Mars Sample Return

Launch and Detection Strategies for Orbital Rendezvous

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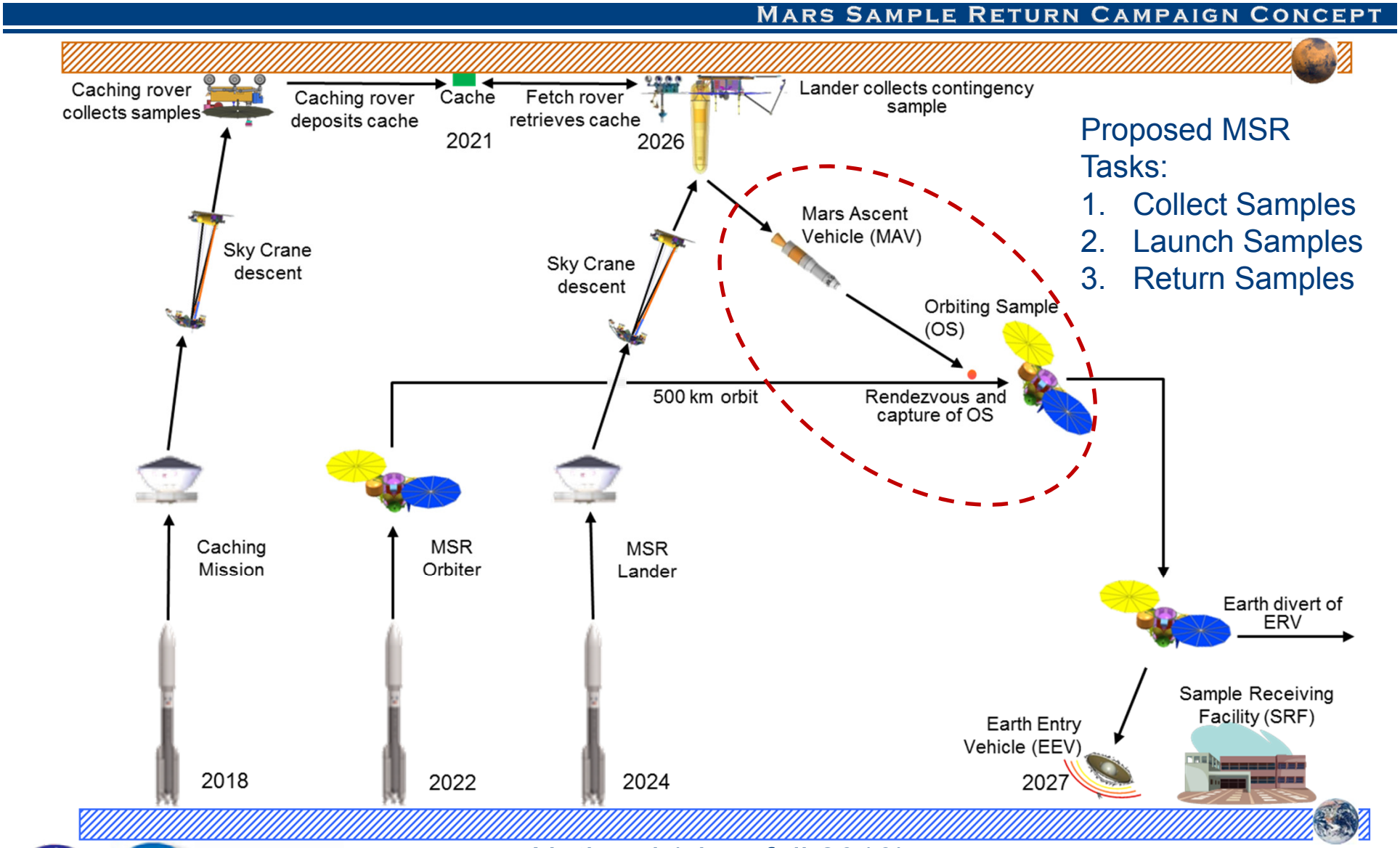
Three-Element Sample Return Campaign Concept



Notional (circa fall 2010)

