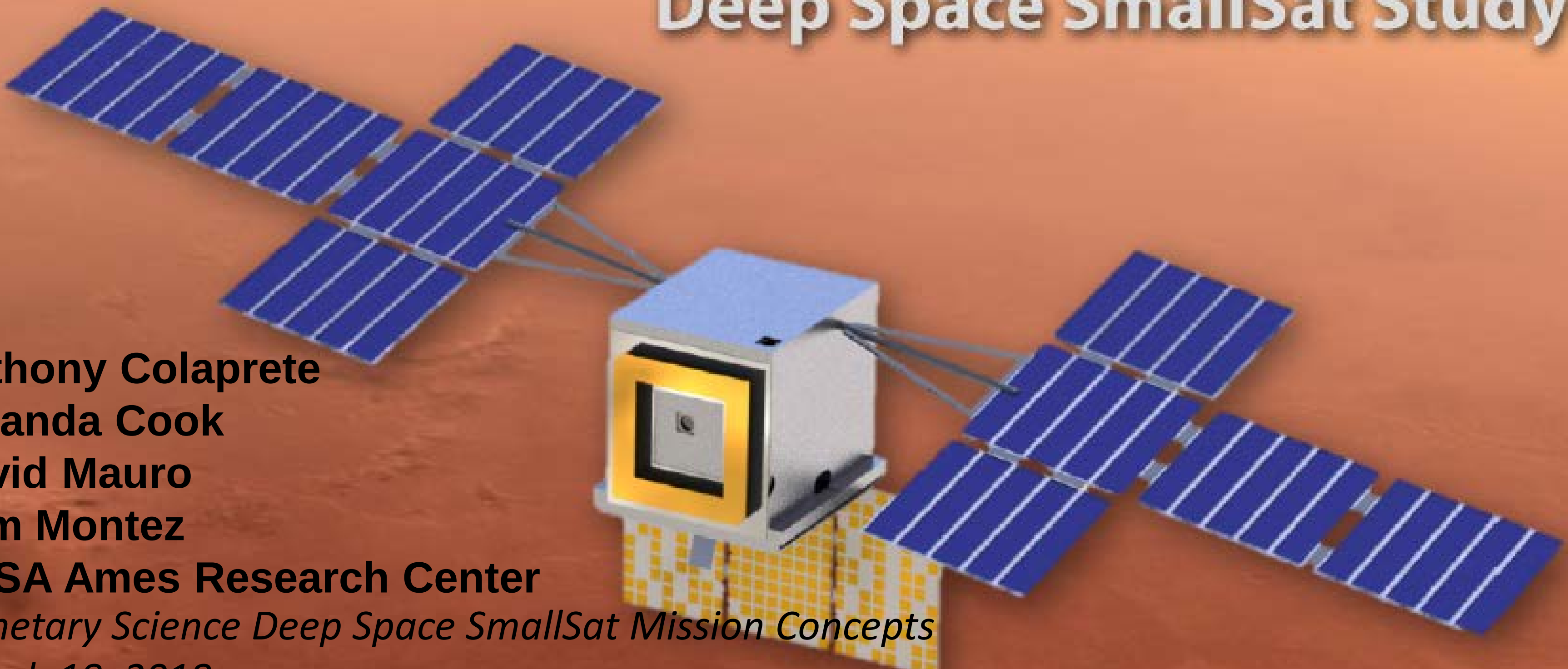
Aeolus

A mission to study the winds and climate of Mars

A 2017 Planetary Science Deep Space SmallSat Study



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Planetary Science Deep Space SmallSat Mission Concepts

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Why Aeolus?

Previous and ongoing missions to Mars have provided a partial definition of the present climate system, but have not - *and cannot* - illuminate the nature of the *processes* involved.

They lack two fundamental observations:

1. Direct measurements of winds
2. Full characterization of the diurnal cycle

- Winds are responsible for the movement of dust, water vapor, CO_2, and trace gases around the planet

