Aeolus
A Mission to Map the Winds of Mars

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35th meeting of the MEPAG, September 25, 2017
**What is Aeolus?**

<table>
<thead>
<tr>
<th>Science</th>
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<tr>
<td>Aeolus will provide the very first direct measurements of Martian atmospheric wind, and correlate them with thermal and radiative forcing agents to bring together a complete systematic description for the global circulation of Mars.</td>
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<table>
<thead>
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<th>Implementation</th>
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<tr>
<td>• Small Spacecraft (45 x 35 x 52 cm)</td>
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<td>• Secondary on Next Mars Orbiter (NeMO)</td>
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<td>• 2-year science mission (all four Martian seasons)</td>
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<tr>
<td>• 3 instruments: Doppler Wind Sounder, Thermal Limb Sounder, Nadir Radiometer</td>
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</table>
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, CO2, 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.
Can derive the wind profile from temperatures using the “gradient balance” approximation
• Relates the latitude gradients in temperature to vertical gradients in zonal wind speed
• Balances the horizontal pressure gradient, the Coriolis force and centrifugal forces

Smith, 2008
Current “Measure” 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
- \textit{Errors frequently exceed 100\%}
Diurnal Significance

There is expected strong diurnal variability in Mars temperatures and winds

- Missions to date have been generally sun-synchronous, thus only observing at 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

- Missions to date have been generally sun-synchronous, thus only observing at two times a day (e.g., 2am/pm)
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 a at surface and in atmosphere and aerosols)
What is the four-dimensional wind structure of the Martian atmosphere from the surface boundary layer to the upper atmosphere?

What are the processes controlling the variability of the present-day climate?

What are the processes coupling the carbon dioxide, dust, and water cycles?

Characterize Mars global circulation processes, including seasonal and diurnal changes.

Determine the global energy balance at Mars by measuring incoming solar radiation, reflected radiation, and thermal emission from the Martian surface and atmosphere.

Measure Martian atmospheric aerosol (H₂O clouds and dust) content.

Science Themes

Winds

Energy Balance

Radiative Drivers
## Addressed MEPAG Goals

### GOAL II: Understand the processes and history of climate on Mars.

<table>
<thead>
<tr>
<th>A. Characterize the state of the present climate of Mars' atmosphere and surrounding plasma environment, and the underlying processes, under the current orbital configuration.</th>
<th>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.</th>
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<tr>
<td>A2. Constrain the processes that control the dynamics and thermal structure of the upper atmosphere and surrounding plasma environment.</td>
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<tr>
<td>A3. Constrain the processes that control the chemical composition of the atmosphere and surrounding plasma environment.</td>
<td></td>
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<tr>
<td>A4. Constrain the processes by which volatiles and dust exchange between surface and atmospheric reservoirs.</td>
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### GOAL IV: Prepare for human exploration.

<table>
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<tr>
<th>B. Obtain knowledge of Mars sufficient to design and implement a human mission to the Martian surface with acceptable cost, risk, and performance.</th>
<th>B1. Determine the aspects of the atmospheric state that affect Entry, Descent, and Landing (EDL) design, or atmospheric electricity that may pose a risk to ascent vehicles, ground systems, and human explorers.</th>
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<tbody>
<tr>
<td>B3. Determine the Martian environmental niches that meet the definition of “Special Region.”</td>
<td></td>
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<td>B4. Understand the resilience of atmospheric In Situ Resource Utilization (ISRU) processing systems to variations in Martian near-surface environmental conditions.</td>
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<tr>
<td>B7. Characterize the particulates that could be transported to hardware and infrastructure through the air (including natural aeolian dust and other materials that could be raised from the Martian regolith by ground operations), and that could affect engineering performance and in situ lifetime.</td>
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## Science Payload

