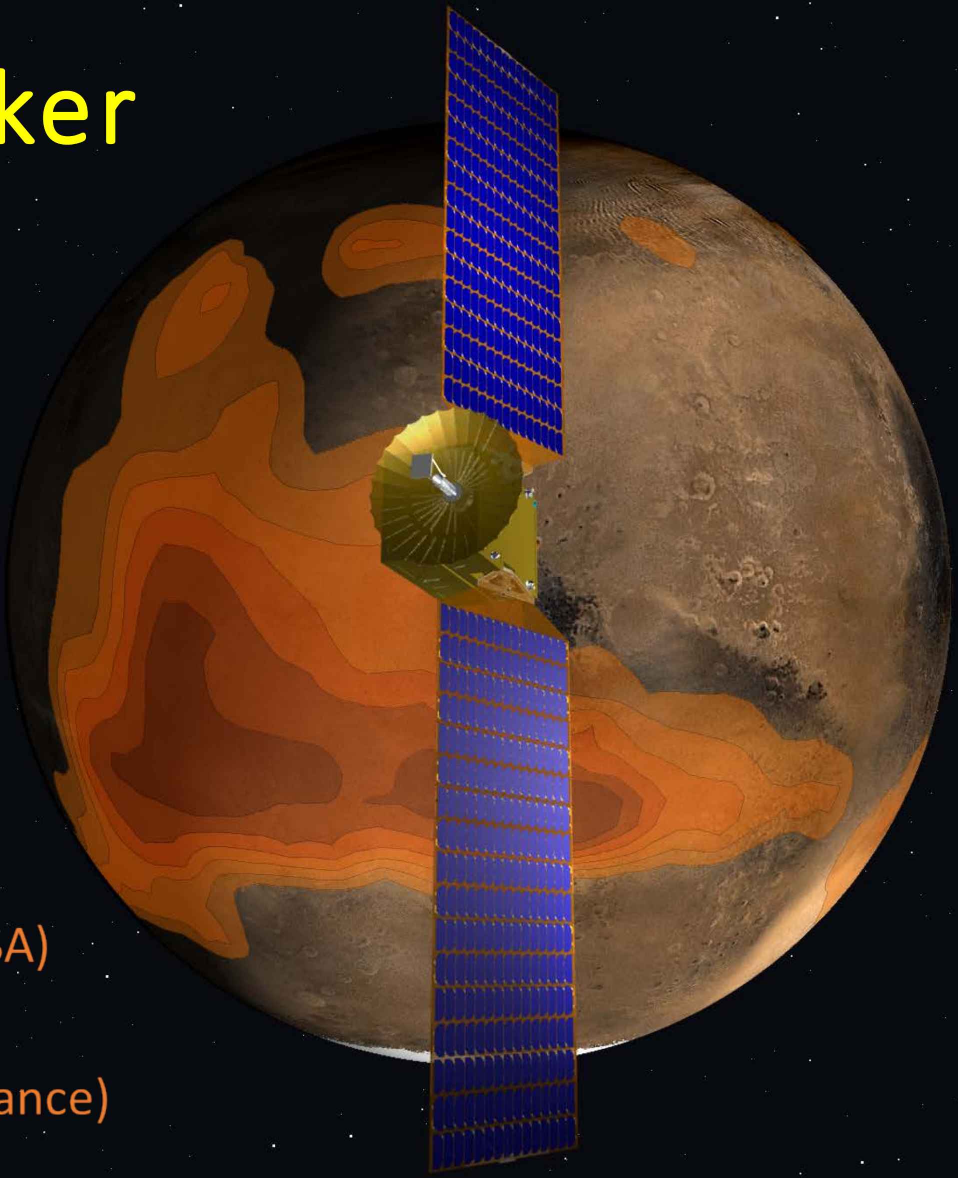
Mars Aerosol Tracker (MAT)



