MARS AEROSOL TRACKER (MAT): AN AREOSTATIONARY CUBESAT TO MONITOR DUST STORMS AND WATER ICE CLOUDS. L. Montabone[1], M. VanWoerkom[2], B. Cantor[3], M. J. Wolff[1], M. Capderou[4], F. Forget[4], and M. D. Smith[5]. [1]Space Science Institute, Boulder, CO, USA (lmontabone@spacescience.org), [2]ExoTerra Resource LLC, Littleton, CO, USA, [3]Malin Space Science Systems, San Diego, CA, USA, [4]Laboratoire de Météorologie Dynamique (CNRS/ENS/IPSL), Paris, France, [5]NASA Goddard Space Flight Center, Greenbelt, MD, USA.

Introduction: The spatial distribution and temporal evolution of dust and water ice aerosols are essential observables for any fundamental or applied study related to the atmosphere of Mars, including weather monitoring for robotic and possible future human exploration missions.

The dust cycle –which dust storms are the most remarkable manifestation of- is considered to be the key process controlling the variability of the Martian atmospheric circulation at inter-annual and seasonal time scales, as well as the weather variability at much shorter time scales [1, 2, 3, 4, 5, 6]. It has also been demonstrated that the radiative effects of the presence of water ice clouds are very important in understanding the details of the atmospheric thermal and dynamical structures [7, 8, 9, 10, 11, 12].

Studying the dynamics of large-scale dust storms (i.e. their onset, transport, and decay) and water ice clouds (i.e. their formation, evolution, and dissipation) in detail requires both continuous and synoptic monitoring[1] of Martian aerosols. The key factor to achieve that is the choice of the satellite orbit, i.e. using a spacecraft in Mars-synchronous (areosynchronous) orbit, which can additionally be circular and equatorial (i.e. Mars-stationary or areostationary, see e.g. [13]).

None of the satellites already in orbit around Mars or currently planned has these orbital characteristics. Polar Sun-synchronous orbits ensure (asynoptic) global coverage –mostly for mapping surface features and properties- but prevent frequent atmospheric observations at the same locations. Nevertheless, Mars Global Surveyor and Mars Reconnaissance Orbiter have contributed to create multi-annual dust and water ice climatologies [14, 15, 16]. Quasi-polar eccentric orbits (e.g. MAVEN or ESA' Mars Express) provide some coverage at different local times and synoptic views of the Martian disk near apoapsis, but they still cannot achieve continuous monitoring of short time scale meteorological phenomena at fixed locations. The planned Emirates Mars Mission is the only spacecraft that, with its orbit, could approach the unique coverage offered by a true areosynchronous or areostationary satellite.

Mars Aerosol Tracker (MAT): We have elaborated a baseline mission concept to put a 12U, 24 kg CubeSat in an areostationary orbit around Mars – 17,031.5 km altitude above the equator. The planned areostationary orbit would be the first of its kind, offering the unequaled possibility to obtain a novel set of frequent observations over a region of the planet that can extend up to 80° away from the sub-spacecraft point (although the portion of the disk useful for scientific purposes might be limited to about 60° away).

The CubeSat (designed by "ExoTerra Resource LLC") uses a solar electric propulsion system based on micro Hall-effect thrusters that allow it to reach, optimize and maintain its orbit, dramatically improving its lifetime and control. The propellant is either gaseous xenon (baseline) or solid iodine. The power source is guaranteed by deployable, flexible, high specific power (160 W/kg) solar arrays designed to meet the power needs of the Hall-effect thruster and payload. Communication is provided by the JPL IRIS Deep Space transponder in association with either a patch (baseline) or KaPDA antenna, in the X-band (baseline) or Ka-band.

The payload (provided by "Malin Space Science Systems") is comprised of one off-the-shelf visible camera (fixed-focus, narrow-angle lens, 3 MP resolution), and two thermal infrared cameras (fixed-focus, narrow-angle lens, 0.3 MP resolution). The infrared cameras are equipped with filter wheels for selecting multiple spectral ranges, and the uncooled microbolometer image sensors are responsive out to 20 μm to include CO_2, dust, and water ice absorption lines.

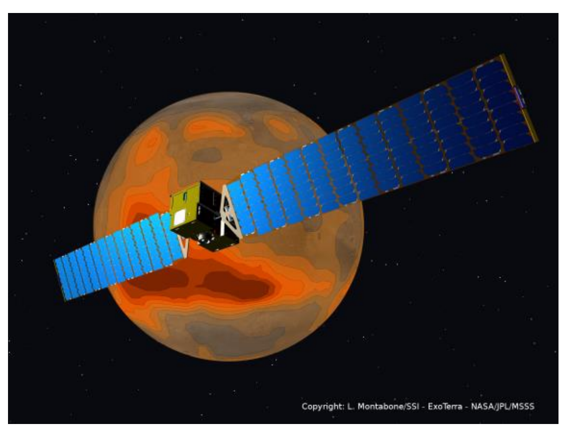

Figure 1: Artist view of MAT overlooking a regional dust storm (darker tones = higher dust optical depth)

---

[1] By *continuous monitoring* we mean obtaining data at a high rate for a long time. By *synoptic monitoring* we mean obtaining data simultaneously over a large area.

