A Mars-Orbiting 2-Micron LIDAR System to Monitor the Density, Winds and Dust of the Atmosphere of Mars

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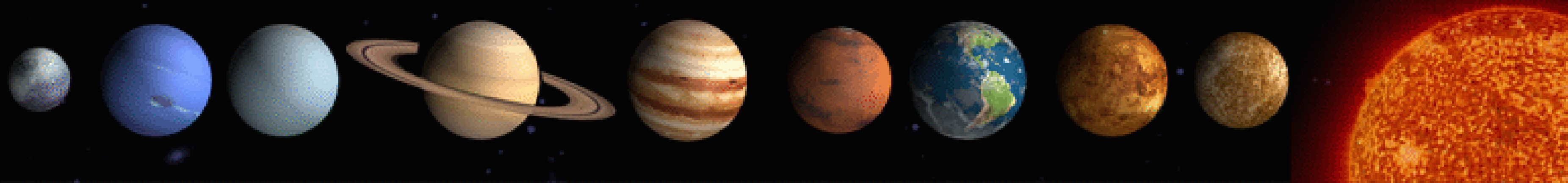
4th International Workshop on Mars Atmosphere: Modeling and Measurements

Paris, France, February 8-11, 2011

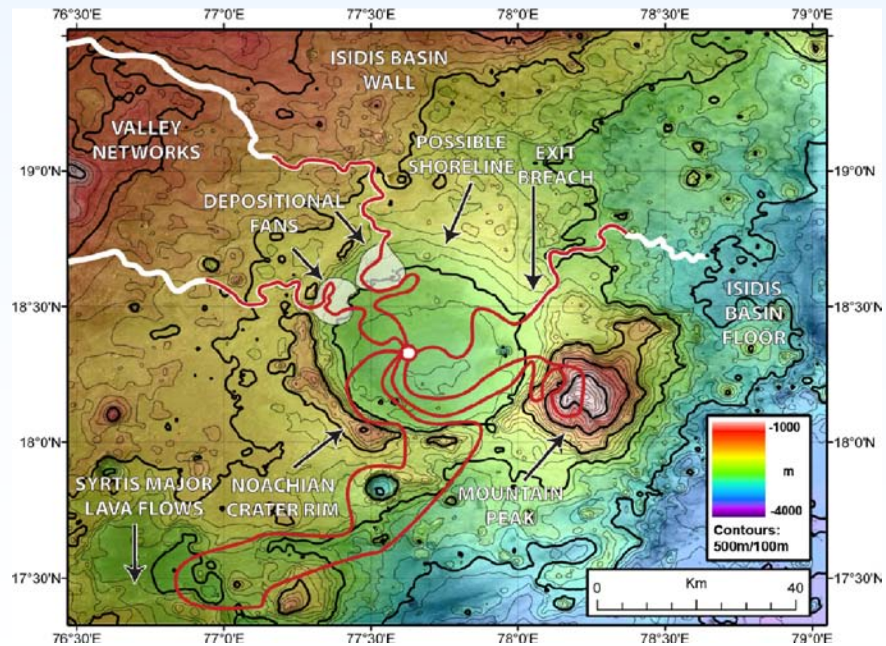


Develop and Demonstrate "Precision" and "Pinpoint" Entry, Descent and Landing (EDL) on Mars

– Why is precision and pinpoint landing important?
  - For robotic missions: Land close to high priority science targets (e.g., geological features/terrain for Mars Sample Return (MSR)
  - For human missions: Land close to supplies and/or ISRU (e.g., sites of sub-surface water)

– Some key precision EDL technologies:
  - GNC
  - Inflatable entry vehicles
  - Large supersonic parachutes or alternatives

– Modeling and prediction of upper atmospheric density and middle and lower atmosphere winds are needed to improve precision



Develop and Demonstrate EDL Technologies for More Massive Robotic and Human Landings on Mars

- “We do not know how to get large masses from Mach 4 down to the ground without ugly consequences.” (Rob Manning, JPL, Chair, Human Planetary Landing Systems Capability Roadmap, Sept. 22, 2005)
  - Current approaches are capable of delivering < 1 metric ton to surface of Mars (Viking Landers, Mars Pathfinder, Mars Exploration Rovers Spirit and Opportunity.
  - Mars Science Laboratory (MSL) is about 0.93 metric ton.
  - Mars Sample Return (MSR) will require > 1 metric ton capability and precision "pin point" landing capability to rendezvous with redeployed assets and cached samples
  - Human landings will be ~30-40 metric tons

Characterization and Prediction of Atmospheric Conditions Needed for Aerocapture & Precision EDL on Mars

- **Problem:** The Mars atmosphere modeling community is in general not focused on Mars EDL and in developing atmospheric flight data!

- **Solution:** A dedicated Mars Orbiter with instrumentation to characterize the structure and variability of atmospheric density and winds as function of altitude, latitude, longitude, local time, season, solar activity level and dust storm activity

Mars Exploration Program Analysis Group (MEPAG) Goal IV: Synthesis by Platform

- **Investigations from Orbit**

  Atmospheric data for large system EDL. Global measurements of the atmospheric temperature and aerosol profiles. Coverage from surface to ~80 km, at 5 km vertical and 10 km horizontal resolution over multiple Mars years and at multiple local times. Also, high resolution (~1 km) atmospheric density profiles below 20 km.

