Orbiters, CubeSats, and Radio Telescopes, Oh My; Entry, Descent, and Landing Communications for the 2018 InSight Mars Lander Mission

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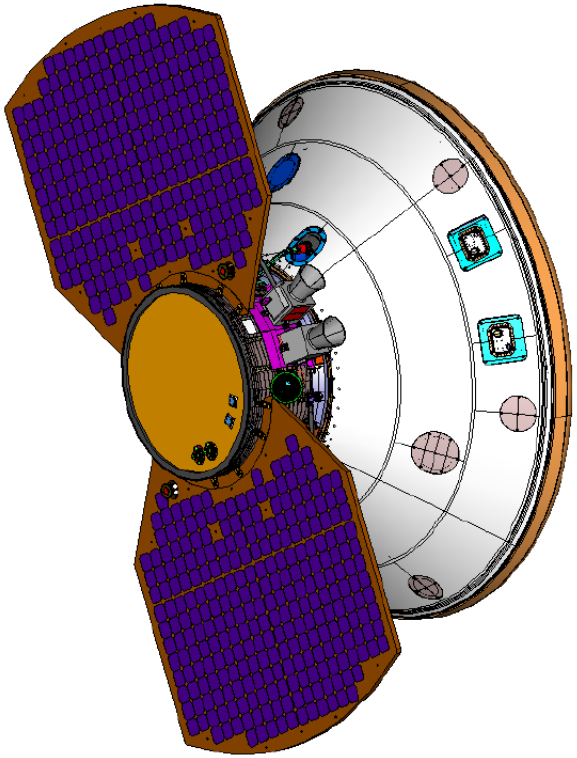
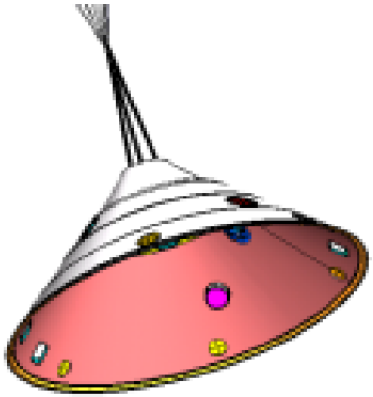
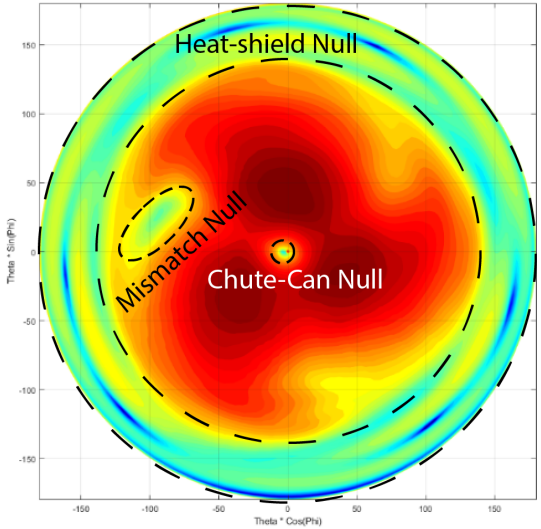
Introduction

- InSight was a Mars lander, and Entry, Descent, and Landing (EDL) is a critical event.
- A communications link back to Earth, either real-time or delayed, is required in order to reconstruct an anomaly, should one occur.
  - Every mission this millennium has had this requirement.
- The InSight Project used a combination of:
  - Mars Reconnaissance Orbiter
  - The twin MarCO CubeSats
  - Two radio telescopes