- Winds determine the distribution of their sources and sinks at the surface

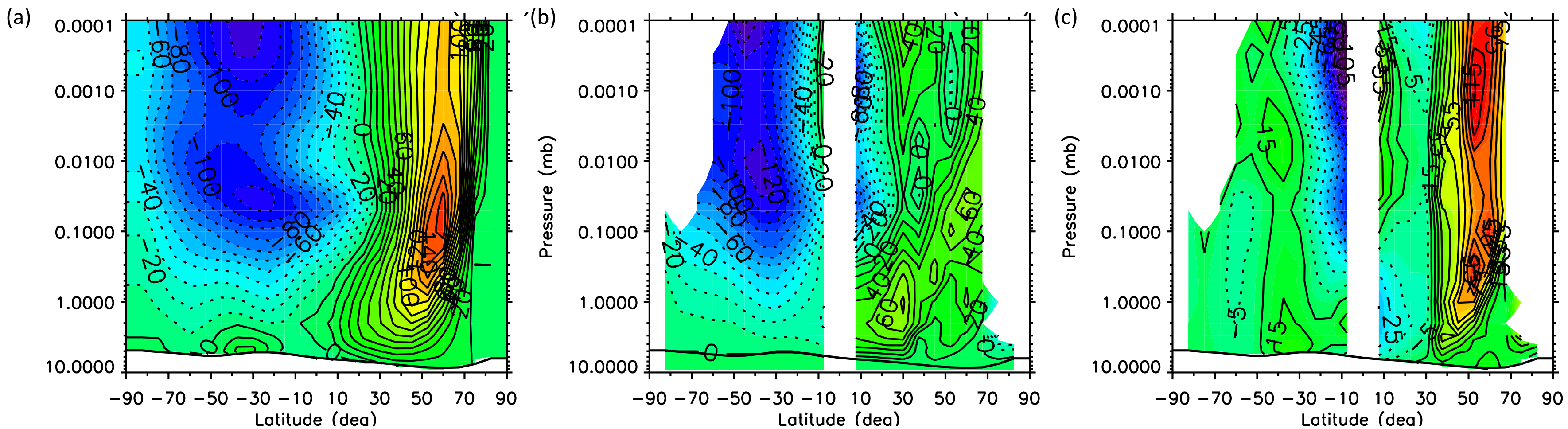
- Winds have a large unmeasured diurnal variation that strongly controls transport

Current Derivation of Winds

The gradient approximation can result in significant errors

- Winds calculated using the gradient method and temperatures from the NASA Ames Mars GCM
- These approximate winds differenced from the “truth” (the model winds)
- Areas in white indicate errors beyond contour levels
- ***Errors frequently exceed 100%***

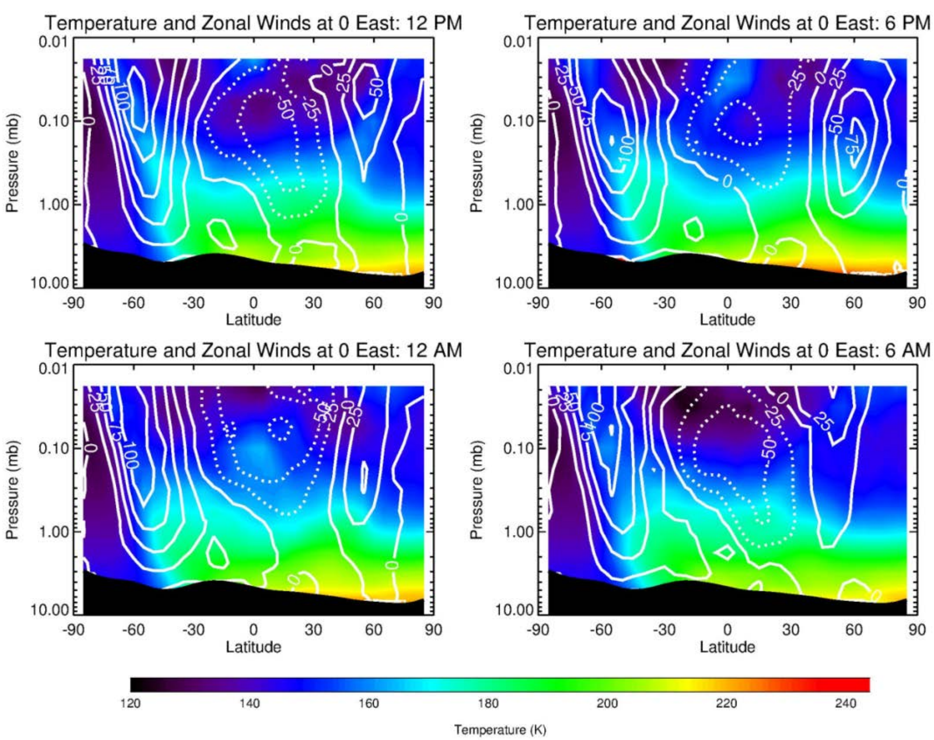
Modeled Wind Speeds | Derived Wind Speeds | Modeled - Derived

