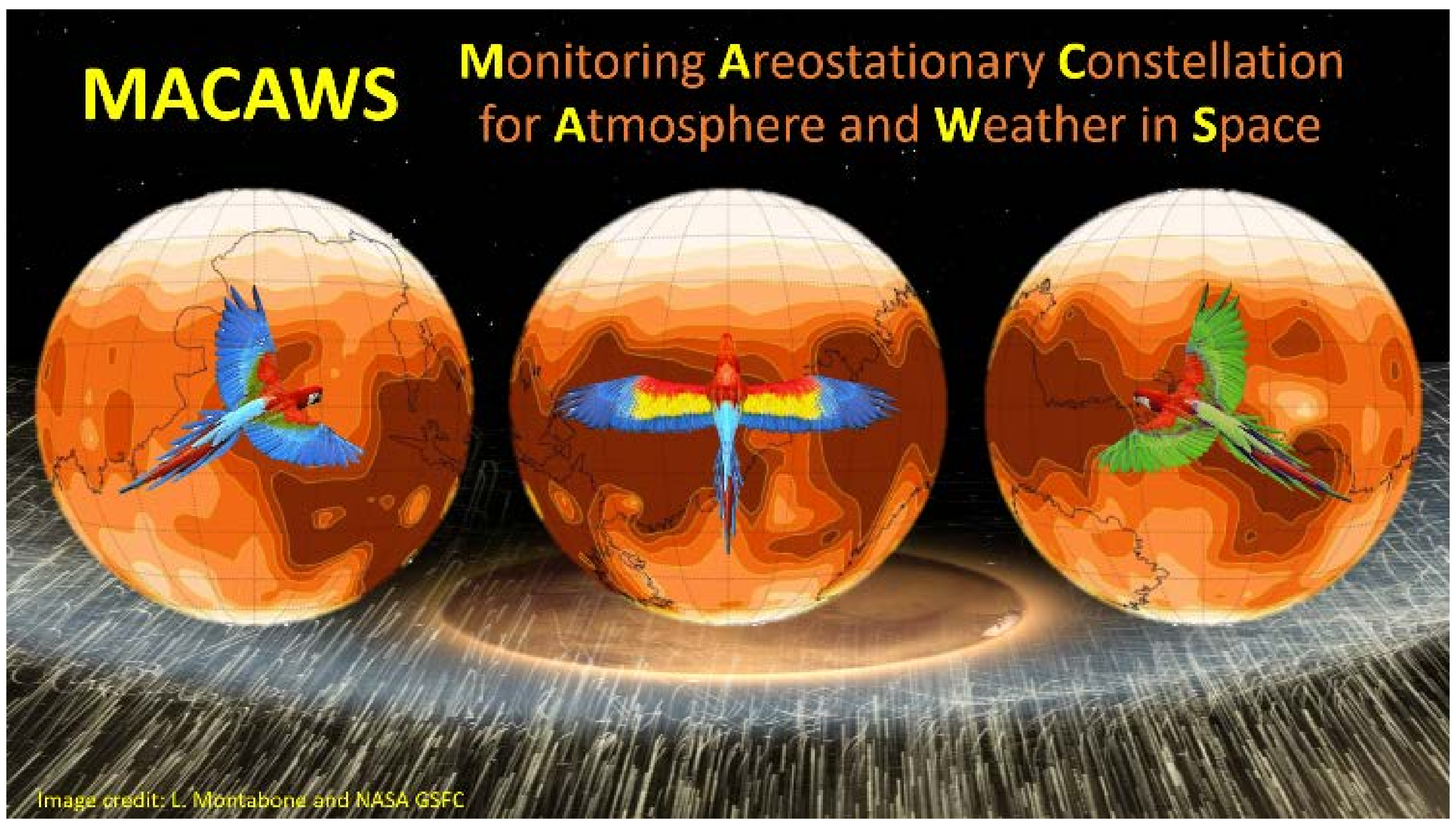

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Please, scan the QR code to access additional resources where you see the symbol:

## Synopsis

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). Observations by any single spacecraft are more or less spatially and temporally discontinuous and asynchronous (see Figure 1). We have developed the "Monitoring Areostationary Constellation for Atmosphere and Weather in Space" (MACAWS) concept 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 (see Figure 2).