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Principle Measurement</th>
<th>Requirement</th>
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<tbody>
<tr>
<td>Wind Instrument for Mars (WIM)</td>
<td>Wind profile</td>
<td>Winds between 10 to 180 m/s, to ±5m/s ~20 to 100 km, 10km resolution Day and night</td>
</tr>
<tr>
<td>Thermal Limb Sounder (TLS)</td>
<td>Atmospheric temperature and aerosol profiles</td>
<td>Temperatures to ±5K 10 to 100km, 10km resolution Day and night</td>
</tr>
<tr>
<td>Surface Radiometric Sensor Package (SuRSeP)</td>
<td>Surface energy balance Column dust and water cloud ODs</td>
<td>Total solar and Thermal to 10% 100km footprint</td>
</tr>
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</table>

**Diagram:**
- Top of Atmosphere
- Bottom of Atmosphere
- 100km
- SC Motion
- Detector Wavelength Dimension
- Detector Spatial Dimension
- ~10km spatial element
- meas
- V wind
- V s
Science Payload

Winds
- Winds are derived from Doppler shifts in emission/absorption lines
- Demonstrated method in terrestrial applications (e.g., UARS observations)
- Difference of spectra show change in spectrum due to Doppler shift (i.e., don’t just not line center position)
- STM requirements allow for Doppler shifts associated with 5 m/s winds to be resolved across a range of observer angles
- Only periodic wavelength calibration (stellar) calibration required

Modeled Spectrum Difference for Shifted and Un-Shifted (5m/s wind speed)
Limb Temperature, Dust and Water Cloud Retrievals

• Temperature, Dust and Water Cloud retrieved using techniques demonstrated by pervious Mars missions, including Mars Global Surveyor (MGS) Thermal Emission Spectrometer (TES) and Mars Reconnaissance Orbiter (MRO) Mars Climate Sounder (MCS)
• The Thermal Limb Sounder uses similar spectral bands to these previous observations (Fig below) ; Retrieval algorithms are based on very mature algorithms from both terrestrial and planetary
• Temperature monitor shutter and Space-looks used for calibration

Six Bands:
1. 9.1 μm – Dust
2. 12 μm – Water Ice Clouds
3. 15.1 μm – Atmospheric Temp
4. 15.6 μm – Atmospheric Temp
5. 17.4 μm – Atmospheric Temp
6. 19 μm – Atmospheric Temp, Dust & Clouds

TLS Spectral Bands
Surface Energy Balance, Atmospheric Temperature, Dust and Water Cloud Columns

- The nadir observations of surface temperature, dust and water cloud column retrieval will be made using proven techniques (e.g., TES and MCS)
- Total Energy balance measurements following terrestrial missions (e.g., Clouds and the Earth's Radiant Energy System (CERES), but utilizing only two bands (Bands 1 and 2)
- Internal temperature compensation, thermal control and space-looks for calibration

Eight Bands:
1. Visible Reflectance 0.3 – 3.5
2. Total Energy (Reflectance + Emission) (0.3 – 100 μm)
3. 7 μm – Warm surface temps (atmospheric window)
4. 9.1 μm – Dust
5. 12 μm – Water Ice Clouds
6. 15.1 μm – Atmospheric Temp
7. 15.6 μm – Atmospheric Temp
8. 25 μm – Cold (CO₂ ice free) surface temps, CO₂ frost grain size
Aeolus Spacecraft

<table>
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<th>Resource</th>
<th>CBE</th>
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<tbody>
<tr>
<td>Volume</td>
<td>45 x 35 x 52 cm</td>
</tr>
<tr>
<td>Total Launch Mass</td>
<td>40.8 kg</td>
</tr>
<tr>
<td>Total Power</td>
<td>46.1 W</td>
</tr>
<tr>
<td>SC Delta V</td>
<td>155m/s</td>
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<tr>
<td>SS Data Storage (Vol)</td>
<td>8Gb</td>
</tr>
<tr>
<td>Data Throughput (UHF DL)</td>
<td>1Mbps</td>
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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.
Mission Design

- Launch with NeMO
- Quiescent for 15 month NeMO cruise and orbit insertion
- After Aeolus deployment transfers to 380km, 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
Science Orbit

SurSep Percent Coverage vs Time

In 10 days orbit will precess about 2 hours in local time, thus “global coverage” obtained over 2 hour period.
Summary

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

- Development via the Planetary Deep Space SmallSat Studies Program
  - Included trade analysis, costing and scheduling to bring the concept to CML 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