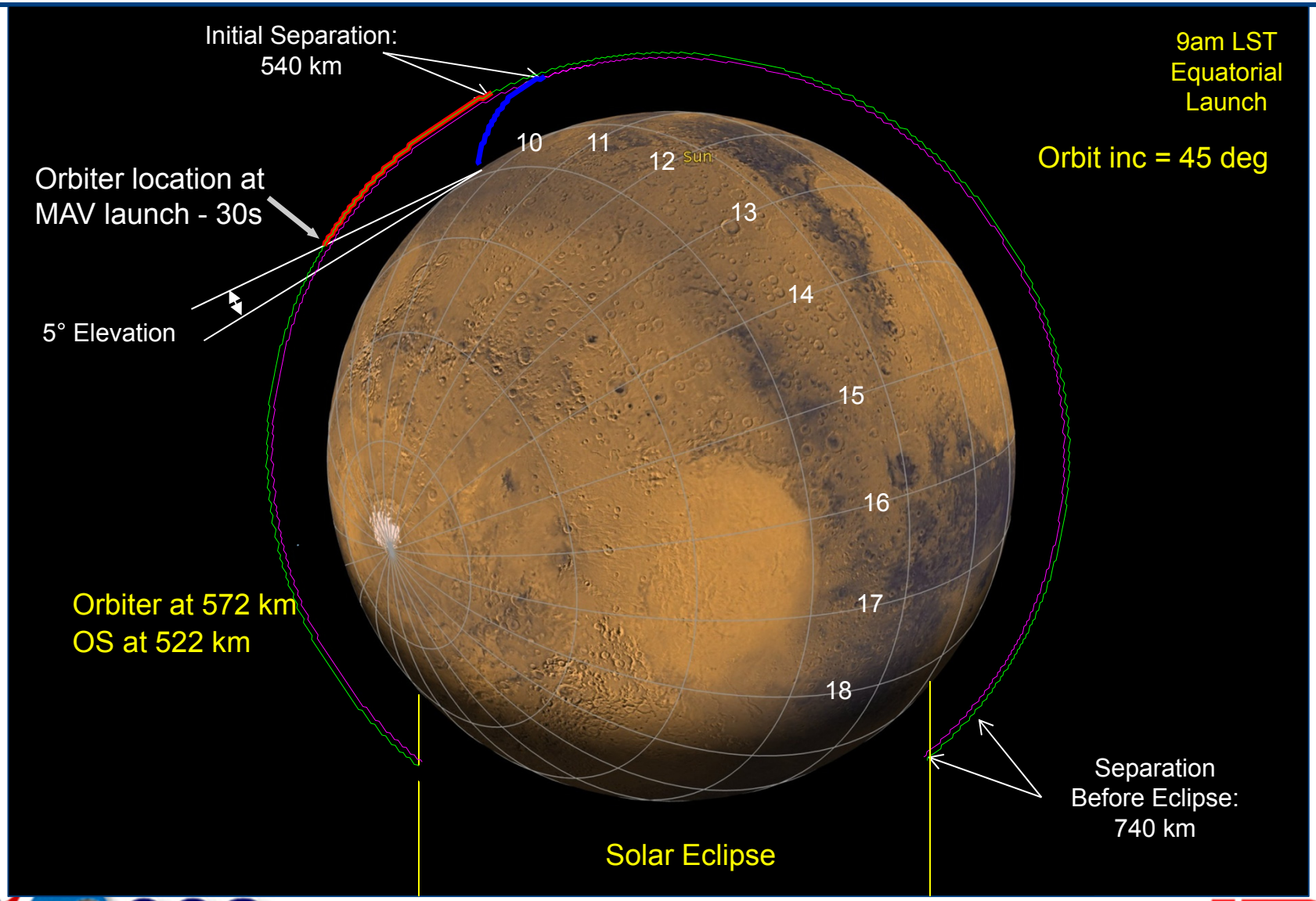
Study Assumptions

Study Objectives: 1) Determine feasibility of remotely launching, detecting, and rendezvousing with the orbiting sample (OS)
2) Identify a potential robust scheme to optically detect and track the OS

The following guidelines and proposed requirements were assumed:

- Orbiter would be in a circular, **45º inclined orbit**
- Mars Ascent Vehicle (MAV) would have the capability to launch the OS to an altitude between **400 – 600 km** with an accuracy of **+/-50 km**
- Launch shall occur between **9am and 3pm local solar time (LST)**, due to thermal constraints on the MAV
- The Orbiter shall be available (i.e., clear LOS) for **critical event telemetry coverage** during MAV launch through OS separation
- The Orbiter shall provide at least **4 opportunities to launch over a 7-day period** which would also satisfy the previous two requirements
- Primary method to detect and rendezvous with OS: **optical navigation**
- Optical telescope would be limited to **searching in the forward, down-track direction**