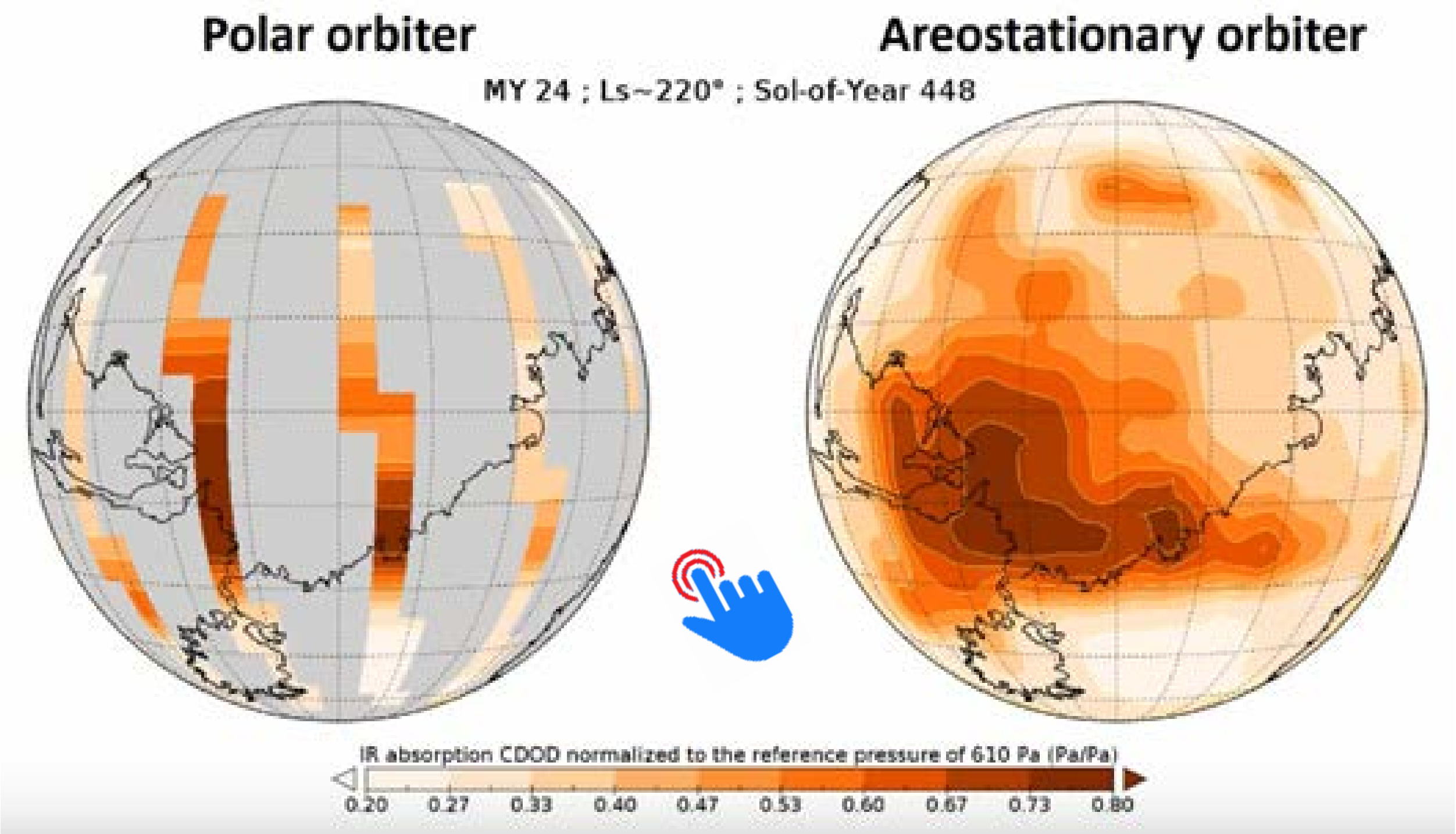


*Figure 1: A regional dust storm observed by Mars Global Surveyor reconstructed as seen by an areostationary orbiter at 17,031.5 km altitude. An areostationary satellite would orbit Mars in a circular and equatorial orbit with a semi-major axis of $a_s$= 20,428 km to be at rest with respect to the rotating Mars with a period of one Martian sidereal day (sol): P= 88,642.663 s*