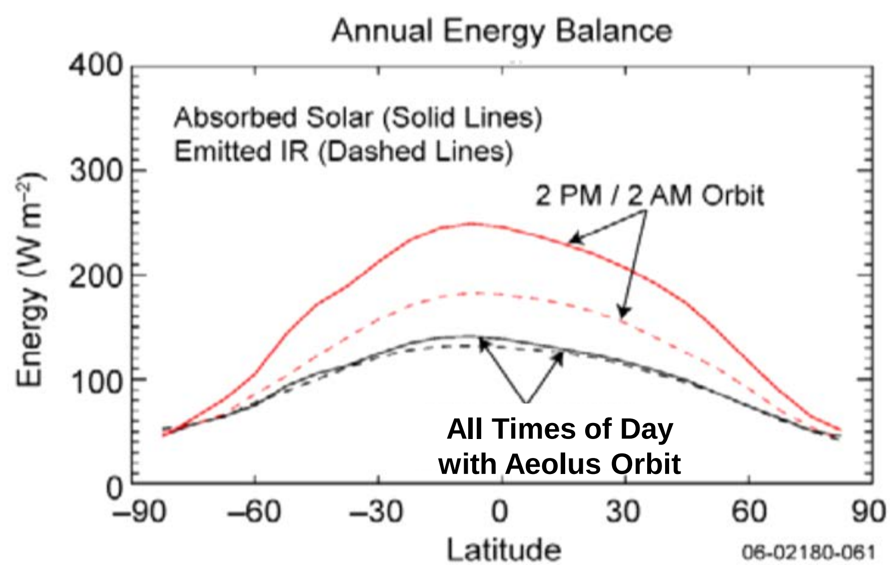


Diurnal Significance

Strong diurnal variability in Mars temperatures and winds

- Missions to date have been generally sun-synchronous, thus only observing two times a day (e.g., 2am/pm)
- The observed energy budget (TOA solar and IR) will be a strong function of local time of observation

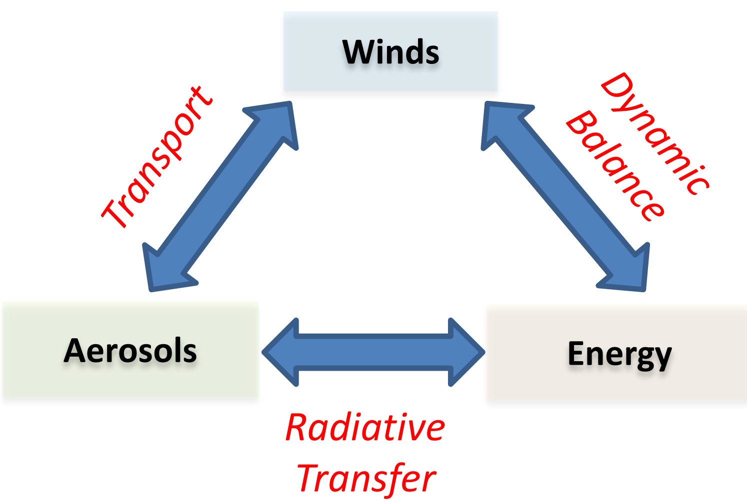


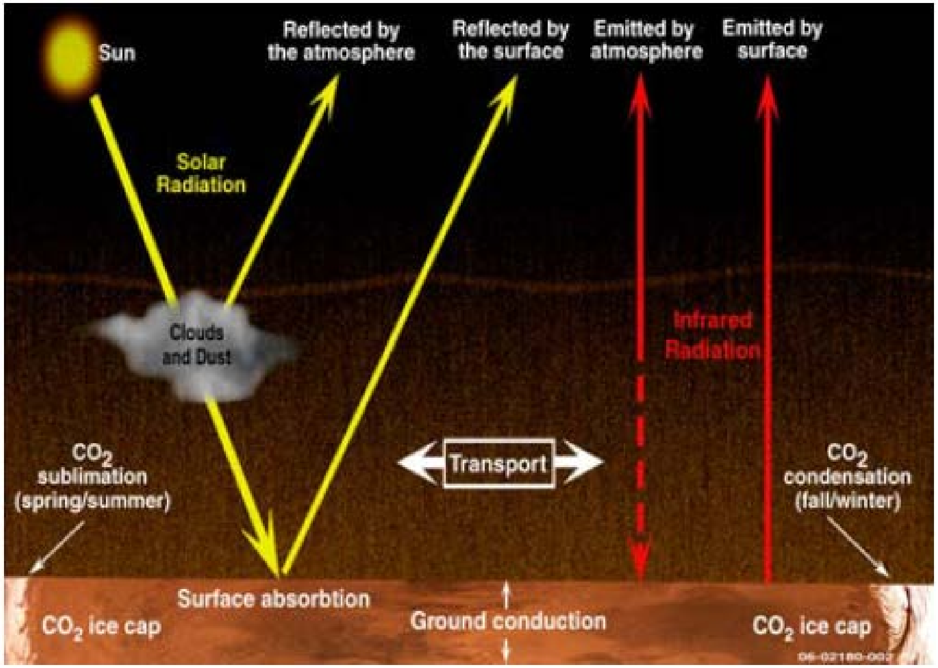


Mars Atmosphere Dynamics

Energy and angular momentum budgets drive the dynamics of the Mars climate system

- Energy in/out at surface
- Energy distributed through the atmosphere (**dust and clouds**)
- The balancing of energy (**temperature**) and momentum results in the winds/transport
- A "full set" of observations would be the product (winds) plus the forcing agents (energy at surface and in atmosphere and aerosols)





