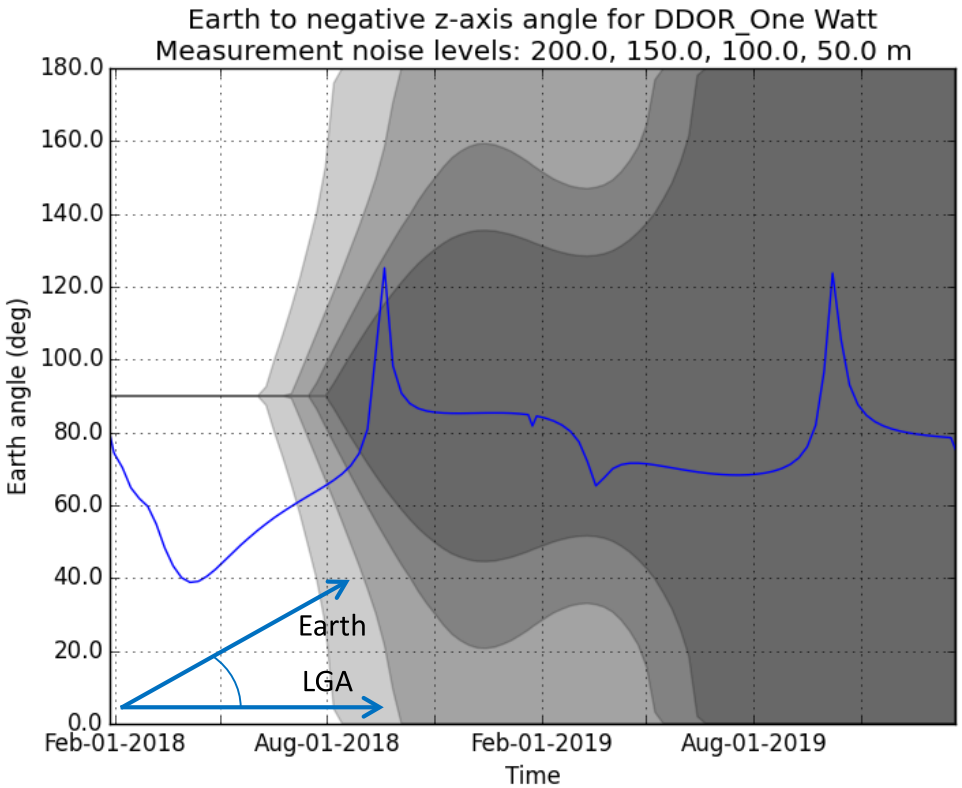
NS Tracking: Doppler



- LGA, 1W
- Gray regions in background indicate the quality of the navigation data
- When the blue line is in lighter shades of gray, the better the data quality
- Includes effect of SC-Earth distance and LGA boresight angle
- Can also estimate slew angle needed to increase the measurement quality

