Mars Aerosol Tracker (MAT):
An Areostationary SmallSat
to Monitor the Martian Weather

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The Martian Weather

Water ice clouds

Dust storms

Atmospheric circulation

Mars Global Surveyor/Mars Orbiter Camera - Credit: NASA/JPL/MSSS
The Martian Weather

Dust devils

Local and regional dust storms

Global-scale dust events

June 10, 2001

July 31, 2001
The case for MAT

- Dust and water ice aerosols affect the Martian weather:
  - They are both radiatively active.

- There is need for **continuous and simultaneous** aerosol monitoring to:
  - Understand the interaction between aerosols and circulation;
  - Enable weather forecasting (e.g. evolution of dust storms);
  - Support robotic AND future human exploration.

- The key factor is the orbit! An areostationary orbiter is ideal to:
  - Observe a large, fixed region (at least 60° from nadir, up to 80°);
  - Provide high sampling rate (fractions of the hour);
  - Monitor throughout the daily and seasonal cycles;

- Therefore it is well suited to:
  - Monitor rapidly evolving meteorological phenomena;
  - Derive surface properties (e.g. thermal inertia, albedo) accounting for the variability of the aerosol contribution.
A regional dust storm from areostationary vs polar orbit

View from about 17,000 km above the equator

**Polar orbiter**
MY 24 ; Ls~220° ; Sol-of-Year 438

**Areostationary orbiter**

Mars Global Surveyor
Thermal Emission Spectrometer
Gridded Infrared Column Dust Optical Depth

Data from:
Montabone et al., Icarus, 2015
Mission objectives

To provide answers to the scientific questions:

What are the processes controlling the dynamics of dust and water ice clouds, and promoting the evolution of regional dust storms into global-scale dust events?

What is the impact of the aerosol variability on the surface temperature and on the derivation of surface properties such as thermal inertia and albedo?

We plan to place and operate MAT in areostationary orbit in order to:

- Monitor at high sampling rate a large, fixed portion of the planet where dust storms and water ice clouds are likely to occur, using visible and infrared wavelengths;
- Observe the temporal evolution of dust storms and water ice clouds in the monitored area throughout the diurnal cycle;
- Derive surface properties accounting for the aerosol contribution (e.g. thermal inertia and albedo when large dust storms occur).
The 45 kg SmallSat with electric propulsion

IRIS transponder + KaPDA antenna

Xenon gas tank

“Halo” 3rd Generation Prototype

Solar Array Deployment
We analyzed 3 mission scenarios

**Case 1**
Rideshare on an orbiter mission to Mars, release after Mars capture, descent into areostationary orbit
*35 kg spacecraft wet mass*

**Case 2 (current baseline)**
Rideshare on a mission to Mars, autonomous Mars capture, descent into areostationary orbit
*45 kg spacecraft wet mass*

**Case 3**
Being released in GTO, autonomous navigation to Mars, autonomous Mars capture, descent into areostationary orbit
*64 kg spacecraft wet mass*
Trajectories to Mars

ΔV capabilities and range estimates

<table>
<thead>
<tr>
<th>Case</th>
<th>Fuel Allocated (kg of Xe)</th>
<th>Delta V (m/s)</th>
<th>Range Estimate (m/s)</th>
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<tbody>
<tr>
<td>1</td>
<td>4.00</td>
<td>1619</td>
<td>850</td>
</tr>
<tr>
<td>2</td>
<td>10.62</td>
<td>3538</td>
<td>1543</td>
</tr>
<tr>
<td>3</td>
<td>25.00</td>
<td>7283</td>
<td>6543</td>
</tr>
</tbody>
</table>

Low High Maneuver

| 50   | 200 | Orbit Maintenance |
| 800  | 2000| Spiral to Operational |
| 693  | 2100| Mars capture |
| 3000 | 3900| GTO to escape |
| 2000 | 3440| escape to Mars soi |
**Payload**

- **One visible camera**: Off-the-shelf camera (ECAM-C50 from MSSS):
  - Fixed-focus, narrow-angle lens;
  - 2592 x 1944 pixels;
  - 29° x 22° FOV (full disk and limb);
  - 4 km resolution.