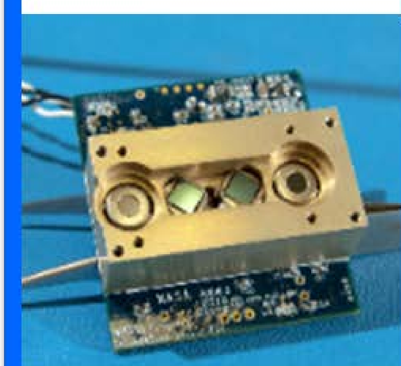
Science Baseline

Planetary Science Decadal Survey Questions	Aeolus Science Objectives	Science Themes
What is the four-dimensional wind structure of the Martian atmosphere from the surface boundary layer to the upper atmosphere?	Characterize Mars global circulation processes, including seasonal and diurnal changes.	Winds
What are the processes controlling the variability of the present-day climate?	Determine the global energy balance at Mars by measuring incoming solar radiation, reflected radiation, and thermal emission from the Martian surface and atmosphere.	Energy Balance
What are the processes coupling the carbon dioxide, dust, and water cycles?	Measure Martian atmospheric aerosol (H_2O clouds and dust) content.	Radiative Drivers

The Aeolus Payload

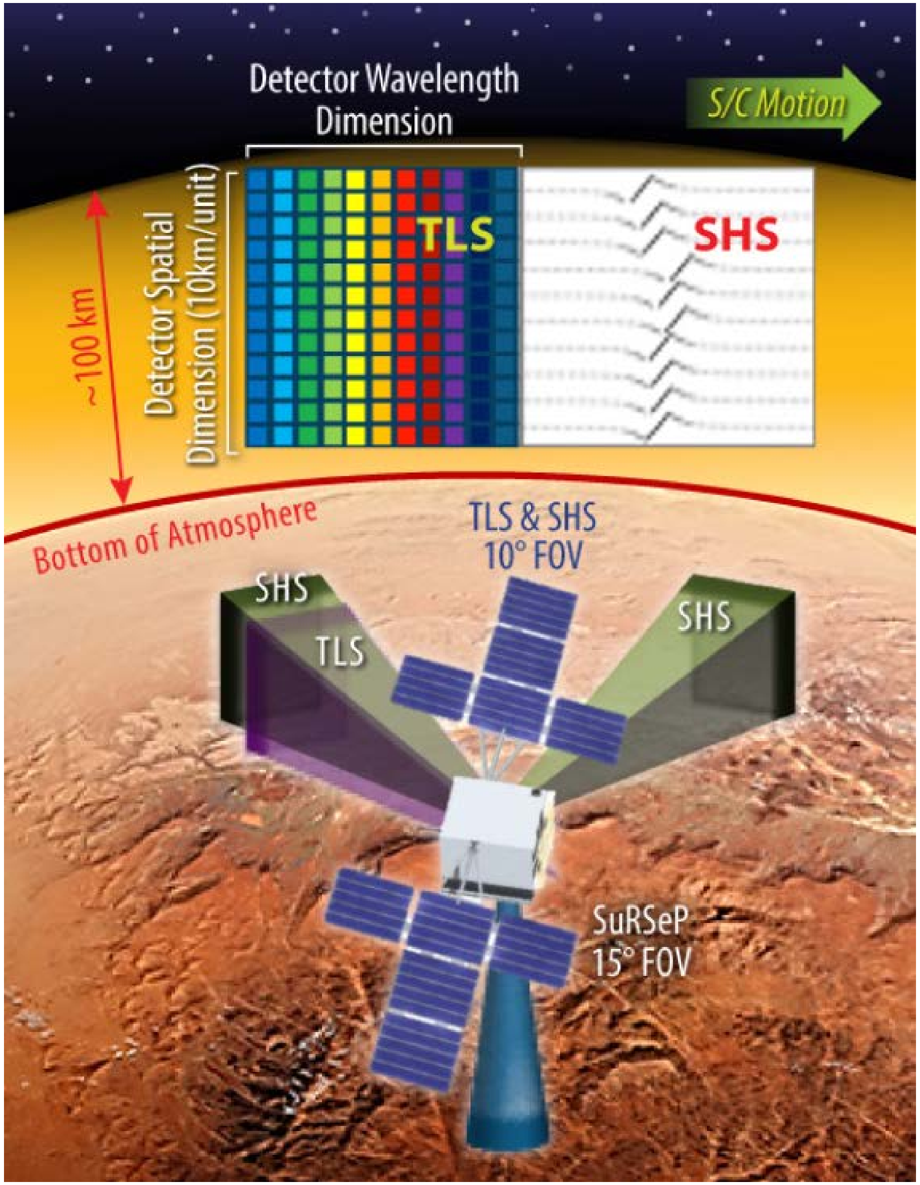
SHS: Stack of four near-infrared spatial heterodyne spectrometers (SHS) fed by two orthogonal telescopes; instrument from Draper Laboratories.