- **Investigations from a Single Lander or Rover**

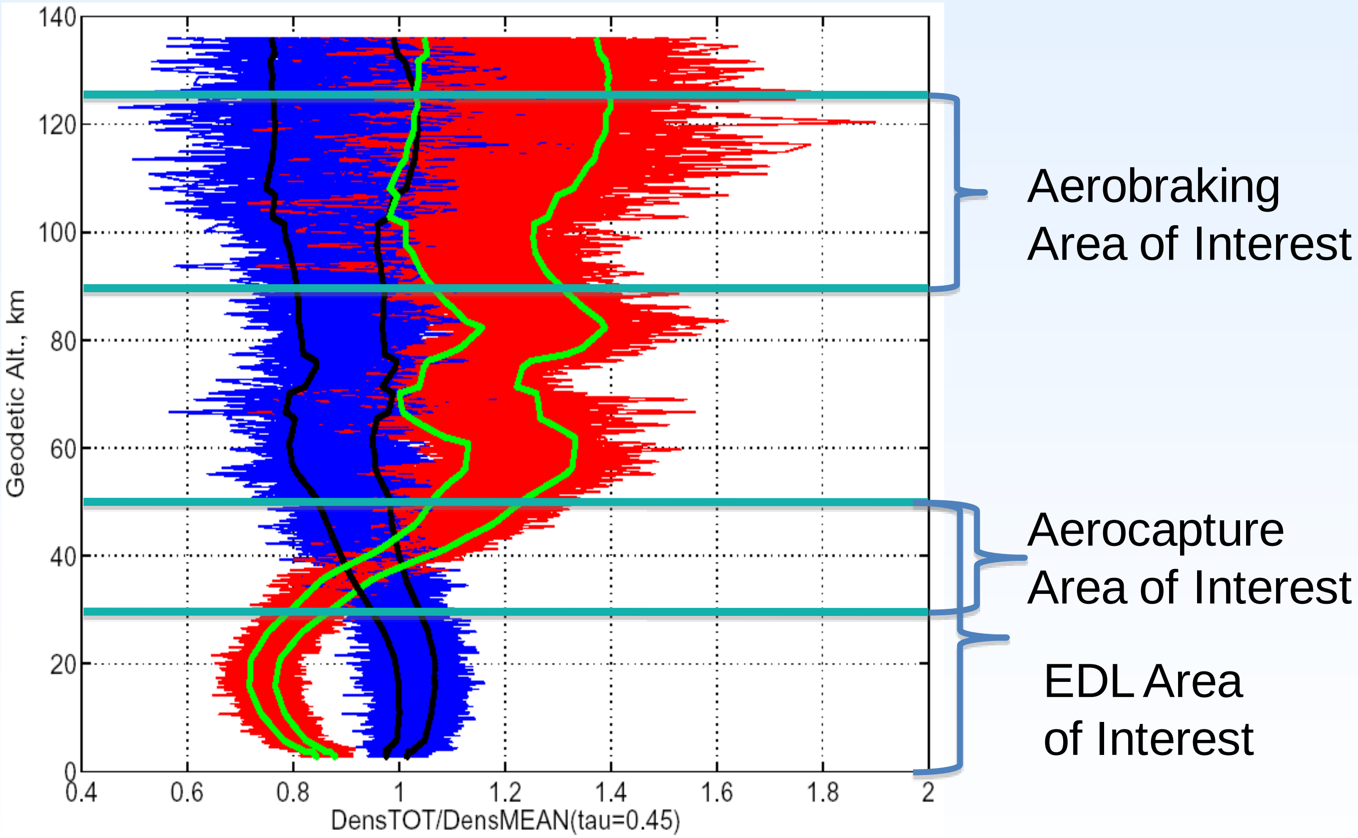
  Atmospheric data for large system EDL. High resolution (~1 km) atmospheric density profiles below 20 km. Surface and near surface measurements of pressure, temperature, aerosols and winds will be useful for model validation.

- **Investigations from a Landed Network**

  Atmospheric data for large system EDL. Global surface pressure measurements capturing seasonal, diurnal and meteorological variability. Surface and near surface measurements of temperature, aerosols and winds will be useful for model validation.

Examples of Atmospheric Density Uncertainties in Performance Simulations for Mars Flight Phases

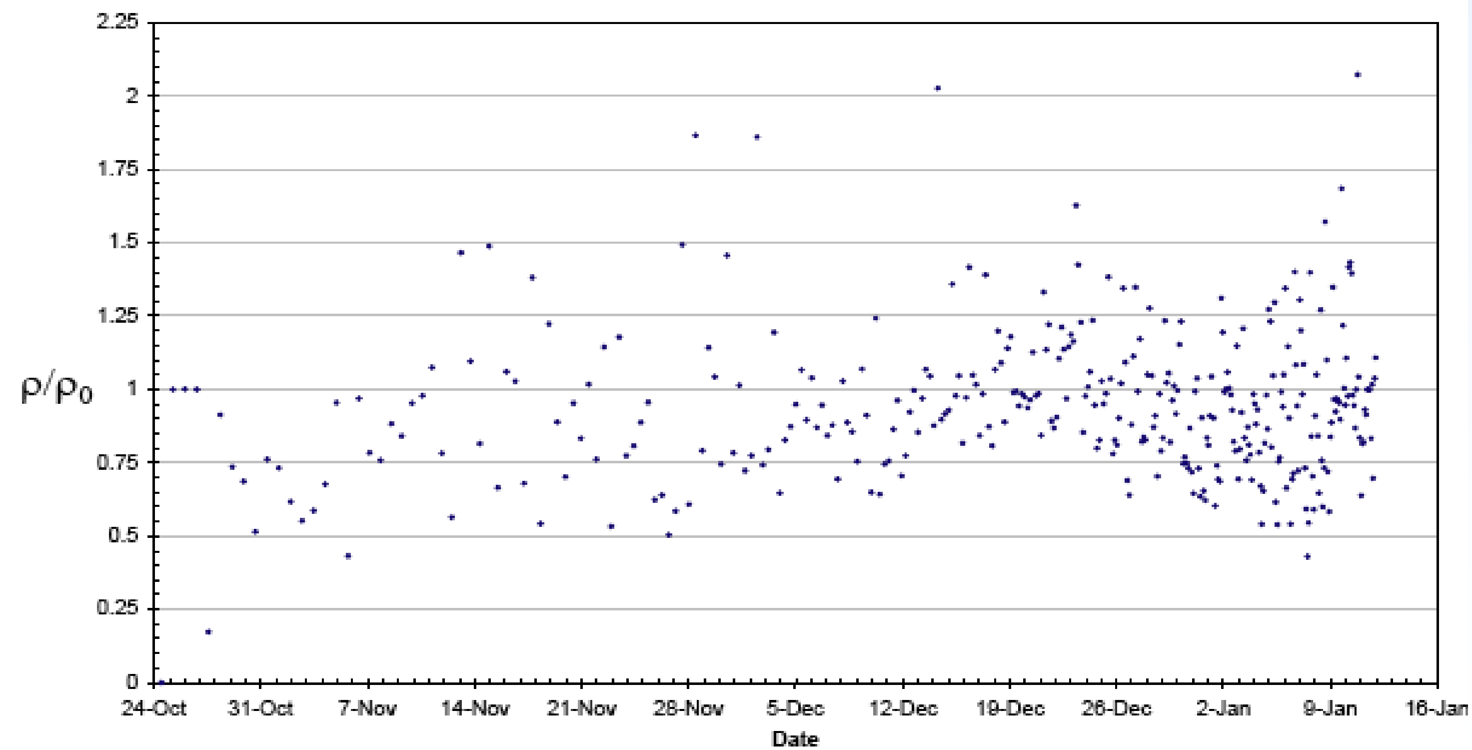
- Stand Alone MarsGRAM 2005-Map Year = 0, Duttau = 0.3 and 3.0, wlscale = 0.1



Blue = DensTOT (dusttau = 0.3) / DensMEAN (dusttau = 0.45)
Black = 1 sigma high and low for blue
Red = DensTOT (dusttau = 3.0) / DensMEAN (dusttau = 0.45)
Green = 1 sigma high and low for red

