James Webb Space Telescope Initial Mid Course Correction Monte Carlo Implementation using Task Parallelism

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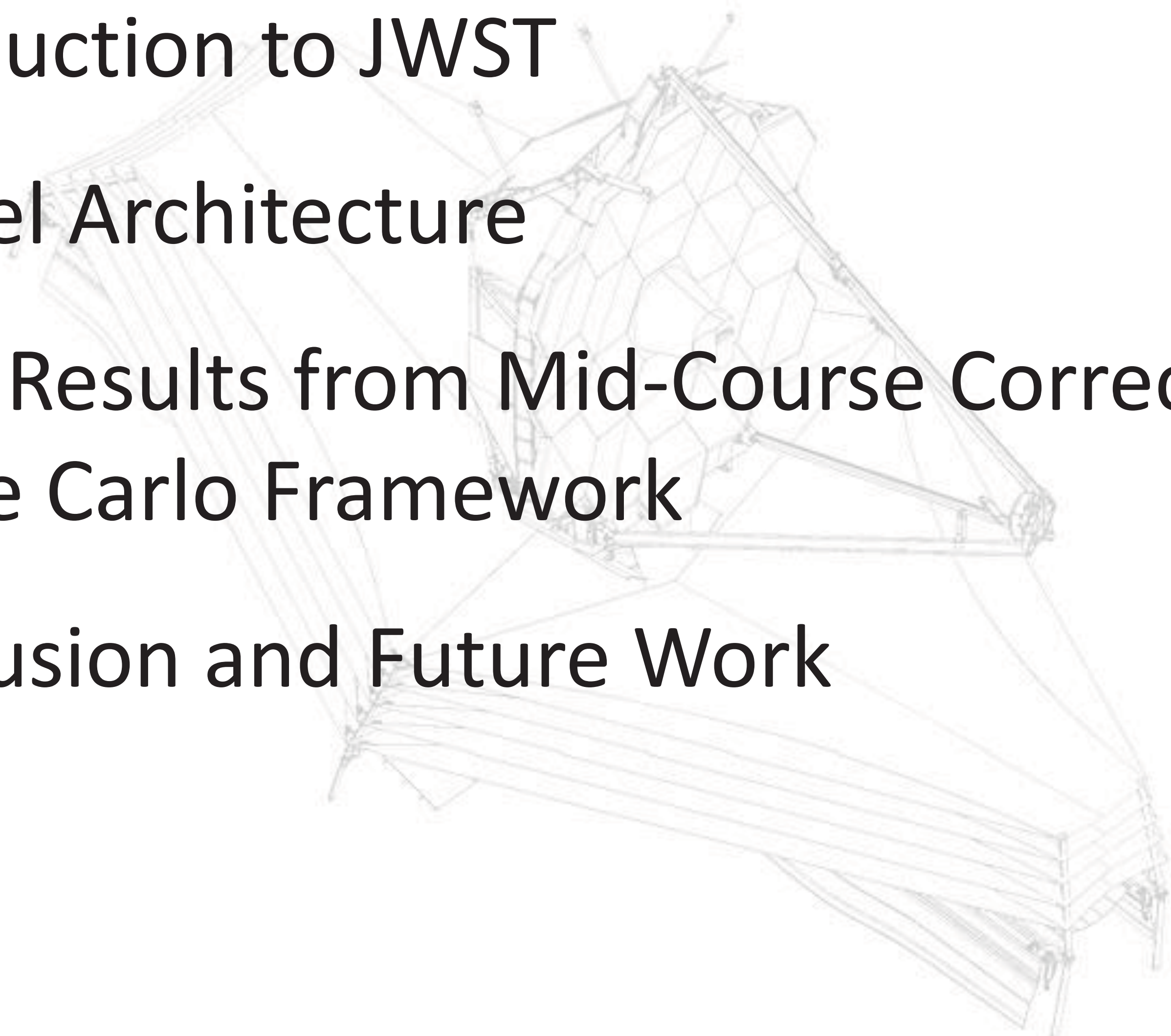
Agenda



- Introduction to JWST
- Parallel Architecture
- Initial Results from Mid-Course Correction Monte Carlo Framework
- Conclusion and Future Work

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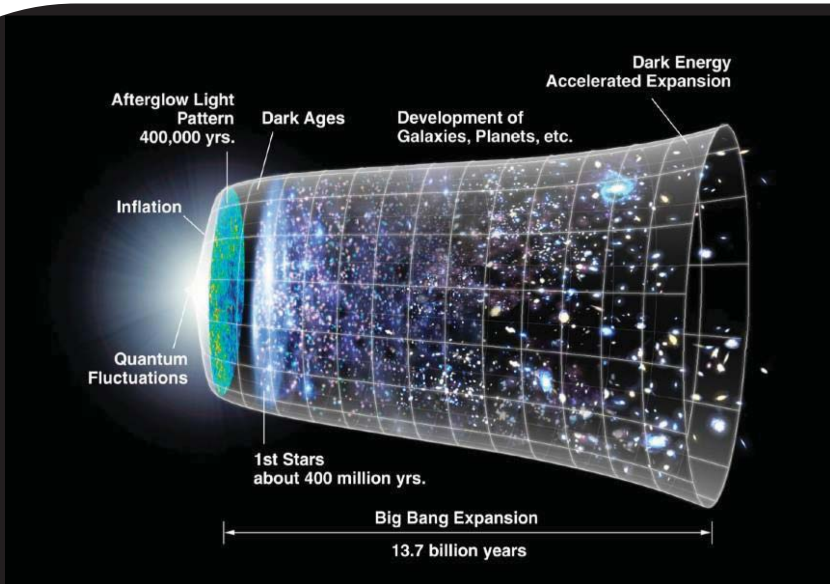
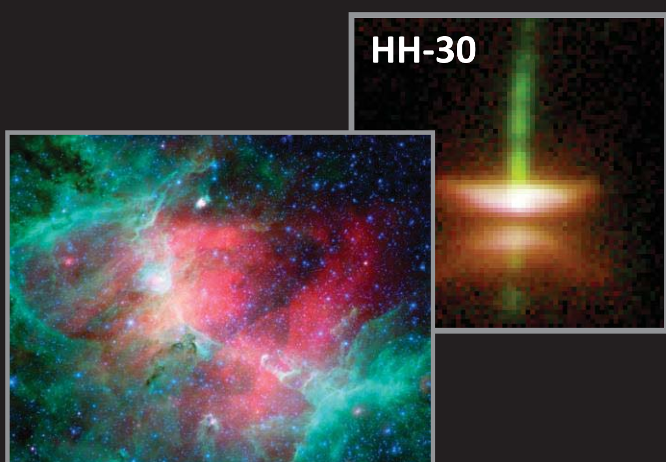
Introduction