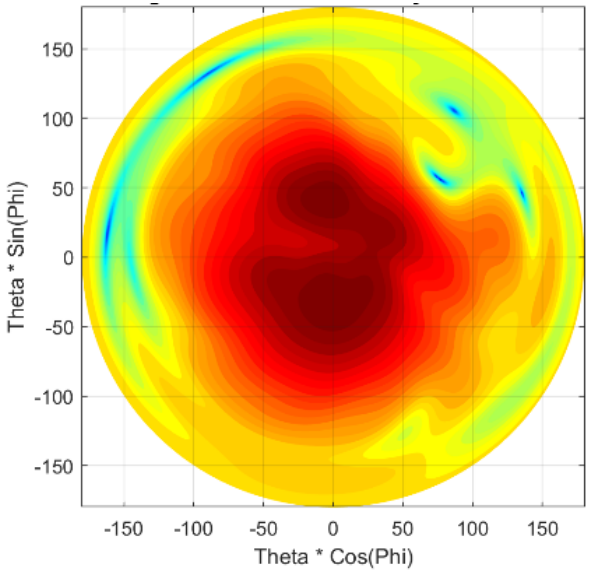
InSight





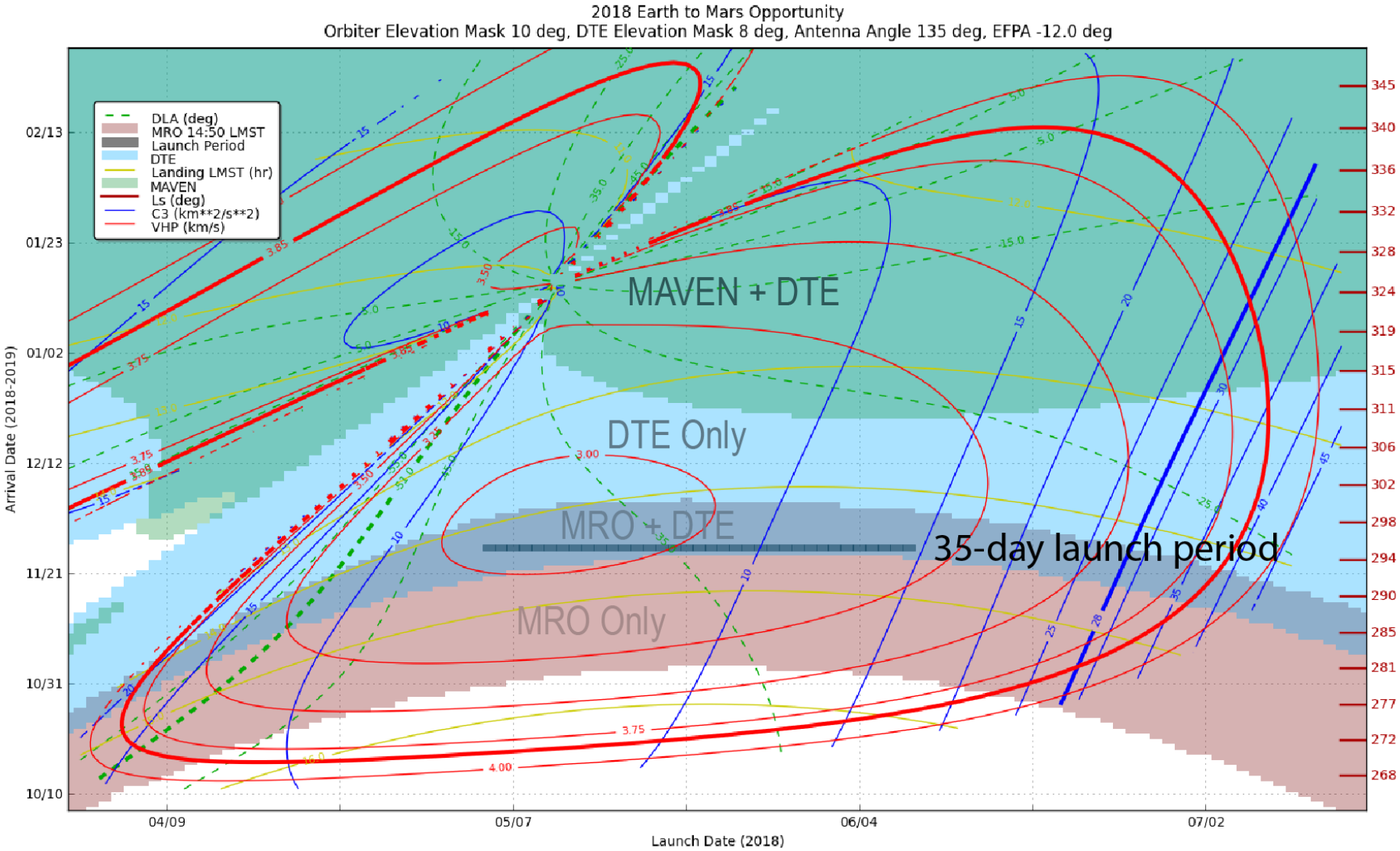


Wrap-Around Antenna

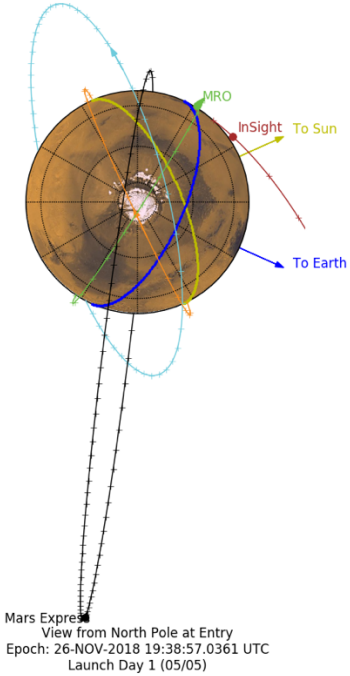


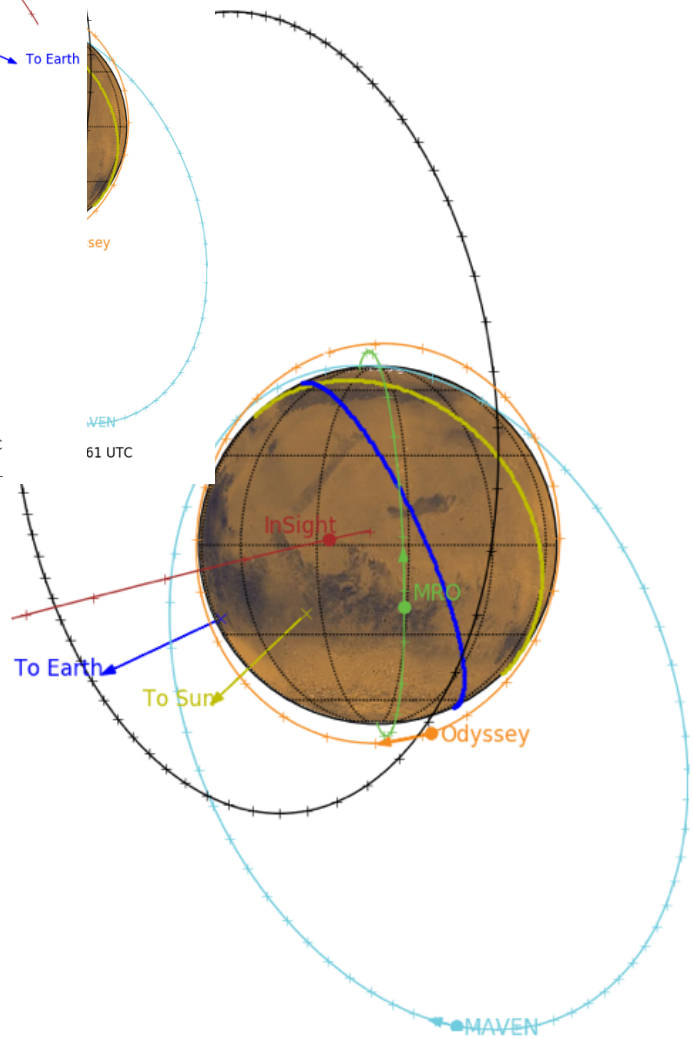
Helix Antenna

Mission Design

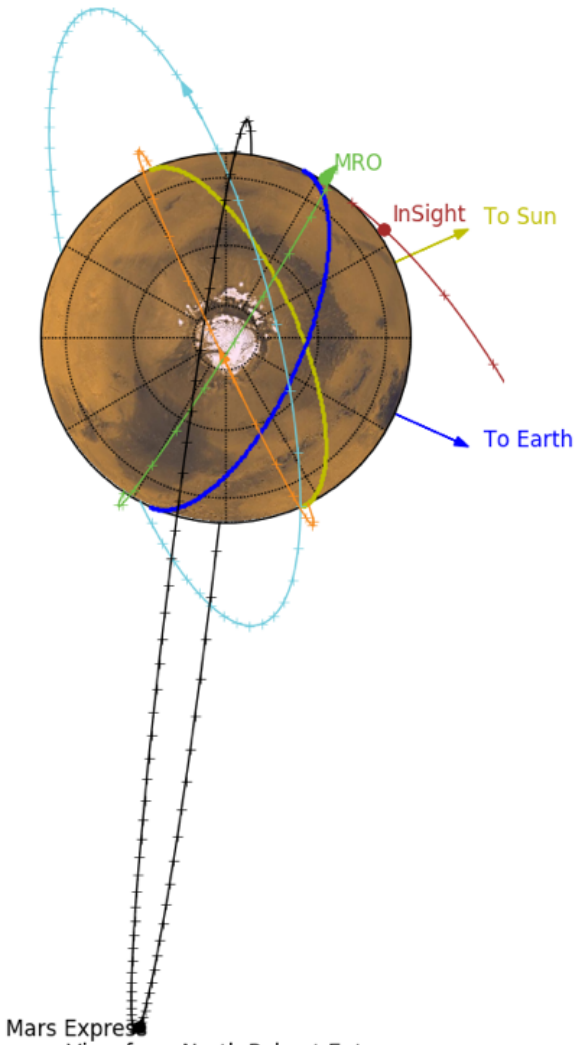


Arrival Geometry



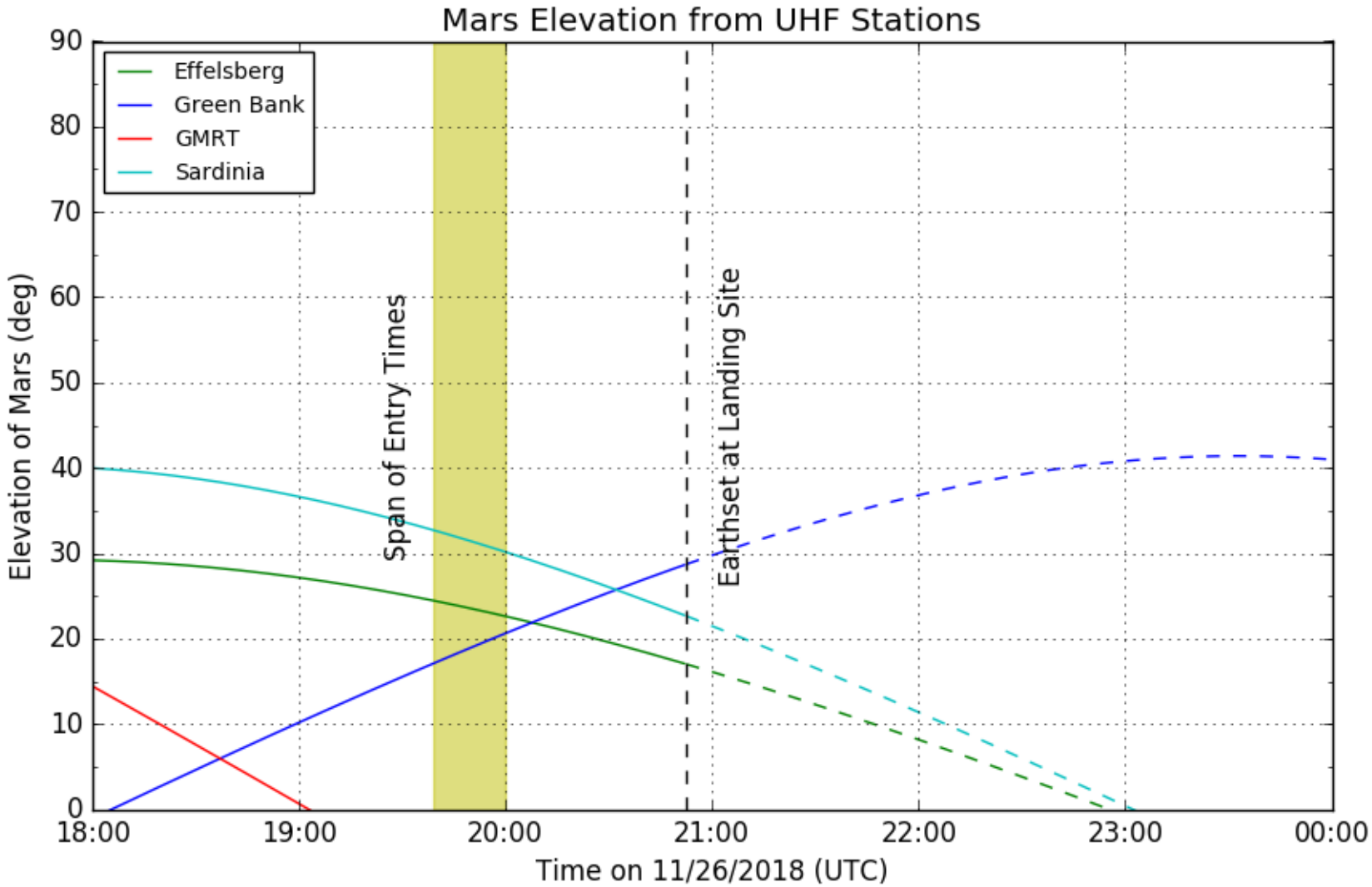


Arbitrary View at Entry
Epoch: 26-NOV-2018 19:38:57.0361 UTC
Launch Day 1 (05/05)