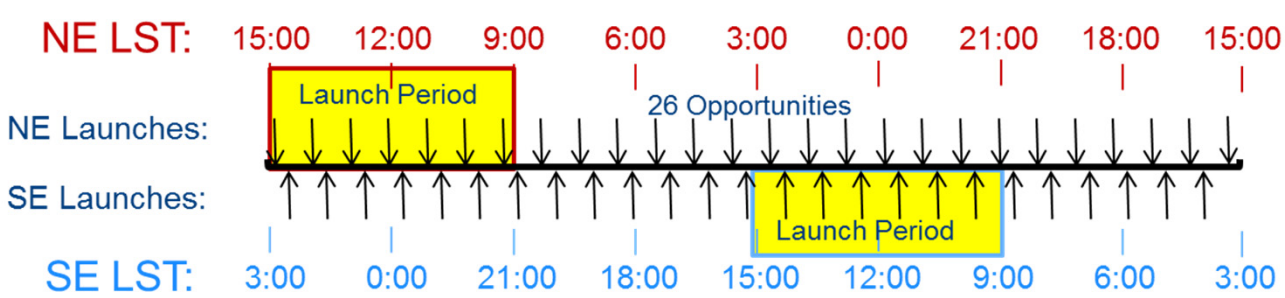
Nominal Launch Geometry



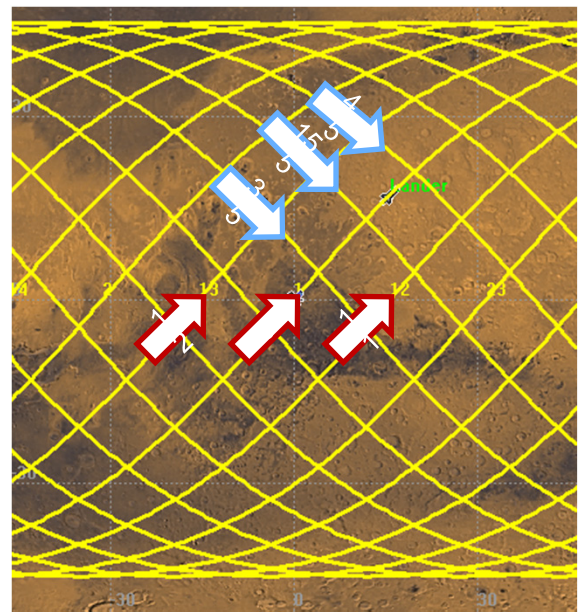
Providing Launch Opportunities

A **ground-track repeat (GTR) orbit** would satisfy the requirements for multiple daytime launch opportunities with suitable geometries

- Multiple GTRs were identified between 400 – 600 km
- Attractive orbits exist for a 1-sol repeat at 456 km and a **2-sol repeat at 572 km** (with the latter selected for this study)
- Orbits at these altitudes regress ~30 in LST per sol → **~50 sol solar cycle**
- Two daytime launch periods exist per cycle – one for NE launches one for SE



51.8 sol solar cycle



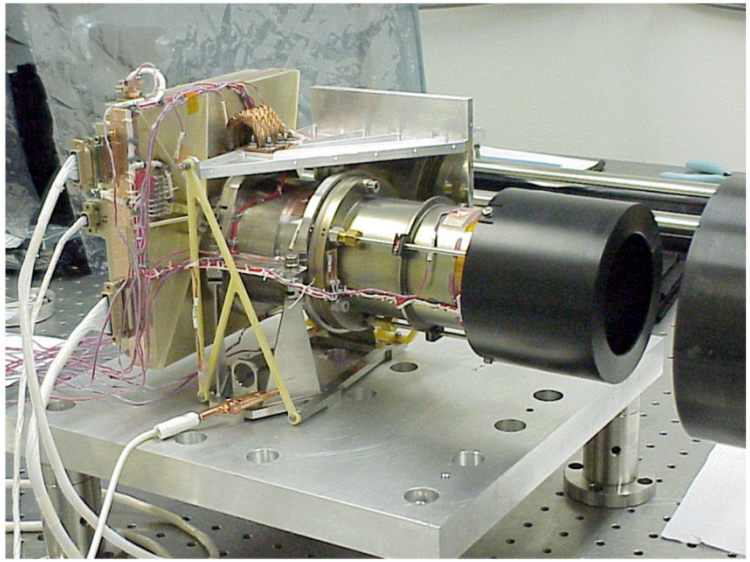
Estimating OS Optical Detectability

SNR = [Camera Properties]*[OS Properties]*[Orbiter-OS-Sun Geometry]/[Noise]