TLS: Thermal Limb Sounder; COTS instrument with custom on-sensor applied filters; instrument from ARC.

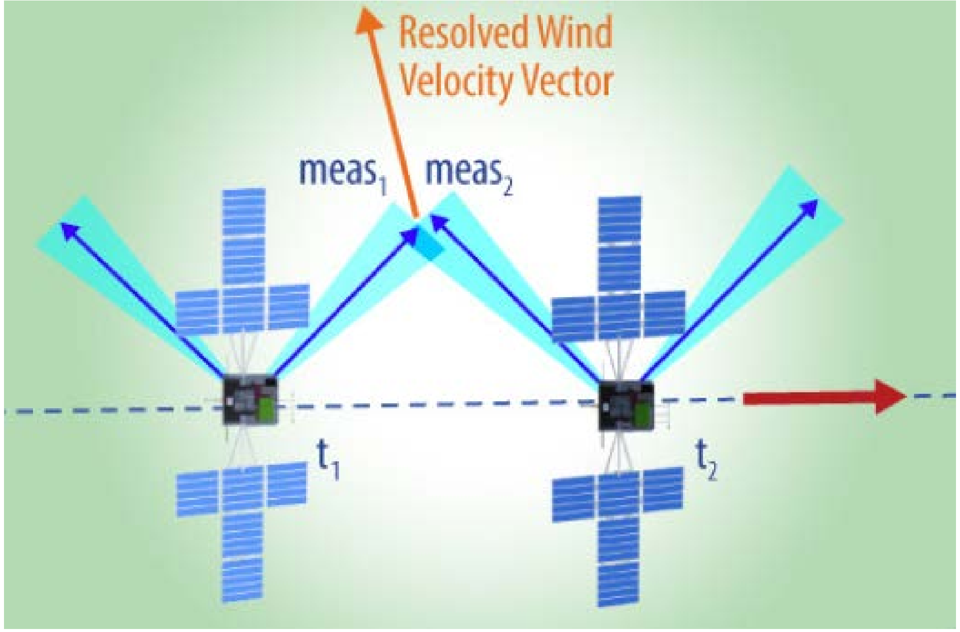


SuRSeP: Surface Radiometric Sensor Package; instrument from ARC.

Payload Fields of View

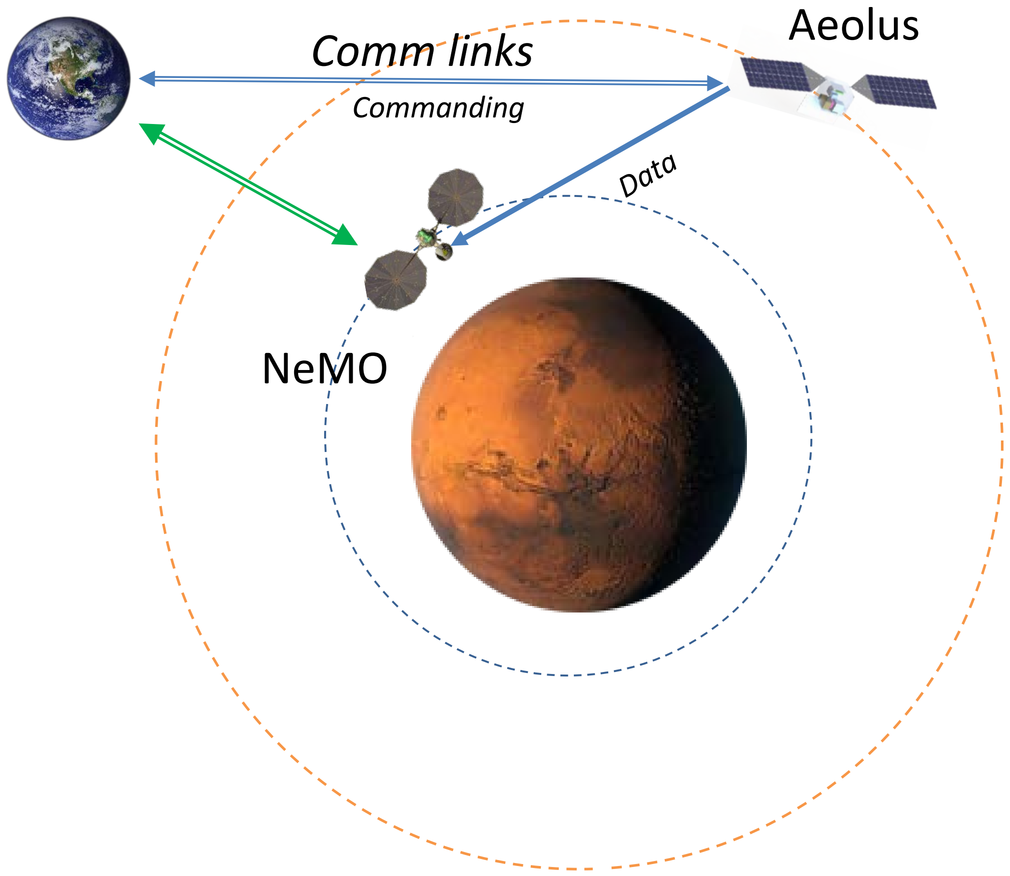


SHS Orthogonal FOVs provide wind vector



- **TLS and SHS total FOV (at limb) is 100km with <5km vertical resolution**
- **SuRSep nadir footprint is 100km**