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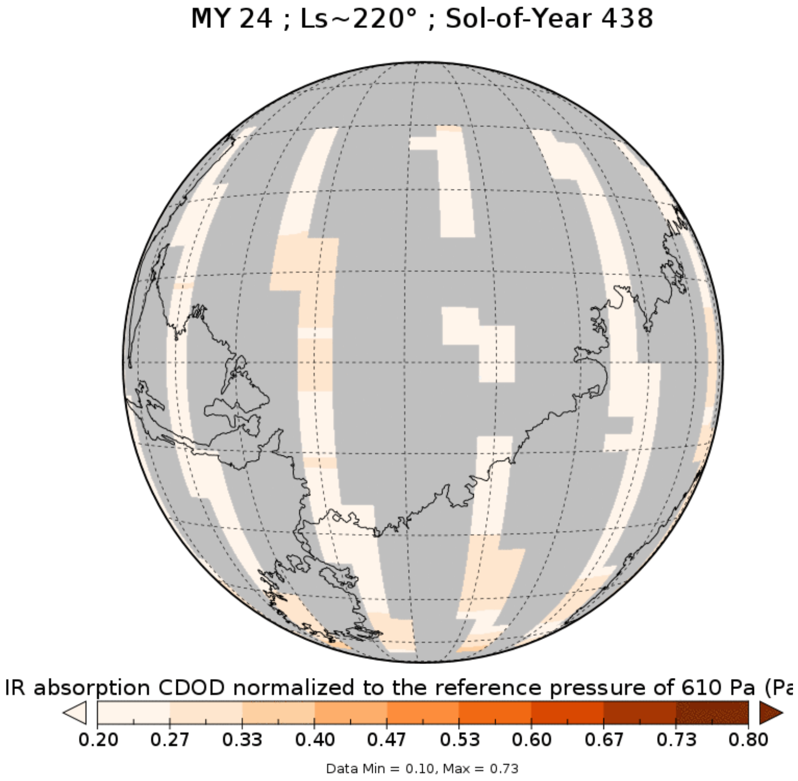
Planetary Science Deep Space SmallSat Mission Concepts
The Woodlands, TX - March 18th, 2018

The case for MAT

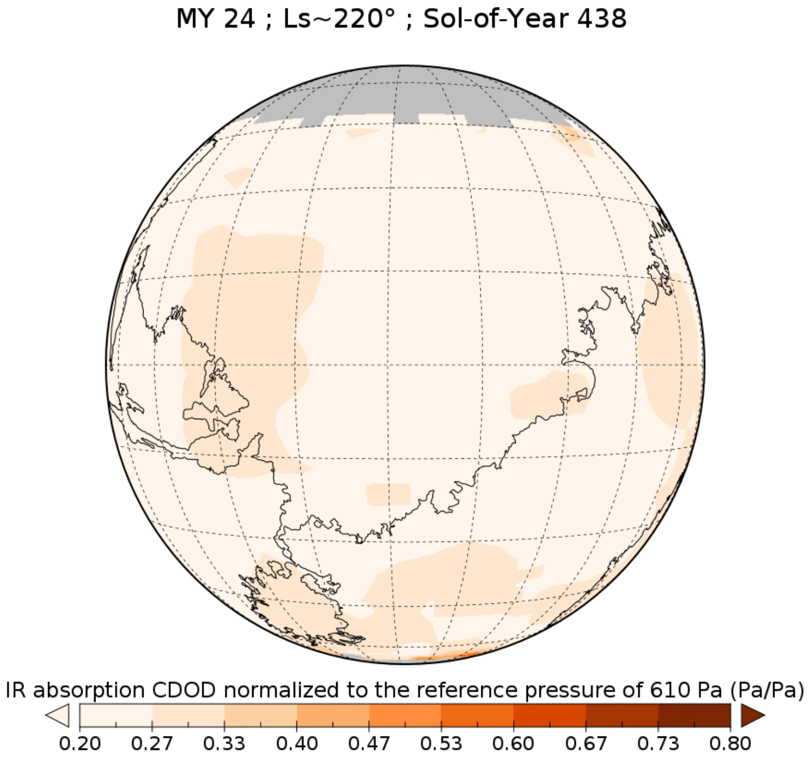
- Dust and water ice aerosols affect the Martian "weather":
  - → They are both radiatively active.
- There is need for continuous and synoptic aerosol monitoring:
  - → To understand the interaction between aerosols and circulation;
  - → To enable weather forecasting (e.g. evolution of dust storms);
  - → To support robotic AND future human exploration.
- The key factor is the orbit! An areostationary orbit 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 continuously/synoptically monitor the aerosol evolution;
  - → To monitor changes in surface properties (e.g. albedo, T. inertia).