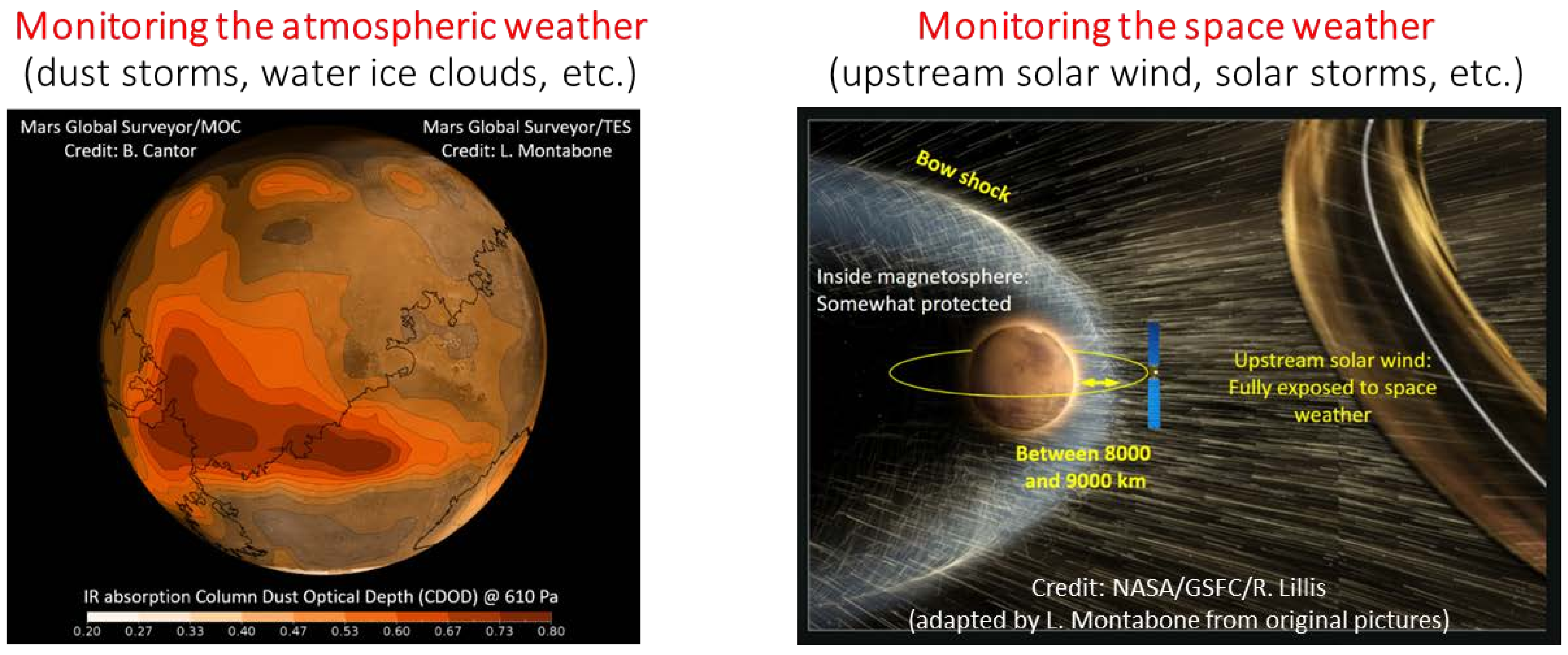
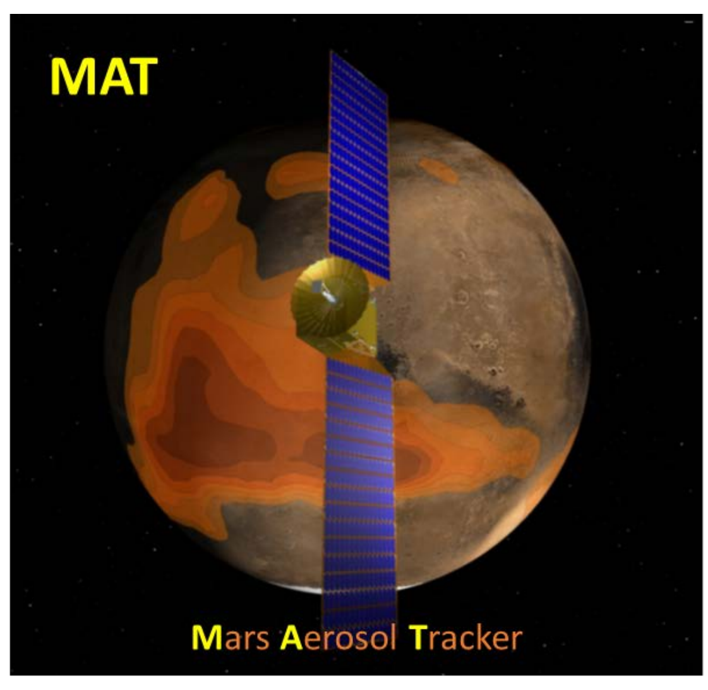
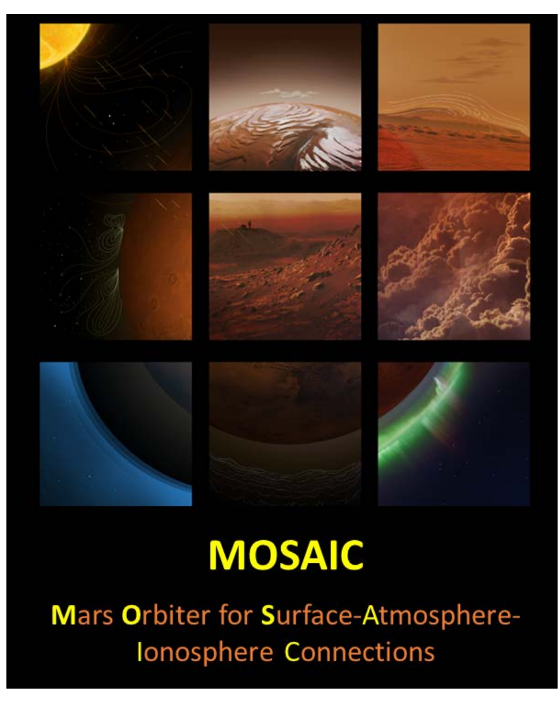