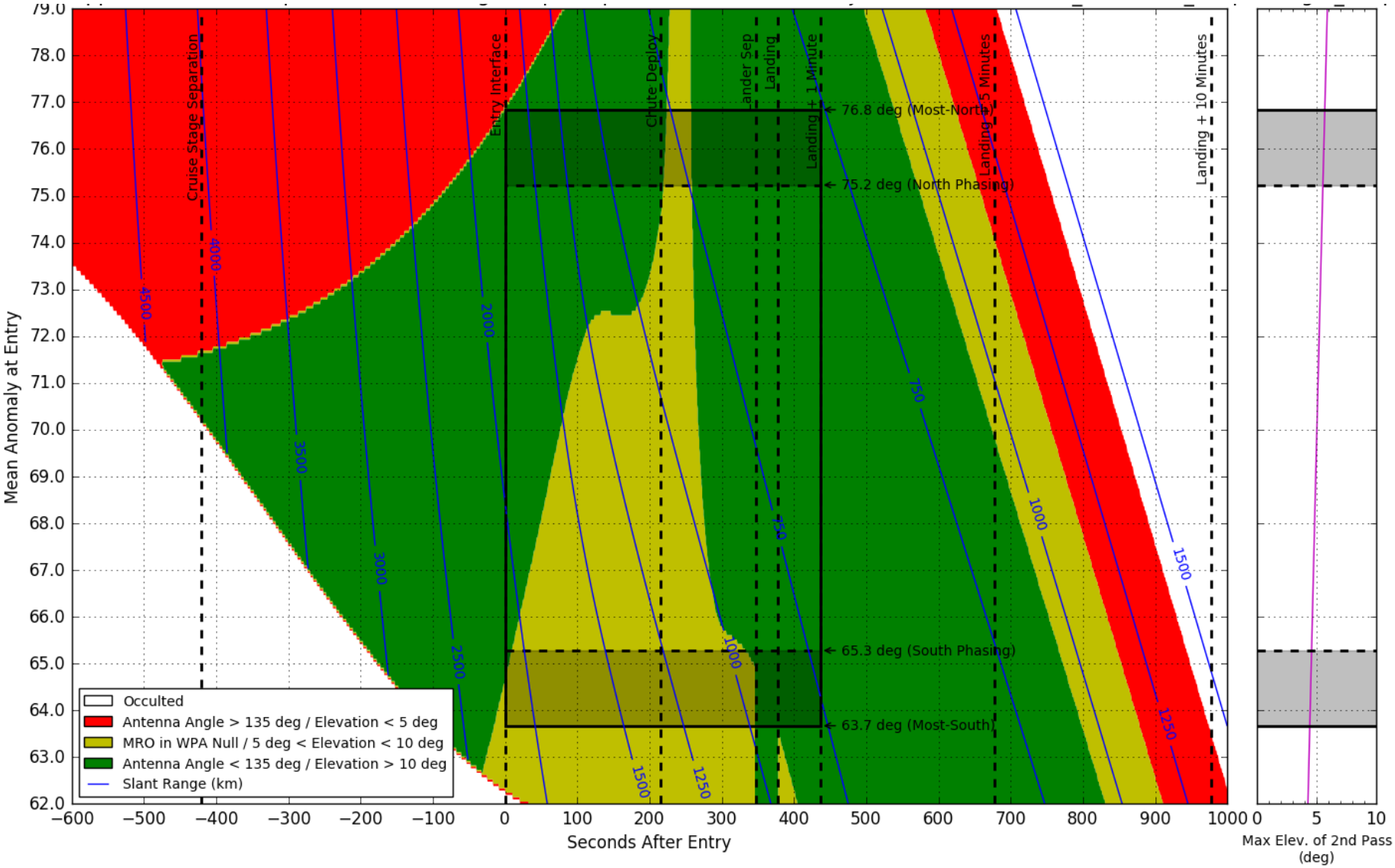


View from North Pole at Entry
Epoch: 26-NOV-2018 19:38:57.0361 UTC
Launch Day 1 (05/05)

Radio Telescopes



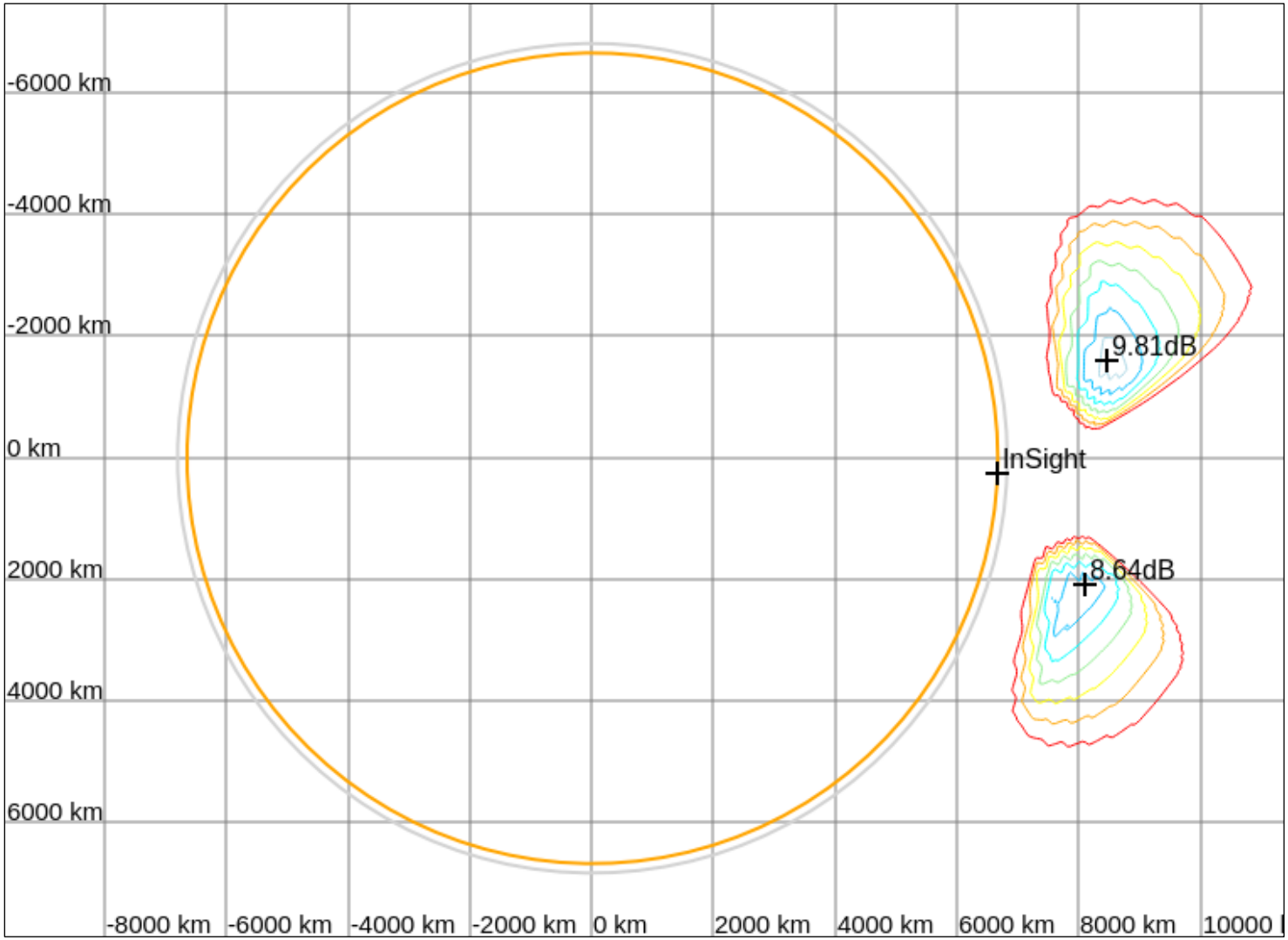
MRO Phasing


Mean Anomaly at Entry
Seconds After Entry
Max Elev. of 2nd Pass (deg)
Cruise Stage Separation
Entry Interface
Chute Deploy
Lander Sep
Landing
Landing + 1 Minute
Landing + 5 Minutes
Landing + 10 Minutes
76.8 deg (Most-North)
75.2 deg (North Phasing)
65.3 deg (South Phasing)
63.7 deg (Most-South)
Occulted
Antenna Angle > 135 deg / Elevation < 5 deg
MRO in WPA Null / 5 deg < Elevation < 10 deg
Antenna Angle < 135 deg / Elevation > 10 deg
Slant Range (km)

