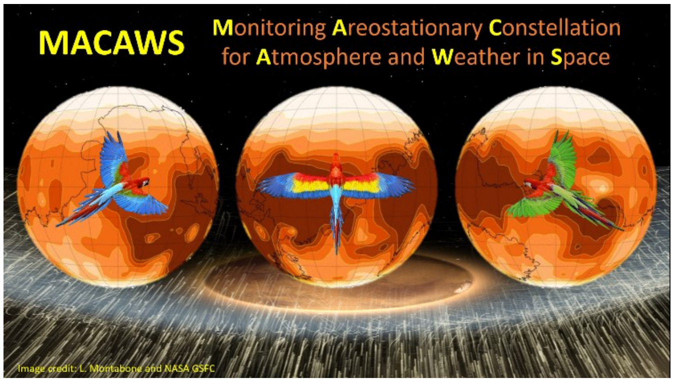

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Introduction

Past and present Mars orbiters have been able to provide an increasingly detailed picture of Mars' surface and atmosphere, up to the magnetosphere, focusing mostly on high-resolution but limited-area observations from orbits that are fixed or slowly varying in local time. However, observations by any single spacecraft are more or less spatially and temporally discontinuous and asynchronous (see Figure 1 and coresponding animation). Mars' atmospheric weather phenomena (dust storms and clouds in particular) as well as the space weather environment (solar wind and radiation in particular) are very dynamic, with rapid temporal variability (from hourly down to sub-hourly scale) and variable spatial extension (from local up to planetary scale). Mars atmospheric and space environments pose hazards to current robotic and future human exploration missions, as well. Two such hazards come from extreme solar and dust storm events, such as the September 2017 intense solar flare and fast coronal mass ejection, or the June 2018 extreme, planet-encircling dust event. The former heated up the Martian upper atmosphere rapidly, sparked a global aurora, and increased the radiation levels on the surface, while the latter lasted for a few months and caused the termination of NASA's solar-powered Opportunity rover mission. In both cases, if there had been a satellite constellation in place in an optimal orbit at both times, one could have monitored the dynamics of these events continuously and simultaneously around the planet. While this is a desirable objective for scientific knowledge, it is a requirement for future human missions. Overall, it is a key exploratory science goal.

Therefore, we have developed the "Monitoring Areostationary Constellation for Atmosphere and Weather in Space" (MACAWS) mission concept. The goal is to be a low-cost orbital constellation mission to continuously and simultaneously monitor atmospheric conditions in the lower atmosphere and space weather in the upstream solar wind. The planned outcomes are 1) an e-fold increase in the scientific understanding of the dynamics of weather events, and 2) the development of an operational monitoring system from orbit, as a precursor to a forecasting system to reduce risks for future robotic and human missions around and at the surface of Mars.

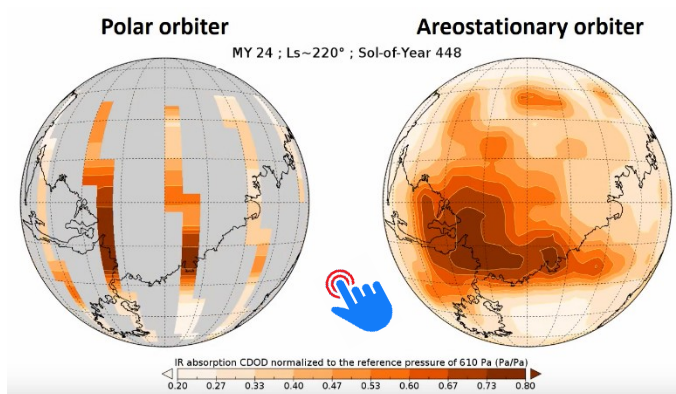

Figure 1: A regional dust storm observed by Mars Global Surveyor reconstructed as seen by an areostationary orbiter at ~17,000 km

NASA has previously funded two mission concept studies with platforms in areostationary orbit (Mars-synchronous, equatorial, circular at 17,031.5 km altitude): the Mars Aerosol Tracker (MAT), part of the Planetary Science Deep Space SmallSat Studies (PSDS3) program [1], and the Mars Orbiters for Surface-Atmosphere-Ionosphere Connections (MOSAIC), part of the Planetary Mission Concept Studies (PMCS) program [2]. MACAWS' emphasis on closing strategic knowledge gaps for Mars atmospheric science and space weather would broadly overlap with the objectives of MAT and MOSAIC. However, MACAWS is an evolution of MAT's objectives, which were centered on regional monitoring with a single areostationary satellite, while it represents a subset of the large and costly (~$3B) MOSAIC constellation, focusing on two out of MOSAIC's nine investigations: atmospheric diurnal behaviour and space weather. Platforms in areostationary orbit are ideally suited for these two investigations, as detailed in [3].

MACAWS concept was first introduced as a mission idea to ESA's Open Space Innovation Platform call "What's next? New space mission ideas and concepts" [4]. Other mission concepts with areostationary or areosynchronous components have been developed in parallel [5, 6]. MACAWS could fly as a standalone constellation or in combination with other satellite platforms (e.g., a low-altitude polar orbiter) to significantly increase the science return. We are currently evaluating the impact on the monitoring of the atmospheric weather when using different configurations of satellite platforms, using an Observing System Simulation Experiment (OSSE) approach [7].

High-level mission requirements

- Continuous and simultaneous coverage from orbit of the lower atmosphere at most locations on planet Mars as well as (for at least one satellite at any time) the space environment outside the Martian bow shock.
- Monitoring of meteorological variables in nadir viewing geometry. Dayside and nightside observations.
- Measurement of heliospheric/space weather conditions from a Sun-facing instrument deck.
- Manoeuvrability capability for sufficient station keeping to maintain position at areostationary orbit.
- Spacecraft slewing capability for scanning in at least one direction if required by atmospheric instruments (e.g. because of small FOV and/or lack of internal scanning mechanisms).
- See list of MACAWS investigations, measurements, and instrument requirements in Table 1, Slide 5 of the poster presentation linked to [8].

Mission architecture

- Constellation of three "ESPA-class" SmallSats (wet mass < 180 kg each) launched together as secondary payload on a piggyback mission to Mars or, alternatively, on a rideshare mission to Geostationary Transfer Orbit (GTO).
- Satellites reaching final areostationary orbit (equatorial, circular with semi-major axis of 20,428 km, and period of one Martian sidereal day) with 120° of longitudinal separation from each other. Alternative orbits such as areosynchronous (i.e. inclined, for additional coverage of the polar regions) or trans-areostationary (i.e. at slightly lower or higher altitude than areostationary, allowing longitudinal drift) could be considered.
- Direct-to-Earth communication link must be available to each member of the constellation to minimize risks. Cross-link must be available to each member of the constellation. Proximity link to ground assets (in the X-band, possibly using steered higher-gain antennas) is optional for communication and data relay, if required.
- Mission architecture would greatly benefit from the availability of a "tug" and/or dedicated data relay platform.

Costs and Timeline

We strive to define a constellation concept with costs (Phases A-F, excluding launch) capped to $250M.

This SmallSat constellation mission could be launched as soon as 2028 in order to be operative at Mars by 2030, if using solar electric propulsion (SEP) and autonomous navigation from GTO to Mars. With the use of SEP, launch dates are not rigidly confined to the standard 26-month ballistic transfer cycle. Launches may occur at almost any time, but the optimal arrival time still roughly follows the 2-year cycle.

The nominal mission at Mars is one Martian year, but two or more Martian years are highly desirable to study interannual variability linked to dust storms for atmospheric conditions and solar cycle for space weather.

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