James Webb Space Telescope
Trajectory Design Overview

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ASTROCAMP

Agenda

- Introduction
- James Webb Space Telescope (JWST)
  - Summary
  - Mission Overview
  - Launch and Early Orbit Trajectory Design
  - Station Keeping Trajectory Design
- JWST L2 Trajectory Driving Design Elements
  - Expanded Launch Window
  - Restricted Attitude Thrust Directions
  - Solar Radiation Pressure Modeling
- Questions

Introduction (1/4)

- NASA Goddard Spaceflight Center (GSFC)
  - Flight Dynamics Engineer in the Spacecraft Navigation and Mission Design Branch
- NASA GSFC Missions (2009 – Present)
  - JWST (Deputy Flight Dynamics Lead)
  - SEXTANT: X-Ray Pulsar Navigation Tech Demo (Navigation, Filter Design, Operations)
  - ARTEMIS: 2 spacecraft Lunar Libration Orbiters (Trajectory Design, Operations)
  - MMS: 4 spacecraft Elliptical Formation Flying Mission (Trajectory Design)
- University of Maryland B.S. and M.S. in 2010 and 2015, respectively
  - Space Systems Laboratory Researcher Alumni

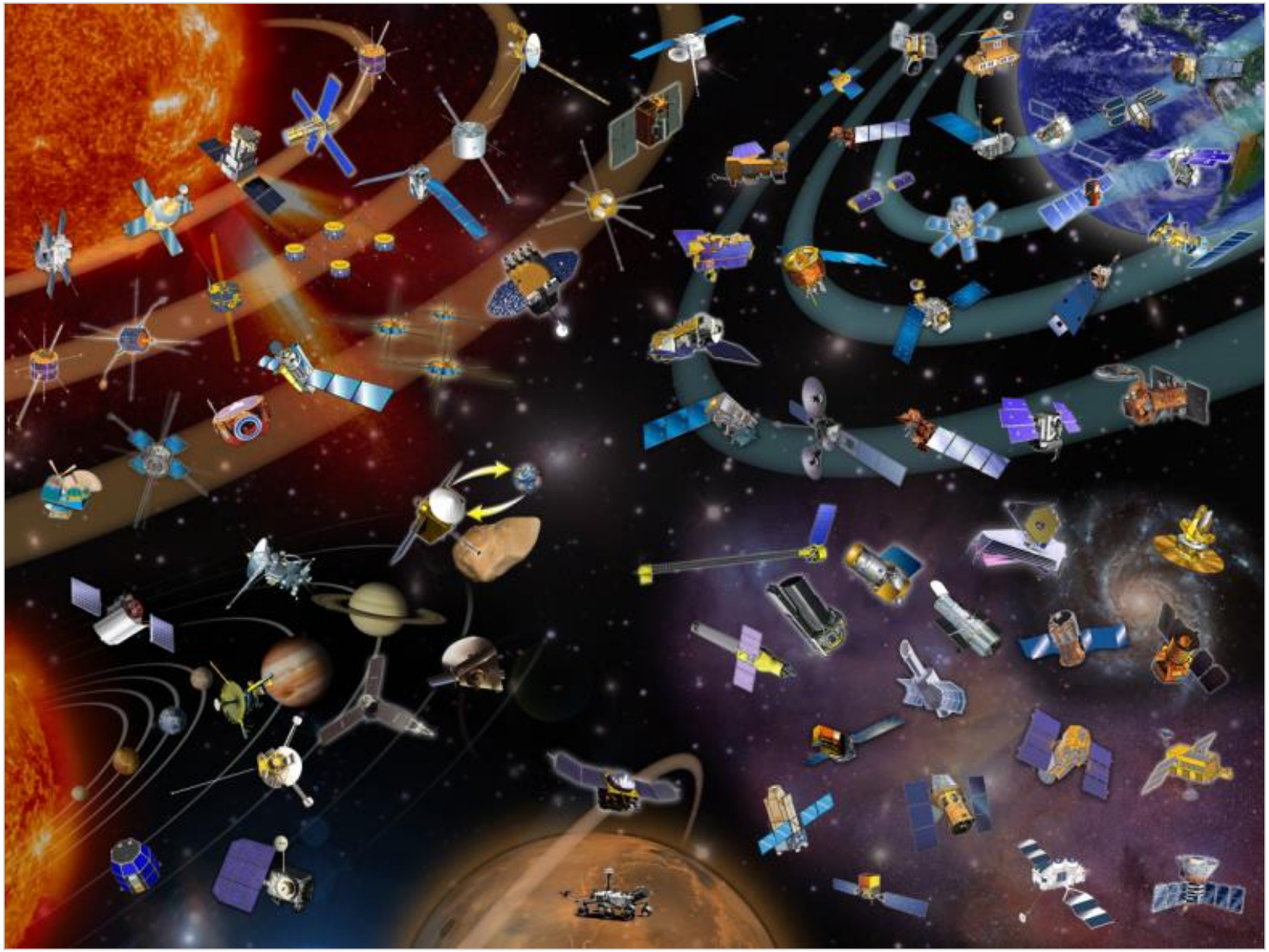
GSFC Navigation and Mission Design Branch (2/4)

- The branch answers the following:
  - What is the spacecraft trajectory that fulfills mission requirements? How is that trajectory supported?
  - How does the project monitor and track that spacecraft during its mission?
- Involved on all levels of spacecraft design
  - Concept design / proposals
  - Launch and early orbit operations
  - Closeout decommissioning
- Exercises a wide range of technical and administrative backgrounds
  - Aerospace, Mechanical, Electrical Engineering
  - Math, Physics, Computer Science
  - Systems Engineering, Business Administration
  - Any background involved in a NASA spacecraft mission helps!

Further information found at:
https://www.youtube.com/watch?v=8UUQAgLO3go

https://etd.gsfc.nasa.gov/590/code595.php

NASA Goddard Missions Past and Present (3/4)



Mission Name	Multibody Libration Orbit Type
ISEE-3	Sun-Earth L1 Halo
SOHO	Sun-Earth L1 Halo
WIND	Sun-Earth L1 Halo
WMAP	Sun-Earth L2 Lissajous
DSCOVR	Sun-Earth L1 Halo
ARTEMIS	Earth-Moon L1/L2 Libration Orbit

NASA Goddard Missions Past and Present (4/4)

Mission Name	Multibody Libration Orbit Type
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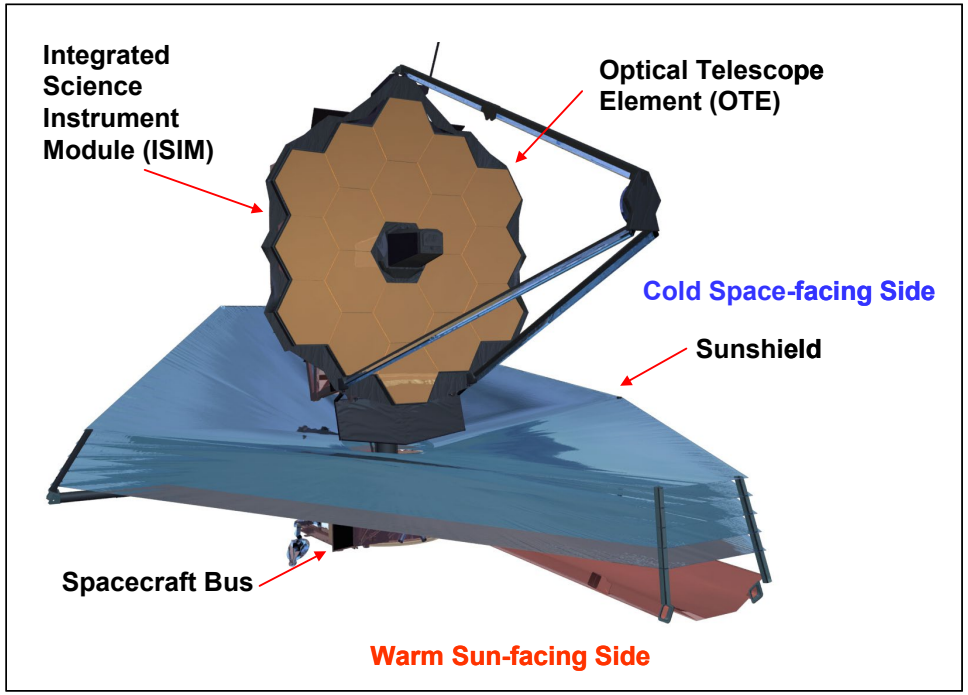
JWST	**Sun-Earth L2**

JWST Summary

James Webb Space Telescope (JWST) is a deployable infrared telescope.