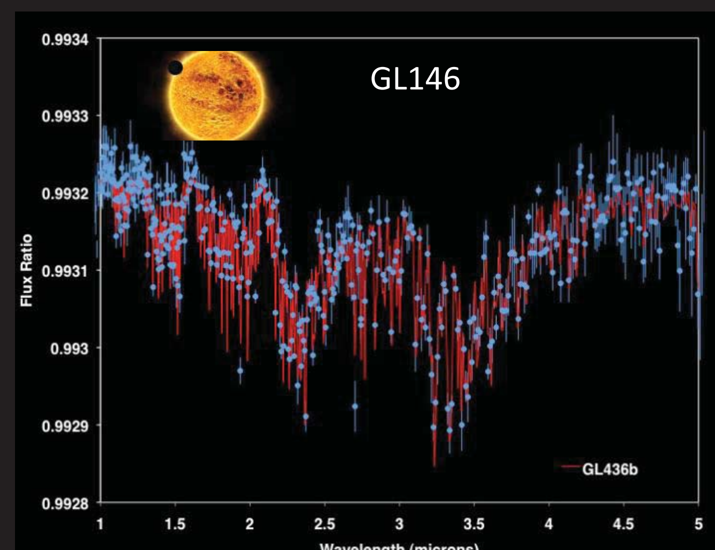


First Light and Re-Ionization

Assembly of Galaxies



Birth of stars and
proto-planetary systems



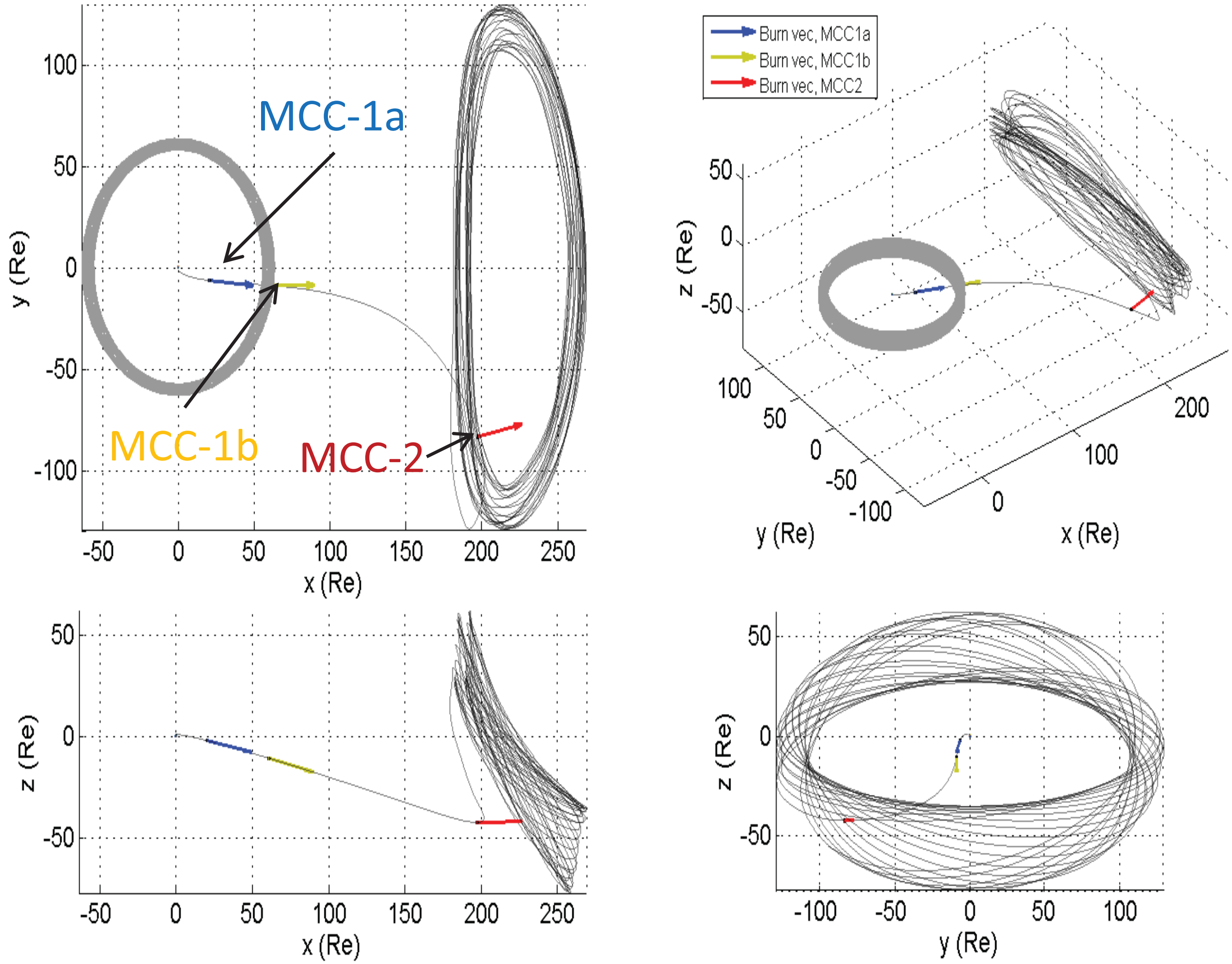
Planetary systems and the origin of life

Representative Example Orbit

Problem: Develop a robust design approach to deliver the observatory to L2.