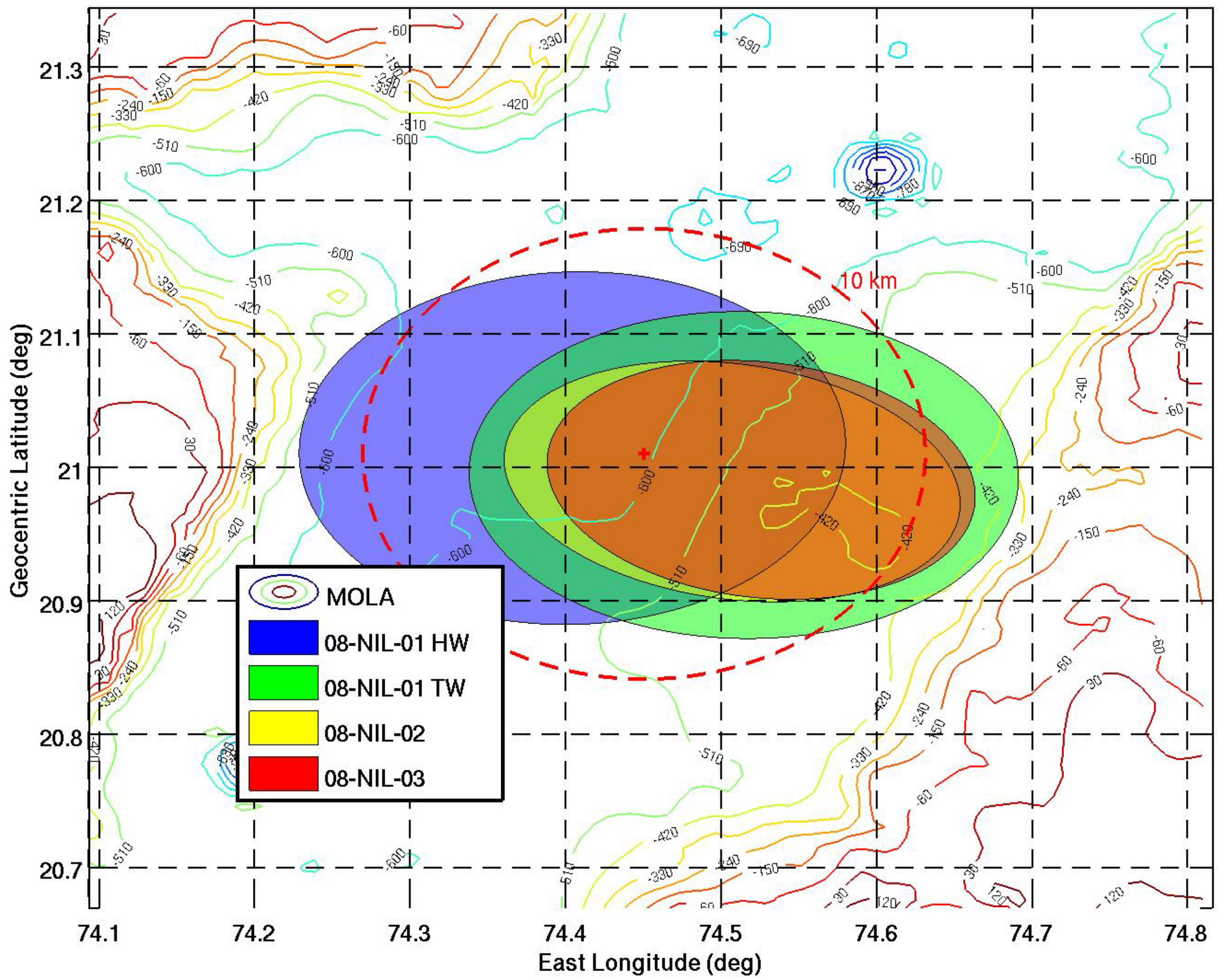
Example: Aerobraking Orbit to Orbit Density Persistence

- Persistence is using one orbit density profile to predict maximum density on next orbit. Ratio of subsequent measured to predicted is a metric for variability which is major concern during operations
- Large variability results in at least 100% safety margin in mission design
- A/B at Mars viewed as a relatively mature technology, and even with large design margins still offers significant mass savings over all propulsive MOI for mass constrained missions



Mars Odyssey Aerobraking - Orbit to Orbit Density Persistence

MSL 08-NIL-01/02/03 Touchdown Footprint: Wind Sensitivities



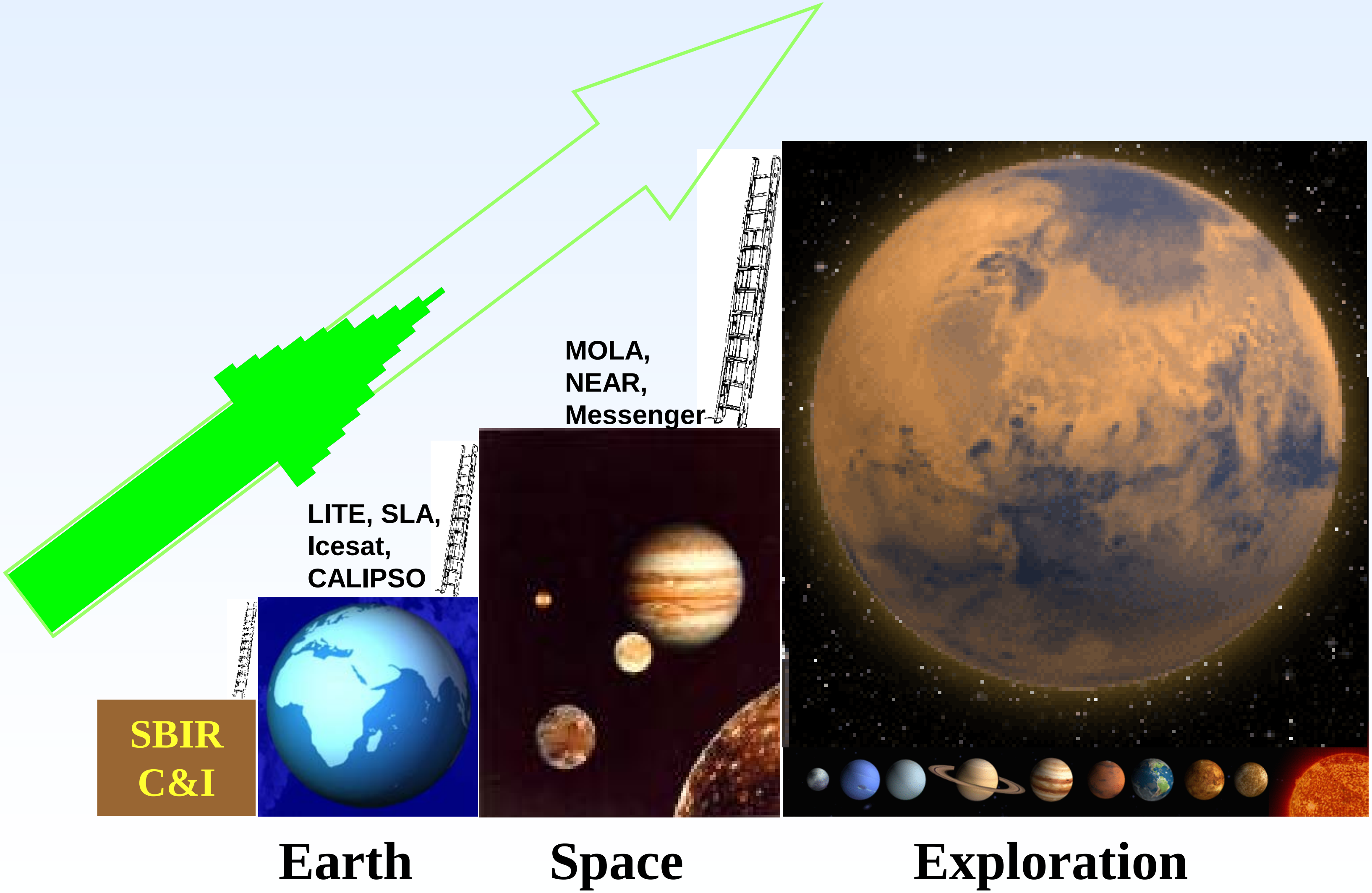
Atmospheric Modeling Requirements for Mars Atmospheric Flight Systems