- **European Space Agency-supplied Ariane 5 with the launch site at Kourou, French Guiana**
- **Science orbit design is a Sun-Earth/Moon L2 libration point orbit**
- **Perform Three Mid Course Correction (MCC) chemical thruster maneuvers to science orbit**
- **Station Keeping (SK) at orbit for a 5 year science mission, with consumables for a 10 year mission**



End of the dark ages: First light and reionization

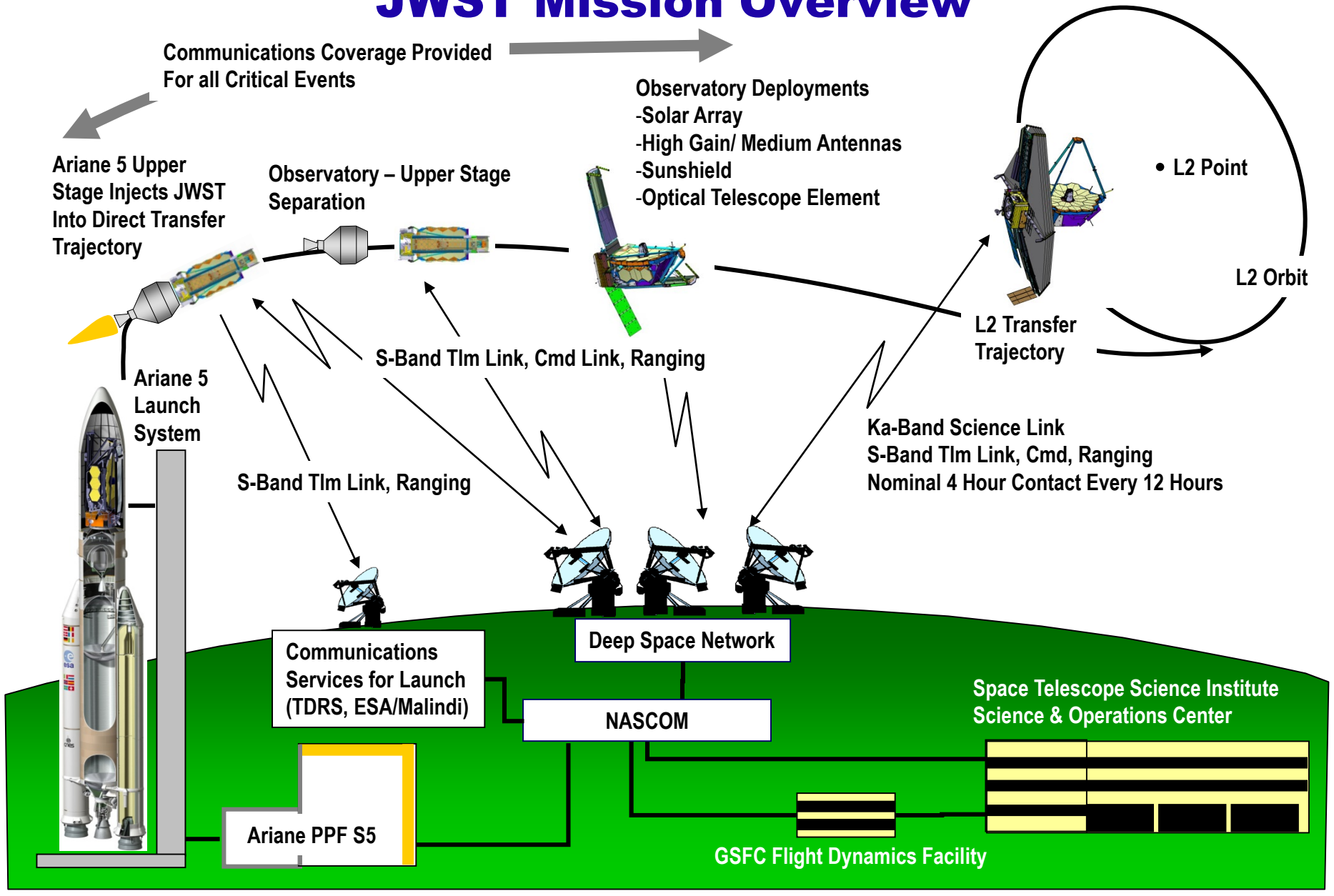
The assembly of galaxies

Birth of stars and proto-planetary systems

Planetary systems and the origin of life

[1] W. Yu; K. Richon; *"James Webb Space Telescope Launch Window Trade Analysis"* (ISSFD2014)

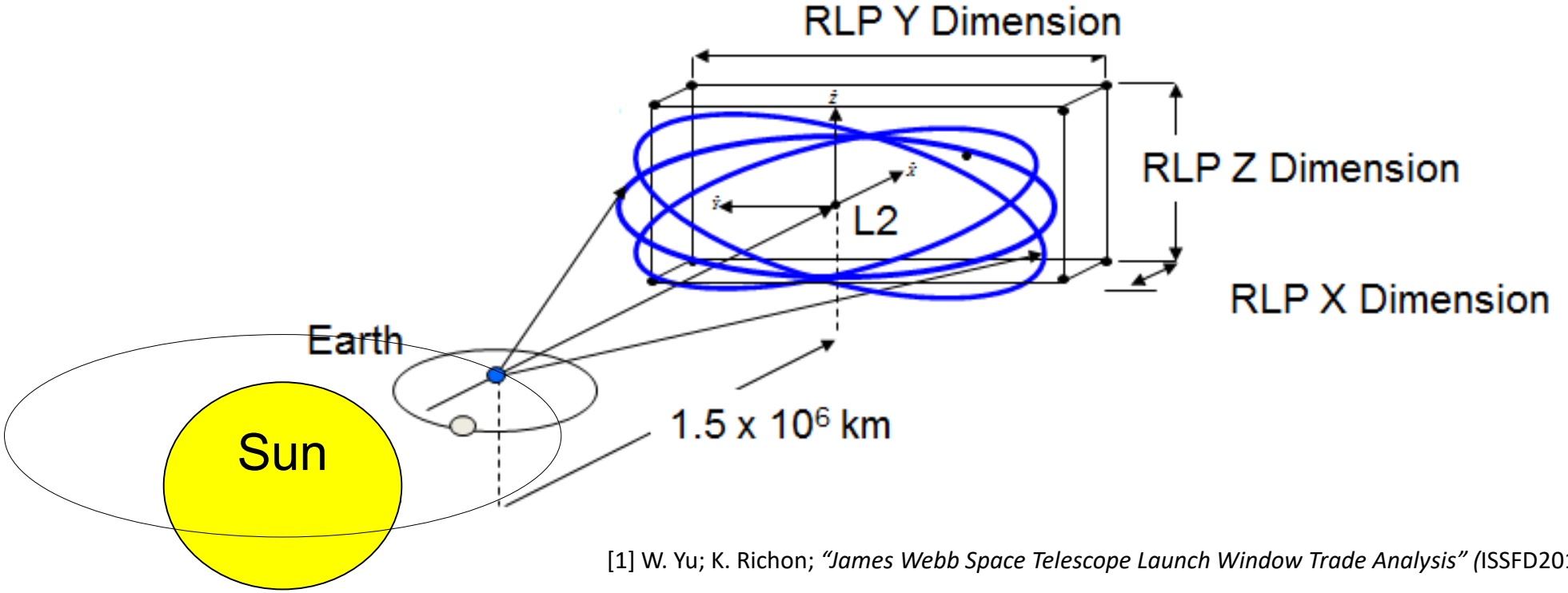
JWST Mission Overview



[2] Greenhouse, M.. "The James Webb Space Telescope: Mission overview and status." 2011 2nd International Conference on Space Technology (2011): 1-4.

JWST Orbit Frame Definition and Requirements

Requirement	Requirements Driver(s)
MCC Maneuver Direction	Science
Available MCC Maneuver ΔV for Nominal Injection	Mass & Propulsion
Lunar / Earth Eclipse	Power & Thermal
Rotating Libration Point (RLP) Size Requirements	Science & Communication



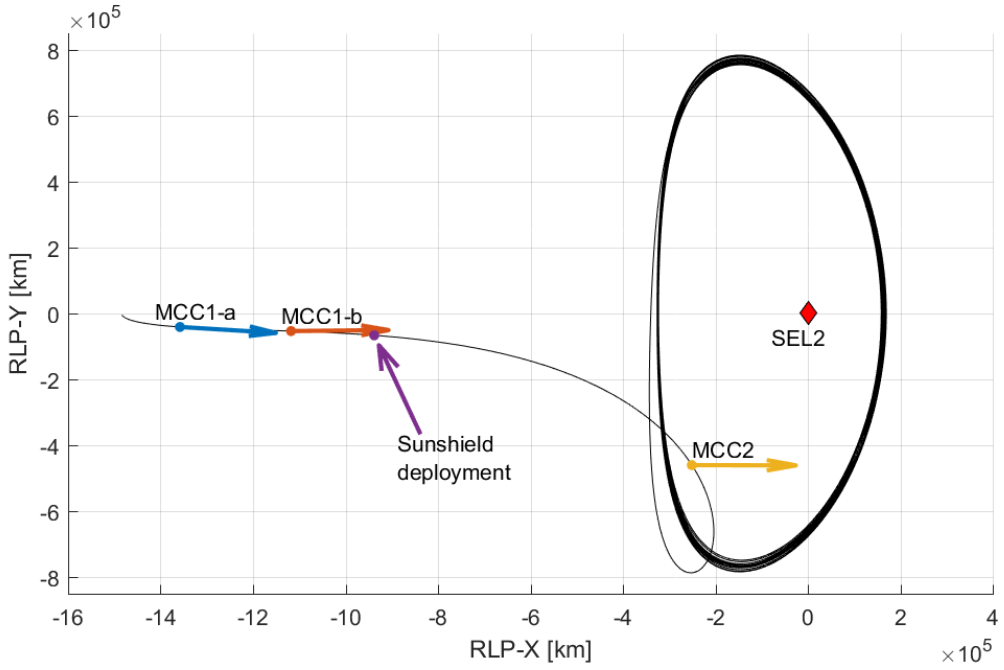
[1] W. Yu; K. Richon; *"James Webb Space Telescope Launch Window Trade Analysis"* (ISSFD2014)

JWST Trajectory Design

JWST will be launched from French Guiana with a launch window opening in late October 2021.