Mission Design

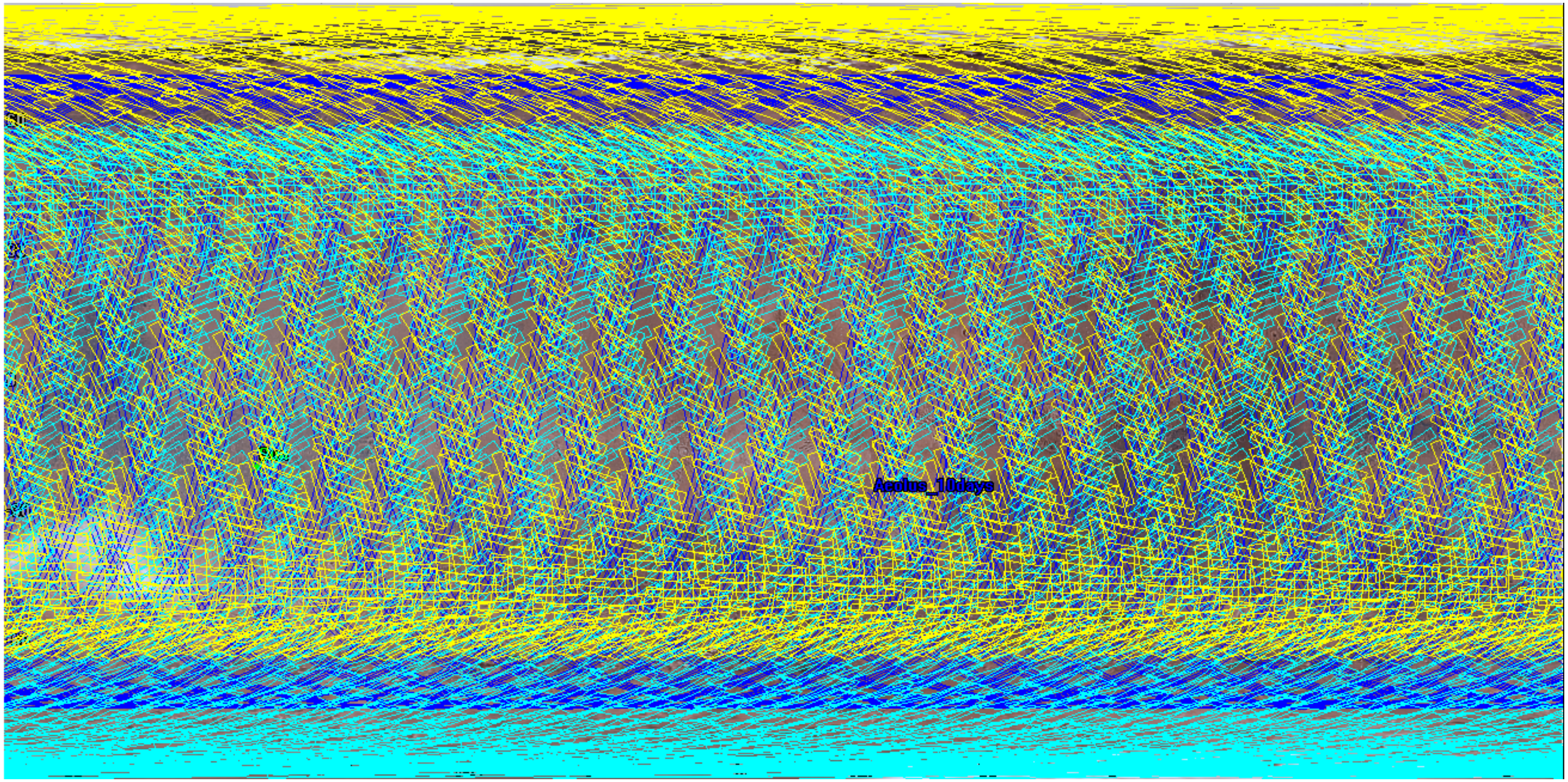


- Launch with NeMO
- Quiescent for 25 month NeMO cruise and orbit insertion
- After Aeolus deployment transfers to 383km, 73deg inclined orbit
- 24 months of science observations