A regional dust storm from areostationary vs polar orbit

Polar orbiter



Areostationary orbiter



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

Data from:
Montabone et al., Icarus, 2015

View from about 17,000 km
above the equator

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 planet-encircling storms?

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.

Mission objectives

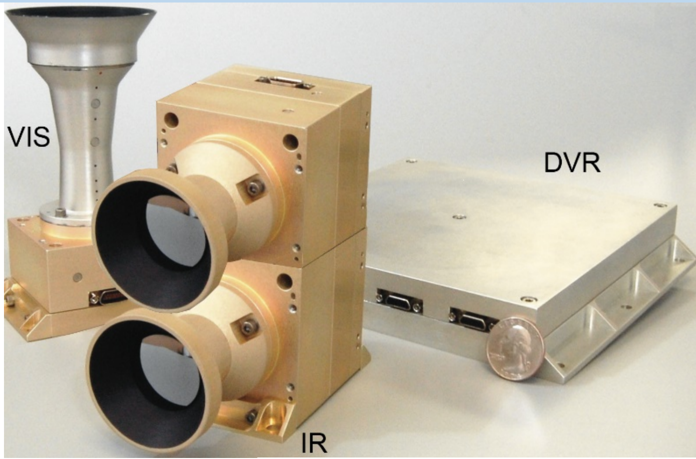
To provide answers to the scientific questions:

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

Relevant to:

- NASA 2014 Science Plan →
  Advance the understanding of how the chemical and physical processes in our solar system operate, interact and evolve
- Decadal Survey, Priority C →
  What are the processes controlling the variability of the present-day climate?
  What are the primary causes behind the occurrence of global dust events?
  What are the processes coupling the carbon dioxide, dust and water cycles?
- MEPAG Goal II, Objective A → *monitoring the Martian atmospheric structure and dynamics*
- MEPAG Goal IV, Objective A →
  variability on diurnal, seasonal, and inter-annual scales
  from ground to >80 km in both ambient and various dust storm conditions