Science Objectives: The overall goal of this mission concept is to track[2] Martian dust storms and water ice clouds, helping to address the scientific questions: *What are the processes controlling the dynamics of dust and water ice aerosols, and promoting the evolution of regional dust storms into planetary-encircling storms?* This goal is aligned with NASA's, MEPAG's, and the Decadal Survey's goals. More specifically, we propose a mission with the following objectives:

- Continuously monitor a large, fixed area on Mars where dust storms are likely to occur and water ice clouds are likely to form.
- Observe the onset, transport, and decay of regional dust storms as well as the formation, evolution, and dissipation of water ice clouds within the monitored area at all local times.
- Detect changes in surface properties (e.g. albedo, thermal inertia) over the observed area, particularly after the occurrence of dust storms.

Science Products: The objectives of the mission would be fulfilled using the following products:

- High-resolution (up to 4.5 km/pixel at nadir), visible images during daytime.
- Mid-resolution (up to 60 km/pixel at nadir), 2D maps of column aerosol optical depth at all local times (or at least during daytime).
- Mid-resolution, 2D maps of atmospheric temperature at a few vertical levels below 50 km.
- Data would be acquired with high sampling rate (up to ½ h) for extended periods, simultaneously over the monitored, fixed region.

Mission Overview: The implementation of the baseline mission scenario involves ridesharing on a primary orbiter mission directed to Mars, and deployment after the initial capture burn (operated by the mothership). This scenario, which limits the use of thrusters, allows for the lowest CubeSat mass and size.

Alternative studied scenarios include either ridesharing on a primary mission directed to Mars with deployment a few weeks ahead of Mars capture (operated independently from the mothership), or an independent journey to Mars all the way from Earth GTO. These two scenarios involve increase of mass and size of the spacecraft, up to about twice the baseline one.

In all three cases, the duration of the (primary) science mission at Mars is planned for one Martian year.

As for the final science orbit, we have also studied scenarios where the orbit is quasi-areostationary, allowing for a slow drift in longitude (e.g. 360° longitudinal drift during one Martian year –0.54 degrees/sol- by raising or lowering the orbit by ~20 km with respect to the nominal areostationary altitude) or a small excursion in latitude (e.g. up to 20° by increasing the inclination). Both cases present scientific advantages, while reducing the constraints imposed by areostationary station-keeping on propellant consumption.

Final Remarks: Flying a CubeSat-class scientific mission to Mars is challenging but highly beneficial.

Key challenges. Propulsion and communication are the two major challenges, particularly if one wants to design a completely standalone mission. Heat dissipation and radiation resilience are next big challenges for a packed spacecraft that needs to last at least 3 to 5 Earth years (including journey to Mars and primary science mission). Finally, pointing accuracy must be carefully designed to dissipate possible disturbances from moving/vibrating parts, and data pre-processing is deemed necessary to reduce data downlink.

Why flying a CubeSat for such a mission? There are general arguments in favor of using CubeSat-class spacecraft for deep space missions: CubeSats are reasonably cheap, they can be built quickly, they enable focused, higher-risk missions, and there could be more opportunities to launch. Arguments more specific to our proposed mission include: paving the way for areostationary satellites at Mars, possibly flying multiple CubeSats for complete longitudinal coverage (should the pioneer succeed), and demonstrating the potential of synoptic weather monitoring, e.g. coupling observations with data assimilation in numerical models.

References:

[1] Newman C. E. et al. (2002) JGR, 107, 5124. [2] Montabone L. et al. (2005) *Adv. in Space Res*., 36, 2146-2155. [3] Lewis S. R. and Barker P. R. (2005) *Adv. in Space Res.*, 36, 2162-2168. [4] Wilson R. J. et al. (2008) *4th MAMO workshop*, Abstract # 9023. [5] Guzewich S.D. et al. (2014) *JGR*, 119, 506-519. [6] Guzewich S.D. et al. (2016) *Icarus* 278, 100-118. [7] Wilson R. J. et al. (2007) *GRL*, 34, L02710. [8] Wilson R. J. et al. (2008) *GRL*, 35, L07202. [9] Steele L.J. et al. (2014) *GRL*, 41, 4471-4478. [10] Wilson R. J. and Guzewich S. D. (2014) *GRL*, 41, 3375–3381. [11] Kahre M.A. et al. (2015) *Icarus*, 260, 477-480. [12] Mulholland D. P. (2016) *Icarus* 264, 465-477. [13] Edwards C.D. et al. (2007) *Acta Astronautica*, 48, 661–668. [14] Montabone L. et al. (2015) *Icarus*, 251, 65-95. [15] Hale A. S. et al. (2011) *JGR*, 116, E04004. [16] Wolff M. J. et al. (2014) *5th MAMO workshop*, Abstract # 2302.

Acknowledgments: The authors acknowledge funding for developing this mission concept from NASA Planetary Science Deep Space SmallSat Studies (PSDS3) program; Grant Number: 80NSSC17K0303.

[2] We refer to *aerosol tracking* as the process of following the evolution of the aerosol spatial distribution.