Mars Aerosol Tracker (MAT):

An Areostationary SmallSat to Monitor Dust Storms and Water Ice Clouds

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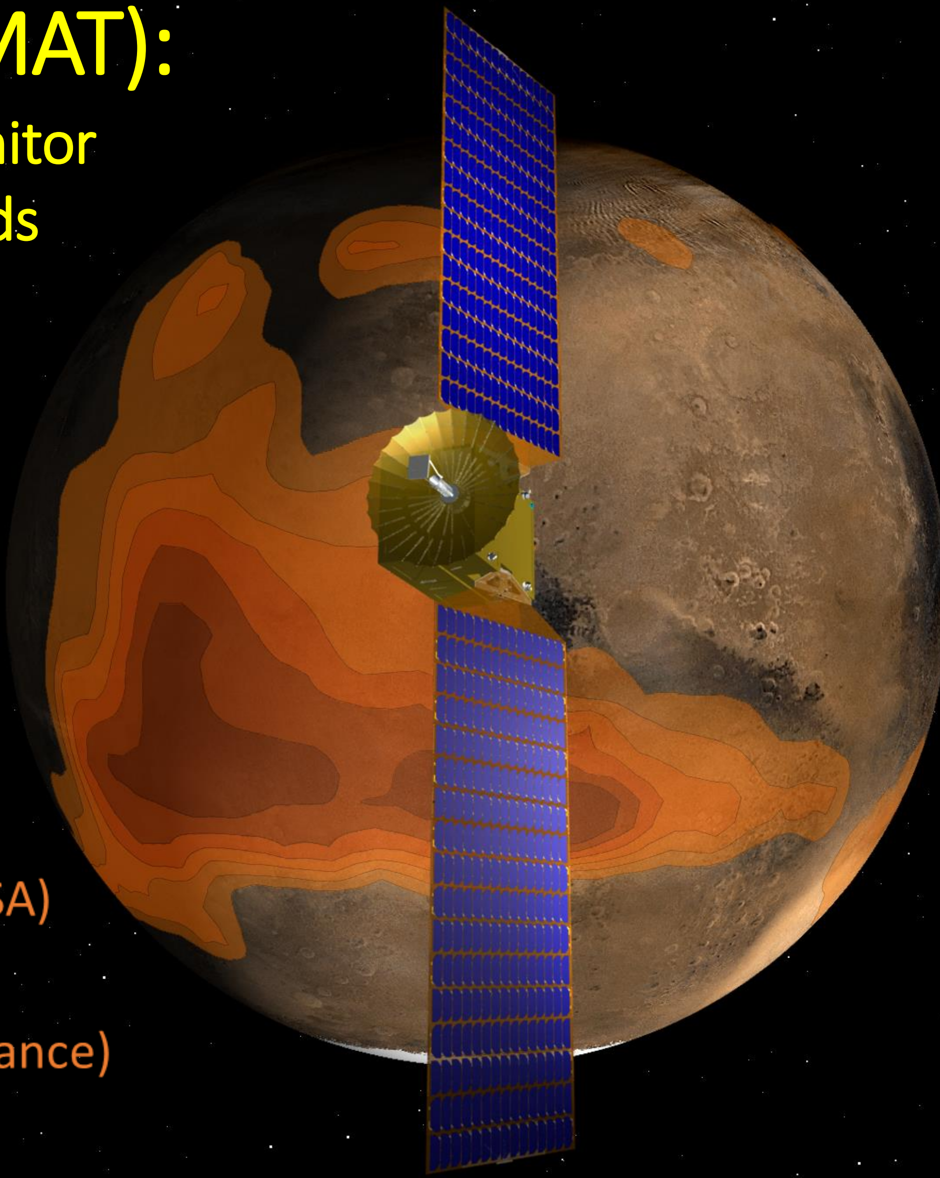

