MARS TEMPORAL OBSERVING REQUIREMENTS AND CONSTELLATION ARCHITECTURE. J. N. Head[1] and V. J. Bray[2], [1]Raytheon Missile Systems, 1151 E Hermans Road, Tucson, AZ 85734, james.n.head@raytheon.com, [2] Lunar and Planetary Laboratory, University of Arizona, 1541 E. University Dr., Tucson, AZ 85721.

Introduction: With Mars orbital reconnaissance entering maturity it is well to plan missions *ab initio* to detect and monitor temporal phenomena of interest. Recent advances in small satellite technical maturation, to include cubesats, brings persistent, repeatable, high cadence monitoring into feasibility. Our nascent capability to extend the earth monitoring regime to Mars means we will soon send to the Red Planet not satellites, but constellations, constellations working in concert to address science problems now studied in an *ad hoc* fashion aggregating data from Mariner IV to MRO *e.g.* [1,2]. We have taken a first step in coupling draft Mars temporal observation requirements with small satellite constellation design to explore via numerical calculation the potential for low mass, volume, and cost satellites to enable the next phase of Mars exploration. We assess initial mission architectures and report insights obtained for more comprehensive study.

Cubesats down to 1U size (10 cm by 10 cm by 10 cm) have been demonstrated in low earth orbit for years. The InSIGHT mission, due for launch in May 2018, will send two cubesats to Mars in addition to the lander [3]. Mars Cube One (MarCO) if successful will push deep space cubesat technology to TRL 9.

Assuming it will soon be feasible to send constellations of 10s of cubesats or smallsats to Mars, what are the temporal observing requirements for phenomena of interest? How are they different at different latitudes? How many satellites are necessary to meet observing requirements? More critically, how many orbit planes would be required? Orbit plane change maneuvers are notoriously expense in fuel; minimizing the number of orbit planes is highly desirable.

Method: We tackled this question in two parts: the science requirements and the constellation options that could meet those requirements. First, one of us developed a list of phenomena of interest for dedicated monitoring, along with estimates of the desired revisit time for each, setting aside as much as possible our preconceptions about what Mars missions have done in the past, *i.e.*, recognizing that a MarCO success would be a significant breakthrough. Listed in Table 1, the requirements are based on years of experience as a HiRISE targeting specialist, yet we recognize they represent a starting point for a conversation about sustained monitoring of Mars.

Second, the other of us devised and evaluated various constellations, assuming cubesats would support the needed sensor suite pointing to any object within 30° of nadir, a heuristic to assure limited atmospheric impact on sensor resolution. Our focus here is the total number of satellites, number of orbit planes, altitude, and inclination that would be required to monitor phenomena at latitudes from 0° to 90°. A numerical study of satellite constellations was conducted varying these parameters. The simulation determines when the satellite can observe any particular point on the surface and tracks the time since the last observing window (gap time). The simulation calculates mean and maximum gap time in the observing system as a function of latitude. We currently can investigate a single orbital inclination at a time. This simulation is instantiated in a Matlab script which generates a 3D view of the constellation and planet, a gap histogram, orbital coverage plots, and a statistical distribution of the gap time characterizing the probability of a given observational gap time. The gap time is calculated for all latitudes observable by the satellite (determined by orbital inclination) for an arbitrary longitude.

Features of Interest	Latitude	Inclination
Avalanches	83 - 86 N	86
Polar Pits	80 - 86 N	86
South Polar Geysers	>80 S	85
North polar dark sand flows on frosty dunes	>72 N	75
Dune Gullies	40 - 60 S	62
New Impacts	20 S - 55 N	57
Active Gullies	30 - 55 S	57
Reccuring Slope Lineae	30 - 50 S	52
Dunes	20 N - 50 S	52
Dust Devils	29.5 - 35 N	37
Most stressing revisit interval:		
Hourly	Daily	Monthly

Table 1. Features of Interest arranged by latitude. Yellow indicates the most stressing cadence, blue the least.

Results: As expected the simulation shows minimum gap times (fast observing cadence) at latitudes similar to the orbital inclination, where the spacecraft velocity vector is momentarily parallel to the object of interest's motion on the Martian surface. Intermediate latitudes suffer a reduced observing cadence in consequence (Figure 1), negatively impacting stressing mid-latitude observing cadence requirements *cf*. Table 1. Figure 2 shows a coverage map with 6 orbital planes at 85° with 2 satellites per orbit (12 satellites total). Gap times range from 1 to 3 hours, depending on latitude (Figure 3). Figures 4 shows the results of twelve satellites arranged in two orbital planes oriented at 30° providing a maximum gap time of 12 hours. Orthgonal orbital planes reduce the maximum gap to 6 hours.