- Validated, configuration controlled whole Mars GCM (WMGCM) from surface to 250 km for mission design and operations
- Validated, configuration controlled Mars mesoscale model(s) from surface to 100 km for mission design and operations
  - Multiple activities, need to focus on engineering versions
- Physics based uncertainty modeling to permit reliable evaluation of atmospheric uncertainty and experiment design
  - Still a research topic. Needs more attention for Mars specific application
- Data assimilation methods for operations and model updates
  - Numerous Earth methods available, need to specialize to Mars

EDL systems engineering must include atmospheric knowledge as a fundamental discipline to ensure a holistic systems based approach to Mars atmospheric flight

Lidar: Earth and Other Planets

Taking Advantage Of Years Of Technology Development



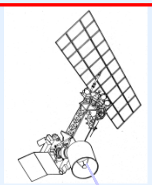
Martian Orbiter Lidar for Exploration

- Provide an instrument to profile Martian atmosphere: wind (by Doppler shift), atmospheric density (by DIAL of CO_2), and aerosol density (by backscatter intensity).
- Measurement of three parameters can be made with single orbiting 2-μm lidar.
- Unknowns of Martian atmosphere , and more specifically its variability, have significant impacts on future exploration:

"**orbital remote-sensing weather station** is recommended to obtain vertical profiles of V, T, and ρ around the globe with high temporal and spatial resolution, particularly emphasizing heights between 0-20 km and 30-60 km."*

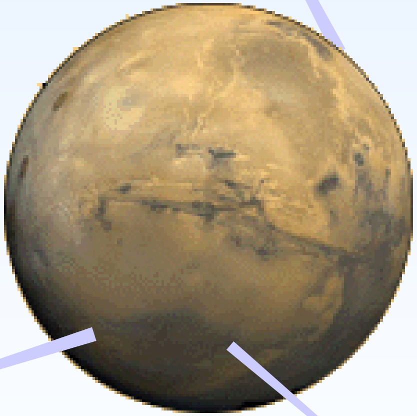
** From NASA draft report "An Analysis of the Precursor Measurements of Mars Needed to Reduce the Risk of the First Human Mission to Mars."*

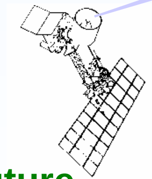
3 Key Measurements with Single Orbiting Instrument Part of Characterizing the Mars Atmosphere

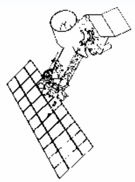


Air Density Profiles
- DIAL Technique
- CO_2 Concentration
- EDL Spacecraft Design
- EDL Payload Mass Optimization
- EDL Mission Success Rate

Wind Profiles
- Doppler Lidar Technique
- Coherent Detection for Excellent Sensitivity & Velocity Accuracy
- Winds affect Dust/Heating/Density
- EDL Insertion Accuracy, Parachute Design & Operation