- Camera based on MRO's ONC, but with 5º FOV (instead of 1.4º)
  - Estimated properties: aperture, efficiency, *effective* exposure
- OS Properties: 16 cm diameter white sphere, albedo 0.5, non-specular reflection
- System noise – assumed constant
- Geometric inputs:

Simulated

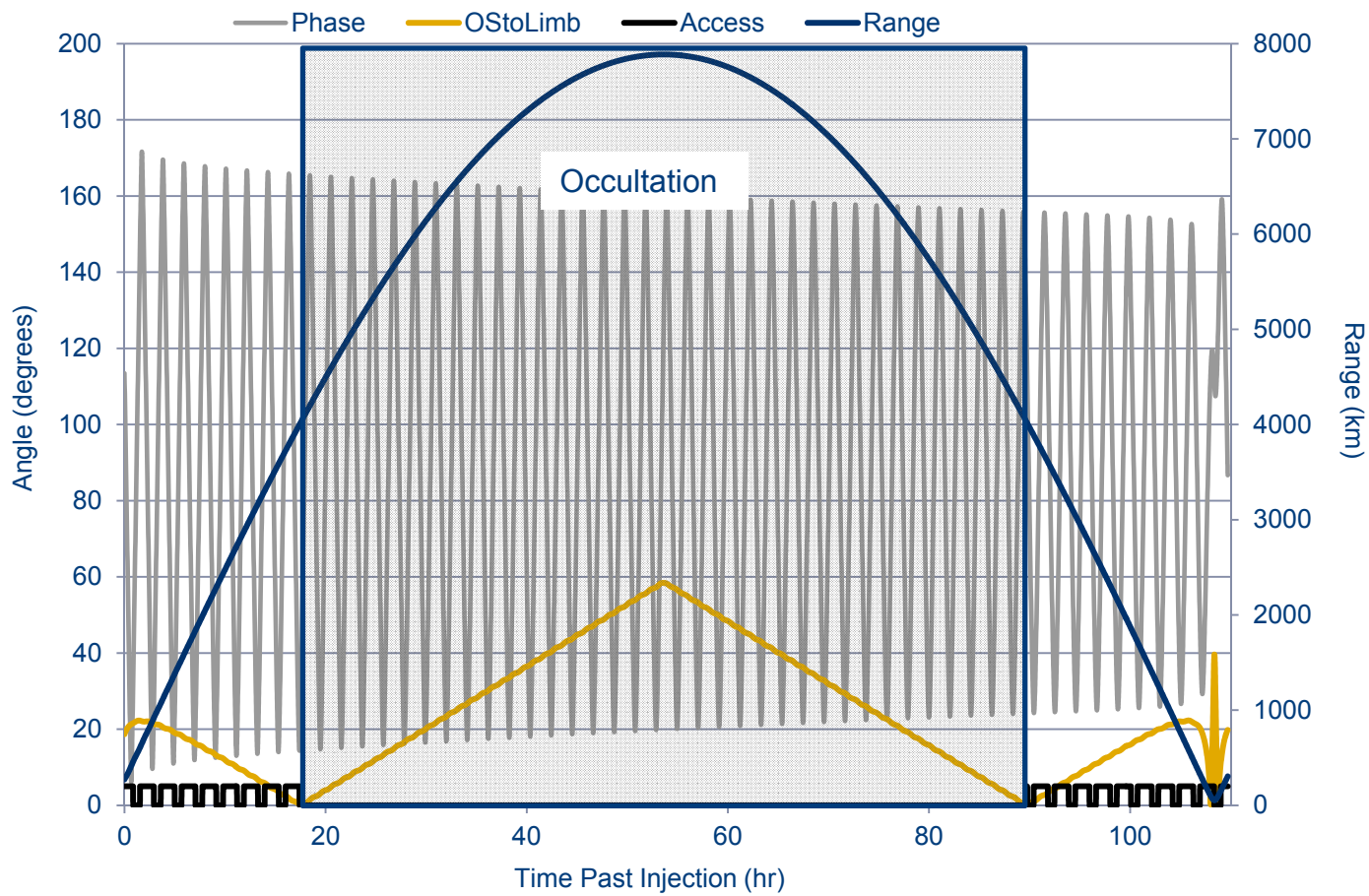
  - **Orbiter-OS Range** – $1/r^2$ law
  - **Sun-OS-Orbiter phase angle** – Phase function = $10^{-0.01*\text{phase(deg)}}$
  - **OS in solar eclipse** - <45 min./orbit
  - **OS to Mars limb angle** - 5º exclusion
  - **OS occultation by Mars** – Orbiter-OS LOS blocked by Mars