*Figure 2: MACAWS planned outcomes are 1) an e-fold increase in the scientific understanding of the dynamics of atmospheric and space weather events, and 2) the development of an operational monitoring system from orbit, as a precursor to a forecasting system to reduce risks for future robotic and human missions around and at the surface of Mars.*

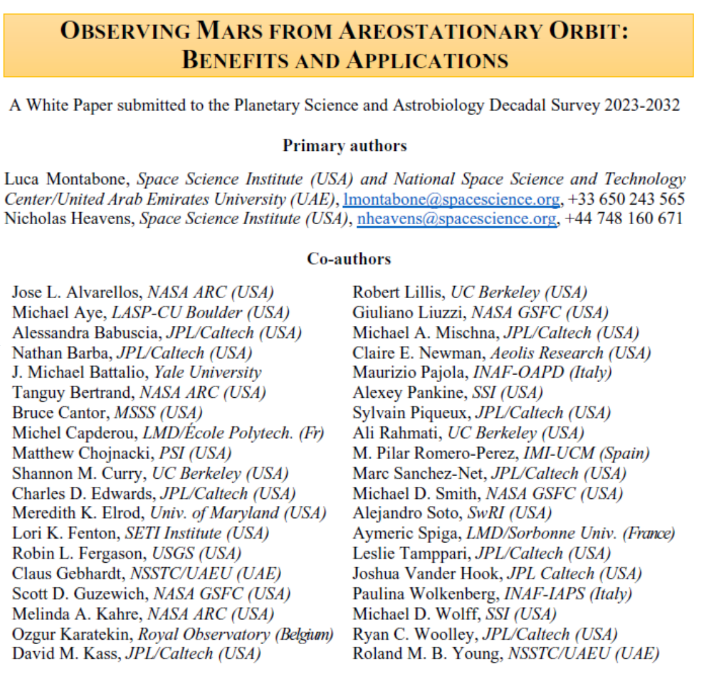
## How did we get to MACAWS?