- **Two thermal infrared camera** developed by MSSS:
  - Fixed-focus, narrow-angle lens;
  - 640 x 480 pixels;
  - Same field of view as visible camera; 16 km resolution;
  - Filter wheel for selecting 6 spectral ranges;
  - Detectors responsive in the range 7.9 - 16 μm.

- **Digital Video Recorder**: Off-the-shelf from MSSS (ECAM-DVR4)
  - Buffer Size: 32 GB Non-Volatile / 128 MB Volatile
Products

- **Visible Images** during daylight
- **Maps from IR retrievals** (daylight/nightlight):
  - 2D maps of $\tau_{\text{dust}}$ and $\tau_{\text{ice}}$;
  - 2D maps of $T$ at a few altitude levels;
  - 2D maps of thermal inertia/albedo;
  - Maps and images are co-located and simultaneous.
- **Three observational modes:**
  - Continuous monitoring (low res);
  - H$_2$O ice cloud observational campaign (high res, only a few sols);
  - Dust storm tracking campaign (high res, 10-20 sols).
- **Bottleneck**: Downlink data rate (estimated to 20 kbits/sec on average)
Key challenges identified for the MAT concept (major to minor)

- **Propulsion**: Solid Iodine fuel technology not yet ready; Xenon gas tank increases mass and volume; Thruster reliability to be tested.
- **Communication**: Despite using JPL KaPDA high-gain antenna adapted to the X-band, the data downlink rate is still low.
- **Heat dissipation**: This is one of the identified top risks.
- **Radiation**: This is another identified top risk, particularly in the Case 3 scenario when leaving from GTO.
- **Data pre-processing**: It would be desirable to develop advanced, automatic event detection algorithms based on machine learning.
- **Launch opportunities**: Few for Case 2, more for 3; Desirable to look at innovative opportunities for Mars capture (e.g. ballistic capture).
- **Station keeping**: Challenging, but we identified mitigation options.
### Summary of the mission concept

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<th>Science Objectives</th>
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<tr>
<td><strong>Monitor:</strong></td>
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<tr>
<td>- The onset, transport, and decay of large (i.e. regional) <strong>dust storms</strong> for extended periods.</td>
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<td>- The formation, evolution, and dissipation of extended <strong>water ice clouds</strong> at high sampling rate.</td>
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<td><strong>Produce:</strong></td>
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<td>- High-resolution (up to 4 km/pixel), <strong>visible images</strong> during daytime;</td>
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<td>- 2D maps of <strong>column aerosol optical depth</strong>, multiple times a day (~60 km/pixel);</td>
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<td>- 2D maps of <strong>atmospheric temperature</strong> at a few altitude levels, multiple times a day;</td>
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<tr>
<td>- 2D maps of <strong>thermal inertia and albedo</strong> taking into account the aerosol variable contribution.</td>
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<th>Baseline Mission Overview</th>
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<td><strong>Spacecraft:</strong> ESPA-class orbiter; 45 kg; Electric propulsion (micro Hall thrusters, Xenon gas propellant).</td>
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<td><strong>Payload:</strong> Visible and 2 thermal infrared fixed-focus cameras (6 filters for selecting IR spectral ranges).</td>
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<td><strong>Journey to Mars:</strong> Rideshare on a primary orbiter mission to Mars; deployment before Mars capture.</td>
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<td><strong>Orbit:</strong> Areostationary (i.e. equatorial, circular, planet-synchronous orbit) at ~17,000 km above the equator.</td>
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<td><strong>Duration:</strong> 1 Martian year (primary mission).</td>
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<td><strong>Cost:</strong> Total anticipated cost estimated below $55M cap (excluding launch).</td>
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Thanks for your attention!

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