NS Ranging and ΔDOR



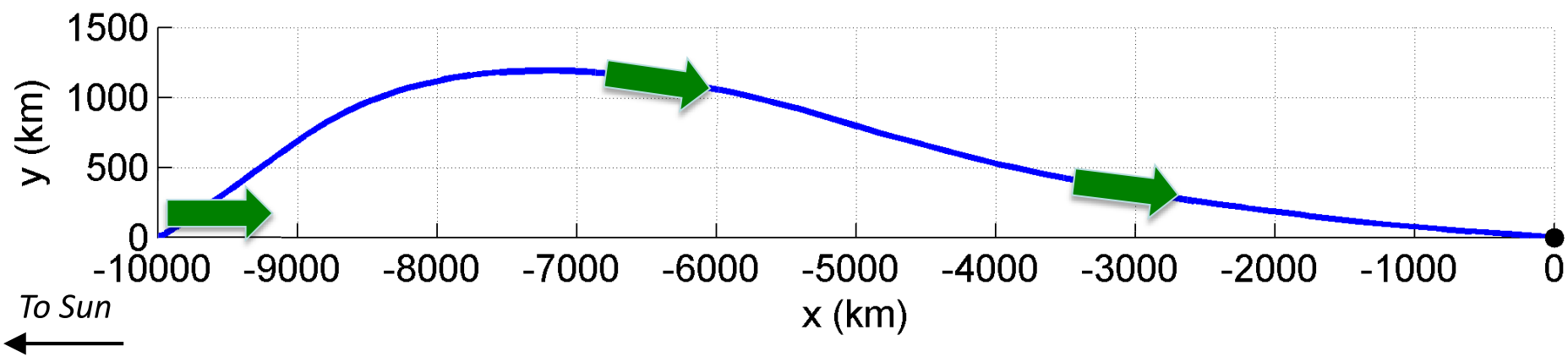


NS 20 day, Detection and Approach

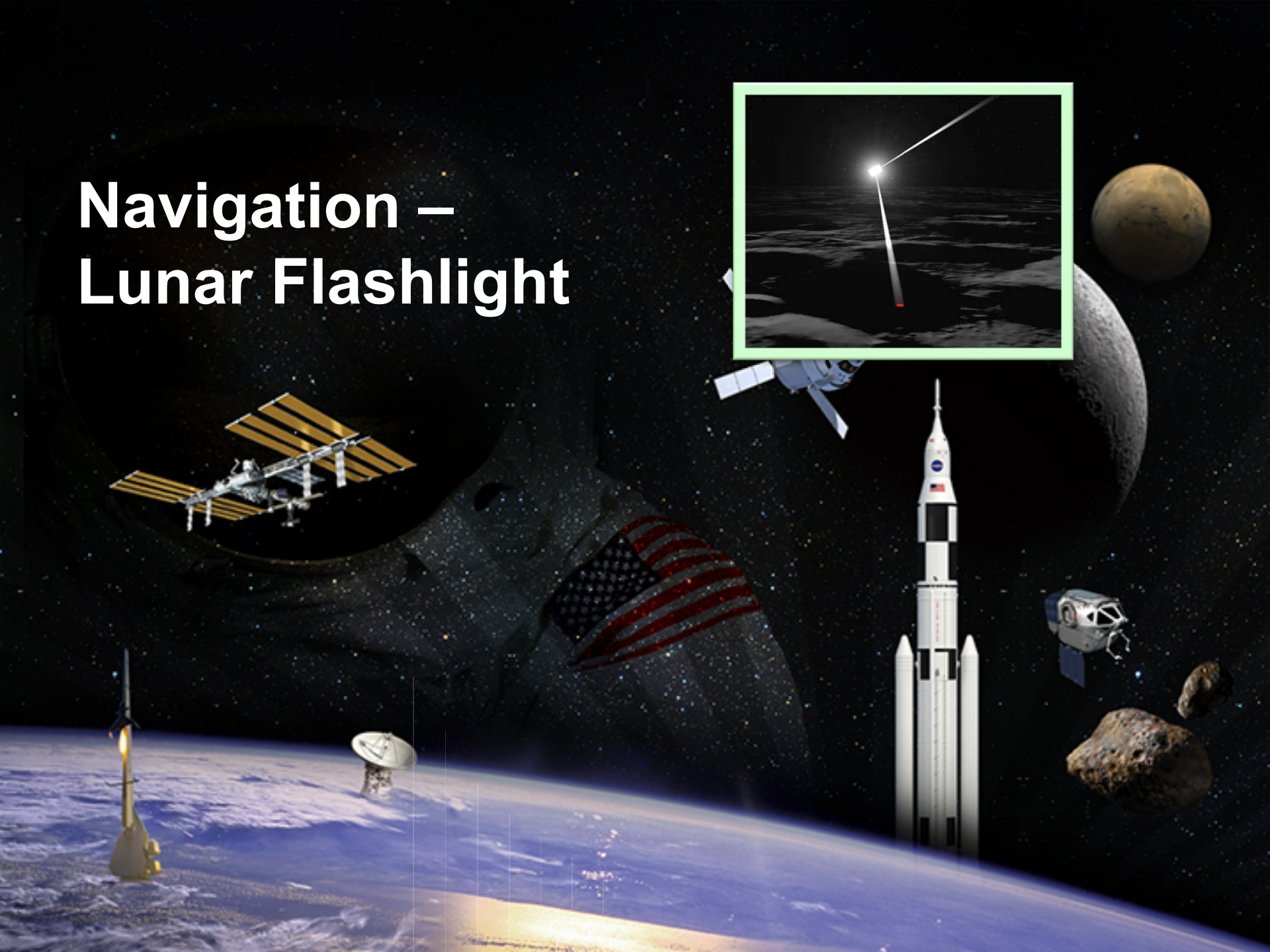
After the first OpNav sets, the original 3400/10/10 km target ephemeris is reduced to ~3/10/3 km.

The mid range OpNavs will reduce the radial component, leaving 2/2/2 km downtrack, radial and out of plane

Earliest resolution at 50 km / 1.5 hr out
Ephemeris errors have reduced to 50/800/50 m (implies **40 s flyby time uncertainty**)



Navigation – Lunar Flashlight



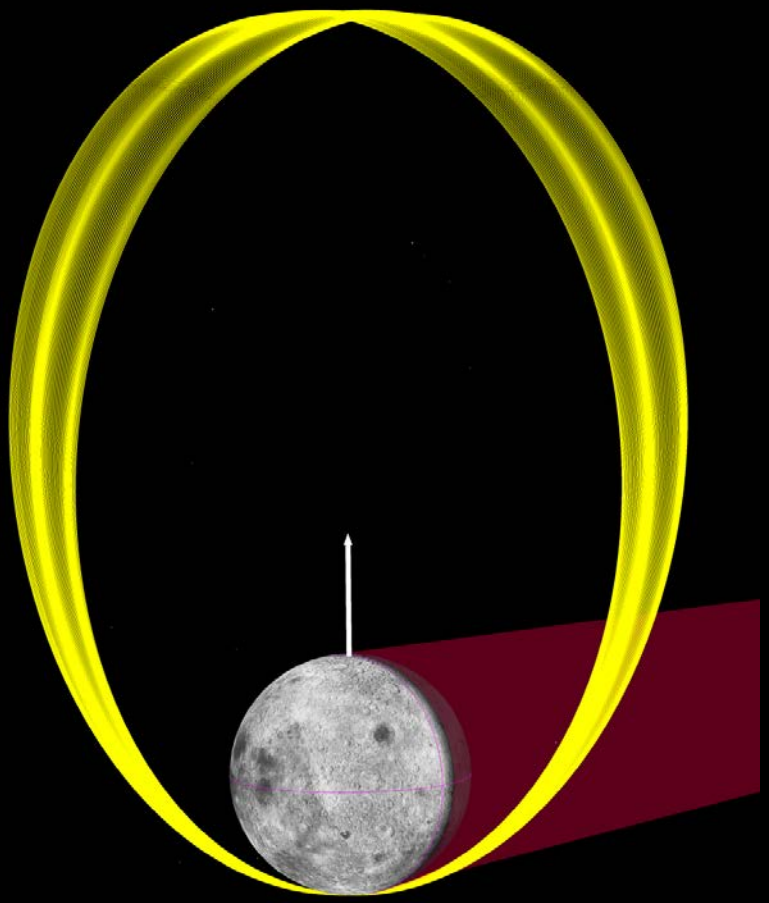
LF Navigation – LF Late Spiral / Science

Late Spiral: July 4 – 8, 2019

- ~1 month before start of science
- Approx. orbit period: 14 hours
- Approx. perilune altitude: 732 km
- Tracking: both sides of perilune

Perilune covariance study:

- RWA desaturation burns
- Sail pointing & modeling
- Duration of tracking passes



LF Navigation – Covariance Study

Nominal Case

Desats:

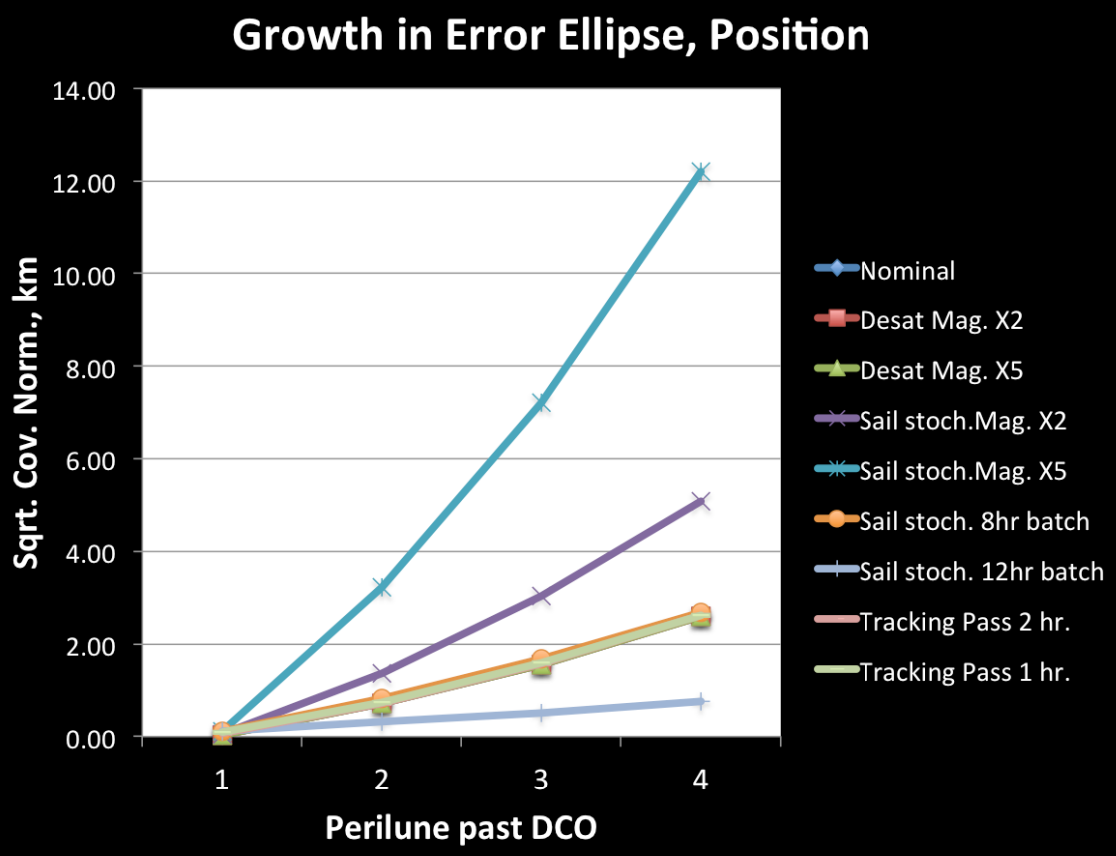
- 1 / week
- 0.21 m/s

Sail acceleration:

- 2 mrad / 1.1 μm/s^2
- Stochastic batches 4 hrs

Tracking passes:

- 4 hrs



Summary

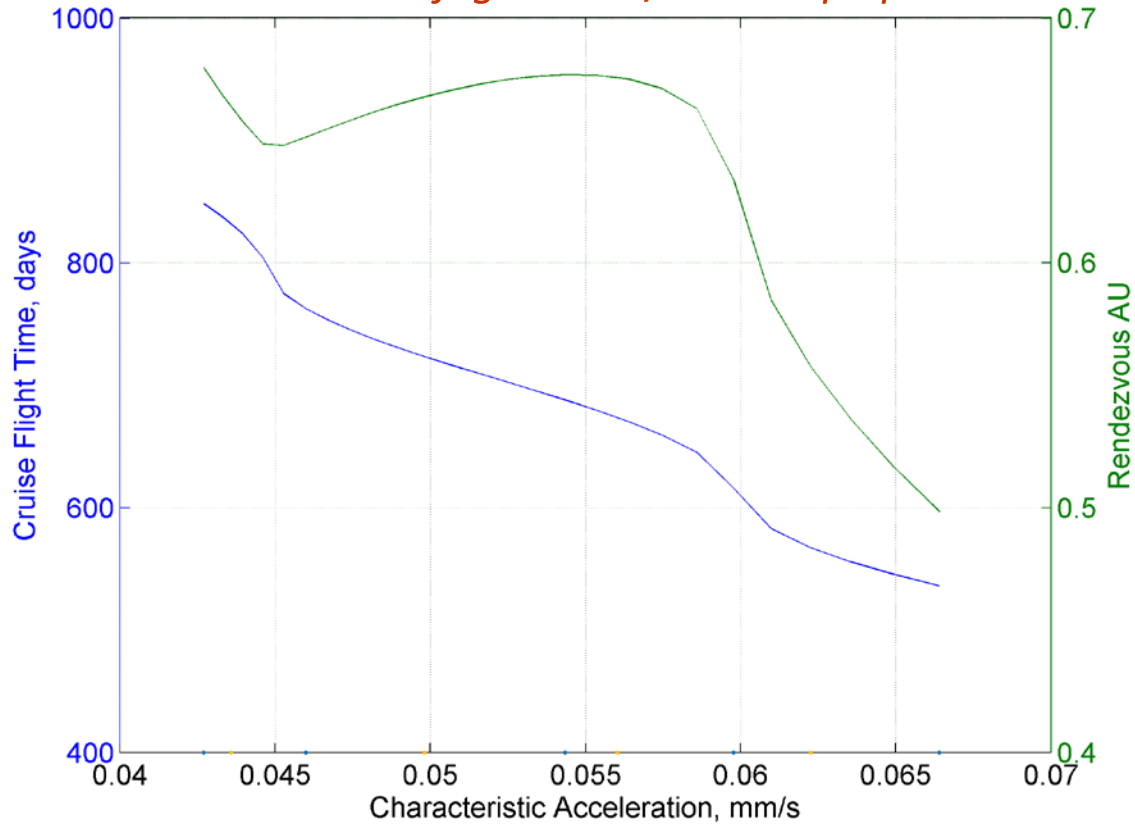
- Two CubeSat missions under parallel development (currently Phase A)
  - Rideshare opportunity with SLS EM-1
  - Nearly identical hardware, including solar sail
  - Very different science objectives:
    - NEA Scout: flyby and characterization of near-Earth object
    - Lunar Flashlight: search for water ice in craters at lunar south pole
- Trajectory Design & Navigation
  - Similar solar sail models
  - Distinct gravitational regimes (after NEA Scout escape)
  - Two design teams
    - Work closely together
  - One team provides nav. support for both
- Big questions still remain (but initial signs are promising)
  - Cost savings
  - Reduction in risk
  - Constraints on trajectory / navigation

Thank you!
Questions?