Optical Navigation Camera (ONC) on MRO (NASA)

Varying Geometric Parameters – Nominal Case

Orbiter: 572 km
OS: 522 km



For OS @ 522 km (nominal)

- Synodic Period: 4.5 days
- Time to OS occultation: 17 hours
- Orbits to Occultation: 8

View from Proposed Orbiter

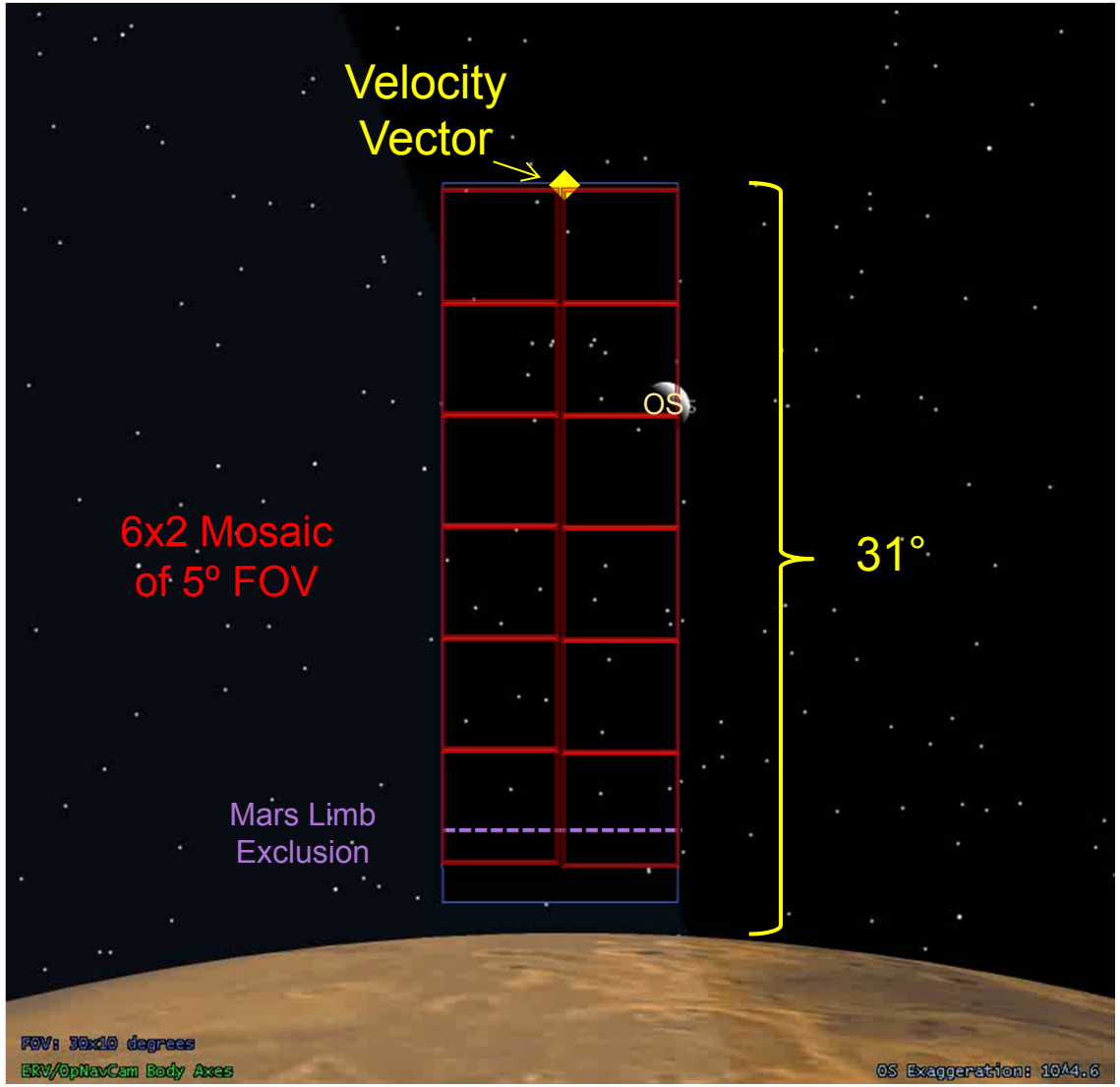
Orbiter: 572 km
OS: 522 km

(Nominal)