The mission outline after the launch using chemical thrusters:

MCC1-a	+12.5 hours after launch
MCC1-b	+2.5 days after launch
Sunshield deployment	+5 days after launch
MCC2	+29 days after launch
Station Keeping	Every 21 days during mission lifetime



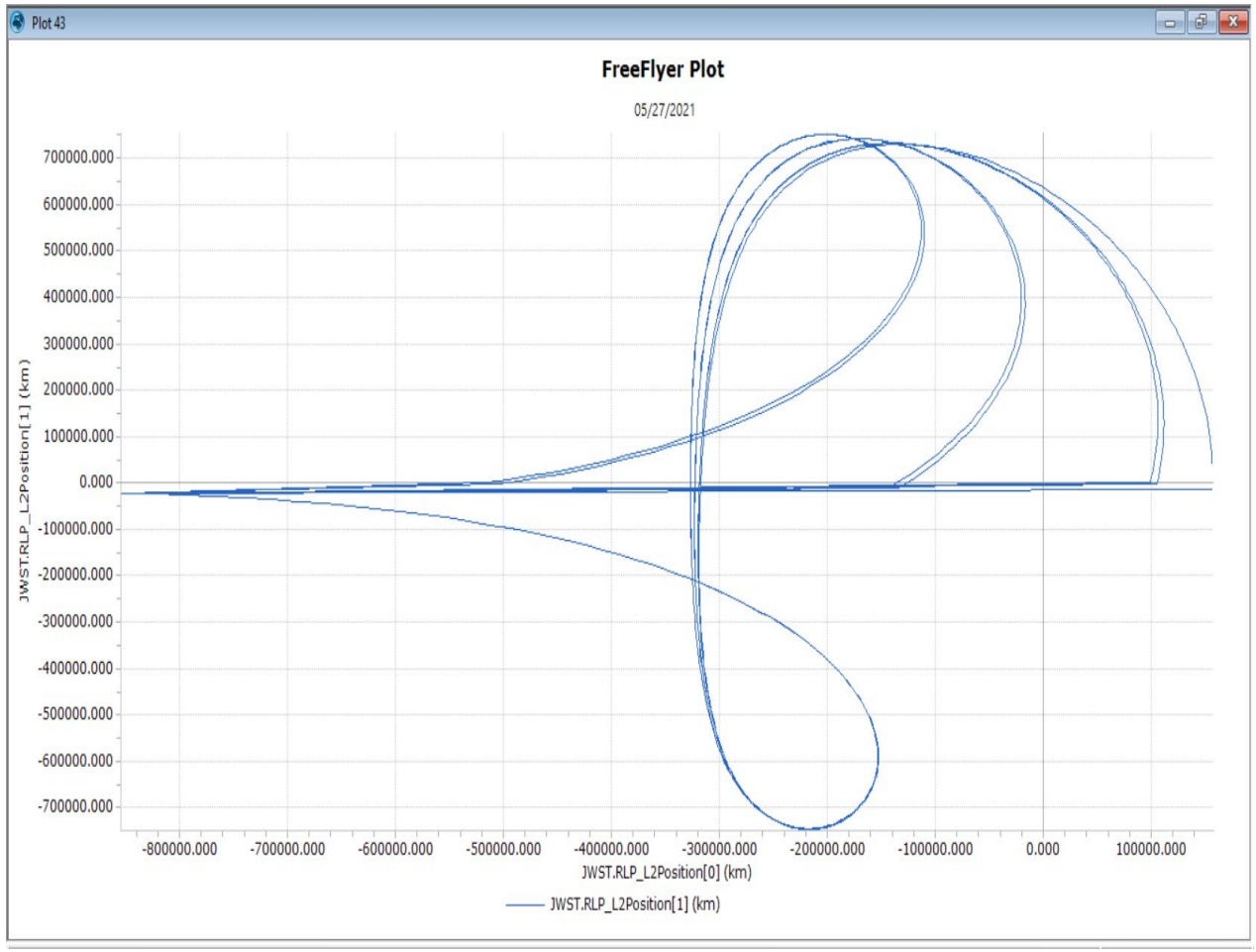
[3] T. Rashied; B. Stringer; J. Petersen "*Mid-Course Correction Analysis for James Webb Space Telescope*" (AAS 19-816)

[4] J. Petersen "*L2 Station Keeping Maneuver Strategy for the James Webb Space Telescope*" (AAS 19-806)

[5] A. Farres "*Solar Radiation Pressure Effects on the Orbital Motion at SEL2 for the James Webb Space Telescope*" (AAS 19-657)

Maneuver Design: Launch and Early Operations MCC1a, MCC1b, MCC2

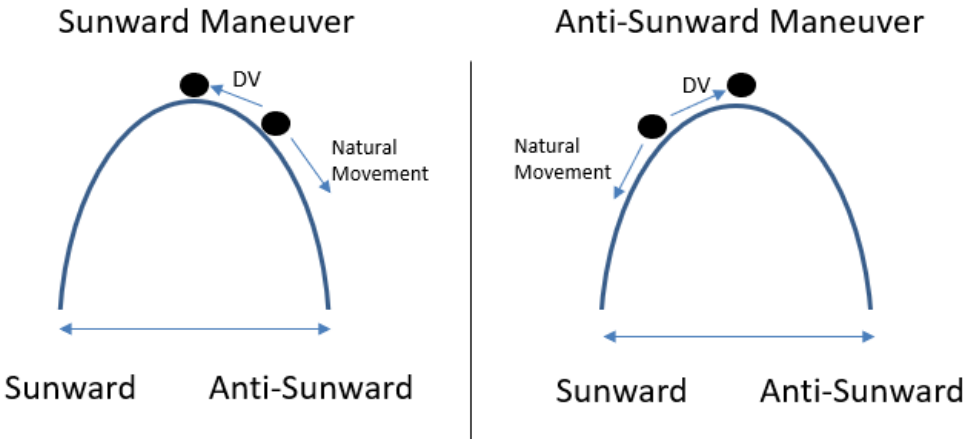
- Current maneuver planning for JWST focuses on refining a mature project design with a fast turnaround for launch operations
  - Refine known libration orbits for a predefined launch vehicle flight trajectory
  - Design a mission design robust to operations (hardware updates, operation contingencies, etc.)
- Goal is to achieve L2 solution for a given launch opportunity with minimum fuel use
  - Initial bisection method bounds the total system energy with the current launch profile to achieve L2
  - Differential correction within the bounds used to refine the solution for minimum delta-V for all MCC maneuvers