NEA Scout Backup

System Sensitivity for 1991 VG

minimum flight time / no escape phase



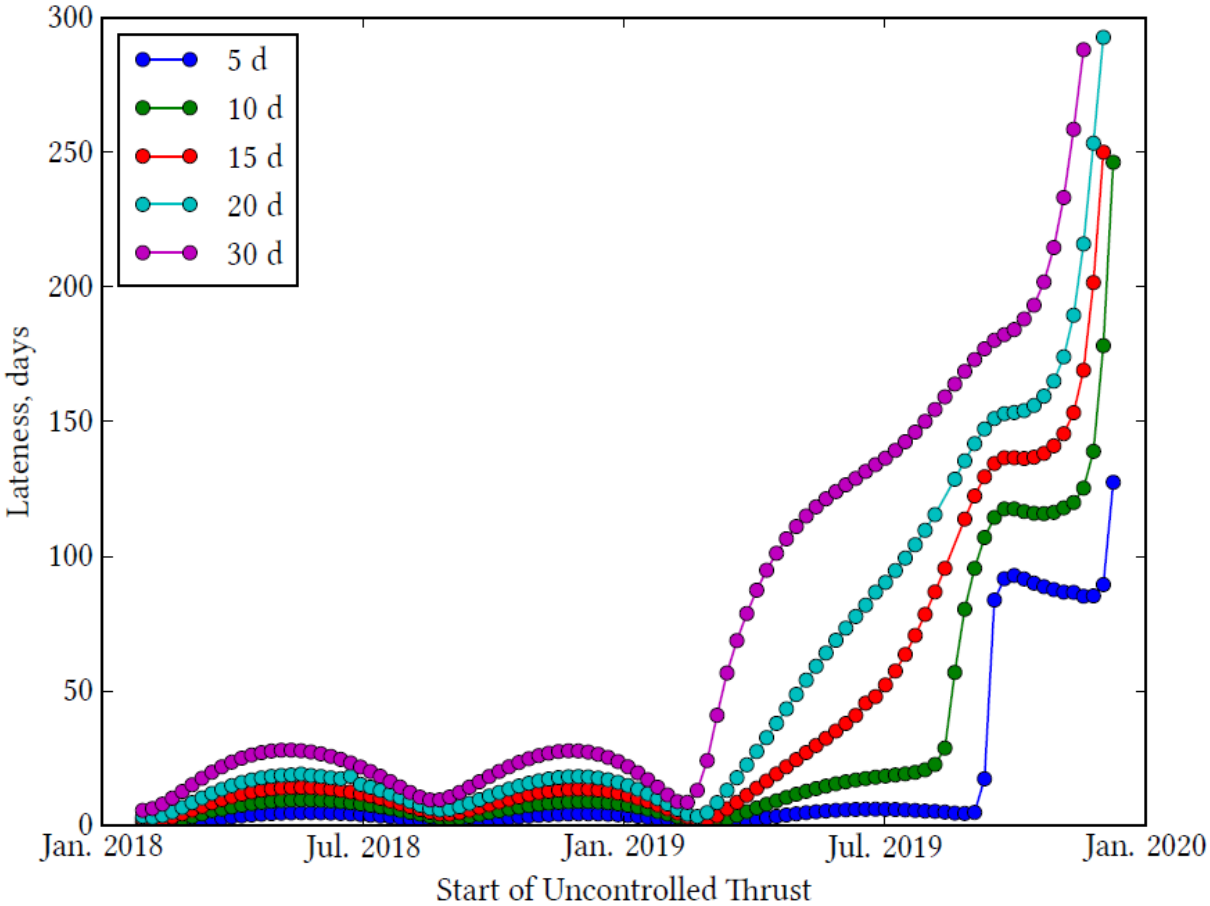
Sail model area for 12 kg & 10% MD margin: 70 m^2, 80 m^2, 90 m^2, 100 m^2

S/C mass for 80 m^2 sail model & 10% MD margin: 14 kg, 13 kg, 12 kg, 11 kg, 10 kg, 9 kg

Baseline design point: 12 kg and 80 m^2

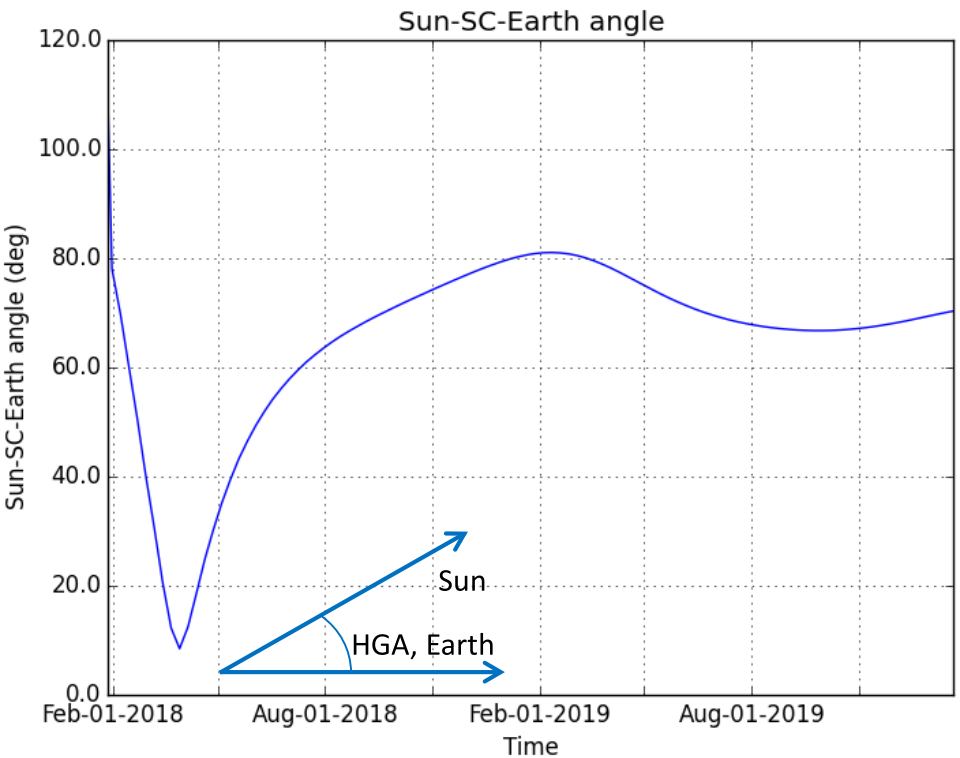
Resilience to Safe Mode
unplanned days pointing at Sun