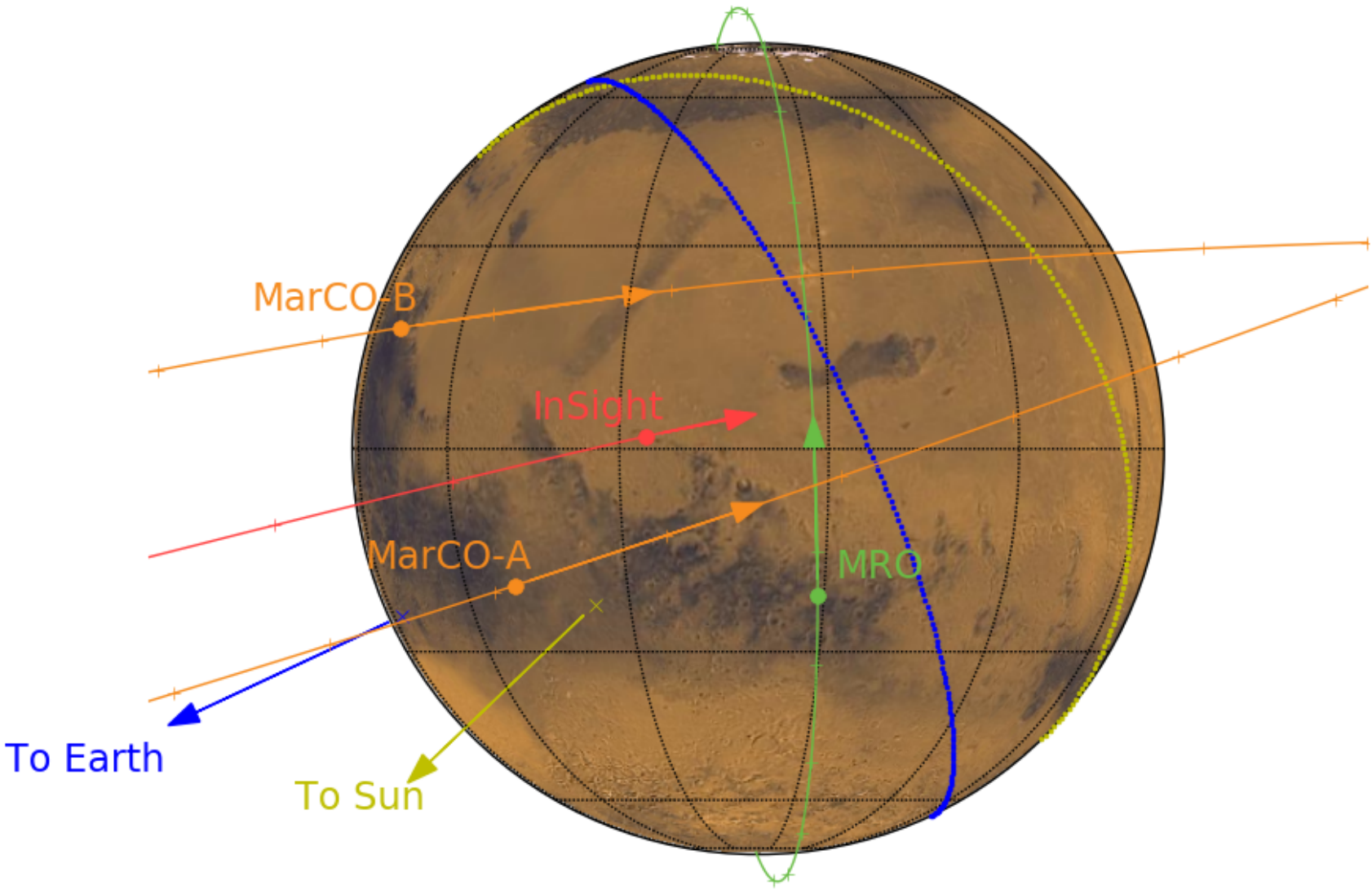
MarCO Design Process

- MarCO targeting is three-dimensional where MRO's is one-dimensional.
- Used a simplified link-budget and maximized the minimum margin using the nominal InSight trajectory
  - 10% low value of InSight gain at a given cone angle
  - 11 deg of "wrist-joint" motion while on the parachute

