MONITORING THE WEATHER ON MARS WITH AN AREOSTATIONARY SMALLSAT

L. Montabone[1], B. Cantor[2], M. D. Smith[3], M. J. Wolff[1], M. Capderou[4], F. Forget[4], and M. VanWoerkom[5]

[1]Space Science Institute, Boulder, CO, USA, [2]Malin Space Science Systems, San Diego, CA, USA, [3]NASA Goddard Space Flight Center, Greenbelt, MD, USA
[4]Laboratoire de Météorologie Dynamique (IPSL/Sorbonne Université/CNRS), Paris, France, [5]ExoTerra Resource LLC, Littleton, CO, USA

Contact: lmontabone@spacescience.org

SCIENCE OBJECTIVES

INTRODUCTION

This poster summarizes our concept of using an areostationary SmallSat (i.e. a low-cost satellite in a Mars-synchronous, equatorial, circular orbit) to monitor the Martian weather (dust storms and water ice clouds).

The dust cycle –lifting, transport, and deposition - is considered to be the key process controlling the variability of the Martian atmospheric circulation on inter-annual, seasonal, and day-to-day time scales. Dust storms are the most remarkable manifestation of this cycle.

The radiative effects of water ice aerosols are also very important in understanding the details of the atmospheric thermal and dynamical structures. Water ice clouds cyclically form at equatorial and tropical latitudes in NH spring and summer, as well as at high latitudes in winter.

Monitoring in detail the rapidly evolving dynamics of dust storms (i.e. their onset, transport, and decay) and water ice clouds (i.e. their formation, evolution, and dissipation) requires both continuous and synoptic* observations of Martian aerosols from space.

*By *continuous monitoring* we mean obtaining data with a high sampling rate for a long time.
By *synoptic monitoring* we mean obtaining data simultaneously over a large area.

THE SCIENTIFIC CASE

- **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 (at least 60° from nadir, up to 80°);
  - → To provide high sampling rate (fractions of the hour);
  - → To monitor throughout the daily and seasonal cycles.

HIGH-LEVEL SCIENCE QUESTIONS

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

RELEVANCE TO MARS SCIENCE AND EXPLORATION

- NASA 2014 Science Plan → *Advance the understanding of how the chemical and* ***physical processes*** *in our solar system* ***operate, interact and evolve [1]***
- 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? [2]***
- MEPAG Goal II, Objective A, Sub-Objective A1 → *Constrain the processes that control the* ***present distributions of dust,*** *water, and carbon dioxide in the lower atmosphere,* ***at daily, seasonal and multi-annual timescales [3]***
- MEPAG Goal IV, Objective A, B, Sub-Obj. A1, B1 → *Determine the aspects of the atmospheric state that affect aerocapture (…) EDL design and that may pose a risk to ascent vehicles, ground systems, and human explorers (…)* including the ***variability on diurnal, seasonal, and inter-annual scales*** *from ground to > 80 km in both ambient and* ***various dust storm conditions [4]***

Perceived gap in MEPAG Goal IV: Robotic and human surface operations require improved **weather forecasting** (e.g. accurate dust storm forecasting). There is insufficient knowledge on the dynamics of dust storms (onset, growth, transport)
→ **Continuous and synoptic monitoring of the Martian weather is recommended**

[1] NASA 2014 Science Plan, p. 61 and p. 113
[2] Vision and Voyages for Planetary Science in the Decade 2013-2022, p. 150
[3] MEPAG Mars Science Goals, Objectives, Investigations, and Priorities: 2015 Version, p. 15
[4] MEPAG Mars Science Goals, Objectives, Investigations, and Priorities: 2015 Version, pp. 45-46

MEASUREMENTS NEEDED

WHAT IS NEEDED TO MONITOR THE WEATHER

Minimum requirements

- **Continuous and synoptic observations**
  - → High temporal resolution for extended periods of time.
  - → Simultaneous observations at multiple locations.
- **Measurements of the thermal state**
  - → Surface temperature.
  - → Atmospheric temperature profiles.
- **Monitoring of the aerosol horizontal distribution**
  - → Column optical depth of dust and water ice.