Operational Orbit Constraints

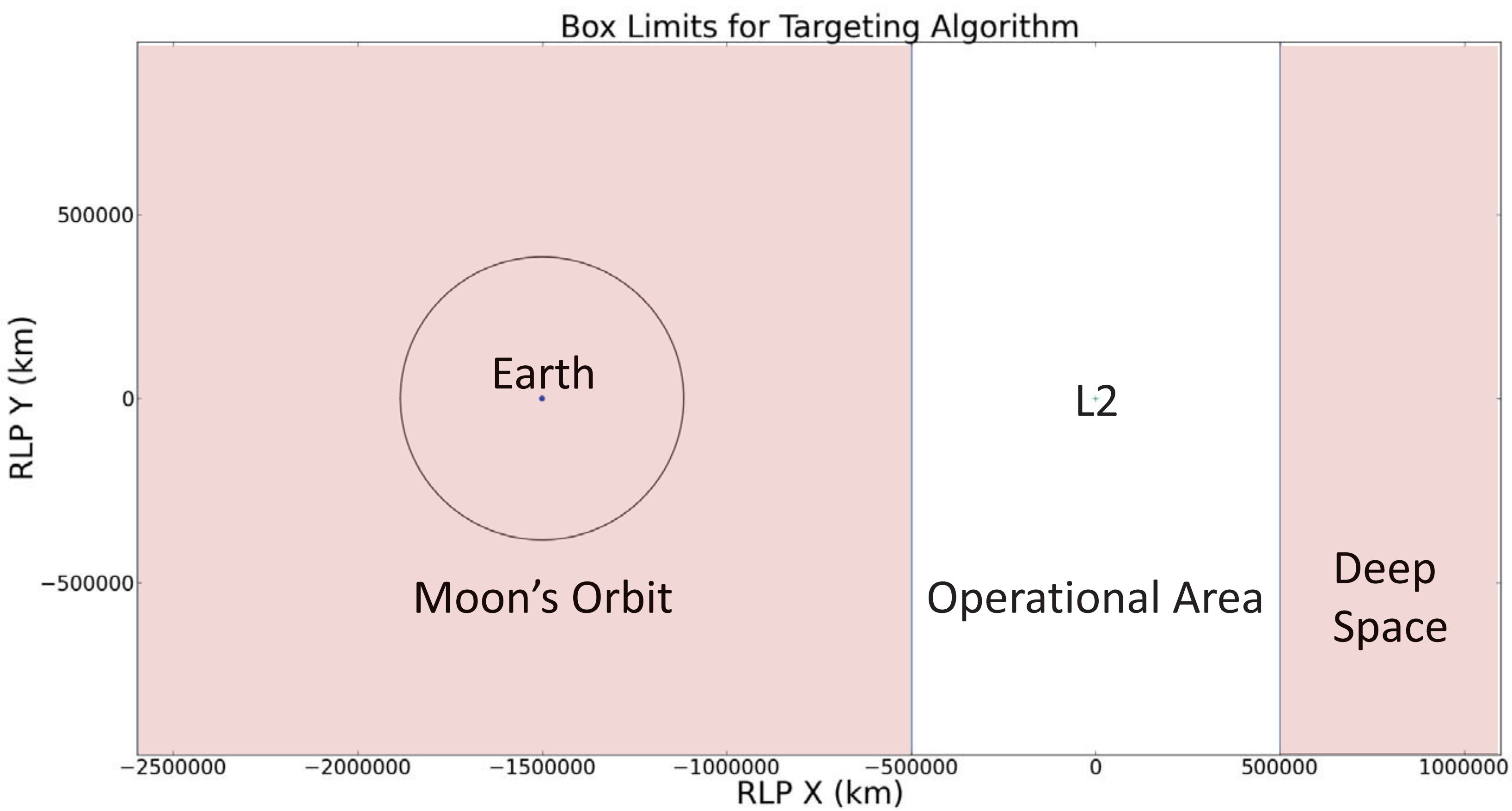
RLP-Y: ±832,000 km (130 Re) / RLP-Z: ±532,000 km (83 Re)



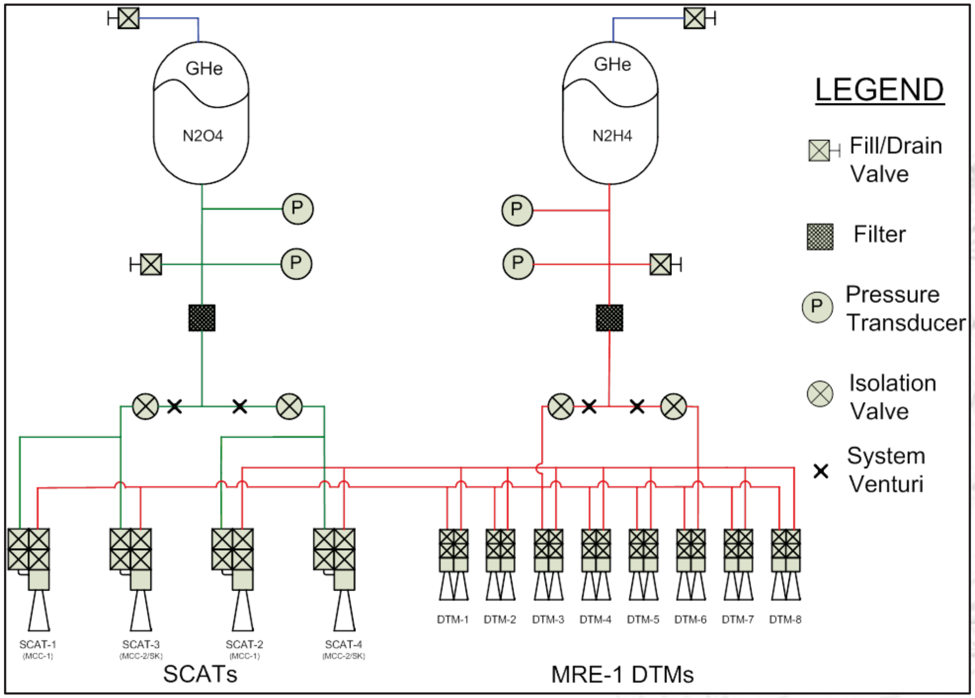
Maneuver Design Approach

Event	Time After Launch
MCC-1a	12 hours
MCC-1a Late	2.5 days
MCC-1b	5.5 days
MCC-2	30 days

Maneuver	ΔV Budget (m/s)	Maneuver	ΔV Budget (m/s)
MCC-1a	41	MCC-2	5
MCC-1a Late	8	Extra Margin	5
MCC-1b	7.5	**Total**	**66.5**