Maneuver Design: Station Keeping (SK) at the L2 Orbit

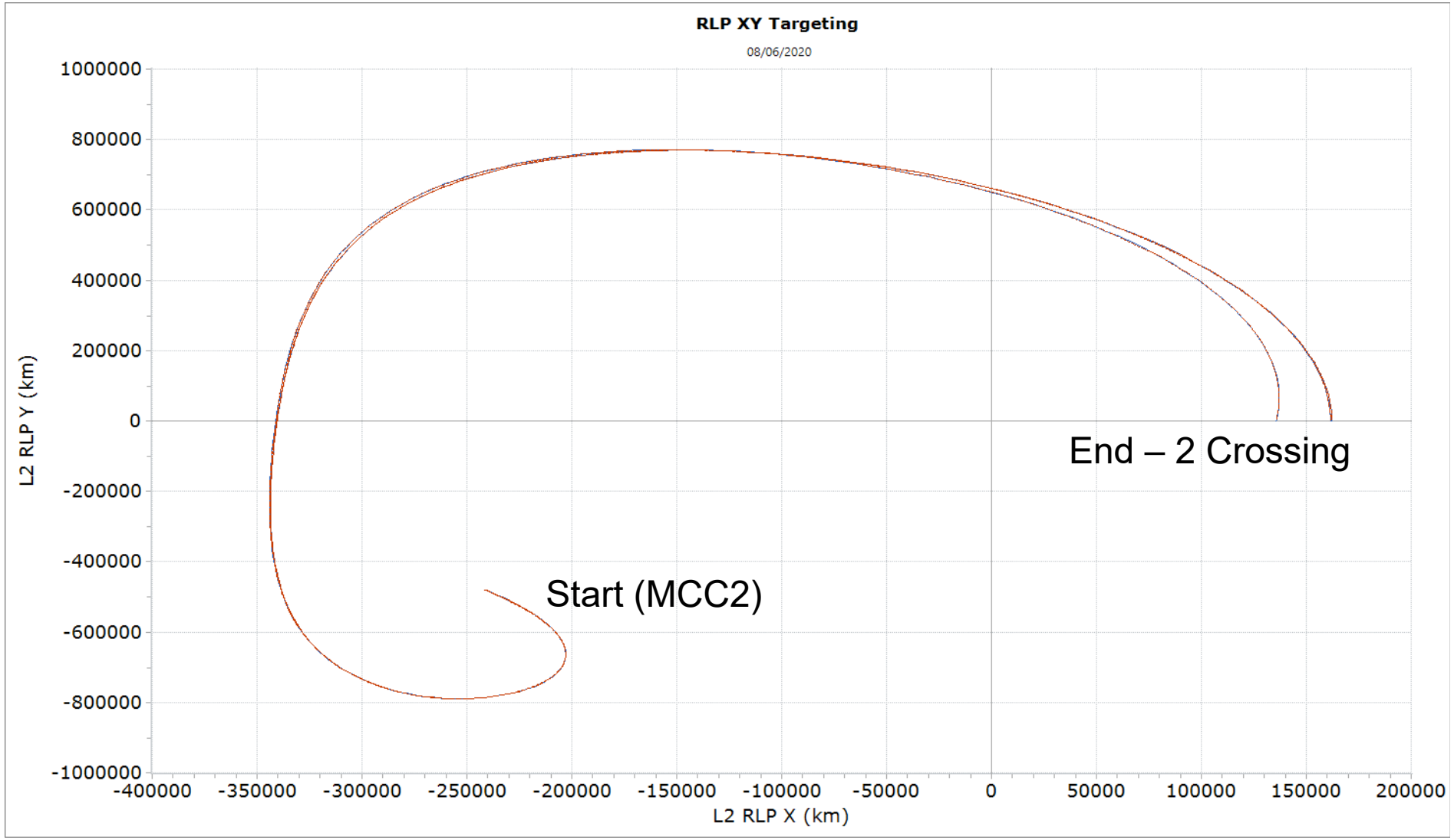
- L2 libration orbits require station keeping maneuvers
- JWST has other known uncertainties that need active maintenance. Examples below:
  - Momentum unloads
  - Orbit determination uncertainty
- To control these factors, station keeping maneuvers are planned every 21 days
- Basic steps
  - Step 1: Determine maneuver direction (sun/anti-sun maneuver)
  - Step 2: Determine maneuver magnitude with differential correction

Step 1: Find SK Maneuver Direction Concept Visual (Not an Orbit)



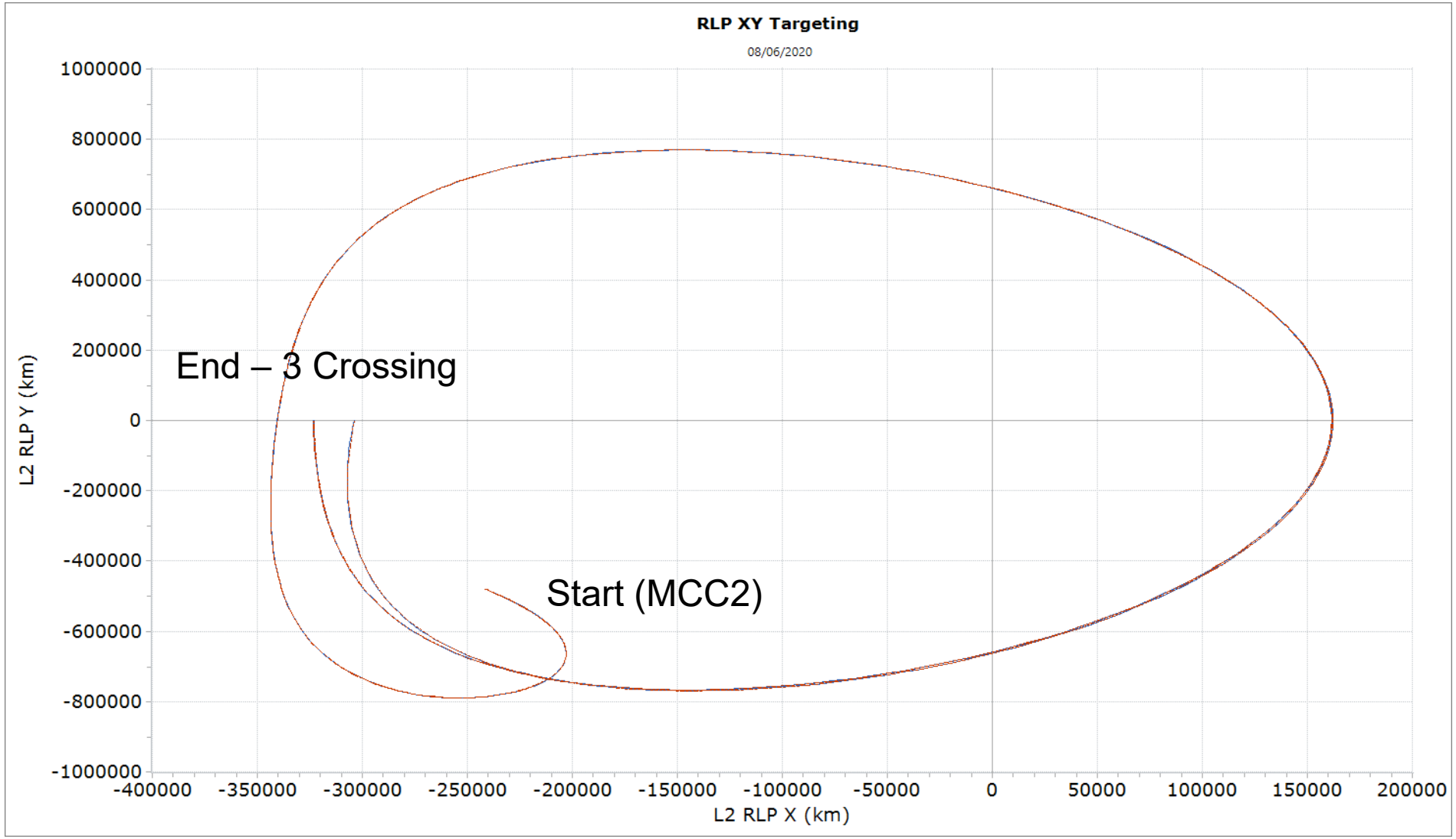
In the Circular Restricted 3 Body Problem, the L2 equilibrium point is an unstable equilibrium, i.e. the state will exponentially diverge from the L2 point.

Maneuver Design: SK Step 2
Differential Correction Process (1/2)



Target Perpendicular RLP-X Axis Crossings

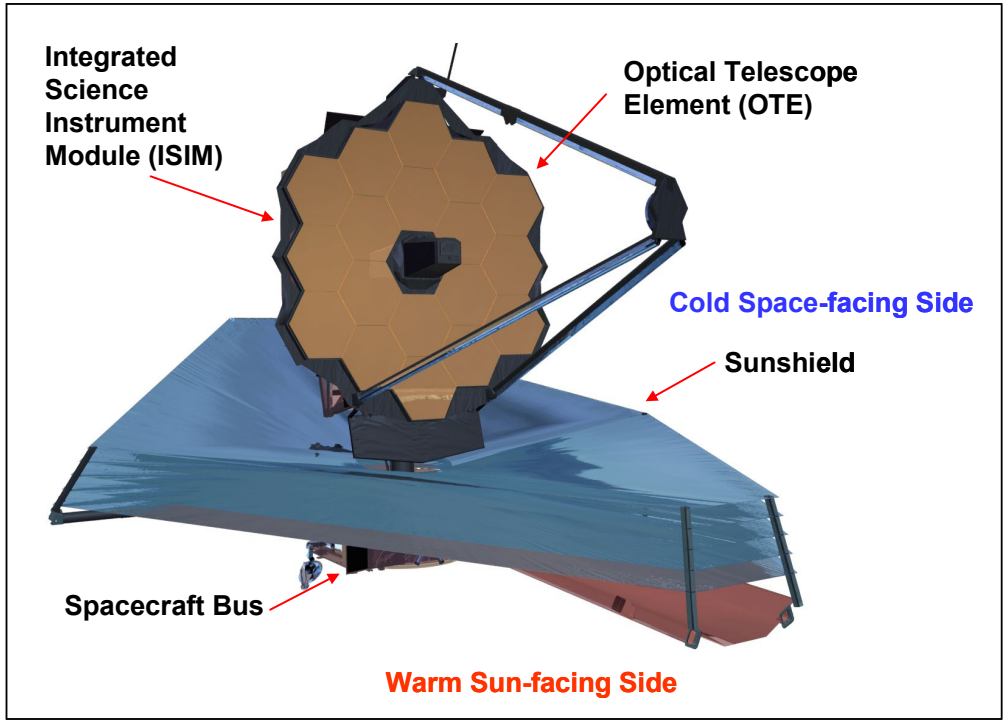
Maneuver Design: SK Step 2
Differential Correction Process (2/2)