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

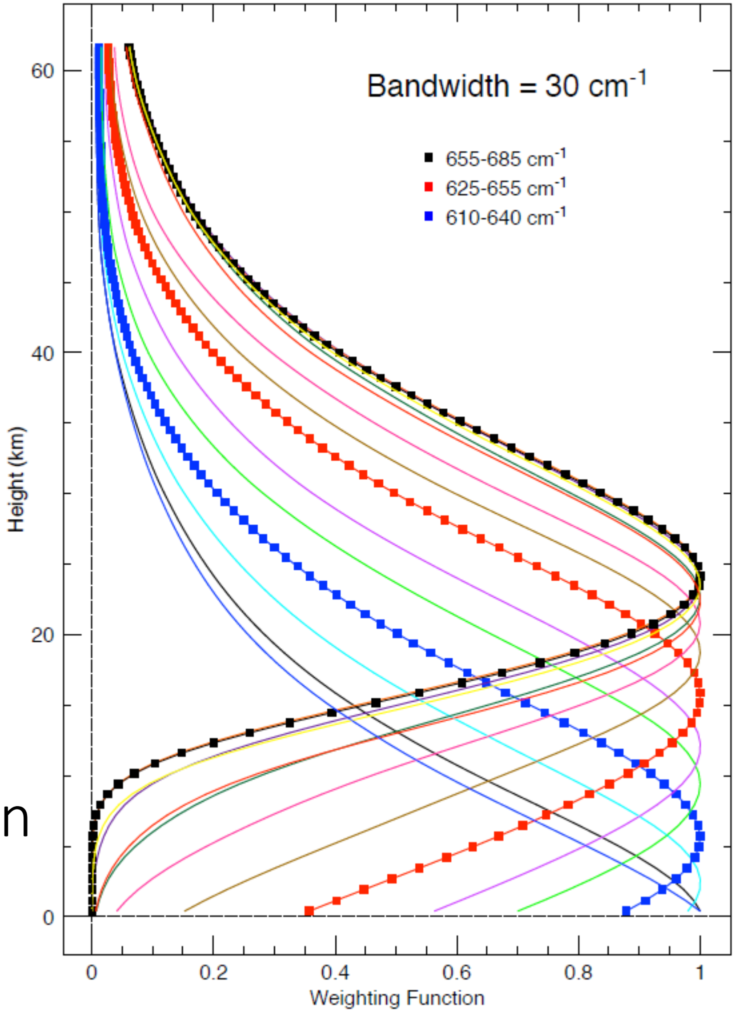
Malin Space Science Systems

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 3 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 (20 kbits/sec on average)



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

Mission Architecture

We analyzed 3 mission scenarios

Case 1 (proposal)

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

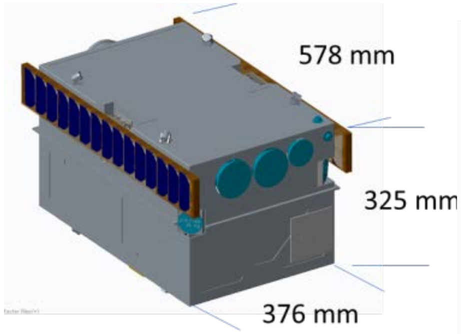
45 kg spacecraft wet mass

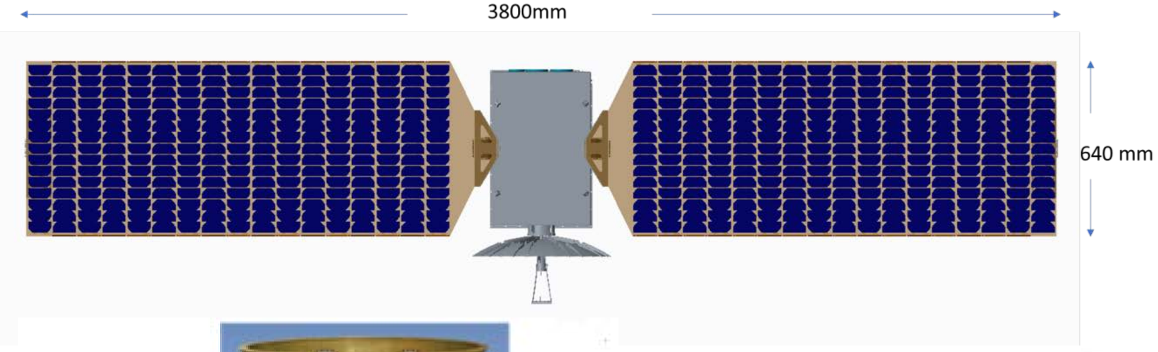
Case 3 (promising)