Propulsion System



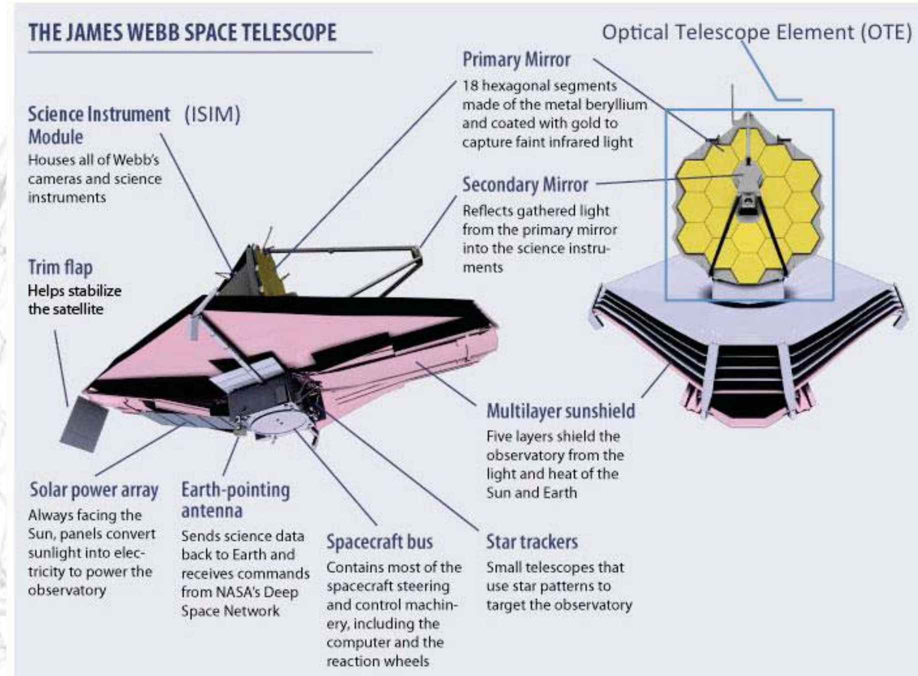
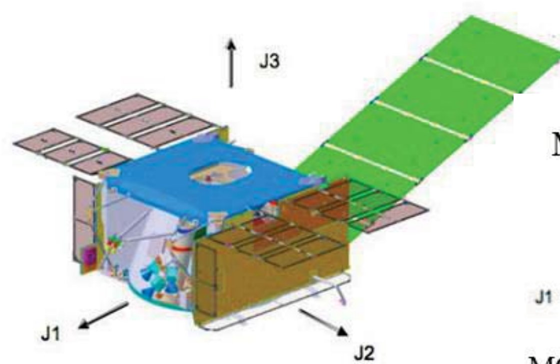


Image Credit: Northrup Grumman

Secondary Combustion Augmented Thrusters (SCATs)

Dual Thruster Modules (DTMs) Monopropellant Rocket Engine, 1 lbf (MRE-1)



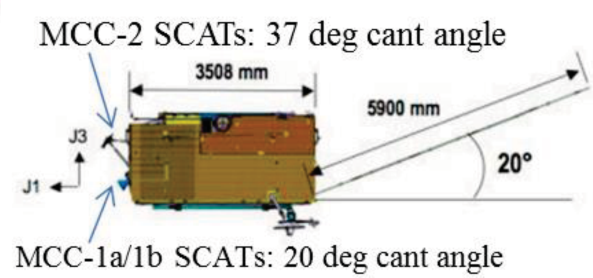


Image Credit: jwst.nasa.gov

Monte Carlo Simulation Variations

- **Problem: How robust is the maneuver design to propulsion performance errors?**
- **Launch vehicle injection state** (discriminate title. Bold/color)
  - Standard deviations and correlation matrix provided by Arianespace
- **Quality of orbit determination** (OD) solution at time of MCC maneuver
- **SCAT thruster performance** Scaling factor ± 5% (3σ)
- **MRE-1 thruster performance**
  - Scaling factor *U*(0,1) applied to the maximum duty cycle

$$a_b = \frac{1}{M}\left(\begin{array}{c} (1 + \xi \cdot \sigma_s) F_s \\ + \sum_{i=1}^{8} \left(\eta_{b,i} DC_{b,i} \cdot F_{m,i} \cos \beta_i \right) \end{array} \right)$$

- **Attitude knowledge accuracy**
  - ± 5% (3σ) in roll, pitch, and yaw.

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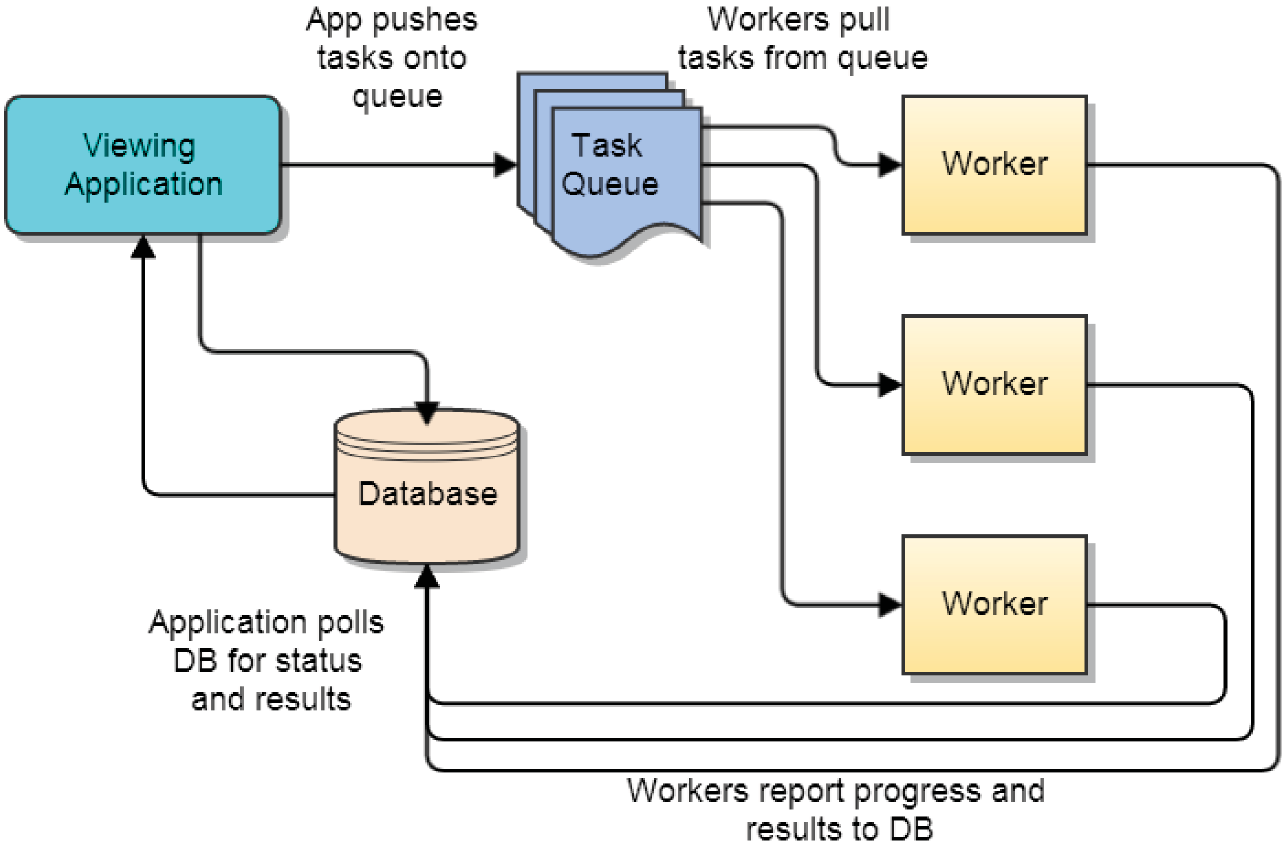
Task Parallelism Architecture