Process continues for multiple crossings, dependent on sensitivity of L2 orbit targeting

Driving Design Impacts to JWST Trajectory Design

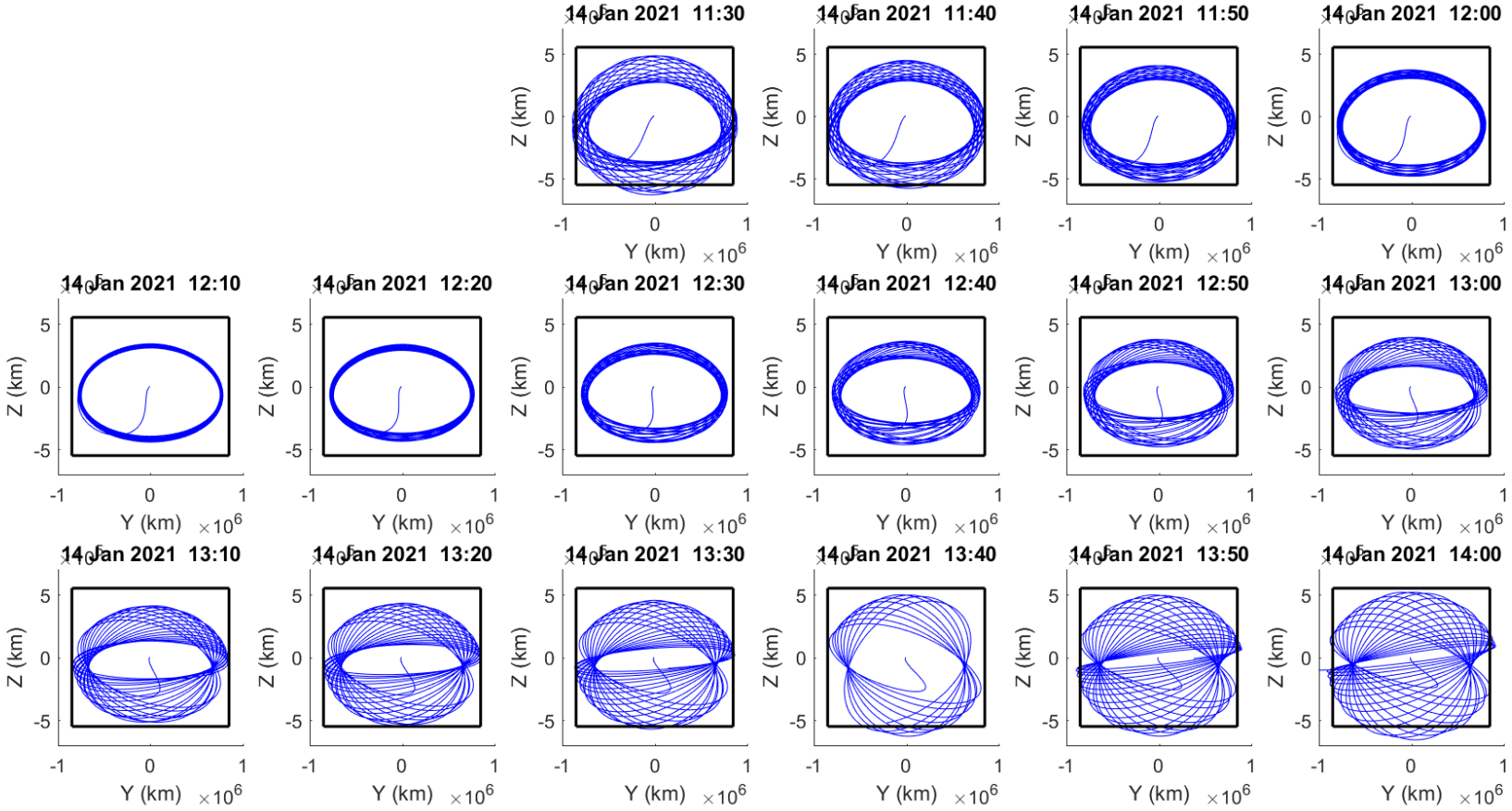
1. Expanded Launch Window Capability
2. Attitude restrictions on the JWST Observatory
    1. Restricted thruster fire directions for both MCC and Stationkeeping
    2. Overburn analysis and mitigation
3. Solar Radiation Pressure Modeling



JWST Requirements need to enforce the thermal requirements of the cold and warm facing sides for the mission lifetime.

Example Launch Window Using 14th January 2021

The type of orbit JWST will be inserted into depends on the time of the day and day of the year it is launched.



[1] W. Yu; K. Richon; *"James Webb Space Telescope Launch Window Trade Analysis" (*ISSFD2014)

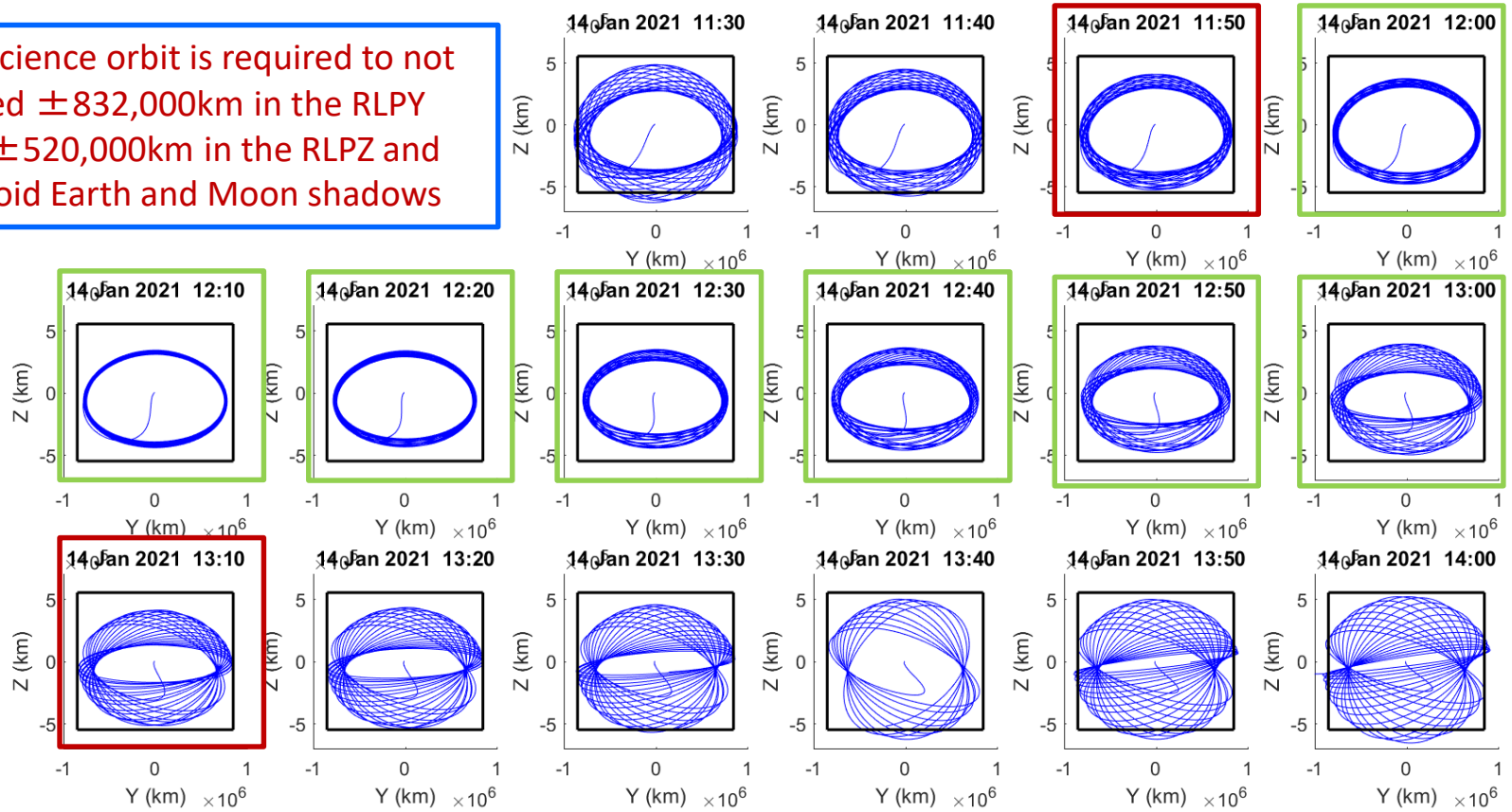
[6] J. Brown; J. Petersen; B. Villac; W. Yu "*Seasonal Variations of the James Webb Space Telescope Orbital Dynamics*" (AAS15-802)

[7] W. Yu; K. Richon; "*Libration Point Orbit Eclipse Avoidance Maneuver Study for the James Webb Space Telescope Mission"*(AAS19-705)

Example Launch Window using 14th January 2021

The type of orbit JWST will be inserted into depends on the time of the day and day of the year it is launched.