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

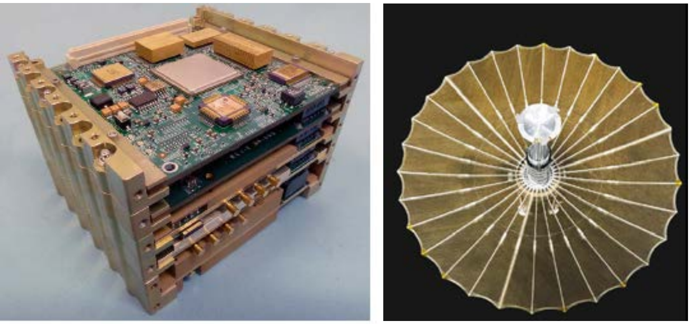
64 kg spacecraftwet mass

The 45 kg SmallSat with electric propulsion

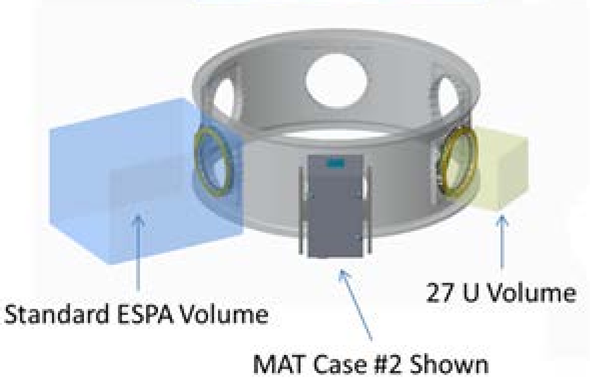




ESPA ring

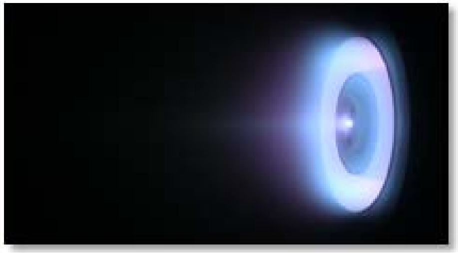


IRIS transponder + KaPDA antenna



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” 3rd Generation Prototype

Solar Array Deployment

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 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 to nearly $24M (no launch nor DSN) + 25% cost reserve

SPACE SCIENCE INSTITUTE

Thanks for your attention !

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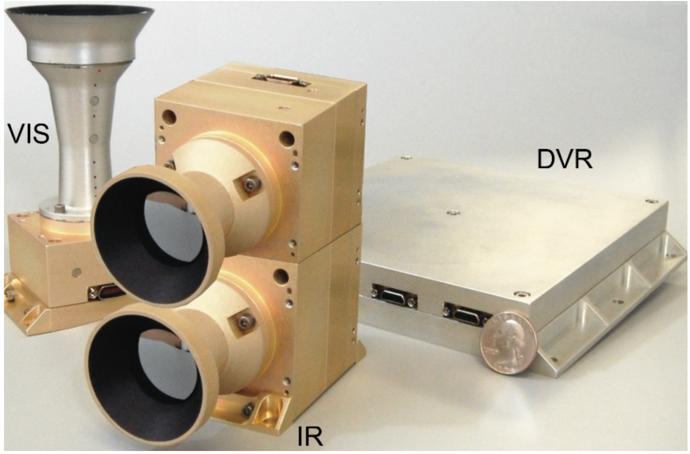
Backup slides

Payload and Products

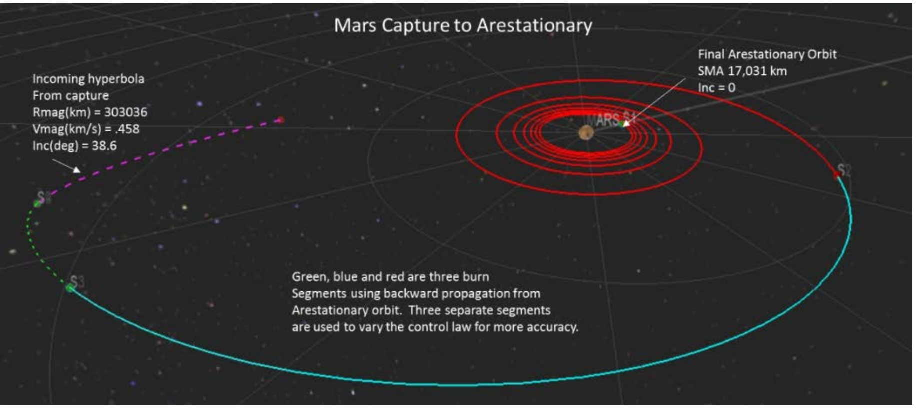
- **VISIBLE CMOS Camera** (ECAM-C50)
  - 2592x1944 pixel (full frame), pixel size: 2.2 µm pixels
  - Bayer Pattern filter for RGB color: (400-500 nm, 500-575 nm, 575-750 nm)
  - FOV: 29 x 22 degree
  - Weight: 360 grams

- **Thermal Imaging System (2 IR cameras, 1 filter wheel and stepper motor)**
  - 640x480 pixel (full frame), pixel size: 17 µm pixels
  - Six Bandpasses: 7.9 µm – 16 µm
    - Camera 1: 7.9 µm, 9.3 µm, 11.8 µm
    - Camera 2: 15.0 µm, 15.6 µm, 16.0 µm
  - FOV: 29 x 22 degree
  - Weight: ~ 1420 grams (camera+wheel+motor)