Initial Range: 540 km

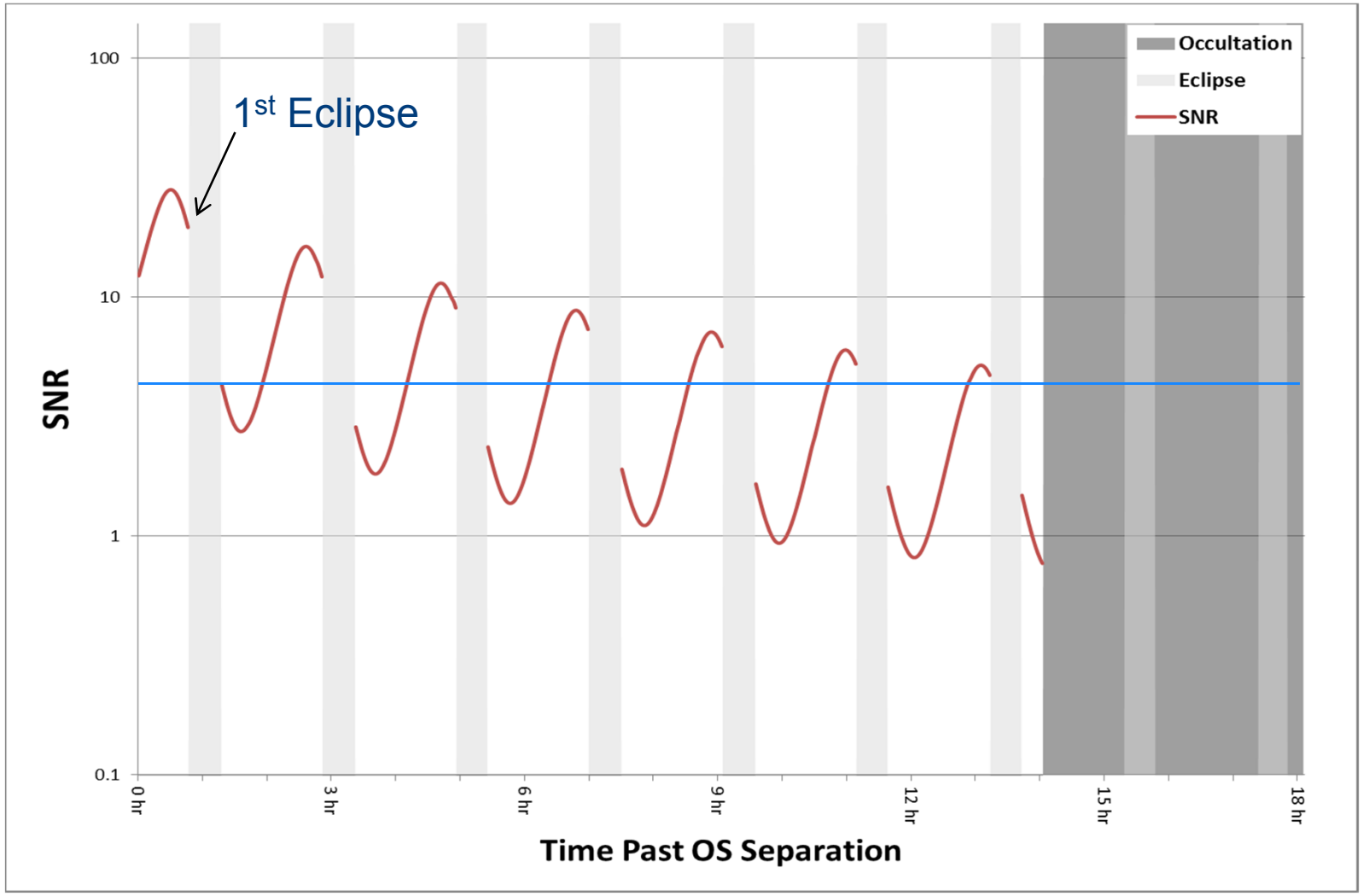
Recedes @ ~500 km/rev

Occultation @ 17 hrs



OS SIZE EXAGGERATED BY $10^{4.6}$
(to show illumination)

OpNav Function to 1st Occultation



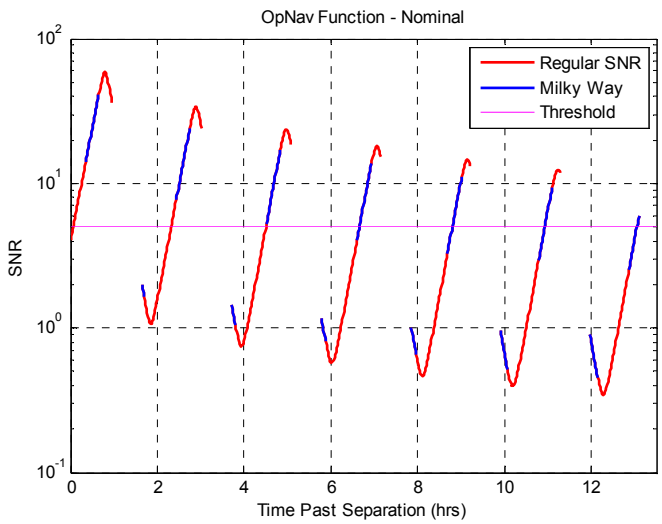
Parameters Affecting OS Detectability

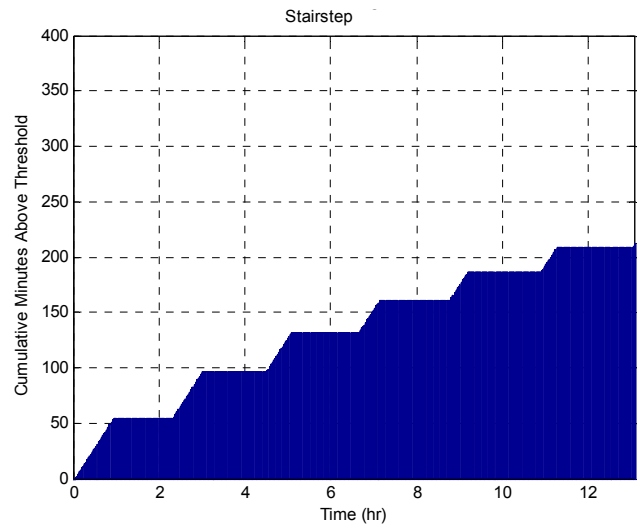
Parameter	Range	Nominal	Notes	Simulation
Orbiter Altitude	400 - 600 km	572 km	Repeating ground tracks	572 km
OS Altitude (relative to Orbiter)	-100 – 0 km	-50 km	Assumed circular	472, 522, 572 km
Initial Range	50 – 800 km	~540 km	Depends on elevation, delay, altitudes, etc.	Calculated
Launch Latitude	-15º to +30º	0 deg	Determined before mission	0°, 30°N
Launch Time	9am - 3pm LST	9am	Increases lit time on first pass	9am, 3pm
Season	150 - 275º	Ls = 230° (Mar. 1, 2026)	Affects eclipse duration	230°, 180°
Launch Azimuth	NE or SE	SE	Availability determined by ground track	SE, NE