Science Orbit

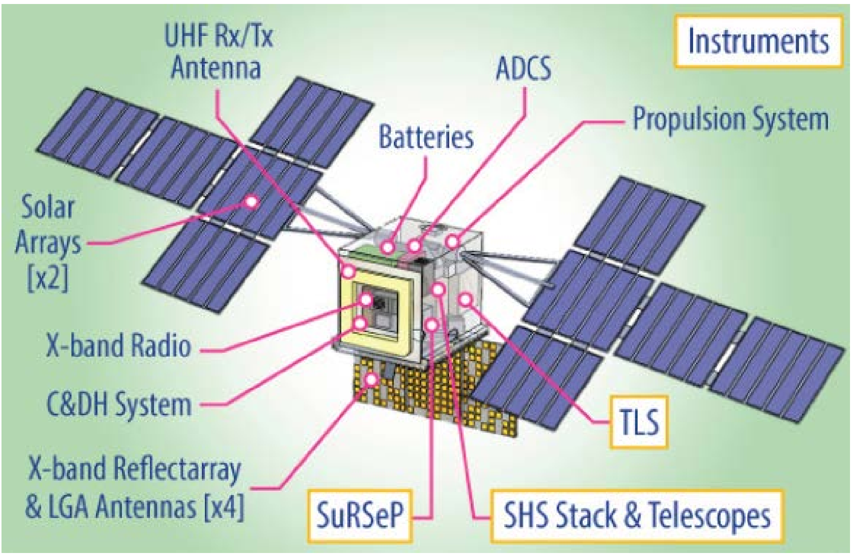
- 383-km average orbit altitude
- 73-deg inclination
- Orbit precession moves local time 2-hours in 10 day
- Measurements every 3 minutes

SHS 10-days of observations with yaw in day 5



Spacecraft Design and Analysis

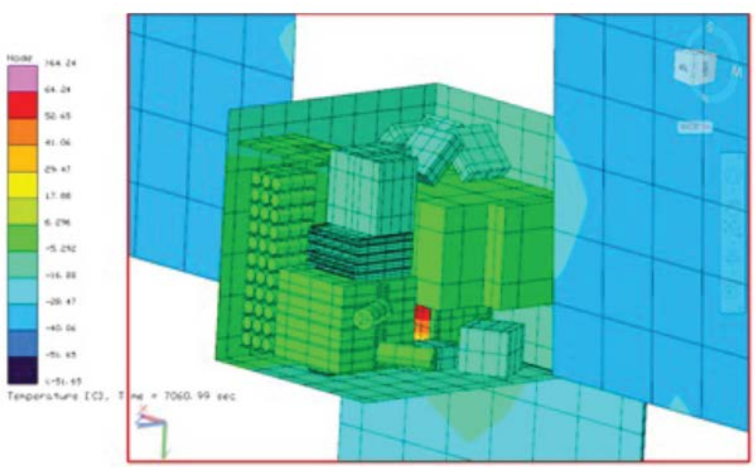
Key Spacecraft Elements



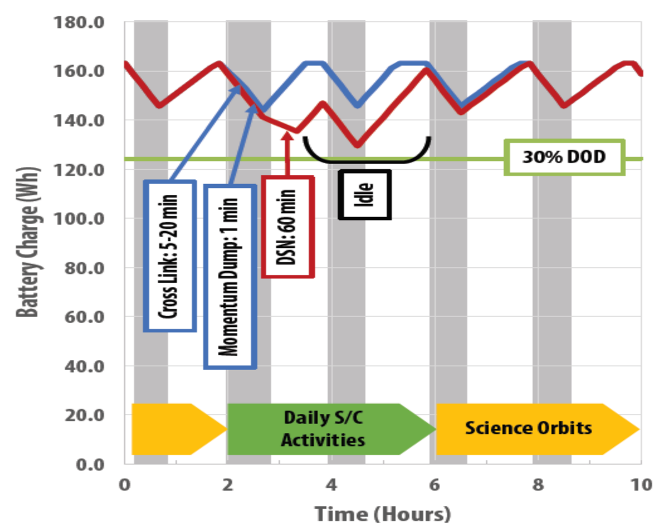
Key Spacecraft Specs

Resource	CBE
Volume	45 x 35 x 52 cm
Total Launch Mass	37.6 kg
Total Power	53 W
SC Delta V	237.5m/s
SS Data Storage (Vol)	8Gb
Data Throughput (UHF DL)	1Mbps