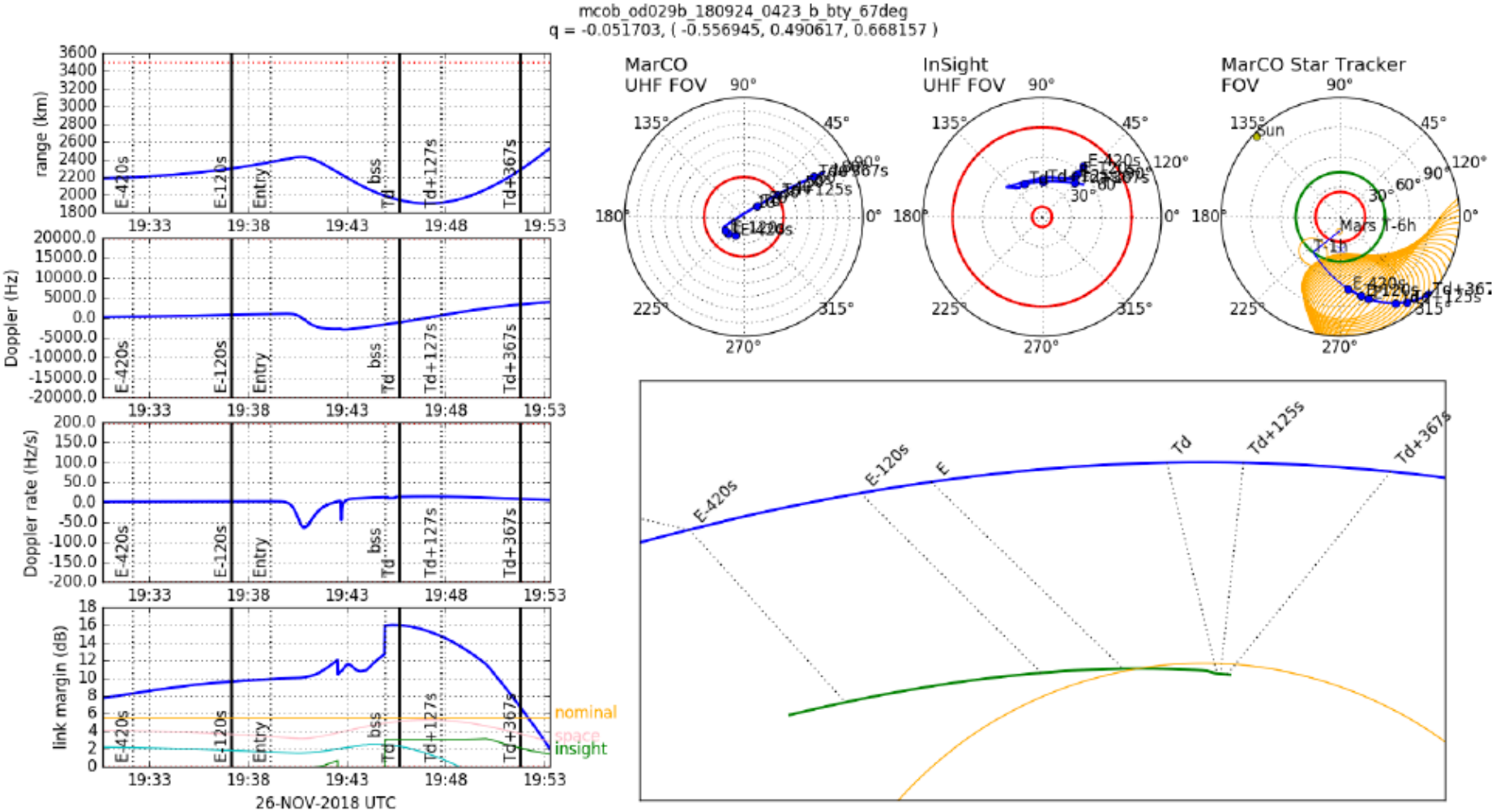
MarCO Preliminary Design



Entry Geometry



MarCO Preliminary Design

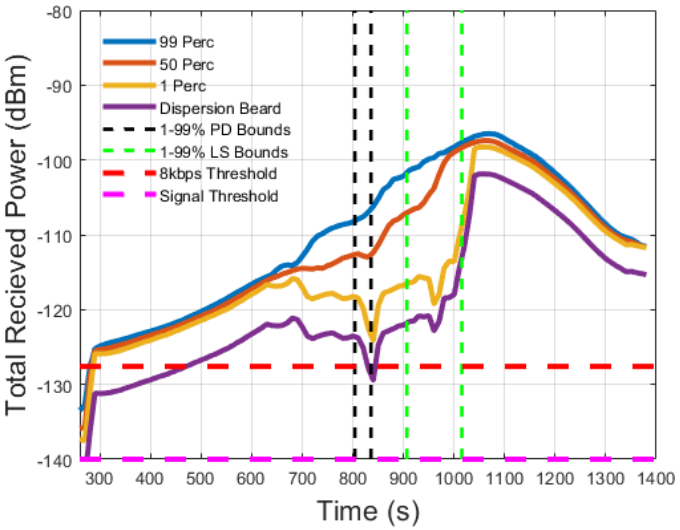


Monte Carlo Validation

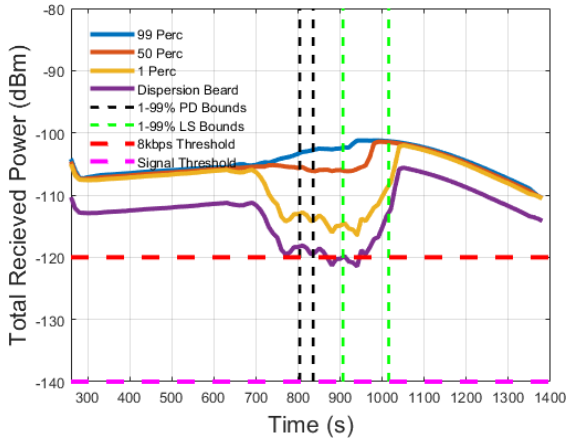
- Used POST2 (LaRC tool) to simulate 900 InSight trajectories varying the atmospheric density, winds, aerodynamic parameters, spacecraft attitudes & mass properties, etc.
- Added a "beard" to 1st percentile values to cover uncertainties in antennas (gains, circuit losses)
- Results at key events tabulated:

Metric	Units	Margin to Requirement: 1st Percentile Monte Carlo minus "Beard"				
		MRO	MarCO-A	MarCO-B	Green Bank	Effelsberg
Link at Entry Interface	dBm	4.7	8.6	1.9	1.6	-8.0
Link at Chute Deploy	dBm	4.4	3.3	4.6	-3.8	-13.4
Link at Lander Separation	dBm	10.4	10.9	9.7	-11.7	-21.3
Link at Touchdown + 1 minute	dBm	25.3	13.6	12.3	2.5	-7.1
Link at Touchdown + 5 minute	dBm	N/A	6.7	6.9	2.2	-7.4
Minimum Elevation from Touchdown to Touchdown + 1 minute	deg	3.5	37.9	40.6	1.7	1.7
Minimum Elevation from Touchdown to Touchdown + 5 minute	deg	N/A	22.6	34.2	10.9	10.9