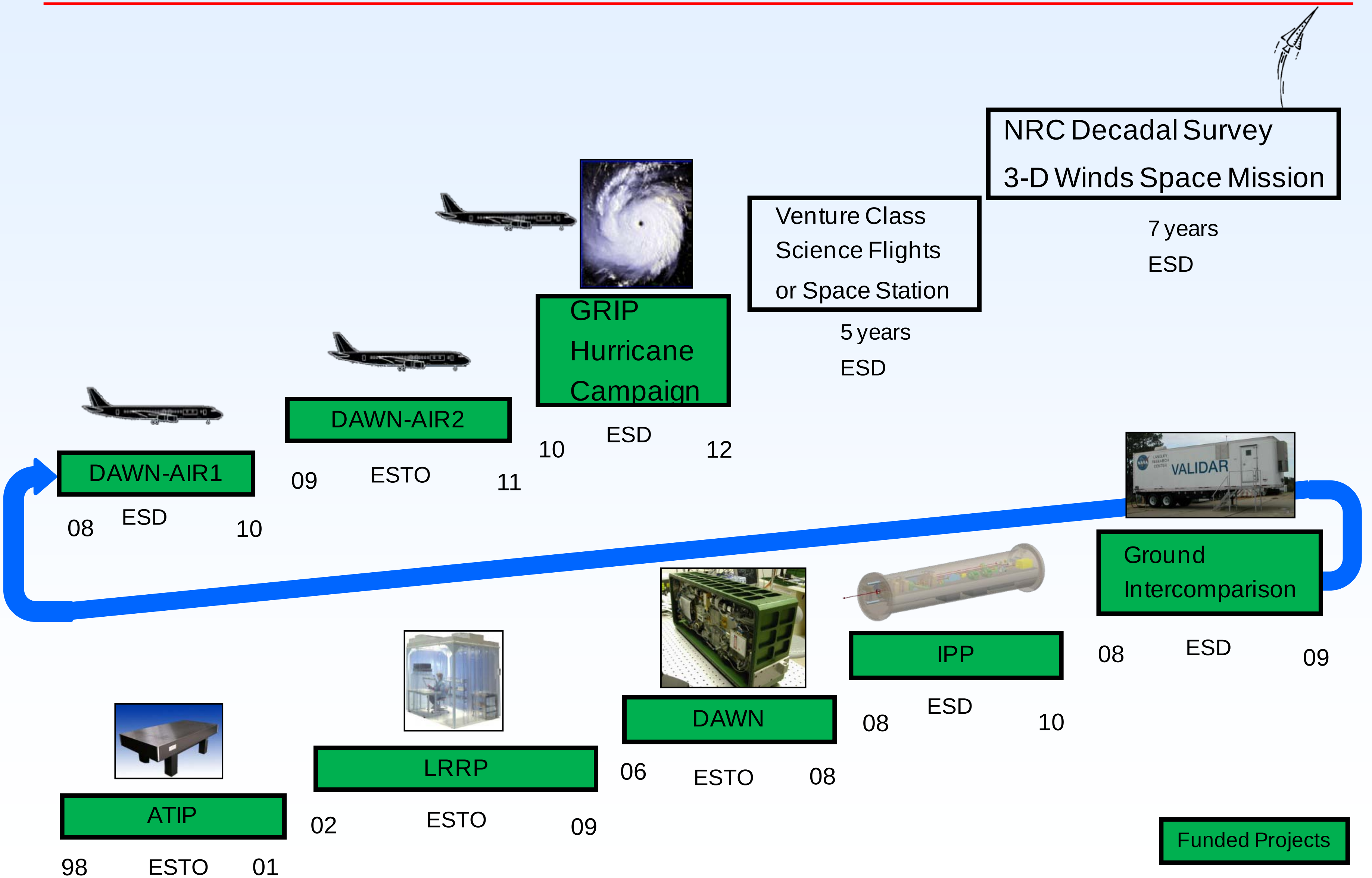




Dust Profiles
- Basic Lidar Technique
- Dust affects Heating which affects Density
- Lander Survivability & Operation
- Rover Survivability & Operation
- Aircraft Survivability & Operation

<u>Same Technology in Future</u>
- EDL Descent Velocity, Wind Field, Dust Loading, Landing Hazard Avoidance
- Surface Wind Profiling
- Ascent Vehicle Rendezvous Range, Closing Velocity, Rotation

Roadmap to 3-D Winds Space Mission
LaRC Coherent Doppler Lidar Program



Doppler Wind Aerosol Lidar (DAWN) System Development at NASA LaRC

Prior to 2007

- **90-mJ energy, 5-Hz rep. rate**
- Breadboard implementation
- Required frequent re-alignment
- Required highly skilled operators
- Required constant oversight

2008

- **250-mJ energy, 5-Hz rep. rate**
- Rugged compact packaging of laser and parts of receiver
- No re-alignment needed, even after transport to field sites
- Requires moderately skilled operator
- Unattended operation
- Installed in mobile trailer

2010

- **250-mJ energy, 10-Hz rep. rate**
- Rugged compact packaging of complete optical system
- No re-alignment needed, even in high vibration environment.
- Semi-autonomous
- Installed in DC8 aircraft

DAWN is the longest range capability coherent Doppler lidar in existence.

2-micron Coherent Lidar for Mars Applications

2 MICRON LASER

Key Technologies
- Pump Laser Diode Arrays
- Optics Damage
- Frequency Control
- Beam Quality
- Electrical Efficiency
- Heat Removal
- Ruggedness
- Lifetime
- Contamination Tolerance
- Radiation Tolerance

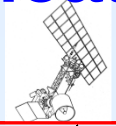
2.05 micron → COHERENT DOPPLER / COHERENT DIAL

Planetary Orbit
- Wind Profiles
- Water Vapor Profiles
- CO_2 Profiles
- Aerosol Profiles
- Altimetry

Descent
- Range
- Velocity
- Attitude/Rotation
- Wind Conditions
- Hazard Detection

Rendezvous
- Range
- Velocity
- Attitude/Rotation

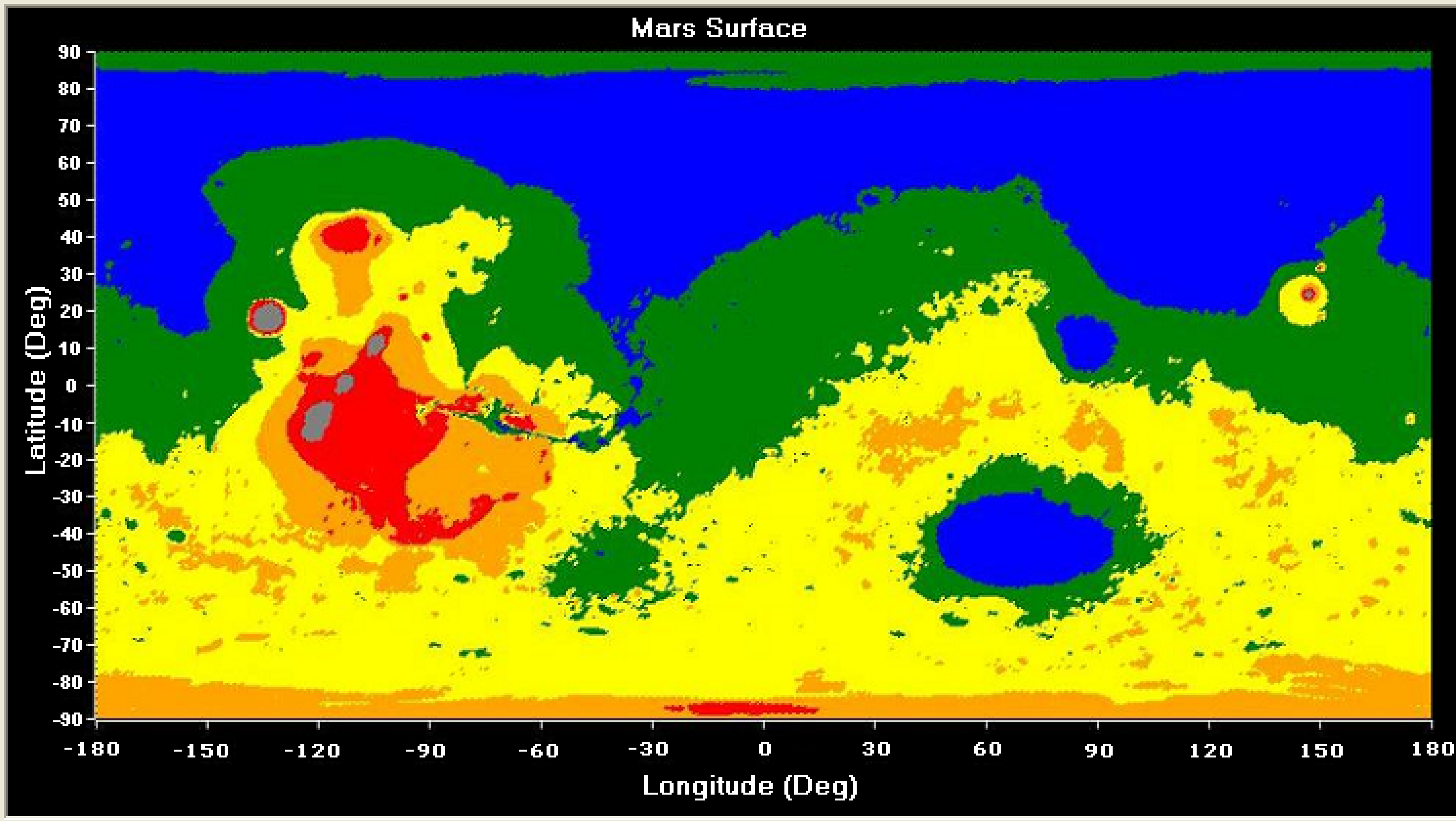
Lander/Rover
- Wind, Water Vapor
- CO_2, Aerosols
- Ranging
- Imaging
- Mineralogy
- Biosensing