- Can accommodate up to two weeks of safe mode first 1.5 years of cruise
- Mission recoverable with additional flight time last 6 months of cruise

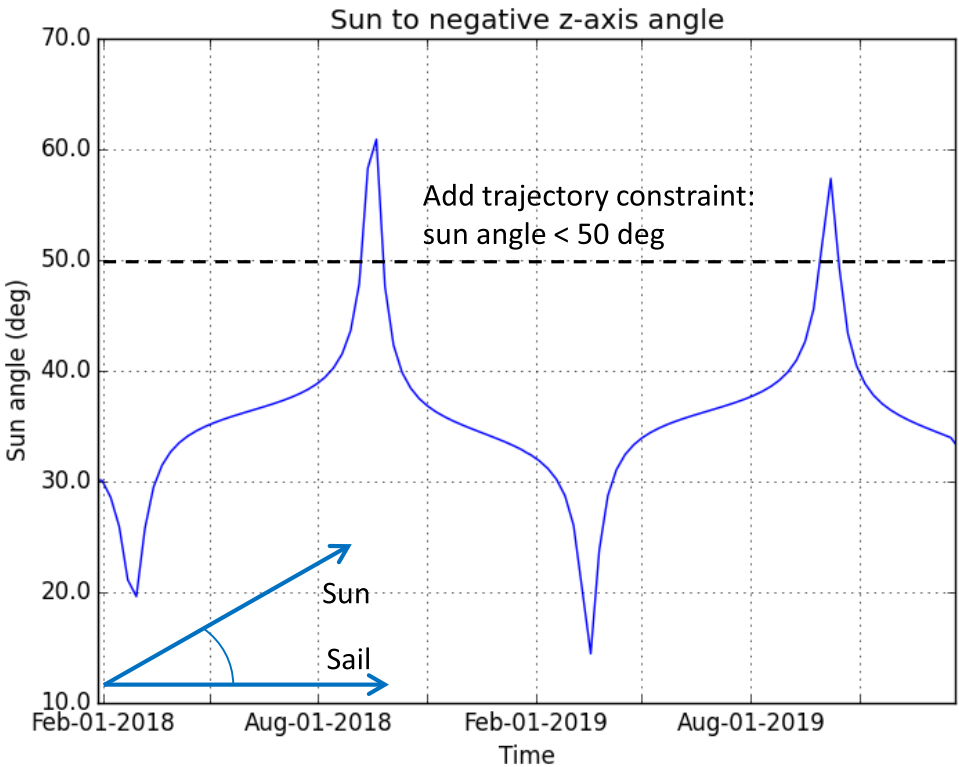


Solar Angles

HGA, Communication



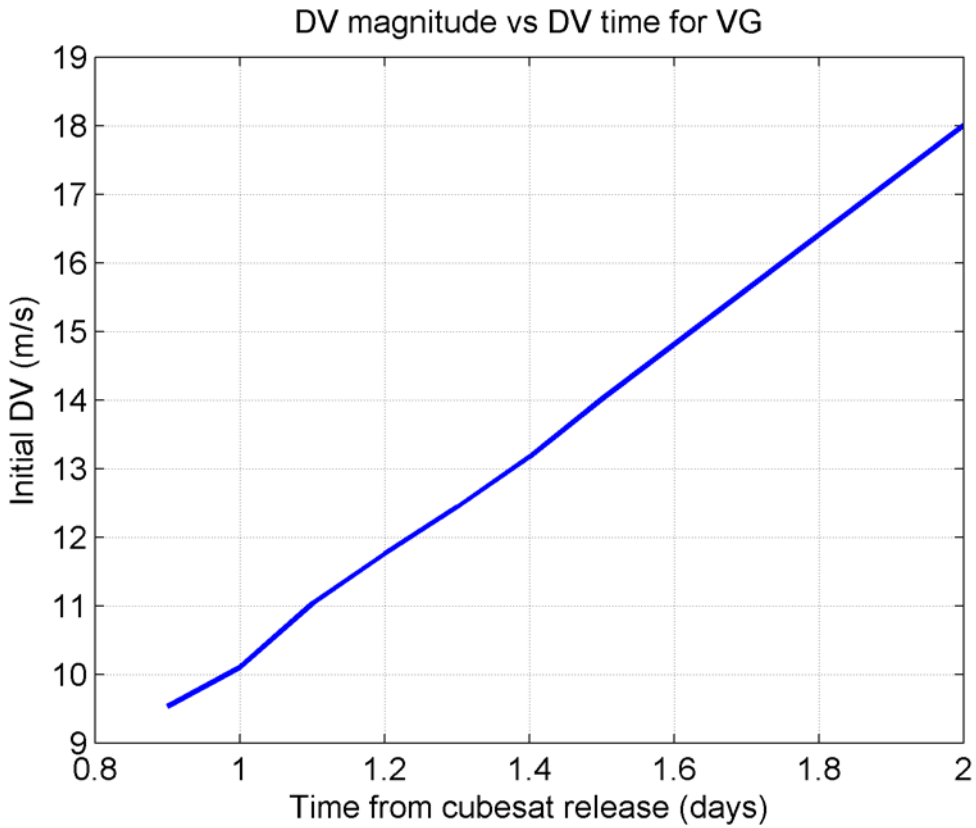