Additional requirements

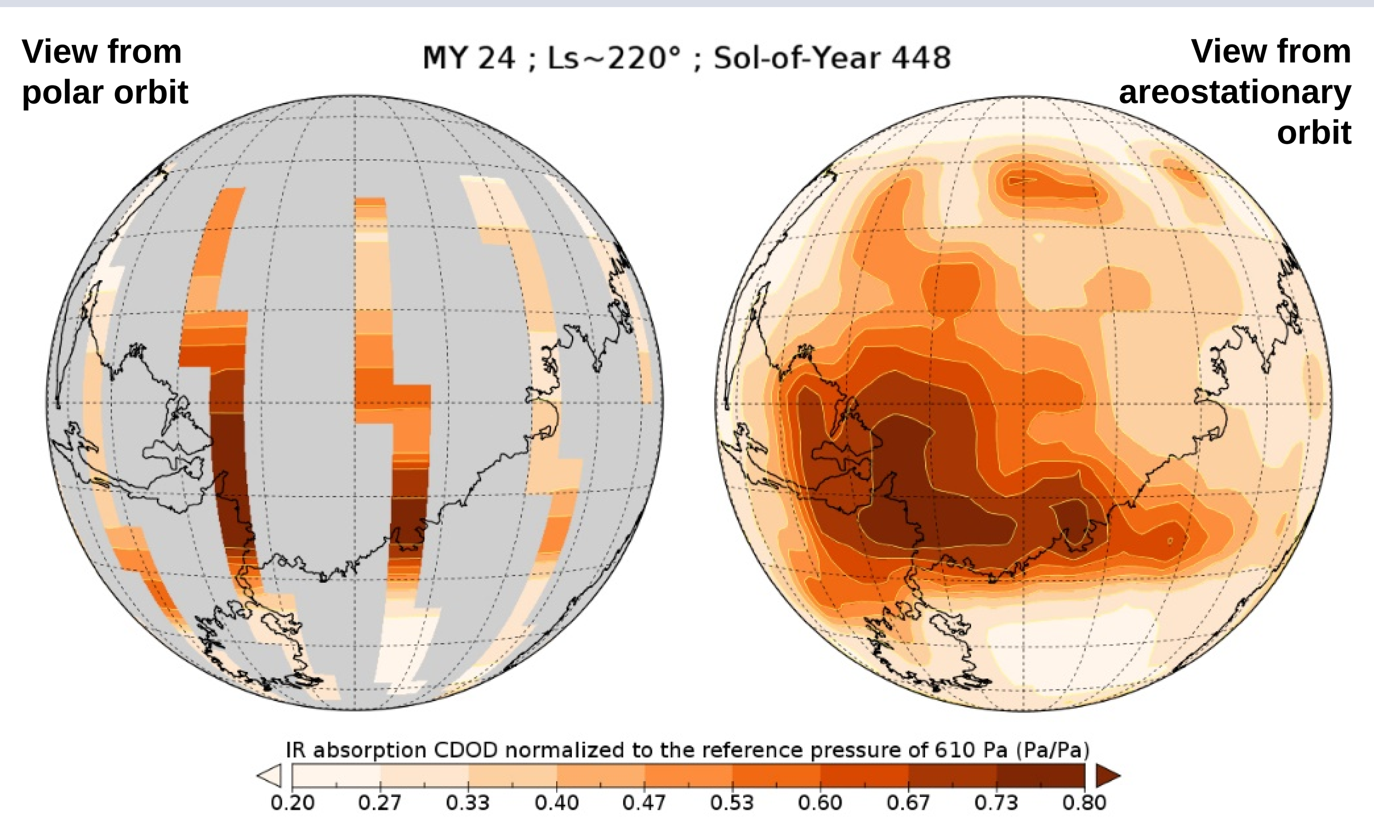
- **Monitoring of the aerosol vertical distribution**
  - → Optical depth profiles of dust and water ice.
- **Measurements of the winds**
  - → Large-scale horizontal wind components.
  - → Small-scale vertical wind in the boundary layer.
- **Measurements of surface variables**
  - → Surface pressure.
  - → Near-surface wind components.

WHAT CAN BE MEASURED BY AN AREOSTATIONARY SATELLITE

A satellite in areostationary orbit can fulfil the **minimum requirements** (as defined above) to monitor the weather on Mars over a region ~60° from the sub-spacecraft point (Three areostationary satellites can monitor the global weather, except over the polar regions). Additionally, it can:

- **Monitor surface changes**
  - → Thermal inertia and albedo, through the daily cycle and after dust storm occurrence.
  - → Seasonal extension of the polar ice caps, possible daily variations.
- **Allow to estimate horizontal winds**
  - → Wind direction and speed determined by (dust, ice) cloud tracking.

VIEW OF A DUST STORM FROM POLAR VERSUS AREOSTATIONARY ORBIT



A regional dust storm shown by MGS/TES gridded IR column dust optical depths (CDOD) during one sol (left panel), and the same storm reconstructed using the same type of data accumulated in seven sols (right panel). Data are taken from Montabone et al., *Icarus,* 251, 65-95 (2015) gridded and kriged datasets. Grey areas imply missing data. We used vertical perspective views with a center distance of 6.03 Mars radii (corresponding to the semi-major axis of the areostationary orbit, 20,428.5 km), center latitude of 0°N, and center longitude of 15°W (close to one of the two stable longitudes of the areostationary orbit, i.e. 17.92°W and 167.83°E according to Silva and Romero, *Planet. and Space Sci*. 87, 14-18, 2013). The dotted longitude-latitude lines are separated by 15°.