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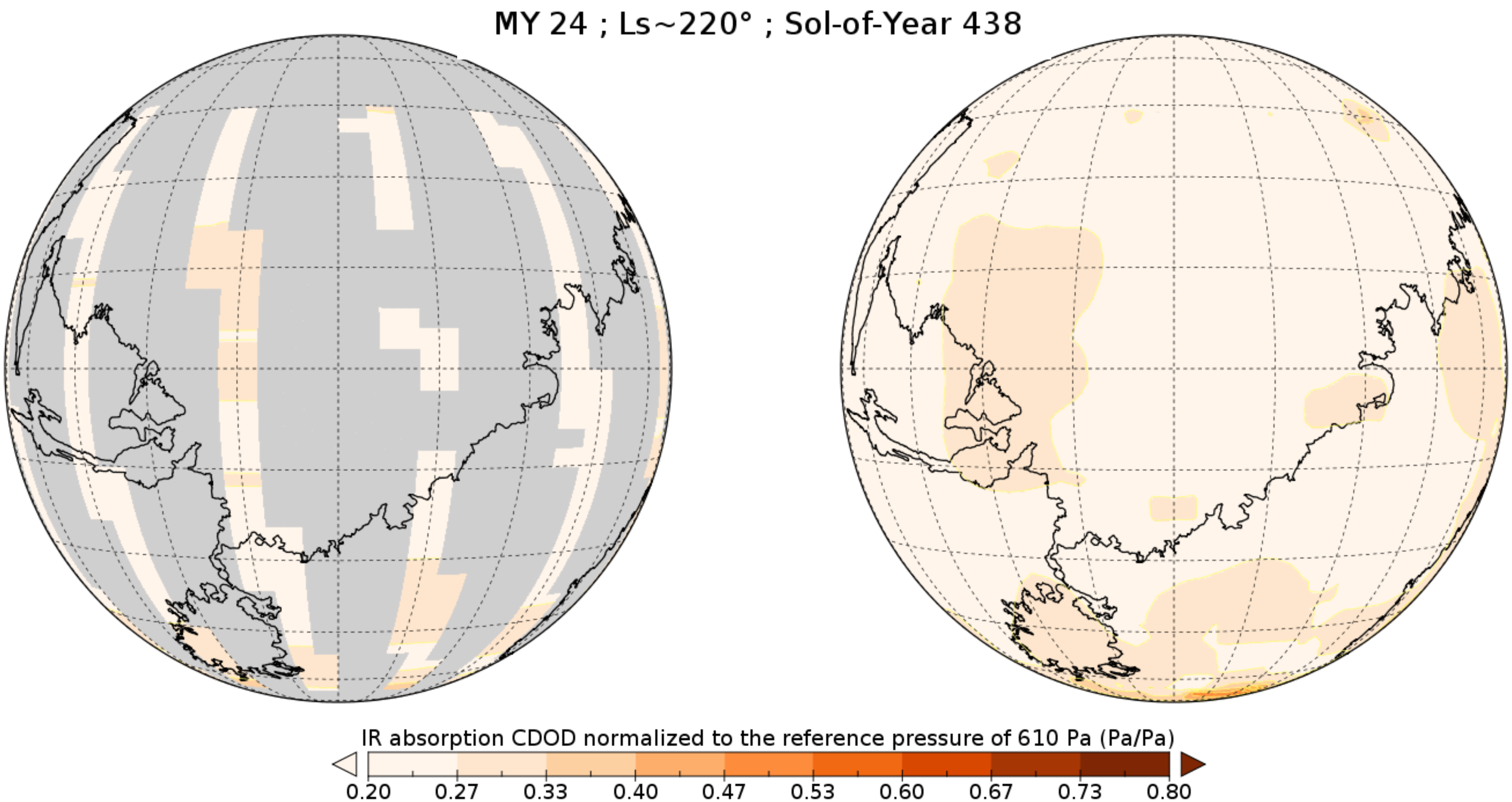
The case for MAT

- **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;
  - → To enable weather forecasting (e.g. evolution of dust storms);
  - → To support robotic AND future human exploration.
- **The key factor is the orbit! An areostationary orbiter is ideal:**
  - → To observe a large, fixed region (~80° away from nadir);
  - → To provide high sampling rate (fractions of the hour);
  - → To monitor throughout the daily and seasonal cycles;
  - → To monitor rapidly evolving meteorological phenomena;
  - → To monitor changes in surface properties (e.g. albedo, T. inertia).