Sail, Thrusting



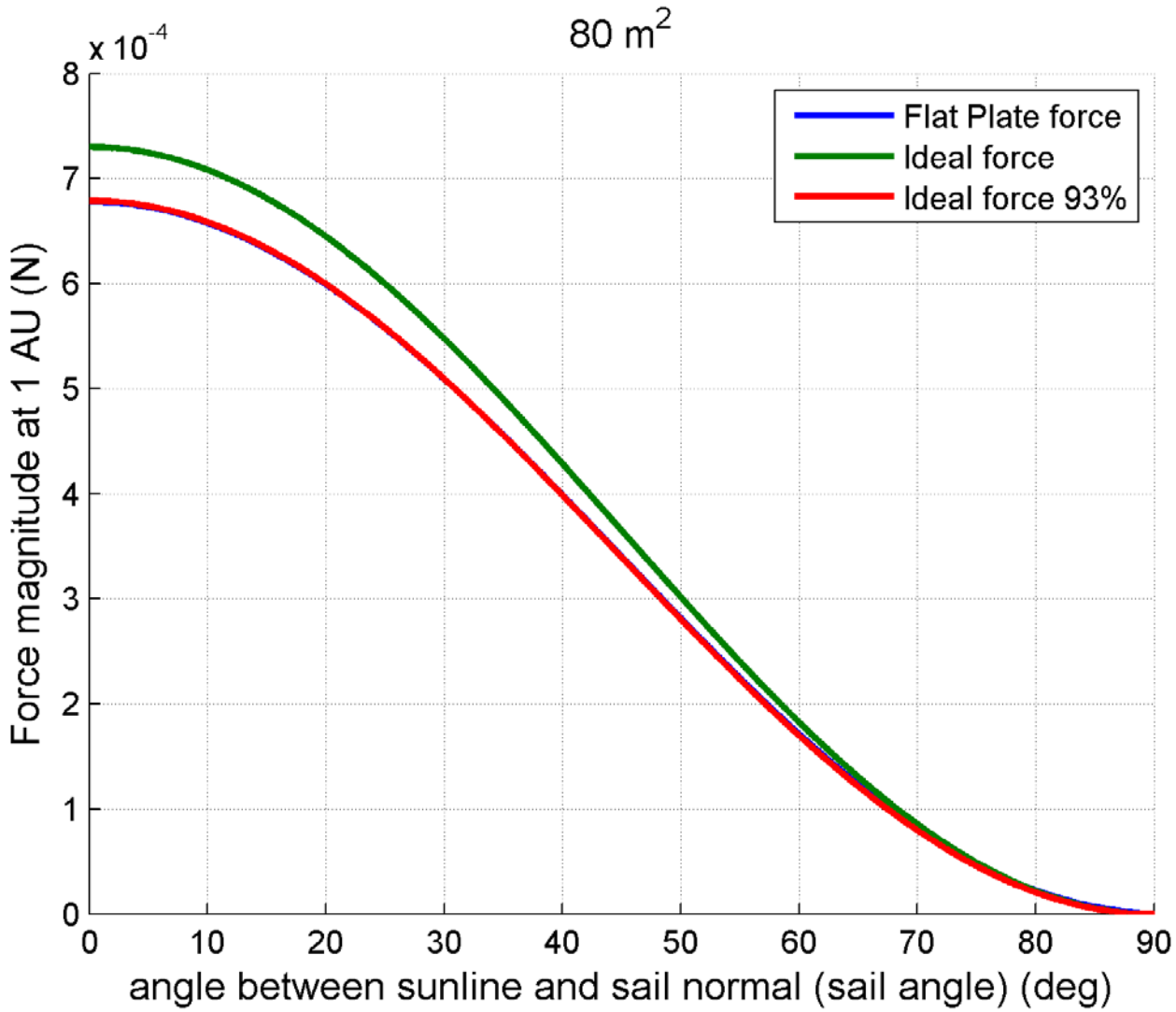
Power-positive when solar angle < 50 deg
(downlinks may occur on batteries)

Initial maneuver time sensitivity

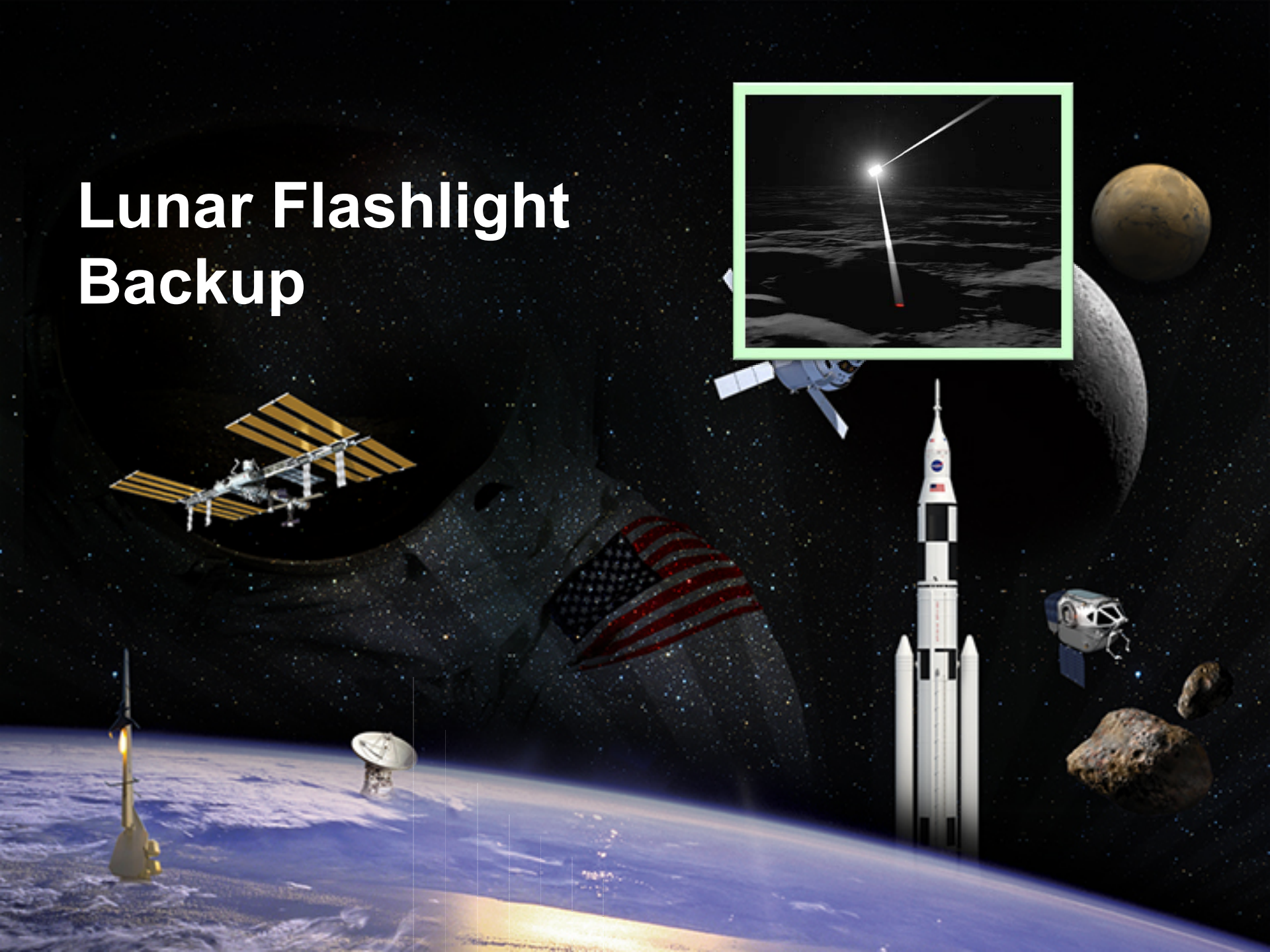
- Delaying the initial maneuver by 1 day almost double the ΔV needed