Problem: Develop an extensible system that allows for fast Monte Carlo simulations.



- Current simulations contain 1000 sample trajectories, each of which take approximately 200 seconds to complete.
- Spreading the tasks over 36 cores (instead of one) reduces the run time from approximately 2 days to 2 hours.

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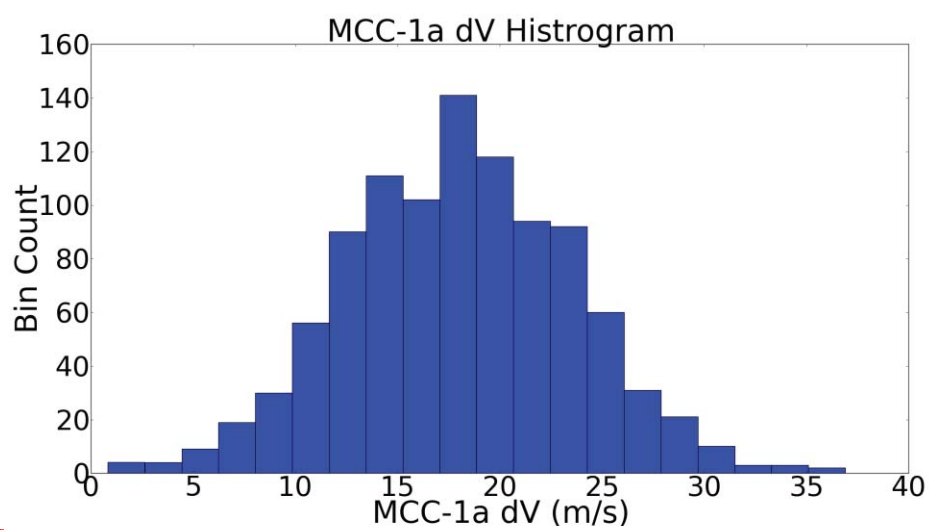
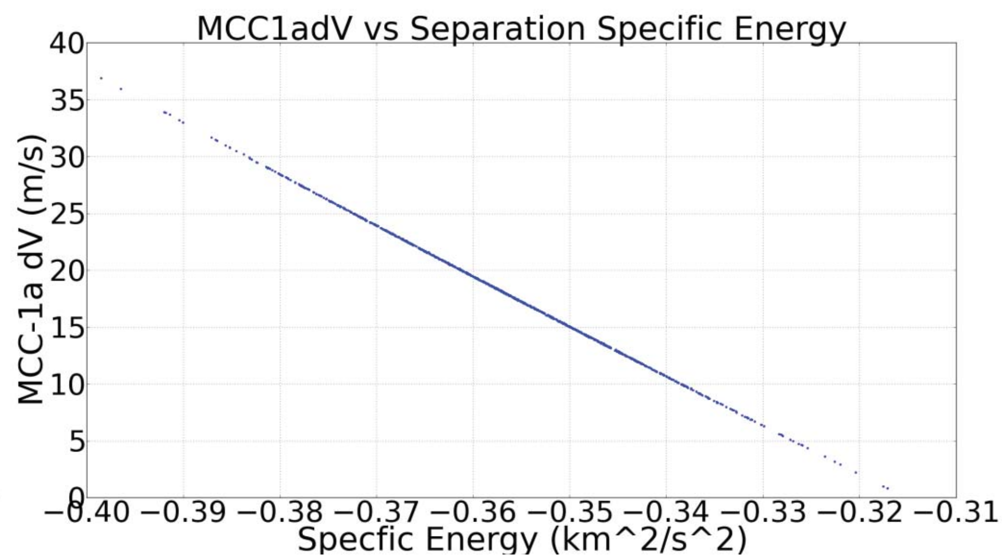
Launch Vehicle Injection Errors

- Launch Epoch: October 01, 2018 13:45:00 UTC
- Injection state: 1.10e6 km apogee height

MCC-1a	Nominal	Mean	- 3 Sigma	+3 Sigma
Separation Specific Energy (km^2/s^2)	-0.35586	-0.35667	-0.39465	-0.31871
Duration (seconds)	3865.57	3976.63	**94.684**	**7858.58**
ΔV (m/s)	17.617	18.017	**1.210**	**34.824**