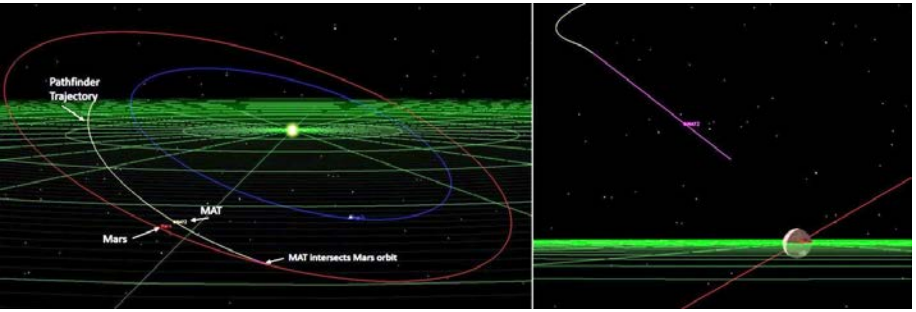


- **Digital Video Recorder** (ECAM-DVR4)
  - Compression: JPEG (Lossy), Huffman (Lossless)
  - Buffer Size: 32 GB Non-Volatile / 128 MB Volatile
  - Weight: 1110 grams

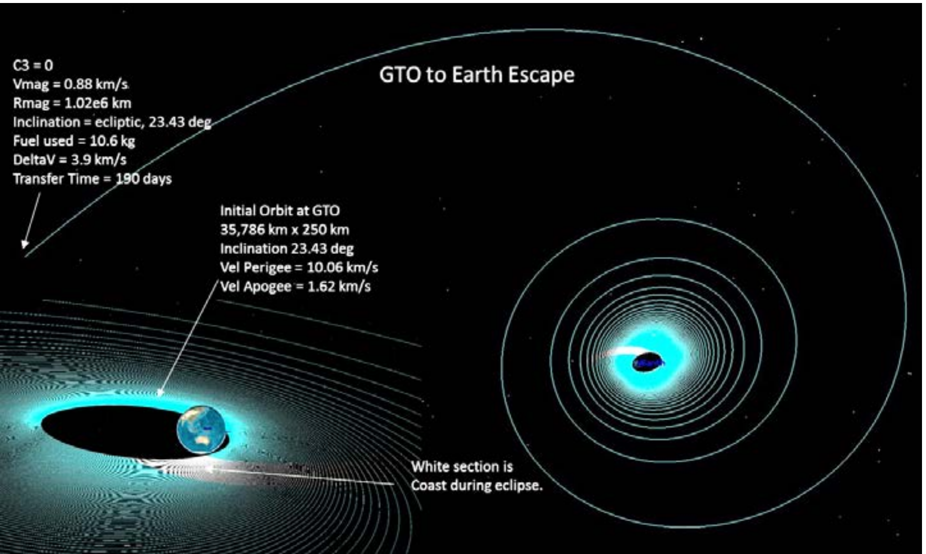
Trajectories to Mars



Case 1: This requires a ΔV of 1.9 km/s, a fuel requirement of 3.5 kg, and a burn time of 35.5 days.