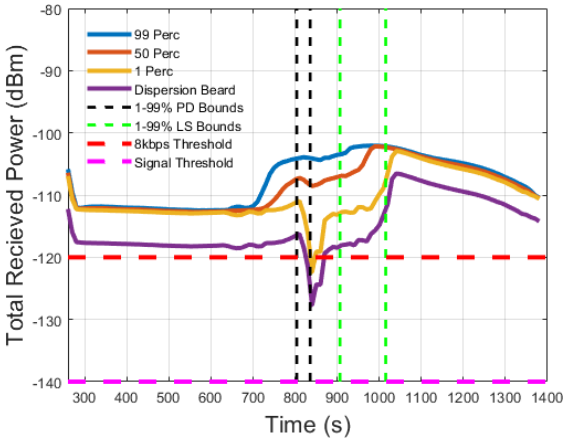
Received Power Plots



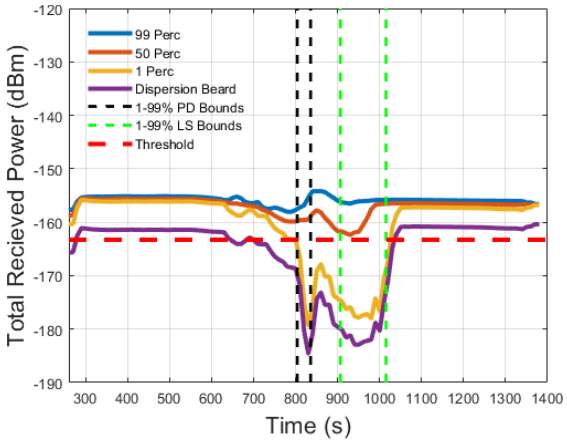
MRO



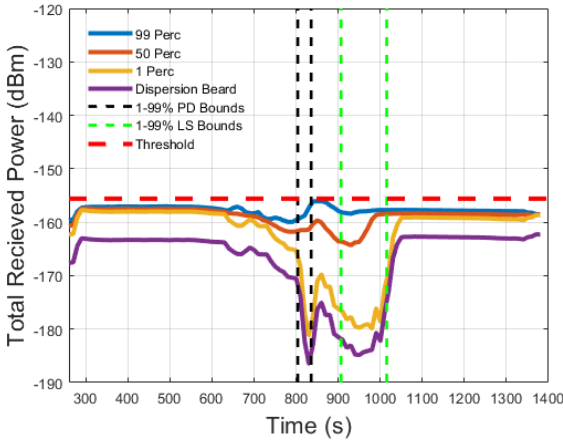
MarCO-A



MarCO-B



Green Bank

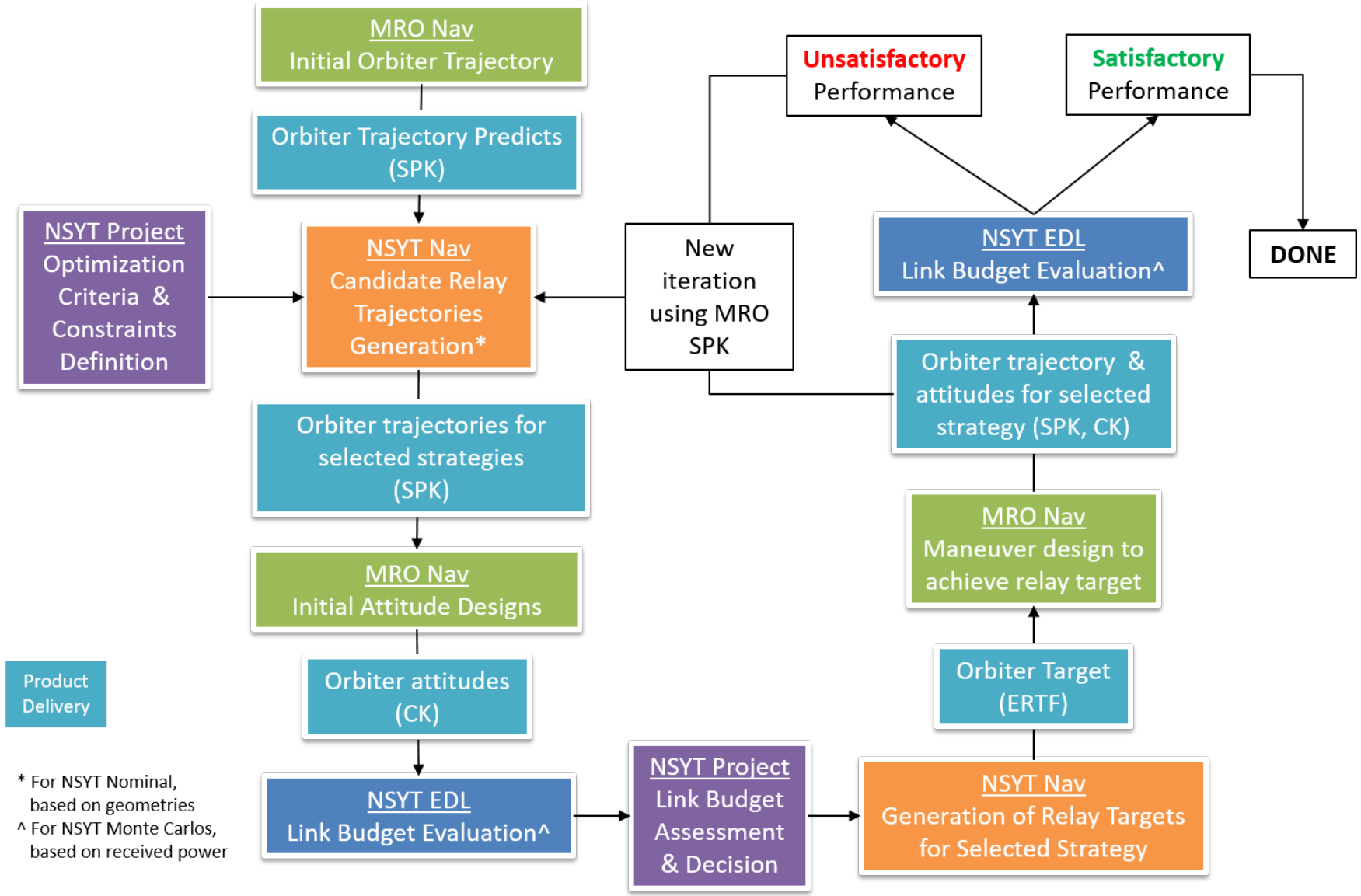


Effelsberg

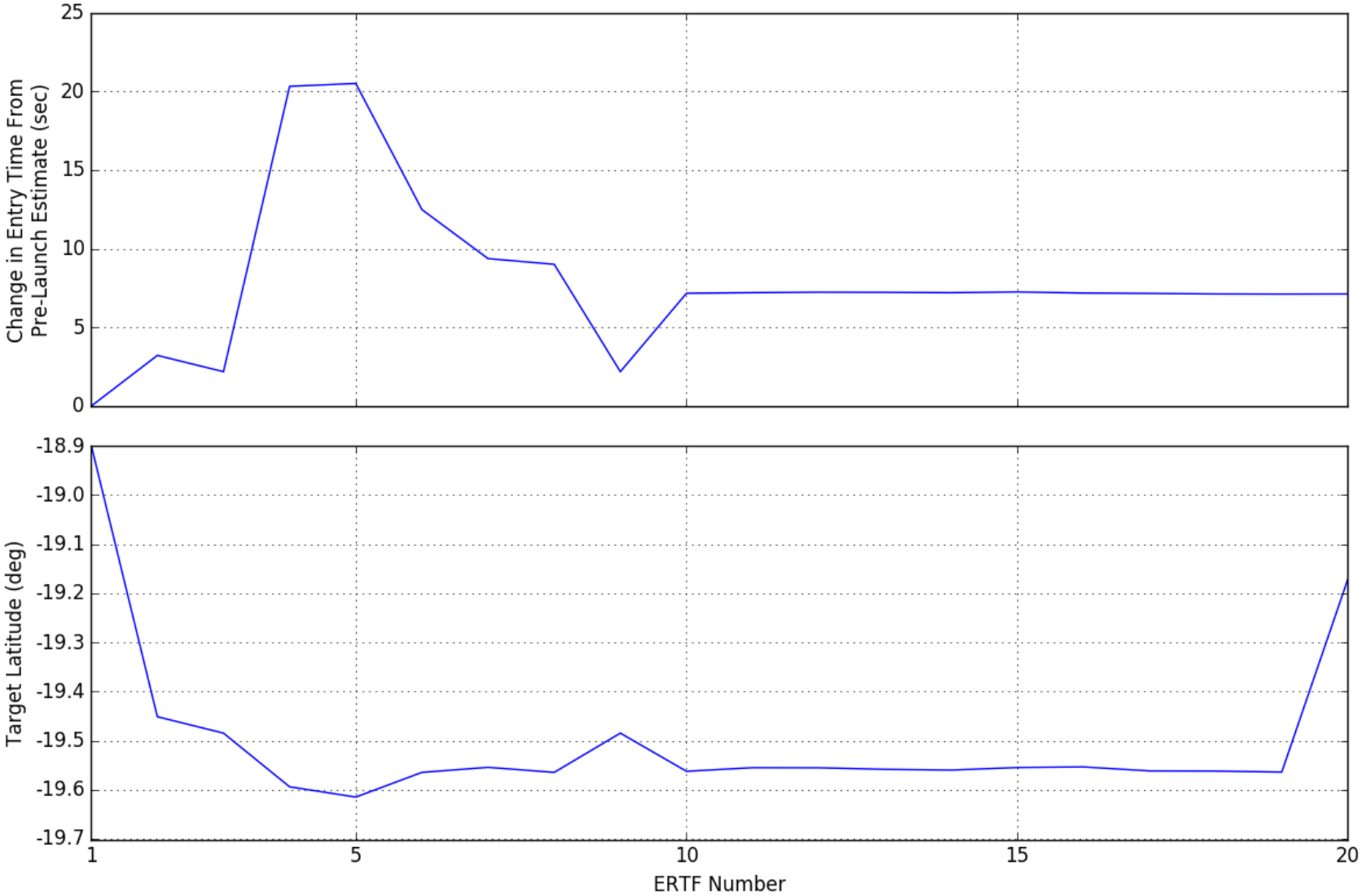
In Flight

MRO

Entry Relay Target File Process



Evolution of Targets



MRO Performance

- August 22nd:
  - First phasing maneuver, based on ERTF-10
  - Reduced phasing error from 55.2 to 12.5 minutes
- October 24th:
  - Second phasing maneuver, based on ERTF-15
  - Removed remaining error
- November 5th:
  - Predicted phasing error: -4.05 ± 24.1 sec (3σ)
  - November 14th maneuver cancelled
- November 12th:
  - Predicted phasing error: -8.7 ± 10.9 sec (3σ)
  - November 19th maneuver cancelled
- Final Result: -8.4 seconds