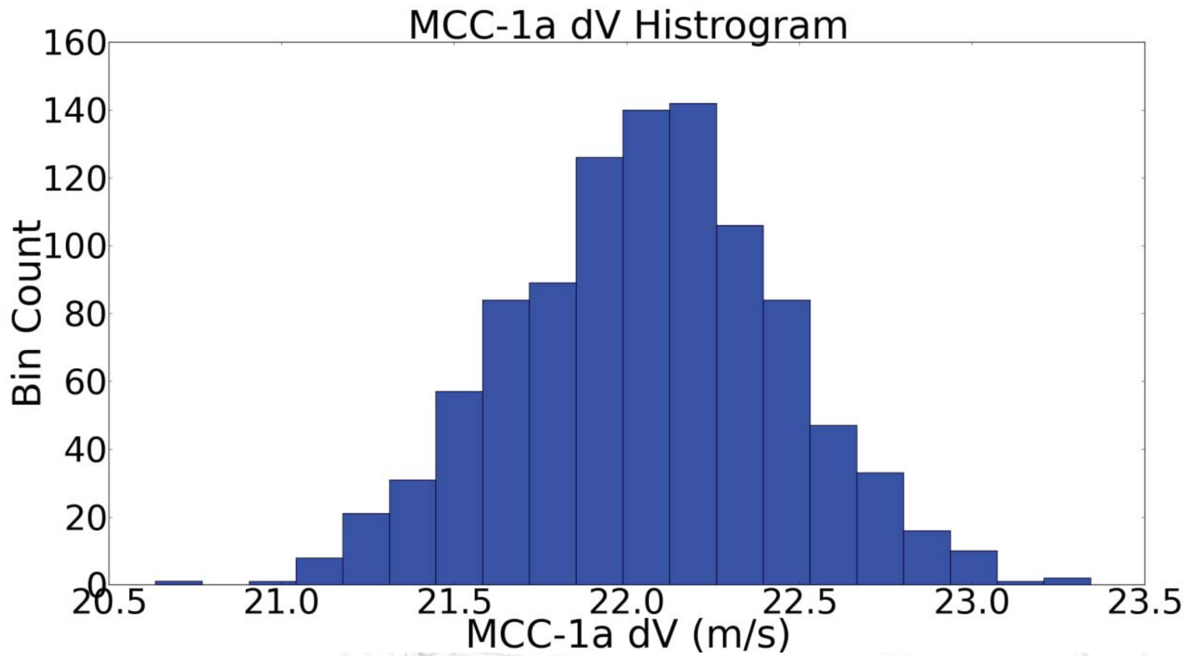
Propulsion Performance (1)

- Launch Epoch: October 18, 2018 12:30:00 UTC
- Injection state: 1.06e6 km apogee height

	Maneuver Time	Nominal Duration (seconds)	Nominal ΔV (m/s)
MCC-1a	Launch + 0.5 days	4952.28	22.279
MCC-1b	Launch + 2.5 days	455.68	1.967
MCC-2	Launch + 30 days	149.40	0.712
Cumulative	--	5557.36	24.958

Propulsion Performance (2)

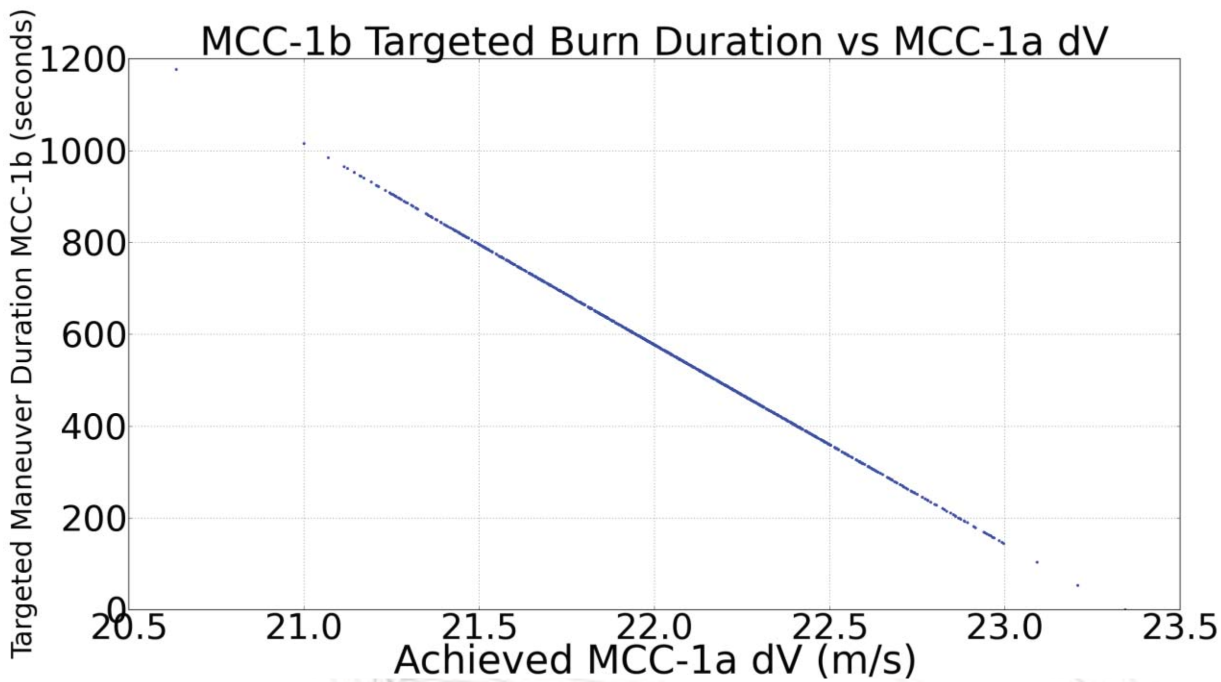
MCC-1a Performance



MCC-1a	Nominal	Mean	- 3 Sigma	+3 Sigma
Targeted Duration (seconds)	4952.28	--	--	--
Achieved ΔV (m/s)	22.279	22.057	20.891	23.223

Propulsion Performance (3)