**NASA PSDS3** 2017-2018



**NASA PMCS** 2019-2020



OBSERVING MARS FROM AREOSTATIONARY ORBIT:
BENEFITS AND APPLICATIONS

A White Paper submitted to the Planetary Science and Astrobiology Decadal Survey 2023-2032

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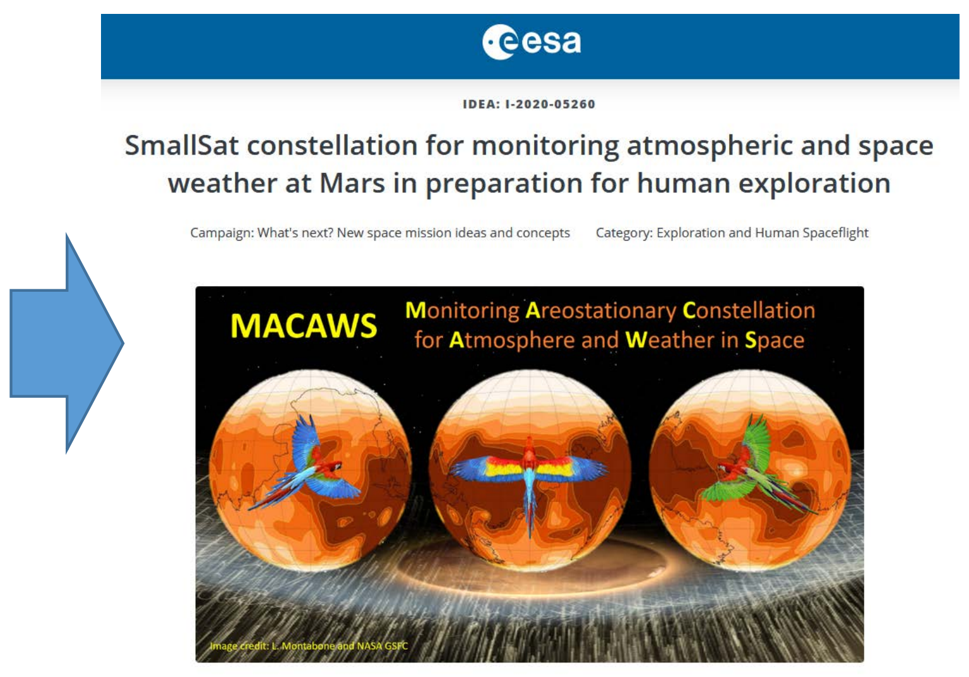
**Decadal Survey WP** 2020



IDEA: I-2020-05260

SmallSat constellation for monitoring atmospheric and space weather at Mars in preparation for human exploration

Campaign: What's next? New space mission ideas and concepts Category: Exploration and Human Spaceflight

**ESA OSIP Campaign** 2020

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.

## MACAWS in a nutshell

### 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 (Day/Night).
- Sun-facing instrument deck to measure heliospheric/space weather conditions
- Manoeuvrability capability for sufficient station keeping.
- Spacecraft slewing capability for scanning in at least one direction if required.

### Mission architecture

- Constellation of three "ESPA-class" SmallSats (wet mass < 180 kg each)
- Secondary payload on a piggyback mission to Mars or, alternatively, on a rideshare mission to Geostationary Transfer Orbit (GTO).
- Final areostationary orbit 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, allowing longitudinal drift) could be considered.
- Direct-to-Earth communication link 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, using steered higher-gain antennas) is optional for communication and data relay.

### Costs and Timeline

- Costs capped to $250M (Phases A-F, excluding launch) .
- Launch as soon as 2028 in order to be operative at Mars by 2030.
- Desired mission duration at Mars is two or more Martian years (1 MY nominal)