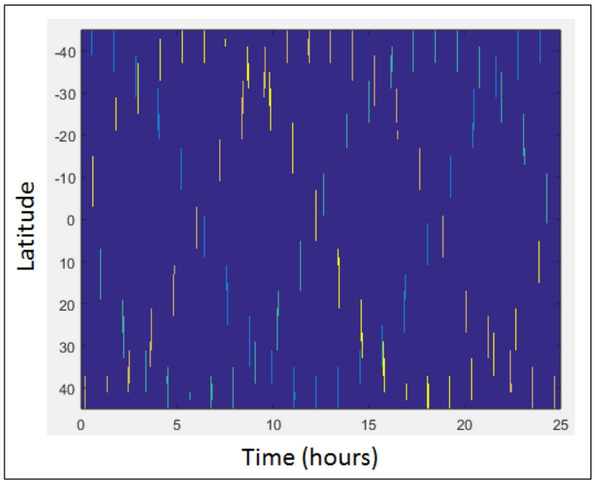

Figure 1. Revisit time map. Higher cadence at the latitude extrema is evident for 4 orbital planes with 2 satellites each. Orbit planes shown by color. Note the ordinate represents time, not longitude.

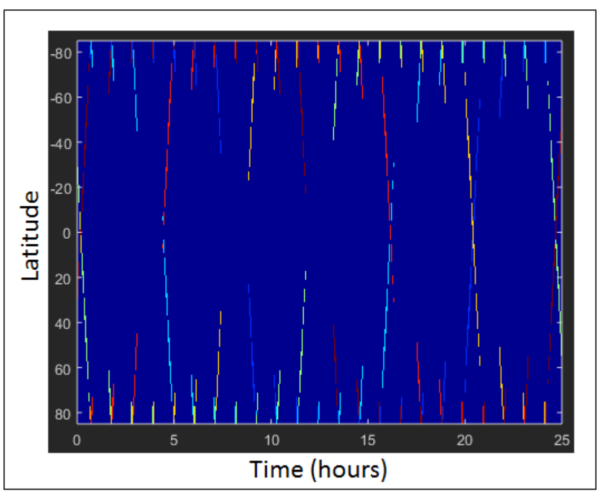

Figure 2. 6 planes of 2 satellites at 85° inclination illustrates difficulty of meeting observing requirements at all latitudes with single constellation.

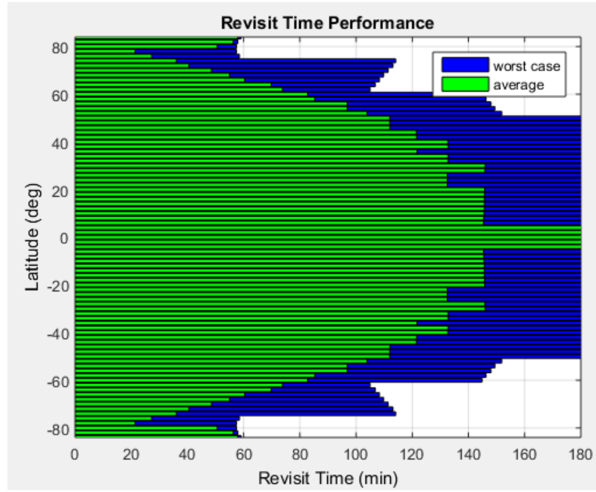

Figure 3. Average and extreme gap times for the 6 plane 2 satellite constellation above. Poleward of 40° average revisit times are consistent with draft requirements.

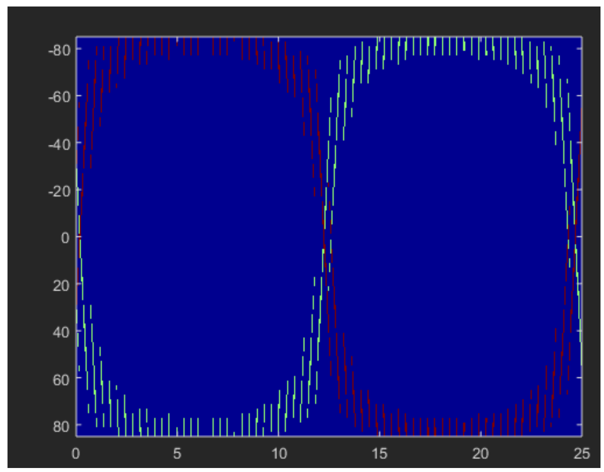

Figure 4. A 2 plane 12 satellite constellation, planes rotated 30° to each other, highlights the low latitude problem. Orthogonal planes reduce the maximum gap to ~6 hours.

Conclusions: A 6 orbit plane, 12 satellite constellation can broadly meet the observing requirements, though implying expensive plane change maneuvers or sequenced Mars orbit insertion events. Two orbit planes suffices if a 6 hour gap is acceptable. An intermediate case, a four orbit plane constellation provides hourly coverage at the latitude of interest.

References: [1] Zurek, R.W. and Surekar, S.E. (2007) *JGR*, *112* E05S01. [2] Sidropoulos, P. and Muller, J.-P (2005) *Planet. Sp. Sci.*, *117* 267-222. [3] Nelson, J. NASA-Jet Propulsion Laboratory, https://www.jpl.nasa.gov/cubesat/missions/marco.php, accessed 7 Jan 2018.