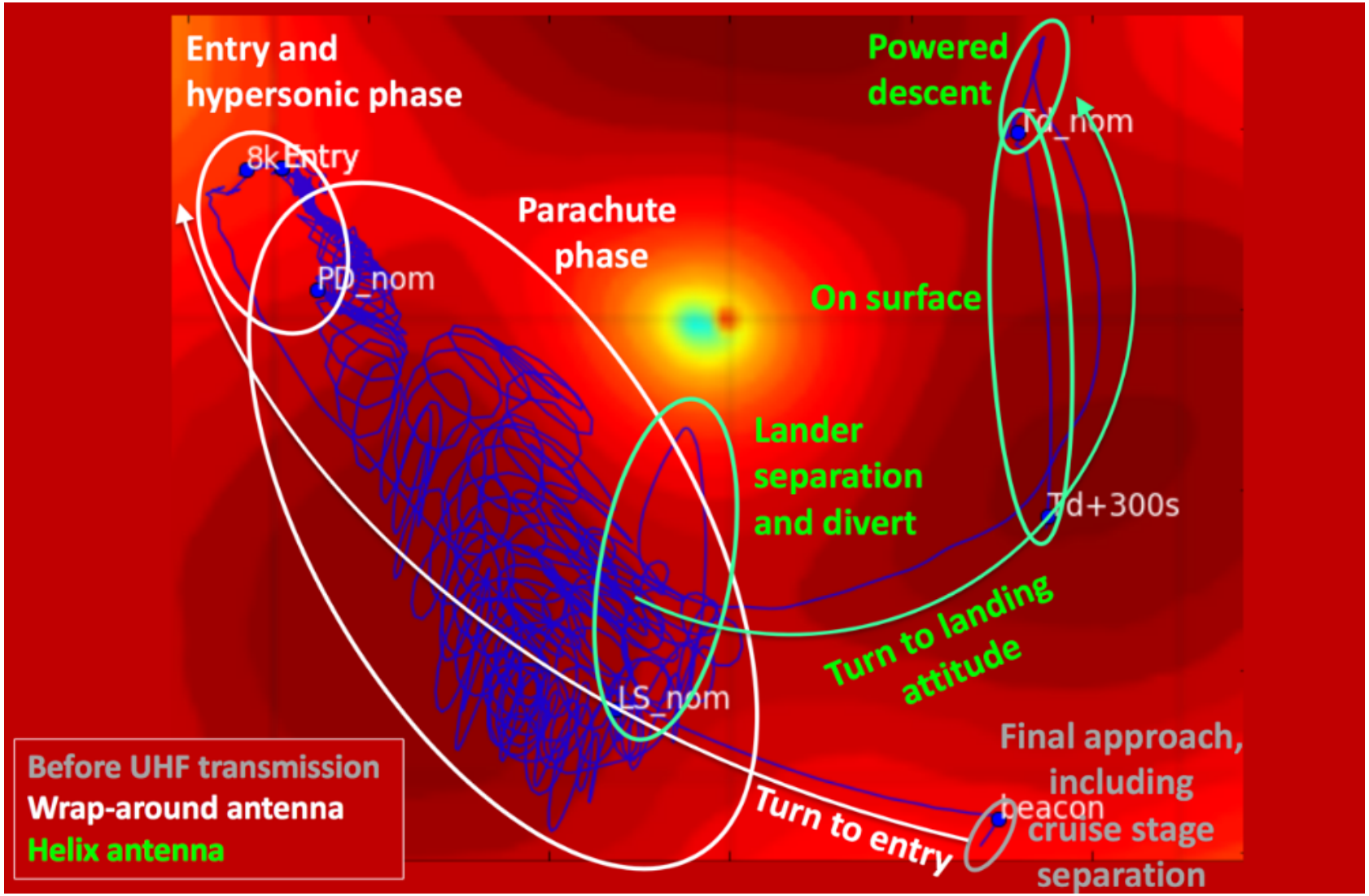
In Flight

MARCO

In Flight: MarCO

- Immediately after launch, MarCO-B developed an internal propulsion system leak that required frequent "blowdowns" which perturbed the trajectory.
  - A thruster leak later developed as well, requiring frequent angular momentum reduction maneuvers
- MarCO-A developed the same internal leak late
- Targets were tweaked to balance margins at the 1st percentile level.
- MarCO-A
  - First TCM on May 22nd
  - Final TCM on October 3rd
  - 320 km from B-Plane target
  - 60 seconds early
- MarCO B:
  - Final TCM on November 16th
  - 110 km from B-Plane target
  - 4 seconds early