MISSION CONCEPT

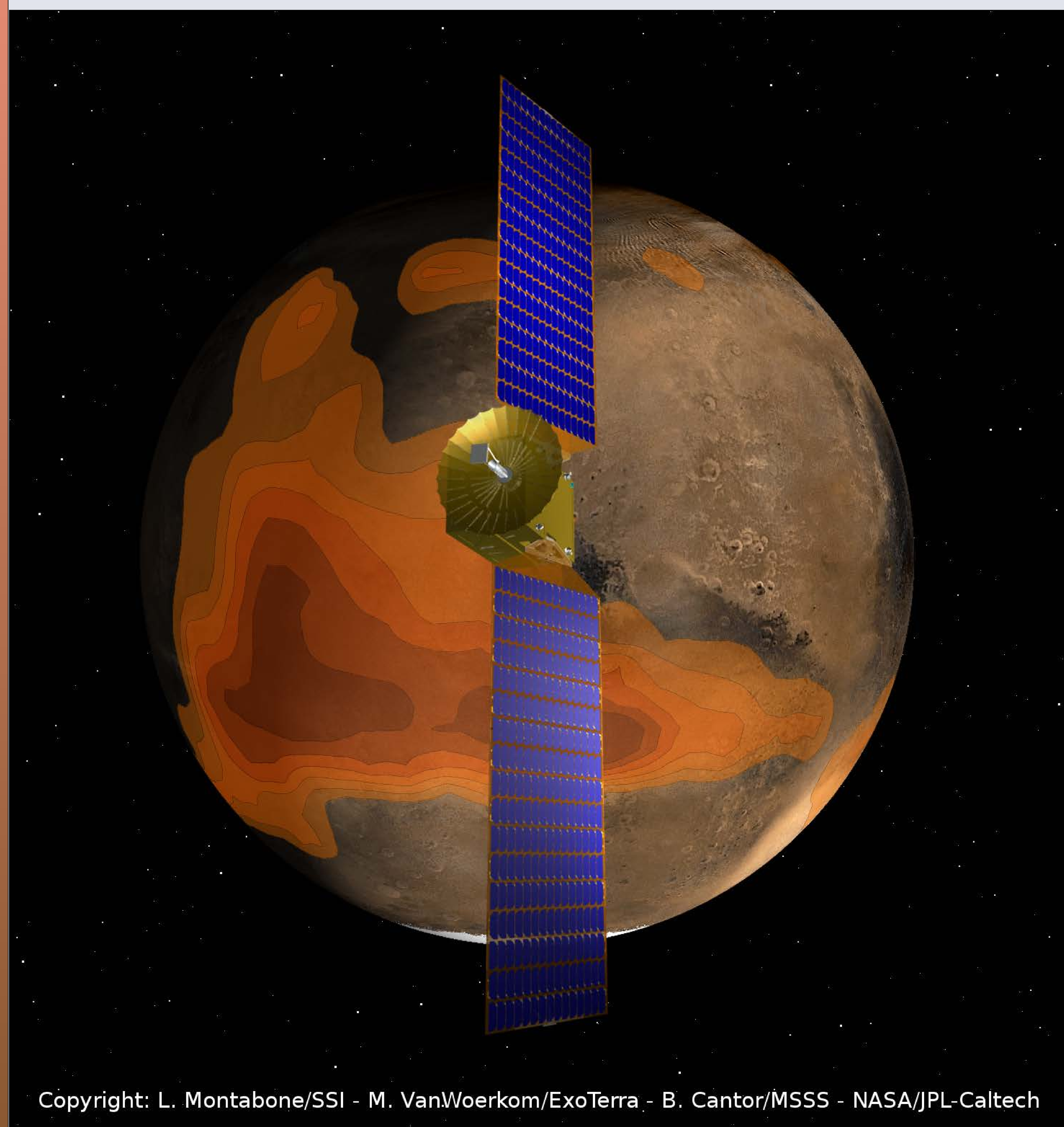
WHY FLYING A SMALLSAT AS AREOSTATIONARY?

An areostationary orbit is at 17,031.5 km altitude above the equator. We have studied a mission concept to put a stand-alone SmallSat (defined as having less than 180 kg of mass) in areostationary orbit.

- **General reasons:**
  - → A SmallSat is reasonably inexpensive;
  - → It can be built reasonably quickly;
  - → It enables a focused scientific mission;
  - → It allows one to accept more risk;
  - →There are potentially increasing number of opportunities for launch as secondary payload (particularly into initial GTO orbit).
- **Specific reasons:**
  - → To pave the way for areostationary satellite missions at Mars;
  - → To enable flying multiple ones for complete coverage in future;
  - → To demonstrate the potential of synoptic weather monitoring and forecast for future robotic and human missions.

ENVISAGED PRODUCTS

- **Visible Images** during daylight.
- **Maps of atmospheric temperature retrieved from IR images,** multiple times a day, several altitude levels below ~45 km altitude.
- **Maps of column aerosol (dust, water ice) optical depth retrieved from IR images,** multiple times a day, up to ~60° from nadir.
- Maps and images are co-located and simultaneous.



The "Mars Aerosol Tracker" (MAT) SmallSat overviews a regional dust storm on Mars from areostationary orbit, obtaining visible images in daytime and column dust optical depth measurements in daytime as well as nighttime.

ACKNOWLEDGEMENTS

The authors are grateful for funding from NASA's "Planetary Science Deep Space SmallSat Studies" (PSDS3) program under grant no. 80NSSC17K0303 to develop the areostationary "Mars Aerosol Tracker" (MAT) mission concept.