**TABLE 1: LIST OF MACAWS MEASUREMENTS**

| Investigation | Physical parameters | | | | | Observable quantities | | Instrument requirements | |
|---|---|---|---|---|---|---|---|---|---|
| | Description | Spatial resolution | Cadence | Range | Precision | Description | Energy / wavelength / frequency | Description | FOR or IFOV |
| Atmospheric weather | Extent of (dust/water ice) aerosol clouds | H ≤ 5 km | ≤ 30 min | 5 km to global | 5 km | Radiance | 400-750 nm (VIS RGB) | Visible camera | IFOV ≤ 0.3 mrad |
| | Duration of (dust/water ice) aerosol clouds | H ≤ 5 km | ≤ 30 min | Fraction of the hour to tens of sols | 30 min | Radiance | 400-750 nm (VIS RGB) | Visible camera | IFOV ≤ 0.3 mrad |
| | Horizontal wind components | H ≤ 5 km | ≤ 30 min | 0-200 m/s | 10 m/s | Displacement of (dust/water ice) cloud feature | 400-750 nm (VIS RGB) or starting from 200 nm (UV) | Visible or UV camera | IFOV ≤ 0.3 mrad |
| | Atmospheric temperature (5~45 km) | H ≤ 60 km ; V = 10 km | ≤ 30 min | 110-260 K | 1 K | Radiance | Around 15 µm (TIR) | Thermal IR spectrometer / radiometer | IFOV ≤ 3.5 mrad |
| | Surface temperature | H ≤ 60 km | ≤ 30 min | 130-320 K | 1 K | Radiance | Around 7.9 µm, or around 32 µm, or beyond 50 µm (TIR) | Thermal IR spectrometer / radiometer | IFOV ≤ 3.5 mrad |
| | Dust column optical depth | H ≤ 60 km | ≤ 30 min | 0 - 5 referenced to 1064 nm | 10-20% | Radiance | Around 9.3 µm (TIR), or a broadband signal in NIR, or at 220 nm (UV) | Thermal IR spectrometer / radiometer – Near-IR spectrometer – UV imager | IFOV ≤ 3.5 mrad |
| | Water ice column optical depth | H ≤ 60 km | ≤ 30 min | 0 - 5 referenced to 1064 nm | 10-20% | Radiance | Around 11.8 µm (TIR), or at 1254 nm or 1500 nm (NIR), or at 320 nm (UV) | Thermal IR spectrometer / radiometer – Near-IR spectrometer – UV imager | IFOV ≤ 3.5 mrad |
| | Carbon dioxide ice column optical depth | H ≤ 60 km | ≤ 30 min | 0 - 5 referenced to 1064 nm | 10-20% | Radiance | Around 22 µm (TIR), or at 1428 nm (NIR) | Thermal IR spectrometer / radiometer – Near-IR spectrometer | IFOV ≤ 3.5 mrad |
| | Water vapour column abundance [1] | H ≤ 60 km | ≤ 30 min | 5-400 pr-µm | 10-20% | Radiance | Around 41 µm (TIR) or near 2602 nm (NIR) | Thermal IR spectrometer / radiometer – Near-IR spectrometer | IFOV ≤ 3.5 mrad |
| | Surface pressure | H ≤ 60 km | ≤ 30 min | 150-1500 Pa | 5-10 Pa | Radiance factor (I/F) | Around 2007 nm (NIR) | Near-IR spectrometer | IFOV ≤ 3.5 mrad |
| Space weather | Solar EUV spectral irradiance | N/A | 16 s | 1E-6 to 3E-2 W/m2/nm | 15% (dI/I) | Same as physical parameter | 10-20 nm, 17-22 nm, 121.6 nm | Solar EUV monitor | -2° to +2°, centered on Sun |
| | Interplanetary magnetic field vector | N/A | 16 s | ~1 to 3000 nT | 0.3 nT or 10% | Same as physical parameter | N/A | Fluxgate mag | N/A |
| | Ion flux | N/A | 16 s | 1E7 to 1E10 eV/(cm2-s-st-eV) | 10% | Same as physical parameter | ~50 eV to 10 keV | Ion energy/angle analyzer | FOV: Cone of half angle 30° centered on Sun |
| | Superthermal electron flux | N/A | 16 s | 1E4 to 1E10 eV/(cm2-s-st-eV) | 10% | Same as physical parameter | ~1 eV to 10 keV | Electron energy/angle analyzer | FOV: 360° x 120° |
| | Energetic ions/electrons flux | N/A | 20 min | 1E1 to 1E6 eV/(cm2-s-st-eV) | 10% | Same as physical parameter | 50 keV to 5 MeV | Energetic ion/electron detector | FOV:40 x 40 deg centered on +/-Parker spiral dirs |

**Mission architecture would greatly benefit from the availability of a "tug" and/or dedicated data relay platform!**