The science orbit is required to not exceed ±832,000km in the RLPY and ±520,000km in the RLPZ and to avoid Earth and Moon shadows



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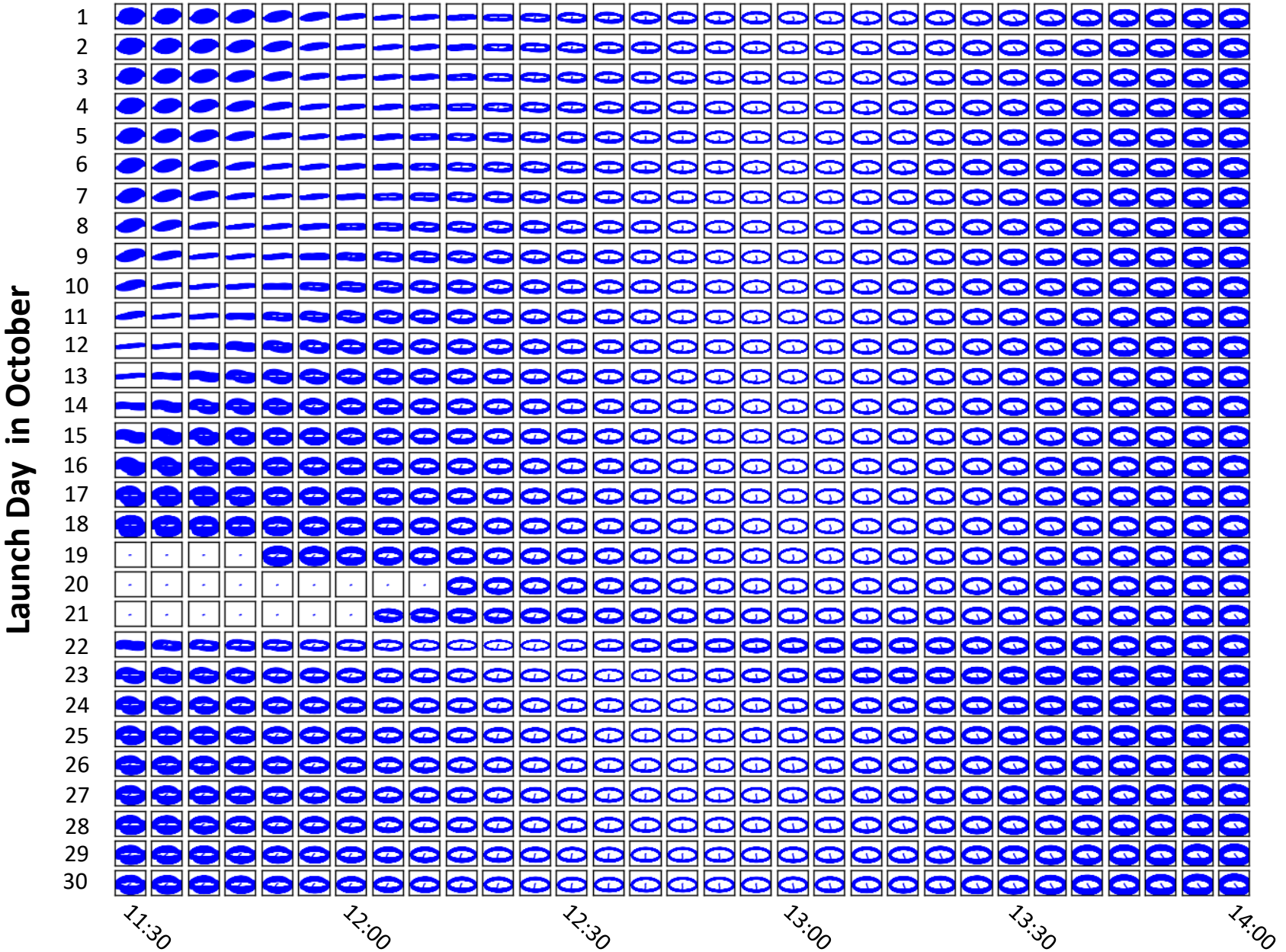
Example Launch Variation in Orbit Geometry (1/2)



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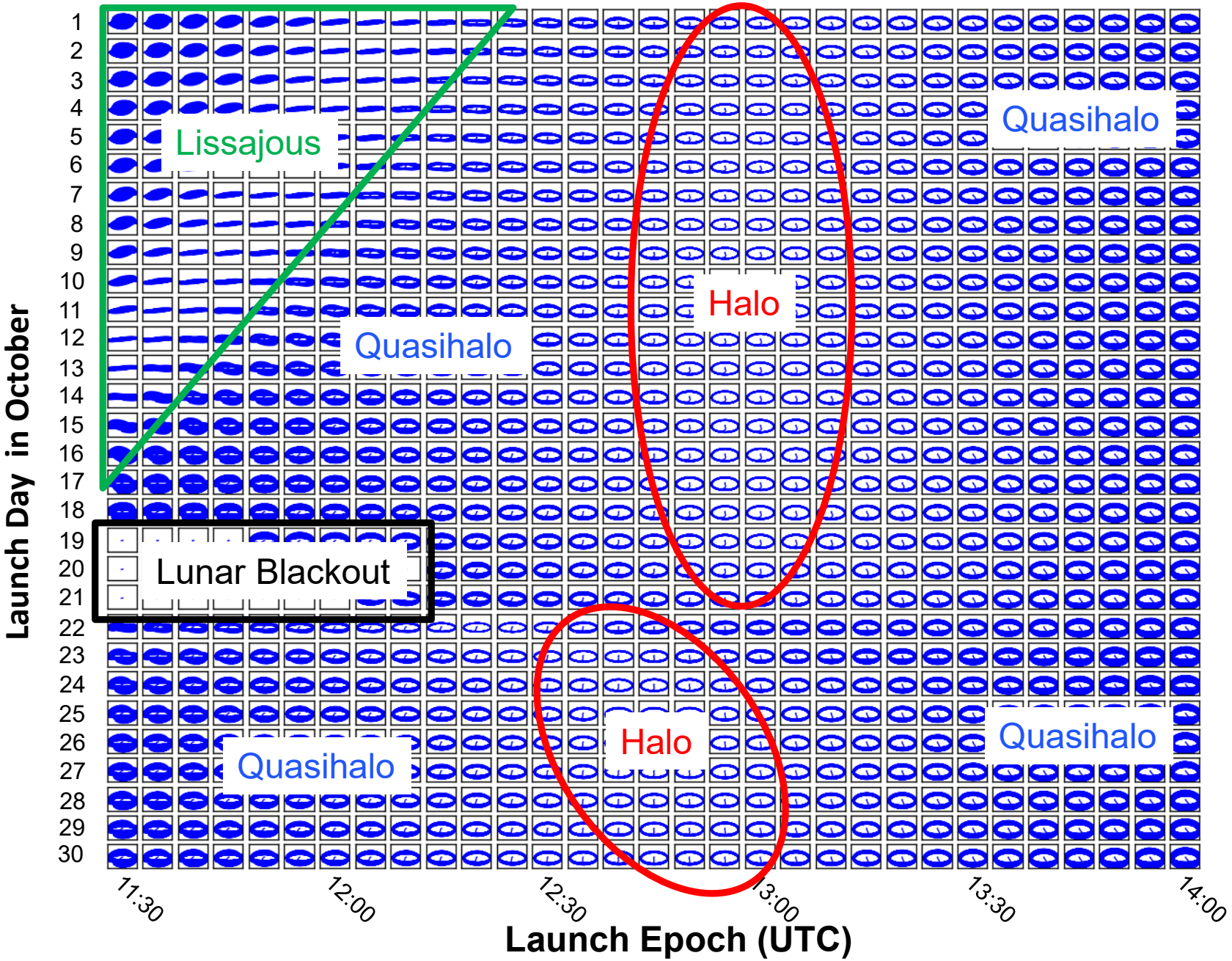
Example Launch Variation in Orbit Geometry (2/2)