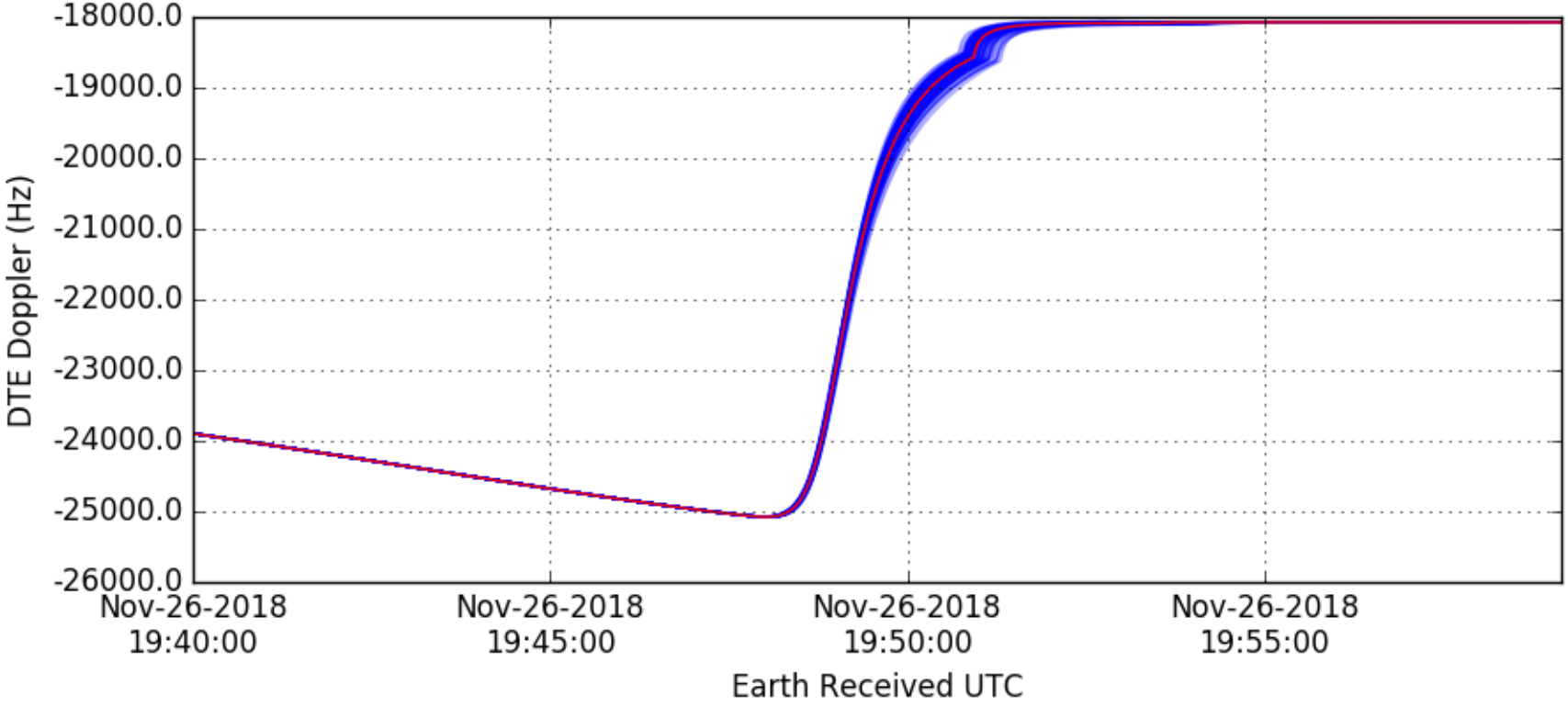
Example MarCO-B Path in WPA



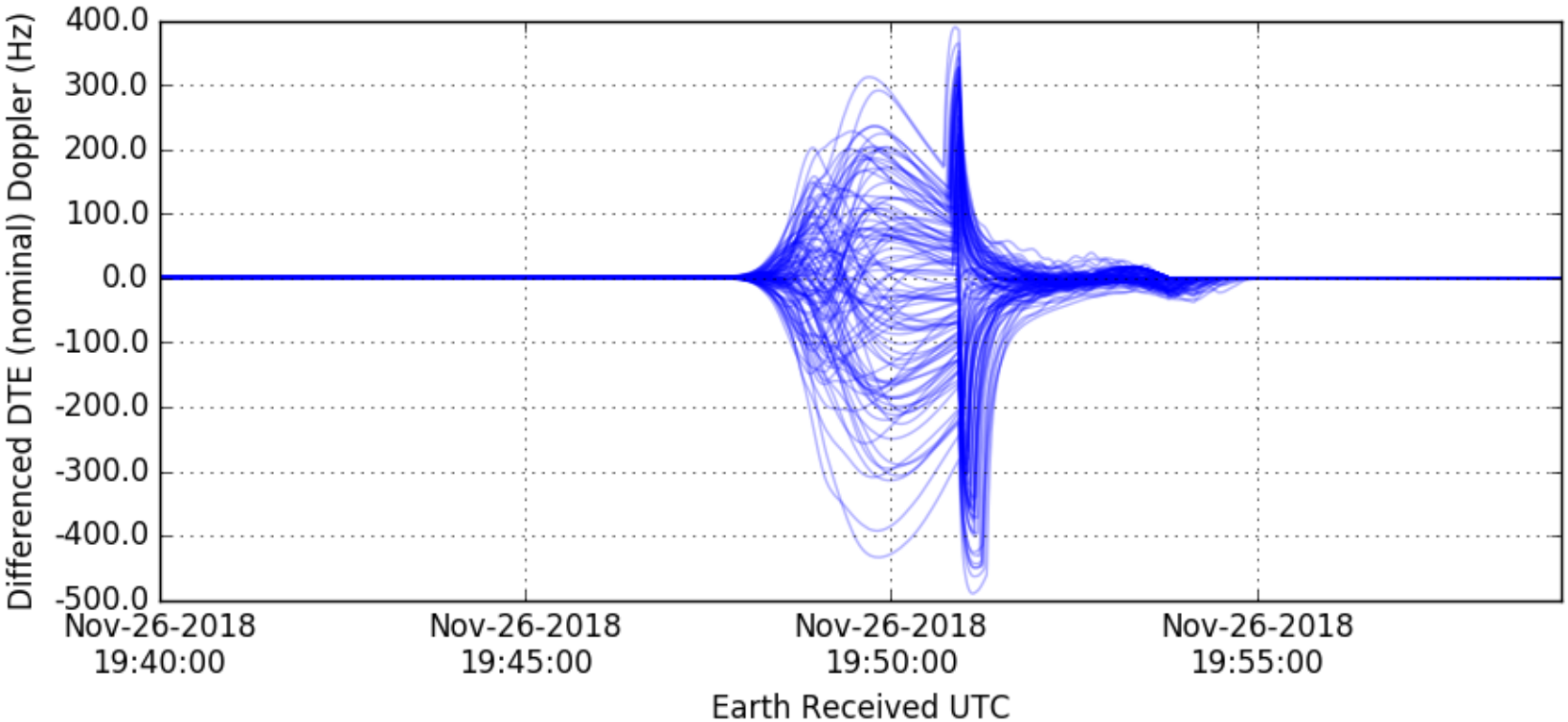
In Flight

EARTH

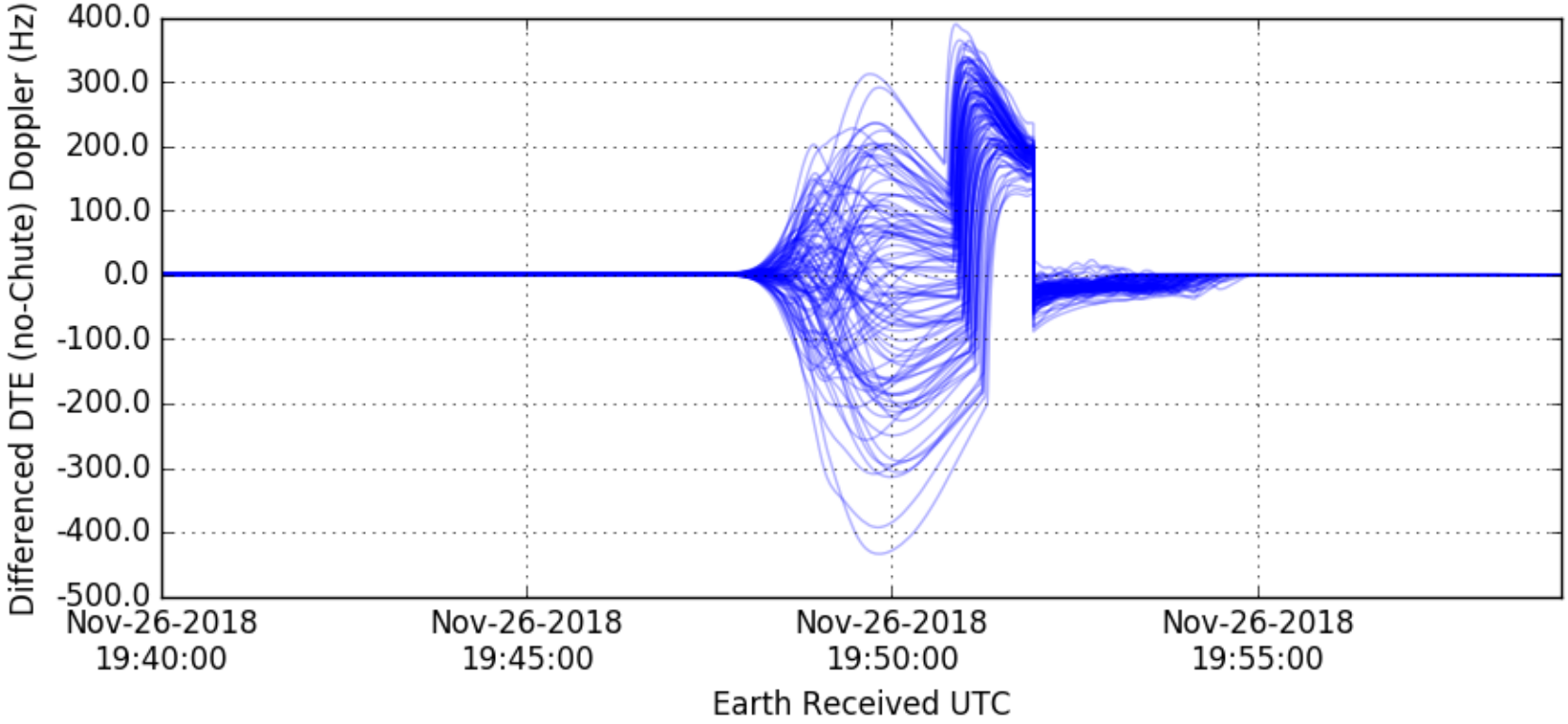
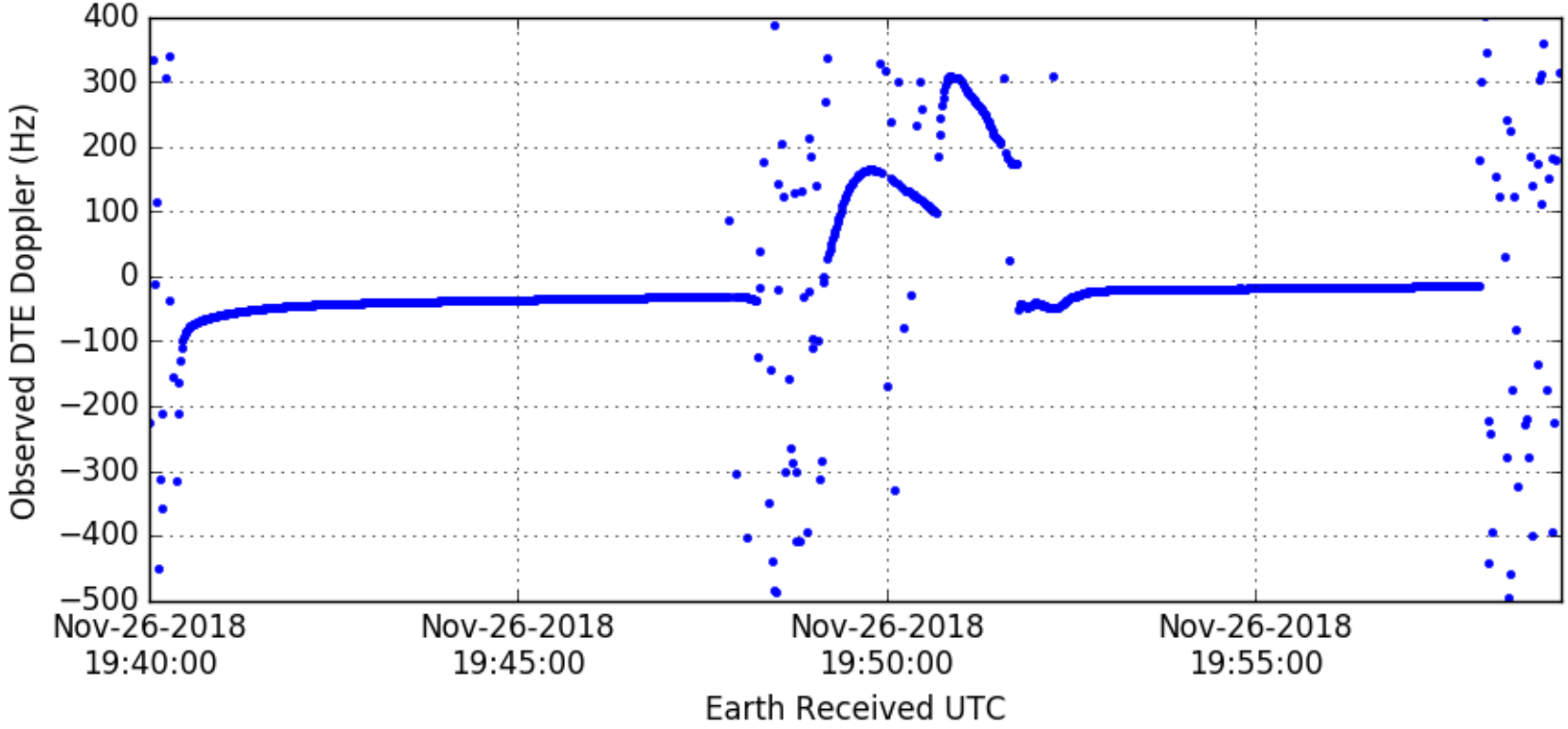
Doppler Predicts



Difference from Nominal



Difference from No-Chute



Recorded Doppler Shift