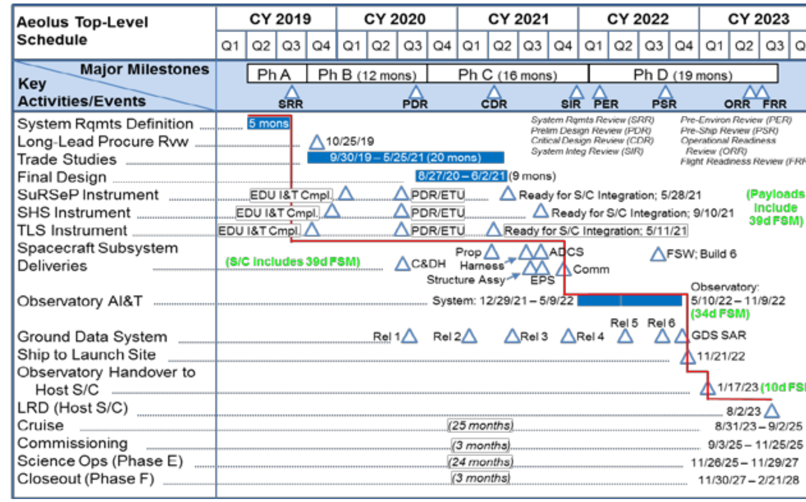
Thermal Modeling of Extreme Cases



Power System Modeling



Budget Estimate



Full grass-roots estimate

- Based on resource loaded WBS and IMS
- 30% reserves on Phase B-D, and 10% on Phase E-F (25.6% overall)

Notes:

- Currently traditional cost estimation tools are incomplete or not applicable for SmallSats
- Cost models do not adequately address existing SmallSat technologies and may underestimate maturation costs

FY18($k)	
WBS Element	**Total (Phase A-E)**
01 PM	$6,952
02 SE	$4,942
03 MA	$1,119
04 Science	$3,094
05 Payload	$7,117
06 SC	$19,318
07 Mission Ops	$6,840
08 Launch Services	$96
09 Ground Systems	$4,436
10 Systems I&T	$3,589
Reserves	$14,715
Grand Total	$72,219

General Recommendations / Findings

1. Establish clear ground rules / expectations for interface mechanisms (ICDs) and level of in-Project development of key systems

2. Telecomm systems represent a major hurdle for deep-space SmallSats

3. SmallSat operations can be as (or more) demanding as their larger counterparts

4. Assuming cost-capped SmallSat programs with limited vehicle resources, missions may be expected to have very few science descope options

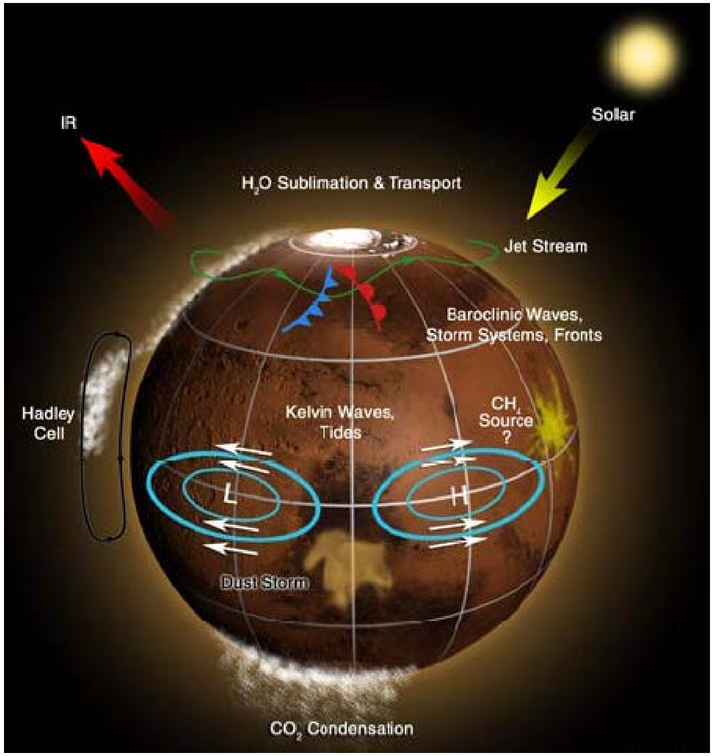
5. SmallSat missions are well suited for Class D classification, however, well defined and stable program requirements are required to keep risks and costs down

6. Due to the immaturity in a number of systems higher than normal margins were maintained (for example, >40% wet mass, >50% power, >35% SC ΔV); this margin provides "commodity" (e.g., mass) used to mitigate risks

Summary

Aeolus is a low-cost, small spacecraft, but delivers big science!

- Development via the Planetary Deep Space SmallSat Studies Program (Thank you!)
  - Included trade analysis, costing and scheduling to bring the concept to CML 4/5
- Completely novel observations of winds, day and night
- Observations across all times of day
- First dedicated energy balance observations
- Simultaneous observations of the key circulation drivers, including temperature and aerosols



Thank you!

Orbit: Driving Requirements

1. To prevent seasonal aliasing in Aeolus, the orbit needs to precess over all local times *at least* once every two months.

2. The inclination of the orbit must be 70-75° to sufficiently measure polar regions.

3. Science requires 10 orbits per day to achieve sufficient mapping resolution.

4. Planetary Protection: the orbit must be stable for at least 50 years.