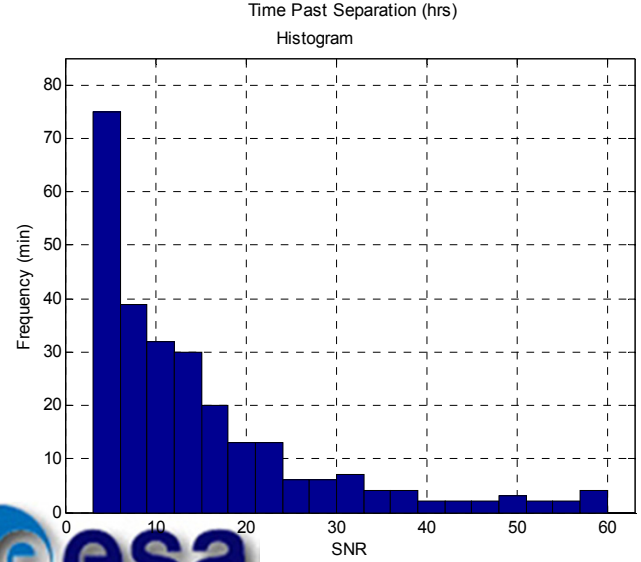
Total Cases Run: 48

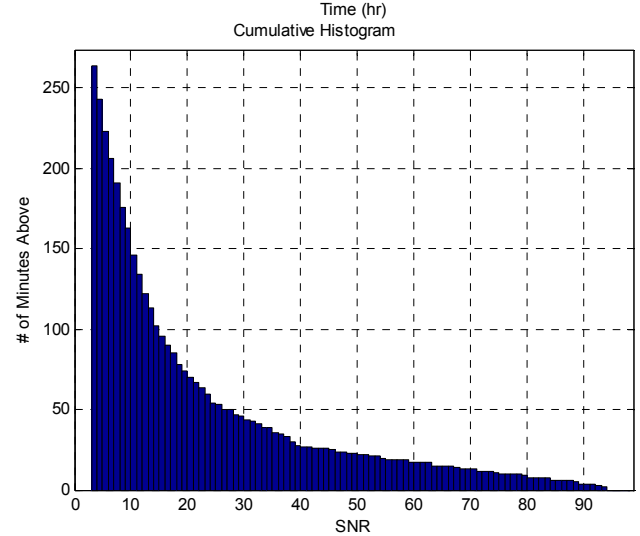
OpNav Function – Nominal Case

Orbiter Altitude	OS Altitude	Launch Latitude	Launch LST	Ls (Season)	Launch Azimuth	Initial Range	Node Bias	Obs. 1st Pass (m)	Obs. Total (m)
572	522	0	9am	232	SE	540	-0.87	54	212









Trade Study Results

Worst Case Mosaic Counts

Complete Mosaic = 3 minutes

SNR > 5

Worst case during nominal season

Case #	Orbiter Altitude	OS Altitude	Ls (Season)	Launch Latitude	Launch LST	Launch Azimuth	Initial Range	Obs. 1st Pass (m)	Obs. Total (m)	Mosaics 1st Pass	Mosaics Total
16	572	472	180	0	3pm	SE	596	30	94	10	30
8	572	522	180	0	3pm	SE	539	32	221	10	71
12	572	472	180	30	3pm	SE	596	36	98	12	31
4	572	522	180	30	3pm	SE	539	38	200	12	64
15	572	472	232	0	3pm	SE	596	39	105	13	33
7	572	522	232	0	3pm	SE	539	41	234	13	75
13	572	472	232	0	9am	SE	596	49	101	16	32
10	572	472	180	30	9am	SE	596	52	107	17	34
9	572	472	232	30	9am	SE	596	53	108	17	34
14	572	472	180	0	9am	SE	596	54	111	18	35
11	572	472	232	30	3pm	SE	596	54	98	18	31
6	572	522	180	0	9am	SE	539	56	218	18	70
2	572	522	180	30	9am	SE	539	55	201	18	64
5	572	522	232	0	9am	SE	539	54	212	18	68
1	572	522	232	30	9am	SE	539	56	205	18	66

Selecting SE launch generally leads to better counts

OS achieved altitude drives total observations

Conclusions

- OS altitude → recession rate dictates total observations
  - Worst case @ 472 km, 30 observations in 4 orbits (~8 hours)
- Orientation of orbital plane determines eclipse duration
- Key metrics for orbit determination
  - Observations before 1st eclipse
    - 20 – 60 minutes, depending on launch LST, latitude, azimuth
    - No eclipse region for select orbits near solstices
  - Observations before 1st occultation (LOS occulted by Mars)
    - 17 hours nominally, 8 hours in lowest case, →infinite for highest case
- "Lost OS" search strategy likely if not detected before occultation
- Sufficient observations for OD even in worst case w/ SNR = 5