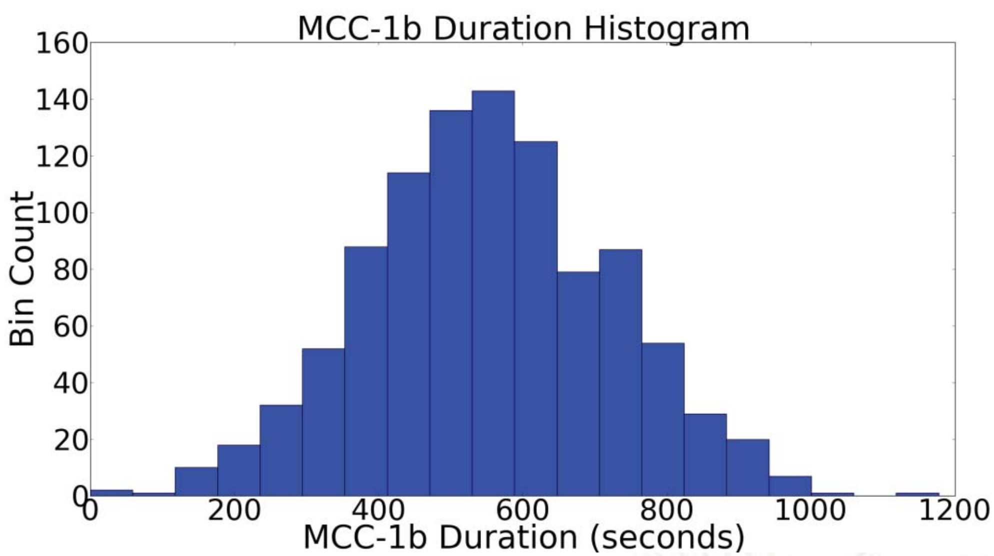
MCC-1b Performance

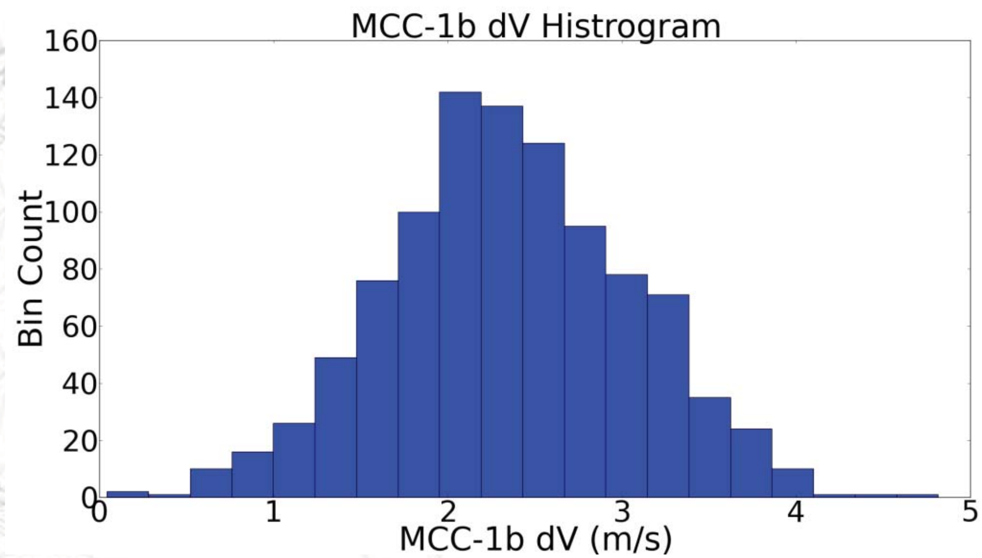


→ The targeted maneuver duration for MCC-1b is strongly dependent on the performance of MCC-1a.

Propulsion Performance (4)

MCC-1b Performance

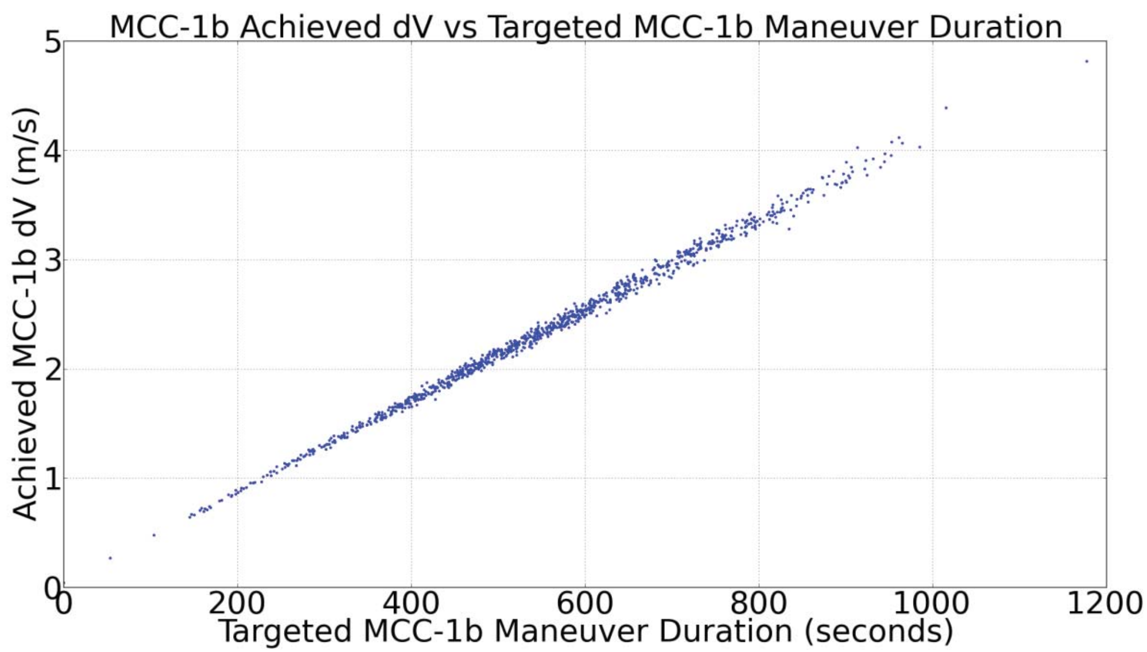




MCC-1b	Nominal	Mean	- 3 Sigma	+3 Sigma
Targeted Duration (seconds)	455.68	552.61	44.394	1060.82
Achieved ΔV (m/s)	1.967	2.347	0.237	4.456

Propulsion Performance (5)