A regional dust storm from areostationary vs polar orbit

View from about 17,000 km above the equator

Polar orbiter **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:

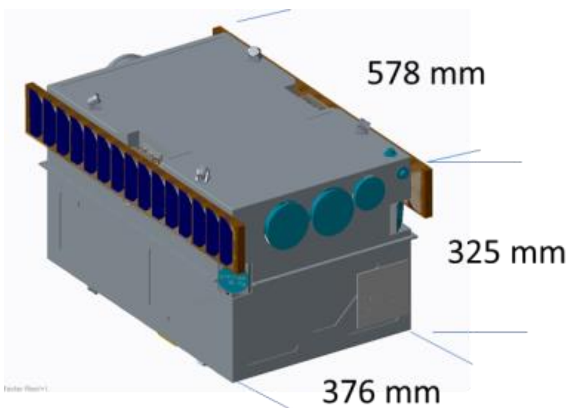
What are the processes controlling the dynamics of dust and water ice clouds, and promoting the evolution of regional dust storms into global-scale dust events?

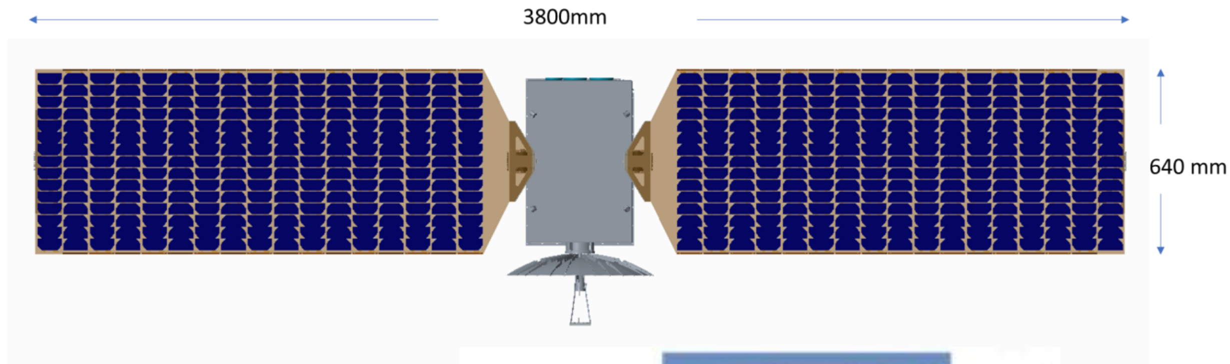
We plan to place and operate MAT in areostationary orbit in order to:

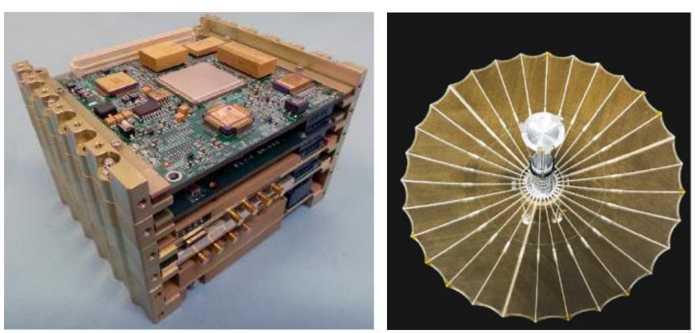
- Monitor at high sampling rate a large, fixed portion of the planet where dust storms and water ice clouds are likely to occur, using visible and infrared wavelengths;
- Observe the temporal evolution of dust storms and water ice clouds in the monitored area throughout the diurnal cycle
- Detect possible changes in surface properties (e.g. thermal inertia and albedo), particularly after the occurrence of large dust storms.