Mars Lidar Simulation Model (MLSM) for Wind, Density and Dust Profiling

Mars Lidar Simulation Model

Experiment Setup | MLSM models | Analysis Toolbox | Graphics Toolbox | Help



MLSM First Time Sequence

- Experiment Set up
- Run Shot Coverage Model
- Run Lidar Simulation Model

MLSM version 1.0

Simpson Weather Associates, Inc.
809 E. Jefferson St., Charlottesville, VA 22902

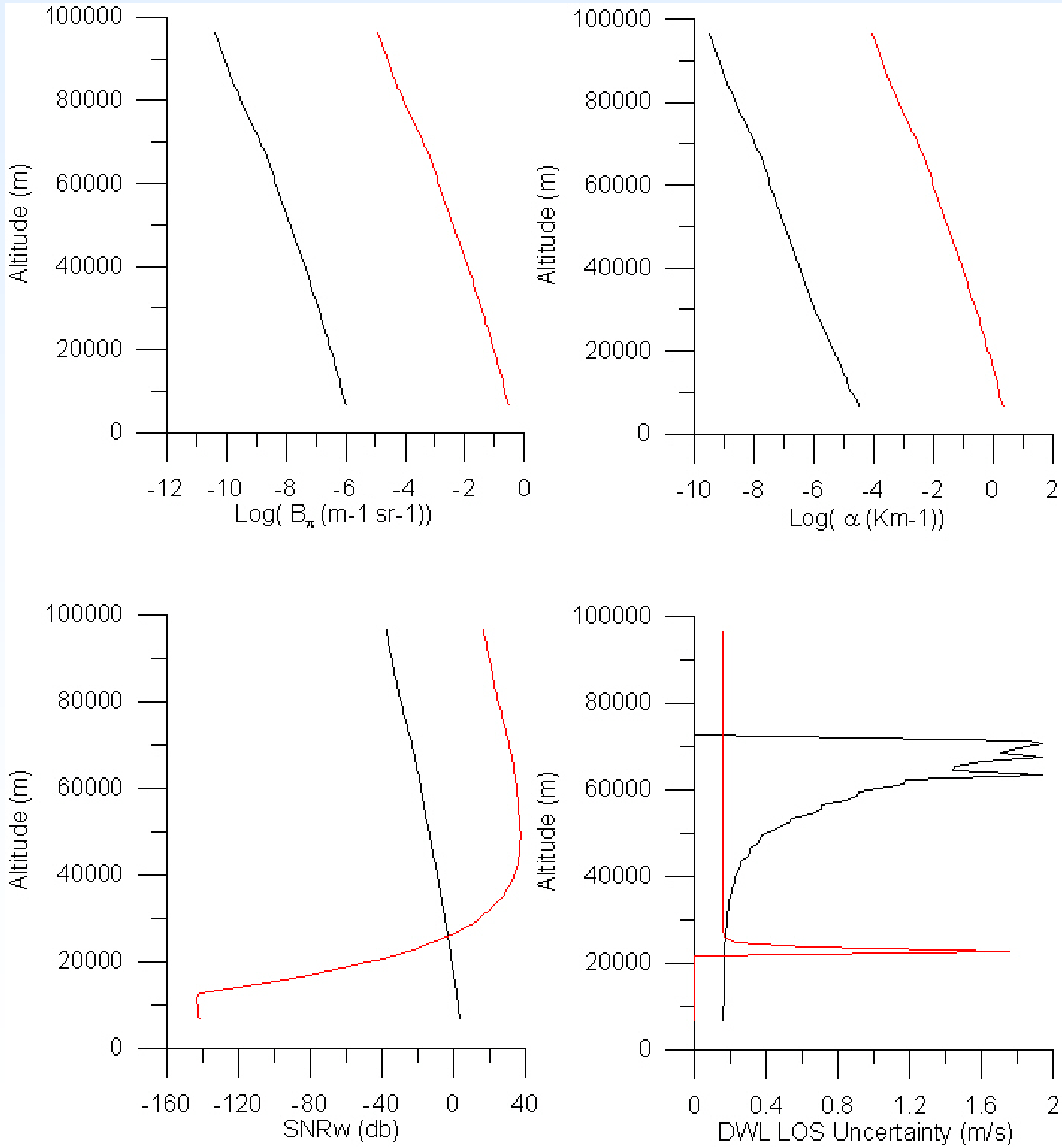
www.swa.com

Voice (434) 979-3571 Fax: (434) 979-5599
Email saw@swa.com or gde@swa.com

Last Modification Date:
Undetermined

Exit

Doppler Wind Lidar (DWL) Single Profile Bracketing Performances



Background Dust
Extreme Dust

PLATFORM INPUTS
Starting altitude of the satellite (km): 400.00
Starting orbit inclination angle (deg): 98.00

LASER SYSTEM INPUTS
Energy per pulse (joules) for DWL lidar: 0.25
Laser wavelength (um) for DWL lidar: 2.053472
Pulse duration (u-sec): 2.00
Prf of the scanner (hz): 10.00

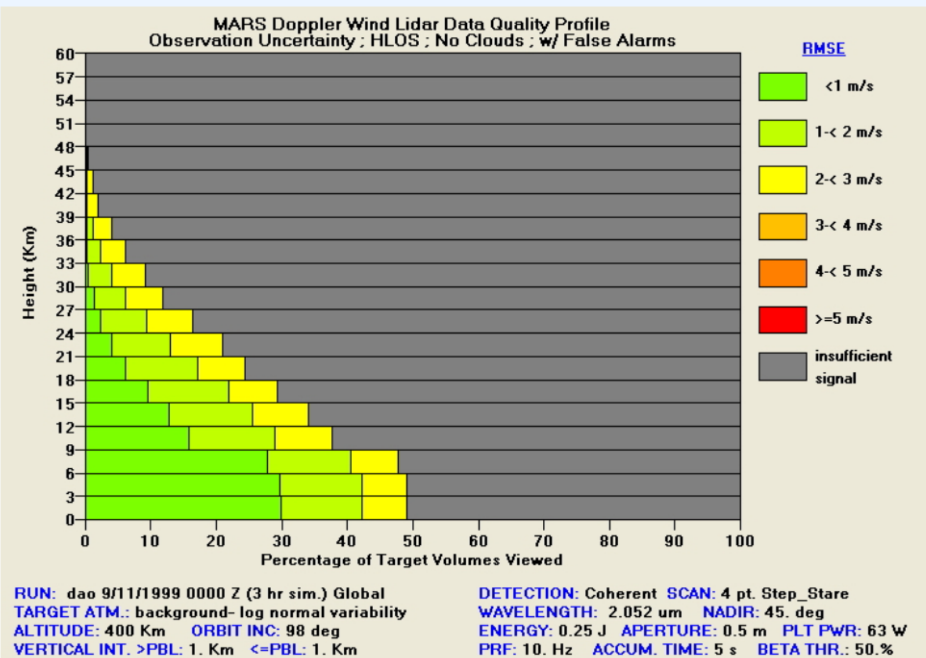
TELESCOPE/SCANNER INPUTS
Scanner shot manager type: step/stare
Diameter of the primary telescope mirror (m): 0.50
Number of discrete azimuths: 4
Nadir scan angle for each azim. ang. (deg): 45.00
Time for a fix/SS beam to fire shots (s): 25.00
Fixed/step-stare discrete azim. ang. (deg): 45.00
Fixed/step-stare discrete azim. ang. (deg): 135.00
Fixed/step-stare discrete azim. ang. (deg): 225.00
Fixed/step-stare discrete azim. ang. (deg): 315.00
Duty cycle of the scan pattern (%): 100.00