MCC-1b Performance

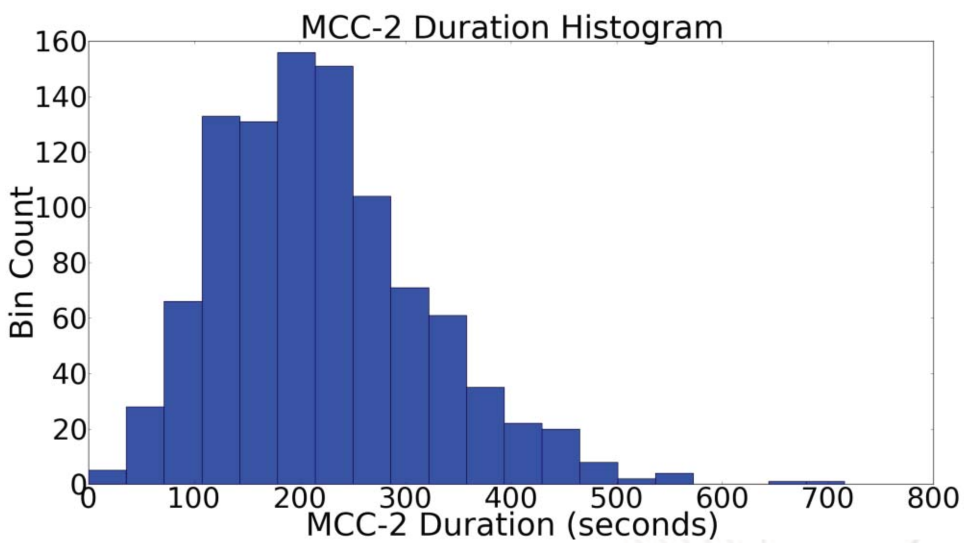


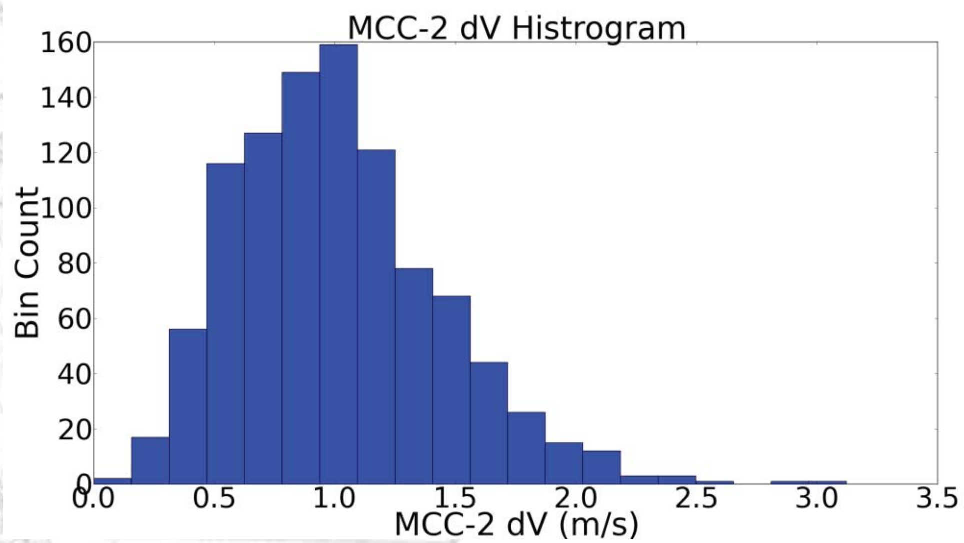
→ The achieved ΔV for a given maneuver duration is not perfectly linear.

→ Fluctuations begin to appear due to cumulative effects of propulsion performance from MCC-1a and MCC-1b.

Propulsion Performance (6)

MCC-2 Performance

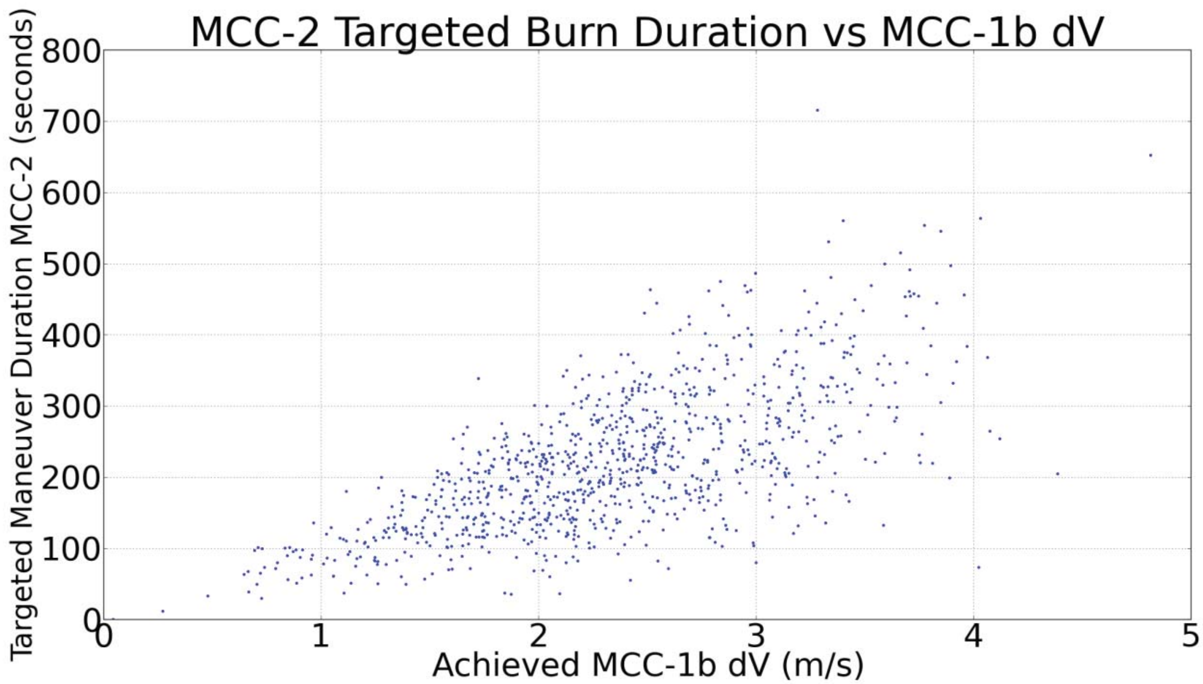




MCC-2	Nominal	Mean
Targeted Duration (seconds)	149.40	221.51
Achieved ΔV (m/s)	0.712	1.011

Propulsion Performance (7)

MCC-2 Performance



→ The results are more disperse due to the combination of propulsion performance from all 3 MCC maneuvers.

ΔV Contribution from MRE-1s

Duration (seconds)	MCC-1a	MCC-1b	MCC-2	Cumulative
SCATs Only	5068.83	466.22	155.17	5690.22
SCATs and MRE-1s	4952.28	455.68	149.40	5557.36
Percent Difference	**-2.300**	**-2.261**	**-3.719**	**-2.335**
ΔV (m/s)	**MCC-1a**	**MCC-1b**	**MCC-2**	**Cumulative**
SCATs Only	22.290	1.960	0.711	24.961
SCATs and MRE-1s	22.279	1.967	0.712	24.958
Percent Difference	**-0.05**	**0.357**	**0.141**	**-0.012**

Conclusion and Future Work

- Task parallelism has been beneficial for generating and analyzing datasets.
- Launch vehicle dispersions strongly influence the magnitude of MCC-1a.
- The ΔV budget and maneuver design approach are robust to statistical variations in the propulsion system.
- MRE-1 contributions can contribute a non-trivial amount of Δ V to MCC maneuvers.
- Future work
  - Incorporate the benefits of the AWS GovCloud to help streamline the task distribution system.
  - Continue to increase the fidelity of the simulation (the propulsion system in particular).
  - Conduct a Monte Carlo simulation that incorporates all of the potential statistical variations to help validate the ΔV budget and the robustness of the maneuver planning strategy.