The 45 kg SmallSat with electric propulsion

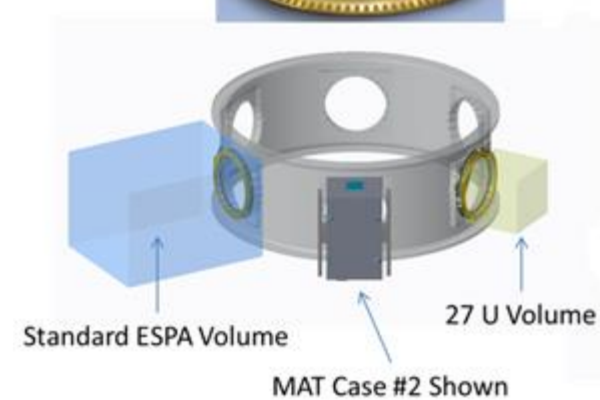
- ~27U Cubesat, 45 kg
- .5m Antenna, 8-128 kbps data rate
- PSC Lightband Interface







IRIS transponder + KaPDA antenna

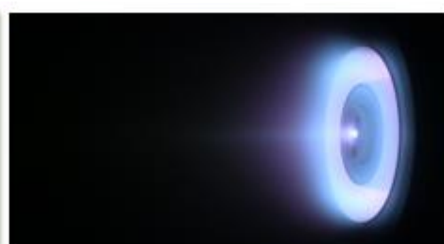


Solar Electric Propulsion System

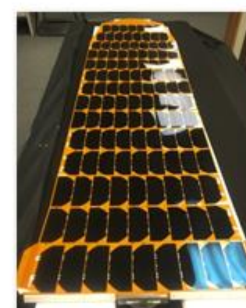
- 800 W BOL Power using 130 W/kg deployable solar arrays
  - 213 W EOL @ Mars Perihelion
- 3.3 km/s ΔV using ExoTerra Hall Effect Thruster
- 96-98% Efficiency PPU. CubeSat form factor

Xenon gas tank

0.65 kg mass
0.25 U volume
Power range : 75-450 W
I_{sp} range : 700-1500 s
Thrust range : 4-33 mN
Flexible propellants : iodine, xenon, krypton, argon, neon