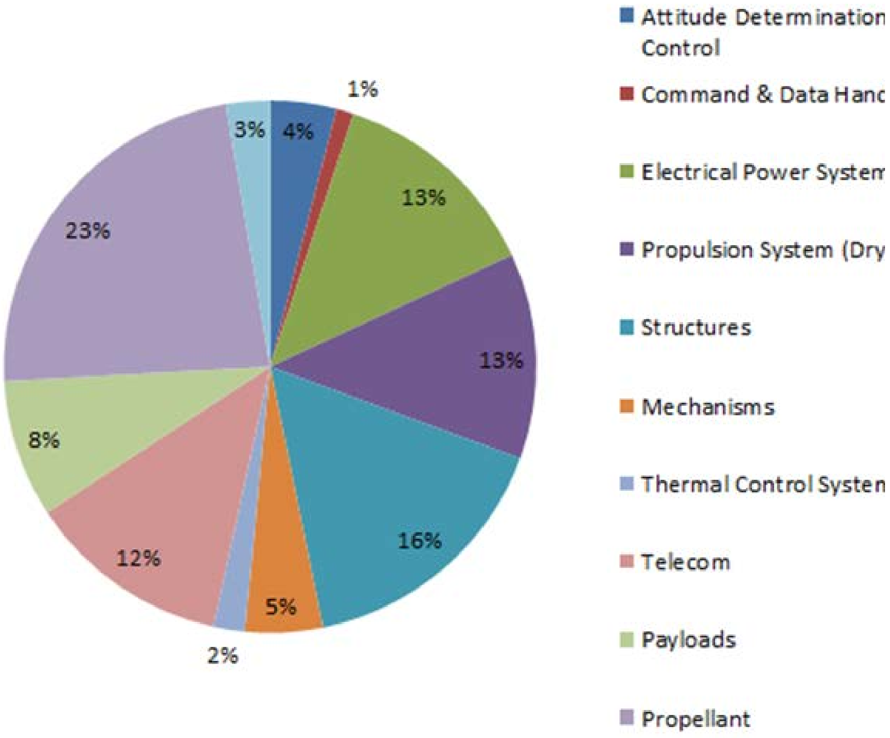


Case 2: An estimate of ΔV ranges from 693 m/s to 2.1 km/s for capture burn, depending on a wide range of assumptions including burn initiation and final capture orbit

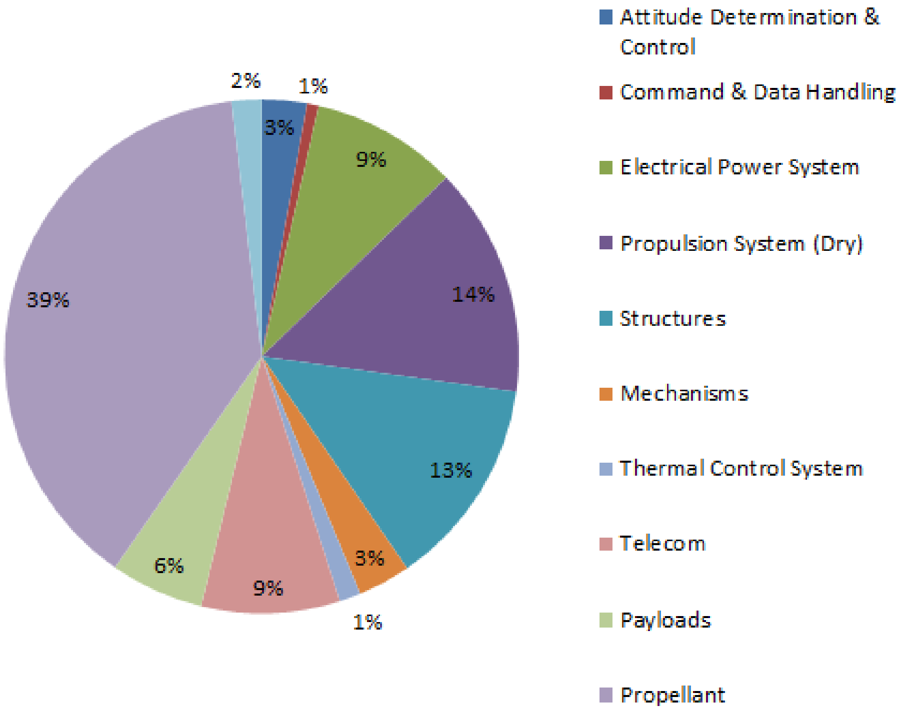


Case 3: If we assume using only one thruster, this requires 3.9 km/s of ΔV, 10.6 kg of fuel and 190 days. If there was an option to use two thrusters, the transfer time to escape would only be 90 days.

The 45 kg vs 64 kg SmallSat configurations



Case 2 Xenon Subsystem
Mass percentage



Case 3 Xenon Subsystem
Mass Percentage