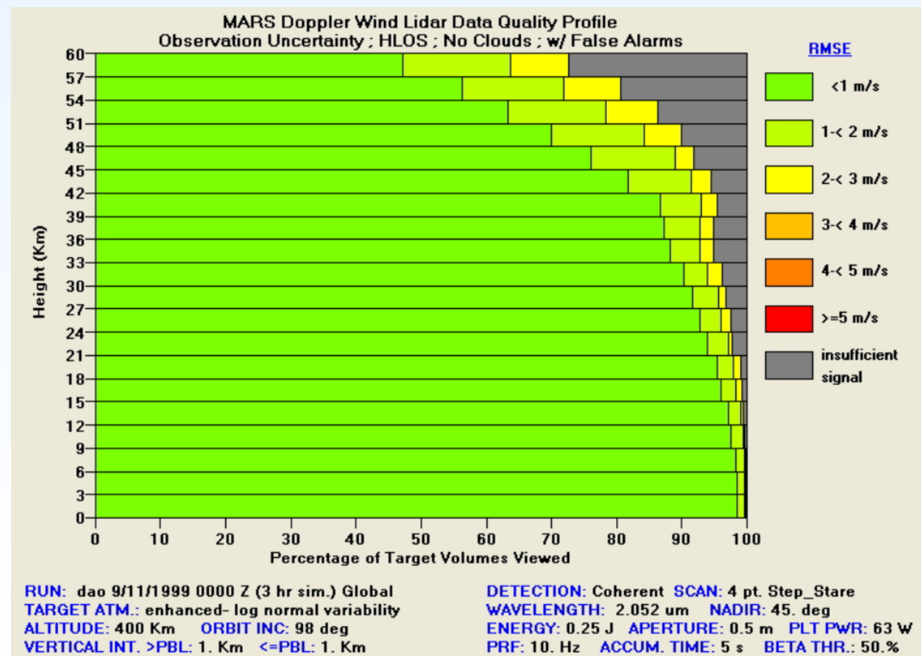
LIDAR SIGNAL PROCESSING INPUTS
Signal proc vel bandwidth (m/s): 15.00
Gross error probability threshold: 0.50
DWL shot processing: accumulation shot processing
Altitude Boundary Level for DWL (km): 3.00
Vertical bin > ABL to accumulate over (km): 1.00
Vertical bin <= ABL to accumulate over (km): 1.00

ATMOSPHERIC INPUTS
Atm. Library: MCD Mars Global Surveyor
Subgrid Scale Variance Option: 9 point
Aerosol Backscatter Option: median
Backscatter Mixing Ratio Option: Constant
Aerosol Concentration: 0.50E+07
Mode Radius (um) Background: 0.30
Elevated Backscatter Mode: user defined
Mode Radius (um) Elevated: 0.00
Elevated Backscatter Mode: Extreme Dust Storm

Doppler Wind Lidar Data Quality Profile

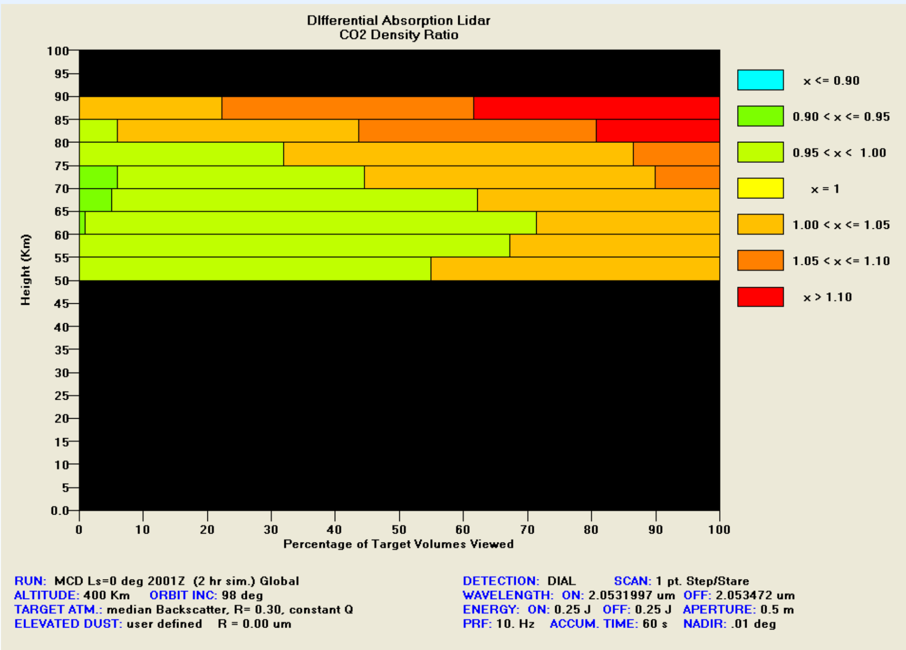
MLSM analysis of wind measurement performance for two cases of atmospheric conditions: a "clear" day (left plot) and "dusty" day (right plot)