“Halo” 4th Generation Prototype



Solar Array Deployment

Mission Architecture

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

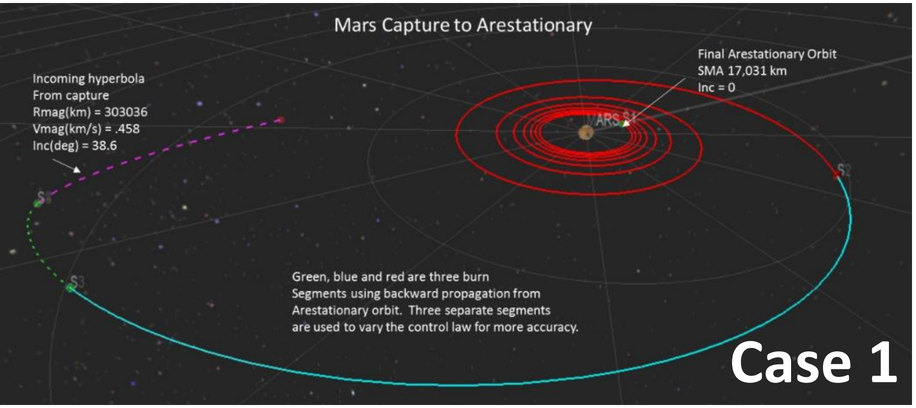
45 kg spacecraft wet mass

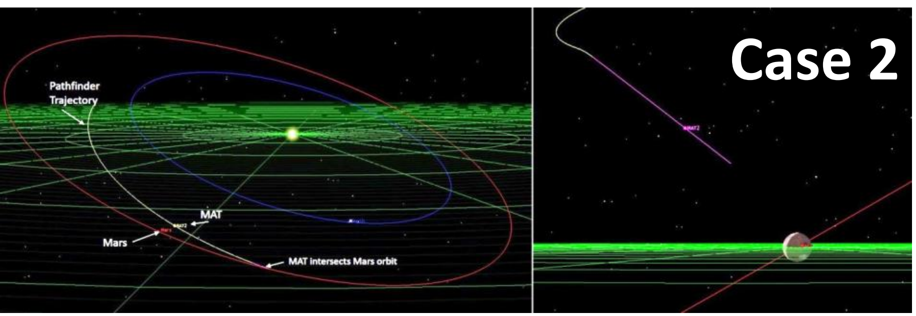
Case 3

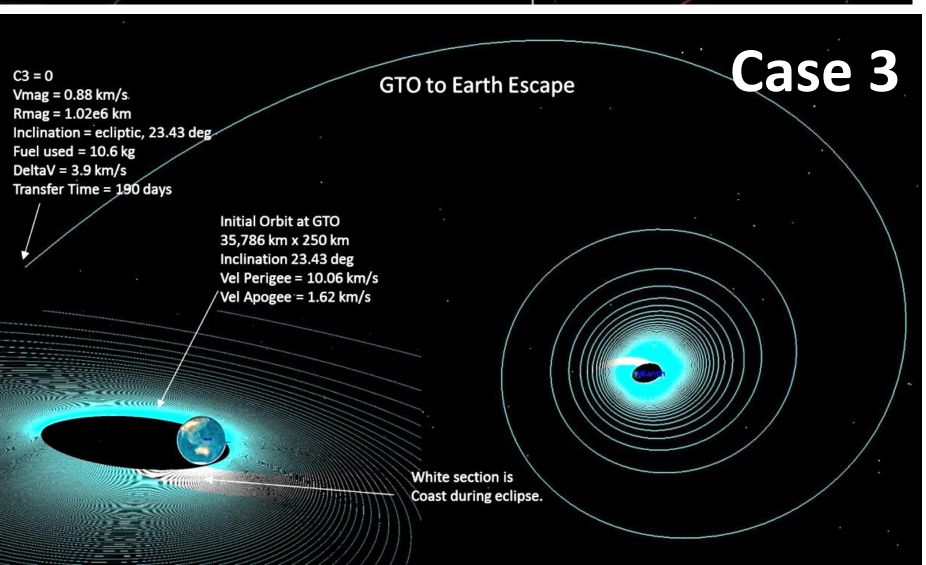
Being released in GTO, autonomous navigation to Mars, autonomous Mars capture, descent into areostationary orbit

64 kg spacecraft wet mass

Trajectories to Mars





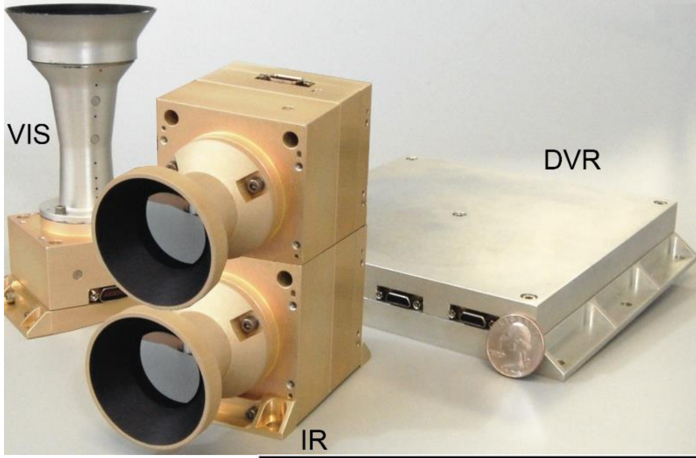


ΔV capabilities and range estimates

Case	Fuel Allocated (kg of Xe)	Delta V (m/s)	Range Estimate (m/s)	
1	4.00	1619	850	2200
2	10.62	3538	1543	4300
3	25.00	7283	6543	11640

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.