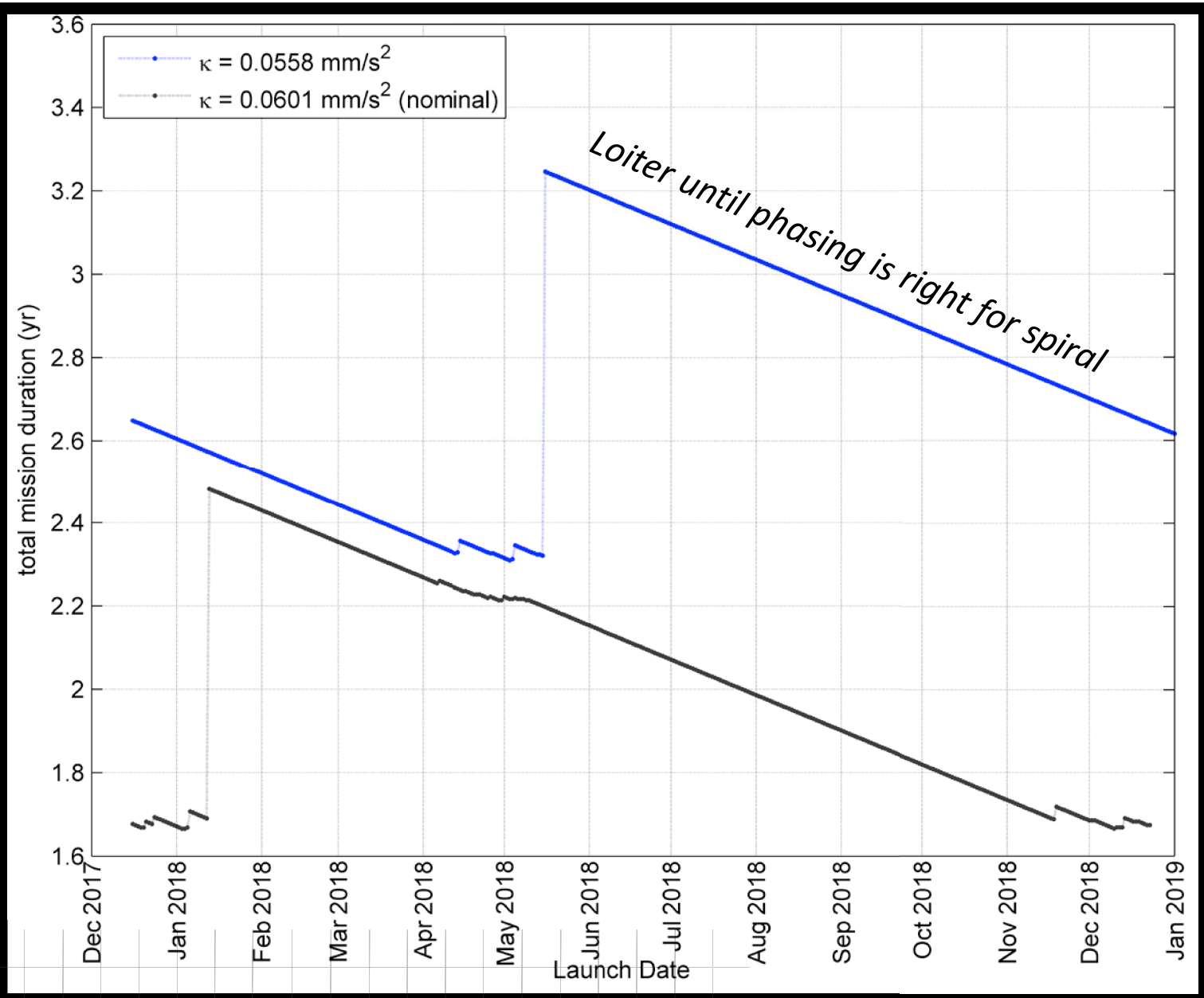
McInnes Flat Plate Model



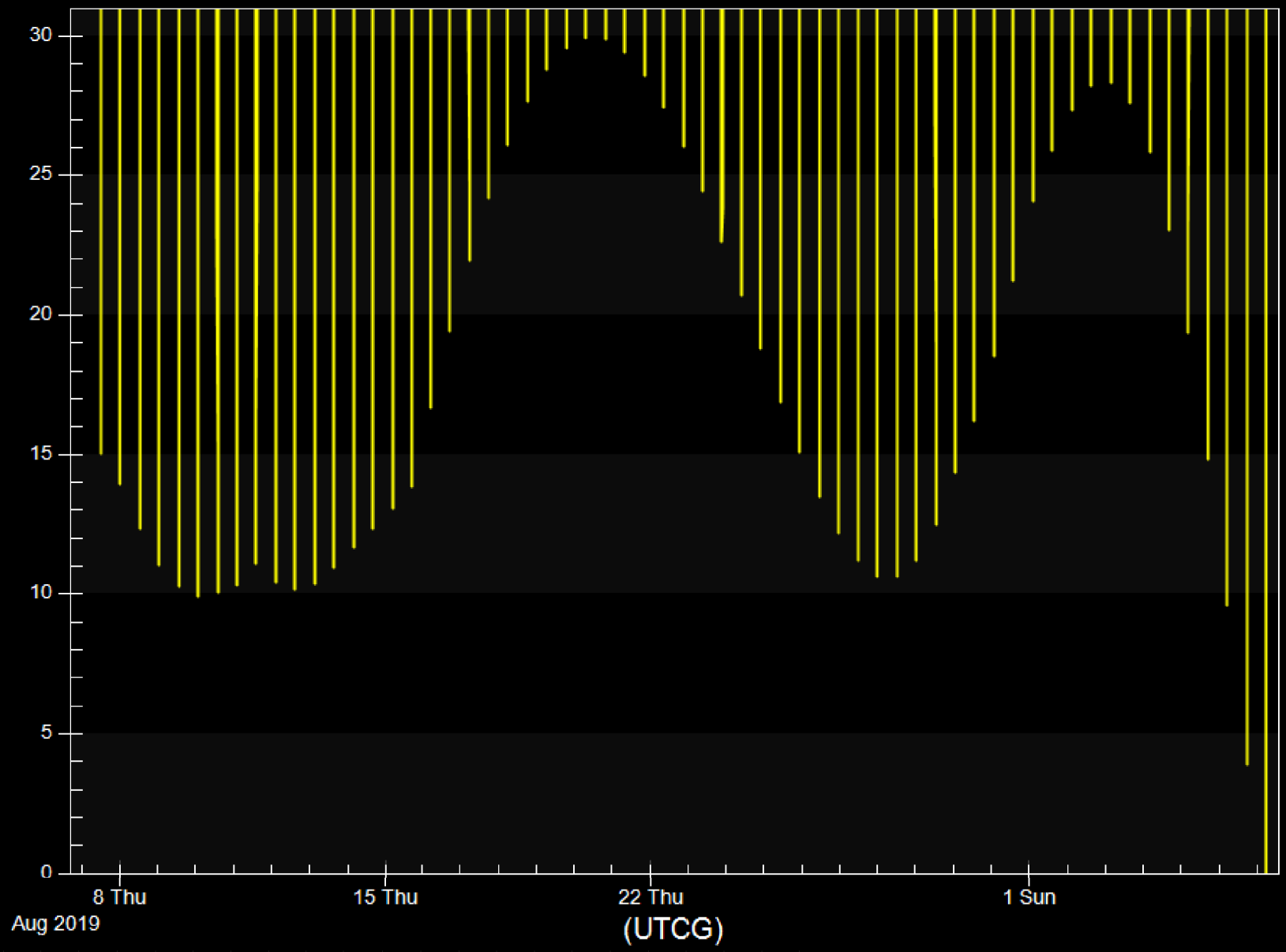
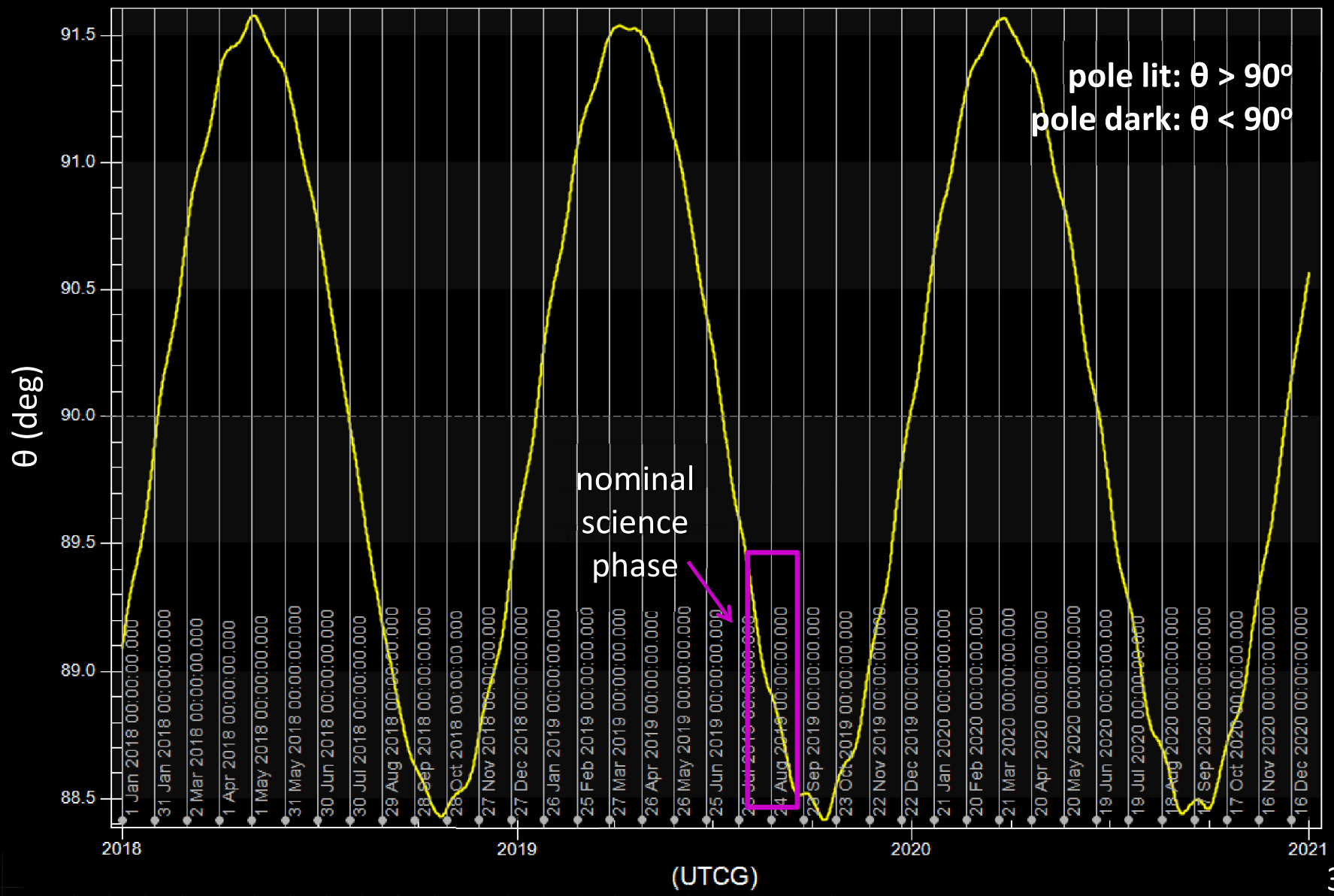
Lunar Flashlight Backup



Effect of Launch Date & Acc on Mission Duration



Science Orbit Geodetic Altitude (km)



Angle between Sun-to-Moon Vector and Moon-to-S.P. Vector