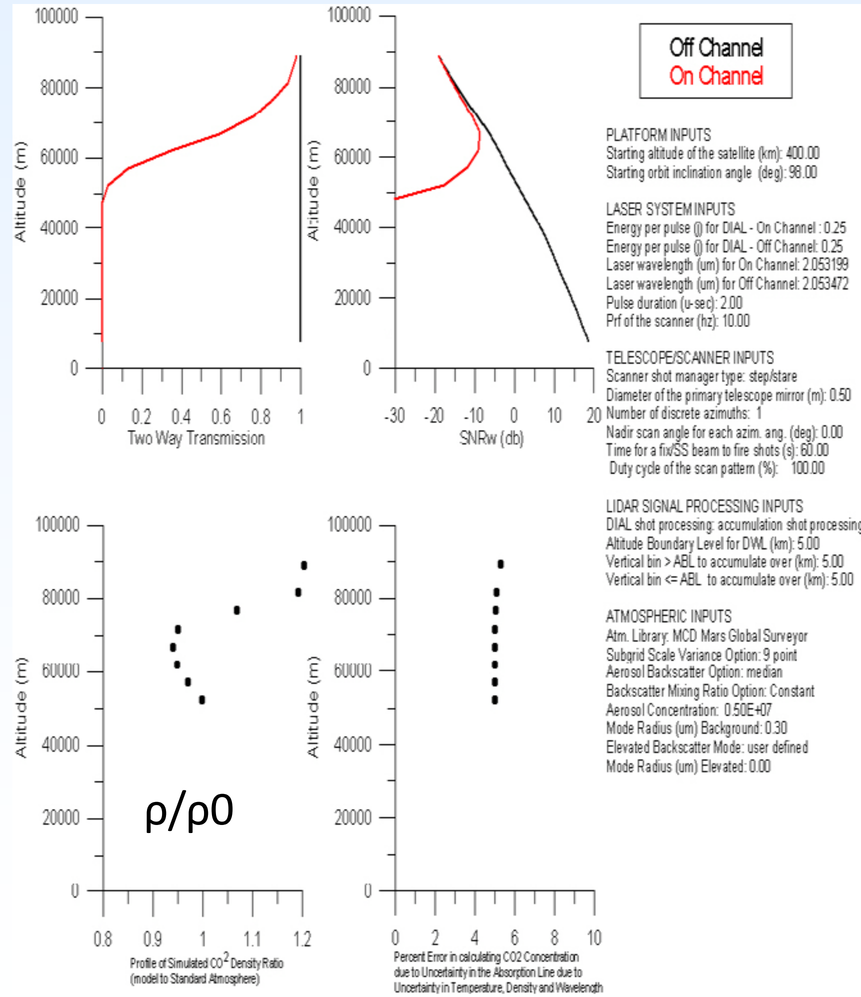


Mars Atmospheric Density Sounding using DIAL

Density ratio of measured/standard atmosphere

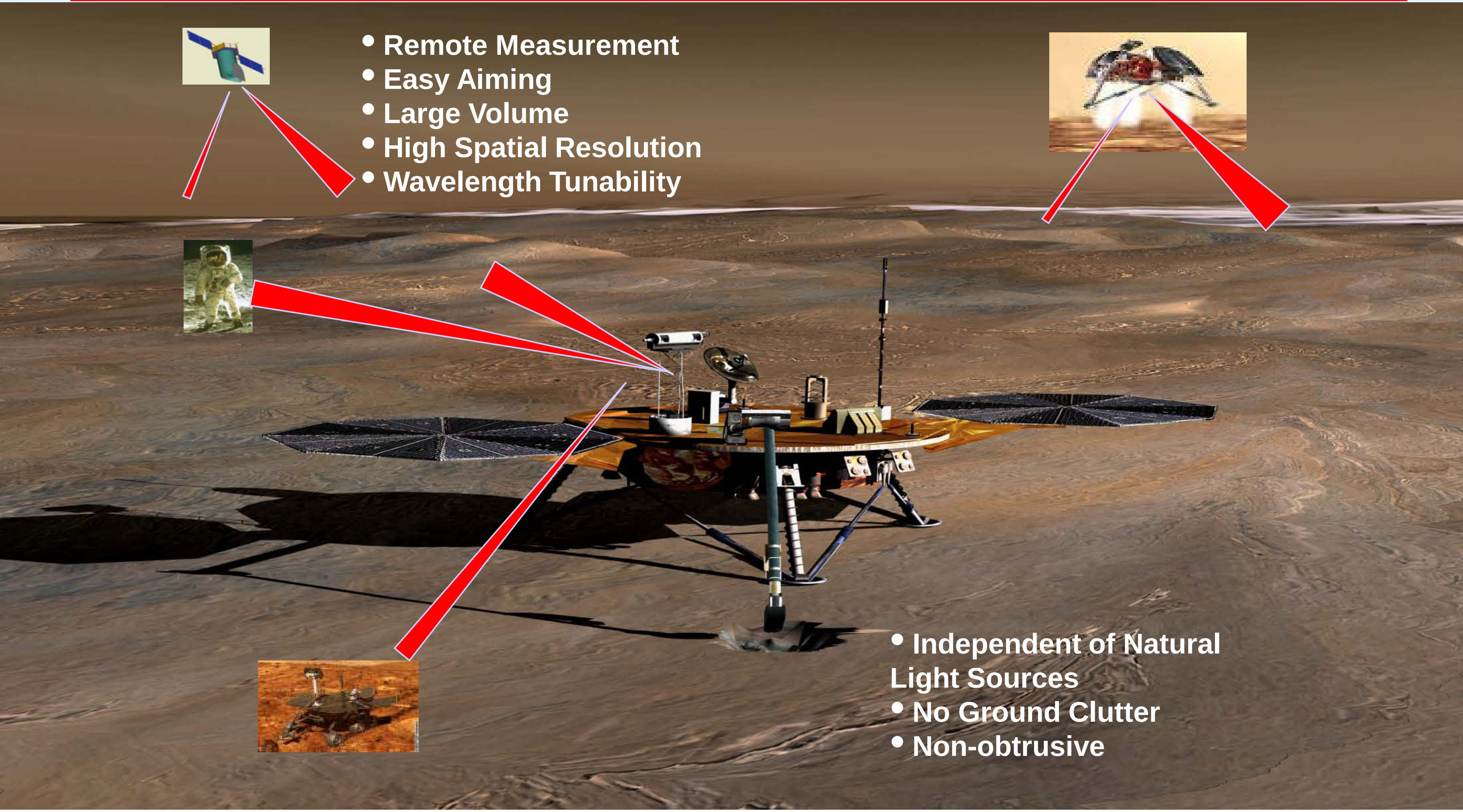


DIAL performance during normal dust loadings



Most useful during the aerobraking phase of EDL (see slide 6)

Laser/Lidar Active Optical Remote Sensing



- Remote Measurement
- Easy Aiming
- Large Volume
- High Spatial Resolution
- Wavelength Tunability

- Independent of Natural Light Sources
- No Ground Clutter
- Non-obtrusive

Summary

- Modeling, simulation and prediction of upper atmospheric density, middle and lower atmosphere winds, and dust profiling is critical for “precision” and “pinpoint” Entry, Descent and Landing (EDL) on Mars
- A single orbiting 2-μm coherent lidar can profile Martian atmosphere: wind (by Doppler shift), atmospheric density (by DIAL of CO_2), and aerosol density (by backscatter intensity)
- NASA Langley Research Center is the world leader in developing pulsed 2-micron coherent Doppler/DIAL/backscatter lidar for Earth remote sensing and have successfully developed and matured the DWL and DIAL technologies and techniques
- These technologies can be customized and matured for Mars through leveraging the knowledge and knowhow acquired by the LaRC team in last two decades
- Simpson Weather Asssociates and NASA LaRC have jointly developed a Mars Lidar Simulation Model to test various DWL and DIAL concepts for a Mars mission
- Preliminary experiments with this model suggest that Mars atmospheric density and wind profiles for EDL could be reasonably estimated from a modest sized 2 micron coherent DIAL system