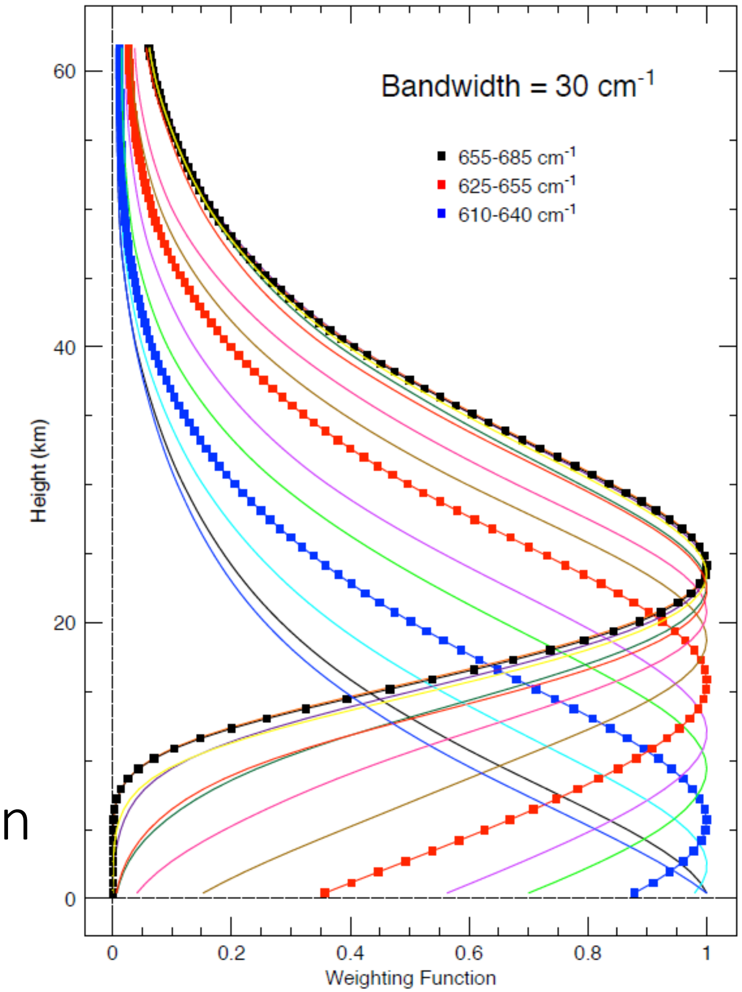
Malin Space Science Systems

Malin Space Science Systems, Inc
Proprietary Information

- **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:** Temperature and aerosols (dust, water ice) optical depth up to ~60° from nadir :
  - → 2D maps of τ_{dust} and τ_{ice} ;
  - → 2D maps of T at a few altitude levels;
  - → Maps and images are co-located and simultaneous.
- **Three observational modes**:
  - → Continuous monitoring (low res);
  - → H_2O 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)



Weighting functions for several spectral ranges on one side of the CO_2 15 µm absorption band.

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 neural networks.
- **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

Science Objectives

Monitor:
- The onset, transport, and decay of large (i.e. regional) **dust storms** for extended periods**.**
- The formation, evolution, and dissipation of extended **water ice clouds** at high sampling rate.
- The changes in surface properties (e.g**. thermal inertia, albedo**) over the observed area.

Produce:
- High-resolution (up to 4 km/pixel), **visible images** during daytime;
- 2D maps of **column aerosol optical depth**, multiple times a day;
- 2D maps of **atmospheric temperature** at a few altitude levels, multiple times a day;

Baseline Mission Overview

- **Spacecraft**: ESPA-class orbiter; 45 kg; Electric propulsion (micro Hall thrusters, Xenon gas propellant).
- **Payload**: Visible and 2 thermal infrared fixed-focus cameras (6 filters for selecting IR spectral ranges).
- **Journey to Mars**: Rideshare on a primary orbiter mission; deployment before Mars capture.
- **Orbit**: Areostationary (i.e. equatorial, circular, planet-synchronous orbit) at ~17,000 km above the equator.
- **Duration**: 1 Martian year (primary mission).
- **Cost**: Total anticipated cost estimated below $25M (but no launch nor DSN) + cost reserve

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Thanks for your attention !

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