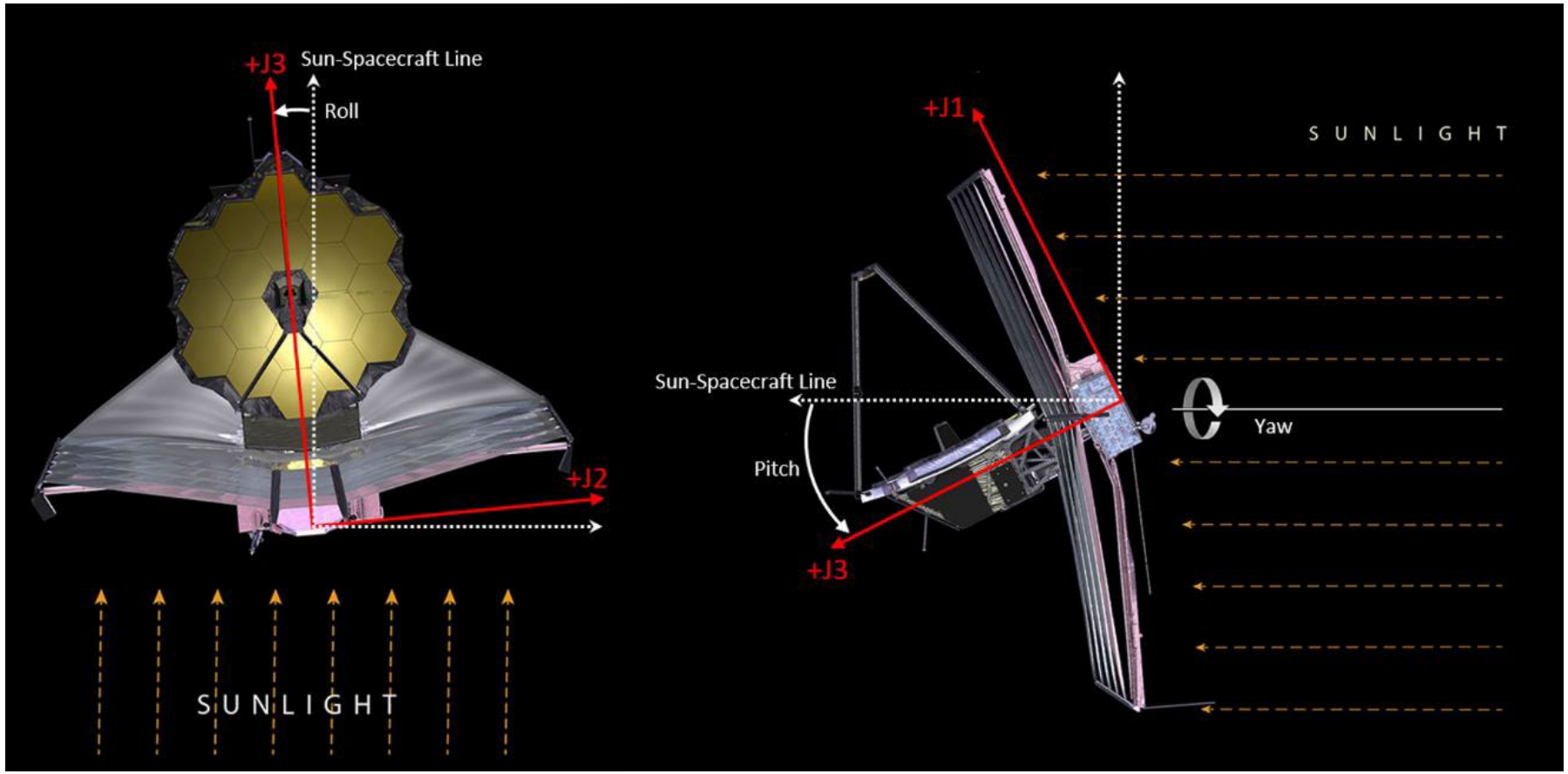


Various families of libration point orbits have been defined based on initial conditions and energy of the spacecraft.

These orbits can vary in and out of the earlier RLP frame and are sensitive to initial conditions (position and time)

[6] J. Brown; J. Petersen; B. Villac; W. Yu "*Seasonal Variations of the James Webb Space Telescope Orbital Dynamics*" (AAS15-802)

Attitude Restrictions of the JWST Observatory (2/2)



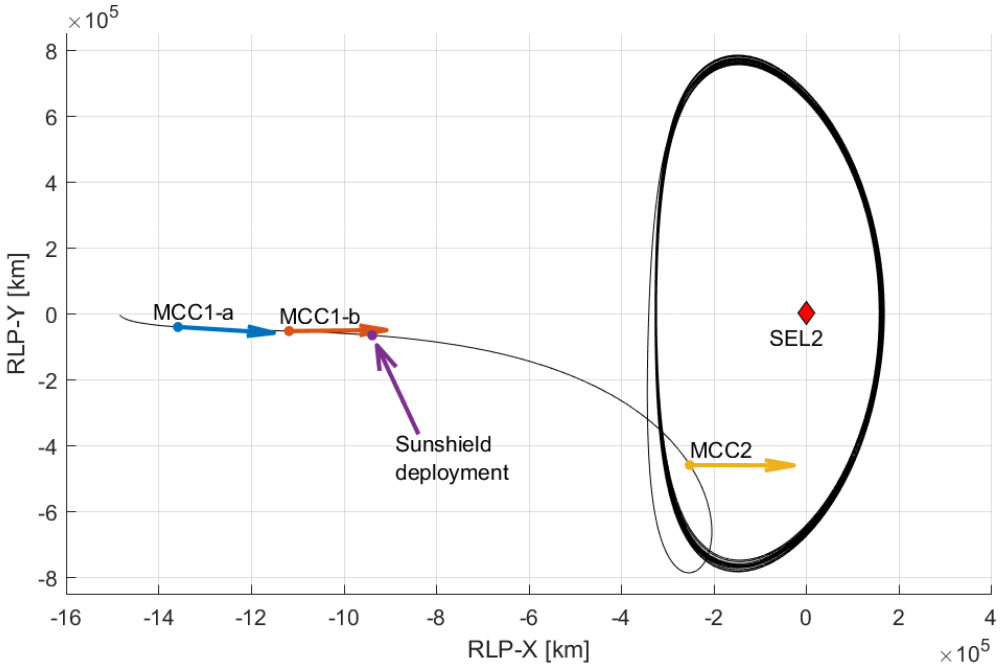
JWST attitude can be defined in terms of the Sun angles.
These angles are limited to: [-53º,0º] for Sun-Pitch, [-5º,5º] for Sun-Roll and [-180º,180º] for Sun-Yaw.
This limits thruster directions to be away from the Sun which impacts all maneuver designs.

[5] A. Farres *"Solar Radiation Pressure Effects on the Orbital Motion at SEL2 for the James Webb Space Telescope"* (AAS 19-657)

JWST Trajectory Design (Attitude Restriction Impact)

The JWST thrusters cannot thrust directly back towards the Sun.
The outbound MCC maneuvers must be scaled down in order to avoid any overburn scenarios.

MCC1-a	Perform 93%	+12.5 hours after launch
MCC1-b	Perform 93%	+2.5 days after launch
Sunshield deployment	SRP starts to play a role	+5 days after launch
MCC2	Perform 100% *(1st station keeping maneuver)*	+29 days after launch
Station Keeping	Perform 100%	Every 21 days during mission lifetime



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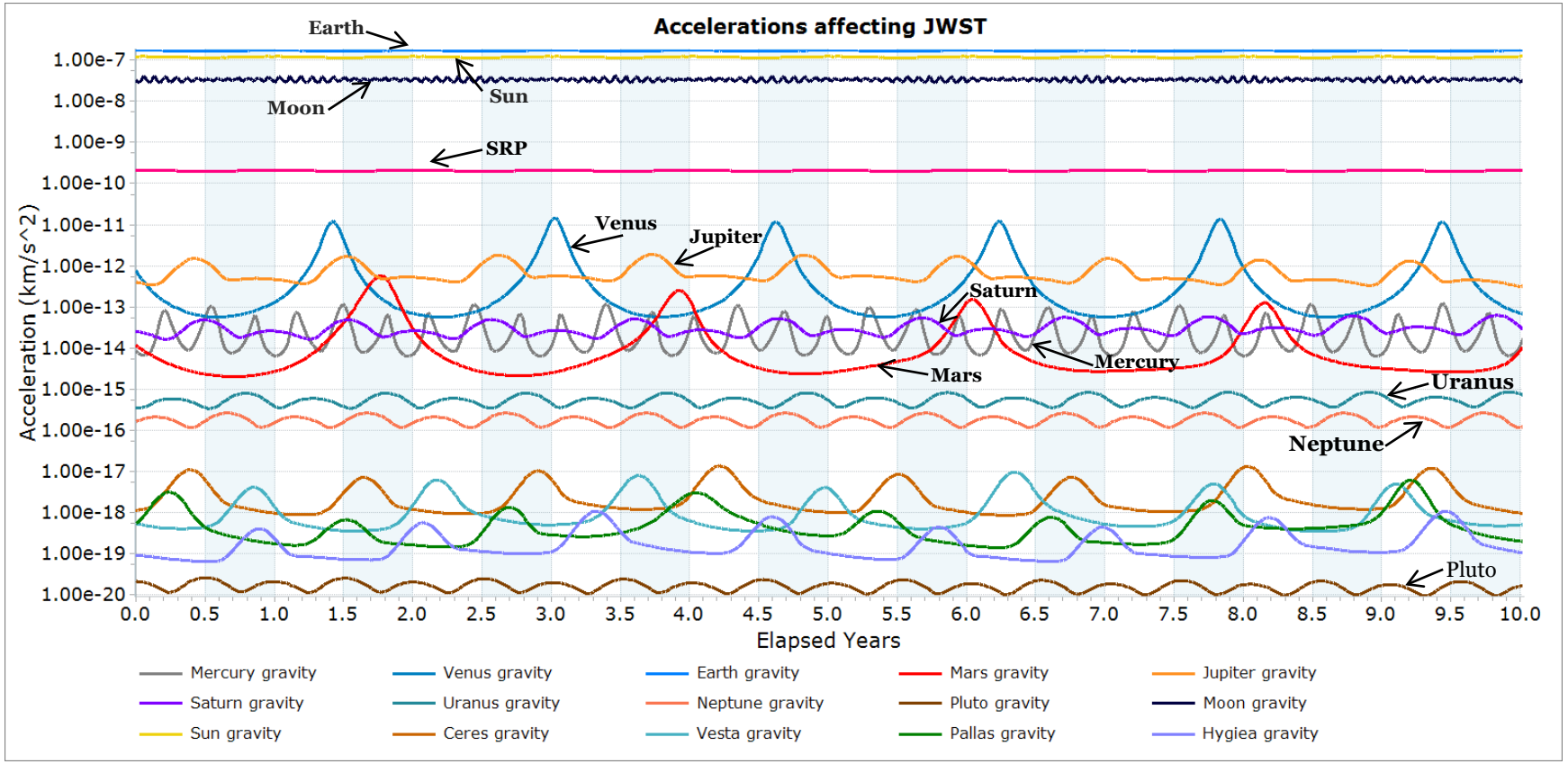
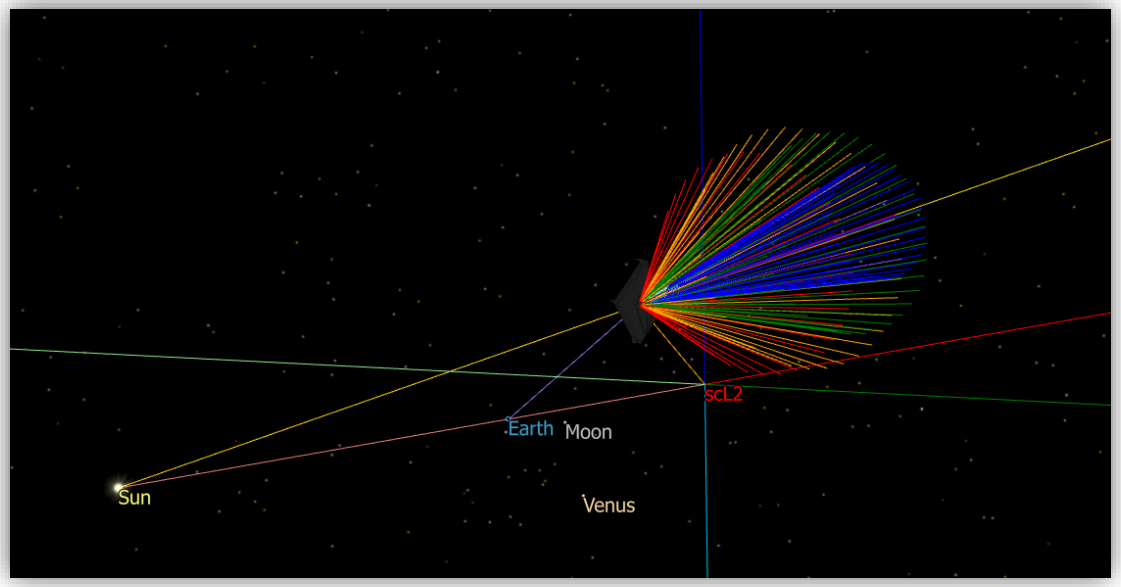
How Relevant is SRP?

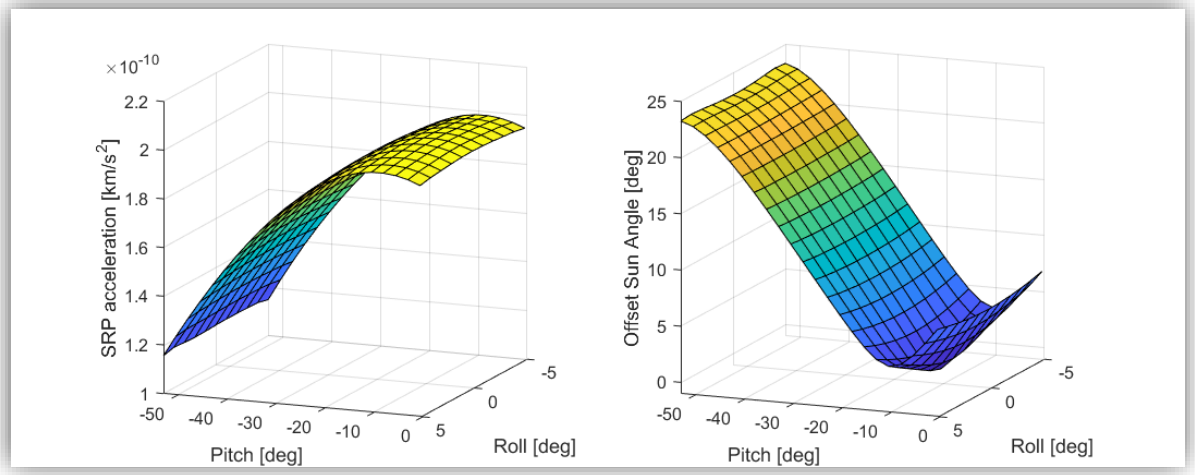
- The SRP perturbation on JWST at SEL2 is almost 2 orders of magnitude larger than the gravitational perturbations of Venus and Jupiter.
- Due to the sunshield high reflectivity the SRP acceleration direction varies with the attitude, making it hard to predict its effect on the orbit.



[5] A. Farres "*Solar Radiation Pressure Effects on the Orbital Motion at SEL2 for the James Webb Space Telescope*" (AAS 19-657)

SRP Modeling for JWST





- The Flight Dynamics team uses a polynomial curve fit provided by the sunshield analysts to have a high-fidelity model for the SRP acceleration.
- The SRP acceleration magnitude varies between 2.05×10^{-10} and 1.15×10^{-10} km/s^2, while the offset angle with respect to the Sun-telescope line can vary up to 24 degrees.

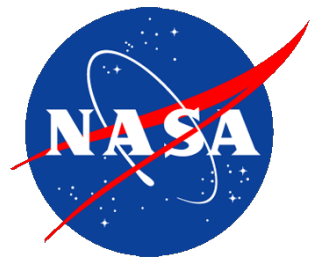
[5] A. Farres *"Solar Radiation Pressure Effects on the Orbital Motion at SEL2 for the James Webb Space Telescope"* (AAS 19-657)

Summary

- JWST Mission Design
  - Early Operations
    - Fixed launch profile from an Ariane V from the launch site in French Guiana
    - Direct Injection to L2 with 3 maneuvers
      - Designed to achieve the L2 orbit by targeting the required orbit energy
      - MCC1a – Staging maneuver to achieve L2
      - MCC1b – Maneuver to correct for maneuver/statistical errors from 1a
      - MCC2 – L2 libration orbit insertion post deployment
    - Station Keeping
      - Designed every 21 days alongside momentum unloads to maintain L2 orbit
      - Minimize fuel use and maintain the L2 orbit
- Driving Impacts on JWST trajectory design
  - Large family of libration orbits allowed to maximize launch opportunities
  - Large sunshield drives increased SRP modeling dependent on the observation schedule
  - JWST Attitude restrictions limits thruster directions and magnitude

Acknowledgements

- Karen Richon (NASA)
- a.i. solutions
  - Jeremy Petersen
  - Taabish Rashied
  - Benjamin Stringer
- Dr. Ariadna Farres
- The JWST team
- NASA GSFC Flight Dynamics Code 595 Branch


NASA

References
(in order of appearance)

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Example JWST 10 year Trajectory